REMANUFACTURING TECHNOLOGY

by

Tomás Agustin González Laugier

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Signature of Author: ______________________
Department of Mechanical Engineering, April 1 1983

Certified by: ______________________
Mr. R.T. Lund, Thesis Supervisor

Accepted by: ______________________
Chairman, Mechanical Engineering Department Committee

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ABSTRACT

Remanufacturing is a useful process for the fabrication of durable products. Remanufacturing processes consume less materials and energy than what is contained in the final product; this is made possible by the recovery of residual value added in discarded product cores. Besides making products out of discards, remanufacturing technology can be used to improve a products' design, efficiency, performance, and extend its useful life.

This study of the technology used by remanufacturers attempts to develop a systematic evaluation procedure for establishing the best remanufacturing process for a wide variety of products. This analysis procedure was developed for products made from of conventional machine elements (gears, bearings, motors, valves, actuators) and used in industrial and commercial applications.

Remanufacturing analysis consists of product and process analysis. Product analysis includes operating systems, components, and the parts of each component. Product condition is affected by corrosion, wear, fracture and deformation mechanisms. Parts are classified by function to determine the damage or failure modes which normally affect each class and select process which prevent their re-occurence.

Process analysis contains a description of the plant organization for a general remanufacturing facility. A filing system of process alternatives (PA files) listing the material conditions for which they are effective is developed. An example of the use of this analysis procedure for complete truck remanufacturing is discussed.

ACKNOWLEDGMENTS

I would like to dedicate this thesis to my parents Mr. and Mrs. Guillermo E. Gonzalez, who made this all possible, and thank them for their economic and emotional support, and the opportunity to turn this research into a real enterprise.

Gracias to Mr. Robert Lund my thesis advisor for his insights on remanufacturing and advice during the various stages of the thesis. The most reliable published information on the remanufacturing industry and the products being remanufactured is that published by my thesis advisor Mr. Robert T. Lund. The reports on energy savings through remanufacture, the industry survey and the two remanufacturing conferences organized by Mr. Lund were an irreplaceable source of information for this research. I hope he gets to continue work in this exciting field

To the Puerto Rico Economic Development Administration for the exellent support which I received through their Scholarship Program. My thanks to Mr Chris Speligene and Mr Ron Clark, of the Fred Jones Manufacturing Company for their time and attention durign my visits to their remanufacturing plant in Oklahoma City.

Muchas gracias to my host in Cambridge, Mr. Doyle "Guido" Skeels, for his valuable insights, rrraighteous editing, magnificent hospitality, and humor. Also to all others who helped out in various ways during the years of work at MIT, and the last few months of the crunch.

Last but not least my regards to my colleagues at Trans Tech Caribe Inc., Mr. G.E. Gonzalez, Dr. Arturo Harlan and Mr. Cesar Delturrondo, all of whom showed exemplary patience during my extended leave of absence while finishing this thesis.

BIOGRAPHICAL NOTE

This thesis was compiled during three years of research and field work on truck and equipment remanufacturing. My first exposure to vehicle remanufacturing was in the fall of 1979 while helping as consultant on the design of a prototype truck to be "remanufactured" for the Puerto Rico Power Authority. The project involved the transplant of utility aerial devices and service bodies from old trucks onto new chasses. The objective was to save the Power Authority approximately $25,000 per vehicle compared to the cost of new chassis and equipment.

I worked during the summer of 1979 as the R.R.R. Project Manager (Repower, Retrofit, Refurbish) for a project remanufacturing forty of the Power Authority vehicles. These jobs involved several different vehicle and equipment designs and conversion types. Variations in bodies, crew cabs, equipment size, truck power trains and overall core conditions had to be dealt with and incorporated in to the project plan.

My experience in that project made me aware of the prospects of research on ways to improve current remanufacturing technology. Many processes related to the preservation and restoration of parts and materials are stil in their infancy. Evaluation techniques used to apply remanufacturing processes to any type of product had to be developed. After receiving my B.S. in Mechanical Engineering in 1980 I worked on another truck remanufacturing project in Puerto Rico. I came back to MIT in the Fall 1980 determined to pursue this field because of its great potential for long term benefit for society.

In the Spring of 1981 I began to work with Mr. Robert T. Lund at the Center for Policy Alternatives (C.P.A.), which had a D.O.E. sponsored research project titled Energy Savings through Remanufacture. I worked on the final phase of the project, a remanufacturing feasibility study of three candidate products: chains saws, garbage disposers and motorcycle parts. This research culminated in the publication in August, 1982 of CPA-82-11: Engineering Feasibility Study of the Remanufacture of Chain Saws. During that research project I developed an interest in the U.S. remanufacturing industry. In August of 1981 Mr. Lund of the MIT Center for Policy Alternatives and the MIT Center for Advanced Engineering Study organized and hosted Remanufacturing in the 80's, the first national remanufacturing conference. At the conference industry leaders from across the nation met to discuss issues related to the present and future of remanufacturing. The conference was so succesful that a second one, Remanufacturing: Remaking the Future, was held in December, 1982.

In the spring of 1981 I decided to do my thesis on truck and equipment remanufacturing, specifically the technology used and the analysis procedure for product remanufacturing. A literature search is the ordinary start to most theses, but in this case no books on the subject were available. Many prosesses were evlauted with information collected from several repair manuals, manufacturers' data books, maintenance manuals and product literature. To familiarize myself with the industry, I made two visits to one of the nations largest engine remanufacturing facilities, attended both conferences and collected several technical articles related to remanufacturing processes.

This document is on product analysis and remanufacturing processes of mechanical products, as opposed to electrical or chemical. This is due to my background in mechanical engineering and interest in design, tribology, and manufacturing.

In September 1983 I became the project manager for the Trans Tech Caribe Inc. remanufacturing division. This project eventually will produce remanufactured trucks and equipment for the Caribbean and Latin American market. I hope this this thesis encourages others to do research in the different economic, social, and technical aspects of remanufacturing.

Long Live Operation Silkpurse

Tomás A. González
Cambridge, Massachusetts, Spring 1983.

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Remanufacturing Technology

1.0 Introduction

The consumption of material and energy resources is a very important issue that will confront mankind for the foreseable future. Mechanical engineers play a key role in the development of processes used to manufacture most of the tools and equipment used by all sectors of industry. The design, testing, development, optimization of material and energy use, and manufacture of most durable capital goods are all part of the responsibilities of the mechanical engineer.

This thesis deals with one of the most promising solutions to the problem of conservation of materials and energy: REMANUFACTURING.

Remanufacturing is a way to produce durable capital goods without having to use all new raw materials. The main raw material used in this industry is the CORE. A core is a discarded, often non-functional product which contains "residual value." The objective of remanufacturing is to economically recover this residual value and rebuild the unit with new or reconditioned components.

1.1 Engineering Feasibilty Studies: A New Methodology

There is very little published information on remanufacturing technology. This thesis is an effort to develop a set of analytical tools for evaluating the remanufacturability of different products.

The approach to this task is to evaluate the current remanufacturing practices and record the current uses of technology. This study focuses on the remanufacture of durable machines and equipment whose operation depends largely on mechanical components and moving parts, i.e., products made of conventional machine elements (structural members, springs, bearings, pistons, valves, gears, brakes and motors) as opposed to electronic products or those made of non-moving parts.

A versatile and effective analytical procedure should consider the following product variables:

- o Market for the new and remanufactured product.
- o Core availability, prices, sources.
- o Failure modes of the original product.
- o Product operation and maintenance.
- o Product design and construction.
- o Local operating costs for a remanufacturing firm.

The type of research work done to analyze these variables can fall in two different categories, engineering and economic feasibility studies. This thesis deals with the technical issues of remanufacturing products. The objective is to develop an analysis procedure which can be used to evaluate the remanufacturability of different poducts. The procedure covers the following areas:

1. Product: Design and construction of a product
2. Process: Remanufacturing process alternatives
3. Development strategies: Economic evaluation of alternatives

Product analysis focuses on the design of different operating systems. All system components are identified and evaluated to determine which should be remanufactured or replaced. Components are analyzed to determine the failure modes and possible design changes which could be introduced in the remanufactured product.

Remanufacturing processes depend on the type of product and the failure or damage which it has received. The most common failure modes found in part are plastic deformation, fracture, wear and corrosion. Methods developed to repair damage caused by each of these modes are used ot repair a variety of parts affected by them. Failure modes result from quantifiable operating conditions and material properties, this thesis covers those measures which can be taken to prevent their occurence in the remanufactured product.

Process analysis begins with the classification of parts into four basic categories:

- o Moving parts
- o Interfaces
- o Fasteners
- o Stationary parts

Each part category has several sub-classifications which can be correlated to specific function and failure modes. Refurbishing processes are correlated to the individual part sub-classifications and material types to complete the general process analysis. A case study of the use of the analysis procedure on Heavy Duty trucks is used to identify its usefulness and suggest areas for further research.

The market and a description of product types covered is studied in Chapter 2. Chapter 3 deals with the general product and process analysisi procedure. The subsequent chapters cover each of the major proceses used to remanufacture products, core procurement, cleaning, disassembly, refurbishing and assembly. The design of remanufactured trucks and a discussion of the uses of the analysis procedure are presented in Chapter 9.

The final step, defining and measuring all relevant operating and marketing costs for truck remanufacturing is not within the scope of this thesis. For an example of how to carry out a full economic feasibility study, the reader might consult An Engineering Feasibility Study of the Remanufacture of Chain Saws, published by the M.I.T. Center for Policy Alternatives (1).

1.2 Definition of Remanufacturing Technology

Remanufacturing Technology is the group of processes and techniques employed in the remanufacture of any durable product which is no longer functional and whose repair is not considered economically feasible using conventional repair techniques.

Remanufacturing Technology includes processes similiar to those used by the Original Equipment Manufacturer (OEM). The single most important difference between manufacturing and remanufacturing is in the raw materials used. Manufacturers will create a product from raw materials supplied in "amorphous" bulk form: rolls, ingots, rods, pellets, or barrels of material. In remanufacturing, about 80% of the final product (by weight) comes from a core.(2)

The main objective of remanufacturing is the reclamation of value remaining in a product after it has failed. A primary benefit of remanufacturing is the creation of products which contain more energy than is used to "reproduce" them. A typical ratio of the energy contained in the product compared to the energy consumed to remanufacture it is 5 to 1.(3)

The value contained in a manufactured product is composed of:

- o Materials and supplies used in making the product.
- o Energy consumed in the manufacture of each part.
- o Other resources (capital and labor) used in manufacture.
- o Materials contained in the product.
- o Value of the design (quality, aesthetics, function).

By recovering this value from a core one saves materials and energy while increasing the productive capacity of the economy. Other benefits of remanufacturing include(4):

- o Stimulation to competition.
- o Employment opportunites.
- o Reduction of solid waste disposal problems.
- o Export potential.
- o Aid to devoloping countries.

The details of these benefits are described in several Center for Policy Alternatives reports, especially Energy Recapture Through Remanufacturing, Final Report of Pre-Demonstration Study. I would recommend those interested to consult that document for additional information.

1.2.1 When and Where Remanufacturing Takes Place

Remanufacturing is usually done after a product has exhausted its designed life, but it can also be done while the product is in service to improve its efficiency and performance. A good example of remanufacture while the product is still operational (often called reconditioning or overhauling) is the work continuously done on the B-52 Strategic Bomber.(5) These planes and other types of military equipment are constantly being remanufactured to the original structural and performance specification or better; new technological improvements in each of the numerous systems and components of the equipment is incorporated during each remanufacturing cycle. Mr. Gordon Frank, the Department of Defense speaker at the 1981 conference, stated:

> The DOD does not strictly call its activities "remanufacturing." Instead, numerous synonyms - ranging from alterations, conversion, growth and modernization to its Service Life Extension Program (SLEP) serve to illustrate the concepts and contributions of remanufacturing durable goods. Much of DOD's equipment has a 20 to 40 year life. Ships, for instance, have an expected 40 year life and receive a thorough remanufacture every 5 years.
>
> The DOD spends $20 billion per year to maintain and "remanufacture" defense equipment. The Defense Logistics Agency (DLA), a supply agency, has six centers distributed nationally which buy and stock parts for remanufacturing and other operations.

Another good example of large scale remanufacturing is Western Electric's program. As both an OEM and a remanufacturer, Western Electric finds it cost effective to plan for remanufacturing when originally designing a product. Remanufacturing specifications are drawn up at the the same time as new developments are made. Seventy percent of all telephone handsets currently in use are remanufactured (34 million annually). Remanufacturing is done at 31 locations throughout the U.S. employing 12,000 people. Co-located with distribution centers, these plants have combined area of 3 million square feet and a net plant worth of $100 million.(6)

1.2.2 Remanufacturing Research at MIT

The CPA report Energy Recapture Through Remanufacture: Final Report of Pre-Demonstration Study(7), listed a set of criteria which can be used to determine whether a product can or should be remanufactured:

- Durable end product or durable component of end product.
- The product typically fails functionally, rather than by dissolution or dissipation.
- There is a "core" or discard that becomes the basis for the remanufactured product.
- Remanufacturing process restore the product to its original function.

These criteria were used to screen products listed in the Standard Industrial Clasification (SIC) to determine which SIC categories could be commercially suitable for remanufacture. In Exhibit 1-1, a segment of the results of the screening evaluation are shown. These categories include most of the products that are currently remanufactured. These and similar products can be studied using the analytical procedure described in this thesis. In this screening, products were placed into one of three groups:

1. Already remanufactured, labeled R.
2. Accepted as having potential for remanufacture, labeled A.
3. Rejected because it failed to meet one or more of the fine screening criteria, labeled with a number indicating which criterion indicated rejection.

The second screening used a different set of criteria remove product groups which would not be suitable for remanufacture. They determined that to be considered for remanufacture the product should have the following characteristics:

- Product is repairable
- Product is factory-built as opposed to field assembled.
- Product is standard with interchangeable parts.
- Product has high percentage of recoverable value-added relative to the original market price of the product. Value-added is defined as all product costs, including profit, except raw materials.
- Product has high economic potential (core economic value minus core market value).

These screening processes provided a useful tool for evaluating the potential for remanufacture of products across the entire spectrum of manufacturing. However, it is not a definitive evaluation of what can or cannot be remanufactured. The original objective of the screening was to select candidate products for an engineering feasibility study of a product not currently remanufactured. (Of three final candidates, chain saws, garbage disposers and motorcycle parts, commercial chain saws were selected for an in-depth study.)

One of the problems with of this approach is the nature of the SIC classification. At the four and five digit level, products are still highly aggregated; they represent product groups, not individual products. Many of the products rejected by this screening can and are being remanufactured. Two specific cases are SIC 37131- Truck, Bus and Other Vehicle bodies (except passenger car bodies); and 37132- Complete Vehicles (except passenger cars and motor homes). These products were selected as cases to be studied in this thesis.

In its conclusions, the report defined a remanufacturable product:

> A successfully remanufactured product must be a durable end product or a durable component of an end product. It is typically a standard product with interchangeable parts that is assembled on a factory basis. The product (technology) tends to be relatively stable, with changes occurring at moderate to slow rates. The characteristic failure mode leaves the product considerably less valuable, but ultimately repairable. Repair is deemed worthwhile because the product typically has a high recoverable value-added relative to the original market price of the product.(8)

1.2.3 Description of Remanufacturing Processes

Remanufacturing is a labor intensive process which usually does not require complex production equipment. If the product is mass-produced, the remanufacturer may benefit from economies of scale and can maintain low per-unit production costs. Many of the processes used in commercial remanufacturing would not be economical if the product were serviced on a one-by-one basis. Typical products remanufactured on a commercial scale include auto parts, refrigeration equipment, internal combustion engines, and hydraulic pumps and valves.

Remanufacturing offers a variety of social and economic benefits. It provides opportunites for training and development of industrial laborers, technicians, and managers. With its low capital equipment requirements, remanufacturing does not drain capital funds. Remanufacturing can be a source of essential industrial equipment, usually at 40 to 60 percent of the price of new equipment. Some of these are particularly valuable in a developing country.

Remanufacturing processes include core analysis, disassembly, cleaning, refurbishing of parts, assembly, and testing. The refurbishing, assembly, and testing processes use technology very similar to that used by the OEM in the manufacture of the product. Remanufacturers differ from OEMs in the processes and techniques which have been developed to disassemble and clean the product and to recondition its parts.

The remanufacturer is in an advantageous position to evaluate the failure modes of a large number of products, often more so than the OEMs. Remanufacturers quickly become familiar with the inherent design weaknesses of products. To prevent the remanufactured product from failing, OEM components which commonly fail may be redesigned by the remanufacturer. This often leads to better performance or a longer life than the original product.

In addition to component re-design, the performance, mechanisms, and controls of many machines can be upgraded to current technology during the process of remanufacture. Adding electronic controls to old machine tools,(9) incorporating laser sighting systems in Army tanks,(10) and retrofitting electronic ignition monitoring and control devices to internal combustion engines are examples of ways which equipment can be upgraded to better than original specifications through remanufacture.

1.2.4 Remanufacturing vs. Servicing.

Remanufacturing is often confused with other processes such as repairing, refurbishing, rebuilding, reconditioning, overhauling, recycling, etc.; but there are important differences which make remanufacturing unique.

To repair a product is to first diagnose the cause of failure and then take whatever action is necessary to make it functional again. When a product is repaired, only the failed part is replaced or fixed; the rest of the product remains the same. Repairs take place throughout the useful life of the product as failures occur.

Rebuilding is synonymous with reconditioning. This process is more comprehensive than repair in that the complete product is inspected and badly worn parts are replaced or refurbished. Usually the objectives is to make the product fuctional again at the lowest possible cost. A rebuilt product will have a number of parts which are worn but which remain in the product for economic reasons. Rebuilding and reconditiong are "stop gap" measures used to extract the last useful life from a product prior to scrapping or replacement. This kind of work may be done by the owner or at a service center. The product usually goes back to its original owner. During repair there is little effort or opportunity to change the design and performance of the product.

Refurbishing usually applies to operations performed on individual components or parts of a larger mechanism. Refurbishing is the process of bringing a component or an individual part back to "like new" condition. Refurbishing is only one of the steps in the remanufacture of a product.

The main features of remanufacturing which distinguish it from these other processes are:

- The final product is "like new" or better.
- Cores are pooled into production batches. This allows use of productions techniques and processes not economically feasible in the one-by-one repair of products.
- A finished product may contain parts from several different cores.
- Regardless of condition, most interface parts (seals, bearings, gaskets) are replaced with new on all units.

Several remanufacturers (producers of a product) choose to call themselves rebuilders (providers of a service). There may be some tax advantages in this choice, but the two terms are generally used interchangeably. The definitions of terms provided lively discussions at both of the remanufacturing conferences held at MIT.

1.3 Types of Remanufacturing Operations

A firm engaged in remanufacturing will either be affiliated with the OEM or will be an independent firm. Subdividing these are two types of operations: commercial and contract remanufacturers. The distinction between commercial and contract remanufacturing is ownership of the core: contract remanufacturers service cores provided by the customers while commercial remanufacturers purchase cores needed for operations. There are only minor differences in the production facilities and organization of firms engaged in these two kinds of remanufacturing, and there is no clear-cut distinction between products which should should be remanufactured on a contract or on a commercial basis. For some products both types are common, and some firms do both contract and commercial remanufacturing.

1.3.1 Commercial Remanufacturing

Commercial remanufacturing is usually done to relatively high-volume, low-priced (less than $2,000) products. The low per-unit values make it possible to collect many cores and process them on a large scale basis. Cores are needed both for work in process and to prepare for future product remanufacture. After processing, cores incorporated in finished products are still owned by the remanufacturer until payed for by the customers.

Commercial remanufacturers usually handle a broad product line which may contain products from several different OEMs. Production involves pooling of interchangeable parts and the consolidation of part numbers for large batches of cores. These are processed on a continuous basis using mass production techniques (assembly lines, production cells, large batches) similar to the OEM's. There is usually a well established distribution network for the product.

1.3.2 Contract Remanufacturing

Firms in this category do not take title to the core. Work is done for the owner or operator of the equipment. A variation is the remanufacturer who purchases cores from a one company and remanufactures them on a contract basis for a different customer. A contract remanufacturer will not begin work without having a firm commitment on a final purchase agreement. Products which are remanufactured under contract include telephone handsets, construction equipment, trucks, airplanes, powerplants, commercial machinery, and railroad equipment.

A firm may engage in both contract and commercial remanufacturing. In the case of complex products remanufactured on a contract basis, many components can be remanufactured on a commercial scale. An example of this type of operation is municipal vehicles where the remanufacture of the engine, transmission, and other drive components is sub-contracted to commercial remanufacturers. Other equipment on the vehicles such as refuse packers, refrigerated bodies, or various kinds of hydraulic equipment may be similarly treated.

EXHIBIT 1-1 PRODUCT SAMPLE FOR STUDY (from.7)

Product Selection Criteria:

1) Durable end product or durable component of end product.
2) The product typically fails functionally, rather than by dissolution or dissipation.
3) There is a "core" or discard that becomes the basis for the remanufactured product.
4) Remanufacturing processes could restore the product to its original shape, nature or condition.
5) Product would be remanufactured with intent to restore its original function.

Analytical Procedure Described in Text Applies to all these Products

INDIVIDUAL DURABLE MANUFACTURED PRODUCTS
SELECTED FROM ACCEPTED INDUSTRY DEFINITIONS

34942	Valves for Power Transfer (Pneumatic and Hydraulic)	R
34943	Other Metal Valves for Piping Systems and Equipment	R
34944	Plumbing and Heating Valves	R
34947	Automatic Regulating and Control Valves	R
34948	Solenoid Valves	R
3519	Internal Combustion Engines,N.E.C.	
35191	Gasoline Engines, Under 11 Horsepower, Except Aircraft, Automobile, Truck, Bus and Tank	A
35192	Gasoline Engines, 11 Horsepower and Over, Except Aircraft, Automobile, Truck, Bus and Tank	A
35193	Diesel and Dual Fuel Engines (Except Automotive)	R
35194	Diesel and Fuel Engines (Automotive)	R
35195	Outboard Motors	A
35196	Gas Engines (Except Gas Turbines)	A
35197	Other Internal Combustion Engines	A
35199	Parts and Accessories for Internal Combustion Engines, Except Aircraft and Gasoline Automotive Engines and Gas Turbines	R
3541	Machine Tools, Metal Cutting Type	
35411	Boring Machines	R
35412	Drilling Machines	R
35413	Gear Cutting and Finishing Machines	A
35414	Grinding and Polishing Machines (Excluding Gear Tooth Grinding), Honing, Lapping, Polishing and Buffing Machines	A

35415	Lathes	A
35416	Milling Machines	R
3542	<u>Machine Tools, Metal Forming Types</u>	
35421	Punching, Shearing, Bending and Forming Machines	A
35422	Presses, Including Forging and Manual Presses	A
3544	<u>Special Dies, Tools, Jigs, and Fixtures</u>	
35442	Industrial Molds	R
35492	Assembly Machines	A
35493	Welding and Cutting Apparatus Except Electric	A
35494	Automotive Maintenance Equipment	A
3585	<u>Refrigeration and Heating Equipment</u>	
35851	Heat Transfer Equipment, Except Electrically Operating Dehumidifiers, Mechanically Refrigerated, Self-Contained	A
35852	Unitary Air Conditioners	A
35853	Commercial Refrigerators and Related Equipment	A
35854	Compressors and Compressor Units, All Refrigerants	R
35855	Condensing Units, All Refrigerants	A
35856	Room Air-Conditioners and Dehumidifiers	R
35857	Other Refrigeration and Air-Conditioning Equipment, Including Soda Fountain and Beer Dispensing Equipment	A
35858	Warm Air Furnaces, Except Electric (Except Floor and Wall) and Parts and Attachments	A
3599	<u>Machinery, Except Electrical</u>	
35992	Hydraulic and Pneumatic Cylinders, Accumulators and Cushion; and Non-Vehicular Shock Absorbers	A
35994	Miscellaneous Machinery Products, Including Flexible Metal Hose and Tubing, Metal Bellows, etc.	5
3623	<u>Welding Apparatus, Electric</u>	
36231	Arc Welding Machines, Components, and Accessories, Except Electrodes	A
36232	Arc Welding Electrodes, Metal	1
36233	Resistance Welders, Components, Accessories, and Electrodes	A
3694	<u>Engine Electrical Equipment</u>	
36941	Ignition Harness and Cable Sets	1
36942	Battery Charging Alternators, Generators and Regulators	R
36943	Cranking Motors	R

36945	Other Complete Electrical and Electronic Equipment for Internal Combustion Engines A Distributors	A
3711	<u>Motor Vehicles and Car Bodies</u>	
37111	Passenger Cars, Knocked Down or Assembled and Chassis for Sale Separately	R
37112	Truck Tractor, Truck Chassis and Trucks (Chassis of own Manufacture)	R
37113	Buses (Except Trolley Buses) and Fire Department Vehicles (Chassis of own Manufacture)	R
37114	Combat Vehicles, Wheeled or Tracked Tactical Vehicles or Carriers (Excluding Tanks and Self-Propelled Weapons)	A
37115	Passenger Car Bodies	5
37131	Truck, Bus and Other Vehice Bodies (Except Passenger car bodies) for sale separately	5
37132	Complete Vehicles (except Passenger Cars and Motor Homes) Produced on Purchased Chassis	5
3714	<u>Motor Vehicle Parts and Accessories</u>	
37141	Parts and Accessories for Motor Vehicles, Passenger Cars, trucks, and Buses	R
37143	Rebuilt Engines and Parts for Motor Vehicles Except Carburetors (Passenger Cars, Trucks, and Buses)	R
	Fuel Pumps	R
	Water Pumps	R
	Oil Pumps	R
	Clutch Discs and Pressure Plates	R
	Engines, gasoline	R
	Automatic Transmissions	R
	Manual Transmissions	R
	Brake Shoe Assemblies (drum brake)	R
	Brake Shoe Assemblies (disc brake)	R
	All other rebuilt parts	R
3715	<u>Truck Trailers</u>	
	Truck Trailers and Chassis	A

Chapter Two: Trucks and Truck Mounted Equipment

2.0 Introduction

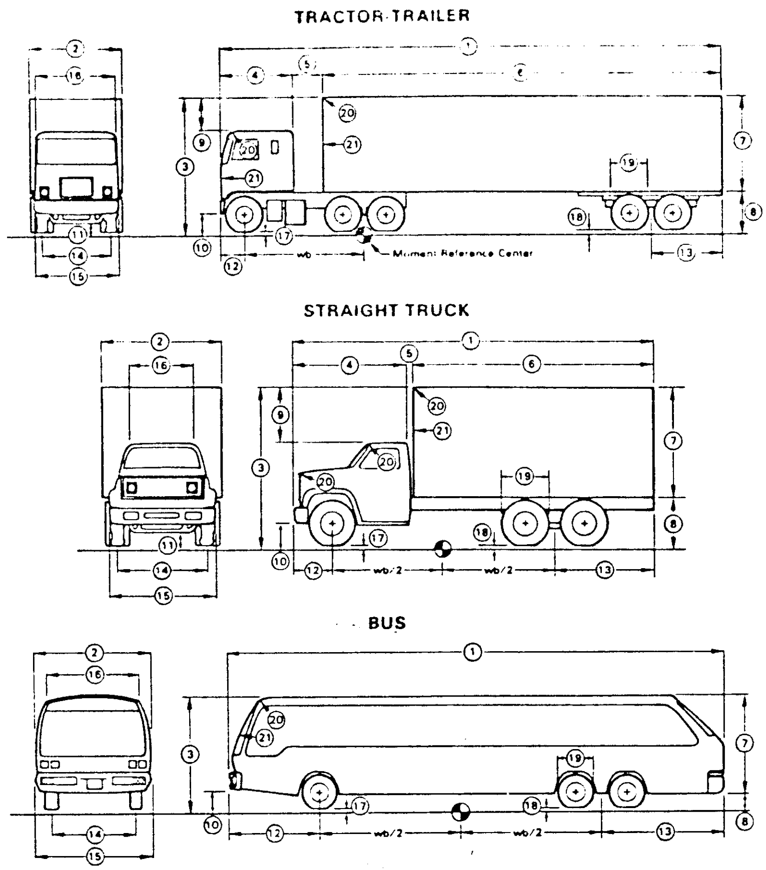
This chapter is a brief introduction to the product, its market, and its role in society. Trucks were selected as typical of products whose remanufacturability may be established using the analytical procedure described in the this chapter.

A truck can be any one of various heavy automotive vehicles designed to carry loads. There are may kinds of "trucks" ranging from the currently popular mini pickup to the 100+ ton off-highway strip mining haulers. Trucks replaced horse drawn vehicles as the chief mode of commercial transport in the early 1900s. Over the years they have become faster, stronger, and much more reliable than their predecessors.

Truck mounted equipment such as dump bodies, cement mixers, pumpers, refuse packers and refrigerated (reefer) bodies have changed the way the utility, construction, and commercial companies operate. Many types of cargo requirin transportation were limited to destinations located along the railways, the need to reach other markets has led to a gradual change over to trucks. Many companies (public and private) depend on trucks for their day-to-day activities. Over the years vehicles and equipment have become more complex and expensive, as a result the need to develop ways to prolong the useful life of the vehicles has been a constant concern of all equipment owners and operators.

2.1 Characteristics of Trucks Currently in Use

There are three basic types of heavy duty vehicles: tractors, straight trucks, and buses. Figure 2-1 shows sketches of the three basic truck applications and the names used for some of the important vehicle dimensions (11).



1. Overall Length
2. Overall Width
3. Overall Front Height
4. Cab Length
5. Gap Length
6. Trailer/Box Length
7. Rear Body Height
8. Rear Ground Clearance
9. Roof Height Differential
10. Front Ground Clearance
11. Minimum Ground Clearance
12. Front Overhang
13. Rear Overhang
14. Front Track Width
15. Front Bumper Width
16. Roof Width
17. Front Wheel Air Gap
18. Rear Wheel Air Gap
19. Typical Tire Size and Diameter
20. Leading Edge Geometry
21. Front Side Edge Geometry
22. Wheel Base
23. Projected Frontal Area

Figure 2-1 Basic Truck Applications (11)

Table 2-1 shows the distribution of vehicles in the United States by use, body type, annual miles traveled, mode of acquisition and model year (12). Although the types of vehicles and their applications change over time, this table can be used as a rough measure of the vehicle and equipment types used by an industrialized nation such as the United States. Additional data such as equipment age, make, and model would be desirable for more complete analysis of the market.

2.2 Vehicle Production Statistics

The production volumes for 1978 and 1979 for the 25 nations that produce motor vehicles are shown in Table 2-2 (13). The United States and Japan are the leaders in the industry, so of course US and Japanese cores are the most readily available. Most of the data gathered for this thesis is related to trucks manufactured in the United States, especially Ford, General Motors, and International Harvester Trucks. Foreign manufacturers will not be considered here due to problems related to access to technical information, cores, and replacement parts.

The production of trucks and buses for each of the major U.S. manufacturers is shown in Table 2-3 (14). The U.S. industry leaders are Ford and Chevrolet with over 1.2 million units per year each. There is no breakdown available to the public on the sales of each model, but the aggregate statistics are useful as a guideline on the size of the market. Imports accounted for 13.5% of truck sales in the U.S. in 1979 as compared to 21.8% of car sales.

Most truck manufacturers have a product line which features several body/chassis combinations. Each model is available in different wheelbase sizes and comes with a wide selection of optional equipment. One reason such a wide range of choices is available from U.S. manufacturers is that users may select components and options which are ideally suited for a specific application.

CHARACTERISTICS OF TRUCKS OWNED (In Thousands)

Characteristic	Total Trucks		Truck Size Class			
	Number	Percent	10,000 Or Less Lbs. GVW	10,001-19,500 Lbs. GVW	19,501-26,000 Lbs. GVW	26,001-Or More Lbs. GVW
MAJOR USE						
Agriculture	4,248.8	16.2%	3,269.8	477.2	288.8	212.9
Forestry	217.5	0.8	111.8	29.8	17.7	58.2
Mining	139.0	0.5	70.2	17.9	10.6	40.3
Construction	1,764.9	6.7	1,237.9	169.9	103.3	253.7
Manufacturing	368.5	1.4	174.4	53.4	30.1	110.5
Wholesale and Retail Trade	2,007.9	7.7	1,252.2	291.6	188.2	275.7
For Hire (1)	653.8	2.5	104.0	124.4	60.4	364.9
Personal Transportation	14,260.6	54.4	14,108.1	150.3	1.9	2
Utilities	481.2	1.8	361.8	57.9	34.1	27.3
Services	1,641.3	6.3	1,371.4	155.2	49.0	65.7
All Other (2)	429.6	1.6	333.3	55.3	18.1	22.8
BODY TYPE						
Pickup, Panel, Multi Stop, or Walk-in	22,151.0	84.5%	21,714.9	429.4	5.8	7
Platform (3)	1,278.2	4.9	269.4	415.6	273.6	319.5
Platform With Added Device	333.1	1.3	66.3	120.8	77.4	68.6
Cattlerack	168.0	0.6	50.6	58.1	32.9	26.2
Insulated Nonrefrigerated Van	58.0	0.2	2.9	13.4	9.8	31.9
Insulated Refrigerated Van	150.5	0.6	6.1	37.7	26.8	79.7
Furniture Van	117.6	0.5	16.8	45.1	20.5	35.1
Open Top Van	30.0	0.1	2.2	8.2	2.9	16.6
All Other Vans	531.3	2.0	15.7	143.7	81.5	290.3
Beverage Truck	67.9	0.3	.6	12.7	26.2	28.3
Utility Truck	200.7	0.8	106.6	55.9	24.4	13.7
Garbage and Refuse Collector	50.7	0.2	1.2	7.7	11.7	29.9
Winch or Crane	92.9	0.4	23.3	38.3	12.5	18.8
Wrecker	101.2	0.4	68.6	23.3	5.4	3.8
Pole and Logging	60.0	0.2	2.0	9.5	8.3	40.2
Auto Transport	15.1	0.1	9	1.2	.6	12.4
Dump Truck	452.0	1.7	31.8	107.0	101.5	211.7
Tank Truck for Liquids	236.9	0.9	7.0	48.5	63.4	117.9
Tank Truck for Dry Bulk	34.8	0.1	–	3.1	7.6	24.1
Concrete Mixer	56.0	0.2	–	--	2.7	53.3
All Other (4)	27.1	0.1	8.0	3.5	6.7	8.8
ANNUAL MILES						
Less Than 5,000 Miles	6,279.7	24.0%	5,083.7	613.6	332.3	250.0
5,000 to 9,999 Miles	6,297.9	24.0	5,616.6	332.5	168.9	179.8
10,000 to 19,999 Miles	9,690.6	37.0	8,851.2	395.8	175.5	268.0
20,000 to 29,999 Miles	2,407.7	9.2	2,045.4	138.6	66.7	157.0
30,000 to 49,999 Miles	980.1	3.7	677.1	75.4	42.5	185.0
50,000 to 74,999 Miles	291.5	1.1	92.8	20.4	12.4	165.9
75,000 Miles or More	265.7	1.0	28.1	6.7	4.2	226.6
ACQUISITION						
Purchased New	12,482.7	47.6%	10,490.1	769.0	409.8	813.7
Purchased Used	13,113.2	50.0	11,416.6	771.1	371.2	554.3
Leased and Not Reported (5)	617.3	2.4	488.3	43.1	21.5	64.4
YEAR MODEL						
1978 and 1977	2,070.6	7.9%	1,897.1	63.5	26.4	83.5
1976 and 1975	4,356.0	16.6	3,829.1	208.1	99.1	219.5
1974 and 1973	5,149.1	19.6	4,439.1	245.6	133.8	330.3
1972 and 1971	3,848.3	14.7	3,327.9	193.8	95.1	231.3
1970 and 1969	3,061.8	11.7	2,586.7	180.7	103.5	190.8
Pre-1969	7,727.3	29.5	6,314.7	691.1	344.5	376.8
TOTAL TRUCKS	**26,213.4**	**—**	**22,395.1**	**1,583.2**	**802.5**	**1,432.5**
TOTAL PERCENT	**—**	**100.0%**	**85.4**	**6.0**	**3.1**	**5.5**

(1) For-Hire includes for hire and daily rental.
(2) All other includes other not in use and not reported.
(3) Platform includes low boy with depressed center and other platform.
(4) Other includes other and not reported, boat transport and mobile home puller.
(5) Leased from someone else and not reported were added together.

SOURCE: U.S. Bureau of the Census, *1977 Census of Transportation, Truck Inventory and Use Survey.*

Table 2-1 Truck Characteristics (12)

WORLD MOTOR VEHICLE PRODUCTION 1978-1979

Country	1978 Passenger Cars	1978 Trucks and Buses	1978 Total	1979 Passenger Cars	1979 Trucks and Buses	1979 Total
Argentina	133,416	45,744	179,160	191,851	61,031	252,882
Australia	316,526	68,440	384,966	405,304	56,164	461,468
Austria	—	5,486	5,486	2,781	6,595	9,376
Belgium	265,765	37,495	303,260	278,259	36,738	314,997
Brazil	535,442	526,755	1,062,197	498,334	629,632	1,127,966
Canada	1,143,425	675,067	1,818,492	987,673	643,988	1,631,661
Czechoslovakia	175,585	42,983	218,568	182,090	49,697	231,787
France	3,111,380	396,550	3,507,930	3,220,394	393,064	3,613,458
East Germany	171,000	36,700	207,700	173,500	36,500	210,000
West Germany	3,890,176(1)	296,188	4,186,364	3,932,556(2)	317,169	4,249,725
Hungary	—	15,973	15,973	—	13,814	13,814
India	32,855	64,258	97,113	29,233	72,044	101,277
Italy	1,508,597	147,967	1,656,564	1,480,991	151,167	1,632,158
Japan	5,975,968	3,293,185	9,269,153	6,175,771	3,459,775	9,635,546
Mexico	242,519	141,608	384,127	280,049	164,377	444,426
Netherlands	64,881	11,316	76,197	90,000	16,850	106,850
Poland	340,000	77,500	417,500	358,800	70,000	428,800
Portugal	—	592	592	—	259	259
Romania	72,000	48,000	120,000	72,200	51,000	123,200
Spain	986,116	157,715	1,143,831	965,809	157,109	1,122,918
Sweden	254,256	51,278	305,534	296,540	58,280	354,820
Switzerland	100	1,201	1,301	—	1,464	1,464
United Kingdom	1,222,949	384,518	1,607,467	1,070,452	408,060	1,478,512
United States	9,176,635	3,722,567	12,899,202	8,433,662	3,046,331	11,479,993
U.S.S.R.	1,312,000	839,000	2,151,000	1,314,000	859,000	2,173,000
Yugoslavia	252,075	27,684	279,759	285,262	29,848	315,110
Total	**31,183,666**	**11,115,770**	**42,299,436**	**30,725,511**	**10,789,956**	**41,515,467**

(1) Includes 264,675 micro-buses.
(2) Includes 274,896 micro-buses.
NOTE: As far as possibly can be determined, production in this table refers to vehicles locally manufactured.
SOURCE: Compiled by the Motor Vehicle Manufacturers Association of the U.S., Inc. from various sources.

Table 2-2 World Motor Vehicle Production (13)

U.S./CANADA MOTOR VEHICLE PRODUCTION

	United States			Canada			Total		
	1977	1978	1979	1977	1978	1979	1977	1978	1979
TRUCKS AND BUSES									
AM General	27,497	20,922	23,934	—	—	—	27,497	20,922	23,934
Chrysler	474,001	488,180	295,228	117,260	95,415	60,872	591,261	583,595	356,100
Ford	1,186,013	1,233,243	1,032,117	212,582	252,313	214,423	1,398,595	1,485,556	1,246,540
Chevrolet	1,122,169	1,216,050	1,015,092	256,351	283,142	288,788	1,699,529	1,874,192	1,641,261
GMC	321,009	375,000	337,381						
International	110,894	123,123	115,453	19,862	19,325	20,153	130,756	142,448	135,606
Jeep	162,231	180,514	134,624	—	17,881	51,925	162,231	198,395	186,549
Mack	30,178	33,114	35,937	4,009	3,534	3,849	34,187	36,648	39,786
Volkswagen of America	—	—	2,407	—	—	—	—	—	2,407
White	25,195	13,217	11,251	2,392	3,457	3,978	27,587	16,674	15,229
Others	29,941	39,204	42,907	—	—	—	29,941	39,204	42,907
Total Trucks & Buses	**3,489,128**	**3,722,567**	**3,046,331**	**612,456**	**675,067**	**643,988**	**4,101,584**	**4,397,634**	**3,690,319**

Table 2-3 U.S./Canada Motor Vehicle Production (14)

Remanufacturing could have a significant impact in this industry by extending the service life of existing vehicles and equipment and by increasing the resale value of existing trucks. Users of equipment can more easily afford to replace old vehicles with new or remanufactured ones by getting higher trade-in allowances.

2.3 Uses and Classes of Truck Mounted Equipment

Truck mounted equipment tailors vehicles to specific work tasks performed daily in industry. The equipment may be used to carry, hoist, mix, pump, refrigerate, tow or store almost any product or material. The role of the truck is to move the equipment to the work site and (in some cases) provide power to the equipment mounted on it.

Truck mounted equipment is sometimes more valuable than the truck on which it is mounted. In most cases the equipment is made by a different manufacturer than the vehicle and installed later by the equipment manufacturer or one of its distributors. Usually the equipment will outlast the truck on which it was originally installed. A common practice is to transplant the equipment on to a new chassis and discard the old chassis. Sometimes this can happen two or more times before the equipment is fully worn out.

Various types of truck mounted equipment are excellent candidates for remanufacture. Table 2-4 shows some of the equipment classes on which data was gathered and studied to determine potential candidates for remanufacture. Equipment and body builders are scattered throughout the United States. They range in size from "mom and pop" companies to some of the largest multinationals. The remanufacturing processes described in the following sections apply to equipment made by any size company.

A remanufacturer planning to handle a sample of the types of equipment listed above must be flexible and well organized. Each type of equipment requires an investment in specialized toolings, inventories, and labor training. One strategy which can be used by the remanufacturer

Table 2-4. Equipment Classes*

1. Utility Equipment for Power Companies
   - Aerial Devices (Insulated and Non-Insulated)
   - Derrick Diggers
   - Line Installation Trucks
   - Insulator Washers

2. Hydraulic Platforms and Aerial Devices for Other Applications
   - Fire Fighting
   - Military
   - Industrial

3. Cranes and Hoists
   - Telescoping Truck Mounted Cranes
   - Knuckle Booms
   - Rigid Boom Cranes
   - Crane Carrier Chassis

4. Construction Equipment
   - Dump Trucks
   - Flat Bed Trucks (cargo and equipment hauling)
   - Cement Pumpers
   - Cement Mixer Trucks
   - Mobile Service Vehicles
   - Earth Moving Equipment

5. Waste Disposal Equipment
   - Refuse Packers
   - Liquid Waste Trucks
   - Hazardous Waste Disposal Equipment
   - Piggy Back Platforms and Containers (Roll Offs)

6. Commercial Equipment
   - Refrigerator (Reefer Bodies)
   - Parcel Vans
   - Beverage Bodies
   - Trailers
   - Yard Tractors
   - Armored Vehicles

7. Buses and Mass Transport Vehicles
   - Mini-Buses
   - Urban Transport Buses
   - Highway Buses
   - School Buses

* This is a partial list of truck mounted equipment. The variety of truck mounted equipment is so large it would require several pages.

is to specialize in certain types of equipment or power systems such as hydraulic or pneumatic and gradually broaden shop capabilities to other equipment as the market demand grows and as financing permits.

Many types of equipment are assembled using similar or identical components and the skills and tools used to remanufacture one specific type of equipment can be extended to others. The biggest problems in covering many products with a limited facility lie in the sourcing of replacement parts and in inventory control. These problem are partially relieved by such practices as consolidation of part numbers and limiting the number of products remanufactured. A practical plan might be to remanufacture products made by three or four OEMs who are willing to offer technical support by providing the necessary parts drawing and technical data. The project is likely to run into difficulty if too many kinds of equipment are serviced.

2.4 Estimating the Market for Remanufactured Trucks

The world vehicle population statistics in Exhibit 2-1 (15),can be used to estimate the demand for automobiles and trucks in selected developing countries. One way to determine the need for vehicles in these nations is to compare the population per vehicle statistics. The United States has the lowest ratio of persons per vehicle in the world with a vehicle for every 1.3 persons. By comparison, Japan has 5.4 persons per vehicle. Most of the "emerging" developing nations, i.e., those that have natural and industrial resources that could support a large vehicle population, have ratios that range from 16 for Brazil to 22,815 for China. The need for vehicles in these countries is reflected by the aggressive national vehicle production efforts. But even with government subsidized production, there is still a greater market for vehicles in these countries than will be satisfied by local production.

In many nations, trucks represent the only form of commercial transportation. In all countries, they provide a vital link between the market and other modes of commercial transport (barges, pipelines, rail and air). In addition to transporting cargo, trucks are used to carry equipment to worksites. Trucks with equipment such as refuse packers, utility devices, cranes, pumps, cement mixers, refrigerated bodies, etc. have become an integral part of the commercial infrastructure of industrialized nations.

The market for the production of remanufactured vehicles on a commercial scale has yet to be exploited. The primary reason for this may be OEM "planned obsolescence" and corporate strategies which emphasize new product sales. The only OEM currently engaged in complete truck remanufacturing is Mack Trucks Inc. This operation only accounts for a small fraction of the potential market.

This situation will change as more large fleets set up programs to remanufacture their trucks and bring pressure to bear on the OEMs. Examples include Wells Fargo (armored trucks)(16), Frito Lay (delivery vans), and Alabama Power and Light, (utility aerial devices)(10). A number of mass transit operators such as AC Transit of Oakland, MARTA of Atlanta, NYCTA of New York, SEPTA of Philadelphia, KCATA of Kansas City, and RTD of Denver have studied contractual versus in-house rehabilitation of their busses.(17)

Present contract remanufacturing of trucks and truck mounted equipment tends to be for a limited number of vehicles. Vehicle cores received by the remanufacturer vary widely in condition, making operations difficult to standardize. Many vehicle fleet operators such as trucking companies, utilities, municipalities, and construction companies have established some type of in-house reconditioning or rebuilding program. Technically speaking, most of these shops are not engaged in "remanufacturing" since the work done is usually a "stop-gap" measure performed to keep the truck on the road at the lowest possible cost. As seen in Table 2-1, used vehicle sales represent 50% of the total truck and bus market.

Many truck dealers and service centers have performend extensive overhauls to all types of vehicles and equipment. Much of this is made possible by the conscious design for repairability and the use of durable materials by the OEMs. There are very few parts in a truck which can not be fixed or remanufactured. In fact, most components sold in the automotive aftermarket are rebuilt or remanufactured components.

The age distribution of the vehicle population infuences the size and composition of the service aftermarket. As vehicles get older, they will require more repairs and complete overhauls. As shown in Table 2-5, the number of vehicles 16 years or older continues to grow. By 1979 over 2.7 million trucks in this age category were registered in the U.S. alone (18). These vehicles create a market for remanufactured replacement components in addtion the retired vehicles are a potential source of cores truck remanufacturers.

Trucks and truck mounted equipment are built for a service life of about ten years. These products are designed for easy service and maintenance. As prices increase, owners have been paying more attention to practices which extend the productive life of their equipment. Preventive maintenance programs and scheduled service are now common practice in the industry.

Automotive products are remanufactured on a commercial scale and have a well-established core market and distribution network. As shown in Figure 2-2 remanufactured auto parts such as alternators, generators, carburators, clutches, starters and water pumps have a larger percentage of sales in the replacement parts aftermarket than new parts (19). If trucks, truck mounted equipment, and components could achieve a market penetration comparable to that of automobile parts, the market demand for remanufactured trucks and equipment would be quite large.

TRUCKS IN USE BY AGE

Age in Years (1)	1965 Number (000)	1965 Percent Simple	1965 Percent Cum.	1970 Number (000)	1970 Percent Simple	1970 Percent Cum.	1975 Number (000)	1975 Percent Simple	1975 Percent Cum.	1979 Number (000)	1979 Percent Simple	1979 Percent Cum.
Under 1	946	7.2%	100.0%	1,262	7.1%	100.0%	1,326	5.3%	100.0%	2,402	7.4%	100.0%
1-2	1,219	9.3	92.8	1,881	10.6	92.9	2,739	11.0	94.7	3,541	10.9	92.6
2-3	1,057	8.1	83.5	1,536	8.7	82.3	2,848	11.5	83.7	3,231	9.9	81.7
3-4	926	7.1	75.4	1,428	8.1	73.6	2,384	9.6	72.2	2,679	8.2	71.8
4-5	732	5.6	68.3	1,483	8.4	65.5	1,730	7.0	62.6	2,006	6.2	63.6
5-6	817	6.2	62.7	1,339	7.6	57.1	1,668	6.7	55.6	2,589	7.9	57.4
6-7	777	5.9	56.5	1,154	6.5	49.5	1,779	7.2	48.9	2,587	7.9	49.5
7-8	550	4.2	50.6	975	5.5	43.0	1,395	5.6	41.7	2,140	6.7	41.6
8-9	623	4.8	46.4	826	4.7	37.5	1,273	5.1	36.1	1,501	4.6	35.0
9-10	662	5.0	41.6	621	3.5	32.8	1,256	5.1	31.0	1,435	4.4	30.4
10-11	696	5.3	36.6	658	3.7	29.3	1,085	4.4	25.9	1,459	4.5	26.0
11-12	486	3.7	31.3	583	3.3	25.6	884	3.6	21.5	1,111	3.4	21.5
12-13	559	4.3	27.6	383	2.2	22.3	697	2.8	17.9	958	2.9	18.1
13-14	482	3.7	23.3	417	2.4	20.1	554	2.2	15.1	906	2.8	15.1
14-15	563	4.3	19.6	414	2.3	17.7	388	1.6	12.9	749	2.3	12.3
15-16	570	4.3	15.3	432	2.4	15.4	391	1.6	11.3	595	1.8	10.0
16 & Older	1,441	11.0	11.0	2,278	13.0	13.0	2,393	9.7	9.7	2,687	8.2	8.2
Subtotal	13,106	100.0%	—	17,671	100.0%	—	24,790	100.0%	—	32,576	100.0%	—
Year Not Given	21	—	—	15	—	—	23	—	—	7	—	—
Total	13,127	—	—	17,686	—	—	24,813	—	—	32,583	—	—
Average Age	7.98 Years			7.33 Years			6.94 Years			6.89 Years		

(1) Each class interval includes lower but not higher age.
NOTE: Data as of July 1 of each year.
SOURCE: Compiled by the Motor Vehicle Manufacturers Association from R. L. Polk & Co. data. Permission for further use must be obtained from R. L. Polk & Co.

AVERAGE AGE OF TRUCKS IN USE IN U.S.

Year	Years Old	Year	Years Old
1979	6.9	1962	8.0
1978	6.9	1961	7.9
1977	6.9	1960	7.7
1976	7.0	1959	7.5
1975	6.9	1958	7.2
1974	7.0	1957	7.0
1973	6.9	1956	6.8
1972	7.2	1955	6.7
1971	7.4	1954	6.6
1970	7.4	1953	6.6
1969	7.4	1952	6.6
1968	7.6	1951	6.6
1967	7.7	1950	7.0
1966	7.8	1948	7.8
1965	8.0	1946	8.6
1964	8.1	1944	7.6
1963	8.1	1941	5.6

SOURCE: Estimated by the Motor Vehicle Manufacturers Association of the U.S. Inc.

MOTOR TRUCKS BY AGE GROUPS

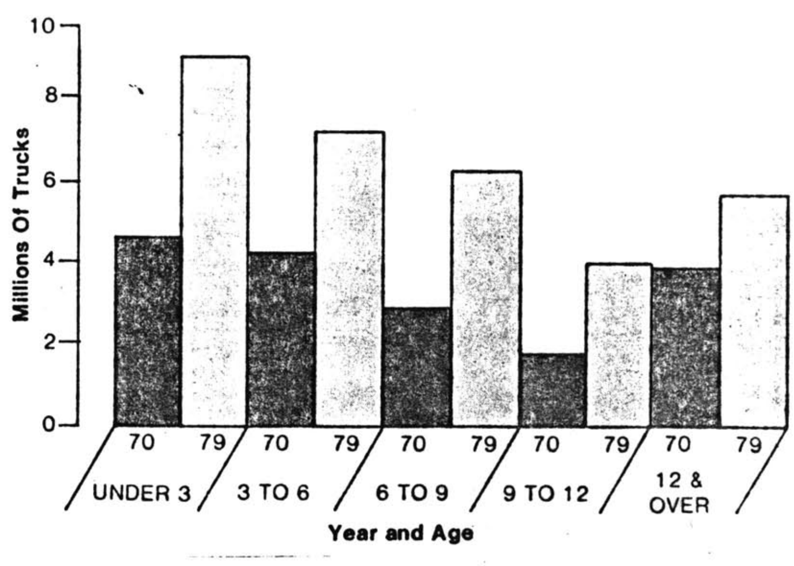
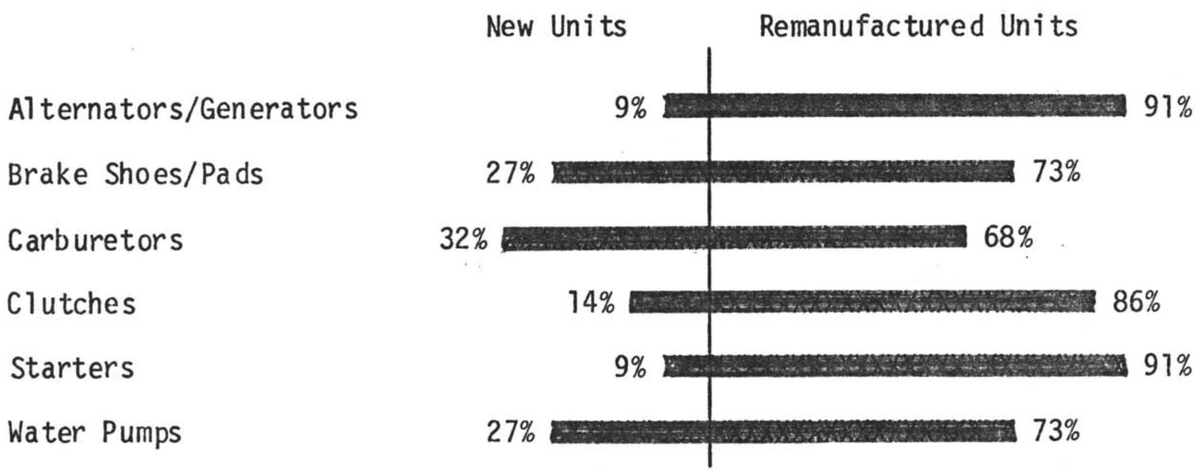


Table 2-5 U.S. Vehicle Population Age Statistics (18)

Figure 2-2. Remanufactured vs. New Product Sales



Source: Mr.C.P. Schwartz, Corporate Profile: Champion Parts Rebuilders Oak Brook, Illinois.

WORLD MOTOR VEHICLE REGISTRATIONS, 1978

Continent/Country	Cars	Trucks & Buses	Total Vehicles	Population Number (000)	Population Per Car	Population Per Vehicle
NORTH & CENTRAL AMERICA						
Antigua	6,500	1,900	8,400	70	11	8.3
Bahamas	37,947	5,668	43,615	230	6.1	5.3
Barbados	25,000	4,000	29,000	250	10	8.6
Belize	7,510	3,500	11,010	149	20	14
Bermuda	13,303	2,580	15,883	54	4.1	3.4
Canada	9,744,994	2,770,798	12,515,792	23,500	2.4	1.9
Costa Rica	65,000	75,000	140,000	2,110	32	15
Dominican Rep.	85,000	45,000	130,000	5,120	60	39
El Salvador	63,688	54,862	118,550	4,260	67	29
Guadeloupe	40,000	7,000	47,000	370	9.3	7.9
Guatemala	124,000	25,000	149,000	6,620	53	44
Haiti	19,500	6,100	25,600	4,830	248	189
Honduras	36,200	19,950	56,150	2,830	78	50
Jamaica	65,200	20,000	85,200	2,090	32	25
Mexico	3,009,809	1,213,858	4,223,667	66,940	22	16
Netherlands Antilles	45,000	7,000	52,000	250	5.6	4.8
Nicaragua	41,035	25,476	66,511	2,400	59	36
Panama	80,000	24,000	104,000	1,830	23	18
St. Kitts	2,400	500	2,900	70	29	24
St. Lucia	4,000	2,000	6,000	110	28	18
St. Vincent	3,911	787	4,698	100	26	21
Trinidad/Tobago	131,467	28,554	160,021	1,130	8.6	7.1
U.S.A.	116,574,999	32,202,966	148,777,965	219,484	1.9	1.5
Canal Zone	17,000	500	17,500	44	2.6	2.5
Virgin Isls.	33,500	6,750	40,250	100	3.0	2.5
Puerto Rico	796,103	184,097	980,200	3,358	4.6	3.4
Total	131,073,066	36,737,846	167,810,912	348,299	2.7	2.1
SOUTH AMERICA						
Argentina	2,729,732	1,133,385	3,863,117	26,390	9.7	6.8
Bolivia	38,140	50,255	88,395	5,140	135	58
Brazil	6,926,866	1,875,000	8,801,866	115,400	16	13
Chile	335,783	192,976	528,759	10,860	32	20
Colombia	470,000	110,000	580,000	25,640	55	44
Ecuador	61,000	123,200	184,200	7,810	128	42
Falkland Isls.	586	90	676	2	3.4	3.0
Guyana	31,918	12,926	44,844	820	26	18
Paraguay	27,500	17,350	44,850	2,890	105	64
Peru	311,040	158,572	469,612	16,820	54	36
Surinam	25,950	7,300	33,250	450	17	14
Uruguay	127,107	104,088	231,195	2,860	23	12
Venezuela	1,269,275	550,845	1,820,120	13,120	10	7.2
Total	12,354,897	4,335,987	16,690,884	228,202	18	14
ASIA						
Afghanistan	34,506	33,056	67,562	17,450	506	258
Bangladesh	37,645	16,000	53,645	84,660	2,249	1,578
Brunei	25,000	5,000	30,000	190	7.6	6.3
Burma	39,000	37,000	76,000	32,210	826	424
China, Peoples Rep.	42,000	700,000	742,000	958,230	22,815	1,291
Hong Kong	176,034	57,116	233,150	4,514	26	19
India	835,000	802,620	1,637,620	638,390	765	390
Indonesia	419,240	260,081	679,321	143,280	342	211
Iran	728,125	528,217	1,256,342	35,210	48	28
Iraq	152,000	75,000	227,000	12,330	81	54
Israel	333,081	118,138	451,219	3,690	11	8.2
Japan	21,279,689	12,841,045	34,120,734	114,900	5.4	3.4
Jordan	69,249	21,014	90,263	2,780	40	31
Korea, So.	173,203	191,596	364,799	37,020	214	102
Kuwait	273,915	100,097	374,012	1,200	4.4	3.2
Laos	16,000	3,500	19,500	3,460	216	177
Malaysia	525,000	160,000	685,000	12,570	24	18
Oman	35,355	21,006	56,361	820	23	15
Pakistan	209,440	97,477	306,917	76,770	367	250
Philippines	548,000	510,725	1,058,725	46,350	85	44
Quatar	26,829	16,126	42,955	100	3.7	2.3
Saudi Arabia	376,415	500,450	876,865	9,520	25	11
Singapore	137,240	61,482	198,722	2,330	17	12
Sri Lanka	100,000	65,000	165,000	13,970	140	85
Syria	57,399	55,708	113,107	8,100	141	72
Taiwan	300,000	62,000	362,000	17,136	57	47
Thailand	375,000	375,000	750,000	45,100	120	60
Turkey	602,000	407,000	1,009,000	43,210	72	43
Total	27,926,365	18,121,454	46,047,819	2,365,490	85	51

Exhibit 2-1 World Motor Vehicle Population Statistics (15)

WORLD MOTOR VEHICLE REGISTRATIONS, 1978—Continued

Continent/Country	Cars	Trucks & Buses	Total Vehicles	Population Number (000)	Population Per Car	Population Per Vehicle
AFRICA						
Algeria	333,600	168,900	502,500	18,510	56	37
Angola	52,000	17,800	69,800	5,800	112	83
Botswana	5,078	13,732	18,810	720	142	38
Burundi	5,400	2,500	7,900	3,970	735	503
Cameroon	52,000	39,000	91,000	7,910	152	87
Central Africa Rep.	14,216	4,041	18,257	2,690	189	147
Chad	9,590	3,895	13,485	4,310	449	320
Congo (Brazzaville)	21,000	13,000	34,000	1,730	82	51
Egypt	323,916	95,065	418,981	39,640	122	95
Equatorial Guinea	4,000	3,000	7,000	320	80	46
Ethiopia	37,918	11,000	48,918	29,710	784	607
Gabon	22,420	15,000	37,420	530	24	14
Gambia	4,500	3,000	7,500	570	127	76
Ghana	64,000	46,000	110,000	10,480	164	95
Guinea	10,000	11,000	21,000	4,650	465	221
Guinea Bissau	3,200	2,000	5,200	540	169	104
Ivory Coast	111,984	67,227	179,211	5,150	46	29
Kenya	123,370	88,121	211,491	14,860	121	70
Liberia	14,554	12,865	27,419	1,800	124	66
Libya	386,043	86,000	472,043	2,430	6.3	5.1
Madagascar	54,800	49,940	104,740	8,520	156	81
Malawi	13,483	13,406	26,889	5,530	410	206
Mali	20,047	4,670	24,717	5,990	299	242
Mauritania	7,500	6,000	13,500	1,320	176	98
Mauritius	25,686	5,897	31,583	900	35	29
Morocco	371,646	153,353	524,999	18,910	51	36
Mozambique	55,000	20,100	75,100	9,680	176	129
Niger	13,000	13,000	26,000	4,990	384	192
Nigeria	115,432	65,427	180,859	66,630	192	368
Reunion	74,000	26,000	100,000	490	6.6	4.9
Rwanda	8,000	1,650	9,650	4,370	546	453
Senegal	52,000	30,000	82,000	5,120	99	62
Seychelles	3,250	1,250	4,500	60	19	13
Sierra Leone	68,000	33,000	101,000	3,470	51	34
Somalia	5,000	6,000	11,000	3,350	670	305
South Africa Rep.	2,334,974	950,181	3,285,155	26,130	11	8.0
Sudan	30,000	35,000	65,000	16,950	565	261
Tanzania	42,759	56,000	98,759	16,070	376	163
Togo	17,000	9,000	26,000	2,400	141	92
Tunisia	110,000	40,000	150,000	6,220	57	42
Uganda	34,000	10,000	44,000	12,780	376	291
Upper Volta	11,000	12,000	23,000	6,290	572	274
Zaire	90,000	77,000	167,000	27,750	308	166
Zambia	105,000	65,000	170,000	5,470	52	32
Total	5,260,366	2,387,020	7,647,386	415,710	79	54
OCEANIA						
Australia	5,462,200	1,359,900	6,822,100	14,250	2.6	2.1
Cook Island	600	700	1,300	26	43	20
Fiji Islands	24,585	12,620	37,205	600	24	16
French Polynesia	21,000	8,000	29,000	140	6.7	4.8
Guam	55,000	11,000	66,000	105	1.9	1.6
New Caledonia	35,000	12,000	47,000	140	4.0	3.0
New Hebrides	3,500	1,100	4,600	100	29	22
New Zealand	1,236,439	243,765	1,480,204	3,110	2.5	2.1
Samoa (American)	2,800	600	3,400	31	11	9.1
Papua New Guinea	17,300	21,290	38,590	3,000	173	78
Total	6,858,424	1,670,975	8,529,399	21,502	3.1	2.5
EUROPE						
Austria	2,040,268	183,892	2,224,160	7,510	3.7	3.4
Belgium	2,973,418	298,856	3,272,274	9,840	3.3	3.0
Bulgaria	480,000	110,000	590,000	8,810	18	15
Cyprus	78,829	18,731	97,560	620	7.9	6.4
Czechoslovakia	1,982,186	335,924	2,318,110	15,140	7.6	6.5
Denmark	1,407,730	271,881	1,679,611	5,100	3.6	3.0
Finland	1,115,265	155,537	1,270,802	4,750	4.3	3.7
France	17,780,000	2,478,500	20,258,500	53,280	3.0	2.6
Germany, East	2,392,284	600,668	2,992,952	16,760	7.0	5.6
Germany, West	21,619,697	1,423,618	23,043,315	61,310	2.8	2.7
Greece	650,000	316,000	966,000	9,280	14	9.6
Hungary	756,300	237,700	994,000	10,690	14	11
Iceland	73,000	8,500	81,500	220	3.0	2.7
Ireland	640,026	70,546	710,572	3,190	5.0	4.5
Italy	16,985,980	1,326,000	18,311,980	56,700	3.3	3.1
Luxembourg	153,051	14,233	167,284	360	2.4	2.2
Netherlands	4,000,000	359,000	4,359,000	13,940	3.5	3.2
Norway	1,146,894	156,604	1,303,498	4,060	3.5	3.1
Poland	1,835,400	605,600	2,441,000	35,010	19	14
Portugal	888,000	214,500	1,102,500	9,800	11	8.9
Romania	220,000	110,000	330,000	21,660	95	66
Spain	6,598,885	1,227,767	7,826,652	37,110	5.6	4.7
Sweden	2,856,177	185,461	3,041,638	8,280	2.9	2.7
Switzerland	2,054,977	163,466	2,218,443	6,340	3.1	2.9
U.S.S.R.	6,600,000	6,200,000	12,800,000	258,930	40	20
United Kingdom	14,416,989	2,116,552	16,533,541	55,820	3.9	3.4
Yugoslavia	2,142,521	216,445	2,358,966	21,910	10	9.3
Total	113,887,877	19,405,981	133,293,858	736,420	6.5	5.5
WORLD TOTAL	297,360,995	82,659,263	380,020,258	4,115,623	14	11

SOURCE: Compiled by the Motor Vehicle Manufacturers Association of the U.S., Inc. from various sources.

Exhibit 2-1 World Motor Vehicle Population Statistics (cont)

Chapter Three: Remanufacturing Product Analysis

3.0 Introduction

Manufacturers normally deal with a defined range of products or parts which are designed and built using facilities specifically tooled for that type of production. Remanufacturers make "new" products out of an undefiend range of discarded cores which have been built and designed by somebody else. In addition they do it with general purpose equipment and tools which usually require modifications to do the job.

Two factors are covered in this analysis: products and processes. The objective of this chapter is to establish an analysis procedure which can be used to determine the process alternatives for product remanufacturing. Remanufacturing techniques and procedures are discussed for cores of the type listed in Exhibit 1-1. In a "generic" analysis procedure capable of rapid and accurate core evaluations, individual product parts are classified into categories exposed to predictable types of damage and failure. This (part-failure mode) data is coded so correlation with process application files can be caried out with ease. Chapters 4 through 7 discuss the different processes which are used to remanufacture a product.

A careful study of the analysis data will determine if a product can be economically remanufactured. As an example, the case of truck remanufacturing analysis begun in chapter 2 is continued in chapter 8.

The objective of analyzing the product is to identify all the components and parts that will be remanufactured and then list the processes which will be necessary. The first step in product and process analysis is to become familiar with the systems, components, parts, and internal functions of the product. The analysis sequence shown in

Figure 3-1 is used to separate products into discrete parts that can be refurbished using currently available processes. Processes are designed to work with various materials, failure modes, and surface contour combinations. Processes can be used on all parts that share the same features. For example, a brass gear refurbishing process can be used on all similar brass gears, regardless of the product from which they came.

Figure 3-1. Product Analysis Sequence

PRODUCT ⟶ SYSTEM ⟶ COMPONENT ⟶ PART ⟶ PROCESS

The following definitions are used for each of these categories:

Product The collection of operating systems used to perform a set of tasks. Product refers to an operationally complete assembly, e.g. a truck, bus, turret lathe, refinery or similar functional unit.

System A set of components which work together to perform a class of functions. Examples include cooling systems, hydraulic power systems, and X-Y positioning systems.

Component A device which performs a particular function in an operating system. Each component must be able to perform its job well and be able to work efficiently with the rest of the components in the system. Components may be remanufactured independently or at the same time as the rest of the product or system. Commonly remanufactured components include automotive engine components, process valves, industrial drive mechanisms, and pumps.

Parts discrete elements from which components are assembled. Parts assembled into functional groups constitute either sub-assemblies or complete components. Each part can be classified according to its function, design and material to determine remanufacturing feasibility.

Process Operation or group of operations used to refurbish each part within a given failure mode and material class to "like new" condition.

Different analytical techniques are used by each remanufacturer to conduct engineering feasibility and production cost studies, with varying degrees of accuracy and efficiency. From an engineering standpoint, the core provides valuable information concerning the performance of a product and the design flaws which lead to its failure. A representative sample of cores must be studied to catalogue common failure modes of all parts of each component. The cost of analysis must be justified by the profit to be derived in the remanufacture of the product. A thorough analysis of a low-value component should not be performed unless the expected production volumes are large enough to justify the expense. In some cases it will be impractical to collect a sample of cores. To compile useful analysis data, the remanufacturer should keep accurate records of each job completed and record the data in a fashion which permits application to all product and process analyses.

The steps used in the proposed remanufacturing product and process analysis are shown in Figure 3-2, the first three steps of which are covered in this chapter. The remanufacturing process analysis culminates in the selection of the best process alternative to refurbish the part to "like new" condition before final assembly and testing of the complete component or product. Refurbishing processes are covered in Chapter 7. To allow correlation with various part conditions, process are described in "application files" which list the type of damage which they correct and materials on which they are effective.

Figure 3-2 GENERAL ANALYSIS PROCEDURE

1. PRODUCT SYSTEM ANALYSIS
Complete System Evaluation

- o Identification of product operating systems
- o Evaluation of system performance
- o Interactions between systems

2. SYSTEM COMPONENT ANALYSIS
Individual Component Evaluation

- o Components in operating systems
- o Component interactions
- o List of components and sub-assemblies
- o Selection of components for local remanufacture

3. COMPONENT PART ANALYSIS
Determining Condition of Each Part

- o Evaluation of failure and damage symptoms
- o Classification of parts by function
- o Part condition codes for each part groups

4. REMANUFACTURING PROCESS ANALYSIS
Processes Alternatives for Each Product

- o Plant organization
- o General refurbishing tasks
- o Refurbishing process description
- o Condition code and process code correlation
- o Process alternatives and preparation of process sheets
- o Identification of areas for further research

3.1 Product System Analysis

Product system analysis involves the identification and evaluation of operating systems in the product. Products can have only one system (e.g. valve, torque converter) or several (e.g. milling machine, ship); each system must be evaluated separately to examine its condition adn performance.

Most industrial equipment is assembled from several interlocking systems which share some or all of the following components:

- o Power sources
- o Control
- o Instrumentation
- o Structural support
- o Environmental protection

Interactions among components and systems can be determined by examining assembly diagrams, service and maintenance books, and other data available from the OEM. If no OEM information is available, sketches, pictures, and flow charts of the operating systems should be prepared as part of the evaluation of the product.

3.2 System Component Analysis

Components are evaluated to determine their condition, i.e., the type and location of damage which they have received. Component replacement rates and refurbishing requirements are recorded throughout the analysis. Most large products are assembled from components and materials made by several Original Equipment Manufacturers (OEMs). Decentralization allows firms to concentrate on the production of components for which they have developed technical expertise. Typical components which are usually made by a specialized manufacturer (independent or affiliated to the OEM) include bearings, seals, electronic components, motors, and valves.

Automotive vehicles are a prime example of this "decentralized" manufacturing. The U.S. auto industry relies on many different sources for its supplies, some of which are listed in Exhibit 3-1 (20). Some components made by different OEMs have similar physical and operating performance specifications, and are analyzed and remanufactured using the same procedure. Some key components are made by the same supplier for several menufacturers, consequently these components are interchangeable among vehicles. For example, a Catepillar 3208 diesel engine in a Ford truck is identical to, and can be swapped with, one used in an International Harvester truck.

Some foreign manufacturers are centralized to a point that they are the only source of replacement parts. Replacement parts are difficult to obtain if the vehicle and components OEMs go out of business. Broken equipment can remain idle unless part or component modifications are made to compensate for the unavailable parts. In a decentralized market the critical replacement parts continue to be manufactured for the service aftermarket long after the product has gone out of production, or as long as there is demand for them.

A possible format for the list of components and sub-assemblies in the product is shown in Figure 3-3. The list of components is different from a bill of materials in that it does list each individual part. This list is used to get an idea of the type and amount of work necessary to remanufacture each system in the product; it is also used as a check list of components which are:

- purchased new
- sub-contracted
- remanufactured locally

The component list should be accompanied by a drawing of the product and all relevant system diagrams.

One advantage remanufacturers have over manufacturers is they do not have to investigate the dynamic behavior of the systems in the product. Components have already been engineered and built to meet all operating requirements. This allows the remanufacturer to concentrate on refurbishing process development for failed and damaged parts. Whenever a product is put together using a new (different) combination of components, dynamic analysis may be necessary. These changes typically occur whenever better components, parts, or materials are made available and incorporated into the remanufactured product.

Figure 3-3. List of Components

Product ______________________ System ______________________

ID. Number	Description	Repl.	Condition Code
XX-YY-ZZ	(component or sub-assembly name)	PP	(eight character code)

Legend:
- ID component identification number,
- XX refers to the system number from the product core appraisal sheet
- YY component number within the system
- ZZ sub-assembly number

Repl.: (PP) percentage of components replaced with new
Condition Code: used to describe the condition of every part of component. Data coded includes: damage and/or failure symptom and mechanism, degree of damage, geometry of damaged area (size, location, shape), material, Several process codes (n) are used for those components which have more than one type of damage.

3.3 Condition Analysis

Material and resource conservation by refurbishing damaged and failed parts is at the heart of every remanufacturing operation. While recovering the maximum value from every core, remanufacturers become familiar with every possible damage and failure mode. Condition analysis is carried out at two levels:

- o Component evaluation
- o Individual part evaluation

Parts are analyzed as a normal part of disassembly, cleaning, and inspection operations. Various nondestructive testing (NDT) methods are available for detecting cracks, voids, delaminations, and other flaws. Visual inspection and some NDT methods recommended by the Society of Automotive Engineers are described Appendix 3-A. Several of these NDT methods are currently too expensive to use in most remanufacturing operations but may become practical in the near future. Most remanufacturer evaluate parts using liquid penetrant or magnetic inspection techniques to detect cracks and other inhomogeneities.

The objective of condition analysis is to record the damage in the core so that corrective and preventive measures can be taken. There are three ways in which a product can become a core:

- o Dissolution, consumption or accidental breakage during use.
- o Obsolescence.
- o Failure due to some mechanism related to its operation and use, e.g., deformation, wear, corrosion, cracking, fracture.

This thesis deals with the third category, i.e. products which cease to function during use (service life) as a result of component failure. Component failure is normally caused by the failure of one or more of its parts. These failures are usually dependent on the function the components perform in a given product. Failure prediction is an inexact science, for a given application a product can fail by one failure mode in one case and by a completely different one in another. One of the goals of having a consistent analysis procedure is to develop a data on a statistical sample of parts and components so that more accurate failure predictions can be made.

3.3.1 Mechanical Failure Modes

Mechanical failure is any change in the size, shape or material properties of a structure, component, or component part that renders it incapable of satisfactorily performing its intended function. Failure and deterioration are usually caused by four basic mechanisms or processes:

- o deformation
- o fracture
- o corrosion
- o wear

Products rarely ever operate in conditions where they are only exposed to one of these failue mechanisms; very often they are exposed to a combination of them.

Figure 3-4 illustrates a convenient way to view the wear processes. Wear occurs in manufactured products as a result of their design and operation or from natural processes. Product components have certain functional requirements such as to transmit motion, store energy, dissipate energy, locate, or seal. These functions expose components to "dissipative processes" which cause changes to the condition of its parts (21). These dissipative processes are defined as tribological and attack components and parts in ways that affect their condition and abililty to perform functional requirements.

Remanufacturers should become familiar with the characteristics of each of the dissipative processes affecting their products. Evidence on where and when deteriorations occurs, what materials are affected, duration of processes, environmental effects, and frequency should be collected whenever possible.

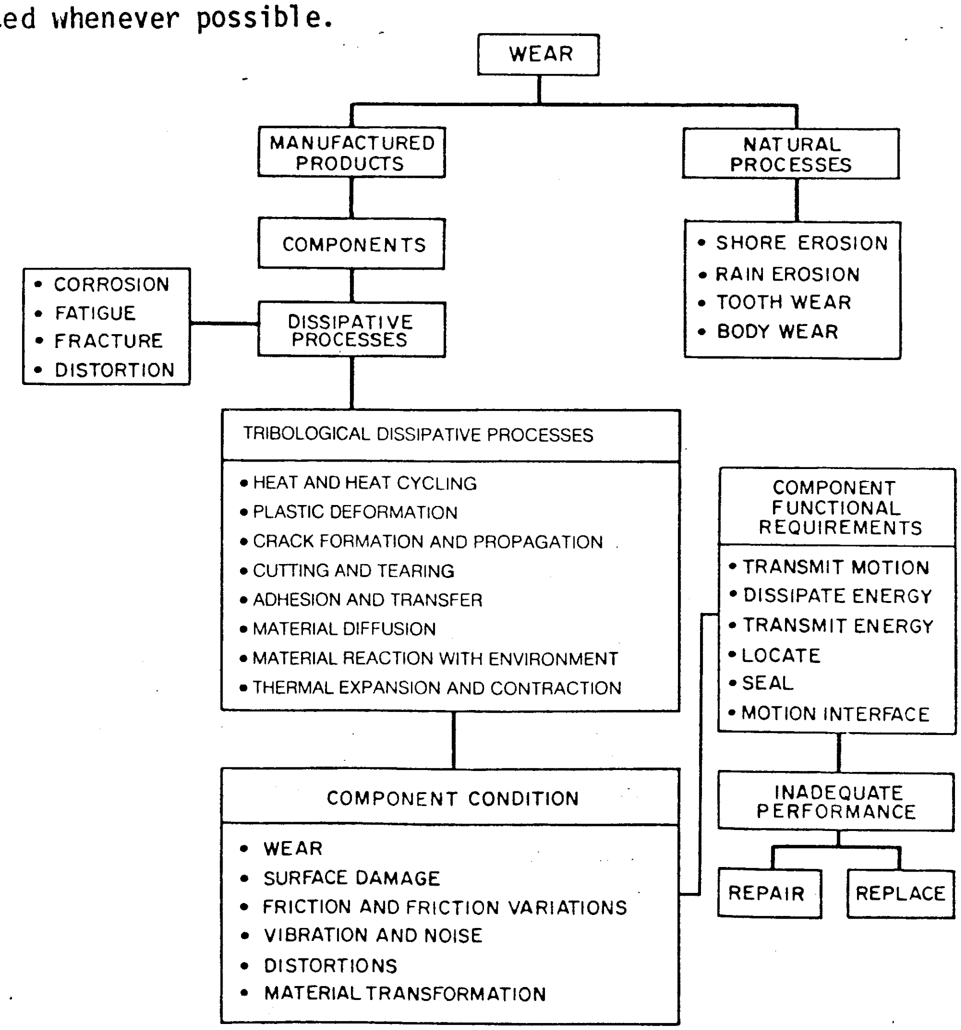


Figure 3-4 A Perspective on Wear (21)

Tribology is the science and technology of interacting surfaces in relative motion and the practices related thereto. A vital element of engineering, it incorporates a multitude of subjects including friction, wear, lubrication, lubricants, and bearing materials. Two aspects of the practice of tribology which warrant special attention are:

- o "Industry is advancing in a direction where conditions require machinery to operate at higher loads, speeds and temperatures and often in extremely hostile environments. Tribological considerations play a constraining role in these technological developments.

- o "Great savings in costs and materials could be achieved through improved tribological practices."(22)

Failure modes will occur independently or operate simultaneously depending on the environment. Examples include: corrosion and fatigue, abrasion in a corrosive medium, fretting combined with corrosion, wear and fatigue, etc. Typically when two modes operate simultaneously on a part, the combined effect is more severe than the two working separately. A list of the common mechanical failure and damage modes is shown in Table 3-1 (23).

Usually a part will go through several deterioration stages before failing catastrophically, so all changes in the condition of a part should be studied carefully. Wear is not only a failure mode but also a prime cause of secondary failures. Worn parts lead to increased vibration, fatigue, shock loading and misalignment, all of which lead to more rapid equipment failure. For example, a shaft may be slightly bent and worn on the bearing surfaces and still be able to function, but it makes the component vibrate and in time may cause the failure of a critical component. All signs of failure and deterioration should be detected so that corrective action can be taken during remanufacture.

Table 3-1 Mechanical Failure Modes of Machine Elements (23)

1. Force and/or temperature induced elastic deformation

2. Yielding

3. Buckling

4. Brittle fracture

5. Ductile fracture

6. Rupture

7. Creep

8. Fatigue
   - A. High-cycle fatigue
   - B. Low-cycle fatigue
   - C. Thermal fatigue
   - D. Surface fatigue
   - E. Impact fatigue
   - F. Corrosion fatigue
   - G. Fretting fatigue

9. Wear
   - A. Adhesive wear
   - B. Abrasive wear
   - C. Corrosive wear
   - D. Surface fatigue wear
   - E. Fretting wear
   - F. Erosion
   - G. Cavitation
   - E. Impact fatigue

10. Corrosion
    - A. Atmospheric corrosion
    - B. Direct chemical attack
    - C. Galvanic corrosion
    - E. Intergranular corrosion
    - F. Selective leaching
    - G. Erosion corrosion
    - H. Cavitation corrosion
    - I. Biological corrosion

11. Radiation damage

12. Thermal Shock

3.3.2 Deformation Damage

Deformation damage and failure results from the application of stresses which exceed the elastic limit or yield strength of the part material. Yielding can occur under bending, twisting, compressive, tensile, and thermal stresses, or from impact stresses (dented, torn, crushed parts). Most deformation damage can be avoided by changing either the material or the operating conditions of the part. Materials with high elastic modulus, high hardness, high yield strength and high creep strength, are resistant to failure from plastic deformations. Increasing the size of the part or changing the load conditions can be equally effective.

Most parts that are damaged or fail by deformation can be treated and bent back to their original shape. The typical process involves the application of stresses (mechanical and/or thermal) exerting an opposite effect to the forces which caused the damage. Further processing may be necessary to reinforce areas of stress concentration. Equipment needed to refurbish deformed parts depends on:

- material
- size of part
- load directions
- shape of part

Equipment is available to inspect, straighten, and test parts such as shafts, tubes, wires, axles, linkages, etc. Small parts like pushrods and brackets can also be refurbished using similar equipment and techniques. Refurbishing techniques are discussed in Chapter 7.

3.4 Damage and Failure by Fracture

Parts are often damaged by the formation of cracks at or near working surfaces and on exposed areas which make the product vulnerable to other forms of deterioration. The refurbishing process is determined by the material, crack size, and location. Fracture is the failure which results when a part cracks or separates into two or more pieces as a result of applied loads which exceed the strength of the material. The most common mechanisms by which fracture damage and/or failure occurs are: fatigue, fretting, brittle fracture, and ductile fracture. Degree of damage is measured by the geometry of the crack (depth and length), and its effect on performance:

Crack Type	Repairs needed
o Micro cracks (surface and subsurface)	cosmetic
o Surface crack (mild scratches)	cosmetic
o Fretting cracks and severe surface scratches	minor
o Deep crack (depth exeeds 5% of part thickness)	medium
o Rips and Tears (crack goes through part)	major
o Fracture (part broken into pieces)	major

Damage geometry, degree of damage, and its effects on performance are recoded in the part condition code using a four character mnemonic code.

3.4.1 Fatigue

Fatigue failure is caused by crack growth resulting from the repeated application of stress and strain. This type of failure is particularly dangerous since the incipient cracks are often invisible and the final failure may occur with disastrous suddenness in high speed machinery or vehicles. Fuchs and Stephens in their book Metal Fatigue in Engineering, estimate that the failures due to fatigue account for over fifty percent of all mechanical failures (24).

Vehicle components exposed to cyclic stresses from rough roads, engine vibration, and constantly changing speeds and loads are affected by fatigue. Fatigue also affects turbine blades which are cyclically loaded as they pass the stator blades; in another case, the high noise levels associated with jets and rockets can cause fatigue problems in neighboring parts that vibrate (25).

Modes of fatigue damage include high cycle fatigue, fretting fatigue and corrosion fatigue. The interaction of fatigue with other failure modes like corrosion, fretting, creep, and thermal stress are not well understood. Environmental effects on fatigue of metals may be more severe than sharp stress concentrations or almost harmless. Corrosion and galling (due to rubbing of mated surfaces) can cause great reduction of fatigue strength, sometimes as much as 90% of original endurance limit (26).

<u>High cycle fatigue</u> involves the slow formation and propagation of cracks under cyclic loading condition. The fatigue strength or endurance limit of a material (stress at which life exeeds 10^6 cycles) depends on the precence of microcracks, inclusions, and part geometry. Rolling contact devices such as ball and roller bearings, transmissions, shafts, gear teeth, cams, and devices in which curved surfaces are repeatedly brought together at high stresses are commonly subject to high cycle fatigue.

<u>Fretting fatigue</u> involves fatigue and wear mechanisms which arise when there is limited motion between two parts. It can occur with less than 10^{-5}mm of relative slip between the mating surfaces. This mode is found in all assembled structures and components that are subjected to or produce repeated motion. The reduction of fatigue resistance due to fretting is of equal importance to notch effects and corrosion fatigue. Fretting fatigue strengths may be 5 to 10 percent of the base unnotched fatigue strengths, which implies fatigue strength reduction factors of between 10 and 20 may occur (27).

Fretting conditions of limited and/or oscillating motion represent the most severe operating condition for conventional bearings, both sliding and antifriction. Coatings of thin layered rubber-metal laminates seem to be ideal solutions for fretting in conventional bearings. Applications of thin layered laminates in compensatory couplings, U-joints, gears, vibration isolators and impact cushioning at joints of mechanisms have been studied a new way to deal with fretting fatigue and wear failure mechanisms (28).

3.4.2 Preventing Fatigue

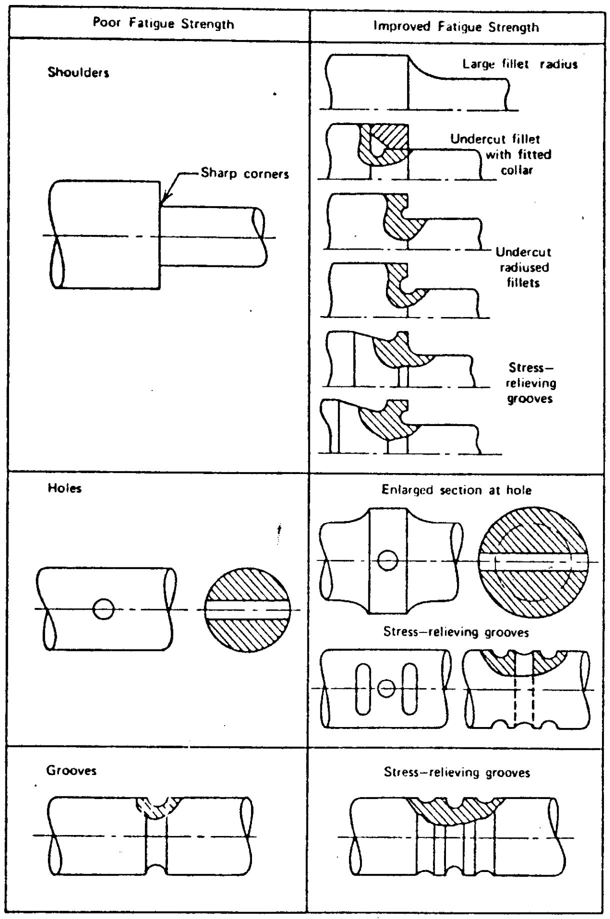
Fatigue failure can be prevented through design, regular inspection, or periodic replacement or repair of parts. One way to achieve longer life is by preventing the formation of inclusions and cracks. Surface features such as roughness, scratches, notches and shoulders all increase susceptibility of a component to fatigue. Design improvements which avoid stress concentrations are illustrated in Figure 3-5 (29). Among the design features which mitigate the effects of stress concentrations are stress relief grooves, adding fillets, shot peening, or larger part dimensions at critical areas.

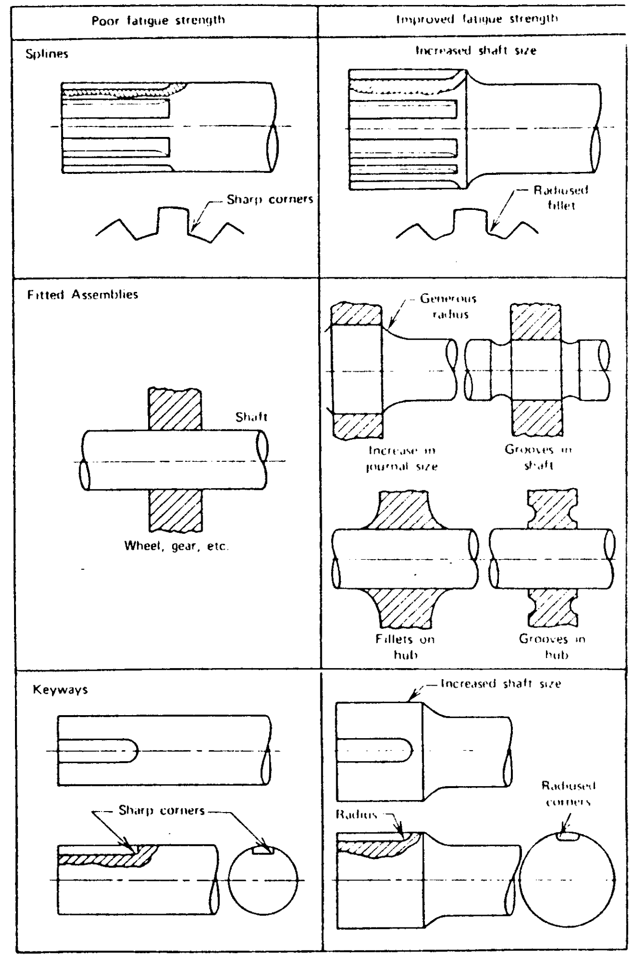
Avoiding unnecessary welding and grinding of parts can increase resistance to fatigue by preventing the formation of harmful residual stresses. Care should be taken to avoid welding or grinding parts which are exposed to vibration and cyclic loads or made of materials succeptible to fatigue. Whenever these processes are necessary, measures should be taken to relieve these stresses so that part life is not adversely affected. Fretting fatigue can be avoided by producing compressive self-stresses (residual stresses), shot peening, surface rolling, or nitriding.

3.5 Corrosion

Corrosion is metals is due to their thermodynamic instability and tendency to react with the environment and produce compounds such as oxides, sulfides and carbonates. Failure by corrosion occurs when the corrosive action renders the device, or its part, incapable of performing its designed function.

Failure by corrosion and protection against failure by corrosion have been estimated to cost in excess of eight billion dollars annually in the United States alone (30). The complexity of the corrosion process may be better appreciated by recognizing that many variables are involved, including environmental, electrochemical, and metallurgical aspects.





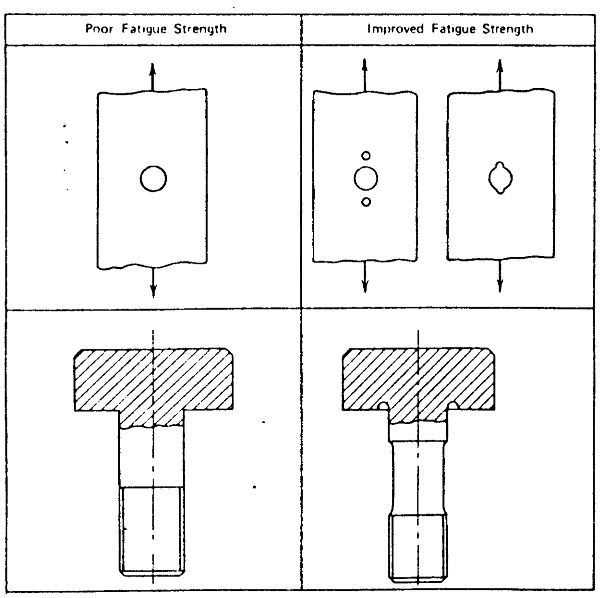


Figure 3-5 Design Improvements for Fatigue Resistance (29)

Some of the factors which affect the type and rate of corrosion include:

- o anodic reactions
- o cathodic reactions
- o corrosion inhibition
- o passivity phenomena
- o fluid velocity and temperature
- o corrosive concentration
- o metallurgical structure
- o rate of oxidation
- o rate of reduction
- o polarization and retardation
- o effect of oxidizers
- o atmospheric composition
- o galvanic coupling

3.5.1 Atmospheric Corrosion

The most common type of corrosion is rust or atmospheric corrosion. Most metals, with the exception of noble metals, can be oxidize by atmospheric oxygen. In most cases water vapor must be pressent, 40% humidity for iron, before appreciable oxidation can take place. After much experimentation corrosion engineers have found three distinctly different corrosion rates in industrial, marine, and rural environments. Salts in marine environments greatly accelerate the corrosion process; other factors, such as the settling and adherence of particles of carbon, ammonium sulfate, and silica cause a marked increase in corrosion (31).

Atmospheric corrosion is caused by corrosive agents in the air which are either oxidants, acidic materials or salts. The total acidity of the atmosphere is closely related to the sulfur dioxide content. Pollution from industrial processes is the greatest source of corrosive agents in the atmosphere. They constantly add oxidizing agents such as ozone, nitrogen oxides, nitric acid, and organic peroxides; all of which attack exposed materials. Various combustion processes release chemicals to the atmosphere where they combine with water to form the following acids:

- o sulfurous acid
- o hydrogen sulfide
- o carbon dioxide
- o tar acids
- o sulfuric acid
- o hydrochloric acid
- o carbonic acid
- o nitric acid

Metals can react in three ways to atmospheric corrosion:

1. corrode rapidly because they are succeptible to attack ad fail to form a protective film, such as Iron.

2. corrode at first but then form a corrosion-resisting film. Examples: aluminum, lead, zinc, brass, nickel, magnesium, copper.

3. no appreciable reaction, type 18/8 stainless, monel, gold.

3.5.2 Direct chemical attack

Among the first considerations in material selection should be wether the material will react with its working environment. Chemically active substances attack all the surfaces of products exposed to the corrosive media, this it is the driving force in most corrosion mechanisms. The rate and extent of corrosive damage depends on the type of corrosive media the material being attacked.

Atmospheric corrosion is often acceletared by the corrosive attack from chemicals in the air. Direct chemical attack is a severe problem in parts used in industrial process equipment, specially those in the oil, food, and chemical industry. Component parts such as pump rotors, valves, tubes and tanks have to be fabricated out of corrosion resistant materials, or coated with a resistant material.

Common engieering metals and the chemicals to which they are vulnerable and resistant, are listed in Table 3-2 (32).

Metal	*Subject to corrosion by*	*Resistant to*
Aluminum and alloys	Acid solutions (except concentrated nitric and acetic); caustic and mild alkalies; sea water; saturated halogen vapors; mercury and its compounds; carbon tetrachloride; cobalt; copper and nickel compounds in solution	Air; water; ammonia; combustion products; halide refrigerants; dry steam; sulfur and its compounds; concentrated ammonium hydroxide; organic acids; most organic compounds
Cast iron	All water solutions, moist gases; dilute acids; acid-salt solutions	Dry gases except halogens; dry air; neutral water; dry soil; concentrated acids (nitric, sulfuric, phosphoric); weak or strong alkalies; organic acids
Chromium and high-chrome steels	Most strong acids (limited use with acetic, nitric, sulfuric, and phosphoric); most chlorides	Air; water; steam; weak acids; most inorganic salts; most alkalies; ammonia
Copper, red brass, and bronze	Mercury and its salts; aqueous ammonia; saturated halogen vapors; sulfur and sulfides; oxidizing acids (nitric, concentrated sulfuric, sulfurous); oxidizing salts (Hg, Ag, Cr, Fe, Cu); cyanides	Air; water; sea water; steam; sulfate and carbonate solutions; dry halogens; moist soils; alkaline solutions; refrigerants; petro-chemicals; non-oxidizing acids (acetic, hydrochloric, sulfuric)
Lead	Caustic solutions; halogens; acetic acid; calcium hydroxide; magnesium chloride; ferric chloride; sodium hypochlorite	Air; water; moist soil; ammonia; alcohols; sulfuric acid; ferrous chloride
Magnesium and alloys	Heavy metal; salts; all mineral acids (except hydrofluoric and chromic); sea water; fruit juices; milk	Most alkalies and organic compounds; air; water; soil; dry refrigerants; dry halogens
Monel metal and Ni-Cu alloys containing in excess of 50% nickel	Inorganic acids; sulfur; chlorine; acid solutions of ferric, stannic, or mercuric salts	Air; sea water; steam; food acids; neutral and alkaline salt solutions; dry gases; most alkalies; ammonia
Nickel and high-nickel steels	Inorganic acids; ammonia; mercury; oxidizing salts (Fe, Cu, Hg)	Air; water; steam; caustic and mild alkalies; organic acids; neutral and alkaline organic compounds; dry gases
Silver	Halogens and halogen acids; sulfur compounds; ammonia	Alkalies, including high-temperature caustic alkalies; hot concentrated organic acids; phosphoric and hydrofluoric acids
Steel, mild, low-alloy steels	Most acids; strong alkalies; salt water; sulfur and its compounds	Air; steam; ammonia; most alkalies; concentrated nitric acid; halide refrigerants
Tantalum	Hydrofluoric acid; concentrated sulfuric acid; strong alkalies	Nearly all salts; most acids; water; sea water; air; alcohols; hydrocarbons; sulfur
Tin	Inorganic acids; caustic solutions; halides	Most food acids; ammonia; neutral solutions
Titanium	Hydrochloric acid; sulfuric acid; hydrofluoric, oxalic, and formic acids; dangerously explosive in presence of nitric acid or liquid oxygen	Oxidizing media; air; water; sea water; aqueous chloride solutions; moist chlorine gas; sodium hypochlorite
Zinc	Acid or strong alkali solutions; sulfur dioxide; chlorides	Air; water; ammonia; dry common gases; refrigerants; gasoline
Zirconium	Concentrated sulfuric acid (hot); hydrofluoric acid; cupric and ferric chlorides	Solutions of alkalies and acids; aqua regia

Notes: Polished surfaces resist corrosion.
Non-uniformity within a metal tends to increase corrosion.
Stress (especially alternating stress) tends to increase corrosion.
Dissolved gases in water (especially oxygen) accelerate corrosion.

Table 3-2 Corrosion of Metals (32)

3.5.3 Galvanic corrosion

Galvanic corrosion is an accelerated electrochemical corrosion, it occurs between dissimilar metals. It is associated with the current resulting form the coupling of dissimilar electrodes (metals) in an electrolyte. The cause of this form of corrosion is the potential difference between the metals, the farther apart on the galvanic series the more serious the corrosion problem will be. The galvanic series for conventional engineering materials is shown in Table 3-3, the materials within any bracketed group exhibit little or no corrosion (33).

Galvanic corrosion may be reduced in severity or prevented by one or a combination of several steps:

- Selecting materials close on the galvanic series
- Use of inhibitors to decrease agressiveness of corrosive medium
- Use of cathodic protection in which a third metal element anodic to both members is used as a sacrificial anode that may require periodic replacement.

Since galvanic corrosion is an electrochemical process, methods of protection are based on isolation of the metal from the corrosive environment and on minimizing galvanic potentials.

Galvanic corrosion is also prevented by eliminating contact between metals, whether direct or through an electrolyte. Surface treatment of steel with a phosphate wash or a primer such as red lead or zinc chrome forms a thin protective layer of stable compound over which an impervious and durable coating can adhere.

3.5.4 Erosion corrosion

This failure mode can be interpreted in two ways; viewed as corrosion it is considered an accelerated direct chemical attack. From the

↑	Platinum
	Gold
Noble or cathodic (protected end)	Graphite
	Titanium
	Silver
	Chlorimet 3 (62 Ni, 18 Cr, 18 Mo)
	Hastelloy C (62 Ni, 17 Cr, 15 Mo)
	18-8 Mo stainless steel (passive)
	18-8 stainless steel (passive)
	Chromium stainless steel 11-30% Cr (passive)
	Inconel (passive)(80 Ni, 13 Cr, 7 Fe)
	Nickel (passive)
	Silver solder
	Monel (70 Ni, 30 Cu)
	Cupronickels (60-90 Cu, 40-10 Ni)
	Bronzes (Cu-Sn)
	Copper
	Brasses (Cu-Zn)
	Chlorimet 2 (66 Ni, 32 Mo, 1 Fe)
	Hastelloy B (60 Ni, 30 Mo, 6 Fe, 1 Mn)
	Inconel (active)
	Nickel (active)
	Tin
	Lead
	Lead-tin solders
	18-8 Mo stainless steel (active)
	18-8 stainless steel (active)
	Ni-Resist (high Ni cast iron)
	Chromium stainless steel, 13% Cr (active)
	Cast iron
	Steel or iron
Active or anodic (corroded end)	2024 aluminum (4.5 Cu, 1.5 Mg, 0.6 Mn)
	Cadmium
	Commercially pure aluminum (1100)
	Zinc
↓	Magnesium and magnesium alloys

Table 3-3 Galvanic Series of Commercial Metals and Alloys in Seawater (33)

perspective of wear it is a complicated case of abrasive wear. This mode results from the abrasive action of a moving corrosive medium, it typically operates at fast removal rates. Most alloys are succeptible to erosion corrosion, and many different types of corrosive medium may induce it, including flowing gases, liquids, and their combinations with solid aggregates. Erosion corrosion can be a problem in such machine parts as:

- pumps
- turbine blades
- conveyors
- blowers
- nozzles
- piping and ducting systems

The resistance of materials to erosion corrosion depends on the, velocity, size, concentration, and angle of impingement of the abrasives in the corrosive media. Hard facing alloys are typically used to create a tough surface on materials exposed to erosive conditions (34).

Corrosion fatigue this failure mode occurs when parts subjected to cyclic loads are operate in a corrosive environment. Corrosion products formed at in the root of cracks and harden the material and cause stress concentrations, making the fatigue crack to grow faster. This results in metal failure occuring substantially below the fatigue limit for non-corrosive conditions. The combined deteriorating effect of these two-corrosion and fatigue- is grater than the sum of their individual damages (35). The way to avoid most corrosion processes is to:

- Change the operating conditions.
  - Chemical composition of the operating environment
  - Temperature
  - Fluid pressure and velocity
  - Content of particulates in the solution
  - Reduce Galvanic Potentials
- Change the material, use corrosion resistant alloy
  - Conversion coatings
  - Rendering the surface passive
- Protect the material with a resistant coating
  - metal such as zinc, tin, lead, nickel or copper
  - paint

3.6 Material Removal: Wear

Wear is the result of the relative motion of bodies in contact, there are many different forms of wear and their effect vary depending on the part material and the operating environment. Material removal caused by wear mechanisms is dangerous beacause it causes the formation of particles which may lead to seizure in moving parts, or it may damage part fit to an extent which can compromise performance.

Material removal from the surfaces is usually a result of mechanical action, or its combined action with chemical attack. The various particle removal processes are shown in Table 3-4 (36), of all the modes listed here adhesion, cutting (abrasion) and surface fatigue are considered "wear". Typical of most wear processes is the small amount of material removed. For example by the time a model 4000 lb. automobile is completely worn out, only a few ounces will have been worn off those surfaces which are in sliding contact (37).

Adhesion and transfer	Materials weld at sliding asperity tips, is transferred to the harder member, possibly grows in subsequent encounters and is eventually removed by fracture, fatigue or corrosion.
Corrosion film wear	A film formed by reaction with the environment or the lubricant is removed by sliding.
Cutting	A sharp particle or asperity cuts a chip.
Plastic deformation	The surface is worked plastically. Cracks form, grow, and coalesce forming wear particles.
Surface fracture	If nominal stress exceeds the fracture stress of a brittle material, particles can be formed by fracture.
Surface reactions	One material dissolves or diffuses into another.
Tearing	Elastic material can be torn by a sharp indenter.
Melting	High temperatures can cause wear by melting.
Electrochemical	The difference in potential on the surface due to a moving fluid can cause a material to go into solution.
Fatigue	The surface is worked elastically. Microcracks form, grow, and coalesce forming wear particles.

Table 3-4 Particle Removal Processes (36)

3.6.1 Classification of Wear Processes

There are many classification schemes and names for wear processes one system divides wear into two general categories: single phase wear and multiple phase wear. The chart shown in Figure 3-6 shows the possible combinations between attacked surfaces, operating environment (carrier), particle type, and the relative motion between them (38). The arrows represent the motions of the solid, liquid, gas or particle which causes the material removal from the wearing surface. The carriers are listed in as rows and the particles by columns. Table 3-5 describes each of the possible processes in more detail and cites some typical examples (39).

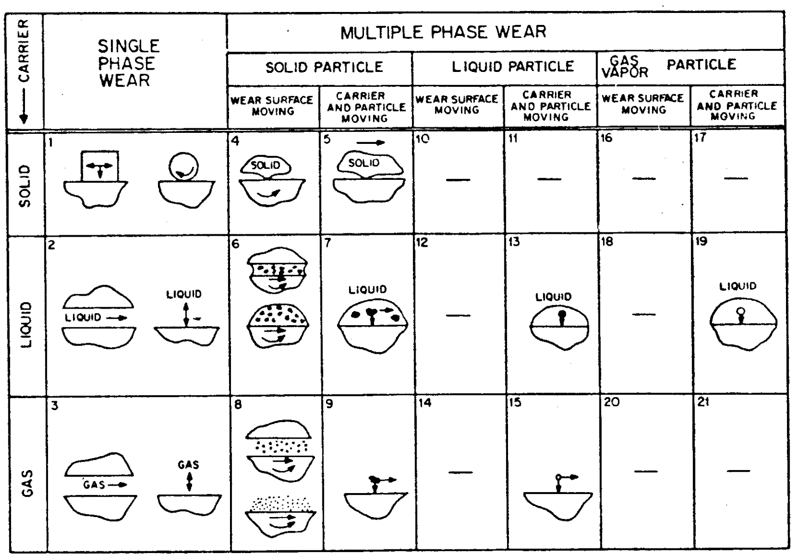


Figure 3-6 Possible Surface Interactions in Wear (39)

In sigle phase wear a solid, liquid or gas moving relative to a surface, causes material to be removed from the wearing surface. The relative motion may be sliding, reciprocating, rolling or impact.

Multiphase wear also consists of a solid, liquid or gas moving across a surface; however in this case, it acts as a carrier for a second phase (particles, asperity, liquid drop, gas bubble) which actually produces the wear.

3.6.2 Adhesive and Abrasive Wear

Adhesive wear occurs when two smooth bodies slide over each other, and fragments are pulled off one surface and attached to the other. It is caused by the strong adhesive forces which occur whenever atoms come into intimate contact. When two surfaces are pressed together they form an area of contact, when the parts come apart there is a probability that they may not break along the original interface. In consequence a transferred fragment will be formed (40). The most effective way to prevent adhesive wear is to select a material combination which has a low wear coefficient, low solubility in mating surface material, resisrance to softening at operating temperature, and proper lubricantion at the contact points.

Abrasive wear occurs when a hard, rough surface slides against a softer surface, digs into it, and plows a series of grooves. The material is removed in the form of loose fragments which become abrasive particles in the system. Abrasive wear can also occur when a hard abrasive particle is introduced between sliding surfaces. To prevent this form of wear one can use materials with higher surface hardness than the abrasive medium, low work hardening coefficient, or protect the part with a hard surface coating. A third approach is to keep the sliding surfaces free of abrasive particles by using seals, filters, bellows and other protective devices.

Surface fatigue wear (spalling) is observed in rolling applicatons, namely gears and rolling contact bearings, it affects metals which have subsurface voids or microcracks, and other brittle materials. It is a variation of high cycle fatigue with particle removal.

No.[1]	Contact	Particle	Motion	Common Names	Typical Examples
1	Solid[2]	None	Sliding	Dry sliding wear metal-metal wear	Bushings, seals, brakes
			Reciprocating	Fretting	Clearance fits, fasteners
			Impact	Impact wear	Electrical contacts, hammers
			Rolling	Rolling wear	Rolling contact bearings, gears
2/3	Gas[3] or liquid[4]	None	Flow	Wire drawing	Water erosion
				Erosion	Valve wear
			Impact	–	Pipe bends, deflectors
			Hammer	–	–
4	Solid[2]	Hard rough surface	Wear surface rolling	–	Tire wear
5	Solid[2]	Hard rough surface	Particle sliding	Abrasion Two-body wear	Abrasive papers, files
6	liquid[5]	Solid	Wear surfaces sliding	Three-body wear Dirt abrasion	Dirt in machinery components Lapping
			Wear surfaces rolling	Three-body wear Dirt abrasion	Dirt in lubricants used for rolling contacts, cams
			Wear surface sliding	Erosion	Mixing, slurry pumping, blades
			Wear surface rolling	–	–
7/9	Liquid or gas	Solid	Particle sliding	Low angle Particle erosion	Pumping & transporting liquids or gases containing solid particles
			Particle impact	90° Particle erosion	Shot & sand blasting
8	Gas	Solid	Wear surface sliding	Three-body wear	Soles of shoes
			Wear surface rolling	Three-body wear	Rock crushing
			Wear surface sliding	Two-body wear Low stress abrasion Soil abrasion	Earth moving equipment Digging
13	Liquid	Liquid	Particle impact	–	Slurry pumping
15	Gas	Liquid	Particle impact	Drop erosion Rain erosion	–
19	Liquid	Gas or vapor particle	Particle impact	Cavitation	Valves, bearings, pipes
			Particle flow	Wire drawing erosion	Valves

1. Refers to numbers in Table 2.
2. Refers to a solid being worn by another solid.
3. Refers to a solid being worn by a gas.
4. Refers to a solid being worn by a liquid.
5. Refers to two surfaces in contact being worn by particles in a liquid trapped between them.

Table 3-5 Wear Process Description and Examples (39)

3.7 Component Part Analysis

To develop a quick and accurate method to determine the refurbishing process alternatives one must be able to classify parts into groups for systematic analysis. Components parts can be classified into four generic categories according to their function and design. The four types of parts from which equipment and machinery are usually built are:

- o Moving parts
- o Fasteners
- o Interfaces
- o Stationary Parts

Each part class tends to fail by predictable failure modes associated with the function, design and use of the part. A correlation between part characteristics and the failure modes is used to determine the refurbishig process. Analysis information on can be used to re-design parts, and improve the performance of remanufactured products.

Before selecting a refurbishing process one should first understand the function of the part and be able to pinpoint the causes and types of damage which it receives during use. Each of the part classes described in the following sections has several different part sub-classifications, it would be inpractical to list or attempt to describe how to refurbish each one individually.

To deal with this problem of diversity, the parts were analyzed in the following sequence:

- o Determine function of part, classify.
- o Determine typical condition for a sample of parts
  - types of failures and deterioration encountered
  - percentage of components damaged by each mode
  - distribution of deterioration
  - replacement parts needed
- o Determine part material, determine suitability for application

Refurbishing methods for different failure modes and materials are covered in Chapter 7. Process selection depends on having an acurate list of part specifications and conditions. The part categories selected cover those used in components of products listed in Exhibit 1, but can be applied to other products.

3.7.1 Moving Parts

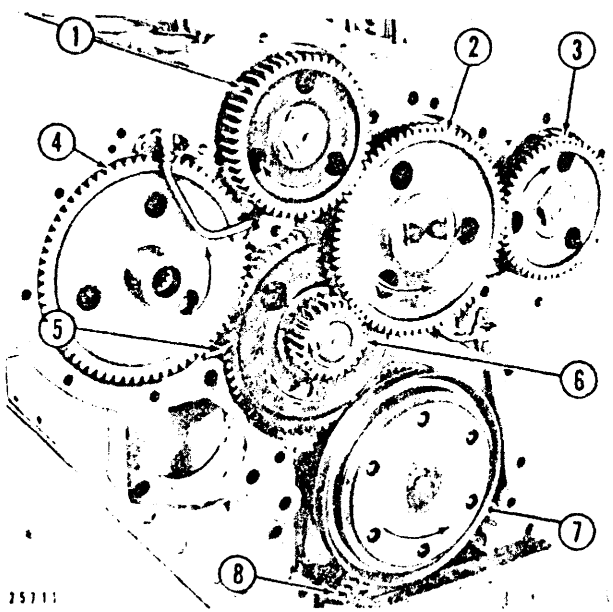
Moving parts of mechanisms and equipment are those used in components which transmit motion, dissipate, store or transmit energy. A mechanism is that part of a machine which contains two or more pieces so arranged that the motion of the one compels the motion of the others according to a definite law depending on the nature of the combination (41). The motion of these parts and their operating environment are the causes of damage and failure. A selection of the moving parts used in a diesel engine is shown in Figure 3-7 (42). Moving parts can be are classified by the typical motions followed during operation. The classes used here are:

- Rotating Parts
- Gears
- Reciprocating Parts
- Springs
- Friction Devices
- Sliding Parts

Each type of moving part has characteristic failure modes which is controled by the function, material, design of the part, and service history of the product. The location of damage depends on the position of the part relative to others, and its interaction with them.

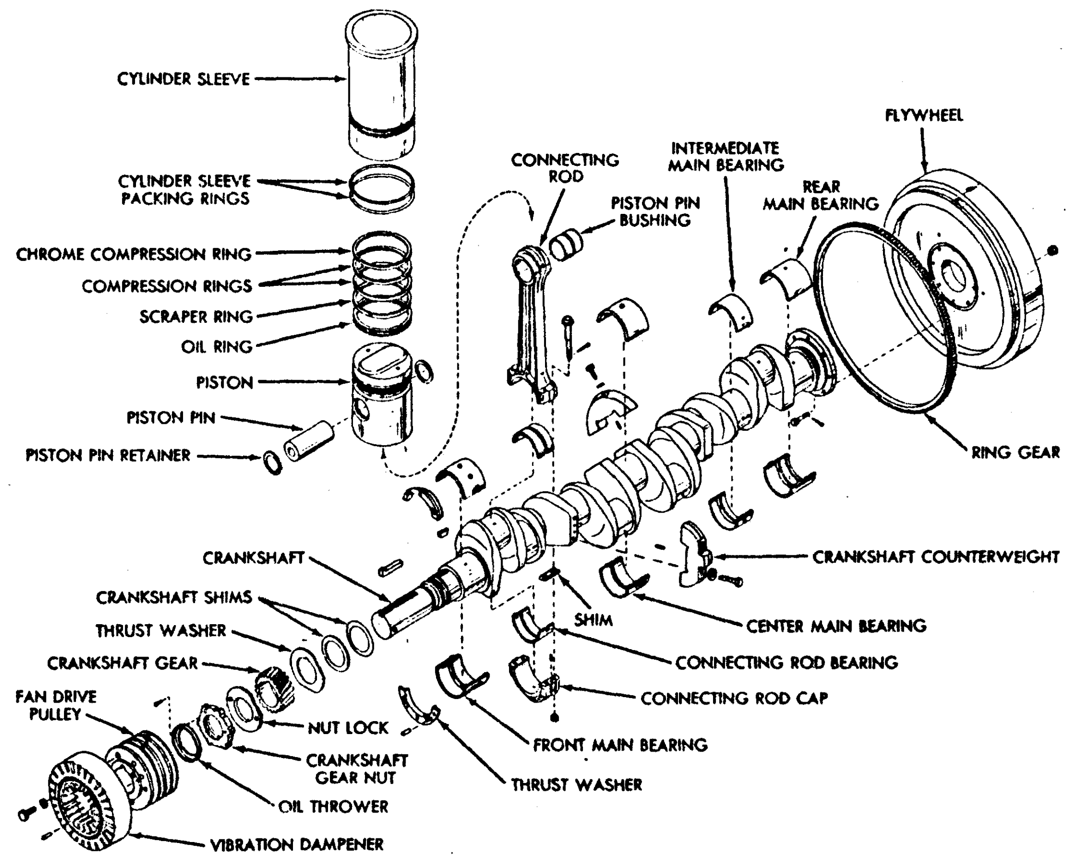
Rotating Parts: There are many uses for rotating parts in machinery, from shafts to flywheels, impellers and gears. Load on moving parts can be transmitted radially and axially, it can be continuous, intermittent, unidirectional or combined. The type of load applied to the part dictates the damage it receives during use.

Cylinder head



TIMING GEARS
1–Camshaft gear. 2–Camshaft idler gear. 3–Fuel pump and governor drive gear. 4–Accessory drive gear. 5–Accessory idler gear. 6–Integral spur gear. 7–Chankshaft gear. 8–Oil pump drive gear.

Courtesy of Caterpillar Tractor Co.



Courtesy of Waukesha Motor Co.

Figure 3-7 Moving Parts in Diesel Engine

The most common rotating parts and general failure modes are:

Types	Modes
o Shafts (driveshaft, cam, crank, axle)	bending
o Flywheels	cracking
o Couplings (solid and flexible)	fretting
o Sprocket	tooth wear
o Drive screw	corrosion
o Pump Elements (impellers, rotors)	abrasion

Gears: Many different types of gears are used in machinery, depending on the application, the most common types are shown in Figure 3-8 (43). Gears are used to transmit power to different parts of a product and are critical elements in the operation of many products, any damage can severely affect product performance. A summary of wear characteristics for these gears is shown in Table 3-6 (44). Each gear found in the components should be inspected carefully and refurbished as well as possible.

Some gears are expensive to make and replace; as a result many field, and shop repair techniques have been developed over the years. These usually involve the rebuilding of the worn surfaces by welding or metal spraying and then carefully grinding each tooth back to its original shape. The best way to prevent gear wear is to use the right material and lubricant. Gear alignment is also critical to their endurance, one should evalutate the wear patterns on the gear teeth to determine the type of mode which caused damage or premature failure. Most product maintenance handbooks contain information on gear inspection and adjustment, they should be consulted whenever possible.

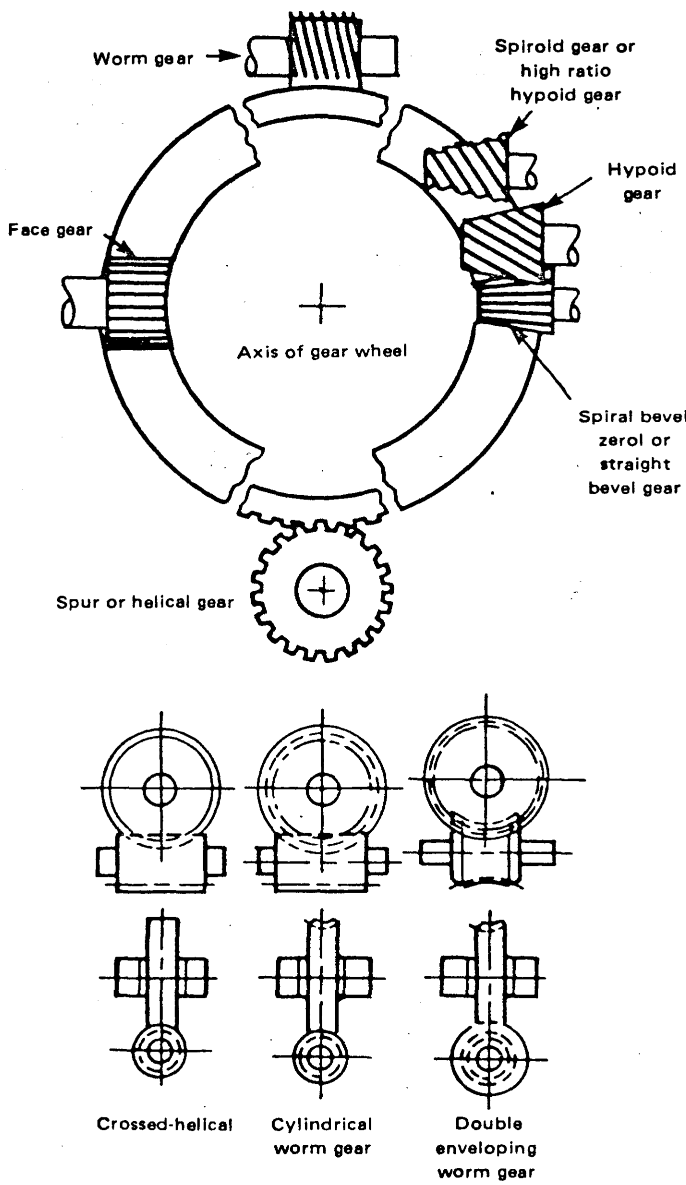


Figure 3-8 Types of Gears Commonly in Used in the Gear Trade (43)

Table 3-6 Summary of Gear Wear Characteristics

Gear Type	Kind of Material	Typical Applications	Comments on Wear
		Coplanar	
Spur, helical or bevel	nonmetallic on nonmetallic	instruments cameras	Usually very lightly loaded. Wear is small. Not suitable for any appreciable speed. May run dry.
Spur, helical or bevel	steel on non-metallic	appliances, light power applications	Tooth loading relatively low. Wear is small if gearing is kept wet with oil or grease. (Some exceptions where nonmetallic has a built-in lubricant.)
Spur, helical or bevel	low hardness steel	industrial power units	Tooth loading low to medium. Oil lubricant (or special grease) needed. Wear may be heavy in life of unit due to both pitting and cold flow.
Spur, helical or bevel	medium hard steel	industrial power units	Tooth loading medium. May be used at all speeds including very high speed. Wear may be moderate due to pitting. Pressurized oil circulation system at higher speeds.
Spur, helical or bevel	full hard steel	industrial power units	Tooth loading high. Scoring and spalling risks must be avoided. Essentially no wear with clean oil and a good design. Oiling system is critical.
Spur, helical or bevel	full hard steel	helicopter drives and other aircraft	Tooth loading very high. Essentially no wear. Design for shorter life than industrial gearing. Oiling system very critical.
Spur, helical or bevel	full hard steel	vehicle gears	Tooth loading extremely heavy in final drive stage. Very small amounts of wear. Lubricant viscosity and additives very critical. EP type oil may be required.
		Nonplanar gears	
Worm gears	steel on nonmetallic	appliances, light power	Light load. Small amount of wear. Oil or grease lubrication.
Worm gears	steel on bronze	industrial power units	Medium tooth loading. Good oil required. Some wear due to cold flow or pitting.
Hypoid or Spiroid	full hard steel	industrial power units	Medium load. Little or no wear.
Hypoid or Spiroid	full hard steel	vehicle gears	Tooth loading may be extremely high in final drive. Very small amounts of wear. EP type high viscosity lubricant needed.

Note: In spite of the poor lubrication situation, most of the open gears function without serious wear problems. Table 15 shows some of the things that tend to keep the wear rates relatively low.

Reciprocating Parts: Commonly used reciprocating parts in machines and equipment are: pistons, connecting rods, valve rocker arms, linear actuators, valve spools and many others. These types of parts are normally exposed to wear from contact with the surfaces on which they slide, bending, thermal shock (engine pistons) and various types of impact damage. Pistons are usually replaced whenever an engine is remanufactured, some remanufacturers have designed their own pistons and claim that they perform better than those provided by the OEM.

Springs: Spring are classified according to the direction of load and the shape of the spring, e.g. coil, leaf, taper, bar, and helical are common examples of spring shapes. Sprigns are usually exposed to fatigue; all springs should be tested to determine if they still exert the right pressure at each specified length, also check for squareness and eliminate those which are bent, cracked or otherwise damaged.

Brakes: Brakes are friction devices used to restrict or stop the motion of moving parts. The most common types of mechanical brakes are: band, block, disk, cone. The lining of the brake shoe is designed to for its friction and wear characteristics. Most wearing parts are also designed for easy replacement and maintenance. A number of electric and magnetic brakes are also in use but these normally exhibit very little wear.

Sliding Parts: Sliding parts are those whose motion is linear or that of pivoting about a point. Examples of this type are: pump vanes, drive chains, sliding parts in machine tools, chuck jaws, cutting edges, and linkages. Linkages can fail by plastic deformation due to bending, compressive, torsional and tensile stresses; they also tend to wear at the pivot points if there is insufficient lubrication.

3.7.2 Interface Parts

Machines often contain a wide variety of seals, rings, gaskets and packings which are necessary for the proper operation of the component. Interface parts is the name given in this document to those parts, this class also includes those parts used to isolate two parts in relative motion e.g. bearings and bushings. Interface parts usually lie between two or more parts of a component and perform a specific task which depends on the parts being separated and their function.

Packings are devices used to prevent or minimize leakage of a fluid through mechanical clearances in either the static or dynamic state. The selection of a gasket or packing is a matter of economics. There are many types that meet specifications for any application, some may be expensive at first but yield trouble-free service; a less costly choice might yield degraded service and fail frequently. Table 3-7 (45) lists some of the symptoms and failure mechanisms for soft packings.

Soft packing are some of the oldest machne elements still extensively used in industry. They perform well even though they have higher leakage rates than seals. The main advantage of soft packings is that they rarely fail catastrophically; if leakage increases the packing can be adjusted. Soft packing are extensively used in hydraulic cylinders and pumps, they will be used with considerable success for decades to come.

Symptoms	Failure mechanism
Packing extruded into clearance between shaft and housing or gland follower	Designed clearance excessive or parts worn by abrasives or shaft bearings inadequate
Packing rings extruded into adjacent rings	Rings cut too short
Leakage along outside of gland follower	Packing improperly fitted or housing bore-condition bad
Used packing scored on outside surface; leakage along outside of gland	Packing rotating with shaft due to being undersized
Packing rings near gland follower very compressed	Packing improperly fitted
Bore of used packing charred or blackened possibly shaft material adhering to packing	Lubrication failure
Shaft badly worn along its length	Lubrication failure. Abrasives in fluid
Excessive leakage	Packing swollen or decomposed. Leakage through ring joints. Rings cut too short or wrongly assembled. Washout of lubricants. Shaft eccentricity. Expansion of stuffing box

Table 3-7 Soft Packing Failure Modes (45)

Seals are used to prevent the leakage of gases or fluids and the introduction of contaminants into the interface between moving parts.

Seals are used in either rotating of reciprocating interfaces. Seals must be tough enough to prevent extrusion and resilient enough to follow irregularities in a cylinder bore. A number of differet seal types and materials are available for different applications. The opearating requirements which govern the selection of the seal are: temperature, pressure, speed, space limitations, environment (air, fluid, oils, chamicals, solvents) and tolerance variations. The typical failure modes of mechanical seals are listed in Table 3-8 (46)

	Symptom High leakage	High friction	High wear and/or seizure
Failure-mechanisms checklist	Seal distortion. Damaged and worn faces. Thermal stress cracking. Solids build up between faces. Crystallisation forms at seal face. Dry running of seal. Faces not flat Chemical change of fluid film between seal faces Vibration levels too high. Housing distortion. Jamming of secondary seal. Excessive pressure or temperature. Failure of elastomeric components Stoppage of auxiliary circuit supplying coolant, etc. Corrosion of shaft or sleeve Incorrect fitting of static seal when assembled Damaged bearings Incompatible face-material combination Solids build up in bellows or springs. Wrong direction of rotation with respect to drive spring	Film vaporisation. High viscosity of sealed fluid Poor hydrodynamic lubrication. Hydrodynamic film overloaded. Seal-face pick-up. Thermal distortion of seal faces. Misalignment of seal faces Housing distortion. Stoppage of auxiliary circuits supplying coolant, etc.	Excessive frictional heat, film vaporises or seal faces distort Poor hydrodynamic lubrication. Overloading of hydrodynamic film Seal-face pick-up. Wrong face-material combination. Solids or crystallisation at seal faces. Corrosion damage to seal faces. Misalignment of seal faces Housing distortion Stoppage of auxiliary circuits supplying coolants, etc

Table 3-8 Rotary Face Seal Failure Modes (46)

Gaskets are interface parts installed in static clearances that normally exist between parallel flanges or concentric cylinders. Some are designed to withstand high temperatures and pressures while others are used simply to separate the parts. Figure 3- (47) shows some of the design and materials currently used in gasket fabrication. Gaskets are commonly replaced 100 percent of the time, since they tend to be inexpensive and are destroyed during disassembly. Modern gaskets materials available in liquid form have eliminated part of the problem of keeping in stock or cutting different gasket sizes and shapes. New gasket materials are much more resistant to high pressures, temperatures, and environments in old ones would have easily failed.

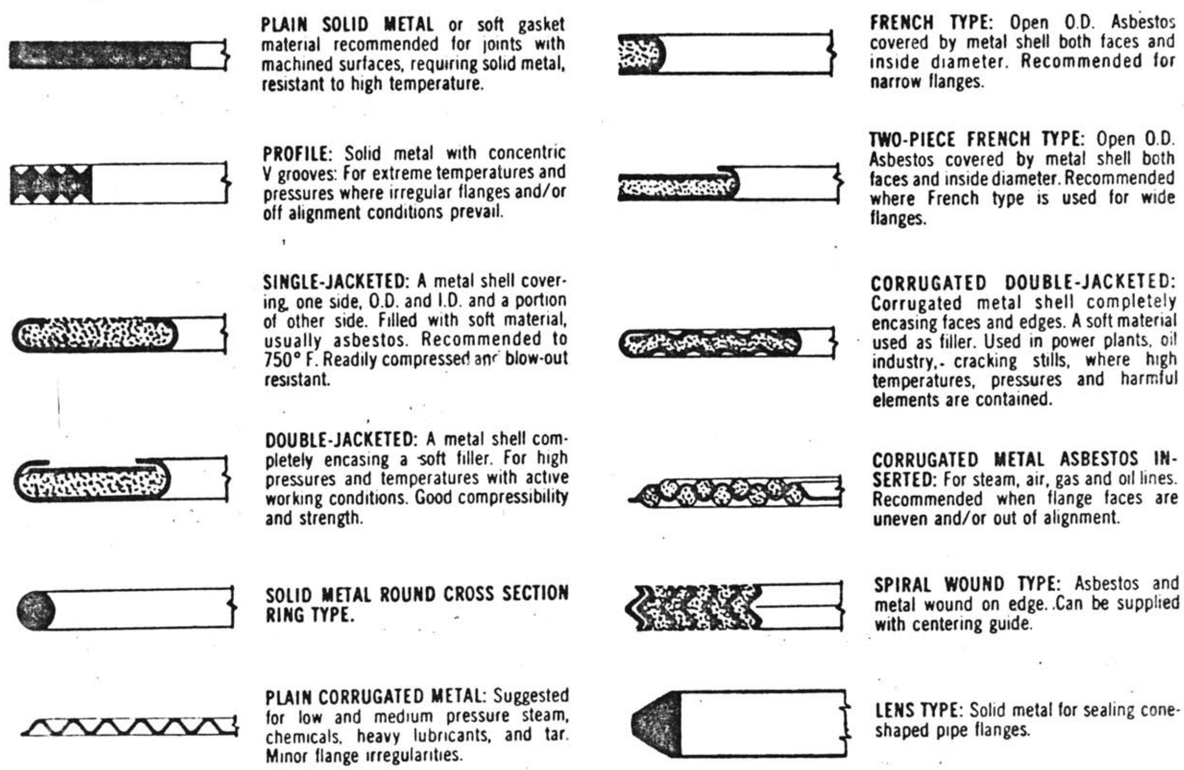
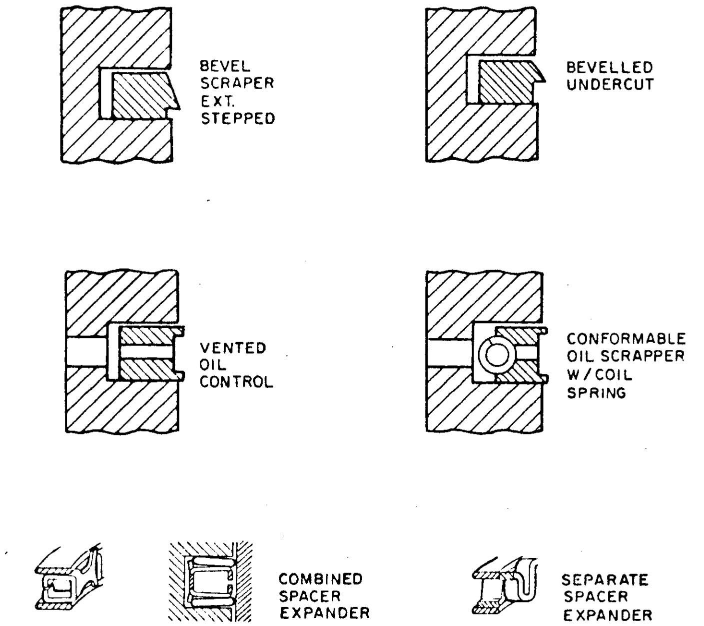


Figure 3-9 Gasket Design and Materials (47)

Piston rings are typical interface parts which represent only a fraction of the compoent's price but are critical to its performance. There are two basic types of piston rings, oil control rings and compression rings. The different designs in use and their properties are illustrated in Figures 3-10 and 3-11 (48). Rings seals and gaskets are standard parts in most remanufacturing bills of materials. All interface surfaces, including ring grooves, are checked for wear and damage to make sure they meet specifications. Whenever necessary these are refinished and fitted with different size interface parts. A good practice is to select specification for seals and gaskets which are one level better than those required by the application.



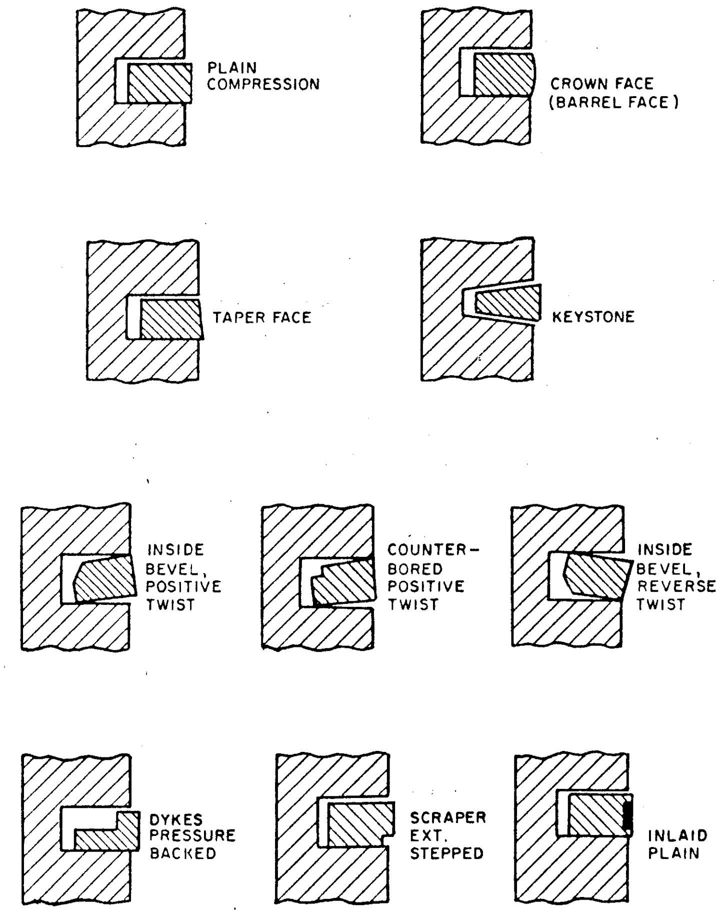
COMMON TYPES OF PISTON RINGS—

OIL CONTROL RINGS

The basic function of the oil control ring is to prevent the passage of excessive lubricating oil into the combustion chamber, yet provide adequate lubrication for the compression rings continuously, as stated previously. Major factors affecting this basic function are: ring-bore contact pressure, ring-bore conformability, sliding surface characteristics, and drainage for the surplus oil. Therefore, the design of oil control ring is basically governed by these factors but other factors, such as the amount of oil transported, oil viscosity, engine operating and temperature conditions, minimum life requirement have to be considered also.

Figure 3-10 Piston Rings: Oil Control

Figure 3-11 Piston Rings: Compression



COMMON TYPES OF PISTON RINGS—

COMPRESSION RINGS

Compression rings have to perform two basic functions, i.e., gas sealing and oil control, under the most hostile conditions because they are exposed to high temperatures, high gas pressures, extreme stresses, impact, corrosion, and even abrasion. They also must be able to operate with a minimum of lubrication and still provide service at low wear conditions. Therefore, the basic design considerations are efficient sealing, light weight, and, good material strength and minimum wear under elevated temperature conditions.

A final class of interface parts includes tubes, hoses, pipes and wires used to connect components and their respective fittings and terminals. These interface parts are designed to handle frequent disassembly and reassembly for servicing and maintenance of components. There are so many types of hoses and fitting that it would be inpractical to list them here. Hoses are replaced in most remanufactured products whenever necessary, sometimes the hose sizes are standardized to reduce inventory problems. Remanufacturers should stock a wide selection of hoses and fittings to cover the types used a broad range of products.

3.7.3 Fasteners

Fasteners are important in the manufacture of most products. This part class includes all those means used to hold parts together in component assemblies. The variety of fastener types currently in use increses all the time. Improvements in adhesive costs and mechanical properties have resulted in widespread use of adhesives in component and product assembly. Fasteners which are molded into parts, such as those found in snap-on assemblies affect the remanufacturability of products.

Fasteners used in remanufactured products should meet the specifications of the ones being replaced. Very often remanufacturers standardize or replace a variety of fasteners with standard items. One should try to consolidate whenever possible to reduce the inventory problems and to facilitate the assembly of the product. In cases where the product cannot be remanufactured a second time, the use of permanent adhesives or rivets is often preferred.

Sorting the fastener hardware is an important job due to the subtle variations is grade, pitch and length for screws and bolts.

The list below illustrates part of the selection of fasteners currently in use.

- o <u>Screw Fastenings</u> (grades, pitch, length, head type etc.)
  - Machine Screws
  - Nuts
  - Eye Bolts
  - Coach and Lag Screws
  - Stove bolts
  - Set screws
  - Wood screws
  - Carriage bolts
  - Wachers
- o <u>Rivet Fastenings</u> (many sizes, shapes and materials)
- o <u>Adhesives</u> (many varieties)

Most screw fastenings fail by either elongation, corrosion or loss of threads. They are commonly replaced whenever it is cheaper than cleaning and sorting the good ones out (most of the time). Rivets tend to become loose or break from fretting or overload. If they need to be removed to remanufacture the product it is done with special tools and later replaced with a new one during assembly.

Other means used to hold part together are:

- o Keys, Pins and Cotters
  - Woodruff Keys
  - Square and flat plain taper keys
  - Sunk keys
  - Feather keys
  - Tapered pins
  - Straight pins
  - Cotter pins
- o Clamps and Latches
  - Hose clamps
  - Housing clamps (air filter assy.)
  - Door locks, latches
  - Tie clasps

3.7.4 Stationary Parts

This class includes all parts which do not fall into the first three classes. The most common function of a stationary parts is to support, locate of protect the components of a product. Stationary parts include the structural elements around which the product is assembled. Components are attached through a series of brackets, mounting plates, adapters and links. Many of the structural failures occur at or near these mounting points. Stationary parts can be sorted into the following categories:

- Structure (product): welded or riveted frame, chassis or body.
- Structure (component): casting, forging, several pcs. or single.
- Bracket: casted, forged, pressed, extruded
- Shielding (enclosure): sheet metal, fiberglall, plastic.

Structural parts in a product usually represent a large fraction of the core weight. Typical structural parts in components include: engine blocks, carburator body, stator assembly, differential or transmission cases, hydraulic power cylinders etc.. These parts tend to be the most complicated parts in a core, some castings have very complex shapes and are designed to perform several functions simulataneously.

Shielding includes those used for protecting the product from the environment. Common exaples include housings, cases, sound shields, bodies. All failure modes are found in stationary parts. These parts are often bulky and difficult to handle. The space and equipment required to work with them in the remanufacturing facilty depends on the product and the production volume.

3.8 Conclusions to Product Analysis

Widespread component interchangeability has made it possible to remanufacture a variety of products in the one facility using similar tools and equipment. Promising remanufacturing opportunities can be explored by using an accurate and reliable analysis technique for determining the optimal remanufacturing process.

Product analysis was structured to improve the process selection procedure using techniques which apply to a broad range of products. All products are broken down into individual parts and then the parts are grouped into general categories for analysis. The categories are general enough to cover most products made from mechanical components and sub-assemblies. The damage and failure modes of each part class can be predicted as long as data on function, material, design, and operating environment of a significant sample of parts are available.

Process analysis is described in the next four chapters. Its effectiveness depends on the accuracy of the part condition analysis. Coded condition information can be used to expedite the selection of processing alternatives. This analysis process lends itself to automation. A future project of the author is to develop the data base necessary to operate a computer program which, given coded conditions for a part, can automatically identify several remanufacturing process alternatives.

The summary of product analysis and preparation of condition codes is shown in Figure 3-12. Every part evaluated is identified by its part number and described using one or more condition codes. Condition codes are listed in decreasing order of magnitude, from most to least harmful. Process analysis concentrates on the worst damage first to determine if the prodctuct can be remanufactured. Figure 3-12 is not meant to be a comprehensive list of all possible failure modes and part conditions, it was compiled from observations on the type of damage remanufacturers normally have to deal with.

	Prefix	Condition
Condition Code: ______ --	___ ___ ___ ___ -	___ ___ ___ ___ ___ n
part number	1. 2. 3. 4.	5. 6. 7. 8. 9.

Symptom Class	Mechanisms	Code
S0-No Damage	....	C000
S1-Deformation:	01-bending	S101
	02-torsion	S102
	03-tension	S103
	04-compression	S103
	05-mild impact (dent)	S104
	06-severe impact (crush)	S105
S2-Fracture:	01-fatigue micro-cracks	S201
	02-fatigue surface	S202
	03-fretting	S203
	04-ductile fracture (torn) ..	S204
	05-total fracture (any type) .	S205
S3-Corrosion:	01-atmospheric (rural)	S301
	02-atmospheric (marine)	S302
	03-atmospheric (industrial) .	S303
	04-direct chemical	S304
	05-galvanic	S305
	06-corrosion/erosion	S306
	07-corrosion/fatigue	S307
S4-Wear:	01-adhesive wear	S401
	02-abrasive (2D)	S402
	03-abrasive (3D)	S403
	04-erosive	S404
	05-spalling	S405
S5-Total Loss	....	S500

Damage and/or Failure Codes:

o 5th character: Degree of Damage — Effect on performance

(Each symptom class has its own criteria)

Degree of Damage	Effect on performance
1-cosmetic damage: no repairs	no effect
2-mild damage: cosmetic repairs	no effect
3-minor damage: minor repairs	minus 0-19%
4-medium damage: normal repairs	minus 20-50%
5-severe damage: major repairs	minus 51-99%
6-total failure: major repairs	minus 100%
7-total failure: no possible repairs	scrap
x-other: consult analysis report	

o 6th, 7th, and 8th characters: Geometry of Damaged Area

-mnemonic code used to specify part material and size, location, and shape of damaged areas. General mnemonic format for all damage/failure mechanisms. Characters 4-7 represent the complete part condition code. They describe the value of the failure mechanism variables which affect the selection of refurbishing process alternatives.

o 9th character: Process Analysis Control Codes

-Sequence number for each condition code. Codes are listed in order of importance (worst damage goes first). Final code of condition sheet is indicated by a period (.) after its sequence number.

Figure 3.12: Product Analysis: Part Condition Codes
General Format for Part with (N) Symptoms

3.9 Plant Organization and Department Responsibilities

For the remainder of this thesis it shall be assumed that all remanufacturing processes are the responsibility of the production division. The departments within the production division and their separate tasks are shown in Figure 3-13.

Figure 3-13 General Remanufacturing Production Division: Departments and Tasks

- o Disassembly Department (Chapter 5)
  - Part Evaluation
  - Product disassembly
  - Component disassembly
  - Scrap handling
- o Cleaning Department (Chapter 6)
  - Product and component cleaning
  - Part cleaning
- o Refurbishing Department (Chapter 7)
  - Shaping
  - Closing
  - Preparation
  - Building
  - Re-Machining
- o Manufacturing (Chapter 7)
  - New part manufacture
  - Part joining techniques
  - Finishing: Coatings
- o Assembly Department (Chapter 7)
  - Sub-assemblies
  - Components
  - Products
- o Testing and Quality Control (Chapter 7)
  - In-process part testing
  - Component and product testing
- o Traffic: logistics and control of:
  - Core, part, materials and supply inventories
  - Work in process and finished goods inventory
- o Maintenance: Machines and Shop

Exhibit 3-1 Common Sources of Components for U.S. Truck Manufacturers (20)

1. Diesel Engines	Caterpillar Cummins Detroit Diesel Allison Deutz Perkins Waukesha Isuzu Mack Motors International Harvester
2. Manual Transmissions	Clark Fuller (Eaton) New Process (Chrysler) Spicer (Dana Corp.)
3. Automatic Transmissions	Allison (Detroit Diesel Allison) Ford
4. Front Alxe 4X4	Kelsey-Hayes Co., Fabco Division Marmon Harrington Rockwell International
5. Front Axle 4X2	Eaton Brake Division Rockwell International
6. Rear Axle	Eaton Rockwell International Spicer Axle Division (Dana Corp.) Spicer Heavy Axle Division (Dana Corp.)
7. Trailer Axles	Eaton K. B. Axle Parish Group, C&M Division (Dana Corp.) Pro-Par Division (Freuhauf) Rockwell International Standard Forge and Axle Co.
8 Anti-Lock Systems	AC Spark Plug Kelsey Hayes Wagner Electric

Exhibit 3-1 Truck Component Manufacturers (Continued)

9. Tandem Axles	Bonnin Truck Equipment, Inc. Cambra Spring Co. Chalmers Suspension Inc. Freuhauf Division Granning Suspensions Hendrickson Manufacturing Co, Tandem Div. Hutchens Industries MOR/RYDE Muncie Division, Dayton Walther Corp. Neway Division, Lear Sigler Parge Suspensions Paris Division (Dana) Pro-Par Division, Freuhauf Reyco Industries Ridewell Corp.
10. Air Compressor	Bendix Midland Brake Division, Midland Ross
11. Alternators	Delco Remy Division, GM Electrodyne Leece-Neville Inc. Motorcraft Motorolla C.E. Neihoff Prestolite
12. Temperature Controlled Fan Drives	Facet Enterprises Horton Industries Kysor/Cadillac Rockford Division, Borg Warner Switzer
13. Seats	American Seating Co Anchorlock, Lear Sigler Inc. Cush 'n' Aire Fleetcruiser General Seating
14. Fifth Wheels	American Steel Foundries Bartlett Lifting Devices Fontaine Truck Equipment Co. Freuhauf Division, Freuhauf Corp. Holland Hitch Transall Truck Equipment Co.

Appendix 3-A Part and Material Inspection

Part inspection is carried out during disassembly, cleaning, and right before refurbishing. Before refurbishing parts one must determine the type and extent of damage which it received during use. The type of material inspection technique depends on the size, location, and orientation of flaw and on the properties of the part material. Different inspection methods have been developed to deal with most common flaw types and characteristics.

The most common evaluation techniques used by remanufacturers in failure analysis include visual inspection, dimensional measurements, and various nondestructive tests. Each of these techniques has a range of used and applicatons. The selection of inspection process depends on the accuracy required, and the cost budgeted for each test. The cost of each test depends on the type of equipment and supplies needed and the labor required to perform the test.

3-A-1 Visual inspection

Analysis begins with the visual inspection of the parts as they are disassembled. Those parts which are obviously beyond repair are discarded right away. The first serious inspection occurs inmediately after cleaning. About 90% of the failed or damaged parts can be detected by a trained inspector with nothing more than simple measuring devices and his eyes (49). Visual inspection is sufficient for identification of corrosion, wear, material changes, cracks and burns.

The evaluation site should be equipped with a small hand-held magnifying glass for observing fracture surfaces. Bore scopes are used to inspect interior surfaces such as tubes, cooling passages, cylinder bores, and other hidden surfaces. Penetrants (described later) can be used to highlight hidden cracks and imperfections.

Visual inspection requires skill in identifying signs of deterioration, some common examples are listed in Figure 3-A-1.

Figure 3-A-1 Common Signs of Failure and Deterioration
Visual Inspection

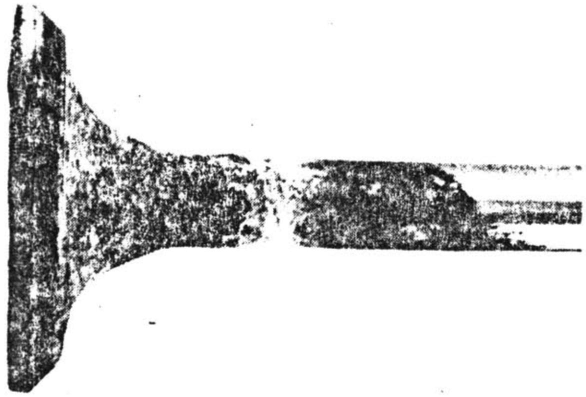
1. Deformation: Yielding from bending, twisting, tensile or compressive stresses; loose nuts or fasteners; crushed structures; buckling; misaligned parts.

2. Cracks or Fracture: surface cracks, crazes, leaks and loss of pressure, internal voids and delaminations; fragments of material.

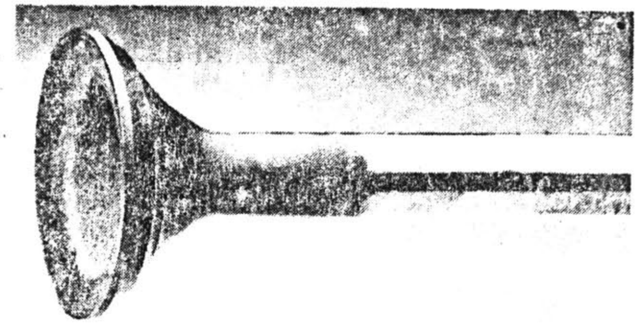
3. Corrosion: oxides, discolorations, blisters, surface anomalies.

4. Wear: wear deposits, scratches, polished surfaces, abraded surfaces.

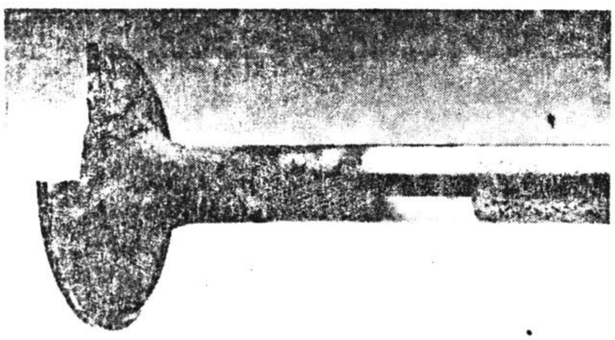
Initial visual inspection is used to screen out worth less cores and for selecting products to be evaluated more extensively by other techniques. This type of inspection is a natural, cheap and effective way of gathering information about the parts in a product or component. Figure 3-A-2 shows the visual interpretation of a series of valves that have failed by different modes (50). Even though most valves may be routinely replaced during remanufacture, their evaluation can yield useful information about other problems in the engine. Similar failure data can be derived by studying seals, pistons, cylinders, bearings, cams, springs and other parts.



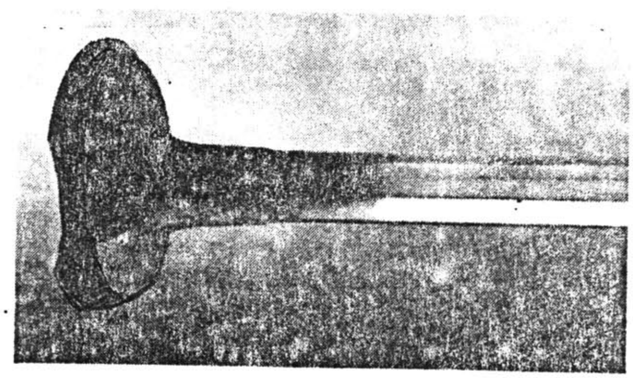
Valve burning is caused by high temperatures leaking past the valve face. The most common causes of leakage are seat distortion and deposit buildup. Seat distortion results from machining runout, thermal distortion (from overheating), and mechanical distortion (from warpage or improper torquing). The picture shows a valve that burned from deposits built up on the valve seat (Courtesy TRW, Inc.)



Valve cupping (tuliping) is descriptive of the valve appearance. This problem develops when abnormally high temperatures weaken the valve, allowing combustion pressures along with spring and inertial forces to deform the valve head. Commonly, elevated valve temperatures are caused by severe engine overloads, improper carburetion, and/or ignition settings and incorrect seat location or width (Courtesy TRW, Inc.)



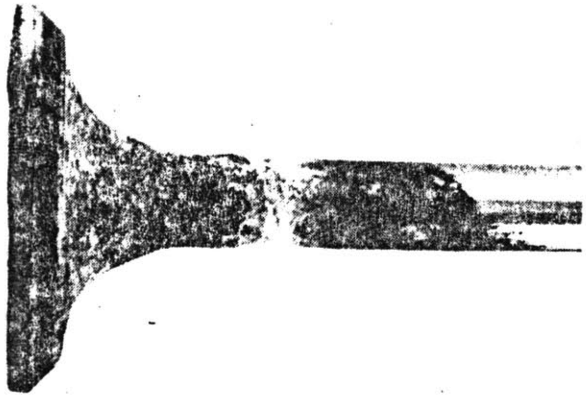
Thermal shock occurs when a valve experiences extreme temperature variations. Extremely heavy engine loading, followed by abrupt unloading, or total engine shutdown creates excessively high internal stresses in the valve head. Consequently, radial cracks form through the valve margin. The cracks can interconnect, causing portions of the valve to break away as shown. Thermal shock can best be eliminated by avoiding severe fluctuations in engine load (Courtesy TRW, Inc.)



The picture illustrates the characteristic melting and blowing of material from the valve face from preignition. This condition develops when the fuel/air charge ignites prematurely. Potential causes of this failure include the glowing of sharp edges or deposits in the combustion chamber, improper spark plug heat range, knife thin valve head margins, and improper ignition timing (Courtesy TRW, Inc.)

The picture shows what develops when lubrication film between the valve stem and guide breaks down. Although the damage itself does not appear to be severe, scuffing can cause the valve to stick in a partially open position. The valve can then burn from leakage or actually break, if struck by the piston. A careful review of both the stem-to-guide clearance and upper valve train oiling will usually prevent scuffing problems (Courtesy TRW, Inc.)

Figure 3-A-2 Visual Inspection of Engine Valves (50)



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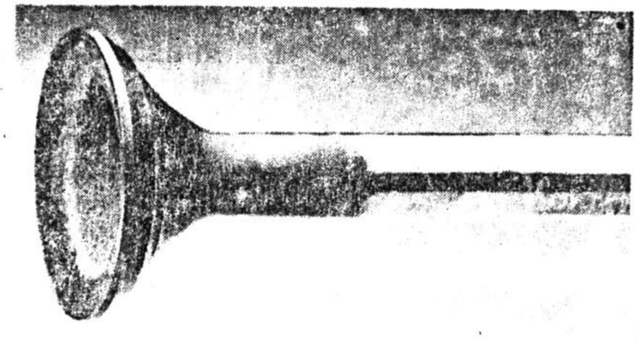

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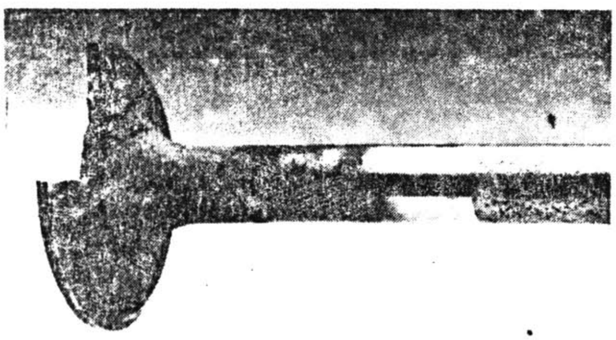

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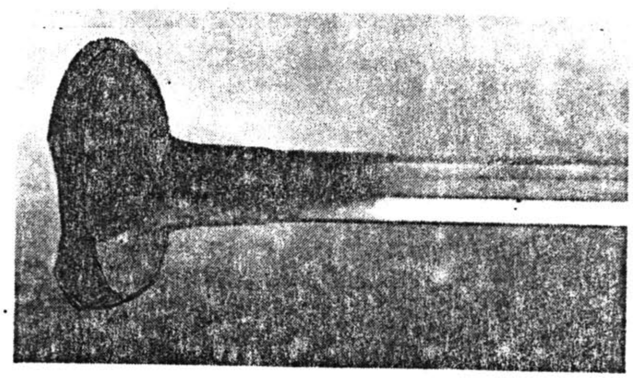

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Figure 3-A-2 Visual Inspection of Engine Valves (50)

3-A-2 Dimensional measurements

Dimensional measuremnts are used to evaluate changes in the shape of a part which are caused by yielding, wear, corrosion and thermal stress. Measurements are taken to determine if a part can be brought back within tolerances and the amount of work needed to do it. A variety of instruments and jigs are commercially available to measure dimensional changes in many different part shapes and sizes. Common changes such as bending, cylinder bore eccentricity, and cam wear are routinely measured in remanufacturing operations. Remanufacturers often build custom test stands to shorten the time required to make common measurements.

3-A-3 Nondestructive Crack Testing

Increasing consumer demand for produt quality at reasonable cost has resulted in the development if nondestructive tests which can be applied to materials and manufactured parts. Although a variety of complementary nondestructive methods is available, development time is generally required for application to specific materials and products. The effect of part contour, surface condition, heat treatment, composition variation, and other variables may limit the ability of certain tests to detect the imperfections with desired accuracy (51).

Usually these tests are used in machinery maintenance to avoid costly unscheduled loss of service due to fatigue or wear. They are used in manufacturing to assure product quality and to minimize warranty costs. Tests are divided into the following basic methods: magnetic-particle, penetrant, radiographic, ultrasonic, eddy-current, microwave, and infrared. Those nondestructive tests recommended by the Society of Automotive Engineers are listed in Table 3-A-1 (52).

Table 3-A-1 Features of Nondestructive Tests (52)

Method	Principle	Material	Applications	Advantages	Limitations
Magnetic particle (SAE J420)	Magnetic particles attracted by leakage flux at surface flaws of magnetic object aid visual inspection.	Magnetic materials	Surface flaws such as cracks, laps, and seams. Some subsurface flaws.	Easy to interpret, fast, simple to perform	Parts must be relatively clean. Usually requires high current source. Parts sometimes must be demagnetized. Standards difficult to establish.
Electromagnetic (eddy current) (SAE J425)	Alternating current coil induces eddy currents in test object. Flaws and material properties affect flow of currents. Information derived from meter or cathode ray tube indications.	Metals	Material composition, structure, hardness changes, cracks, case depth, voids, large inclusions, tubing weld defects, laminations, coating thickness, porosity.	Intimate contact between coil and material not required. Versatile. Special coils easily made. Fast operation can be automated. Electric circuit design variations permit selective sensitivity and function. Sensitive to surface and near surface inhomogeneities.	Sensitive to many variables. Sensitivity varies with depth. Reference standards needed. Response often comparative.
Liquid penetrant (SAE J426)	Liquid penetrant is drawn into surface flaws by capillary action, then revealed by developer material to aid in visual inspection.	Nonporous material, metals, plastics, glazed ceramics	Surface flaws such as cracks, porosity, pits, seams, and laps.	Simple to perform, applicable to complex shapes, on site inspection.	Only surface flaws detected. Surfaces must be clean. Penetrant washes out of wide defects. Standards difficult to establish.
Penetrating Radiation (SAE J427)	General—Penetrating radiation is differentially absorbed by materials, depending upon thickness and type of material.	Most materials	Internal defects such as inclusions, porosity, shrink, hot tears, cracks, cold shuts, and coarse structure in cast metals; lack of fusion and penetration in welds. Thickness measurement. Detection of missing internal parts in an assembly.	More standards established than for other methods. Internal defects detected. Permanent film record. Automatic thickness gaging.	Health precautions necessary. Defect must be at least 2% of total section thickness. Film processing requires time, facilities, and care. Difficulty with complex shapes. Most costly nondestructive test method.
Ultrasonic (SAE J428)	Mechanical vibrational waves (frequency range 0.1–25 MHz) are introduced into a test object. This energy is reflected and scattered by inhomogeneities or becomes resonant. Information is interpreted from cathode ray tube or read from meter.	Metals, plastics, ceramics, glass, rubber, graphite, concrete	Inclusions, cracks, porosity, bursts, laminations, structure, lack of bond, thickness measurement, weld defects.	Variety of inspection elements and circuitry permits selective high sensitivity. High speed test. Can be automated and recorded. Penetrates up to 60 ft (18 m) steel. Indicates flaw location. Access to only one surface usually needed.	Difficulty with complex shapes. Surface roughness may affect test. Defect orientation affects test. Comparative standards only. Requires couplant.
Infrared (SAE J359)	Electromagnetic radiation from test objects above a temperature of absolute zero is detected and correlated to quality. Information is displayed by meter, recorder, photograph, or CRT.	Most materials	Discontinuities that interrupt heat flow: flaws, voids, inclusions, lack of bond. Higher or lower than normal resistances in circuitry.	High sensitivity. One-sided inspection possible. Applicable to complex shapes and assemblies of dissimilar components. Active or passive specimens.	Emissivity variations in materials, coatings and colors must be considered. In multilayer assemblies, hot spots can be hidden behind cool surface component. Relatively slow.
Acoustic Emission (SAE J1242)	Acoustic emission is a transient elastic wave generated by rapid release of energy from a localized source within a solid material. Rate and amplitude of high frequency (0.1–1 MHz) acoustic emissions are noted and correlated to structure or object characteristics.	Most solid materials	Determine or monitor integrity of structures such as weldments or castings.	Remote and continuous real time surveillance of structures is possible. Inaccessible flaws can be detected. Location of flaws can be determined. Permanent record can be made.	Part must be stressed. Non-propagating flaws cannot be detected. Non-relevant noise must be filtered out. Transducers must be placed upon the object.
Leakage Testing (SAE J1267)	Material flows across an interface at a leak site. Rate of flow is pressure, time, and leak size dependent. Detection of the trans interface migration is done in one of eight or more ways.	Totally independent of materials.	Any vessel containing a product at a pressure different from ambient or a vessel in which a pressure different from ambient can be created for evaluation.	Provides assurance that the vessel will retain contents as designed. Advantages vary for the individual methods.	Vary from method to method.

Magnetic Inspection of Parts

Magnetic inspection or "Magnaflux" is a popular method of inspecting ferro-magnetic metal parts for cracks. Magnetic particle inspection is used as an aid to visual inspection of objects. Surface discontinuities that might not be seen even with the aid of optical magnification are often dependably detected in manufacturing and service maintenance operations using these techniques. The usual basic steps are: cleaning, magnetization, application of particles, inspection and demagnetization.

The type of magnetization selected is determined primarily by the need to establish magnetic flux lines perpendicular to the direction of anticipated surface imperfections (48). An electromagnet is used to create a magnetic field in the part to be inspected. A crack through the material creates a discontinuity in the field which attracts iron powder sprayed on the part. The iron powder outlines the crack and makes it readily visible.

Their pattern outlines the crack or defect and gives definite indications of the exact location of a crack and the shape of a defect, even under the surface. Some of the advantages of magnetic inspection are that the process is:

- good on rough surfaces, such as castings, forging welds,
- can be in a clean and dry fashion
- does not leave oil deposits on material
- can be used on carbon and through rust

Another method that uses a magnetic fields is Magnaglo. In this case particles are mixed with a special fluorescent paste and oil to form a suspension of fluorescent and ferromagnetic particles. This solution is sprayed on the part being checked while the current is on. When viewed under ultraviolet light, a crack, if present, will appear as a streak of white against a bluish black background. Magnaglo is used to detect small cracks not visible in Magnaflux inspection. Its disadvantage is that it is more time consuming and expensive and requires very clean surfaces (free of oil) to achieve satisfactory results.

Penetrant Methods

Liquid-penetrant testing is a nondestructive testing method used to locate defects open to the surface of nonporous materials. The test object must be thoroughly cleaned before testing by washing, degreasing or etching. Penetrating liquid is applied to the surface of a test object by a brush, spray, flow, or dip method. A time allowance (1 to 30 minutes) is required for liquid penetration of surface defects. After penetration the surface is dried and coated with a developer.

The next step is to locate the imperfection by observing penetrant concentrate at the discontinuity. Finally parts are cleaned to remove any residual penetrant and developer. A number of different methods are available. Selection of method depends on surface roughness, surface treatment, size of discontinuities to be disclosed, environment, production required, equipment available, type of material, subsequent use of the part, disposal restrictions, cost and others (53).

The dye penetrant method of material inspection consists of using an oxide and a mixture of 25 percent kerosene and 75 percent light engine oil. Brush the mixture on the suspected area then wipe dry. Immediately apply a coating of zinc oxide dissolved in wood alcohol. If cracks are present, the white coating will become discolored at the defective area. This method is effective in locating the extreme ends of visible cracks or for checking the areas where acrack is suspected.

The Zyglo dye penetrant method makes use of fluorescent penetrant that is viewed under UV light. This inspection method can be used on practically all solid materials, both magnetic and nonmagnetic. The essentials of this method are as follows: 1) penetration of the defect by a fluorescent oil-base penetrant; 2) removal of excess penetrant from the surface by washing with hot or cold water; 3) developing the indicator using wet or dry developer; and 4) inspection under blacklight. A brilliant fluorescent indication will mark the crack.

Chapter Four: Cores

4.0 Sourcing and Accumulation of Cores

The remanufacturing industry owes its existence to the availability of large quantities of inoperative durable goods which have residual value. The supply of discarded products that can be remanufactured is constantly expanding and represents a huge waste of embodied materials and energy. An important benefit of remanufacturing is the conservation of materials and energy embodied in cores and the ability to create a "like new" durable good from a discarded core. This significantly reduces the consumption of resources needed to make replacement products.

Some important core related considerations that must be evaluated before a product can be remanufactured include:

- Sources of Cores
  - for Contract Remanufacturing
  - for Commercial Remanufacturing
- Core Pricing
- Core Pipeline (number of cores needed)
- Classification of Cores

The United States is the largest source of cores for almost any remanufacturable product. Remanufacturing can be a significant industry both in the local and export market. Nobody has estimated the potential for various remanufacturing different products can be. The best estimate of the types of products which could be remanufactured was can be made from the C.P.A. report: Energy Recapture Through Remanufacture: Final Report to Pre-Demonstration Study (7). The Appendices dealing with the remanufacturability of the products listed in the Standard Industrial Classificaton (SIC) give a reasonable estimate of what the range of the industry could be. To get additional information, each product has to be evaluated separately.

Since this thesis has already dealt with trucks as a case study, a brief discussion of the truck core supply is appropiate. Every year in the United States over 11 million vehicles are retired from use; of these 1.9 million are trucks and buses(54). As seen in Figure 4-1 there are some variations from year to year but this is irrelevant considering the huge quantities being retired and the small amount being remanufactured. It should be clear from this figure that there is an abundant core supply.

MOTOR VEHICLES RETIRED FROM USE (In Thousands)

Year Ending June 30	Pas-senger Cars	Trucks & Buses	Total	Year Ending June 30	Pas-senger Cars	Trucks & Buses	Total
1979	9,312	1,916	11,228	1969	6,348	966	7,314
1978	7,907	1,426	9,333	1968	6,200	861	7,061
1977	8,234	1,668	9,902	1967	6,984	947	7,931
1976	6,829	1,097	7,926	1965	5,704	736	6,440
1975	5,669	908	6,576	1963	4,741	720	5,461
1974	7,194	1,047	8,241	1961	4,294	647	4,941
1973	7,987	1,208	9,195	1959	2,982	372	3,354
1972	7,058	1,048	8,106	1957	4,309	630	4,939
1971	6,021	1,044	7,065	1955	3,247	468	3,715
1970	7,461	837	8,298	1953	2,466	616	3,082

NOTE: Figures represent vehicles failing to re-register.

Table 4-1 Vehicles Retired From Use 1978 (54)

These cores can be used for both the local and export market. By foreign country standards, American truck cores are in excellent shape. In most foreign countries the vehicles are used for a much longer time and are repaired until they have absolutely no residual value left. In the United States, for tax and depreciation purposes, the vehicles are retired way before their value is completely used up. These U.S. cores can be the "raw material" for a significant export industry.

4.1 Core Sources by Type of Operation

Core procurement policy will be determined by both the consumer behaviour relative to the product and the type of remanufacturing organization. An independent remanufacturer will have different core procurement practices than an OEM. As seen in Table 4-2, core brokers, salvage operators and nonwarranty service exchanges supply 63% of the cores remanufactured by independents while this same group provides only 30% of the OEM's cores (55).

Table 4-2 Sources of Cores by Organizational Group (%) (55)

SOURCES OF CORES	INDEPENDENT REMANUFACTURER	OEM/REMANUFACTURER
Warranty Returns	4	8
Core Brokers	18	7
Nonwarranty Service Exchange	33	18
Lessor/Renter	2	7
Returned by Owner for Rebuild	32	51
Salvage Operators	12	5
SURVEY COUNT	100	35

4.1.1 Contract Remanufacturing

Contract remanufacturers usually do not have to purchase cores to create a core bank. In most cases the owner of the product cores sends the cores to the remanufacturer's shop for processing and receives the same products back. Contract remanufacturing may be done by either the OEM or an independent firm.

A second type of contract job requires the remanufacturer to locate cores to be remanufactured for a third party. In these cases the cores are not actually purchased until a firm commitment to purchase has been made on the part of the third party. Cores for such contracts can be procured through used equipment brokers, OEM distributors, users of the equipment, and other outside sources.

Third party contract remanufacturing could be done for export sales to developing countries. For example, a remanufacturer may find a market for a specific type of equipment in a foreign country. Suitable cores can be located in a more industrialized country. A bid is prepared by the remanufacturer for the customer. Only when there is a firm commitment, such as an irrevocable letter of credit, from the customer will the remanufacturer purchase the cores and begin work.

4.1.2 Commercial Remanufacturing

In commercial scale remanufacturing the core collection issue is a crucial aspect of the business. The remanufacturer must have a steady source of workable cores at all times. Commercial remanufacturers work closely with their distribution network and other sources to maintain a steady core supply. Cores purchased by these remanufacturers include some products which they feel may go into production at a later date. It is common to have huge stockpiles of cores just to control the market for a given product.

Most cores are obtained as exchanges for products sold through the distribution network. Typically, someone purchasing a remanufactured product is given a "core credit" for returning a core. Deductions are made for broken or missing parts. Table 4-3 lists the sources of cores by market segment (56).

Table 4-3 Sources of Cores by Market Segment (%) (56)

SOURCES OF CORES	AUTOMOTIVE	INDUSTRIAL	COMMERCIAL
Warranty Returns	5	5	6
Core Brokers	23	8	8
Nonwarranty Service Exchange	37	17	23
Lessor/Renter	4	1	5
Returned by Owner for Rebuild	22	56	47
Salvage Operator	9	11	11
SURVEY COUNT	61	43	29

Table 4-3 uses different definitions for the market segment categories. These classifications refer to the type of product, not the type of core ownership or method of production.

Industrial equipment remanufactured includes such products as process valves, hydraulic equipment, production metal working machinery, and oil production equipment. Products in this sector are frequently custom made for a specific application and must be remanufactured one at a time. Commercial products which are commonly remanufactured include office machinery, refrigeration compressors, and communications equipment. As with industrial equipment, complex or custom made products must be remanufactured one-by-one. Both of these categories include products which are remanufactured on a contract and commercial basis, as defined in this thesis. The high percentage of cores returned by the owner for rebuilding indicates the majority of them are done on a contract basis.

4.2 Core Pricing

Core pricing is an important part of the competitive strategy of a remanufacturer. A remanufacturer will usually have at least two kinds of core pricing systems:

1) the price paid for a core
2) the price used for accounting purposes.

Two factors which exert opposing influences on the purchase price of a cores are availability and profitability. The price paid for a core must be high enough to encourage owners to turn them in to remanufacturers. Lowering a core price will tend to curtail returns and encourage owners to repair the core themselves or cannibalize it for parts. If a core is in high demand, the amount paid for it will be high as remanufacturers compete for the limited supply. On the other hand a remanufacturer will always try to get a core for the lowest price possible to increase profitability.

The price paid for a core is dependent upon the condition of that core. Condition is determined by the dealer or broker at the time of acquisition of the core. Each model has a predetermined value for a complete, useable core. A standardized schedule of deductions is used to determine the net core value depending upon what parts of the core are missing or damaged beyond repair. Commercially remanufactured products are handled in such high volumes that there is a well established price system for them. The prices are set according to the need for that model by the remanufacturer and according to the market value of the used product. The price paid by the remanufacturer is usually a "core credit" given to the purchaser of the remanufactured product. When purchased from other sources, it is the price paid to core brokers and salvage operators.

In the remanufacture of large, complex products the purchase price of cores is a function of such variables as type of product, source, condition, and quantity. For example, when buying surplus MBTA buses the remanufacturer would probably pay much less if the purchase involved a package deal on a number of adequate and not so good cores, than if he bid only on the best bus cores.

Large (one of a kind) cores like process machinery, sugar mills, printing presses, oil refineries and locomotives have no easily defined price. The availability of these cores is very sporadic and their purchase requires a great deal of bargaining skill. The best source for these cores is companies going out of business which are forced to dispose of their assets.

Core accounting is an area which has recently received considerable attention. Corporate internal financial decisions play a large role in determining what value is assigned to a core within the firm. Economic variables such as property taxes, need of collateral, availability of cash, and inventory controls have a great deal of influence on the treatment of core in the acounting process. An exellent source of information on this subject, a speaker at both MIT remanufacturing conferences, is Mr. Robert Baker, a consultant to the Auto Parts Rebuilder Association (APRA) (57).

4.3 Core Pipeline

The core pipeline is a term used by commercial remanufacturers to define the number of cores needed to complete the cycle from collection through remanufacture to receiving a core return. The number of cores required for the pipeline depends on the type of process and the product being remanufactured. The total supply of cores must be large enough to account for a core inventory, work in process, finished units, and units shipped to dealers. There must also be an allowance for the time lag in the return of cores to the remanufacturer's inventory.

Filling the pipeline at the outset of business is a costly process. Many remanufacturers "seed" the distribution network by selling new products as remanufactured to get the core return process started. Cores in the core inventory, work-in-process inventory, and finished goods inventory represent a materials investment. The number of cores in any stage of the pipeline can be determined by multiplying the daily output of the plant by the number of days spent in that stage. A typical pipeline (58) for commercial scale remanufacture of durable consumer goods (chainsaws) is shown in Figure 4-1.

Core Inventory	Remfg Process	Finished Stock	Distribution and Transit	Retail Sale	Core Return
40 days	20 days	10 days	15 days	45 days	10 days

Figure 4-1 Core Pipeline for Chain Saws (58)

4.4 Classification of Cores

Core classification usually applies to the components of larger systems. Complex machinery is assembled from components manufactured by several different original equipment manufacturers (OEMs). Each component must be classified and evaluated separately. While some parts of a machine may be easy to remanufacture, other components may be impossible to repair and will have to be replaced.

The degree to which a product will serve as a core is diretly related to its construction, design, use history and age. The condition of the cores availabile to remanufacturers is the biggest variable in the industry. One approach for classifying products was presented at the 1982 remanufacturing conference by Dr. Alf Walle. He called it the "Continuum of Coreability" (59). This set of categories is useful for durable consumer products.

Captive Core	Active efforts are made by manufacturer and/or client to promote remanufacturability and to create means of retrieving cores. Examples: Computers, robots, machine tools, military hardware, space shuttle
Conscious Core	Product is manufactured to tolerate remanufacturing but the OEM is not necessarily interested in actual remanufacturing operations. Services may be offered to remanufacturers by OEM to enhance product acceptance. Examples: Internal combustion engines, hydraulic actuators, motors, valves.
De Facto Core	Remanufacturability is greatly enhanced by factors such as readily available supply of cores for some reasons and/or by products which by their nature can be remanufactured even though such characteristics are not intended by manufacturers. Examples: Trucks, Refrigerators, torque converters, Hi Fi Speakers.
Quasi Core	Product could be remanufactured, although such efforts are not currently cost effective. Examples: Garbage disposers, ignition modules, satellites
Non Core	Product cannot normally be remanufactured. Examples: Pacemakers, computer chips, nuclear reactors, light bulbs

Cores within a given core classification can be sub-classified according to their condition and the degree of work necessary to remanufacture. Large products such as trucks and truck mounted equipment tend to have a mix of core types in the components from which they are assembled. The greatest portion of the vehicle is assembled out of conscious cores (transmission, engine, clutch, brakes, wiper motors, pumps, compressor) and some de facto cores (cab, tanks, chassis). This means that most of the components are suitable for remanufacturing (many already are being remanufactured).

The remanufacturer of large products should accumulate cores of the system components commonly found in the products remanufactured. These can be used as replacement cores (pumps, cylinders, accumulators, brackets, housings, tanks, etc.) or cannibalized for parts to remanufacture other cores. The key to success in large equipment remanufacture is <u>flexibility</u> to meet the customer needs, and <u>foresight</u> to anticipate the core, tooling and spare part needs.

Chapter Five: Product and Component Disassembly

5.1 Obstacles to Disassembly

Component disassembly is necessary to inspect and refurbish most parts. Processes, and tools used depend on the component and part design, construction material, and original joining process. The condition type and condition of part interfaces also affects the difficulty of disassembly. Parts that are designed for rapid assembly and mass production are usually built in such a way that their ability to be removed for service is compromised. Welded, glued, crimped, and riveted surfaces are common part interfaces where the possibility of damaging parts is likely.

In some cases, measures taken to protect delicate parts of a component or mechanism impede disassembly and remanufacture. A good example of this problem which is currently under intensive study is the remanufacture of automotive electronic control modules. Component circuitry embedded in epoxy usually cannot be serviced without destroying the parts. Lack of access represents an obstacle in some products, to reach a faulty component (or part) for inspection and repair it may be necessary to take apart, destroy, or remove several functioning parts. This additional work increases the costs of replacement parts and assembly labor and may render the product's remanufacture uneconomical. Remanufacturers can take measures to improve the serviceability of the product by improving access to these parts.

Part damage is the biggest obstacle to rapid and easy disassembly. Damage done to parts during disassemly should be minimized as much as possible. A certain amount is often unavoidable; in these cases a ranking system of the affordable damage has to be devised. Criteria to be used include the value of the different parts, their role in the final remanufactured product, availability of replacements. Economic factors often require that parts which are expensive to refurbish or replace get handled more carefully.

5.2 Classification of Processes

The disassembly process depends on the type of part interface and the fastening technique used. Parts can be held together at their interfaces by fasteners or fastening techniques which provide varying amounts of trouble to the remanufacturer. The processes used to remove the various interface fasteners can be grouped into three levels of difficulty.

Easy Disassembly The ideal situation would involves only products which are designed for easy disassembly and repair. Assuming there are no complications such as bending or corrosion most part interfaces held together by "conventional" fasteners are easy to take apart. These fasteners include: screws, bolts, nuts, keys, and pins. Common machine part interfaces also considered simple to disassemble include, splines, couplings, and shrink and press fits. Products which are meant to be serviced are held together conventional fasteners. In these cases the manufacturer often provides detailed disassembly and repair instructions along with parts kits.

Medium Difficulty This category includes any conventional fastener which is damaged by corrosion or plastic deformations, factors which usually complicate removal. Common production interfaces such as crimps or welds may be considered of only medium difficulty whenever they are accessible. In these cases the interface can be cut apart (at or near the weld) without destroying the part.

Problematic Disassembly Problems are encountered whenever parts have glued surfaces, inaccesible welds, crimps, or are made in ways that cause exetensive damage during disassembly. Remanufacturers have to develop procedures to get around these problematic interfaces and allow the refurbishing of damaged parts. Special remotely operated cutting, positioning, bonding and inspection tools can be used to remanufacture delicate products without extensive disassembly. Certain amounts of damage will have to be accomodated unless there are ways to remove or work on the damaged parts remotely.

5.3 Steps in Disassembly

The sequence of disassembly depends on the product being disassembled, its construction, and the objectives of the task. There are several reasons to disassemble a product:

- o to remove a part for use in another product (cannibalism)
- o to repair
- o to inspect parts
- o to separate the materials for scrap recovery.

All disassembly steps should be carefully recorded. All design features whose failure or derioration affected the performance of the product should be recorded. This is done so that those parts can be improved when the product is reassembled.

5.3.1 Pre-Production Disassembly

During evaluation, disassembly should be done very carefully to allow examination of the performance and wear of parts. Failure analysis can be used to determine why those parts have deteriorated and suggest corrective action most easily before the part has been removed from its proper location. A good practice during prototype disassembly is to keep the parts that are to be discarded as a reminder of what needs to be replaced.

Sediments and deposits should be collected and analyzed to determine their sources and implication on the condition of the various component parts. Key areas to look for damage in mechanical systems are:

- o bearing surfaces
- o seals
- o wear surfaces
- o seams
- o sliding surfaces
- o fits
- o linkages
- o welds

Damaged seals, bearings and sliding surfaces can be indications of contaminants or inadequate lubrication. Dimensional changes in parts that must meet tight tolerances should be detected and recorded whenever possible.

Useful aids for Pre-Production Disassembly are:

- o Handbooks
  - Parts Catalogs/ Sevice Manuals
  - Data books and Engineering drawings
- o Notebook or recorder
- o Camera
- o Adequate facilities
  - Clean room and work areas
  - All necesssary tools for disassembly
  - Evaluation equipment (microscope, non-destructive tools)
  - Containers for labeling, sorting and storage of parts

If no drawings of the product are available, it is helpful to keep a written and photographic record of the proper location of all the components and the sequence in which they were removed. Whenever a product is disassembled without paying attention to the exact position and location of certain components it may be difficult to reassemble or understand the interaction of all parts.

5.3.2 Production Disassembly

After a careful product and process analysis one should be able to list all the possible ways in which a product can be disassembled. If careful records are kept of the sequence, time, and tooling used the optimal disassembly process for large-scale production can be determined. An accurate process model aids in making projections of the cost of operating a continuous disassembly line.

Disassembly areas are usually laid out as a reverse assembly line. Cores start at one end of the line and are gradually separated into parts as the core moves down the line. Remanufacturing facilities that handle several hundred units a day have a specially designed diassembly area, which is segregated from the rest of the plant isolate dirt in one area. Batches of cores are fed into the disassembly line according to the production schedule.

5.4 Disassembly Equipment

Typical tools used in product and component disassemlby are:

- o Hand tools
- o Power tools:
  - air wrenches
  - air hammers
  - electric power tools
- o Hydraulic presses (and accesories)
- o Gear pullers, clamps, brackets
- o Cutting equipment:
  - oxyacetylene torch
  - saws (hand and power)
  - machine tools
- o Penetrants, solvents and lubricants
- o Material handling equipment

Brute force disassembly approaches should be discouraged whenever they cause exessive part damage. An oxyacetylene torch (commonly referred to as a "blue tip wrench") is sometimes an effective method of removing rivets, welded parts, and frozen or corroded fasteners. This may be an effective short term solution, but if done carelessly it causes irrepairable damage to the parts being disassembled.

Disassembly tools are selected for rapid and efficient work. Air power tools are preferred for a product using conventional fasteners. Disassembly should be done with tools specifically designed for the fastener because the damage caused by using the wrong tool can cost the remanufacturer more that the price of the correct tool. Most high speed power tools may seem very expensive but their productivity usually pays them off in a short period of time (verify through break even analysis). All labor saving approaches should be considered by remanufacturers engaged in large scale production.

Some of the criteria used in selecting tools are:

- Dimensions and weight of equipment to be disassembled
- Type of interface to be disassembled
- Minimal damage to parts
- Tooling costs
- Minimum time required
- Operator skills needed

During disassembly, parts are sorted into baskets, bins, racks, or containers according to the cleaning which they will receive. The size of the product and its parts determines the type of materials handling equipment needed. Large product disassembly areas must be equipped with hoists or forklifts in addition to a variety of clamps and jigs designed to handle specific parts and components.

Space requirements can also be an issue during disassembly. Large products require enough space to accomodate all the components in an orderly fashion. The amount of space taken up by the components of a product can occupy many times the area of the assembled product. For example, a truck and its equipment which may occupy 400 square feet before disassembly may require anywhere from 1000 to 2000 square feet when separated into its main components.

Chapter Six: Cleaning Processes and Equipment

6.0 Introduction

Cleaning is a surface preparation technique which removes dirt, soil, grease, corrosion and various contaminants and adherents from part surfaces. Most cleaning techniques do not remove material form the part surface nor are they used to improve surface finish for appearance or fit (60). These processes include a wide variety of techniques ranging from chemical, steam, vapor degreasing to ultrasonic and flame cleaning.

Remanufacturers have a broad range of objectives for their cleaning department. In addition to removing all contaminants, cleaning processes are used to remove damaged material and improve material properties. Remanufacturers often use particulate cleaning processes involving the impingement of surfaces with abrasive particles or the application of mechanical pressures. Multiple particle collisions onto the work surface are used to remove surface asperities and close subsurface cracks, resulting in fatigue and wear resistance surfaces.

Remanufacturers are changing from the traditional cleaning approaches to those methods which improve part fit, surface hardness, and wear resistance. Promising "new" methods under development include:

- o Thermal cleaning (controlled pyrolysis)
- o Vibratory finishing.

These and other methods are gaining acceptance in the industry because they reduce the overall costs of production associated with cleaning.

6.1 Selection of Cleaning Approaches

Cleaning is one of the most energy intensive and expensive processes in remanufacturing. The CPA Remanufacturing Survey (61) contained a set of questions regarding the inputs (labor, equipment, and energy) used in the different remanufacturing processes. The remanufacturers from the automotive segment described cleaning as energy and equipment intensive; the industrial segment described it as labor and energy intensive. It is interesting to note that cleaning is the only process stage described regularly as energy intensive. Other processes are more labor and equipment oriented. Before selecting a cleaning method, a remanufacturer should carefully consider all costs associated with the process including:

- o energy
- o supplies (chemicals, detergents, solvents, spare parts)
- o labor
- o waste disposal (and/or treatment)

The selection of cleaning method depends on the material being cleaned and the contaminant removed. Objectives of this process are to expose clean surfaces for inspection, measurement, refurbishing, and appearance. Increasing production and operating costs related to both energy (used to heat up chemicals or operate furnaces) and to compliance with tightened hazardous waste disposal regulations have inspired remanufacturers to develop alternative cleaning methods. Experiments proved that it was possible to clean many types of metal parts by heating them in ovens at elevated temperature and then using mechanical finishing methods to remove the scale and crud. This process, now known as baking or controlled pyrolysis, not only cleans the part surfaces but, also increases hardness, and wear resistance and gives a better surface finish (58). This cleaning process represents a revolutionary change in an industry which typically undergoes gradual "evolutionary" changes.

6.2 Principal Forms of Surface Contamination

Contaminants attach themselves to surfaces by a variety of machanisms ranging from simple entrapment in the interstices, wetting of the surface by liquid soils, or electrostatic bond to soil-surface chemical reactions. Some contaminants such as paint and adhesives are attached by strong chemical bonds and require extensive effort for removal.

6.2.1 Liquid Contaminants

Moisture, oil, hydraulic fluid and solvent residues are typical liquid contaminants. Usually they interfere with remanufacturing processes requiring a dry surface (painting) or they react with the surface in an adverse fashion (warpage, rust, blisters). Moisture is a serious problem on precission machined surfaces and electrical components. If a part is stored after chemical cleaning, the the solvent residue might be desirable for rust prevention, but it constitutes a hindrance to certain refurbishing processes such as electroplating or phosphatizing (63).

6.2.2 Environmental Contamination

This category includes contaminants that become attached to the surface from the environment in which it operates. Mud, loose dirt, greasy soils, sand, salt and biological contaminants are examples of environmental contamination from outdoor use. Dirt adheres to oil and grease which are on the surface as a result of a leak, spill or normal lubricaton of the part. Environmental contaminamination also includes those substances which adhere to the product during its normal use. Work environment contaminants such as weld spatter, paint, scale, ash, chips and particulates must be removed form all cores during cleaning. Sand and other gritty contaminants are a problem, especially in threaded holes. If some of it is present during assembly it may cause severe damage to the fastener and the threads.

6.2.3 Adherent Contaminants

Adherent contaminants include those found on part surfaces as residues of some previous surface coating or corrosion protection treatment. Adhesives, gaskets, sealants and other materials used at interfaces are also considered adherent contaminants. Some adherent contaminants like paints and adhesives are difficult to remove since they were designed to form a strong bond with the part surface. Other adherents are combustion residues (carbon deposits), baked-in oil, varnish and other evaporation residues, and welding and brazing residues.

6.2.4 Corrosion

Corrosion typically results in rust and other surface oxides which damage machined surfaces, reduce strength, hide flaws and look bad. Corrosion is usually found near cracks, around chipped paint, and on any surface exposed to a corrosive environment. Some corrosion deposits are tenaciously bound to the surface of the material and can only be removed using mechanical abrasives.

6.3 Conventional Cleaning Approaches

Most conventional cleaning systems incorporate soil-removal mechanisms. These generally use a liquid suspension medium, cleansing agents and some form of agitation or bombardment. Cleaning results in detachment of particles from the surface, suspension of solids or emulsification of liquids, or dissolution of contaminants either by physical means or by chemical reaction (64).

6.3.1 Hand cleaning:

Wiping surfaces with cloths soaked in solvent is probably more widely used than any other cleaning method. Wiping produces a surface that appears clean but has some residue. Workers using solvents should exercise precautions to avoid skin contact or inhalation of toxic solvents. Whenever solvents are used, work should be done in a recirculating parts washer, spray booth, or other suitably ventilated and drained area.

Hand cleaning is widely used for parts made of sensitive materials like plastics, leather, or composites. This is the preferred method for use in "clean rooms" where delicate precission parts are cleaned and refurbished.

The particle removal process is often aided by the use of rinses, brushes, scrapers, and mild abrasives. Carbon deposits may be removed with hand scrapers or with a wire brush before the part gets its final cleaning. Material removal can be accelerated by using power tools equipped with wire brushes, polishing wheels, or other abrasive devices. Flamable or hazardous substances such as gasoline and trichloroethylene should not be used as hand cleaning solvents.

6.3.2 Liquid Contaminant and Moisture Removal

If water is the liquid contaminant, simple removal techniques can be usually employed. Covering the part with warm sawdust is an old and effective method of moisture removal, but there are some problems related to sawdust residue on parts. Moisture can also be removed by immersing the part in oil or other liquid above $100^{0}C$. This may leave a contaminant on the surface, hence its effectiveness should be ascertained on a case by case basis. Heating contaminated part surfaces in ovens or with a direct flame is an effective way to quickly drive off moisture . It is important to maintain proper ventilation while using an oven drying procedure, otherwise humidity levels become counterproductive.

A common method used against moisture and other liquid contaminants is the application of hot pressurized air to the surface. This method is also used to dry parts with intricate shapes and surfaces. Air blasting is inexpensive and effective for many applications but care should be taken to assure that the air is dry and free of contaminants.

6.3.3 Chemical Cleaning

Chemical cleaning operates by a solvent or chemical action between the cleaning material and the contaminant. A number of chemical cleaning methods which utilize currents are used in industry. A comparison of chemical cleaning methods is shown in Table 6-1 (65).

Factors	Alkali cleaning without current	Alkali electrocleaning	Emulsifiable-solvent cleaning	Chlorinated-solvent degreasing	Acid pickling	Molten-salt descaling
Equipment	Still tanks or conveyorized spray washers of various sizes and capacities	Open steel tanks with d-c current source, bus bars and control equipment	Same as for alkali cleaning without current	Specially designed solvent degreasers, hand operated and conveyorized, various sizes and capacities	Appropriate corrosion-resistant tankage	Low-carbon-steel tanks with high-temperature heat source
Cleaning medium	Appropriate proprietary cleaners in water solution properly inhibited for sensitive metals	Same as alkali cleaning without current	Mineral solvents mixed with suitable emulsifiers; used in water solution	Trichlorethylene or perchlorethylene	Various acids	Mixture of fused salts
Operating temp deg F	140–212	120–200	Room temp to 180	Tri, 188; per, 250	Room temp to 180	700–950
Health hazards	Safe when body contact is avoided	Safe when body contact is avoided	Safe when body contact is avoided	Safe with well-designed equipment used properly	Safe with protective clothing, face shields, goggles, etc.	Safe with protective clothing, gloves, face shield, goggles, etc.
Fire hazard	None	None	None	Very slight	None	Slight
Type soil removed	Both organic and inorganic matter	Normally used for final cleaning prior to plating to remove slight contamination and to activate surface	Both organic and inorganic matter	Organic matter and inorganic particles	Oxides, scale, rust, etc.	Scale, oxides, etc.
Effect on base metal	None when properly inhibited	None when properly inhibited	None	None	Slight surface etching when properly controlled	Sometimes slight etch
Time required, min	1–30	½–3	1–15	1–5	1–30	1–15

Table 6-1 Comparison of Chemical Cleaning Approaches (65)

Many chemical cleaning processes methods are used; common process variables are:

- o selection of the solvent
- o solvent application procedure
- o time of exposure
- o temperature of solvent
- o size of batch
- o mechanical action between solvent and surface (agitation, concentrated jet, vapor condensation).

Chemicals can be applied to the surface by: hand brushing, spraying, vapor deposition, or immersion. The product variables which affect the selection of application process are (66):

- o degree of cleaning required
- o size and shape of the part
- o composition of material and construction
- o nature of soil or contamiant
- o hazards (of process)
- o overall cost

Chemical Spraying: Spray cleaning is an effective way of simultaneously dissolving contaminants and mechanically washing away embedded particles and nonsoluble soils by the force of liquid or gaseous streams(66). A spray booth system generally includes:

- Tank, or cabinet in which the process takes place
- Pump, for recirculating the solution
- Pipes, for carrying solution to nozzle(s)
- Spray Nozzle(s), deliver solvent stream
- Sheet Metal Enclosure for work area
- Other: Ventilation system, heaters, drainage, rinse, controls

In process cleaning machinery a variety of work positioning devices such as conveyors, turntables, hanging racks and chains are used to expose all the surfaces to be cleaned to the spray stream.

Spray cleaning uses large quantities of solvent some of which is not recoverable. Hazard may arise if quantities of solvent are evaporated; this presents toxic and flammable vapor hazards (67). Respiratory protection should be worn by the spray equipment operators when using toxic or dangerous solvents.

Immersion Cleaning: Immersion or dip cleaning is a process in which parts to be cleaned lowered and raised into and out of a tank contained solvent. More solvent is conserved than in spraying or manual cleaning. Tank applications are limited in two areas: With the exception of small parts, they are unsuited to high-production areas when large volumes of parts are processed; and tank operations limit the size of the parts that can be handled.

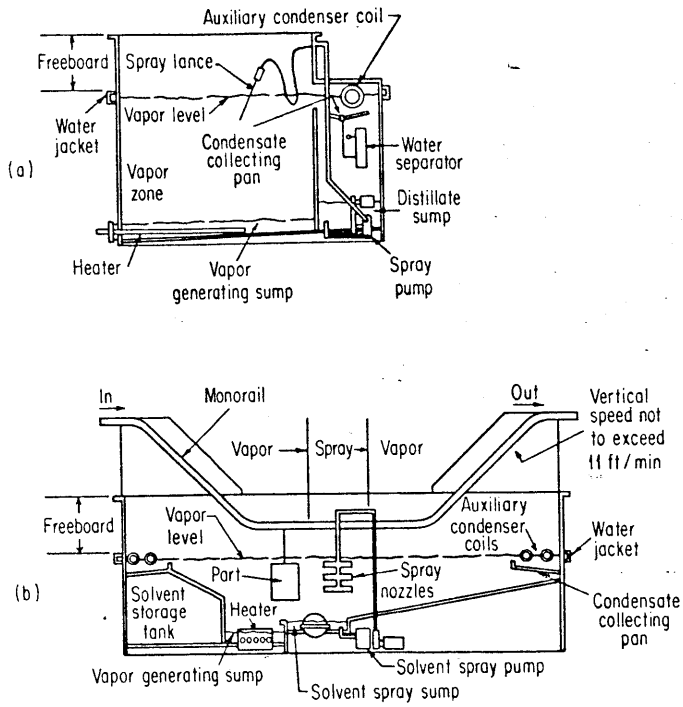
With some detergents, parts can be cleaned in simple steel tanks. With other solvents, specially lined tanks may be necessary. Depending upon the detergent (solvent) selected, the immersion may be done at temperatures varying from room temperature to 100^{o}F. Cleaning time may vary from a few seconds to a day or longer.

which are commonly used in vapor degreasers may present certain health hazards. For this reason, the use of vapr degreasers is recommended only for situations where alternative methods are not effective and where the solvent can be tightly controlled.

Vapor degreasing is a method for physically removing solvent soluble soils and other soils trapped on the surfaces of metal, glass, and other objects. The process operates by bringing the soiled articles, which are at room temperature, into contact with hot solvent vapor. The hot solvent vapor condenses on the articles in sufficient volume to form a liquid flow which carries away the soil as the solvent drains by gravity. Applications of typical solvents used for vapor degreasing and factors affecting their selection are shown in Table 6-2 (69). The process is a rapid and economical procedure for preparing dry, clean articles for subsequent finishing and fabricatng steps, usually without further treatment.

In cases where the solid portion of the soil is not removed, components are added to the tank to increase the effect of the vapor cycle with a forceful spray of liquid solvent, as shown in Figure 6-1 (70). The recommended cleaning cycle is, immersion in boiling solvent, followed by immersion in a cool clean rinse and then passage through a final vapor rinse and dry zone. Some machines have a conveyorized system which takes the part through all these steps automatically.

The advantage of vapor degreasing is that it can be used to clean all common industrial metals. It also can clean assemblies containing different metals. By the proper choice of solvents, glass, plastic, and electronic components can be cleaned as components or in assemblies such as a completed printed circuit. This process may not be effective in removing contaminants that are not soluble in solvents or that do not contain a sufficient portion of solvent-soluble material. These are materials such as metallic salts, oxides, heat-treatment and welding scale, carbonaceous deposits, and inorganic soldering, welding and brazing fluxes (71).



Spray-augmented vapor-degreasing tanks: (*a*) simple vapor-distillate-spray type; (*b*) vapor-spray-vapor type.

Figure 6-1 Vapor Degreasing Tanks

Application	Solvent	Factors affecting selection
Removal of soils from parts	Trichloroethylene	Most commonly used solvent
Removal of slightly soluble (high-melting) soils	Perchloroethylene	Used where higher operating temperature is desired
Removal of water films from metals	Perchloroethylene	Rapid and complete drying in one operation
Cleaning coils and components for electric motors	Methyl chloroform Trichloro-trifluoroethane Perchloroethylene	Solvent must not damage wire coating or sealing agents Requires special equipment design. Selection should be based on preliminary trials
Cleaning temperature-sensitive materials	Methylene chloride Trichloro-trifluoroethane	Used where part must not be exposed to higher vapor temperatures during cleaning
Cleaning components for rockets or missiles	Trichloroethylene	Cleaned parts must be free of soils or residue which might react with oxidizers
Cleaning with ultrasonics	Trichloroethylene Perchloroethylene Methylene chloride Fluorinated hydrocarbon	For cleaning efficiency beyond that obtained from standard vapor degreasing. Solvent must be kept clean by continuous distillation and filtration during use. Selection should be based on preliminary trials

Table 6-2 Typical Applications of Vapor Degreasers

6.4 Mechanical Cleaning Approaches

Surface cleaning and finishing can be performed simultaneously with the mechanical cleaning methods described in the following subsections. These operations may be performed (72):

- o before machining, heat treatment, forming, or similar processing
- o as an intermediate operation between two other manufacturing operations such as edge radiusing and deburring
- o following rough machining
- o before finish grinding
- o prior to plating, coating, and painting

Figures 6-2 to 6-6 (73) are photographs taken during the authors' second visit to the Fred Jones Manufacturing Company in Oklahoma City, Oklahoma. Fred Jones is an Authorized Ford Remanufacturer and one of the largest engine remanufacturers in the nation with a productive capacity of 250 engines and over 2000 components per day. This company was a pioneer in the baking or controlled pyrolysis cleaning method. They are currently engaged in eliminating all chemical cleaning systems and replacing them with mechanical cleaning systems as described in the following sections.

6.4.1 Controlled Pyrolysis

In this cleaning process, parts are heated in ovens at elevated temperatures for several hours to burn off surface and penetrating contaminants. This method removes paint, gasket materials, adhesives, carbon and oil deposits, solvents, grease and most other contaminants. Before loading into ovens, parts are given a brief brushing to remove caked on deposits and sorted into baskets. Figure 6-2 shows a large cleaning oven loaded with crankshafts. Variables in the baking process are:

- o time/temperature
- o cooling cycle
- o post baking scale removal (metal particle blasting)
- o finishing treatment

Smaller component parts like carburetor housings and water pumps are also cleaned with the baking process. After baking these smaller components are cleaned mechanically using a vibration finishing machine.

Parts come out of the ovens covered with a layer of scale and ash. This residue is removed from large parts with a dry blasting machine which bombards the surfaces with magnetized steel particles (aluminum shot is used for sheet metal parts and precision parts) for about 50 seconds. The shot blasters used shown in Figures 6-3 and 6-4 are commercially available units which were customized by the manufacturer to accomodate crankshafts and engine blocks.

Parts coming out of the blasting machines are covered with magnetized particles. The parts must be demagnetized and placed in a tumbler to remove shot and dirt trapped in the casting's cavities. Figure 6-5 shows a tumbling machine used to remove the metal shot out of engine blocks. Finished crankshafts and the loding basket used to move them about are shown in Figure 6-6.

To prevent formation of flash corrosion and to remove any residual contaminants, iron and steel parts are given a quick bath in caustic soda solution. The last step is to pressure wash the parts with a rust inhibiting solution and dry them with compressed air. Before refurbishing cleaned parts, all shot must be removed form the castings. Any particles left inside the part can lead to rapid deterioration and failure when the produt is put back in service.

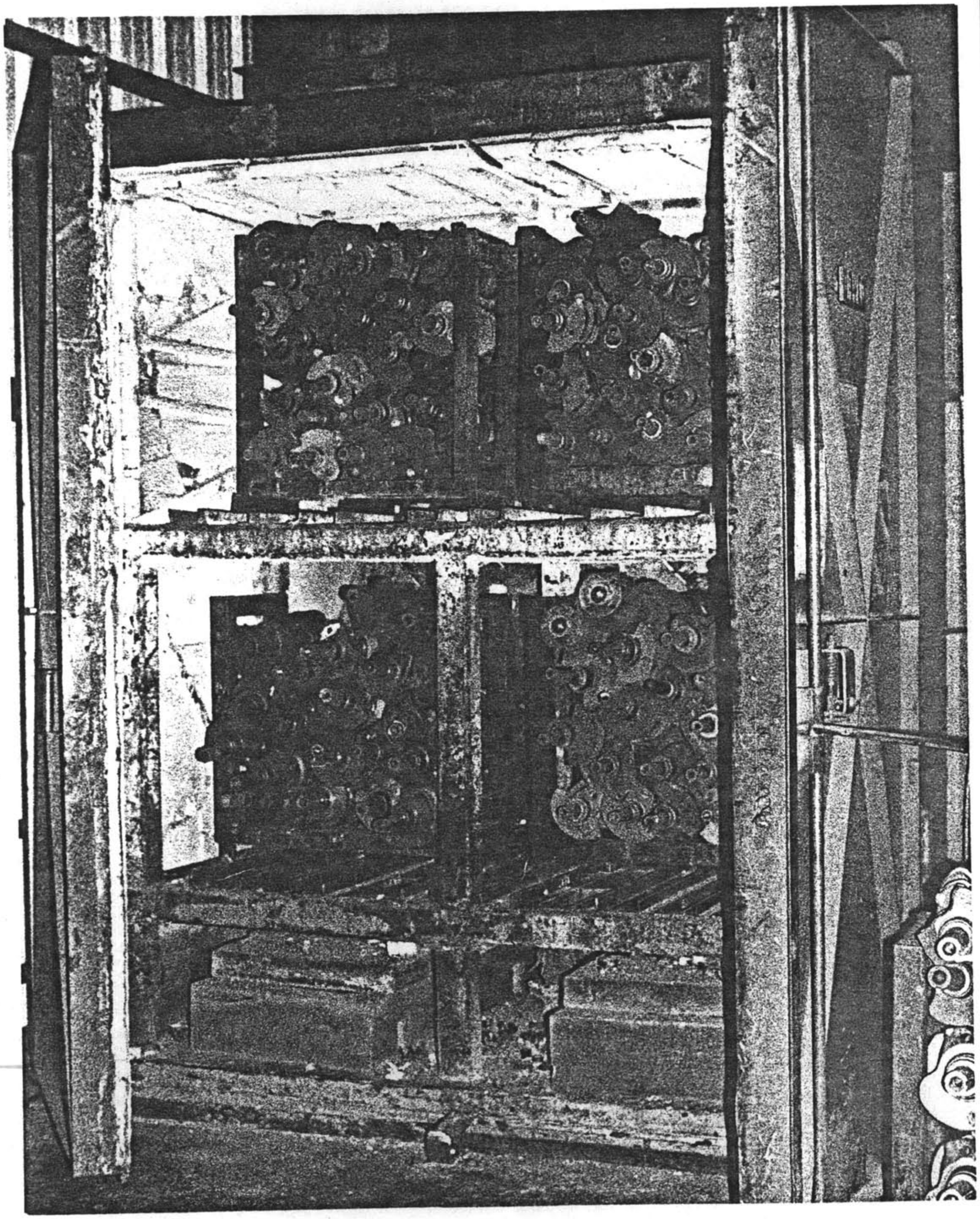


Figure 6-2

Large Oven for Parts Cleaning

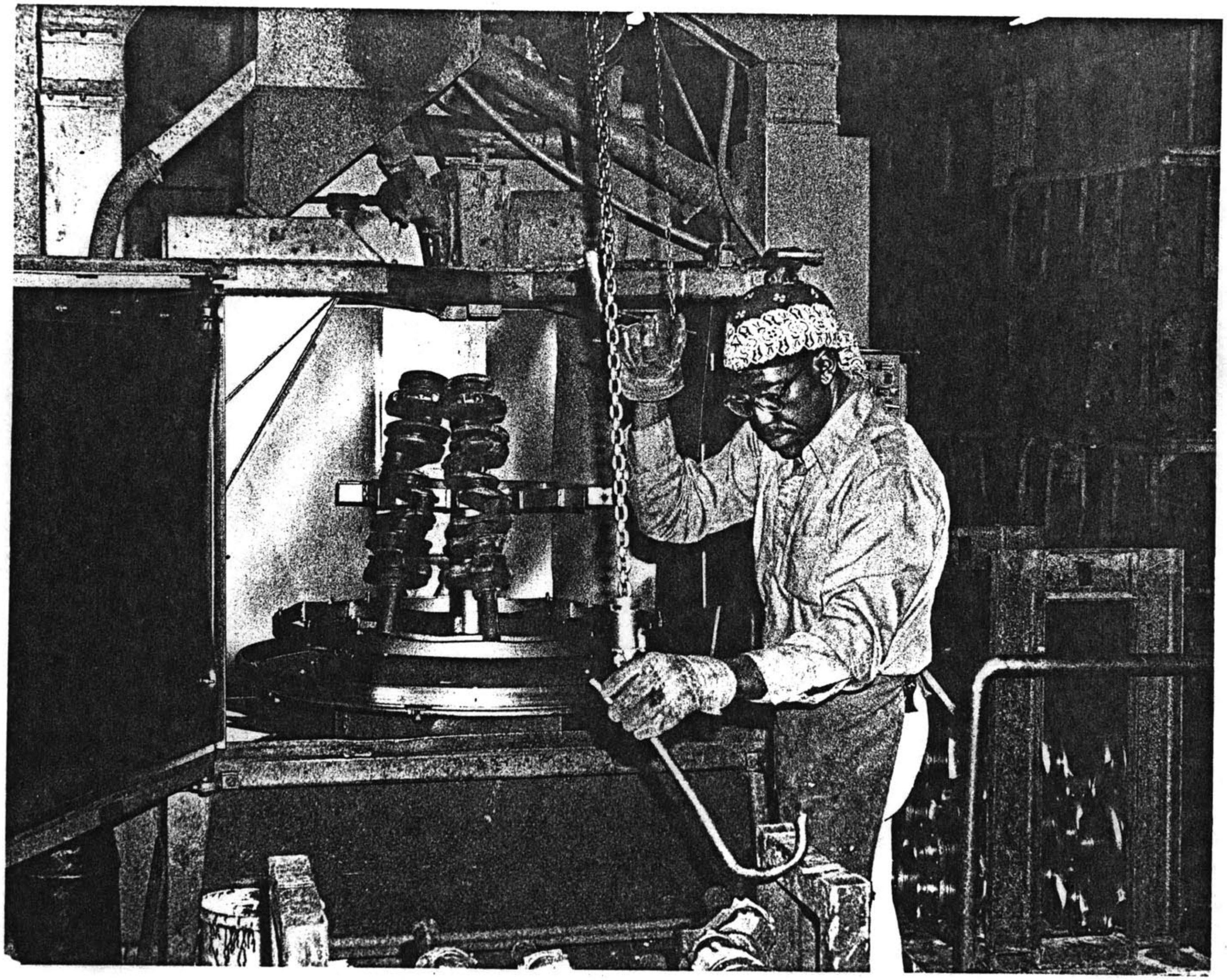


Figure 6-3

Dry Blast Unit

Crankshaft Cleaning

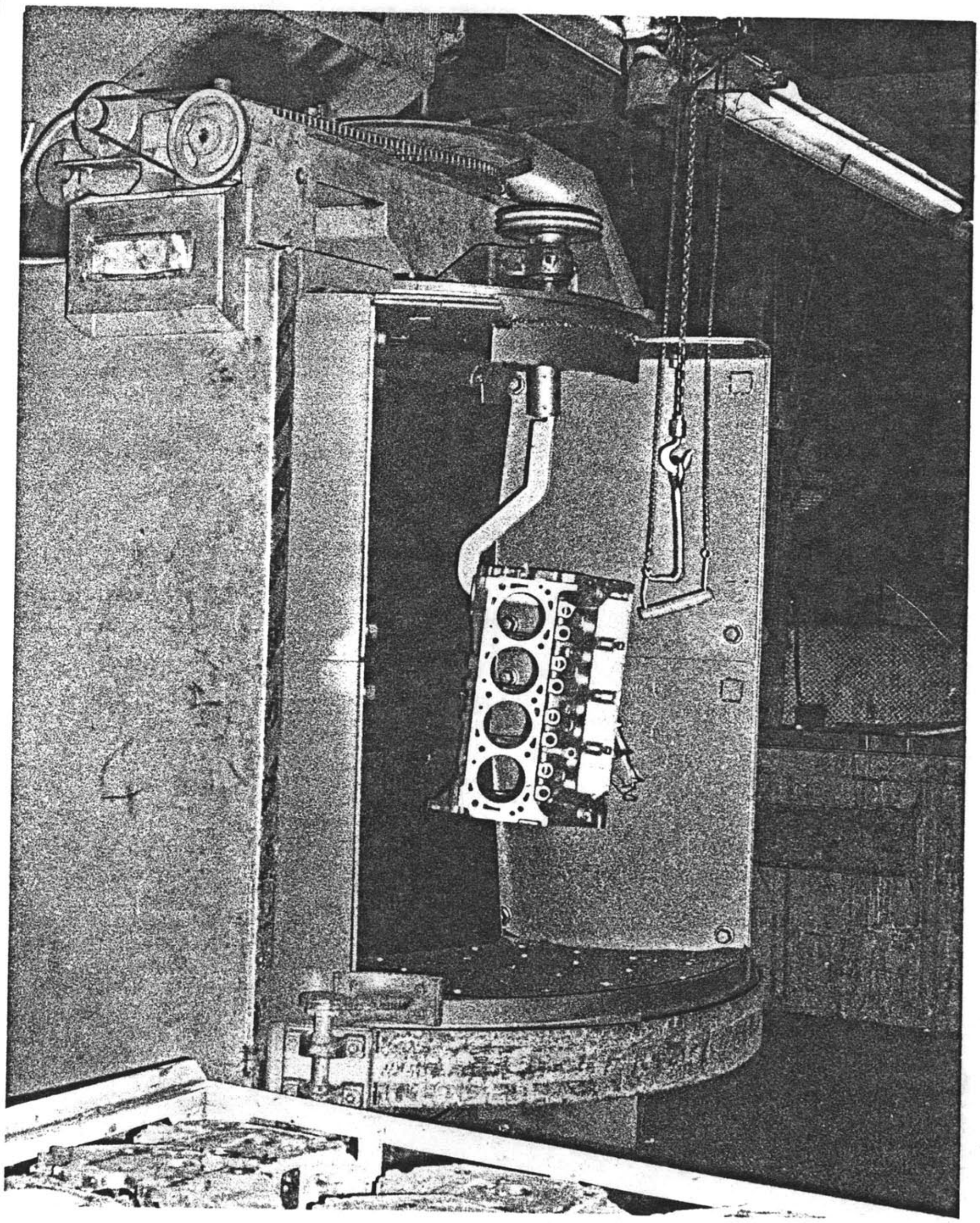


Figure 6-4

Dry Blasting Unit

Engine Block Cleaning

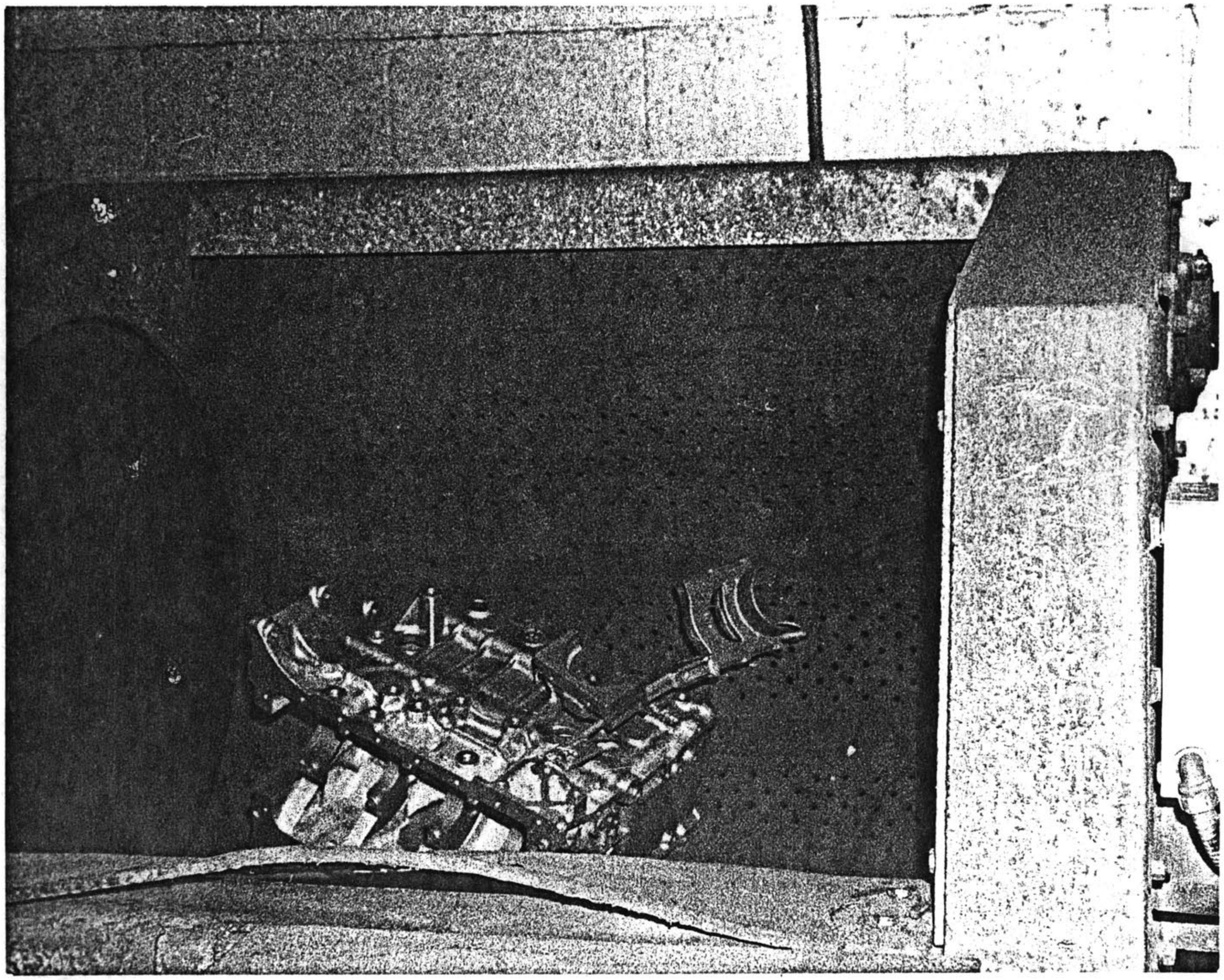


Figure 6-5

Barrel Tumbling Machine Being Used to Clean Out Metallic Shot from Engine Block

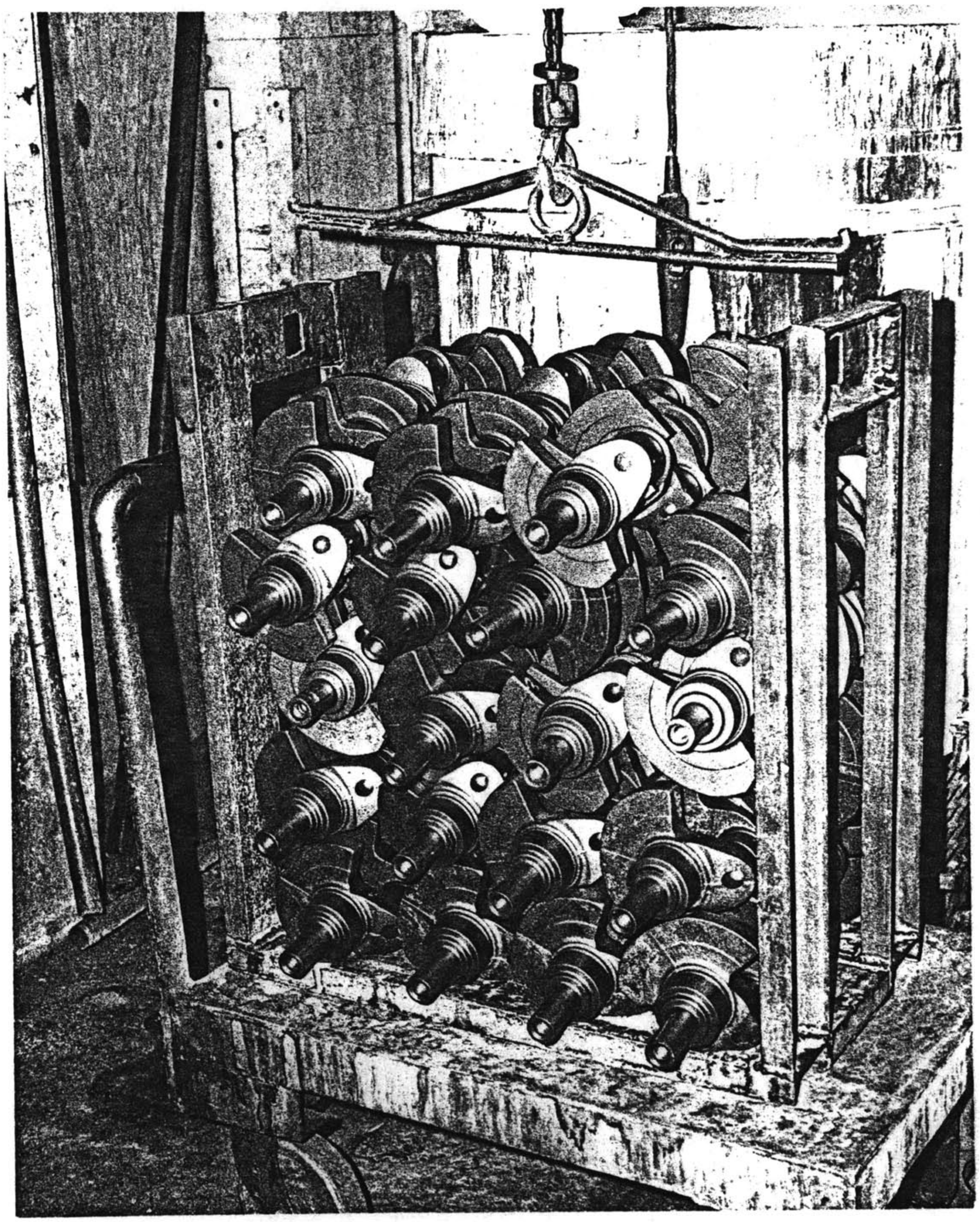


Figure 6-6

Rack of Clean Crankshafts after Baking and Blasting

6.4.2 Cleaning by Blasting

In blasting processes, material surfaces are cleaned by a high velocity stream of water, abrasive materials, or steam. A wide variety of abrasives types and accelerative processes are used. Some blast cleaning methods like shot peening, are frequently used to improve the fatigue characteristics part. The process is used extensively on leaf and coil springs, gear teeth, drive shafts, torsion bars, oil well drilling equipment, and high-strength fasteners (74).

The most important types of abrasives used in blast cleaning processes are (75):

- Sand was the most widely used abrasive in industry. Sand blasting (wet and dry) is one of the oldest cleaning methods still in use. Sand is gradually being replaced by aluminum oxide, silicon carbide and slag. A problem with sand is the rapid wear of machine components. Sand blasting is commonly used to clean large pieces of equipment. The advantages of the system are its cutting speed, portability, and low cost. Sand blasters can be used to remove paint, rust, carbon deposits, adhesives, epoxies, scale, and other thick surface contaminants.

- Chilled Iron Shot has a longer abrasive life than sand, aproximately five times longer. Cast steel and cut wire shot have even longer useful abrasive life (25 times longer than sand).

- Metallic Grit is used for an etched finish.

- Non-Ferrous Shot is typically made of aluminum. It is used for materials softer than steel such as aluminum, brass, and Zinc.

- Non-Metallic Abrasives include materials like sawdust, nut shells, apricot pits, and plastic and glass beads. These abrasives are used to remove light fins from aluminium casting and carbon deposits from intricate parts.

Dry Blasting: This method of cleaning consists of blasting the surface with abrasive material traveling at relatively high velocity. It lends itself to high-volume production in cases where the contaminant to be removed not greasy or oily. Dry blasting is usually done is a cabinet which protects the operator form the particles and allows the recycling of the abrasives. Gun designs can be varied to control the surface finish and particle dispersion patterns. Typical uses for this process include (75):

- o removal of contaminated surface layers
- o removal of oxides, corrosion products, and mill scale
- o production of hammered or matte finish (shot peening)
- o conditioning of surfaces for better bonding of paint
- o removal of burrs, scratches and surface irregularities
- o removal of paint and dry surface dirt

Before Dry Blasting surfaces should be cleaned by degreasing or baking to remove grease and oil. Paricles can be accelerated and delivered to the surface by two methods: air blast and air-less blast (centrifugal). The selection of abrasive depends on the material to be cleaned and the intended surface finish, the typical abrasives and equipment used for dry blasting are listed in Table 6-3 (76).

Workpiece material	Purpose	Abrasive material	Abrasive size	Equipment*
Cast iron	Cleaning	Steel	S230	C
	Coating preparation	Iron or steel	G50–G80	A, C
Gray iron	Cleaning	Malleable iron	S460	C
	Descaling	Malleable iron	S550	C
Steel:				
Cold-rolled	Cleaning	Iron	G80	A, C
Hardened	Descaling	Iron	G80	C
Hot-rolled	Paint preparation	Iron	G80	A
Rod, bar	Cleaning	Steel	G40	C
	Coating preparation	Iron	G80	A
Structural	Paint preparation	Steel	G40	C
Welds	Descaling	Steel	G25	C
Aluminum	Satin finishing	Sand	50	A
	Paint preparation	Iron	G80	C
Bronze	Satin finishing	Sand	50	A
Plastic:				
Clear	Frosting	Sand	50	A
Molded	Deflashing	Walnut shells	...	C
Phenolic	...	Sand	50	A

*A—air-blast; C—centrifugal.

Table 6-3 Abrasives for Dry Blasting

Wet Blasting: Considerations which led to developing of wet-blasting processes were:

- o dust prevention
- o the desire to use fine abrasive particles
- o prevention of immediate oxidation

With wet blasting no dust collection system is necessary, floor space requirements are minimized, and health hazards and equipment damage due to airborne grit are eliminated. Wet blasting machines can use a nonhygroscopic abrasive medium as fine as 3 micron. The process is generally considered to be a precision finishing operation. The characteristics and applications of various abrasives is shown in Table 6-4 (77). Additives such as rust inhibitors, wetting agents, and anti-clogging and anti-settling compounds can be used with the fluid medium to improve results.

6.4.3 Barrel and Vibratory Finishing

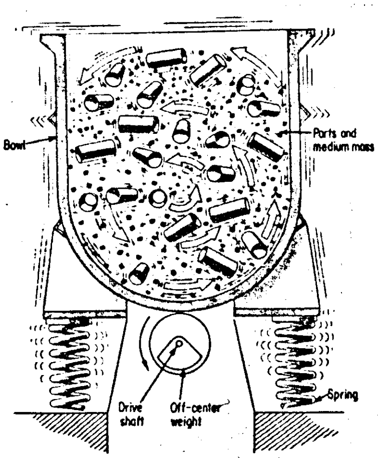
Vibratory finishing is a very flexible process. The same machine can be used with a wide variety of processing compound formulations and mechanical motion settings to produce exellent surface finish in almost any kind of material.

Vibratory and barrel-finishing methods (78) are primarily bulk load finishing procedures suited to descaling, deburring, edge radiusing, and surface improvement. It is best suited for relatively large quantities of small parts for which manual finishing would be inappropiate. Large parts may also be effectively treated. It is often possible to produce substantial improvement in surface condition at relatively low cost compared to other finishing techniques. Process justification hinges on the ease of adapting these methods to a wide range of different parts and finishing requirements, using versatile equipment and a minimum of manual labor.

Grade of abrasive	Applications
40- to 80-mesh silica	Deburring steel and cast iron; removal of oxides from all forms of steel. Fast-cutting and will remove metal. No close tolerances can be observed
50-mesh silica	Deburring steel and cast iron; removal of oxides from all forms of steel. Fast-cutting and will remove metal. No close tolerances can be observed
80-mesh silica	Deburring steel and cast iron; roughing of surfaces; plastic bonding or rough plating; peening action. Fast-cutting and will remove metal. No tolerances can be observed
80-mesh ground silica	Heavy burrs; light or medium scale; bad rust conditions. Use on nickel-alloy steels also. Exceptionally fast-cutting and will remove metal. No tolerances can be observed
100-mesh novaculite	Cleaning of carbon from pistons and valve heads; deburring of brass, bronze, and copper. Can also be used on crankshafts. Fast-cutting will remove metal. No close tolerances can be observed
100-mesh ground quartz	Blending in preliminary grind lines on steel, brass, and die castings. Removal of medium-hard carbon deposits. For small-radius requirements. Fast-cutting and will remove metal
140-mesh silica	Removal of small burrs on steel, copper, aluminum, and die castings. Can be used on rough cleaning of dies and tools. No close tolerances can be observed. Will remove metal
325-mesh novaculite	Second stage for cleaning aluminum pistons, impellers, and crankshafts and valves. First stage in cleaning master rods and all glass. Will follow close tolerances to 0.0025. Cuts slowly
400-mesh aluminum oxide	Excellent abrasive agent when working under oil-contamination conditions. Fast-cutting agent on stainless steel, zinc, and aluminum die castings. Tolerances can be held
1250-mesh novaculite	Second stage for crankshafts, rods, pistons, impellers, valves, gears, and bearings. For polishing all metals; also dies, tools, and die castings. Tolerances can be held
5000-mesh novaculite	Should be used on any parts where an extra-fine surface is needed
Glass beads from 40 mesh to 325 and even finer	Use for removal of light heat-treated scale and/or discoloration; also light oxide removal for jet engines and electronic components. No metal removal

Table 6-4 Characteristics of Wet Blasting Abrasives (77)

Many users of vibratory finishing equipment are finding that product break-in periods can be substantially reduced when functional parts are vibratory-cleaned prior to operation. The roughness of the original surfaces and the degree of improvement desired are very important. Parts that have original surface finishes from above 300 to below 150 uin rms may be reduced to 50 to 60 uin rms in a single operation if the surfaces to be finished are exposed and the size and shape are within reasonable limits (79). Figures 6-7 and 6-8 illustrate the basic design of vibratory finishing machines (80). The abrasive media are listed in Table 6-5. Processing media may contain a number of chemical, abrasive, descaling, cleaning, deburring, burnishing, coloring and dry-finishing compounds.



Vibratory-finishing bowl showing rotation of parts and medium during vibration.

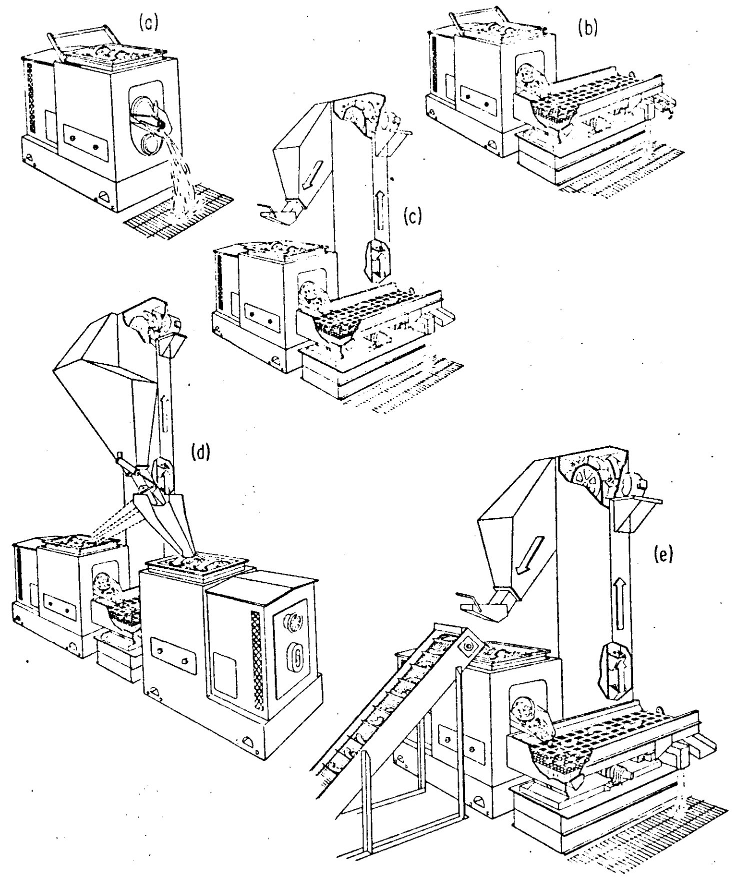
Figure 6-7 Basic Vibratory Finishing Bowl

Chief Vibratory- and Barrel-finishing Processing Media, Applications, and Average Density

Medium	Application,*,†	Density, lb/ft^3
Silicon carbide (carborundum)	1, 2, *A*, *E*	135
Granite	1, *A*	100
Sand	1, *A*	
Quartz	2, *A*, *E*	
Pumice	1, *A*, *B*, *E*	
Garnet	2, *A*, *E*	
Feldspar	2, *E*	
Talc	2, *E*	
Steel shapes	1, 2, *C*, *D*	300
Zinc shapes	1, 2, *B*	282
Corundum (alum oxide)	1, 2, *A*, *E*	152
Emery	1, *A*	
Rouge and crocus (iron oxide)	1, *E*	
Limestone	1, *B*	110
Marble, dolomite, and calcite	1, *E*	
Boron carbide	1, *A* (hardest synthetic)	
Ceramics	1, 2, *A*, *B*	100
Glass beads	1, 2, *D*, *C*	109
Wood chips	1, 2, *A*, *B*	32

*Key to equipment: 1, barrel finishing; 2, vibratory finishing.
†Key to process: *A*, deburring, rough polishing; *B*, lustering; *C*, burnishing; *D*, peening; *E*, dress

Table 6-5 Vibratory Finishing Processing Media



(*a*) End-unloading vibratory-finishing machine with (*b*) separating screen for parts and medium, (*c*) bucket conveyor for return of medium, (*d*) swiveling-medium conveyor tower for simultaneous operation of two machines, and (*e*) automatic parts-loading conveyor.

Figure 6-8 Vibratory Finishing: Continuous Process

6.4.4 Steam and High Pressure Water Cleaning

Steam and high pressure water cleaning processes are used on large products which cannot be cleaned practically using other techniques. They are also used on products made from materials sensitive to abrasive bombardment. Steam is effective for removing grease, mild rust, and most surface contaminants. One of the advantages of steam cleaning is that it combines heat, pressure, and chemical action. It can be used in conjunction with a detergent or solvent to improve its effectiveness at grease cutting.

High pressure water blasting can done with plain water or detergent, degreasers and abrasives can be added to the water to improve cleaning effectiveness. System working pressures ranging from 500 to 20,000 psi and flow rates from 5 to 50 gallons per minute are used in high pressure washing systems. Applications include the removal of resins, loose paint, iron oxide, sediments, dirt and many other contaminants. Common types of high pressure washers are cabinet blasters and gun blasters. The latter are usuallyportable and are sometimes combined with steam cleaning in one machine.

6.5 Chemical Versus Mechanical Cleaning

There are two basic approacles to cleaning:

- o traditional chemical methods
- o newly developed mechanical methods

Criteria used to compare the two approaches include:

- o quality of the cleaning job
- o material properties after cleaning
- o production volumes
- o direct costs (energy, labor, materials and equipment)
- o indirect costs (waste disposal, fines and taxes, legal).

Most remanufacturers are currently looking towards mechanical and hybrid (mechanical/chemical/thermal) cleaning approaches as the long term solution to this important part of the remanufacturing process. The reason for the change, as in many other innovations, is money. Chemical cleaning has become too expensive as fuel prices, chemical prices, processing costs, and legal risks (OSHA and EPA) all continue to climb and force remanufacturers to seek alternative methods. A comparision of chemical versus mechanical cleaning methods is shown in Figure 6-9.

Figure 6-9 Cleaning Method Comparison

Chemical Approaches	Mechanical Approaches
1. Contaminants removed must be soluble in solvents.	Remove all contaminats when combined with mild chemicals.
2. Leave residue on surface	Rust inhibitor film, particles
3. Present waste disposal disposal prodlems	Designed to minimize pollution and disposal problems*
4. Hazards: toxic, flammable	Hazards: heat, noise dust
5. May attack material	Improve surface properties
6. Require secondary cleaning before coating or processing	can be coated after drying
7. Medium to small part batches	Ideal for large part batches

*as long as furnaces are equiped with afterburners

From this table it should be clear that new mechanical and mechanical/chemical cleaning approaches are promising alternatives to the traditional methods of cleaning. The final selection depends on the economic factors of each cleaning approach. Factors such as investment required, cleaning cost per part, cleaning time, labor requirements, and energy and supplies have to be calculated for each of the process alternatives. The final selection can be done after a cost-benefit analysis of the various alternatives is carried out.

Chapter Seven: Remanufacturing Process Analysis

Process analysis covers the design and control of all production functions in a remanufacturing facility. The conclusion of Chapter 3 listed the departments within the production division of a general remanufacturing facility. Each department has a set of responsibilities to which it must attend. The last two chapters dealt with processes related to disassembly and cleaning. This chapter lists and briefly describes the tasks of:

- refurbishing
- manufacturing
- assembly
- testing and quality control

7.1 Refurbishing Process Analysis

Discussion will focus on the refurbishing department because it covers the most productive and technical aspects of remanufacturing. Other departments (except some cleaning and disassembly processes) use technology which is similar or identical to that of manufacturers. These have been studied extensively by other writers.

The refurbishing process begins after all parts in a product are cleaned, identified, classified, and sorted into production batches. Process analysis includes techniques used in the selection and evaluation of refurbishing processes for parts. The selection of these processes is determined by the type of damage and deterioration found during product analysis.

Theoretically there is no limit to the range of parts which can be remanufactured as long as suitable processes are developed or adapted. The approach followed in this refurbishing process analysis is to design and set up a series of general purpose Process Application (PA) files for each of the processes and techniques used by the remanufacturer.

Parts, materials, and their conditions can be combined in a nearly infinite number of ways. However, flexible process descriptions can be used to evaluate any product's remanufacturability by using progressively finer evaluation screens. Detailed process descriptions help make the process selection task easy and consistent. Processes included in the files are important for:

- o refurbishing parts.
- o operating on materials in various conditions.
- o meeting the economic constraints of the task at hand.

Table 7-1 lists the steps in refurbishing process analysis and explains the first stages of file design and development. Companies which operate several production facilities and deal with a variety of products could benefit from the use of a consistent filing and organization system. At the other extreme, those involved in the study of a completely new process need both an accurate organizational model and a method of producing reliable estimates of economic and technical viability. The way to satisfy both of these needs is to design a model which organizes real production data to manage and control the actual production facility and to serve as a data base for the resarch and development projects.

7.2 General Refurbishing Tasks

Refurbishing tasks discussed here cover only a portion of the refurbishing techniques used by remanufacturers. Tasks vary depending on the product type and other factors. Two types of remanufactured products which use drastically different technologies are electronic and mechanical products. The following sections deal exclusively with the remanufacture of mechanical products.

After files have been drafted, the technical aspects of each process alternative can be studied to determine individual uses, advantages, and limitations. To select the "best" process one must estimate and compare such variables as:

- o output quality
- o process operating requirements
- o direct and indirect costs
- o worker skill levels
- o break-even volumes

Table 7-1 Steps in Refurbishing Process Analysis

1. Refurbishing Tasks Listing general processes used to perform each refurbishing task. Numbering system for processes and alternatives.

2. Process Analysis Evaluation of refurbishing process alternatives, uses and limitations.

3. Part to Process Analysis Using flexible format for PA files. List of file entries covering cost factors and requirements for equipment, tools, materials, and supplies. Correlating part condition codes with refurbishing process alternatives.

4. Process Design Combination of processes in a facility. Economic considerations in process selection. Sequence of refurbishing operations.

5. Process Selection Election of specific processes and equipment to perform necessary tasks. Initially, these are selected for their ability to refurbish a variety of parts in different physical conditions.

7.3 Process Analysis

Table 7-2 lists the general tasks for which the refurbishing department is responsible. All processes are listed under one of these five general tasks. This organization is used to make the correlation of parts to processes easier. Once a group of tasks has been selected, they are subjected to several rounds of analysis. Each successive round of task analysis will utilize more detailed screens to identify:

- General task applications
- Process alternatives for each task
- Applications of process alternatives
- Variations and requirements for each application

Table 7-2 General Refurbishing Tasks

- Shaping: Refurbishing deformed parts; reversal of plastic deformation, warps, dents, and other dimensional irregularities.

- Closing: Fixing surface damage, microcracks, tears, scratches, and scuff marks; filling and joining broken parts.

- Preparing: Removal of corroded sections and surface layers, surface preparation for subsequent processing.

- Building: Rebuilding worn and corroded surfaces, addition of inserts and wear resistant surfaces.

- Re-Machining: Operations used to return part to original specifications before assembly; miscellaneous operations.

The first round correlation between general refurbishing tasks and part conditions is illustrated in Table 7-3. The (X) indicate that the task is frequently part of the refurbishing process for a given part condition. The (o) indicates that the task is sometimes part of the refurbishing process.

Table 7-3 First Round Correlation
Refurbishing Tasks and Part Condition

	Part Condition			
Refurbishing process	(S1)	(S2)	(S3)	(S4)
Shaping	X	X		
Closing	o	X	o	o
Preparing	o	X	X	X
Building			X	X
Re-Machining		o	o	X

CODE: (S1: Deformation), (S2: Fracture), (S3: Corrosion), (S4: Wear)

In the second round of analysis, the condition of the part and the type of task are combined to generate a chart of process alternatives. A general list of the Refurbishing Process Alternatives is presented in Table 7-4. This chart matches processes to damage mechanisms and the degree of damage which the process can refurbish. Most process selections may be determined at this level of analysis.

Table 7-4 Refurbishing Process Alternatives

Legend: (X) process is frequently used, (o) process is occasionaly used

Refurbishing Process Alternatives	S1: Deformation	S2: Fracture	S3: Corrosion	S4: Wear	Notes and Comments
-R1 Shaping					
R101- Manual Straightening	x	o			
R102- Press Straightening	x	o			
R103- Parallel Roll	x				circular or rectangular stock
R104- Epicyclic Straightening	x				new; I-beams shafts axles
R105- Pulling	x				
R106- Body Repairs	x	x	x		all dents and collision damage
-R2 Closing					
R201- Impingement	o	x	o		shot peening
R202- Mechanical pressure	o	x	o		rolling and edge radiusing
R203- Gas welding		x			
R204- Arc welding		x			industry standard process
R205- TIG welding		x			high quality
R206- Adhesives		x			mostly non-metallic
R207- Fasteners		x			braces and clamps
R208- Fillers	o	x	o		cosmetic
-R3 Preparation					
R301- 3-D abrasion			x		corrosion removal
R302- Gas Cutting			x		metal removal
R303- Saws	x		x		any material removal
R304- Impact with power tools	x		x		heavy deposit removal, cutting
R305- Chemical Inhibitors			x		prevention
R306- Conversion coatings			x	o	prevention
R307- Anodizing			x		prevention
R308- Electroplating			x	o	prevention
-R4 Building					
R401- Welding up				x	high deposition, thick layers
R402- Metal Spraying				x	large area cover, variable
R403- Hard Facing				x	special alloys
R404- Build up for non-metal surfaces	o			x	many varieties available
R405- Inserts	o			x	can be of upgraded material
R406- Wear Plates (overlays)				x	can be of upgraded material
R407- Replacing part sections	x	x	x	x	universal refurbishing process
-R5 Re-Machining					
R501- Cylinder boring	x			x	very common
R502- Honing	x			x	
R503- Polishing	x			x	
R504- Thread Repair	x	x	x	x	various techniques available
R505- Turning	o			x	reduce built up surfaces
R506- Milling	x			x	
R507- Flat Grinding	x			x	contact surfaces
R508- Contour Grinding	x			x	cams and eccentric shafts
R509- Heat Treatment			x	x	
R510- Motor Rewinding					

7.3.1 Analysis of Shaping Tasks

Shaping processes are used to correct dimensional deviations and return deformed parts to their original shapes. Parts with condition codes begining with (S1: deformation) are refurbished with the processes in this group. Some parts with fracture damage (S2) are partially refurbished using shaping processes; often the cracked surfaces have plastic deformation and must be returned to shape before closing. Shaping processes can be used to repair damage in a complete part or only a portion. The typical refurbishing sequence is to:

1. Measure the part and list all deviations

2. Inspect yield zones for cracks which may open up during shaping.

3. Determine location, magnitude and rate at which restoration forces will be applied.

4. Secure part in fixture (jig, vise, clamp).

5. Apply forces (mechanical and/or thermal), deform part beyond original shape, allow it to recover.

6. Measure dimensions. (If not within specifications go to step 2)

7. Reinforce, weld, or normalize material as needed.

8. Inspect yield zones for cracks, stress concentraions and other abnormalities. If these are present attack determine the extent of damage and select the best refurbishing process.

The refurbishing process used depends on:

- Specific failure mechanism and part condition
- Required load amplitudes and direction
- Shape and size of workpiece
- Temperature at which process will take place

Areas of technical interest in shaping tasks include:

- o Effects on material properties of different processes
- o Methods of stiffening the yield zones
- o Work hardening and its effects on the refurbishing process
- o Stress relieving techniques
- o Adverse hardening effects

7.3.2 Analysis of Closing Tasks

Closing tasks involve the identification and removal of cracks, voids, scratches, and other forms of damage from materials as well as the repair of torn and fractured parts. Closing tasks apply primarily to parts which have some form of fracture damage (S2), but are also used to close parts with condition codes (S1, S3, and S4). Process alternatives which work on most materials subject to cracking are available. The process can be effective as long as a strong bond is formed with the material surfaces. Two basic approaches are used:

o Closing or filling cracks without adding material
  - -impingement (shot peening)
  - -mechanical pressure (cold working: rolling finishing)

o Fixing cracks by joining, or filling the crack surfaces using processes which add material.
  - -welding
  - -glueing
  - -filling cracks

Some closing processes are secondary results of mechanical cleaning steps described in Chapter 6. An example of an impingement cleaning process which is also a closing process is shot peening. Sand and metal shot blasting are also effective at removing surface cracks, but care must be exercised to prevent exessive damage to the part. Rolling finishing is a recently developed surface-finishing technique based on metal cold forming in which high forces created at the contact zone between a roller and the workpiece are used to remove cracks and reduce surface roughness. The objective of these processes is to form a compressive-stress layer on the surface of the workpiece.

Welding is the most common process used to refurbish cracked and fractured parts. This process is also used for rebuilding and joining parts. A variety of welding processes are available to be used to refurbish parts made out of practically any metal. Each welding process operates in a slightly different fashion and will produce unique results. Some of the desirable factors in a welding process are:

- high operating speed
- deposition rate
- weld penetration
- smooth weld (good bead)
- high quality weld
- easily removed slag
- applicability to wide range of part thicknesses

An example of a use of welding in remanufacture is shown in Figures 7-1 and 7-2. These pictures were taken at the Fred Jones Manufacturing Co. in Oklahoma City. They show a submerged arc welding machine used to fix cracks and build up bearing surfaces on crankshafts. Like many other tools used in remanufacturing facilities, this machine was modified from conventional equipment for this specific application.

Adhesive joining (also a manufacturing task) is used primarily to join non-metallic parts. The effectiveness of the adhesive is measured by its wetting properties and its ability to form a strong bond. With a good adhesive, the joint interface is frequently stronger that the bulk material. Several commercially available adhesives form high strength bonds with glass, metal, and plastics. Adhesives are gradually becoming more popular in assembly lines as a result of the widespread use of plastics and other non-metallic materials. Adhesives are available in many forms, including liquids, pastes, films, tapes and powders. Adhesive manufacturers will often prepare custom made adhesives for the user's requirements.

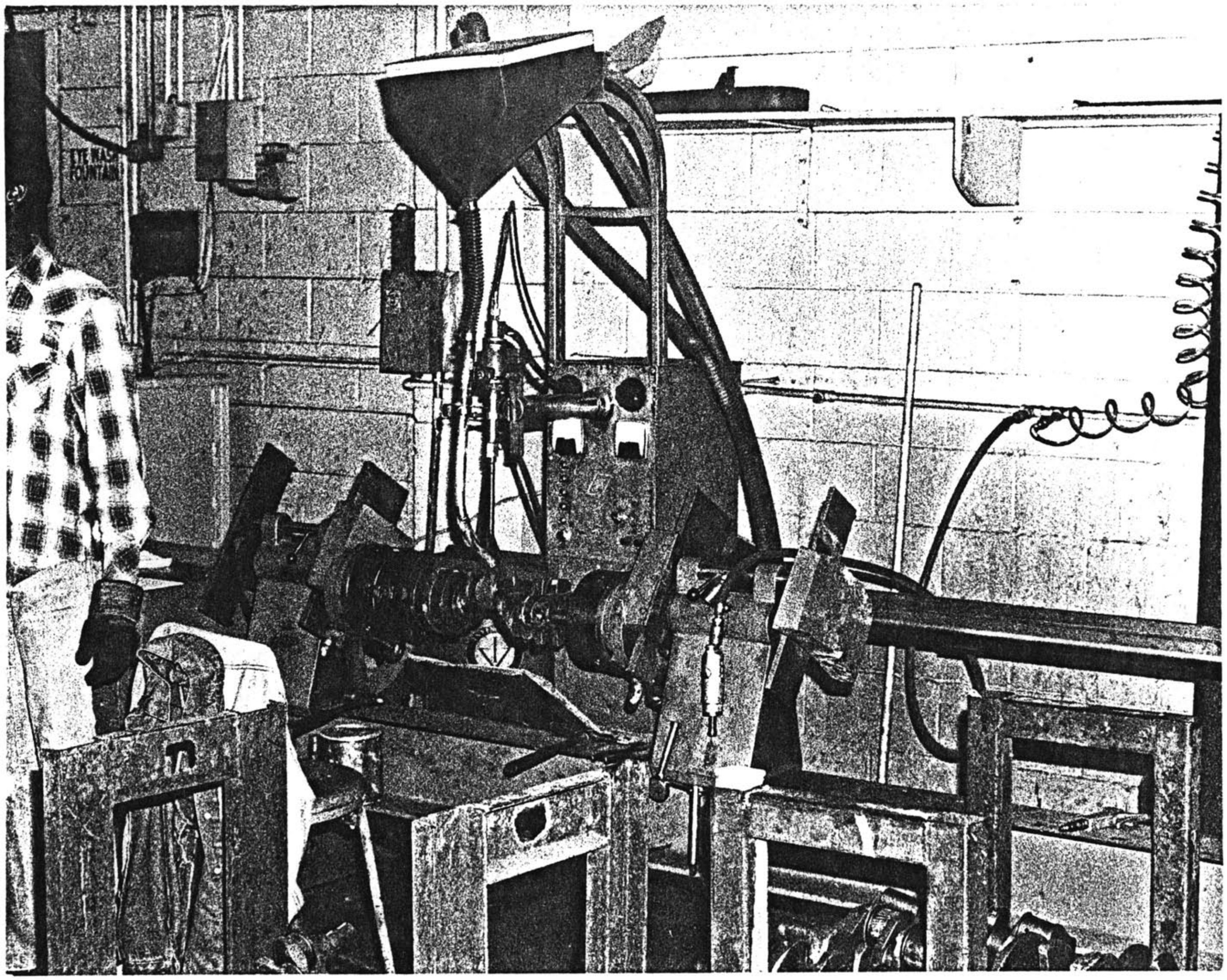


Figure 7-1

Submerged arc Welding Machine

Crankshaft Set Up

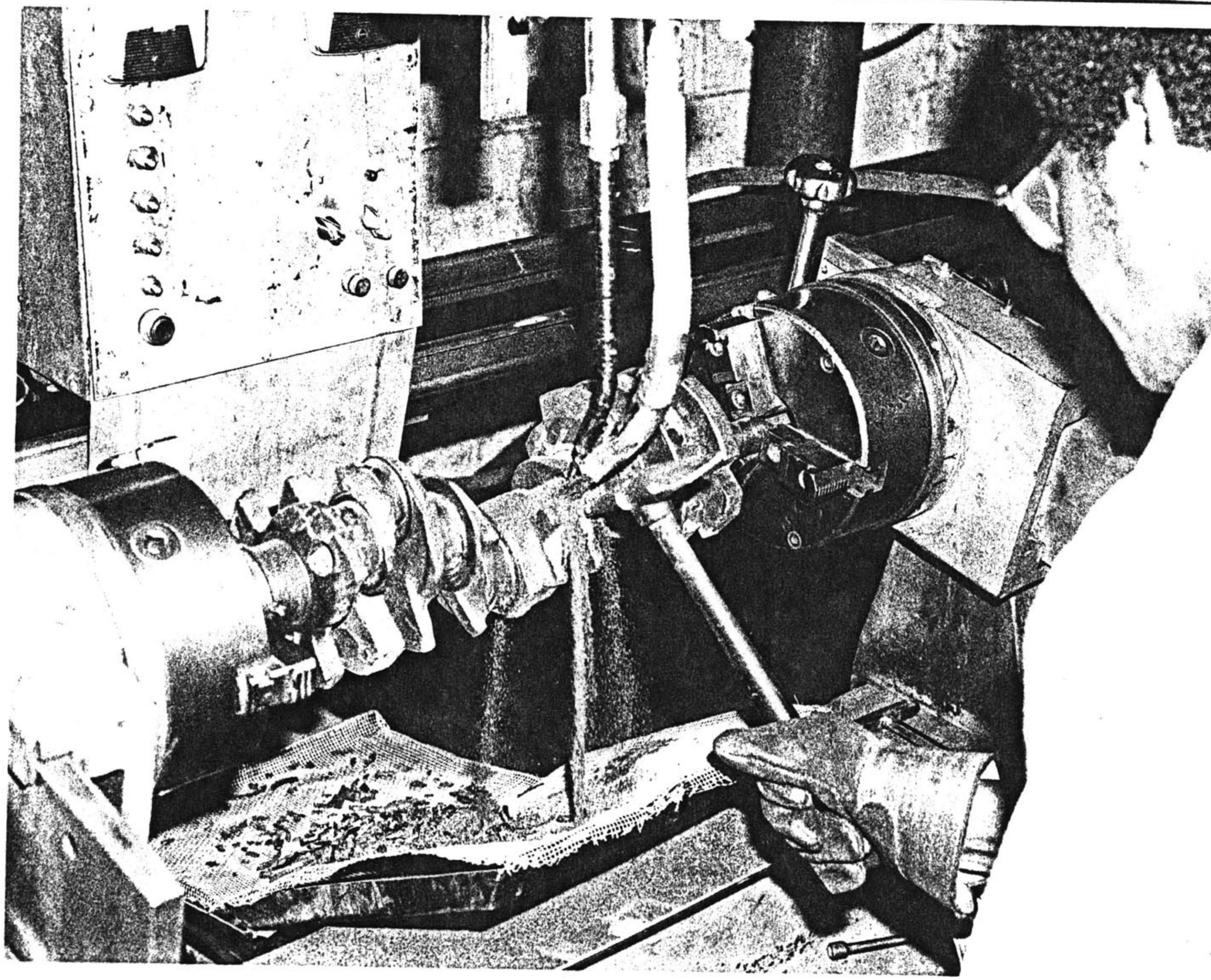


Figure 7-2

<u>Close Up of Crankshaft Welding</u>

Cracks and surface voids can sometimes be filled with plastic, solder, or epoxy resins. These cosmetic approaches are used when the crack does not affect operation of the part. In general when repairing cracks by adding material:

1. Inspect crack and select best alternative closing technique
2. Clean surfaces to be repaired; remove all residues from cleaning process; remove burrs and particles not remaining after cleaning; remove any material that prevents accurate part fit
3. Prepare crack surface to improve bond strength; work on surfaces to assure part fit:
   - -machine bevels, flanges or other features that improve adhesion
   - -improve wetting of adhesive or weld metal (flux)
4. Close crack or join crack surfaces
5. Inspect and test the closed part

7.3.3 Analysis of Preparation Tasks

Preparation tasks include those used to remove old material and condition part surfaces for subsequent processing. As seen in Tables 7-3 and 7-4, these tasks play a role in the refurbishing of almost every part and material condition. There are two steps in surface preparation:

- o removal of undesirable material
- o conditioning of material to improve its durability and performance

Removal tasks involve trimming off all material which will not form part of the finished product, which is irrepairably damaged, or which obstructs other refurbishing operations.

Corroded (or unwanted) sections can be removed by cutting (torch or saw), impact shearing (pneumatic hammer), or by using heavy abrasive blasting. Trimmed parts are immediately wiped clean and painted with a primer or given a surface treatment to inhibit corrosion and prepare the surface for the next process.

Surface preparations include coatings used to protect the substrate against abrasion, heat, corrosive environments, electrical potential, radiation, or some combination of these factors (81). Materials which are chemically stable and structurally strong comprise the bulk of succesful coatings. Processes used to apply these coatings often involve high temperatures, and so are limited to thermally resistant materials. Surface preparation processes include:

- o Conversion coatings(phosphate or chromate baths)
- o electroplating
- o anodizing
- o sintering
- o liquefaction

7.3.4 Analysis of Building Tasks

The objective of these processes is to add new material to build up worn or eroded surfaces. This task usually follows surface preparation. Three common techniques for metal rebuilding are welding, hard facing, and metal spraying. Welding was described in Section 7.3.2. The difference between building by welding and closing by welding is the selection of welding rod or wire.

Hard facing is a technique of applying special alloys as thin weld deposits on metals. Thicknsess of deposition can range from 1/32 to 1/4 inch, or as much as 3/8 inch in exceptional cases (82). Compared with other surface protection methods, hard facing has the following advantages:

- o applicable to exact wear area
- o permits use of very hard wear resistant compounds
- o readily applied outside the manufacturing facility
- o economical (conserves expensive alloys)

Metal spraying is used to apply metallic, ceramic, and certain organic coatings to metallic substrates. Coatings are typically used for wear and corrosion resistance. Three basic approaches are used:

- o Combustion Flame Spraying (with Oxy-Acetylene gas mix)
- o Plasma Arc
- o Detonation gun

Traditional remanufacturing practices include the regular use of inserts for extending the life of parts with highly concentrated wear. Holes worn eccentric can be bushed back to size, and worn sliding surfaces can be built up with the overlay of a wear plate. If properly designed, an insert can last longer and perform better than the original surface since it can be made of a material different from the base part.

7.3.5 Re-Machining Tasks

Most re-machining processes used by remanufacturers to machine parts back to their original specifications are simply modifications of such conventional manufacturing processes as:

- o Boring and honing
- o Drilling, reaming and tapping
- o Grinding and polishing
- o Electric motor rewinding

Heavy machining operations are seldom necessary. Grinding, polishing, and honing are much more common in remanufacturing than turning, milling, or broaching operations. Crankshaft grinders (Figure 7-3) and engine block boring machines are among the most complex machine tools used by remanufacturers. Most re-machining operations are done with a drill press, lathe, or small hand tool. Motor rewinding is included in this list as a common mechanical remanufacturing operation.

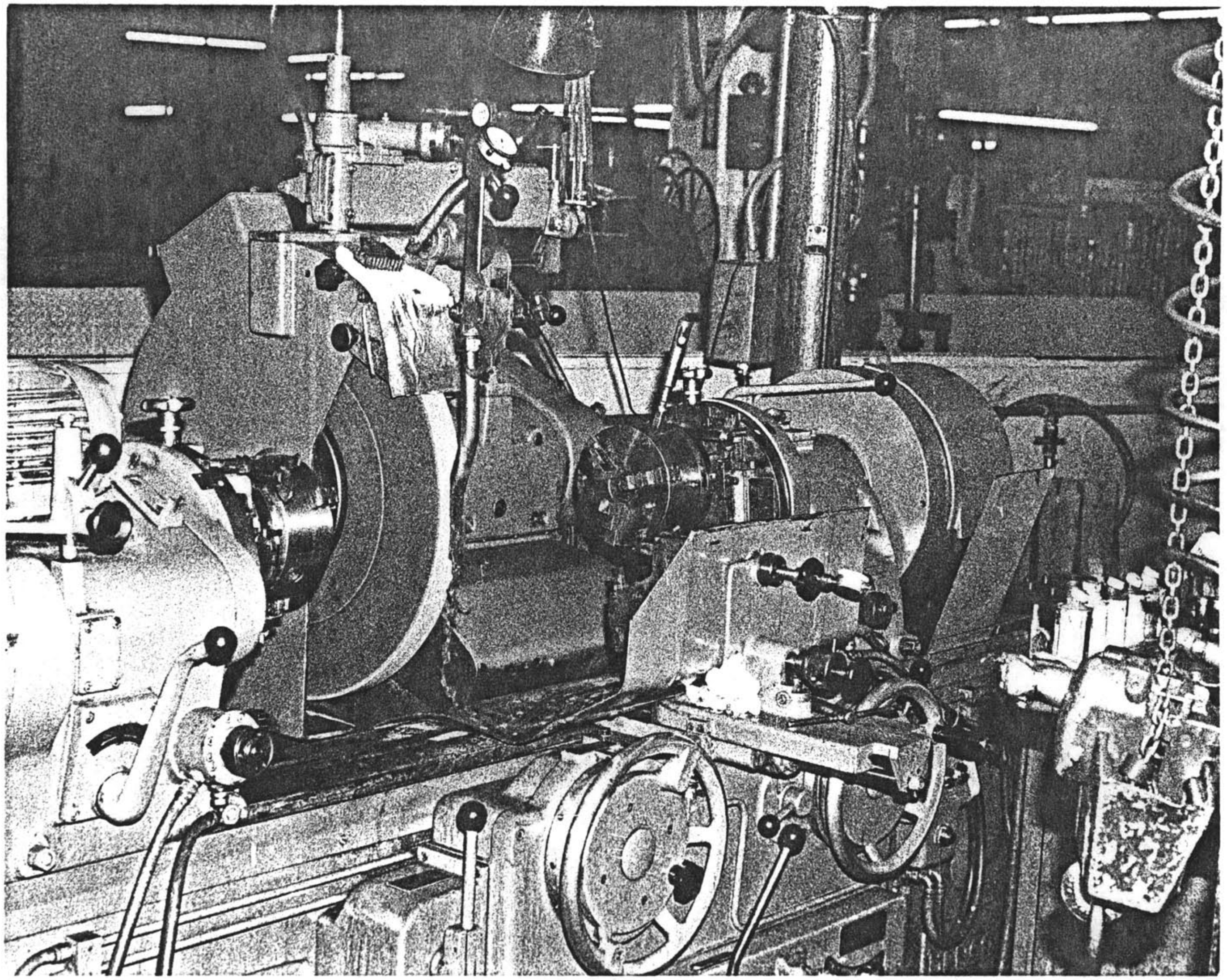


Figure 7-3

<u>Crankshaft Grinder</u>

7.4 Part to Process Analysis

Part to process analysis follows the sequence in Table 7-5.

Table 7-5 Part to Process Analysis Sequence

1. Determine condition of part as described in Chapter 3. List condition codes for the part in reverse order of importance.

2. Match first four digits of condition code to task and general process. Repeat until all the condition codes are assigned general processes.

3. Combine as many processes as possible, then match second four digits of condition code to PA files

4. Determine requirements of refurbishing process alternatives for specific part design, material, size, and condition. Select: machine, work holding method; tooling; sequence of operations; materials; supplies; and labor required.

5. Evaluate economic feasibility of proposed alternatives, selecting those which have the lowest effective cost for the facility.

Parts are matched to remanufacturing process by comparing condition codes (see Chapter 3) to the Process Application (PA) Files. A sample Process Application File is shown in Figure 7-4. The file typically lists the task, the process, and the alternatives and their uses. To determine whether an alternative is adequate, process requirements are listed for each alternative.

Figure 7-4 Process Application File

File # ________ Task ____________________ Process ____________________

Process Alternatives:

Description	Applications	Part Type	Material
1.			
2.			
3.			
4.			
5.			
6.			

Requirements for Implementation of Alternative:

Surface: surface condition necessary for process

Equipment: essential and secondary equipment for process

Tooling: for different material and part types, jigs, fixtures

Materials: materials and supplies

Process var: process variables: batch size, set-up and work time

Economics: economic factors: cost per part, labor rate, operaion time

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Process Application (PA) Files are used to:

- o describe each process alternative
  - -applications: part, material, and size types.
  - -applications: range of product conditions
  - -requirements: equipment, tools, materials, supplies, energy.
  - -limitations: break even volume, costs, hazards

- o store real production data on each process
  - -economic factors related to process implementation
  - -technical constraints to specific applications
  - -tooling costs
  - -store data on new processes
  - -store data on new materials, and supplies

- o generate a process data bank for future analysis
  - -aid in selecting process alternatives for any part
  - -allow easy retreival and correlation of all process data

Coding of PA files for each alternative must be easy to understand and apply to all process alternatives. Methods for correlating the condition codes to the PA files will develop as remanufacturers generate production data.

7.4.1 Multiple Processes

Many parts go through more than one process during a refurbishing cycle. All parts in a remanufacturing facility must be scheduled and tracked as they go through all necessary processes. Ideally a scheduling system would track each job on a daily basis, detect choke points, and predict likely supply shortages in the facility. The sequence and processing schedule for each part should consider the following factors:

- Level of utilization of capital equipment required to make process economically justifiable
- Priority assignment for refurbishing each part
- Current job mix in the plant

7.5 Process Design

Once the process alternatives are selected for each part, they are listed on a part refurbishing process sheet. These sheets are pooled to determine the requirements for the complete product being analyzed. Product process sheets are then checked against the existing department layout to determine necessary changes. By aggregating the data for all products to be remanufactured, the refurbishing department layout can then be designed.

To start-up and operate a refurbishing department efficiently, useful process information such as:

- New tools and equipment
  - specifications
  - prices
  - uses
- New materials, parts, and supplies
  - substitute materials for parts
  - improved parts
  - refurbishing supplies

This information should be collected and filed in the proper PA files. The more data available in the PA files, the more accurate cost estimates become. Over time an increasingly sophisticated data base storage and retrieval system can be developed. Process design involves the coordination of the productive efforts of all departments.

7.6 Manufacturing Department

Conventional manufacturing of new replacement parts is commonly done by remanufacturers. Implementation of these processes is usually quite straightforward and so will be given only cursory mention here. Manufacturing processes used in remanufacture include:

New Part Design and Manufacture: Certain new parts may have to be manufactured locally for the remanufactured product. This occurs whenever there are no sources for replacement parts, or when the old part design of the part has been improved. Production plans should consider possible sales of parts to other remanufacturers and to the replacement part aftermarket. This would permit higher production volumes with attendant lower unit costs and possible higher profits.

Part joining methods: Methods for part joining in sub-assemblies and parts should be evaluated according to their efficiency and effectiveness. The selected technique may or may not be the same as that used by the OEM.

Finishing: Finishing includes painting and other final surface treatment of the parts, components, and products. Paint selected should produce a durable, wear- and corrosion-resistant coating. Application methods are determined according to the part shape, size, material, surface finish requirements, production volume, and cost. Common methods include:

- o Brush Coating
- o Dip Coating/Flow Coating/ Roll Coating
- o Spray Coating
- o Electrodeposition
- o Polymerization methods
- o Undercoating
- o Lettering, decals, warning labels, and other details

7.7 Assembly Techniques

Production volumes in remanufacturing assembly are only a fraction of OEM production, so the assembly process is generally more labor intensive. Assembly operations include parts selection, fitting, fastening, inspection or functional testing, surface finishing, and packaging for shipment. These operations are performed as part of both component assembly (subassembly) and final product assembly. Operations are performed by teams of workers who specialize in particular operations. Some amount of cross-training of assembly technicians is useful to prevent employee boredom and to allow for absenteeism. Remanufacturers are constantly seeking ways to improve the production efficiency of their facilities. These include:

- Working on large batches of identical parts
- Standardizing assembly processes
- Building jigs and tools to minimize assembly time
- Training assembly workers

7.8 Testing and Quality Control

Testing is required at various stages of the remanufacturing process. It is done to assure that materials, parts, and subassemblies meet specifications. During assembly, subassemblies are tested to make sure the parts fit properly and the subassemblies function as required. Test stands in the assembly lines are used to insure that only 100% functional parts are included in the finished units. There are many types of commercially available testers for automotive and industrial components. Test stands should have the capacity to be easily modified to allow easy set up and testing of components.

An example of a test stand used by component and equipment remanufacturers is the hydraulic test stand commonly used to test pumps, motors, valves, and cylinders. Pump testing determines performance and efficiency. In a typical test, the pump is driven to simulate operating conditions, and output flow is measured. A universal hydraulic test stand can be used to test vane, gear, orbit, axial, and radial piston pumps as well as hydraulic motors, valves, and cylinders.

Similar performance tests which simulate operating conditions are done to virtually all remanufactured components and products. The objective of testing is to improve the quality of all products being remanufactured.

The best way to maintain quality control is to make sure the part is made 100% right during each stage of its production. Statistical process controls may be used to check the quality of production, but 100% testing is preferred to insure every part works properly. Some remanufactured products have a lower warranty return rate than comparable new products. This helps the remanufacturer develop a reputation for quality as well as reducing warranty service costs.

7.9 Analysis of Refurbishing Costs

The data for evaluating the economic constraints to a product's remanufacturability are collected at all stages of the analysis procedure. Every cost incurred from the collection and purchase of cores to production and final delivery must be estimated, measured, or accounted. There would be no sense in trying to recover the residual value in a core if the cost of recovery (money/ energy/ materials) exceeds the value of the finished product. Production should concentrate on those products which yield a useful and economically productive life.

Economic evaluation of parts refurbishing processes consists of tallying the costs of required equipment, labor, materials, and special tooling. The same analysis procedure is repeated for all parts to get a complete report on the cost of all refurbishing processes for the component. To select the "best" refurbishing process:

- o Define process characteristic which affect costs, store in PA files.
- o Compare various alternatives (cost-benefit analysis).
- o Select best alternative.

The processes sequence and the total (direct and indirect) cost of remanufacturing each component must be determined. By the end of a process analysis, every component will have a completed part yield and cost analysis sheet similar to the example shown in Figure 7-5.

The average refurbishing cost for eacj component is used to decide which components to remanufacture locally, which to subcontract, and which to purchase new. Individual part yield and cost analysis sheets are combined to determine the total remanufacturing cost for the product. After a product goes into production, a modified version of this sheet can be used to order parts and schedule production.

Figure 7-5 Part Yield and Cost Analysis

Product: ____________ Model: ______________ Component: _____________

No.	Part #	Description	Qty	%repl	$repl	%ref.	$ref.	$tot
1.								
2.								
3.								
4.								
5.								
6.								
7.								
8.								
9.								
10.								
11.								
12.								

Legend:

No.: remanufacturer's part number
Part #: part number in the OEM catalogue
Description: name of part
Qty: quantity of this part in the component
%repl: percent of units in which this part is replaced
$repl: cost of new replacement part
%ref.: percent of units in which this part is refurbished
$ref.: cost of refurbishing
$tot.: total cost of replacing and/or refurbishing part

Chapter Eight: Truck Remanufacturing

Trucks were selected for this example because they are durable products, essential to most economies, and have a large worldwide market. There are no firms currently engaged in large scale scale truck remanufacturing (continous daily production of at least 8-10 vehicles). Several contract remanufacturers are operating in the United States, but their work is usually limited to small scale production within a narrow range of vehicles, some cases of truck and bus remanufacturing were mentioned in Section 2-4 (p. 37).

Many developing nations have a definite need for trucks and truck mounted equipment essential to the development of a commercial and public transportation infrastructure. Given the right conditions (money, cores, parts, know-how, and plenty of cheap labor) it might be possible to export surplus U.S. cores to these markets and remanufacture them locally on large scale basis. Truck and equipment rebuilding has been practiced in developing nations for a long time due to the limited supply of equipment and spare parts. Many foreing mechanics have mastered the art of inventing a replacement part out of a broken part or a piece of scrap metal. The skills developed in repairing products with practically no supplies could easily be applied to the remanufacture of complete vehicles.

If these countries had access to sufficient cores and replacement parts they could set up and benefit from large scale remanufacturing. Remanufacturing is labor intensive therefore ideal for economies with a surplus of inexpensive (unskilled; low-skill, and high skill) labor.

The following discusion on the design and production of remanufactured trucks was prepared by evaluating a number of truck designs and specifications. And speaking to several experienced sellers and users of trucks and truck mounted equipment. This is only an outline of the issues involved in complete truck remanufacturing, the complete analysis will be carried out at a later date once adequate financial and technical resources are available. The truck described in this case study can be any of a wide variety of medium duty trucks in classes 3-5, ie. 10 to 26,000 pounds of Gross Vehice Weight (fully loaded vehicle weight).

8.1 Assumptions Made for Case Study

Several logistical issues must be resolved, before carrying out a realistic product and process analysis. Key variables such as the market and investment capital must be estimated and held constant so that technical issues can be analyzed. It is assumed that a market exists and that the capital needed to launch this venture is readily available. In addition the following set of assumptions are made:

1. The remanufacturer has access to parts and materials for the trucks, equipment and components thereof.
2. Cores of the products selected are available in sufficient quantities at reasonable prices.
3. Remanufacturer has all necessary specifications, data books, operator manuals, and engineering drawings.
4. Materials compatible with the OEM's are available.
5. All necessary tools and equipment are available.
6. Production and supervisory personnel are available.

These assumptions are reasonable in light of the well-developed aftermarket for truck and equipment servicing. During pre-production analysis the remanufacturer should do a thorough evaluation of all part, materials, supplies, and equipment required and the potential sources for them.

OEMs are the primary source of replacement parts and technical information for most remanufacturers (83). Some might consider remanufactured vehicles a threat to new truck sales. On the other hand other OEMs might be interested in helping firms remanufacture their trucks to improve its customer loyalty to their product. The "Authorized Remanufacturer" program has been in used in the automotive and in other market sectors with favoreble result for a number of years.

8.2 Truck Vital Statistics

The first step in truck remanufacturing analysis is to establish the vehicle requirements, ie. what tasks the vehicle must do. The analyst must look at existing equipment and determine operational needs such as annual mileage, terrain, and road and traffic conditions in which the vehicle will operate. Consultation with the users will help define the nature, weight, and size of products and equipment to be produced. One must also consider the driver requirements. The various vehicles currently in use are classified by:

1. The Manufacturer
2. Vehicles Series, Model and year of assembly
3. Truck Class

   GVW or Gross Vehicle Weight, indicates the allowable load for an individual vehicle, including the weight of the vehicle.

Class 1:	0-6000 lbs.	Class 5:	16,001-19,500 lbs.
Class 2:	6,0001-10,000 lbs.	Class 6:	19,501-26,000 lbs.
Class 3:	10,001-14,000 lbs.	Class 7:	26,001-33,000 lbs.
Class 4:	14,001-16,000 lbs.	Class 8:	33,001 lbs. and over

4. Wheel Power 4x2, 4x4, 6x2, 6x4, 6x6 etc. (number of axles X number of driven axles)
5. Wheelbase The distance between the centerlines of the front and rear axles. For trucks with tandem rear axles the centerline is midway between the two rear axles.
6. Power Train The group of components used to transmit engine power to the wheels. The power train includes engine, clutch, transimission, universal joints, drive shaft and rear axle gears and shafts.

Performance data from existing equipment such as:

- o operating costs
- o component performance
- o maintenance records
- o fast moving replacement parts

The service and operating records, if available, are used to determine which parts of the truck typically need service and require the closest scrutiny during remanufacture. Analysis data is used to design trucks with the lowest possible product life-cycle-cost. The importance of low operating costs is reflected by the fact that before a vehicle is retired, it will have cost five to seven times its original price in operating costs. (84)

8.3 Trucks: Product and Process Analysis

The analysis procedure is specifically designed to help create a model of a truck remanufacturing facility. An engineering feasibility study covers the design of the complete vehicle and remanufacturing process. This example will cover the following issues:

- o General analysis
- o Selection of truck components for local remanufacture
- o Design of remanufactured vehicles
- o Assembly of remanufactured trucks
- o Applications of analysis results

The main systems in a truck are those involved in [1] holding the entire product together, [2] making it roll in an efficient and controlable fashion, and [3] providing the necessary power for motion. These general systems and their sub-systems are listed in Table 8-1.

Table 8-1 Systems in Medium-Heavy Duty Trucks

		system code
1. Structure and Operation:		
	1.1 Chassis	01
	1.2 Cab stucture	02
	3.3 Cab equipment	03
2. Rolling and Control:		
	2.1 Steering system	04
	2.2 Front axle and suspension	05
	2.3 Rear axle and suspension	06
	2.4 Brake system	07
	2.5 Wheels and Tires	08
3. Propulsion System:		
	3.1 Fuel system	09
	3.2 Power train components: Engine	10
	Clutch	11
	Transmission	12
	Driveline	13
	3.3 Engine cooling system	14
	3.4 Exhaust system	15

These components and systems are for a typical medium-heavy duty truck, with a gross vehicle weight of 24,000 to 26,000 pounds. System lists are usually supplemented with a cost breakdown of the product and a comprehensive list of all components in each system.

The large variety of vehicles in use reflects the wide range of truck applications. To maintain production of vehicles on a commercial scale, a product must be designed which can be tailored to the needs of many users.

Pre-Production analysis emphasizes prototype development and the need to establish a product with reliable functional performance. This places a constraint on the type of jobs which should be taken in, only vehicles and remanufacturing jobs which are related, or contribute to prototype development should be worked on.

In the development stage the remanufactured truck should use proven, readily available systems and components. Production equipment and processes should be flexible since changes in the product and process will occur frequently. The success of this type of project greatly depends on the innovative and administrative resources of the remanufacturer.

8.4 Selection of Components for Remanufacture

Vehicles will be assembled using both new and remanufactured components. Components which should be remanufactured are determined by design, core availability, replacement parts, and local productive capacity. Usually a limited amount of investment capital is available, and cost-benefit analysis is carried out for each important decision to avoid getting involved with in-house remanufacture of components which are cheaper to purchase or subcontract. Many firms have gone bankrupt by trying to handle too many products or doing all the work in-house. Comparing local vs. outside sourcing is a time consuming but essential aspect of pre-production analysis; an accurate model of the operation is often very useful.

Raw materials consist mainly of cores. In many cases, the components of purchased cores will differ from those needed for the remanufactured truck. A system for getting all the necessary cores and trading those not handled in the facility will have to be developed. All components removed from the core are reclaimed either by the remanufacturer or some subcontractor.

The following section lists the components in each of the systems of a Ford F600 truck. Initially most of the components on the truck will be sent to different subcontrators for remanufacture. The facility will concentrate on assembly and the remanufacture of systems and components which do not require large production volumes or extensive amounts of equipment.

Since this is the first screening of truck components, they will be labeled :

- o [L] to be remanufactured locally
- o [S] components to be subcontracted
- o [N] to be replaced with new

Subsequent rounds of analysis will involve the evaluation of samples of component cores to determine the average core condition. The core evaluation data is then used for the process analysis described in the last chapter.

Note on References for Truck Diagrams:

All diagrams shown in this chapter are from the 1976 Ford Truck Shop Manual (85). Each reference number has six digits corresponding to the section, subsection and page of the diagram in manual. The first two digits determine the reference volume from which the diagram came, if the reference number begins with:

- o Numbers 10 through 17, are from volume 1
- o Numbers 20 through 29, are from volume 2
- o Numbers 30 through 47, are form volume 3

8.4.1 System 01: Truck Chassis

All systems and their components of the truck are installed on a chassis. The standard Ford chassis is made of two straight steel channels held together by riveted cross members. Other manufacturers use high strength bolts to assemble the chassis, making them easier to take apart. All chasses must be checked for bends, cracks and corrosion damage. Wear is usually not a problem with chassis since it is not in contact with any moving parts.

The only refurbishing operations done to a chassis are cleaning by sandblasting, inspection, drilling, reinforcement and finishing. The only machining work done on chasses is the occasional drilling to relocate axles and crossmembers, and changes to the engine crossmembers.

8.4.2 System 02: Cab Structure

This system includes the welded cab shell and its doors, windows and interior moldings. The shell and doors are usually damaged by corrosion and dents. Parts that wear include door latches and the floor mats and rugs, these are usually replaced in all trucks. Cab parts made of plastic or fiberglass are subject to cracking and delamination.

The cab shell and its components are remanufactured locally using conventional body work processes. The following components are included with the cab shell:

0201 Shell:

- 020101 shell: walls, roof, floor, door frame L
- 020102 insulation .... N
- 020103 moldings and headboard L
- 020104 carpets and floormat .... N

0202 Door Assemblies: (Figure 8-1)

- 020201 doors (left and right) L
- 020202 latch, lock and handle assembly L
- 020203 hinges L
- 020204 window mechanism L

0203 Hood and Fender Assembly:

- 020301 fenders (left and right) L
- 020302 radiator grille L
- 020303 hood, hinges and latch assembly (Figure 8-2) L
- 020304 fender upper and lower supports L

0204 Glass: (replace as needed, fix seals)

0205 Dashboard: (new coating may be necessary) L

Figure 8-1 Door Assembly

System 02, Cab Shell
Sub-Assembly 0202, Door assembly
Ref. (44-11-2; 42-04-4)

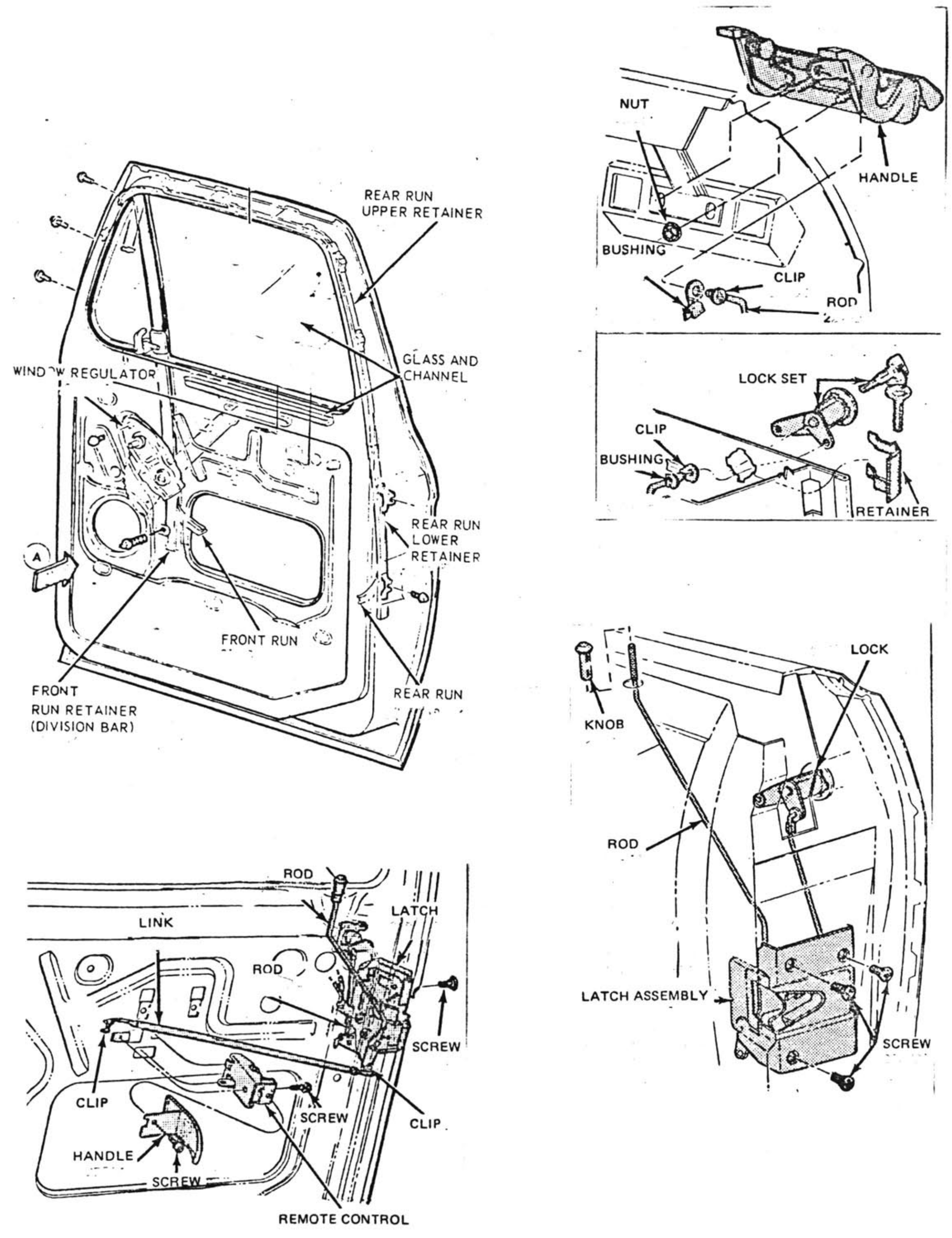
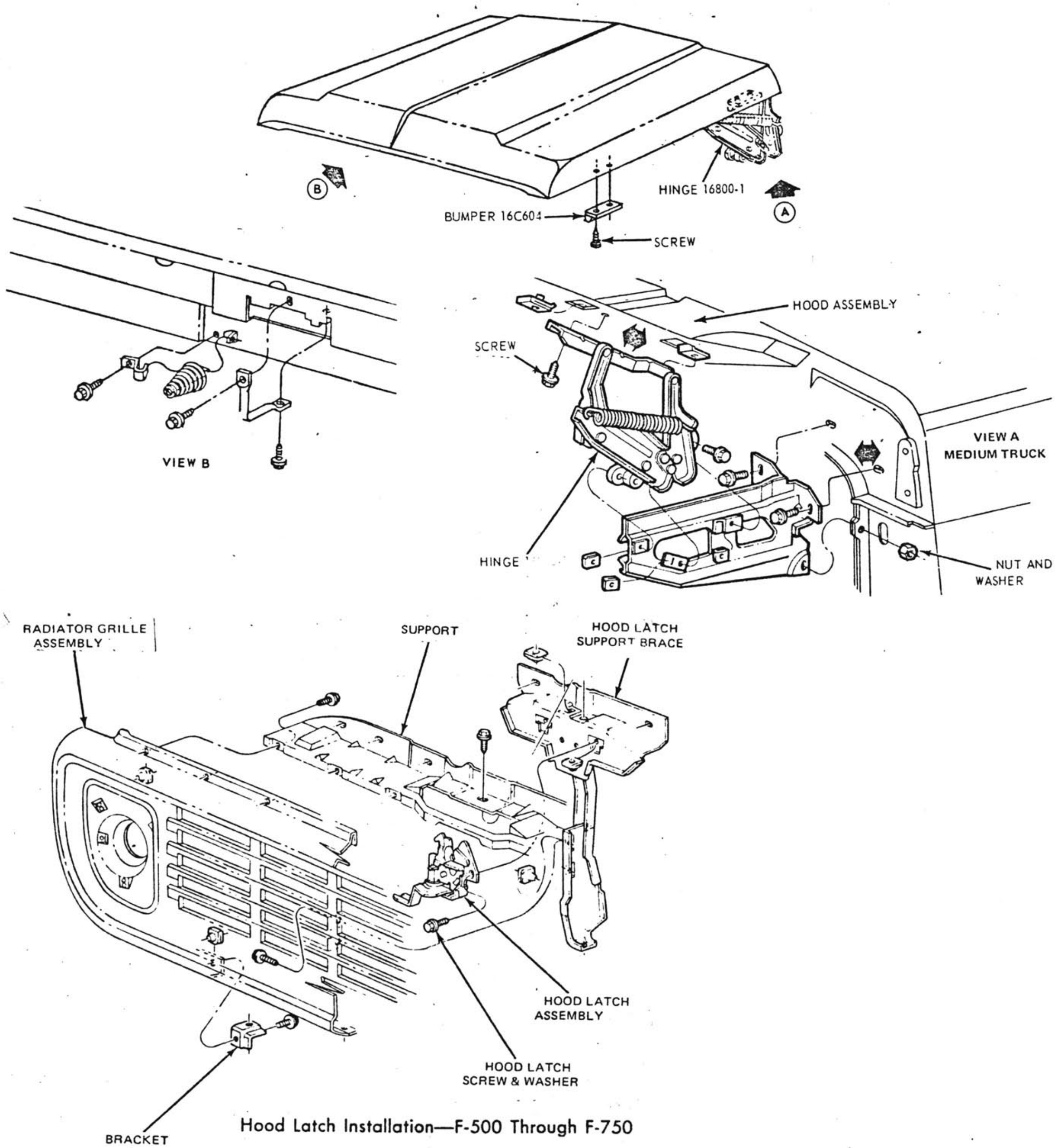


Figure 8-2 Hood, Hinges and Latch

System 02, Cab Shell

Sub-Assembly 0203, Hood, hinges and latch assembly

Ref. (44-31-3)



Hood Latch Installation—F-500 Through F-750

8.4.3 System 03: Cab Equipment

0301 Seats

030101	frame and spring	L
030102	upholstery	L
030103	adjusment mechanisms	L

0302 Air Conditioner System (Figure 8-3) .... S

030201	compressor	S
030202	condensor	S
030203	receiver	S
030204	evaporator	S
030205	valves	S

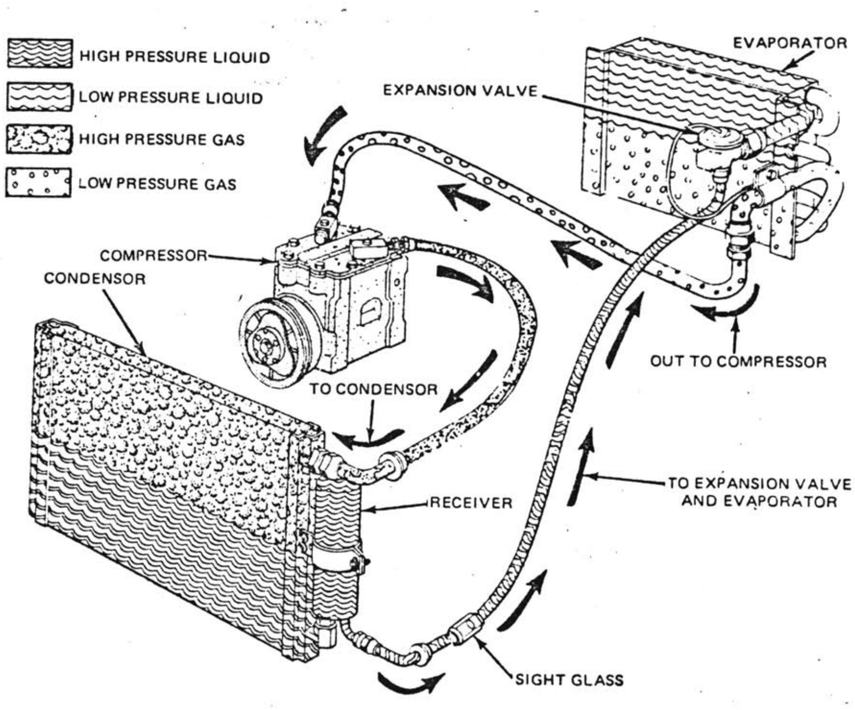


Figure 8-3 Typical Basic A/C System

Ref.(36-30-2) .

0303 Heater System L

System 03: Cab Equipment (continued)

0304 Windshield Wipers .... S/N

030401 motor assembly

030402 arm and pivot shaft assembly

030403 controls

030404 blade and blade saddle assembly

0305 Windshield Washer .... N/L

030501 washer pump

030502 hose, nozzle and reservoir

0306 Horn (switch and horn assembly) .... L/N

0307 Instruments (clean, refurbish and replace as needed)

030701 speedometer

030702 tachometer

030703 oil pressure and temperature

030704 engine temperature

030705 ammeter

030705 fuel gauge

030706 ignition switch

0308 Radio/ Antenna/ Speakers (instal whenever specified).. L

0309 Mirrors .... N

0310 Lighting System .... N

031001 switches

031002 headlights, parking lights

031003 turn signals and emergency flasher

031004 interior and cargo lights

0312 Wire Harness, Circuit breakers .... N/L

0313 Control Pedals and Linkages L

8.4.4 System 04: Steering System

The pump and gears of the power steering system are already being remanufactured for the truck market. In complete vehicle remanufacturing there might be some modifications to the location of some of the compoents. Figure 8-4 show the components in this system.

0401 Steering Column Assembly L
0402 Power Steering Linkage L
0403 Power Steering Pump and Gear .... S
0404 Cylinder L

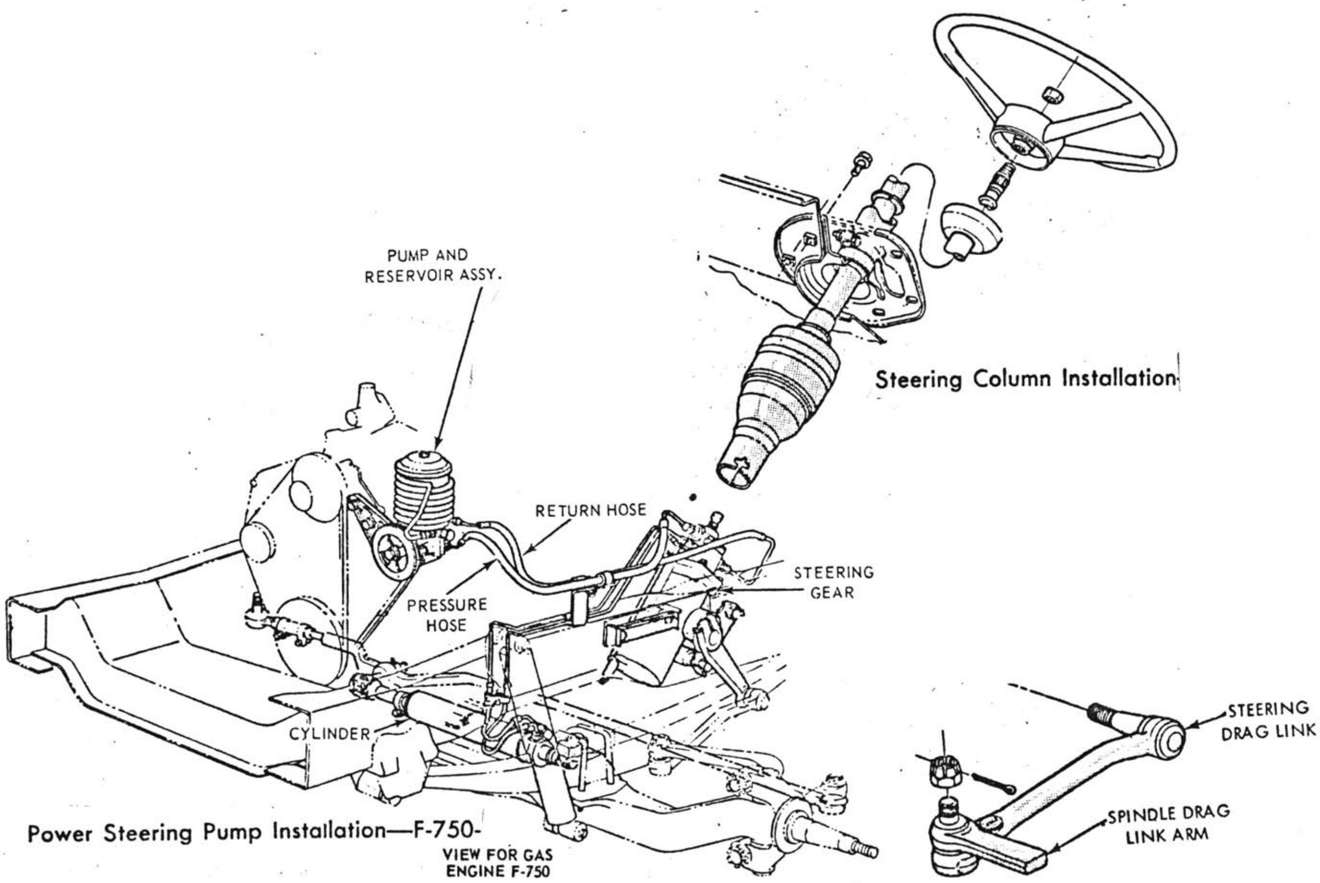


Figure 8-4 Steering System

Ref.(13-51-1; 13-07-1)

8.4.5 System 05: Front Axle Assembly and Suspension

Front suspension is normally made of semi-elliptic, leaf type springs. The springs are mounted on the frame to the side member (channel) and are held in place on the axles by U bolts. Damage to the front axle can result from overloading and rough driving conditions. All parts should be checked for deformations and cracks. The following assemblies fall in this category: (Figure 8-5) (ref 14-20-5 and 14-20-9)

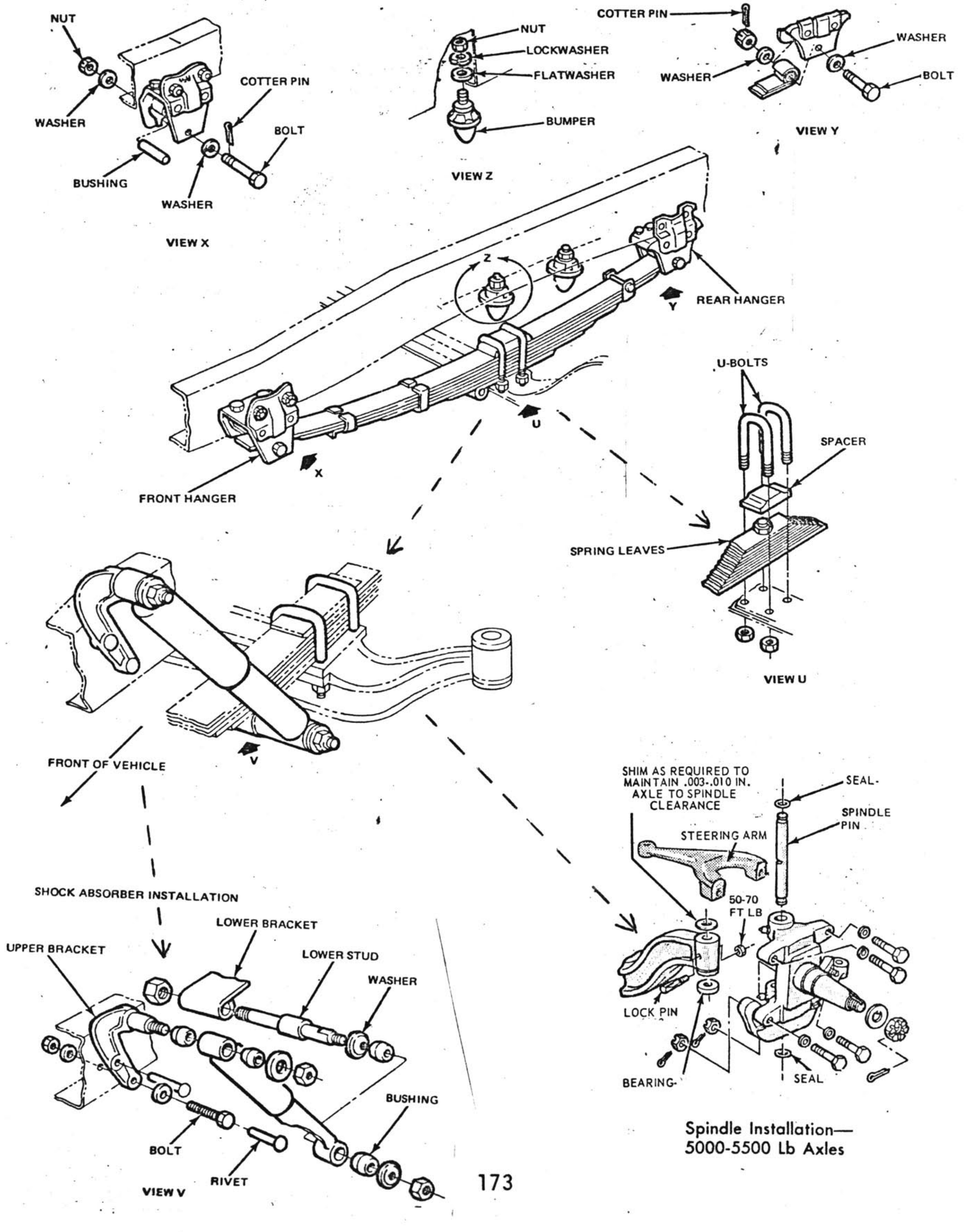
0501 Leaf Spring Assembly (re-arching and shot peening) ... S
0502 Hangers and Pins .... N/L
0503 Shock Absorber Assembly .... N/L
0504 Spindle Assembly .... N/L
0505 Axle (solid I beam) L

8.4.6 System 06: Rear Axle Drive and Suspension

0601 Leaf Spring Assembly (re-arching and shot peening) ... S
0602 Hangers and Pins .... N
0603 Axle Shaft L
0604 Differential and Housing (Figure 8-6) L

Figure 8-5 Front Axle Assembly

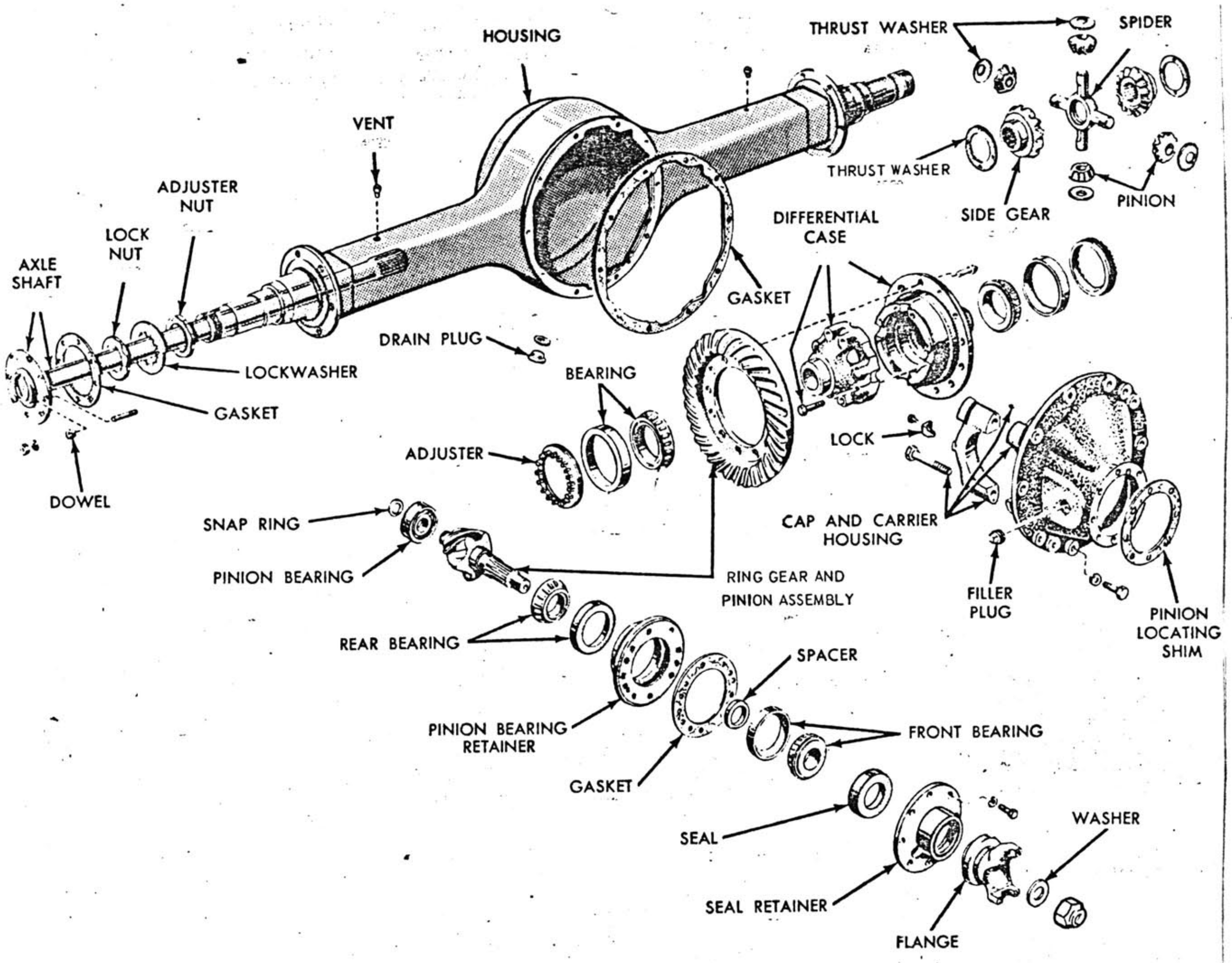
System 05, Ref. (14.20.5; 14-20-9)



Spindle Installation—
5000-5500 Lb Axles

Figure 8-6 Typical Differential

System 06, Rear Axle
Component 0604, Differential and Housing
Ref. (15-16-4)



Typical Single-Speed, Single-Reduction Axle—Rockwell

8.4.7 System 07: Power Brakes

0701 Air Brake System (Figure 8-7)

070101 brake chambers .... S

070102 valves (limiting, check, foot) L

070103 solenoid .... S

070104 tanks (primary, secondary and supply) L

070105 compressor and governor .... S

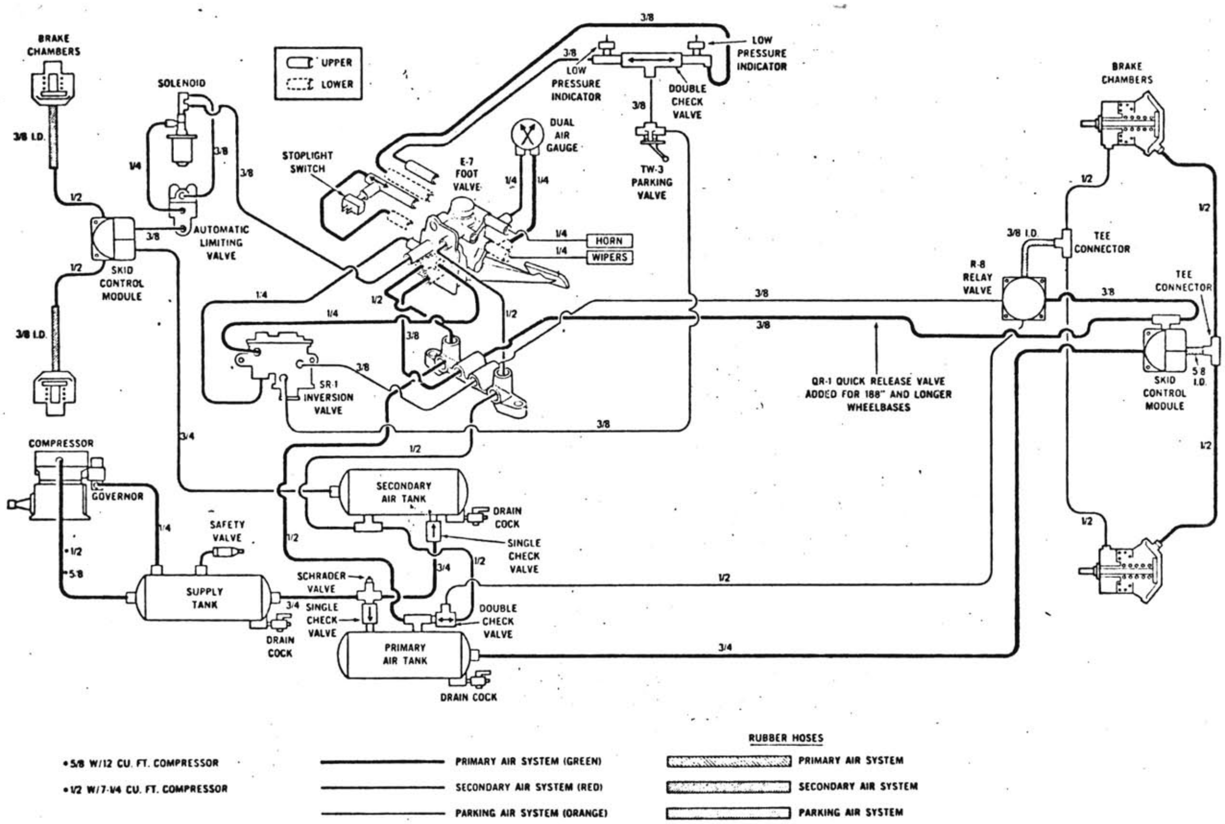


Figure 8-7 Air Brake System

Ref.(12-40-5)

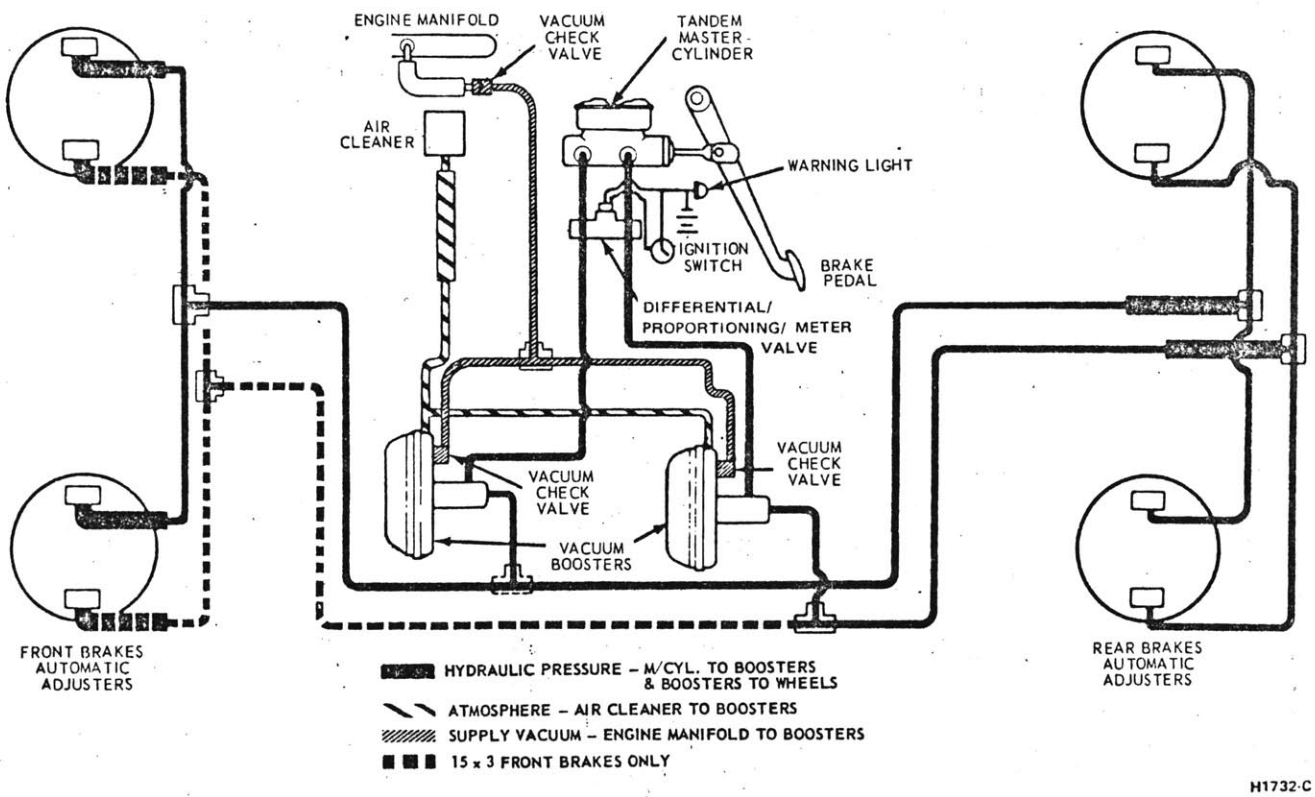
0702 Hydraulic Brake System (Figure 8-8)

- 070201 master and slave cylinder .... S
- 070202 pedal assembly L
- 070203 vacuum booster .... S
- 070204 metering valve L

0703 Drum Brake Assembly (Figure 8-9) L

0704 Disk Brake Assembly L

0705 Parking Brake L



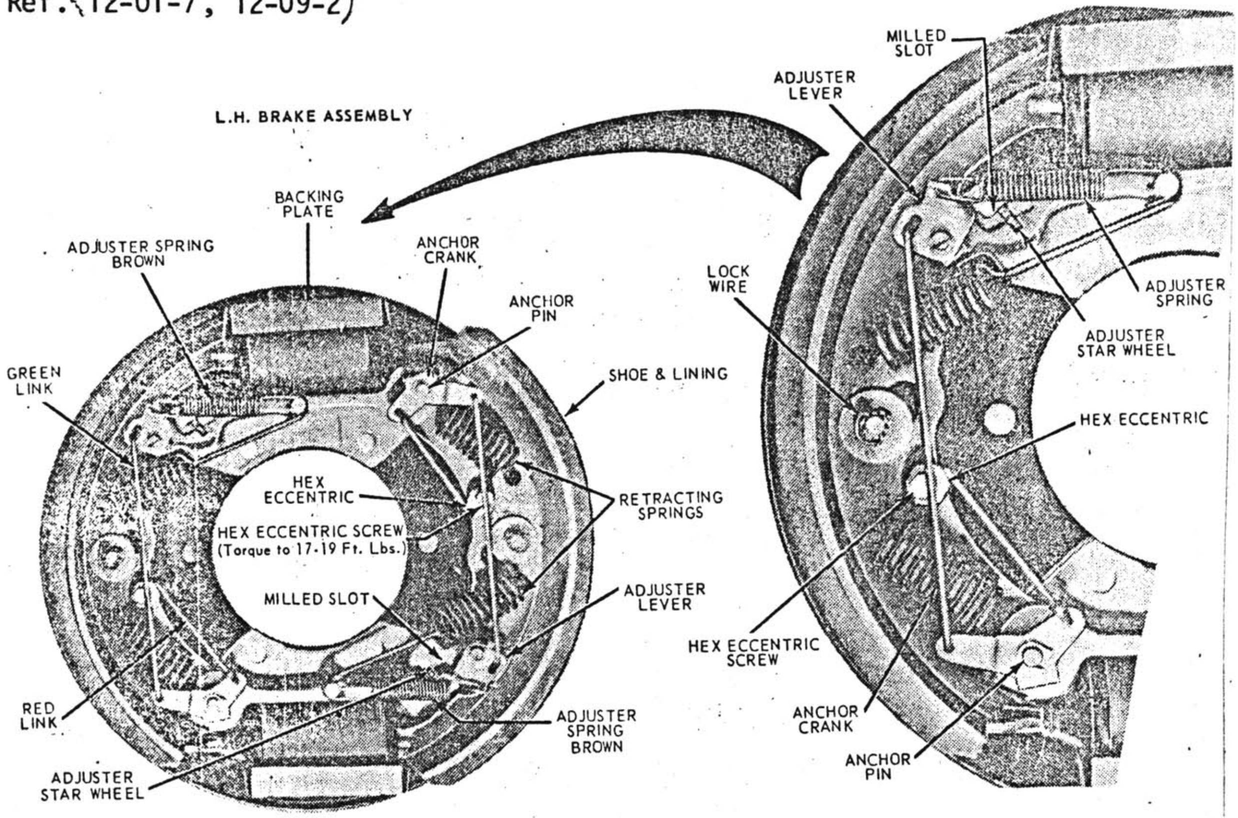
Split Hydraulic Brake System with Frame-Mounted Boosters—500-900 Series

Figure 8-8 Hydraulic Brake System

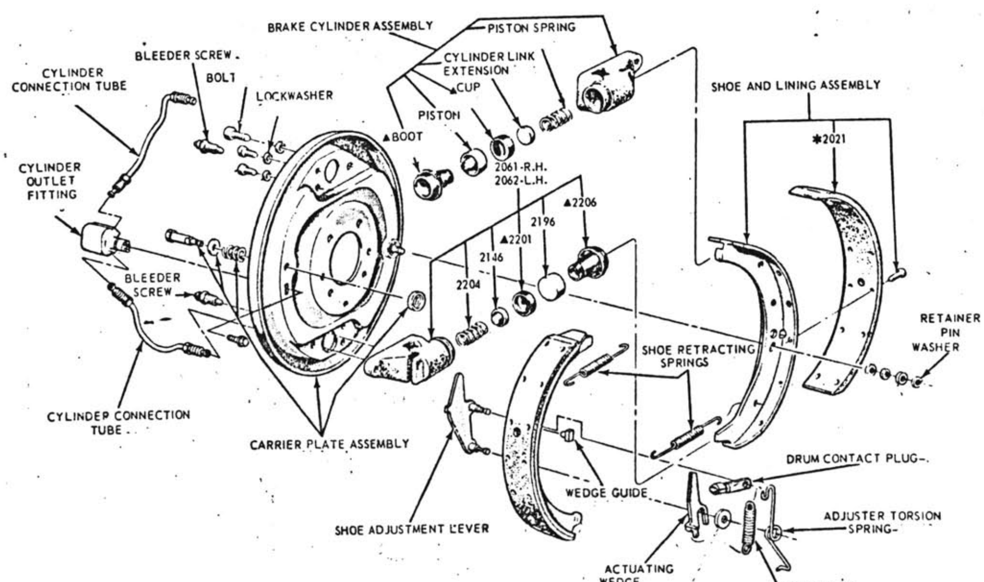
Ref.(12-01-12)

Figure 8-9 Drum Brake Assembly

Ref.(12-01-7, 12-09-2)



Two-Cylinder Brake Assembly (Wagner)



*ALSO SUPPLIED IN 2007 LINING KIT
▲ALSO SUPPLIED IN 2221 WHEEL CYLINDER REPAIR KIT

Two Cylinder Brake Shoe (Wagner) —Disassembled View

8.4.8 System 08: Wheels and Tires (Figure 8-10)

0801	Tires (front and rear)	N/S
0802	Hubs	L
0803	Bearings	S/N
0804	Wheels	L

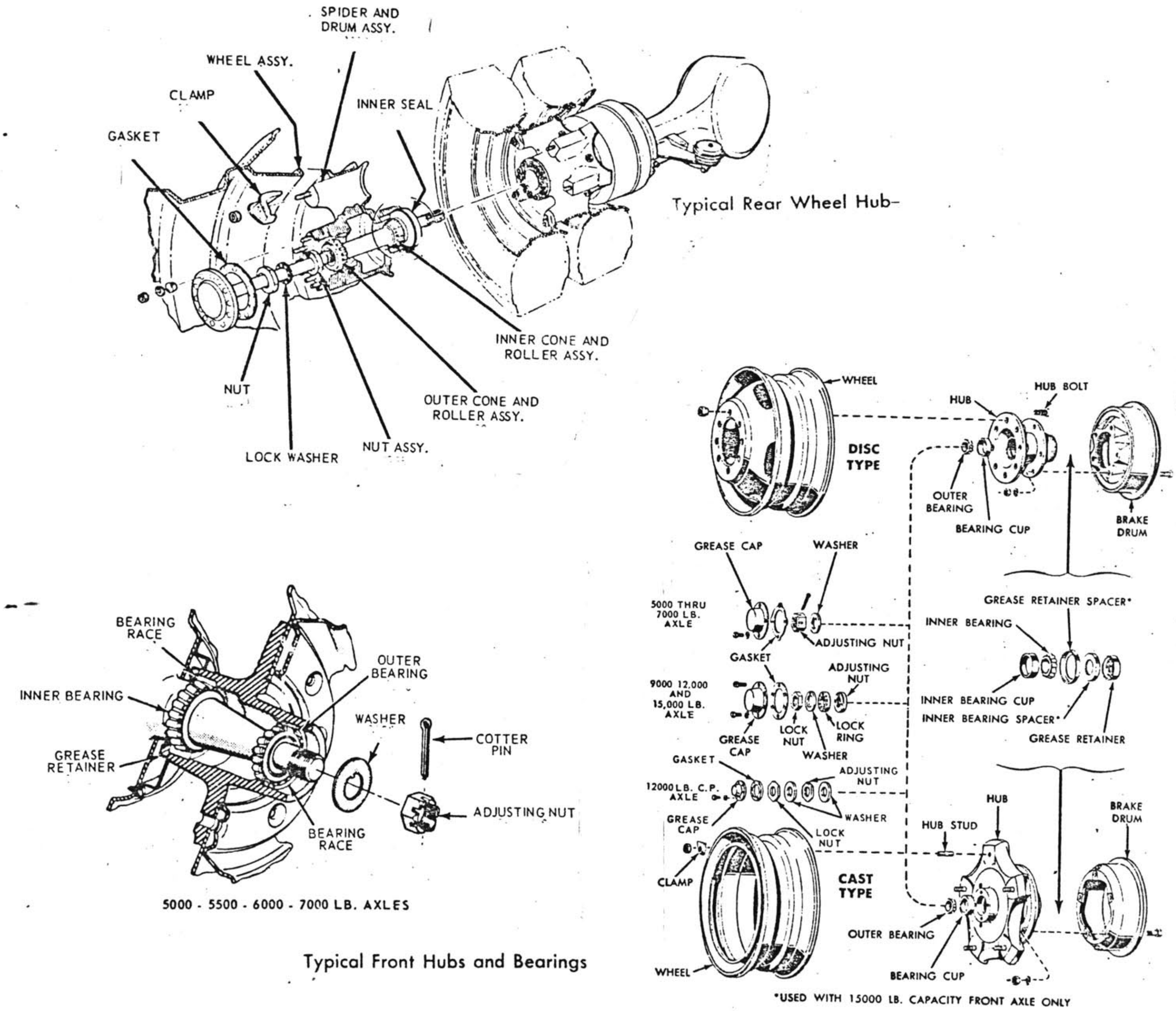


Figure 8-10 Typical Hub and Wheel Assemblies

Ref.(11-10-2, 11-10-3, 11-14-2)

8.4.9 System 09: Diesel Fuel System

0901 Fuel Tank L
0902 Fuel Pump and Priming Pump .... S
0903 Fuel Transfer Pump .... S
0904 Filter .... N
0905 Bypass Valves L

8.4.10 System 10: Diesel Engine

Hundreds of diesel engines are rebuilt and remanufactured every day. Engine remanufacturing is a process which requires large and consistent production volumes in order to justify investment in the parts, tools, and equipment. The prototype truck remanufacturing facility will repower all its vehicles with new diesel engines, therefore most engine cores will be traded for credit to other remanufacturers. A few engine cores will be saved for evaluation and spare parts.

Repowers or conversions from gasoline to diesel involves a number of changes to the instalation, careful notes should be kept for use during the analysis of different vehicles. Among the most important are:

- Engine to transmission housing adapter L
- Front engine mount design and fabrication L
- Rear engine mounts design and fabrication L
- Cross member modifications L
- Hydraulic Clutch instalation bracket L
- Air filter instalation L
- Mounts, brackets and linkages L

8.4.11 System 11: Clutch (Hydraulic)

1101 Disc and Pressure Plate .... S
1102 Housing and Adaptor Plate .... N
1103 Conneting Arm L
1104 Master and Slave Cylinder .... N/S

8.4.12 System 12: Transmission .... S

8.4.13 System 13: Driveline (Figure 8-11)

1301 Yokes L
1302 Universal Joints L
1303 Shaft Assembly L
1304 Hanger Bearings .... N

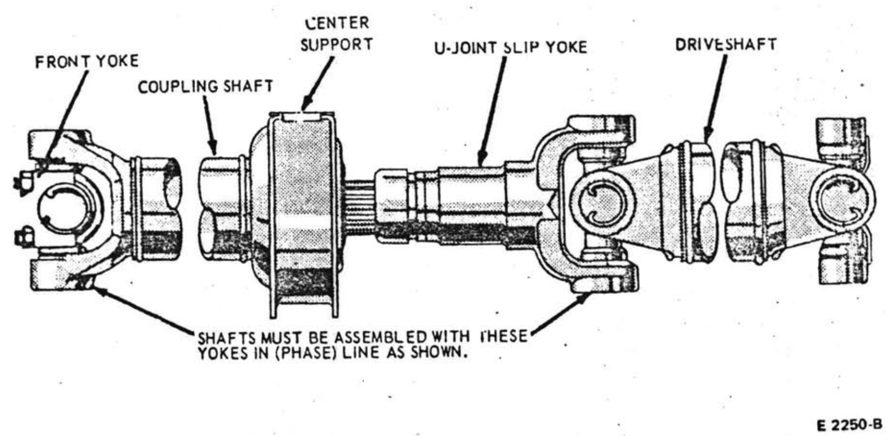


FIG. 2 Two Piece Drive Shaft With U-Bolt Attachment to the Transmission

Figure 8-11 Driveline Assembly

Ref.(15-60-1, 15-62-7)

8.4.14 System 14: Engine Cooling System

1401 Radiator and Shroud (modify to new engine)............ S/L
1402 Hoses L
1403 Fan and Clutch L
1404 Water Pump (comes with new engine) .... S

8.4.15 System 15: Exhaust System

1501 Tubes, Hangers and Clamps .... N/L
1502 Muffler Assembly .... N

Note:

The production statistics of each vehicle are stored in the PA files and the individual project files. As mentioned earlier the PA files are used to determine the bill of materials, operations sequence, tooling, and costs related to the remanufacture of additional vehicles. This information is useful in cases where identical or similar vehicles will be remanufactured and an accurate cost breakdown is needed to prepare a bid. The mix of Local/ New/ Subcontracted work varies depending on the content and condition of the various components in the vehicle core, and the productive capacity of the plant.

8.5 Core Evaluation

To aid in evaluation and purchase of vehicles, a standard truck core appraisal sheet should be used. Table 8-2 shows a sample truck core appraisal sheet might look like. The blanks in the sheet are filled with a description of the condition of each component and sub-assembly in the vehicle. An actual sheet for field evaluation would have much more space for comments on the various components. These evaluation forms are usually supplemented with photographs of the vehicle and close-ups of the sections that need special attention.

Core evalulation will have to be done by a person with considerable experience in used truck appraising and trading. Some of the information listed in the evaluation sheet is difficult to collect without having access to the vehicle records (purchase orders) or partial disassembly. This person is responsible for filling out the truck core appraisal sheet and for preparing a bid for the cores which are going to be purchased. The objective of filling out these forms is to:

- o record price paid for truck cores in various conditions
- o simplify inventory control of cores

A problem with many truck rebuilders and service centers is monitoring used part and component inventories. Data on the evaluation sheet can be used to log in components in vehicles as they arrive at the remanufacturing facility. Truck component cores not to be used in the remanufactured truck may be catalogued for re-sale.

Serial numbers are necessary as several truck and equipment components may be made for years under the same model description. However, it is likely that a great many parts will be modified during the years that the trucks and equipment are in production. In some cases the parts books will show one part number for components with serial numbers up to a perticular number and a different part number for trucks with later serial numbers.

The serial number of the vehicle provides much valuable information. For example the seventeen digit Ford Truck serial number has encoded the: class, line, world manufacturer, brake type and GVWR class, series, chassis, cab, and body type, engine type, model year, and plant of manufacture (86). Other vehicle and component serial numbers can be decoded using the appropiate data books.

Table 8-2 Truck Core Appraisal Sheet

A. Source: firm name: ______________________ contact ______________
address: ______________________________ tel. no. __________

B. Quantity ____ Make ______________ Model ____________ Year ________
serial no. ______________________ Vehicle no. __________

C. Inspector: ____________________ Date: ____________________

01. Chassis: Type ____________________ wheel base ______________
crossmembers ____________ bumper ______________
suspension brackets ____________ body mounts ______________
modifications ______________________________

02. Cab Structure:
shell ______________________________
door R ______________ door L ______________
moldings ______________ floor ______________
fender R ______________ fender L ______________
windows R/L ______________ hood ______________
windshield ______________ fittings ______________
dashboard ______________ vents ______________

03. Cab Equipment: Seats ______________________________
A/C ______________ Heater ______________
wipers ______________ motor ______________
washer ______________ pump ______________
instruments ______________ harness ______________
mirrors ______________ radio ______________
lights ______________ linkages ______________

04. Steering: column and wheel ______________ linkage __________
power steering pump ______________ lines __________

05. Front Axle: model ______________ capacity ________ beam ________
spindle ______________ hubs ______________
springs ______________ brackets ______________

06. Rear Axle: model ______________ capacity ________ speeds ________
ratios ______________ housing ______________
carrier assy. ______________ hubs ________ shafts ________
springs ______________ brackets ______________

07. Brakes: type ______________ master cyl. ______________
booster ______________ brake cyl. ______________
elec. anti skid ______________________________

08. Wheels and Tires: ______________________________
hubs ______________ bearings ______________

09. Fuel System: tank size ______________ filter ______________
hoses and fittings ______________ fuel pump ______________
bypass valves ______________ selector valve ______________

Table 8-2 Truck Core Appraisal Sheet (cont)

10. Engine: model ____________ diplacement ________ H.P. ________
ser.no. ____________ water pump ____________
starter ____________ alt. ____________
turbo ____________ ignition ____________
mounts ____________ throttle ____________
air cleaner ____________ governor ____________

11. Clutch: model ________ size ______ type ________ links ________
master ____________ slave ____________

12. Transmission: model ________ ser.no. ________ speeds ________
shift links ____________ case ____________
PTO ____________ transfer ____________

13. Driveline: shaft ____________ U joint ____________
yokes ____________ splines ____________
bearings ____________ supports ____________

14. Cooling: radiator cap. ____________ type ____________
mounts ____________ thermostat ____________
fan ____________ shroud ____________

15. Exhaust: muffler ____________ manifolds ____________
catalytic converter ____________ pipes ____________
brackets ____________ emissions ctrl. ____________

16. Equipment A: Type ____________ make and model ____________
cylinder ____________ motor ____________
pump ____________ control valves ____________
hoses ____________ fittings ____________
controls ____________ other ____________
____

17. Equipment B: type ____________ make and model ____________
____
____
____
____

18. Notes and comments: (use additional pages if necessary) ____________
____
____
____

19. Does vehicle start ____ work ____ how well ____ Are records available ____

20. Purchase bid refer to document # ____________ Revised by ____________

In many cases the truck core will be purchased without filling out the evaluation sheet completely. This occurs when an agreeable price is negotiated without having to go through formal bidding for the core, or when a large quantity of vehicles are involved and it is impractical to fill out individual sheets for all of trucks. Core purchasers with large amounts of experience usually can bid on a core after a brief evaluation.

Regardless of the purchasing procedure: Once a core is purchased, and delivered to the facility, the evaluation sheet is filled out in detail.

8.6 Design of Remanufactured Trucks

The number of parts and components needed to assemble a truck make remanufactured truck design an exercise in standardization and compromise. It is impossible for a remanufacturer to provide even a fraction of the component selections available from the OEMs.

The remanufactured truck should be strong enough to meet the requirements of several different applications. The most important components (cab, engine, transmission, clutch, axles, differential, brakes) must must be standardized and useable in several different vehicle makes and models.

A mix of prototype vehicles was designed as a guideline for the truck remanufacturing feasibility study. Three "general purpose" vehicles, the model numbers R3000, R5000 and R6000 were designated for those truck selected as possible candidates for "large scale" remanufacturing. These vehicles were designed to be built out of commonly available cores. Since the cores can come for various types of vehicles extensive component standardization was necessary.

The specifications of the prototype trucks are shown in Tables 8-3, 8-4 and 8-5. The "R" means the truck is remanufactured, the numbers indicate the type of truck.

1. The R3000: 100 HP diesel engine, 10,000 GVW; cores may be:
   Ford F350
   Chevy C30
   Chrysler D30

2. The R5000: 145 HP diesel engine, 21,000 GVW; cores may be:
   Ford F500 and F600
   Chevy C50 and C60
   IHC 1600

3. The R6000: 145^{+} HP dieles engine, 25,500 GVW; cores may be:
   Ford F600 and F700
   IHC I700
   Chevy C79

These trucks were selected because there are large quantities of cores available. Three vehicles weight ranges cover 60% of the commercial user needs above 10,000 GVW. In addition they represent over 50% of the new and use truck sales in the U.S. market (Table 2-1). The prototype truck specifications were prepared with the aid of my father, Mr. G.E. Gonzalez, who has over 25 years of experience in the trucking industry both in the United States and Puerto Rico.

In addition to compoent standardization, expensive or hard-to-get parts e.g. tilt hoods, can be replaced by a locally designed and built universal fiberglass tilt hood assembly. As production capacity is built up, other body and component parts can be made by the remanufacturer or subcontracted to a local supplier.

Table 8-3 R3000 Remanufactured Truck Specifications

Core Models: Chevy C30; Ford F350; Chrysler D30.

1. Maximum Gross Vehicle Weight (GVW).....10,000 lbs.

2. FRONT AXLE:
   - rating, lbs. 3850/4200
   - steering (type) power
   - model: Ford Twin I Beam

3. REAR AXLE:
   - rating, lbs. 7,400
   - model (preferred) Dana 70
   - ratios: 3.73, 4.10, 4.56

4. ENGINE: ISUZU Diesel QD 100
   - displacement (cu.in.) 235
   - power BHP/rpm 87/3200
   - torque Ft-Lb/rpm 166/1900

5. CLUTCH: diameter (in.) 10
   - area (sq.in.) 95.7

6. U Joints (Spicer) std. 1480

7. TRANSMISSION: four or five speed manual (optional automatic)
   - makes and models: New Process 435; Warner T-19; Ford C6 (auto)
   - ratios: New Process 435: 6.69, 3.34, 1,79, 1.0 (fwd); 8.26 (rev)
     Warner T-19: 6.32, 3.09, 1.68, 1.00 (fwd); 6.96 (rev)
     Ford C6: 2.46, 1.46, 1.00 (fwd); 2.18 (rev); 1.86 converter

8. FRONT BRAKES: disc
   - vaccuum power (Bendix)
   - rotor (ID/OD) 12.56"/8.62
   - lining area (sq.in.) 50.6
   - swept area (sq.in.) 242.44
   - master cyl. dia. 1.062"
   - booster O.D. 9.38"
   - stroke 1.617"
   - slave displ (cu.in.) 1.337

9. REAR BRAKES: drum
   - size (in.) 12x3
   - wheel cyl. dia. 1.0"
   - lining area (sq.in.) 147.52
   - swept area (sq.in.) 226.2

10. RADIATOR: 13 quart.
11. CAB: F Series Ford (or similar)
12. Short Fiberglass Tilt Hood

13. WHEELS: disc
    - size 16x6.0
    - studs 8"
    - bolt circle 6.5"
    - wheel capacity (lbs.) 2780
    - cap. dual (lbs.) 2100

14. TIRES:

	8ply.main	10ply.alt.
front (single)	750X16D	750X16E
max psi.	60	75
capacity (lbs.)	2440	2780
rear (dual)	750X16D	750X16E
max psi.	60	75
capacity (lbs. ea)	2140	2440

Applications: tow truck (wrecker)
winch or crane
multi stop delivery vehicle
vans
light dump truck
mobile service vehicle
utility truck

Table 8-4 R5000 Remanufactured Truck Specifications

Core Models: Chevy C50, C60; Ford F500; International Harvester 1600

1. Maximum Gross Vehicle Weight (GVW).....21,000 lbs.

2. FRONT AXLE:

rating, lbs.	7000
steering (type)	power
model:	Ford Twin I Beam

3. REAR AXLE:

rating, lbs.	15,500
model(preferred)	Rockwell F106
ratios:	6.18, 6.83, 7.17

4. ENGINE: ISUZU Diesel QD 145

displacement (cu.in.)	353
power BHP/rpm	130/3200
torque Ft-Lb/rpm	253/1900

5. CLUTCH:

diameter (in.)	12
area (sq.in.)	159.8

6. U Joints (Spicer) std. 1480

7. TRANSMISSION: four or five speed manual (optional automatic)
   makes and models: Clark 285V; Warner T-19; Ford C6 (auto)
   ratios: Clark 285V: 6.99, 4.09, 2.24, 1.47, 1.0 (fwd); 5.89 (rev)
   Warner T-19: 6.32, 3.09, 1.68, 1.00 (fwd); 6.96 (rev)
   Ford C6: 2.46, 1.46, 1.00 (fwd); 2.18 (rev); 1.86 converter

8. FRONT BRAKES: drum

vaccuum power	(Bendix)
drum I.D. (in.)	14X2.5
lining area(sq.in.)	146.46
swept area (sq.in.)	242.44
master cyl. dia.	1.5/1.75"
booster O.D.	12.75"
slave dia.	0.875"
slave displ (cu.in.)	2.75

9. REAR BRAKES: drum

size (in.)	15x5
wheel cyl. dia.	1.5"
lining area (sq.in.)	306.32

10. RADIATOR: 13 quart.
11. CAB: F Series Ford (or similar)
12. Long Fiberglass Tilt Hood

13. WHEELS: disc

size	20x7.0
studs	6"
bolt circle	8.75"
wheel capacity (lbs.)	4375
cap. dual (lbs.)	2100

14. TIRES: 10 ply main

front (single)	825X20E
max psi.	75
capacity (lbs.)	3550
rear (dual)	825X20E
max psi.	75
capacity (lbs. each)	2050

Aplications: delivery truck
stake or platform
van
wrecker
light dump truck
and other applications requiring 12-14 foot body length

Table 8-5 R6000 Remanufactured Truck Specifications

Core Models: Chevy C60, C70; Ford F600; International Harvester 1700,1800

1. Maximum Gross Vehicle Weight (GVW).....25,500 lbs.

2. FRONT AXLE:
   - rating, lbs. 7000
   - steering (type) power
   - model: Ford Twin I Beam

3. REAR AXLE: two speed
   - rating, lbs. 18,500
   - model(preferred) Eaton 17221
   - ratios (high) 5.57, 6.14, 7.17
   - ratios (low) 7.60, 8.38, 9.71

4. ENGINE: ISUZU Diesel QD 145
   - displacement (cu.in.) 353
   - power BHP/rpm 130/3200
   - torque Ft-Lb/rpm 253/1900

5. CLUTCH: diameter (in.) 12
   - area (sq.in.) 159.8

6. U Joints (Spicer) std. 1480

7. TRANSMISSION: five speed manual
   - ratios: Clark 285V: 6.99, 4.09, 2.24, 1.47, 1.0 (fwd); 5.89 (rev)

8. FRONT BRAKES: drum
   - air power
   - drum I.D. (in.) 15X3.5
   - lining area(sq.in.) 214.0
   - swept area (sq.in.) 242.44
   - air compressor: Borg Warner
   - displacement (cu.in.) 7.25
   - psi: in/out 100/120
   - cooling type: water
   - reservoir main 20944 cu.in.(8X20) secondary 10653 cu.in.(7X19)
   - alternate air compressor: ISUZU-KIKKI

9. REAR BRAKES: drum
   - size (in.) 16.5x7
   - wheel cyl. dia. N/A
   - lining area (sq.in.) 440.6

10. RADIATOR: 13 quart.
11. CAB: F Series Ford (or similar)
12. Long Fiberglass Tilt Hood

13. WHEELS: cast-rim
   - size 20x7.0
   - studs 6"
   - bolt circle 8.75"
   - wheel capacity (lbs.) 4375
   - cap. dual (lbs.) 2100

14. TIRES: 12 ply main
   - front (single) 900X20F
   - max psi. 85
   - capacity (lbs.) 4500
   - rear (dual) 900X20F
   - max psi. 85
   - capacity (lbs. each) 4500

Aplications: Small Refrigerated Body
Delivery
Utility
30 passenger bus
winch or crane
cattlerack
tanker

These specifications are production guidelines, there can be changes in some or all of the components according to:

- o supply of cores
- o customer specifications
- o market conditions
- o supply of spare parts

Minor variations (ie. do not affect performance) will occur in several assemblies such as the nose-cab interface, fuel tanks, cab access and many other details related to the particular application intended for the truck.

8.7 Remanufactured Truck Assembly

A similarity to the original assembly is that most components arrive at the assembly line ready for instalation; the similarities end there. Remanufactured truck assembly is a much more labor intensive process than convential OEM assembly lines. In addition many of the components and parts used by the remanufacturer are purchased in much smaller size lots than the OEM, hence the price is much higher.

One solution tried out by a particular remanufacturer is to try and achieve vertical intergration within the facility. The maximum possible number of new and remanufactured parts and components are made locally (refurbished) and assembled to final products under the same roof.

Issued that will affect the design and operation of the assembly line include:

- o Keeping track of different work done to each vehicle
- o Scheduling local component remanufacturing
- o Timing of subcontracted remanufacture work
- o Sourcing and inventory control of components, parts, materials

The differences in capital requirements between and OEM and a remanufacturer can be quite dramatic. While it may take over a billion dollars to set up an OEM truck plant, a truck remanufacturer can go into action with aproximately two or three million dollars. Most of the capital intensive processes such as steel forming, glass making, casting, stamping, heavy machining, and complete body assembly (from scratch) are not done by remanufacturers and therefore the equipment cost are saved..

The lead time required to set up an assembly line is much shorter than that for an OEM. It may take three to five years after the final product is developed to design, build and put into action a medium size truck assembly plant. A typical truck assembly plant produces over one hundred vehicles per day and requires many production workers.

Truck remanufacturers have some definite advantages over the OEm whin it comes to project overhead and implementation lead time. The time required to go from prototype vehicle design to producting the first unit can be less than two years. Shop layout is not as complicated as the OEM's assembly line. In the latter case all vehicles follow the same path so equipment locations and relationship to the assembly line must be studied ery carefully, the remanufacturer uses a flexible layout where equipment can be moved around easily to accomodate changes in production requirements. Truck remanufacturing operations are much smaller than those of the OEM so should be easier to manage effectively.

The next step in this study would be to estimate the production cost for the prototype vehicles listed in Tables 8-3 to 8-5. If the estimates are favorable a prototype shop is set up to evaluate each of the processes required in this project and refine the prototype's design.

Chapter Nine: Conclusions

Remanufacturing has proved to be a useful process for the fabrication of durable products. Remanufacturing processes consume much less materials and energy than is contained in the final product; this is made possible by the recovery of residual value added in product cores. The technology used by remanufacturers can be analyzed to develop a systematic evaluation procedure for establishing the best remanufacturing process for any of a wide variety of products. The analysis procedure in this thesis was developed for products made from of conventional machine elements (gears, bearings, shafts, castings, motors, valves, actuators) which are used in industrial and commercial applications. The systematic product analysis involves determining:

- Operating systems in the product
- Components in each system
  - component compatibility with remanufactured product
  - selection of components for local remanufacture
  - engineering improvements
- Parts in each component
  - types of parts (list and distribution)
  - damage and failure modes in each part
  - percentage of parts in each condition
  - possible improvements to part
- Part condition codes for process analysis

After analyzing the product, its components and parts, remanufacturing processes can be systematically selected for the product. Each refurbishing task can be accomplished with different processes which have alternatives designed for specific applications. Starting with a wide choice of alternative processes, a series of screens is used to identify those processes which can most efficiently refurbish the parts of a given product to "like new" conditions.

9.1 Applications of Analysis Procedure

An accurate product and process analysis will help a remanufacturer maximize profits and produce high quality products. The data used for the analysis is stored in process applications files designed for flexibility, easy storage, and retrieval.

To make these PA files realistic and useful, information is collected regarding:

Product:

- o prices and markets
- o design and construction trends
- o new component features

Processes:

- o equipment
- o tools
- o materials
- o supplies
- o sequence of operations
- o new developments

Other Production Data:

- o layout options
- o flow of work through plant
- o costs for each refurbishing process
- o operating costs for facility

9.2 Conclusions and Directions for Further Research

This systematic analysis procedure is simple enough that the software for correlating part condition codes to processes can be operated on a small computer. The data base necessary to make an effective model can be prepared from actual production statistics or estimated from manufacturing process handbooks. The next step after completing this thesis will be to develop a computer model that can generate process work sheets and bills of materials for the remanufacture of products similar to those listed in Exhibit 1-1.

To make this model useful additional work must be done on several of the topics covered in this thesis, including:

Part condition codes: establish criteria of degree of damage for each of the failure/damage mechanisms within each condition group.

Part condition codes: design a general purpose alphanumeric code for the description of failure and damage geometry.

Condition codes: can be used to select refurbishing processes after a data base of part types, conditions, and the effectiveness of different refurbishing processes is established.

Process Application Files: should be designed specifically for the requirements of each remanufacturer. The example discussed in this thesis illustrates a way to develop process applications charts for truck remanufacturing.

Refurbishing process hardware: current industrial practices need to be defined and carefully evaluated for every product to be remanufactured.

Methods of inspection: are available for the evaluation of different materials and part types. Standards should be set for the classification of part and component conditions.

Statistical analysis: of the condition of different part types should be carried out after sufficient products have been analyzed. This data can be used to determine the demand for the refurbishing processes used by the remanufacturer.

Finally, remanufacturers should cooperate with OEMs to find ways to develop remanufacturing while protecting the new product market. They should emphasize that remanufacturability helps maintain product loyalty by providing the user with a long-lasting, easily serviced product which can be upgraded when product improvements are introduced.

Research on the various economic impacts of remanufacturing should be studied from a social policy standpoint, Examples include:

- o Exports
- o Reduction of inflation by lowering average product purchase price
- o Creation of entry-level jobs

The ultimate objective is to develop an integrated design for products which will allow the product life to be extended over the technological life of the product design.

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