The Conversion of an Otto
Cycle into an Atkinson Cycle

By

Ferdinand F. Ferrary

Submitted in Partial Fulfillment of the Requirements for the Bachelor of Science Degree in Mechanical Engineering

from the

Massachusetts Institute of Technology

1937

Signature redacted

Acceptance:

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Instructor in Charge of Thesis,.....

May 19, 1937

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May 19, 1937

Brooklyn, N. Y.
May 19, 1937

Professor George W. Swett
Secretary of the Faculty
Mass. Institute of Technology
Cambridge, Mass.

Dear Sir:

I herewith submit a thesis entitled "The Conversion of an Otto Cycle into an Atkinson Cycle" in partial fulfillment of the requirements for a degree of Bachelor of Science in Mechanical Engineering.

Very respectfully,

Signature redacted

Ferdinand F. Ferrary

ACKNOWLEDGNENT

The author wishes to express his appreciation of the helpful suggestions and assistance rendered during the course of this investigation by Professor C.Svenson of the Mechanical Engineering Department and by the members of the Machine Tool and the Automotive Laboratories.

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I

Sometime ago I became interested in the Atkinson cycle as a means of securing greater economy in a gasoline engine. By economy I mean, of course, the lowest fuel consumption per brake horsepower output. In order to understand fully the principles upon which this cycle operates a short survey of the theory behind internal combustion engines will be made.

The earliest attempts to obtain motive power from heat was made by igniting inflammable powder and utilizing the force of the explosion. As a source of energy this preceded the steam engine. A cannon is one of the oldest types of heat motors. The expansion resulting from the burnt powder supplies the motive force to propel the ball. In modern heat engines a cylinder takes the place of the cannon and the piston, the ball. It was found, however, that it was difficult to secure continuous expansion and to control the violence of the explosion. For these reasons the idea was abandoned in favor of steam engines.

The first to propose the use of explosive powder was Abbe Hautefeuille. In 1678 he proposed the construction of a heat motor to raise water. The powder was burnt in a vessel attached to a reservoir of water. As the gases cooled after combustion, a partial vacuum was formed and the atmospheric pressure raised the water from the reservoir. Soon afterwards, in 1680, Huyghens constructed an engine employing a piston and cylinder. The powder in this motor was ignited in a little receptacle in the bottom of a cylinder. The latter was immediately filled with flame and drove all the air out of the cylinder. The atmospheric pressure drove the piston down in the vacuum thus formed. This

engine was found impractical. It was impossible to remove more than four-fifths of the air.

For about one hundred years the study of steam and its application to power held the stage, then in 1794 Robert Street took out a patent for a engine using inflammable gas produced from spirits of turpentine or petroleum. The gas was obtained by sprinkling the turpentine on the bottom of a cylinder and evaporating it by a fire beneath. The up stroke of a piston admitted some air which mixed with the inflammable vapor. This mixture was ignited by a flame drawn through a port uncovered by the piston. The explosion drove the piston up and its energy was utilized. Although the engine foreshadowed many modern ideas it was very crudely made. The next significant step was made by Barrett in 1838 who proposed compressing the charge and igniting it at the dead point. Barrett, however, did not recognize the merit of his ideas, besides, he did not make sufficient provision for removing the burnt gases. Incomplete expansion was also a fault of his engine.

The next great improvement was made by Lenoir in 1860. The action of the engine is as follows: The exhaust valves are closed and the piston is at the end of the stroke. The air port is already slightly open and the valve admitting gas begins to open as the piston moves down. About half way down the cylinder all valves close and the air gas charge is ignited by means of an electric sperk by a method similar to that used in automobiles today. The explosion drives the piston to the end of the cylinder. At this point the exhaust valves open. The momentum of the flywheel carries the cylinder back to its starting point and meanwhile expels

most of the burnt gases. Lenoir's engine was very successful and a number of them were built, although false claims made for it almost ruined Lenoir. The defect of the Lenoir engine was the large consumption of gas to the work done.

In 1862 a very remarkable discription upon the subject appeared by Beau de Rochas. He was the first to understand and appreciate the theory of the cycle of operations which should be carried out in a gas engine to utilize more completely the heat supplied. His cycle was as follows:

1. Drawing in of charge of gas and air
2. Compression of this mixture
3. Ignition at the dead point, with subsequent explosion and expansion.
4. Discharge of the products of bombustion from the cylinder.

Beau de Rochas also laid down some principles which he believed were essential to economy.

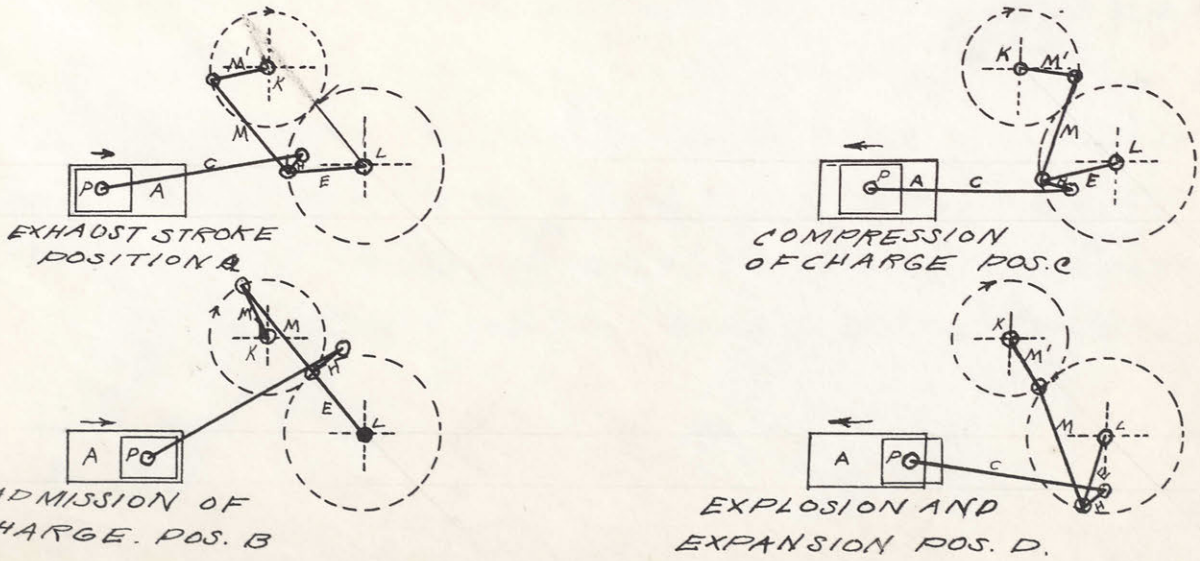
1. The largest cylindrical volume with the smallest circumferential surface.
2. Maximum piston speed.
3. Greatest possible expansion
4. Highest pressure at beginning of expansion

Numerous attempts were made by engineers to follow the principles set forth by Beau de Rochas, then in 1876, the celebrated German engineer Otto brought his engine to its modern form. He is accredited with being the inventor of the modern internal combustion

gasoline engine. Since everyone is familiar with its working cycle it is not necessary to go into a detailed explanation if it. He built his engine to follow out Beau de Rochas ' theory in every respect, although, it is said, he didn't fully comprehend the underlying reasons.

The Otto engine is a four cycle engine, utilizing a separate stroke for intake and exhaust. The compression stroke and expansion stroke of this engine are entirely unrelated except that mechanical construction make them the same length. This fact set many engineers to thinking. Experiments had proved that only about one-fifth of the heat given to the best Otto engine was utilized as power. Defective expansion was one of the chief causes of this loss of power. It was recognized that the only way to utilize this lost expansion was to increase the ratio of the expansion stroke to the compression stroke. This problem was very ingeniously solved by Atkinson.

The kinematics involved in Atkinson's engine are difficult to explain but they have the effect of making the expansion stroke about twice as long as the compression stroke. He performed this by several methods, but his best is his cycle engine of which a diagram is shown:

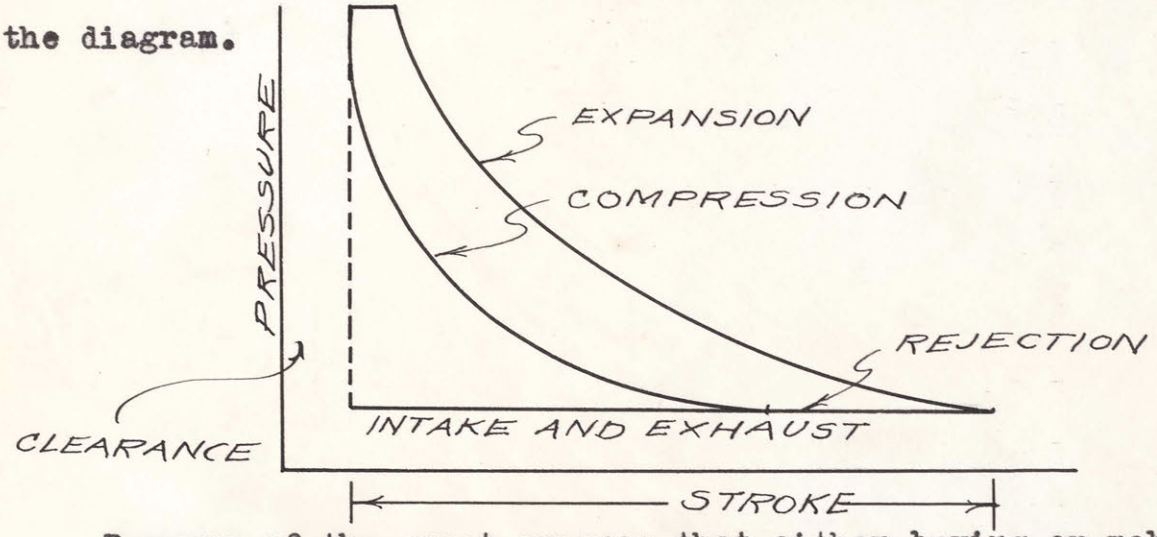


This engine looked very much like the usual cycle Otto engine. The drawing shown on the preceding page gives a very good idea how this engine works. It was found that the engine was slightly more economical than the straight Otto cycle, but the mechanical complications involved soon caused it to be abandoned.

A is the cylinder and P the piston as before. c is the connection rod to the small vibrating link H, which, through E, is joined to the fixed point L. M is the lever connecting through the crank M_1 to the crank shaft K. Position (a) shows the end of the exhaust stroke, when the piston is at the inner dead point. The piston moves out, drawing in the charge, and the lever M rises, carrying the link H with it. At (b) the crank has performed nearly a quarter of a revolution, and H and M are in their highest positions. The momentum carries M and M_1 round, forcing down H (position c) and the piston moves in, compressing the charge, but not to the point from whence it started. The clearance space left at the end of the cylinder is slightly larger than before, and the charge is driven into it, at a pressure of about forty-five pounds. The proportion of compression to admission is as four to five. At the end of this stroke, When the crank has performed another quarter revolution, and ignition follows. The piston is driven out to the extreme limit of the cylinder M and H are both in their lowest positions (d), and the crank has completed three-quarters of a revolution. The exhaust stroke following is longer than the expansion, since the piston moves in to the extreme end of the clearance space. M and H are raised, the crank completes its revolution, the products of combustion are thoroughly discharged, and the cylinder ready for the next admission stroke.

II

In my engine I propose to secure the same differential expansion without introducing these mechanical complications. The connecting rod and crank will remain exactly the same as in any ordinary Otto cycle. The method of securing this irregular expression was suggested to me by Professor Svenson and it operates as follows: The mixture of gasoline vapor and air is drawn in on the admission stroke. As the piston reverses its direction, the charge, instead of being compressed, as it would in the Otto engine, is rejected to the intake manifold for about one quarter of the stroke. At this point all the valves close and compression begins. At the dead point the charge is ignited and expansion occurs for a full stroke. The gases are then expelled in the usual way. A pressure-volume representation of this cycle is shown in the diagram.



Because of the great expense that either buying or making a special engine would involve, I selected the engine of a 1929 Chevrolet auto to convert into an Atkinson cycle. This engine was selected primarily because it had overhead valves.

As was explained before, to convert an Otto, such as an ordinary automobile cycle, into an Atkinson cycle it is necessary only to arrange the admission valves so that part of the charge is rejected to the intake manifold on the compression stroke. I accomplished this by building an overhead camshaft on this engine to work in conjunction with the motor camshaft. The auxilary camshaft has its follower ride on the intake rockers, which are operated by the engine camshaft. When the regular camshaft begins to release the intake valve, as the engine approaches the dead point, the auxilary camshaft begins to keep open this valve until the engine is about one-quarter along its compression stroke, then it releases it and compression takes place. All six cylinders are operated in this manner.

III

As was mentioned before, the engine of a 1929 Chevrolet was used for the conversion. Due to hard usage the engine was found to be greatly in need of repairs before it would make a satisfactory engine. All the bearings were rebabbited, the cylinders were rebored, new pistons and rings were inserted, the gaskets were changed, the spark-plugs, wires, and distributor cap were renewed, and the old carburator replaced by another one. The engine finally mounted upon a carriage to facilitate working.

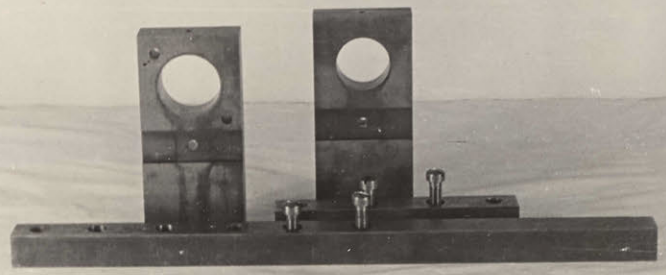
In order to secure the requisite valve motion it was necessary to build an overhead camshaft to work in conjunction with the engine camshaft. It was constructed as follows. Instead of making a new camshaft, it was found that one from a similar Chevrolet would do as well. To make the bearings for this camshaft two blocks of cast iron were used, planed down to size. The exact dimensions of the apparatus are not important since they were determined by the sizes of engine parts. A hole was drilled through each block to fit the auxiliary camshaft bearings. These blocks were then fastened to one inch square bars which were drilled to accommodate the head bolts of the engine. After these were bolted in place on the engine head, it was necessary to make a guide for the camshaft followers. For this purpose a one inch square steel bar was used. The bar was cut slightly longer than the space between the bearings. The bearing blocks were then recessed and the bar fastened to them. The cam follower holes were then correctly spaced off on the bar and holes drilled to fit the followers.

The cam followers were made of tool steel and hardened. The barrel was drilled and threaded for an adjusting screw and lock nut. A hole under the head was drilled for inserting a small bar to keep the barrel from turning while the screw is being adjusted. The followers were fitted into the guide holes.

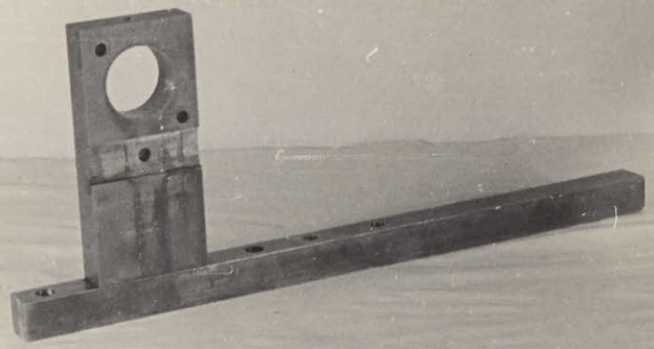
The auxiliary camshaft was rotated by the engine camshaft itself by means of gears, sprockets, and a chain. The engine camshaft gear drives a cast iron gear. This gear drives another cast iron gear which is meshed with the overhead camshaft gear by means of chain and sprocket. It was necessary to make both gears because they were not standard parts. Both gears were force-fitted into their shafts. The cast iron bushings in which these gears run ~~was~~ were also force-fitted into their brackets. The upper bracket, similar in form to the camshaft bearings, was fastened to the one inch square bar upon which the camshaft bearings had already been fastened, care being taken that the gear had very little backlash. The triangular bracket of the lower gear was similarly fitted except it was fastened to a part of the engine itself. The sprockets were set-screwed on the gear shafts and the chain passed over them. The bar upon which the camshaft bearings were mounted was fastened to the engine by means of headbolts. Proper tension in the chain was secured by placing large mashers between the bearing mount and the head of the engine. It was necessary to build up flat surfaces on the top of the valve side of the intake rockers so that the auxiliary cam followers would have a satisfactory place to bear against. Oil holes were drilled whereever

necessary . The following photographs show the details of construction.

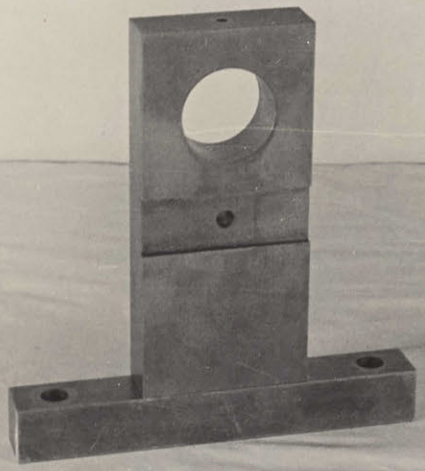
1. Auxiliary camshaft used.



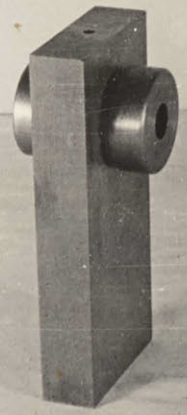
2. End bearings planed down to size and drilled to fit camshaft and bases.



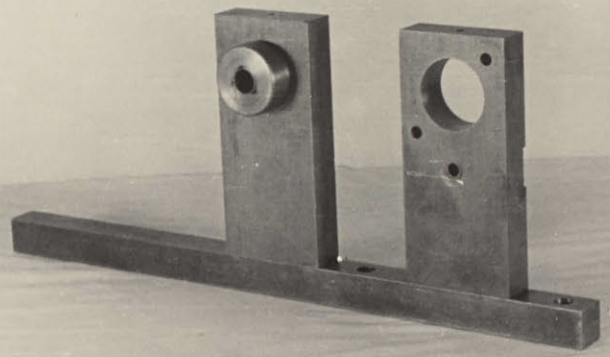
3. Front bearings fastened to base.



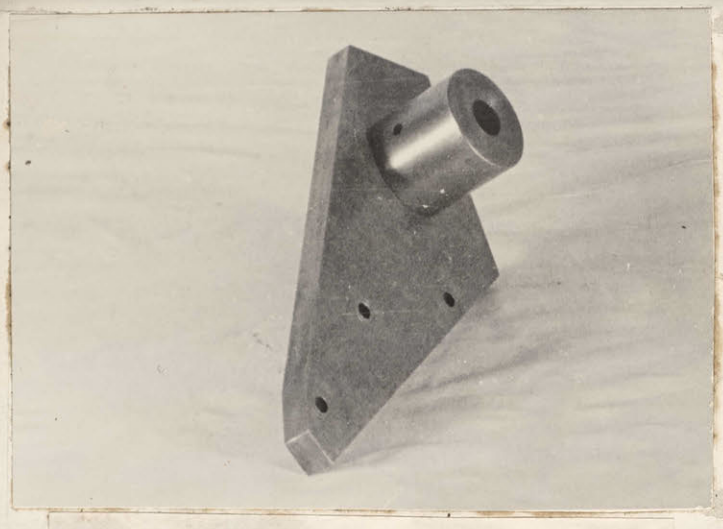
4. Rear bearings fastened to base.



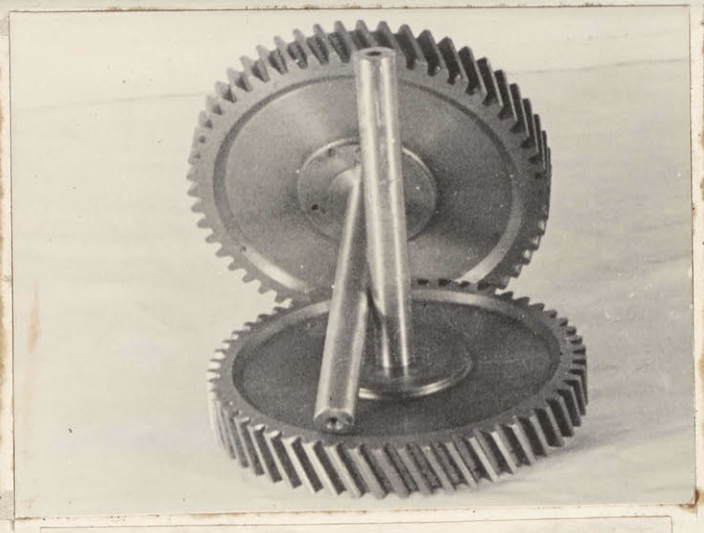
5. Gear bracket and bushing for upper gear.



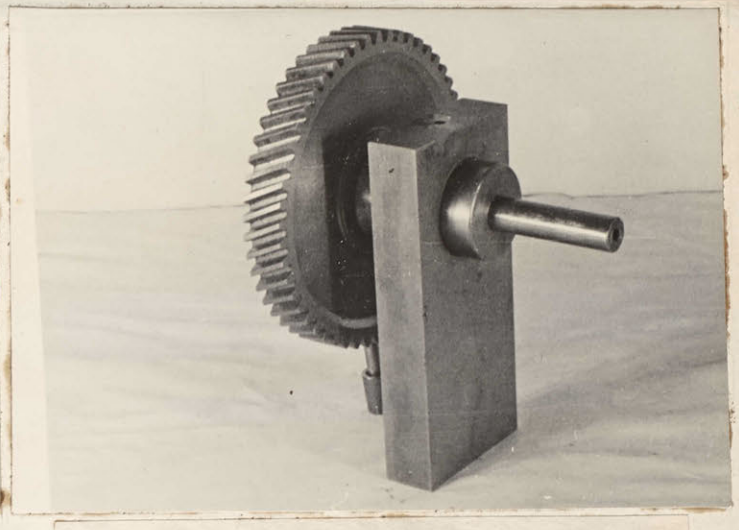
6. Bracket fastened to base.



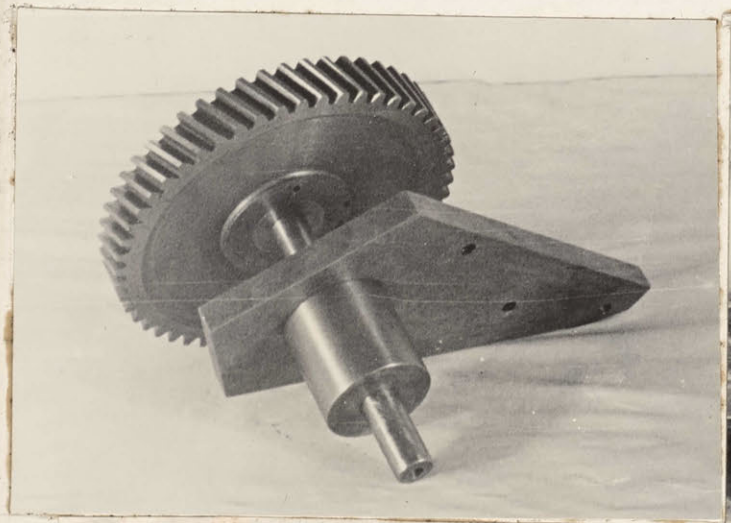
7. Lower gear bracket and bushing.



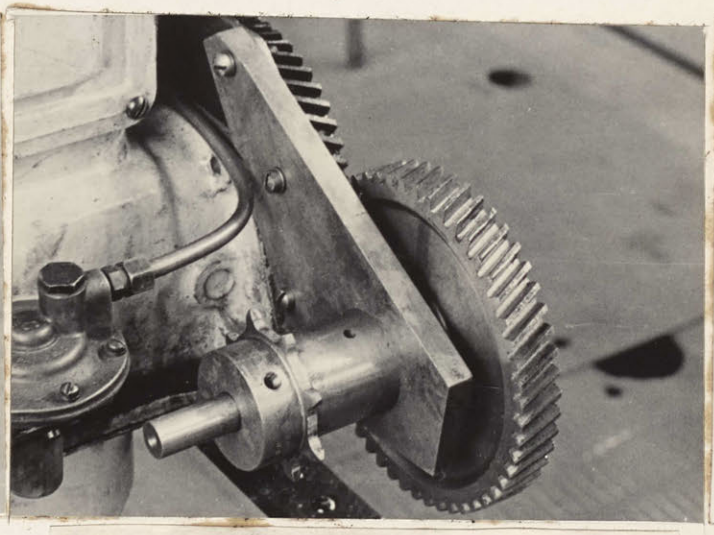
8. Gears used to transmit power to upper camshaft.



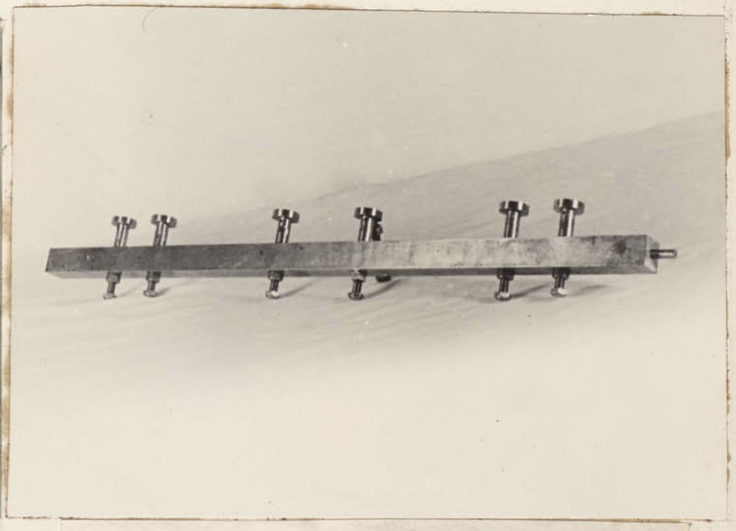
9. Gear inserted in upper bracket.



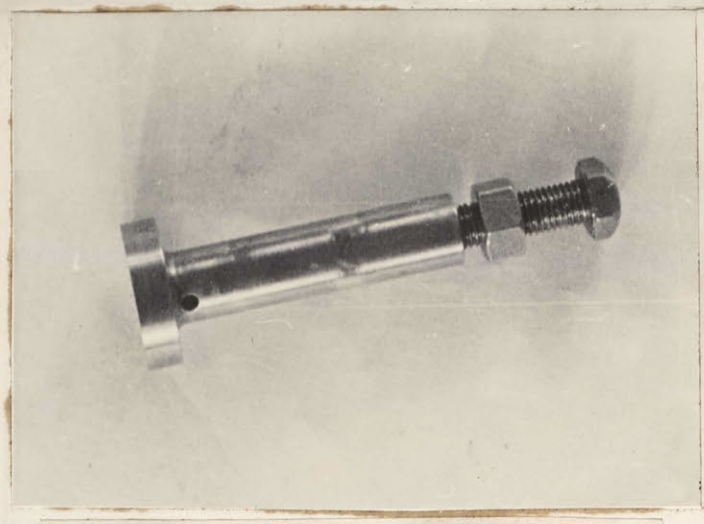
10. Gear inserted in lower bracket.



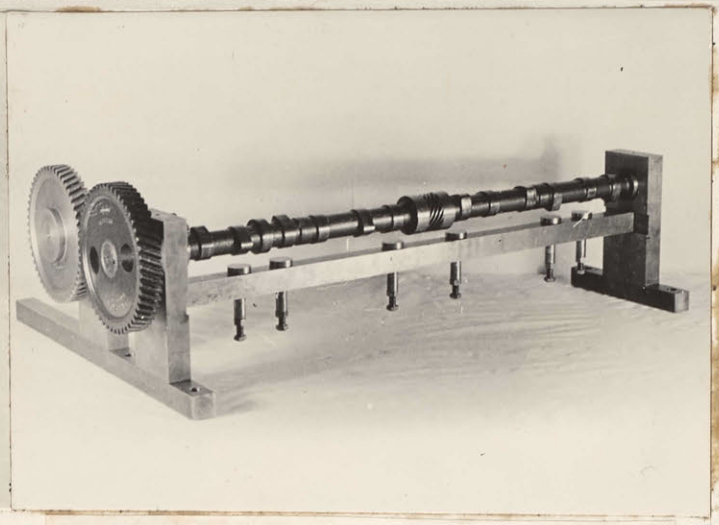
11. Gear bracket fastened to engine.



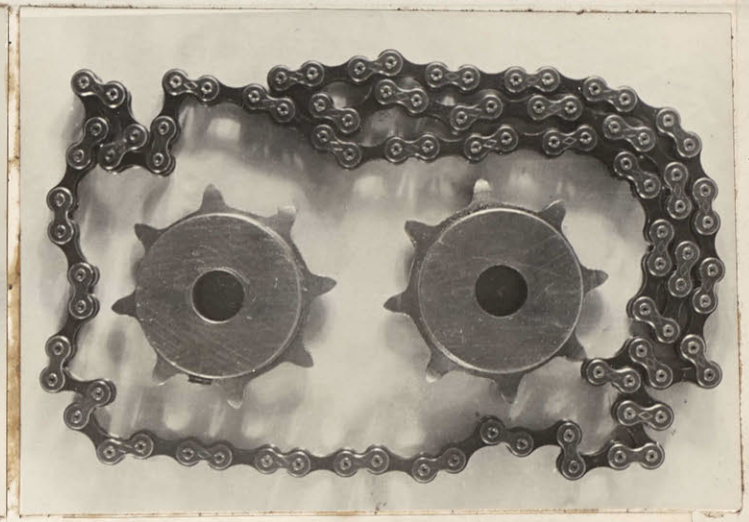
12. Cam followers inserted in guide.



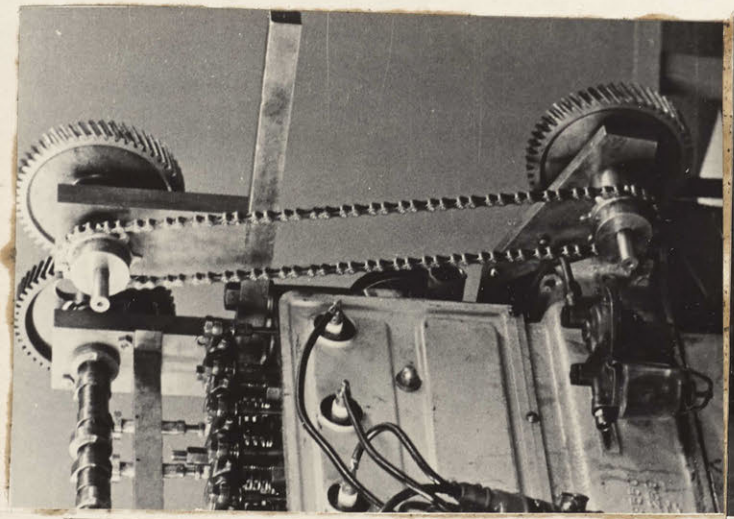
13. Cam follower and adjustment screw.



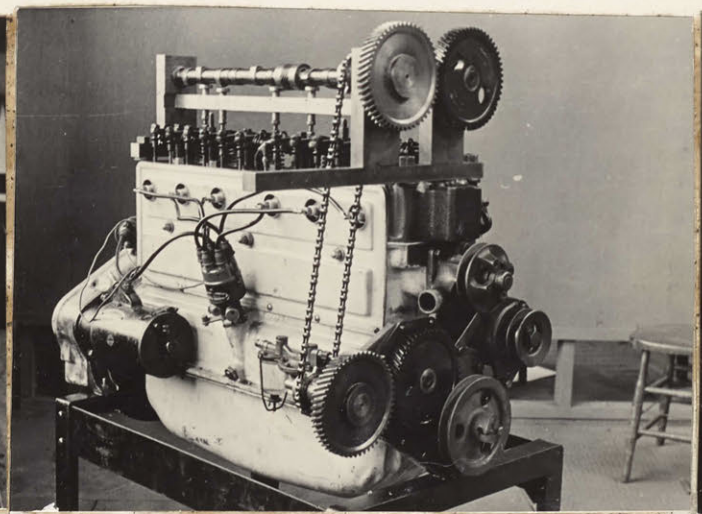
14. Complete assembly of overhead camshaft.



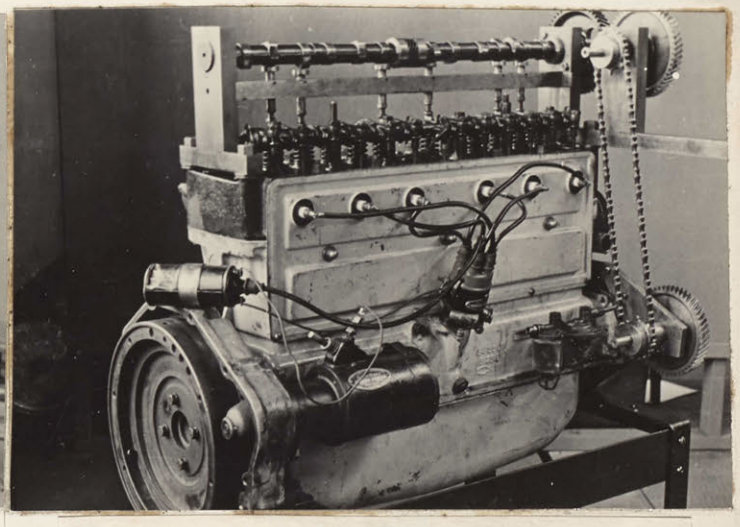
15. Sprockets and chain used to drive upper camshaft.



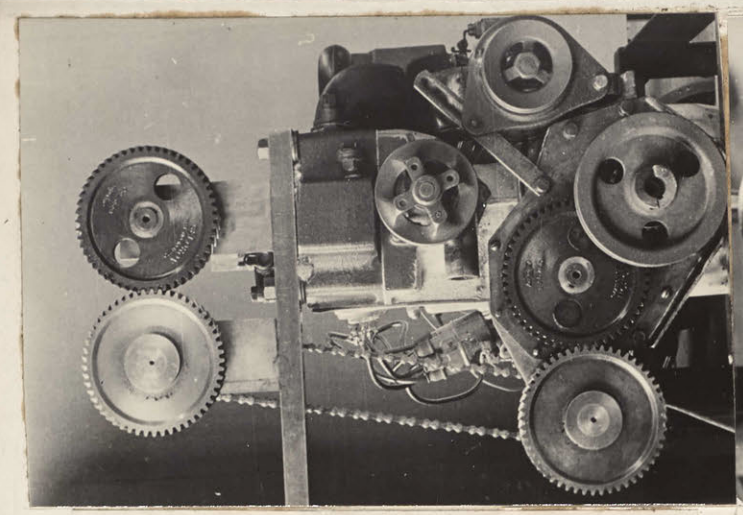
16. Sprockets and chain mounted on engine.



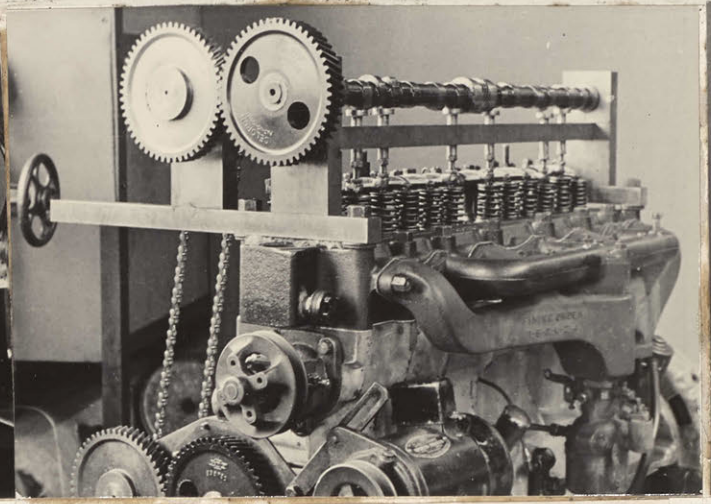
17. Front view of engine showing method of driving upper camshaft.



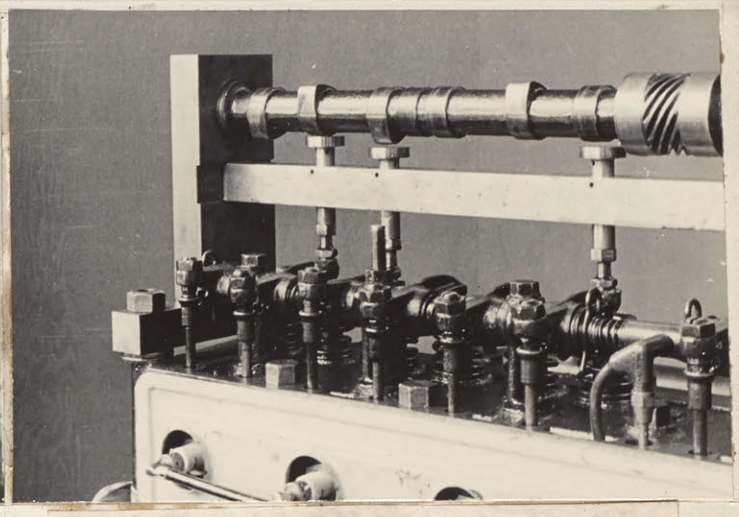
18. Rear view of engine showing upper camshaft mounted on it.



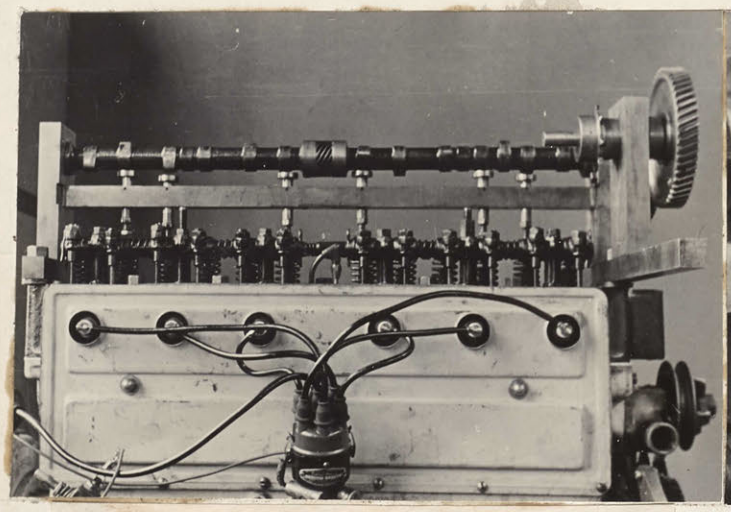
19. Close-up of gear drive.



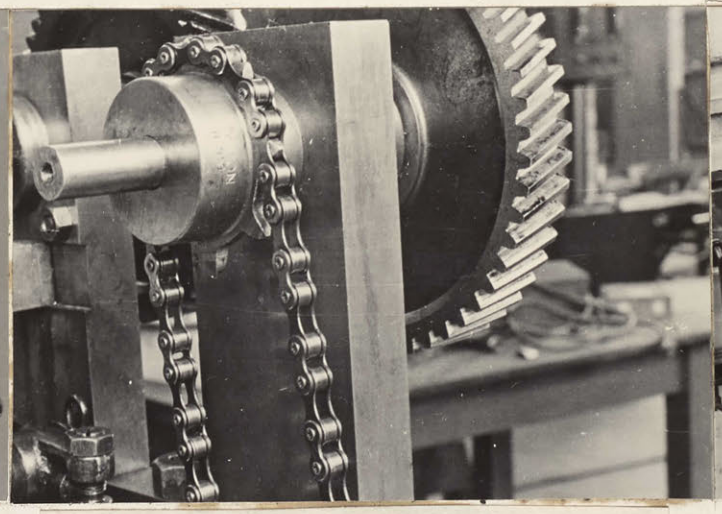
20. Front bracket.



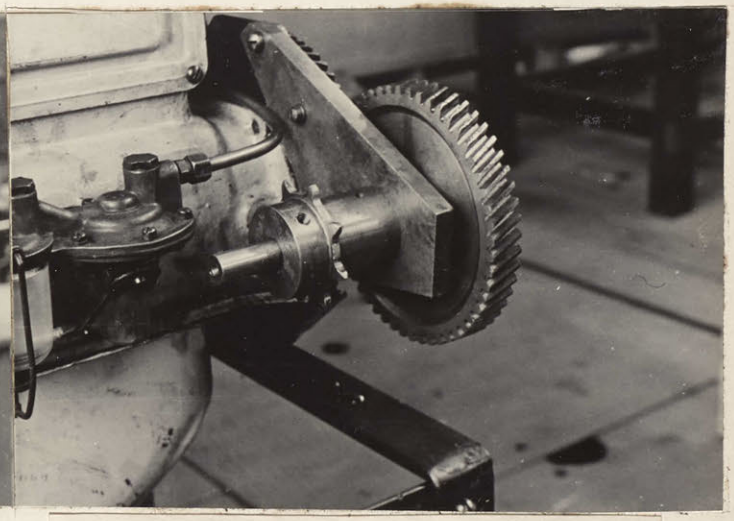
21. Rear bracket and cam followers.



22. Side view of cam followers and guide.



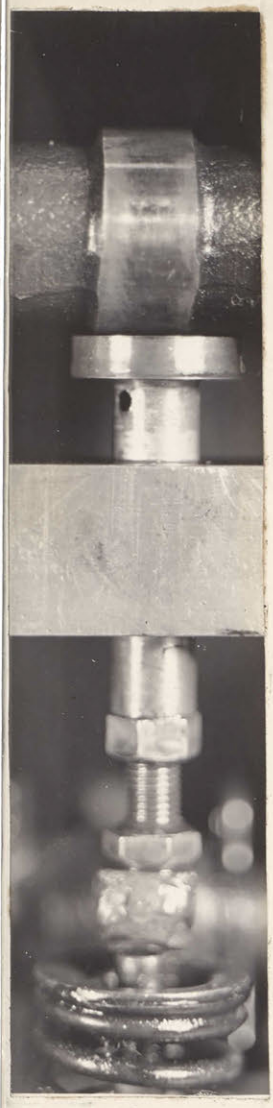
23. Chain fastened to upper gear.



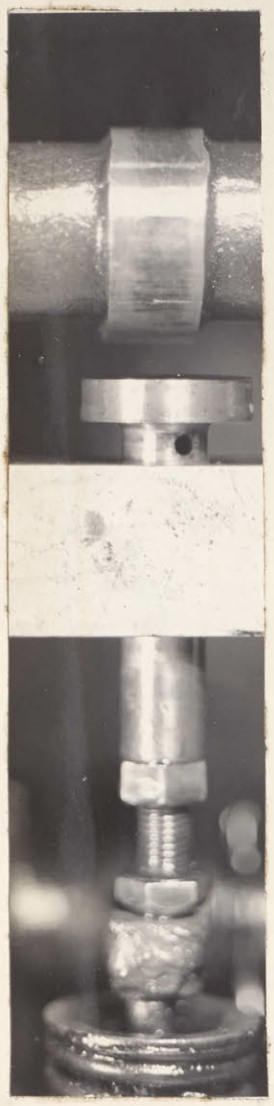
24. Sprocket fastened to lower gear.

IV

It has already been explained that the differential compression stroke is secured, by holding open the intake valves on the compression stroke so that as the piston moves up it rejects some of the charge to the intake manifold. It has also been stated that opening the intake valves in this manner is accomplished by means of an auxiliary camshaft which has its followers ride on the intake rockers. It must be emphasized that the exhaust valves are operated only by the engine camshaft and that the auxiliary camshaft works in conjunction with the engine camshaft in operating the intake valves. The engine could not operate if the engine camshafts were removed but it could if the auxiliary camshaft were not used. The exact operation of the auxiliary camshaft will be explained photographically. Since all the valves operate alike the action of one valve only will be illustrated. At the very top of the picture is the cam which is rotated in a manner already shown. The cam follower has a flat surface on it so that the cam will push it down when it comes in contact with it. The follower moves up and down in its guide which shows as a broad white line in the photograph. The head of the adjustable screw on the follower rides on top of the built up rocker. The other side of the rocker is, of course, operated by the pushrod operated by the engine camshaft. Beneath the pushrod is the intake valve and its spring.



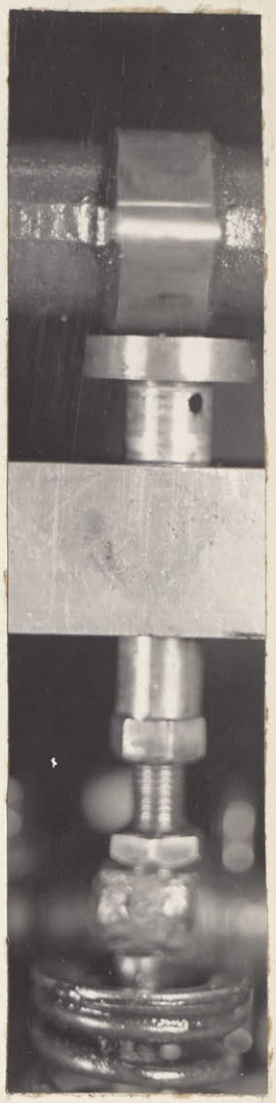
1



2

3

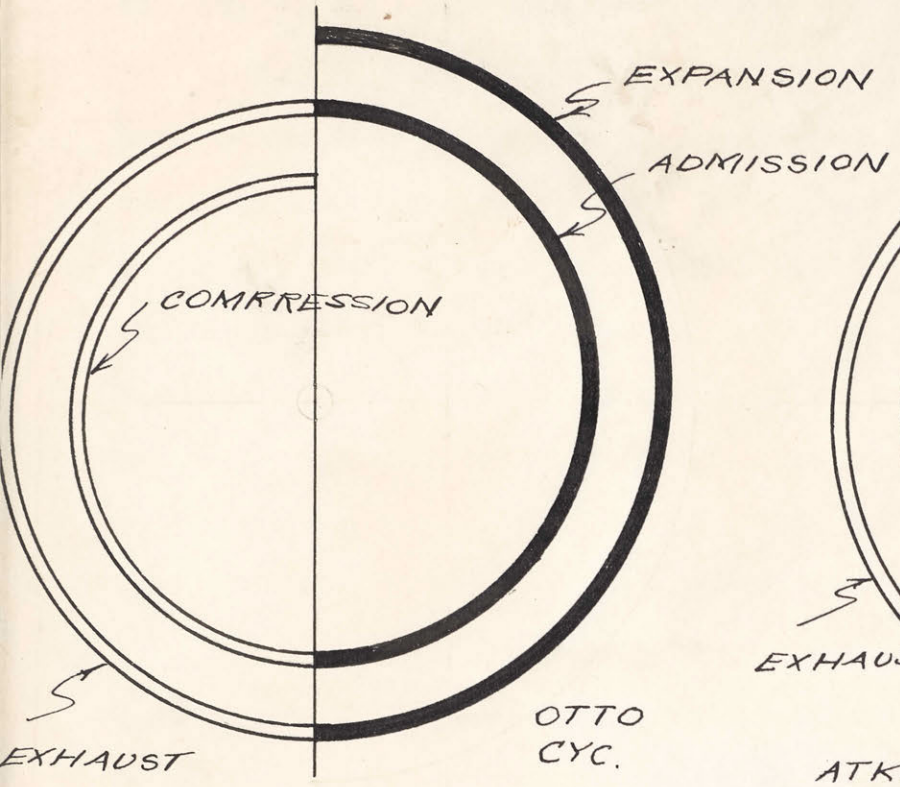
4

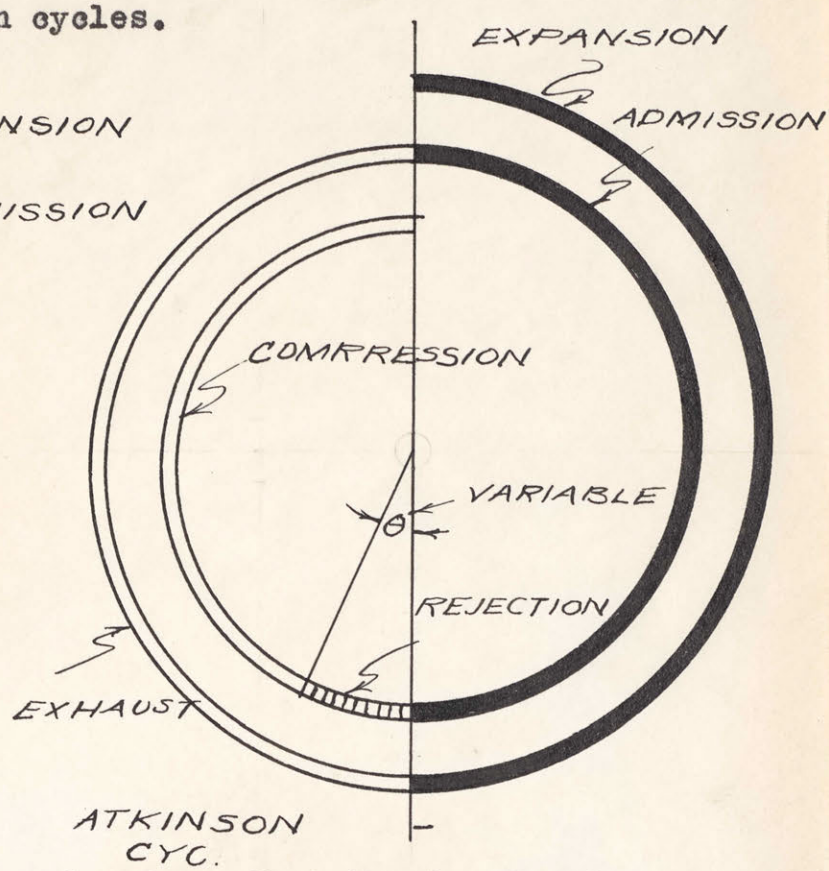


5

1. Intake valve completely closed.
2. Engine camshaft fully opening intake valve.
3. Engine camshaft releasing valve. At same time overhead camshaft moves into position and again opens intake valve.
4. Intake valve almost closed. Piston about one third way down. Cylinder on compression stroke.
5. Intake valve fully closed. Compression begins at this point.

The other operations in the engine take place exactly the same as in any Otto cycle. The following drawings representing one complete cycles in two revolutions show clearly the difference between the Otto and the Atkinson cycles.





The diagram for the Atkinson cycle shows that the length of the compression stroke can be adjusted to any amount. This is, of course, regulated by the amount of rejection. Loosening the set screw in the upper strocket permits the auxiliary ccanshaft to be set to keep open the valves for any amount of piston movement on the compression stroke. It is possible to go from no rejection at all i.e. Otto Cycle to complete rejection in which case the engine would not go for lack of fuel.

V

It would seem at first sight that it would have been much simpler if the conversion had been done on a small one cylinder engine having overhead valves instead of a large six cylinder automobile engine. However, there was a very definite reason why the latter was chosen despite the greater work involved. It has been shown that during rejection, part of the charge taken in by the cylinder was rejected to the intake manifold. In the case of a one cylinder engine this would build up pressure in the manifold and on the carburetor probably ruining the latter. Such pressure cannot develope in the manifold of a six cylinder engine because there is always one cylinder that is drawing in charge. Part of its charge will be taken as the rejection from another cylinder and the rest from the carburetor.

In this engine no provision was made for maintaining the compression ratio constant. The compression ratio depends directly upon the amount of charge rejected by the cylinder. Since the compression ratio is the ratio of the cylinder volume at the end of compression to that at the beginning of compression and since the volume at end is constant we see that if possible for the ratio to diminish down to zero. This loss of compression will decrease the power of the engine. For actual comparison tests between the Otto and the Atkinson cycle provision should be made to maintain a constant ratio of compression in the latter. The only method of doing this is by providing a variable clearance space.

A short run was performed on the engine when it was completed

The engine was set so that one-third of the charge of the cylinder was rejected. The results were fairly satisfactory. Lack of shielding on the chain and gear made it dangerous to go near them. It was also necessary to oil everything by hand because no provision for it was made. If any extensive tests were to be performed it would be necessary to shield and oil the entire unit including the chain and the lower gears. It is likely to require extensive redesign.

The claims made for the Atkinson engine were that it would be more economical, producing power at lower cost, although the engine would weigh more than any other Otto engine of equal horsepower. It is probable that Atkinson was disappointed by the performance of his engine. This is understandable when we consider that the mechanism to produce the differential stroke consumed sufficient power to offset the economy. The method employed in this thesis does not require heavy links and shaft, but is light and does not consume much more power than the engine camshaft itself. It is likely that greater economy may be secured.

Bibliography

Gas, Oil, and Air Engines Bryan Donkin