# THE DESIGN OF LUMBER PRODUCING MACHINERY

by

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Chairman, Departmental Committee
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The Design of Lumber Producing Machinery
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Submitted to the Department of Mechanical Engineering
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Opportunities for the use of new methods or machines or the improved design of existing machines for the conversion of logs to lumber were studied. The object of the work was to devise machines which would in some way be better by being either more productive, more useful, more salable, or cheaper than the machines in use.

The principal result of the work is the proposal of a mechanical system of lumber grading. Grading is done in order to make maximum utilization of lumber. Reliable grading allows structures to be built using optimally-sized lumber since large "unsurity" safety factors are made unnecessary. The strength of lumber is affected mainly by the size and location of knots and splits and by the slope of the grain. These quantities have been related to the strength ratio (the ratio of the strength of the imperfect piece being graded to the strength of a clear specimen of the same wood) in research at the Forest Products Laboratory, and it is this information which makes mechanical grading possible.

The proposed machine uses the output of photoelectric cells to identify knots. The slope of grain and check size are manually determined.

The measurements which are necessary vary between types of boards according to their use; systems of relays provide the correct information signals to the computing part of the machine. The signals are voltages and are varied for defect position corrections with sets of appropriately valued conductances.

The machine uses analog methods for the necessary computations, but many digital decisions are also made.

Electronic elements have been held to a minimum because of the rugged conditions prevailing in sawmills. In addition to the sensing elements, the machine mainly consists of relays, resistors, and the lumber handling apparatus.

As it is proposed, the machine would operate at lumber capacities of one linear foot per second, which would be enough to handle the output of the largest mills. Approximately four men would be required for the same job. Parts for the device have a total cost in the neighborhood of $7000.

The three important potentialities of the machine are that more reliable grading would be possible, more uniformity in grading between mills could be expected, and financial savings would be significant.

A simple device for the continuous sharpening of saw blades was also proposed, but an empirical design method seemed necessary, so the idea was not further developed.

The study of wood, lumber, and sawmilling which led to the proposed design is presented in the latter part of the report.

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# TABLE OF CONTENTS

## LIST OF FIGURES

## INTRODUCTION

The machine for lumber grading which is described in the next three sections of this report is a result of a very general study of the problems associated with the conversion of logs to lumber. The work which led to this result is included in the appendix, and that section forms the actual "Introduction" to the work.

## ACKNOWLEDGEMENT

There are two ways to find the obscure little lake where the fish bite and fight the best. One is to have been there before, the other is to stumble along and arrive by chance. My path has been of many stumbles and wrong turns--but one who has made the trip often offered the necessary encouragement and helpful direction and knew that I would remember the route only after all the stumbling. And now we both wonder if where I cast is actually the place. For the help and especially for the constant wondering, I wish to thank my guide, Professor John Arnold.

## LUMBER GRADING

The defects in wood reduce the usefulness of different pieces of lumber by varying amounts. A reliable measure of the usefulness of a piece of lumber, according to its defects, has been determined through research at the Forest Products Laboratory. The results of this research have been presented in such an orderly, mathematical fashion that the mechanical grading of lumber can be envisioned. A machine to accomplish that task is developed on the following pages.

The actual grading of lumber depends on more factors than the strength properties alone; however, the strength properties form the basis of all grading systems and are by far the most important considerations.

The strength grading system which has been developed is accomplished in the following steps: (1.) Lumber is divided into categories by its cross sectional size according to the kind of use to which it will be put. (2.) The defects, such as knots and splits, are measured by very specific procedures according to the effect the defect will have for the type of stress which occurs at the defect. (3.) The size and position of the defect are used to determine from tables the amount by which the allowable stress is lowered below the value for a clear specimen of the same wood. This quantity is the strength ratio and is defined as the ratio of the allowable stress in the piece being graded to the allowable stress in a clear specimen.

In general, the effects of defects do not accumulate;

the allowable stress is simply a function of the "worst" defect in the board. A thorough description of the grading procedure is necessary for an understanding of the proposed machine since the steps made by the machine must be equivalent to the ones specified in the grading procedures. The tables of research data have been approximated (quite closely, however) with rather simple equations, and the device uses these equations in its grading procedure.

There are three types into which lumber is divided according to use. They are:

1. Joists and planks, which are two to less than five inches thick and are four or more inches wide. These boards are graded for bending stress about either axis.
2. Beams and stringers are five inches or more thick and eight or more wide. The loading on this category is assumed to be bending on the narrow face.
3. Posts and timbers are square pieces with sides of five inches or more. Posts and timbers are loaded mainly in axial compression.

The defects which are considered for structural grading are knots, slope of grain, shakes, checks and splits (which are similar), decay, and density. The last two items are not quantitatively evaluated as are the others. Decay is not permitted in the structural grades; extremely light weight pieces are also prohibited.

The measurement of knots is exactly specified for each type lumber as follows: For joists and planks, knots showing on the narrow face are measured only if they do not appear on the wide face and are measured as the distance between encasing lines along the axial direction of the board. Knots which occur on the corner of the cross section are measured as the minimum of the distances from the corner to the axial encasing lines on either face. Knots occurring on the wide face only are measured as the average of their maximum and minimum diameters.

Knots on beams and stringers are measured as follows: Knots showing on both the narrow face and on the outside one quarter of the wide face are measured as the smallest diameter which shows on the wide face. Knots showing on the narrow face only are measured between axial encasing lines, as for joists and planks. Corner knots are also measured as under joists and planks. Knots occurring on the wide face only are measured as the minimum diameter.

The size of any knot on posts and timbers is the average of its maximum and minimum diameters, except knots on the corners which are measured as for joists and planks.

I have made a translation of the wording of the specifications on knot size as a function of the place of the knot in the beam. In the working specifications, for example, the functions are given as the maximum diameter permitted for knots at the end of the board is twice the value at the center of the board (in a given stress grade.) My set-up of these relations involves translating each knot size to its equivalent at the center of the beam. In the example the knot size at the end of the board would be multiplied by one-half to determine its equivalent size. This transformation is made in order to facilitate the use of the simplified equations which express the strength ratios as functions of the knot size at the center of the beam.

The equivalent knot sizes are given by the following rules: Measurements of knots which occur in the middle third of the length of a beam are used directly. Outside this region the size of knots on the narrow face and on the outside of the wide face is multiplied by a factor which decreases linearly with the distance from the one-third point, so that sizes at the one-third point are multiplied by unity, and sizes at the end are multiplied by one-half. Sizes of knots along the center line of the wide face of a board are not changed. Knots which occur off the center line are multiplied by the factor of unity at the center and whatever factor is applicable at the edge of the board. This last function is three dimensional and is formed of nearly plane surfaces, trough-shaped in the middle third and tending to a tent shape at the ends. (See Figure 5.)

No adjustment factors are used for posts and timbers since their loading does not vary the stress over the section.

Allowance is made for detrimental groups of knots by giving them equivalent sizes. In joists and planks the sum of the sizes of knots which occur on any face in the middle half of the length when divided by four and one-half is the equivalent knot size. For beams and stringers the sum is divided by four. In posts and timbers the sum of knot sizes in any six inch length when divided by two is the equivalent knot size; also in any six inch length two equal knot sizes must be added instead of considered separately.

Shake, which is a separation of the wood in the plane of the growth rings, is measured in joists and planks and in beams and stringers as the distance between two encasing lines which are parallel to the wide face of the board, measured at the ends only. Only shake in the middle half of the depth of the board is measured. In posts and timbers the measurement of a shake is the maximum of the distances between the pairs of lines encasing the shake and parallel to the four faces.

A check is similar to a shake, but it is perpendicular to the growth rings and extends into the length of the beam. The measurement is taken as the width (as measured for shake), multiplied by the length and divided by three times the depth of the board. Check lengths are measured only to three times the width of the board from the end. When checks are nearly opposite on parallel faces the sum of their sizes is taken. Splits are measured in the same manner.

The measurement of slope of grain must be made over a length sufficient to determine the average value. In joists and planks and beams and stringers the slope of grain is considered only in the middle half of the length.

Pitch pockets are not considered defects in structural grades; and the effect of wane, the lack of material at one corner or the occurrence of bark, is negligible. It has been shown that heartwood and sapwood have the same strengths; this condition need be considered only if preservative treatment is necessary.

The conversion of all this information--board type, defect type, knot size and location--to strength ratios is the next step in grading. This is done at the present time with tables which give the ratios as functions of the different parameters, and it is the mathematical structure of these tables which makes mechanical grading seem like a straightforward operation. In general, the strength ratio tables may be transformed into linear functions with slopes determined by board widths (however, in a nonlinear but nearly hyperbolic relationship). The equation which determines grade is then:

$G = 100 - MK$ where $G$ is the grade
$M$ is the slope of line
$K$ is the equivalent knot size

M is determined by an equation of this form,

$M = \frac{c + bw}{w - a}$ where $M$ is the slope
$w$ is the board width

a, b, and c are constants determined by the type of board and face and type of measurement.

In order to relate these equations to the original measurements, I will give the equations for equivalent knot size.

On joists and planks and beams and stringers

$$k = \left[1 + \frac{1.66}{F}\,\frac{2Y}{w}\right]K$$

where $k$ = equivalent knot size (for knots on wide face)
$Y$ = distance from center line of board to center of knot
$w$ = board width
$1.66$ = a factor determined by the ratio of size at the center for the same grade, which is approximately 0.6.
$F$ = a function of board length that varies linearly from 1/2 to 1 in first third of the length, remains at 1 in the middle third, and returns to 1/2.

$$s = SF$$

where $s$ = knot size on narrow face
$S$ = measured knot size
$F$ = same as above

There is no correction applied to the knot sizes in posts and timbers.

The effect of shakes and checks on the horizontal shear strength of joists and planks and beams and shakes is given by:

$$G = 100\left(1 - \frac{d}{w}\right)$$

where $G$ is the grade
$d$ is the check or shake size
$w$ is the board width

The effect of slope of grain on the strength ratio for extreme fibre in bending is:

$$G = 100\left(1 - \frac{n}{13}\right)$$

where $G$ = grade
$n = \frac{20\,g - 1}{2g}$

where $g$ = slope of grain

The effect of slope of grain on compression parallel to the grain is given by:

$$G = 100\left(1 - \frac{p}{13}\right) \quad \text{where } p = \frac{15g - 1}{2g}$$

The complete operation of grading has now been stated in mathematical terms; translation of the mathematics and the measurement requirements into machinery follows.

## DETAILS OF THE MECHANICAL GRADER

The critical elements of a mechanical grader will be the sensing devices. Devices capable of identifying three quantities are necessary. The quantities are:

1. Knots, which differ from their surroundings by
    - a. Color.
    - b. Reflectivity.
    - c. Hardness.
    - d. Direction of grain.
    - e. Density.
    - f. Chemical structure (often).
    - g. All physical quantities affected by above.
2. Checks, shakes, and splits, which are defined by the lack of material in an otherwise solid body. There are so many differences between a void and solid that a listing seems unneccessary and a formidable task.
3. Direction of grain, which is determined by the average orientation of the tracheids. (Man normally observes this quantity by the difference in color of spring and summer wood, which form in the grain direction.) There is the least differentiation between this quantity and the surrounds of any of the quantities to be measured.

The most obvious characteristic of a knot in a board is its differing color; this is the quantity which man normally uses to identify knots. A similar sensory ability is available in mechanical elements in the form of photoelectric cells. The strong light-difference signals which can be produced from knotty lumber make the use of such cells seem to be the most direct and reliable means of mechanical knot identification.

The four types of photocell available are barrier layer cells, photoemissive vacuum tubes, photomultipliers, and thermopiles. Of these, the barrier layer cell is the simplest in physical structure, and therefore is the sturdiest. Each type has rather low values of energy output, and each is sensitive to fatigue from high level exposure. In order to use the output of these cells, an amplification is necessary. This can be accomplished with an amplifier or a relay. The combination of cell and amplifier which is the simplest and probably most reliable is the barrier layer cell with a sensitive, balancing-type relay. The suggested type of relay operates effectively on the photocell output; furthermore, it is mechanically quite sturdy. The general construction of the relay is similar to a motor; there is a permanent magnet field and a rotating armature. The armature of the very sensitive relays is pivoted in needle bearings. In operation the relays are given two signals and swing to the direction of the maximum.

For use in the lumber grader a threshold value of voltage will be applied to one side of the relay, and the photocell output will be compared with this value. Adjustment of the threshold value will probably be different for each cell because of manufacturing differences. The threshold must be further variable to account for different types of lumber or variations of reflectivity among pieces. These adjustments must be incorporated in the first model of the machine and are indicated in the circuit diagram for the knot-sensing cell, Figure 1. It is hoped that these adjustments could be eliminated from production models when empirical, statistical data on knot and board light reflectivity variations became available. If the variation between boards is found to be high, the adjustment of the threshold source value might have to be controlled by another cell giving a signal proportional to the average reflectivity of the board.

The sensing of splits in wood cannot be done easily with light metering because of the small area of the split. The discontinuity of the surface seems to offer the best possibility for sensing. Several systems were considered, among which were measuring the flow of air under pressure on the wood surface, the local density of the material, the motion of a feeler gauge, and the conductivity of the surface when wetted with salt solution.

None of these were felt to be completely acceptable; the last would work, but an improved method is desired. With this sytem the surface of the board would be sprayed with a salt solution. Pairs of electrodes would then contact the surface. A voltage would be applied across the electrodes, and the resulting current, if any, would be sent through a sensitive relay. When the electrodes span a split, the resistance is infinite, no current flows, and the relay would open. The arrangement of the electrodes is shown in Figure 2, as is the necessary circuitry.

The operation of split measuring might be accomplished while the slope of grain is being measured, which is before the board starts to move past the knot-sensing elements. Since a reasonable amount of time is available here, the electrodes may be "scanned," and a considerable saving made in signal and sensitive relays. The necessary circuitry is very similar to other circuits in the machine, and it is not detailed here. The signal relays would be of the latching type and would be released after the board starts through the machine.

This salt water and electrodes method of check sensing is not attractive; if offers no advantage over manual measurement. The most likely system at the present would use manual split measurement, since it is actually a rather simple operation. Automation of the operation can be considered when a more suitable sensing means is found. Manual check measurement is assumed for the overall design at this time. (See Figures 8 and 9.)

The measurement of slope of grain involves considerable integration since the variation within a board can be considerable and the cues to direction may take widely variant forms. At the present time, no mechanical means of measurement has been devised which would be either simpler, more reliable, or cheaper than manual measurement. Another compromise of automation is suggested at this point, and manual measurement of the slope of the grain is included in the design.

In order to determine the type of board and, therefore, the correct mode of defect measurement, the width and thickness of the board must be determined. These measurements are also necessary to the grading computations. Feeler gauges or photoelectric off-on switches would do the job equally well. For the sake of continuity and mechanical simplicity, the light cells are used. The decision as to board type is made directly at the thickness and width measuring relays. The necessary circuitry is shown in Figure 3.

The circuitry of the knot recording relays is the most complicated of all the circuits in the machine because more flexibility is demanded of it and more information is handled at this point. A review of knot-measuring techniques, as presented in the preceeding chapter, shows that this circuit must: (1.) differentiate between corner and interior knots, (2.) provide "encasing lines" signals (notice that the extremes of a knot may not become obvious to the machine at the same time,) (3.) provide area signals, (4.) provide adjacent corner knot encasing lines signals for comparison. Furthermore, it must allow for more than one knot occurring on the same face at the same cross section of a board.

The necessary circuitry is shown in Figure 4A, and an example of the signal routing for different knot locations is given. The circuit is capable of handling two knots occuring on the same face at the same time; however, this number could be increased with more complex, but analogous, circuits. Notice that two signal relays are necessary for each knot-sensing unit; one is energised only while the sensing unit is over a knot and is used for area signals, the other has a short memory and remains closed as long as any of its neighbors are closed. This allows encasing lines to be determined if they do not occur at the same time. When the knot has been passed by all the sensing elements which intercept it, the "memory" relays open as a group.

As has been the case in many other machines, the oversimplification of certain decision criteria has resulted in "optical illusions" in the sensory experience of the machine. These illusions are best described pictorially, and that is done in Figure 6. The effect of these illusions on machine operation is described in the Discussion Chapter.

The signal which is handled by these circuits is essentially a variable current which results in a proportional voltage signal across a resistor in the output section of the circuit. The current is regulated by attaching a resistor to each signal relay, as shown in Figure 5. Since the resistors occur in parallel, the current is directly proportional to the number of resistors in the circuit and, therefore, to the knot size. (The signal resistances must be large compared to the resistance of the rest of the circuit.

(The signal resistances must be large compared to the resistance of the rest of the circuit.)

By correct manipulation of these signal resistances, the "place corrections" can be made at this point, removing the necessity of a formalized computor. Since the resistors occur in parallel and therefore experience the same potential at all times, it is convenient to think in terms of conductances; thereby the relation between these signal controllers and the signal becomes more direct. It would be helpful if a simple conductance control could be devised to yield the desired correction surface as a function of the board width, length, and position in the machine; however, this investigation did not find such a simple answer. The reciprocal relation between resistance and conductance is the main complicating factor in this case, but it shares its glory with Mr. Kirchoff's set of manners for electrical circuits.

The solution which is proposed is a stepwise approximation of the actual correction surface, which is accomplished by switching appropriately valued resistors into the signal regulation position at the correct time and for the pertaining board width. The theoretical correction surface and its approximation are pictured in Figure 5. Two automatic acting, multi-position, multi-bank switches and a large number of resistors are needed for each face; however, these items are not expensive and are simple and reliable. The necessary switching is straightforward and is not described in detail. An idea of the operation is given in Figure 5.

The switching of the correction conductances must be based upon the position of the board relative to the sensing elements. This quantity is determined by two measures, the width of the board and the position along the length of the board relative to the sensing elements. The board width has already been determined, and an appropriate signal is available. The position along the length can be given as a function of time since all boards move through the machine at a constant rate. The length correction will be switched in by a stepping relay (one which moves a space every time it receives a pulse.) The timing pulse will be generated by a drum with alternating make-break contacts spaced around it so that a pulse occurring at fifteen equally spaced intervals in the travel of any board may be obtained. The drum will be driven by a synchronous motor.

The corrections and switching circuits have now been developed so that all the necessary signals are available for computation. There are two operations necessary to the measurements which are more than simple digital choices. The first of these is knot-area measurement and will be accomplished with commercial analog computer integrating elements consisting of a resistor in series with a high-gain amplifier which is paralleled with a capacitor. The integrators must be controlled in the system so that they return to zero (possible by shorting the capacitor) whenever the input signal becomes zero. (Another set of integrators must sum over the whole length or half the length.) The second nondigital operation which is necessary is the choice of a minimum measurement when a knot occurs at the corner of a piece. By using a balancing relay, powered by slight drains on the size signals, the minimum (or maximum) of two signals may be chosen.

The outputs of the measuring devices are available at a number of different places. It is a simple matter to connect the desired readings according to board type to the actual grading mechanism.

The "computation" of strength ratios is no more after all this preparation than putting the resultant voltage signal through an appropriate resistor, which may be done, again, with simple switching operations controled by board type.

The computed stress grades, which appear as voltages, act upon the grade recording device which is a servo-mechanism turning a gear proportionally to the input signal. The servo-mechanism must be ratcheted so that at the end of the board, the gearhas been turned proportionally to the maximum appearing signal voltage, not the sum. The maximum signal voltage is seen to be equivalent to the minimum grade; no signal voltage and no rotation of the servo or gear would result in a grade of 100. An amplifier of the voltage signals is necessary to the operation of the servo-mechanism.

Since various output signals appear at many points and only the maximum is of interest, and only one can be handled by the servo-mechanism, some method of choosing the maximum of a number of voltages is necessary. A system of balancing relays, such as used for comparing corner knot dimension, can accomplish this feat. The arrangement of these "maximizers" is given in Figure 7.

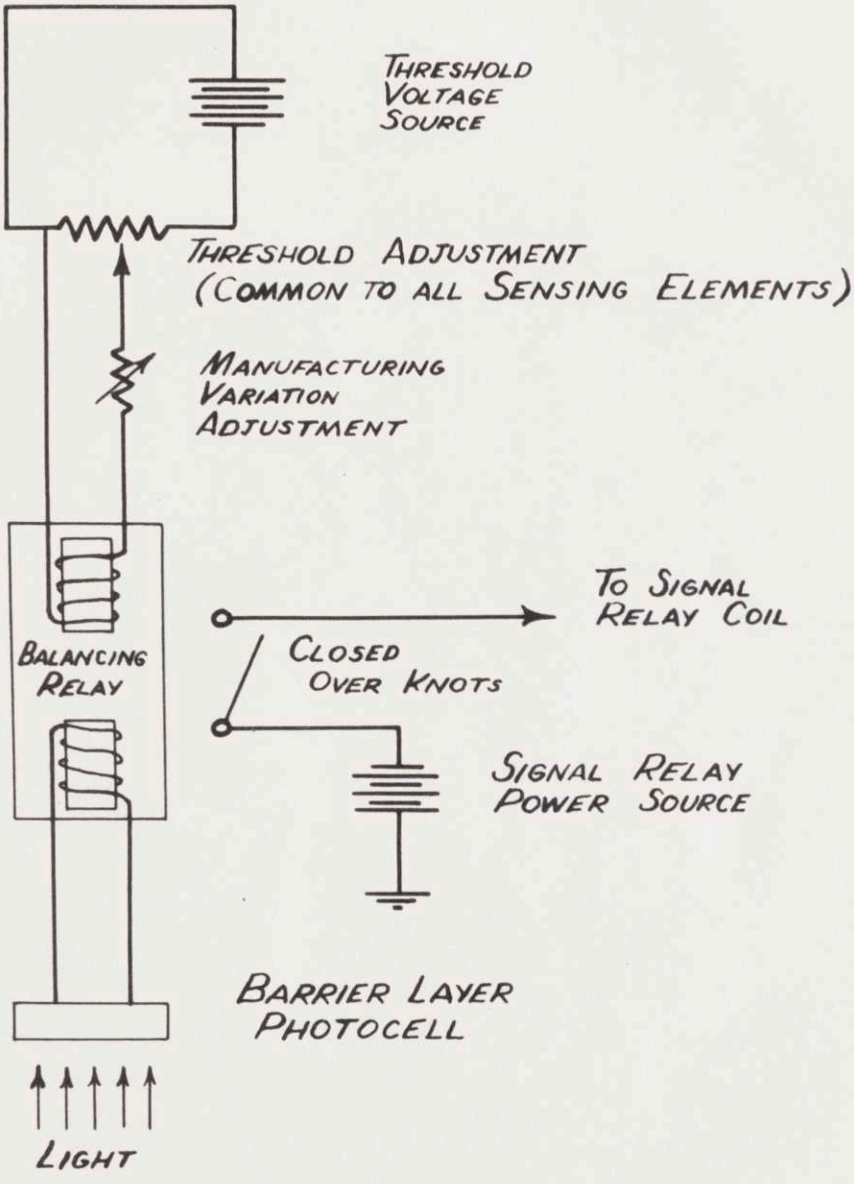
Requirements in the grading procedures for the sum of knot sizes in the middle half of joists and planks or beams and stringers and in any six-inch length of posts and timbers are satisfied by using four more integrators, one for each face in joists and planks and in beams and stringers and one to start integrating every one and one-half inches for posts and timbers. The impulse timer will be fitted with a timing control for operation of the integrators when posts and timbers are measured.

The computation of stress grade as a function of slope of grain is simple and is described only in mathematical terms. The effects of splits are handled in a similar manner.

The physical setup of the machine could assume many forms; a general idea of the arrangement is shown in Figure 9. It is important that all the knot-sensing elements operate on the same cross-section of the piece in order to prevent the necessity of more memory units; a drawing of how this is accomplished is also given in Figure 9.

FIGURE 1

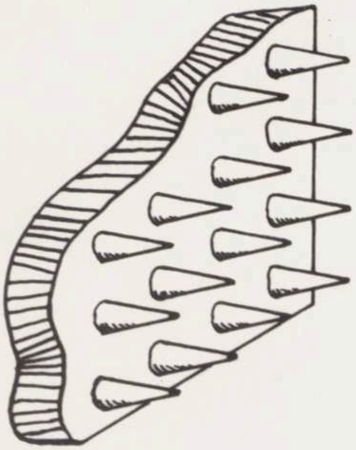
## KNOT SENSING CIRCUIT

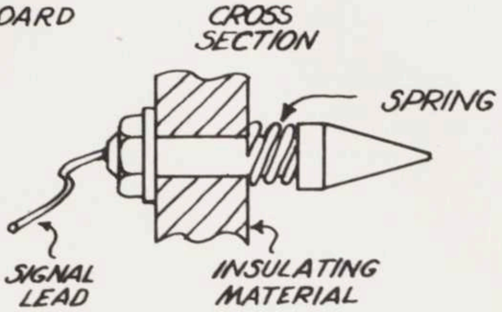


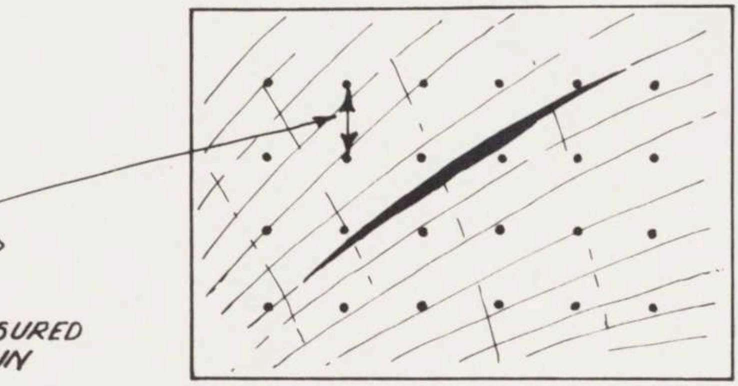
# FIGURE 2

# ELECTRODE SPLIT MEASUREMENT

ELECTRODE ARRANGEMENT FOR USE AT END OF BOARD

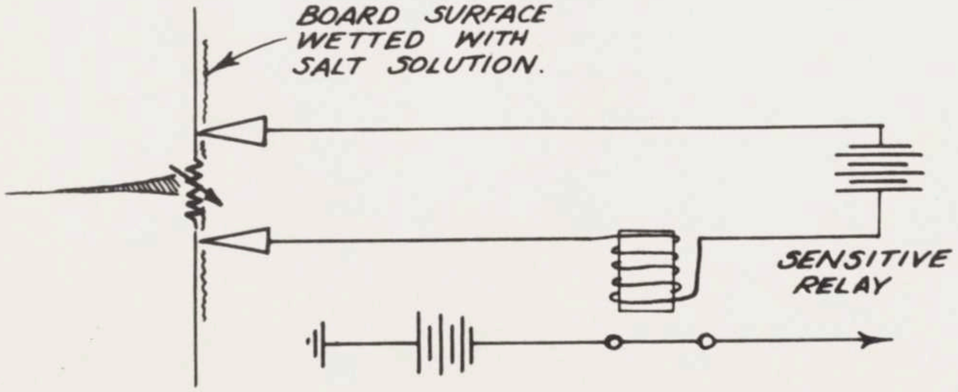






RESISTANCE MEASURED BETWEEN PAIRS IN THIS DIRECTION.

## SENSING CIRCUIT

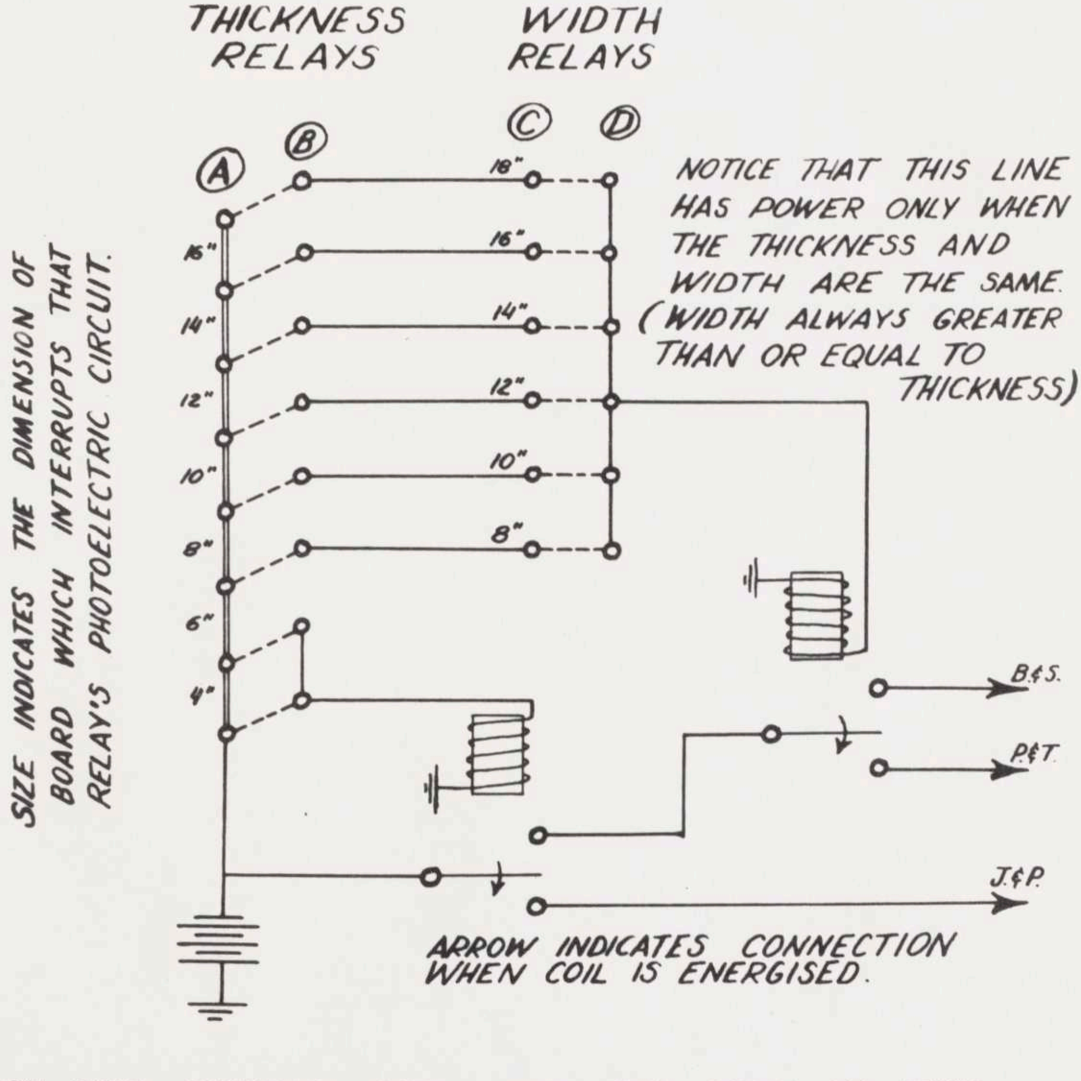


## FIGURE 3

## BOARD TYPE DECISION CIRCUIT

○═○ CLOSED ONLY WHEN PHOTO-ELECTRIC CIRCUIT INTERRUPTED.

○---○ CLOSED FOR UNINTERRUPTED PHOTOELECTRIC CIRCUIT.



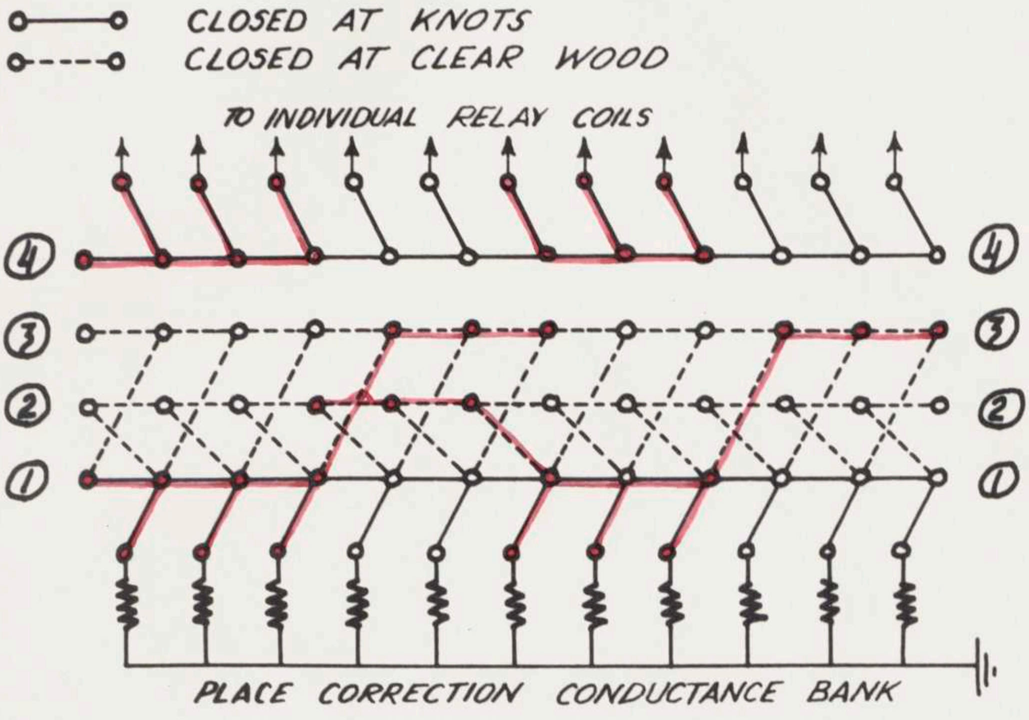
NOTICE THAT THIS LINE HAS POWER ONLY WHEN THE THICKNESS AND WIDTH ARE THE SAME. (WIDTH ALWAYS GREATER THAN OR EQUAL TO THICKNESS)

ARROW INDICATES CONNECTION WHEN COIL IS ENERGISED.

EXACT SIZE SIGNALS ARE ALSO AVAILABLE IN THIS CIRCUIT: THICKNESS AT THE COLUMN OF POSTS LABELLED Ⓑ, WIDTH NOT INDICATED HERE, BUT IDENTICAL TO THICKNESS CIRCUIT.

FIGURE 4A

## KNOT SIGNAL RELAY CIRCUITRY



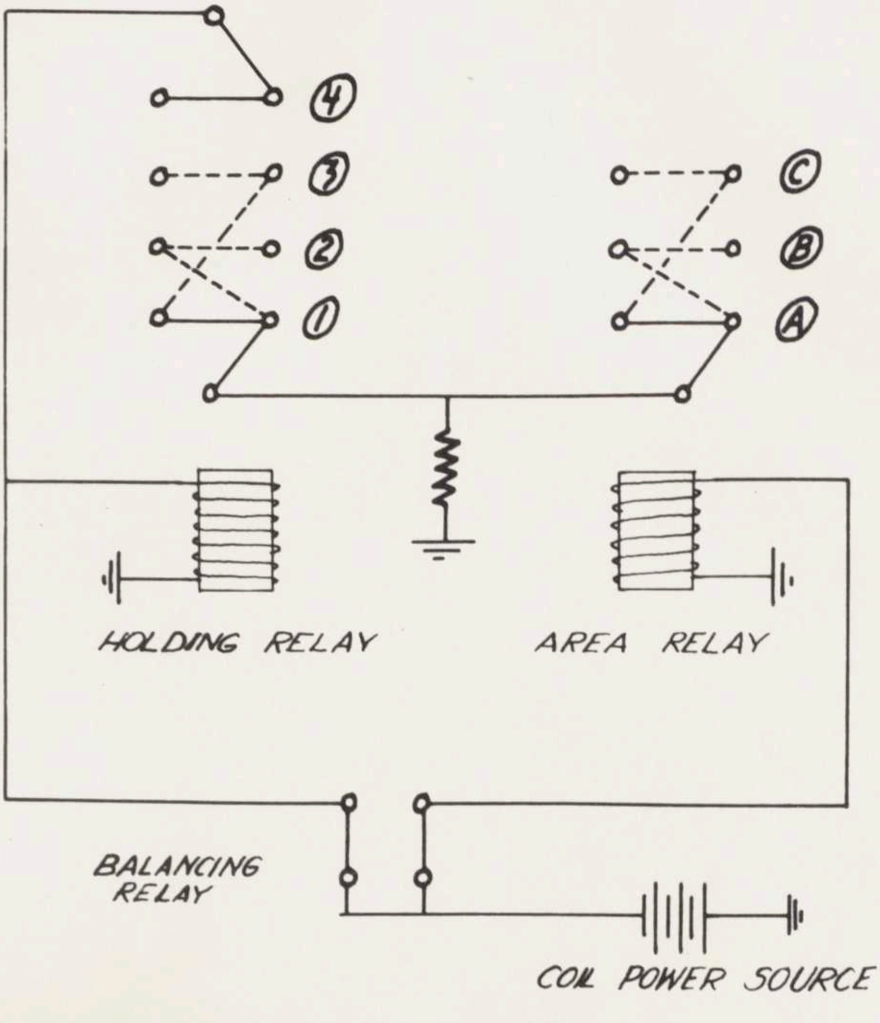
EXPLANATION

1. SIGNALS OF KNOTS WHICH OCCUR ON CORNER OF BOARD APPEAR AT ①. (EXAMPLE, RED CIRCUIT AT LEFT.)
2. SIGNALS FROM INTERIOR KNOTS APPEAR AT ② ON THE LEFT AND ③ ON THE RIGHT.
3. THE CIRCUIT AT LEVEL ④ PROVIDES THAT ALL RELAYS WHICH THROW DURING A SINGLE KNOT REMAIN CLOSED UNTIL THE KNOT IS COMPLETELY SURVEYED, THEREBY PROVIDING A MEASURE OF THE ENCASING LINES.
4. NOT SHOWN IS THE AREA MEASURING CIRCUIT, WHICH IS IDENTICAL TO THIS EXCEPT LEVEL ④ IS ELIMINATED.
5. LEVELS ② AND ③ ARE UNNECESSARY ON THE WIDE FACE SINCE ENCASING LINES OF INTERIOR KNOTS ARE NEVER MEASURED THERE.
6. THE RED LINES DENOTE ALL LIVE CIRCUITS DURING THE SURVEY OF A CORNER AND INTERIOR KNOT.
7. THE PLACE CORRECTION BANK IS VARIABLE, AS SHOWN IN FIGURE 5, NOT FIXED AS SHOWN HERE FOR SIMPLICITY.

FIGURE 4B

## KNOT SIGNAL RELAY COIL CIRCUIT

(FOR SINGLE SENSING ELEMENT)

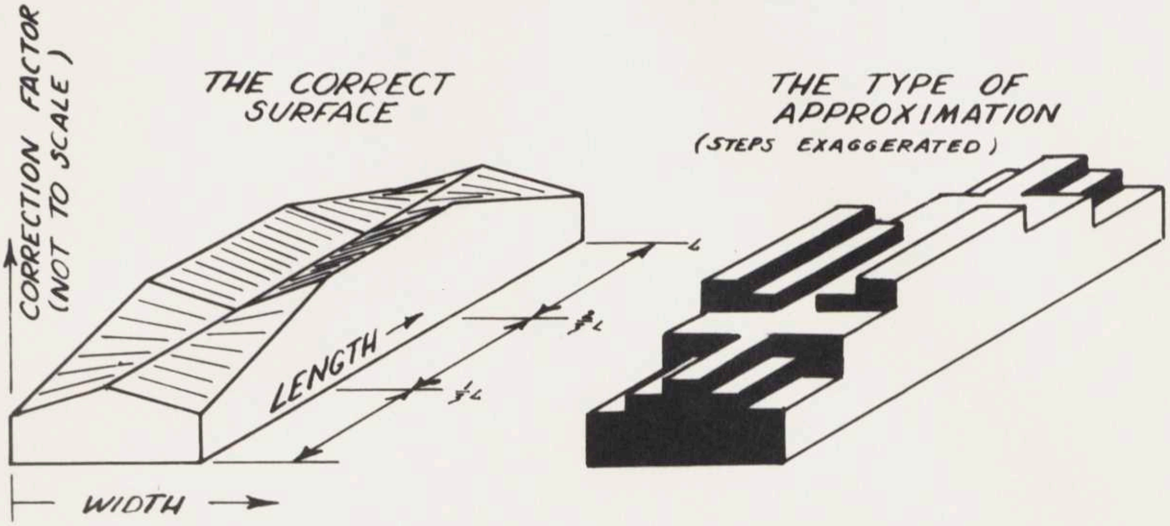


### EXPLANATION

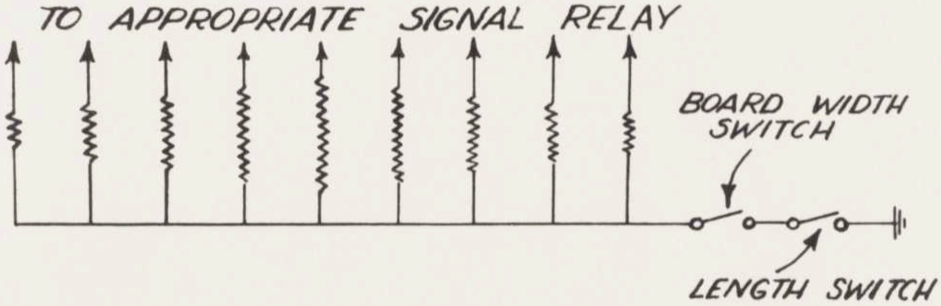
1. NOTICE THAT IF A NEIGHBOR OF THE HOLDING RELAY IS CLOSED AT THE SAME TIME AS THE ONE PICTURED, AND THEN IS RELEASED BY ITS BALANCING RELAY, IT WILL REMAIN CLOSED BECAUSE OF THE CURRENT IN LINE ④.
2. WHEN ALL THE BALANCING RELAYS HAVE OPENED POWER IS NO LONGER AVAILABLE TO LINE ④, AND THE SIGNAL RELAYS OPEN.

FIGURE 5

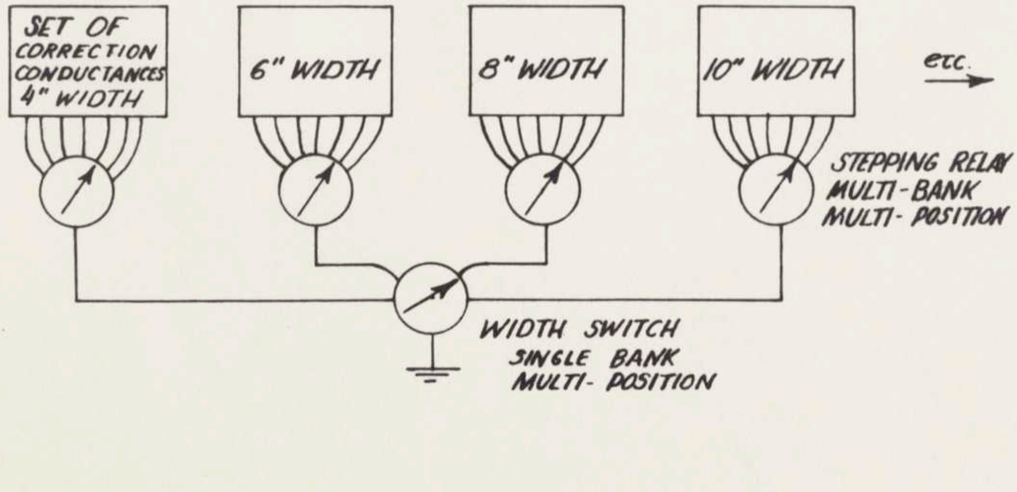
# THE PLACE CORRECTION



THE CORRECTION CONDUCTANCE ARRANGEMENT
(FOR A SINGLE BOARD WIDTH AND
DISTANCE ALONG BOARD.)

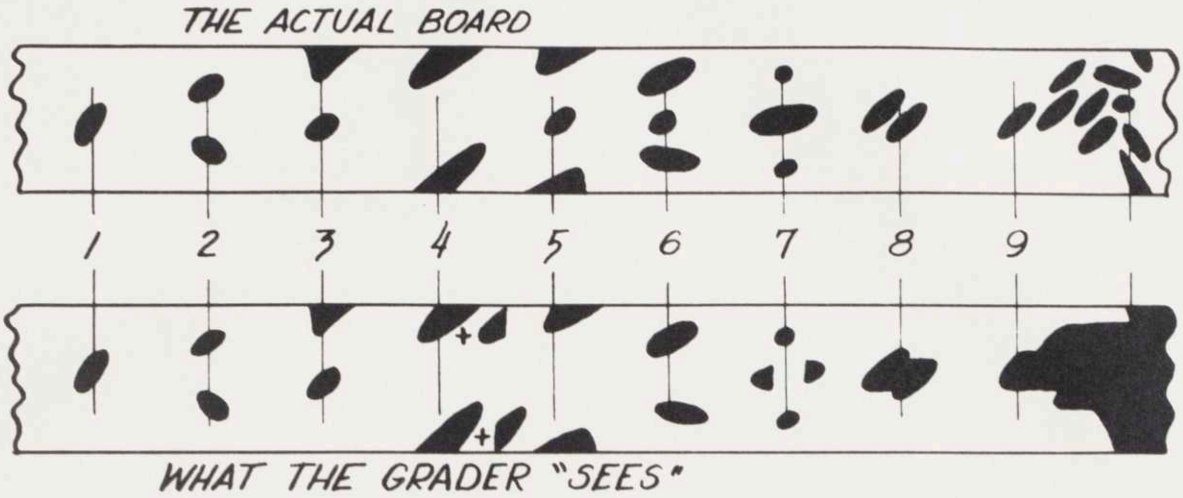


THE NECESSARY SWITCHING



## FIGURE 6

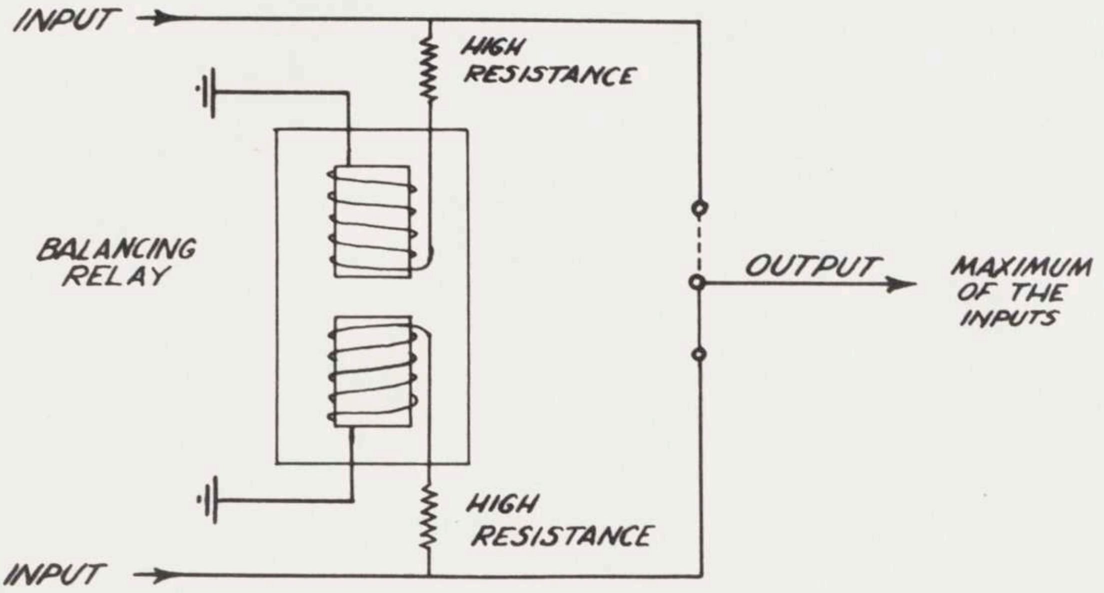
## "OPTICAL ILLUSIONS"



### EXPLANATION (ALSO SEE "DISCUSSION")

1. OKAY
2. OKAY
3. OKAY
4. SLIGHT ADDITION TO AREA MEASUREMENT, ENCASING LINES NOT AFFECTED.
5. CENTER KNOT NEVER RECORDED.
6. CENTER KNOT NEVER RECORDED.
7. LARGE CENTER KNOT SPLIT IN TWO, MAIN EFFECT ON AREA MEASURE.
8. ENCASING LINES MEASURED AS SINGLE KNOT, AREA MEASURED CORRECTLY.
9. MACHINE EXPLODES.

## FIGURE 7
## MAXIMIZING CIRCUIT



IN COMBINATION

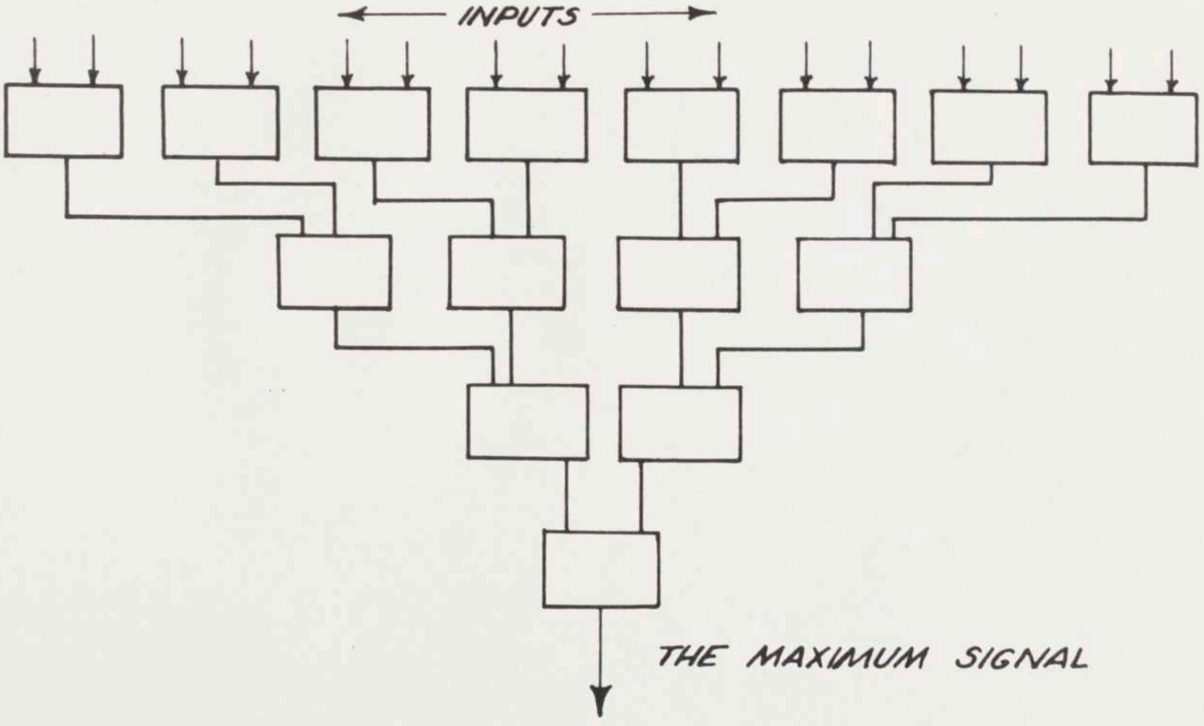
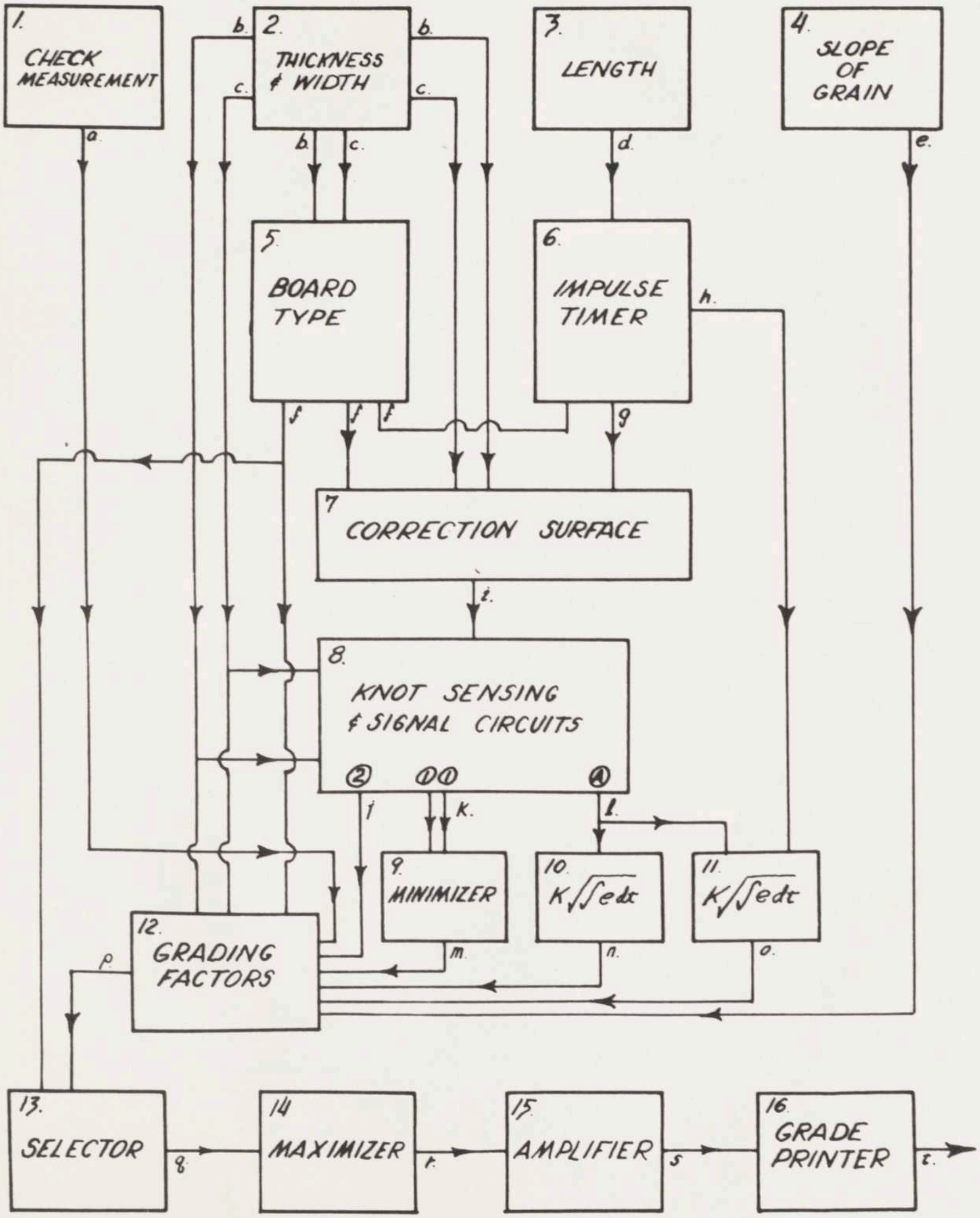


FIGURE 8

## THE OPERATIONAL BLOCK DIAGRAM

(SEE NEXT PAGE FOR DESCRIPTION OF ELEMENTS)



## OUTLINE OF THE ELEMENT FUNCTIONS FOR CLARIFICATION OF FIGURE 8

1. The check size element is operated manually and produces an output of voltage which is proportional to check size (a).

2. The thickness and width measurements are made by interrupting photoelectric circuits, appropriate switching produces voltage in only one line of a multi-channel outlet (b) and (c).

3. The length measurement operates identically to the thickness and width device andproduces a similar output. (d).

4. The slope of grain measuring is done manually; a voltage proportional to the cotangent of the slope must be produced (e).

5. The board-type circuit uses the width and thickness measures to determine the type and produces an output of power in one of the three possible lines (f).

6. The impulse timer produces fifteen equally-spaced pulses during the movement of a board through the machine (g); it pulses every inch and one-half of the board length or closes a circuit during the middle half of the board length (h) according to the board type (f).

7. The correction surface adjusts the conductances of the signal relay circuits (k) at each impulse from the timer (g) according to board dimensions (b) and (c). Nocorrection is made when the board type is posts and timbers (f).

8. The knot signal circuit produces voltages proportional to instantaneous knot width at Ⓐ or (l), voltages proportional to the encasing line distance for corner knots at ① or (k), and voltages proportional to the encasing distance for interior knots at ② or (j). Only one corner of the four-cornered display is indicated here. The knot signal circuit is also set up to tap the signal circuits at the appropriate places for various diminsions of boards.

9. The minimizer selects the minimum dimension voltage (m) for adjacent corners (k).

10. The integrating unit determines the average of maximum and minimum diameters; the output is a proportional voltage.

11. The second integrating unit sums knot sizes over given lengths of board as controlled by the impulse timer (h); the voltage output is proportional to total size.

12. Application of the grade factors (the grading equations ofthe first section of the report) is simply multipication by a constant determined by board type (f) and dimension (b) and (c).

13. The selector chooses the measurements which are appropriate to the type of board being graded (f).

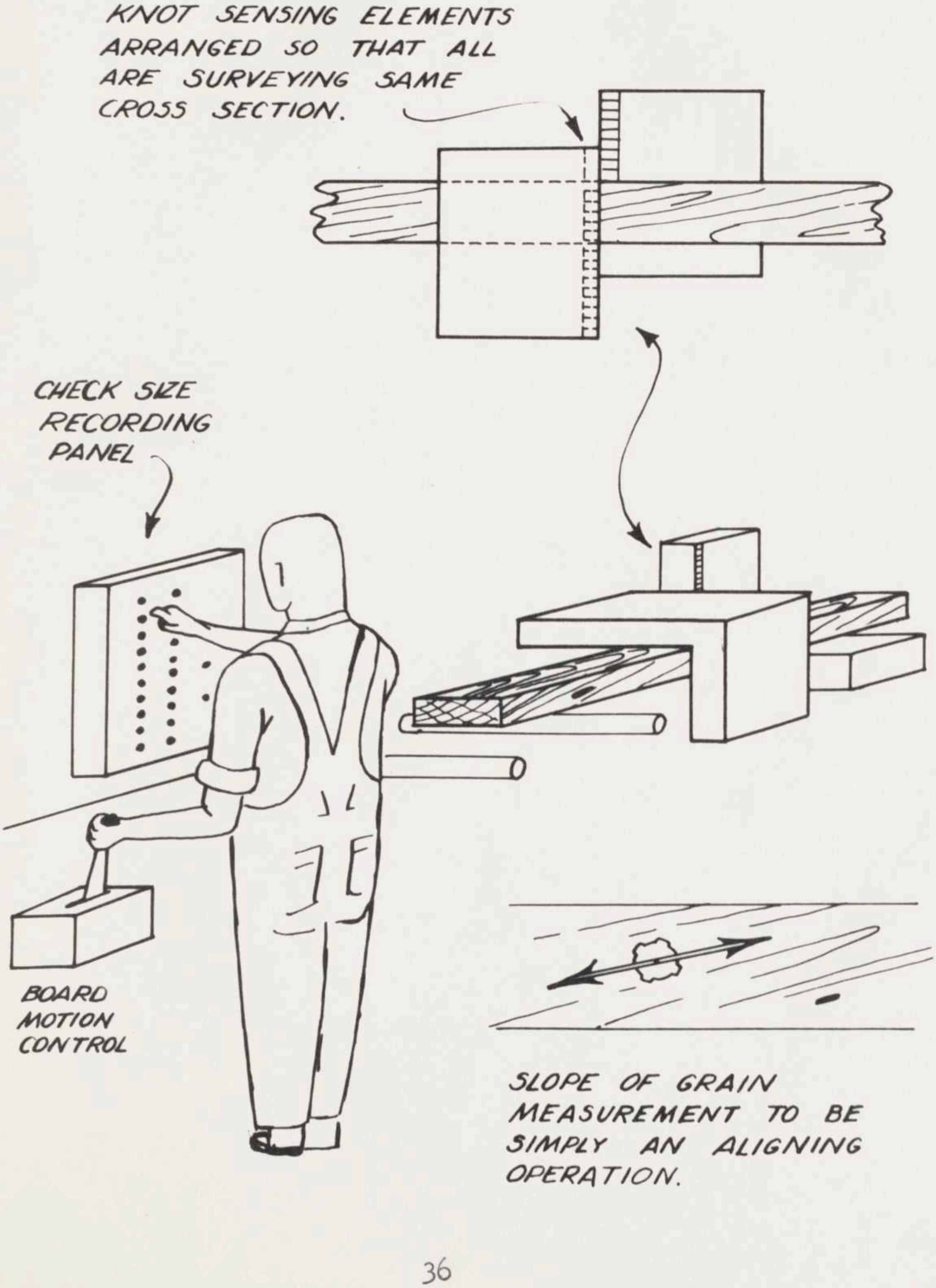
14. The maximizer chooses the maximum of the outputs of the selector (q).

15. The amplifier multiplies (q).

16. The grade printer is a servo-mechanism controlled by (s) which prints grades below 100 as a linear function of the imput voltage.

FIGURE 9

THE PHYSIQUE



## DISCUSSION OF MECHANICAL GRADER

An estimate of the total cost of the machine components is summarized in the table on page 40. Representative retail prices were used when available; prices of special items were estimated. The figure was not purposely made high or low. Assuming that the machine could be constructed for twice the cost of the parts the market price is approximately $15,000. One operator is required for the use of the grader, but the output of the machine (two boards per minute) is equal to that of several manual graders, assuming strength ratio grading is being done carefully. (No exact figure could be found--my estimate is more than four men.) Operating costs are negligible.

The mistakes inherent in the machine, as indicated in Figure 6, tend to cause it to neglect certain defects which occur in unusual patterns. For the case of a knot neglected because of inclusion between two other knots the effect is not important for bending stresses if the inner knot is not much larger than the outer ones since the outer knots are much more destructive. For compression, however, the neglect of a large centered knot might be serious. The changed form of a corner knot which occurs at a large angle to the edge of the board should have no effect since only the narrow dimension is desired and this should occur on the adjacent face for this type knot; the extraneous separate knot which appears to the machine would normally be small, and its computed effect should be less than that of the parent knot.

The approximation of average diameter from area which is used is quite reasonable; however, the use of average diameter for minimum diameter (in beam and stringer measurements) is rather poor, but results in a lower than necessary grade and therefore a "safe," though wasteful, error. The step approximation of the place correction surface can be made well within the accuracy limits of the machine and will have a negligible effect on the resulting grades. The size of the individual surveying areas has a definite effect on the accuracy of the device. Empirical data are necessary for a final choice of the optimum size.

It would be pleasant to be able to measure the slope of the grain and check size automatically if just to grant the device a degree of continuity, but no suitable methods were devised.

A great simplification could be made if the defect position corrections could be made continuously and in a single procedure. Although the attempts in that direction failed there was a certain amount of promise; the quest was rather challenging and enjoyable, and should be continued.

As long as most of the design problems have been mentioned it seems that one of the worst closet cases should be brought out. Some knots are the same color as the surrounding wood. Some knots have centers which are the same color as the surrounding wood. (Fortunately, some knots are dark black and most are at least dark.) There are solutions to these difficulties, but such refinements seem out of place at the present.

There is one important consideration that should be brought out, and that is of the basis of this design--the suggested grading practice. As it is given, the procedure is arranged for human use using the sense of vision for defect identification. With machines extra-human senses are possible, and more detailed calculations may be made without losing great amounts of time. Therefore, it seems appropriate to review the design, consider the wood research data, and the increased potentialities of the machines; and in this way to attempt to revise the mechanical grading procedure so that strength ratios would be predicted more accurately and directly.

The direction now--and these are my suggestions for "further work"--seems to be:

1. Test the knot-sensing apparatus. Information on its operation for different kinds of wood and knots would be valuable, as would data on the sensitivity and reliability of the device.
2. Develop new concepts of split and perhaps slope of grain measurement.
3. Develop the detailed design.
4. Build and test working model.
5. Apply for patent.
6. Sell the patent rights.
7. Buy new Jaguars for girl friend and her room-mate.

## SUMMARY OF COSTS

| Item | Number | Unit Cost | Total Cost |
|---|---|---|---|
| Photoelectric Cells | 140 | 8 | 1120 |
| Balancing Relays | 140 | 20 | 2800 |
| Recording Relays | 280 | 5 | 1400 |
| Integrating Elements | 8 | 25 | 200 |
| Servo Amplifier | 1 | 25 | 25 |
| Servo Motor | 1 | 20 | 20 |
| Synchronous Timing Motor | 1 | 50 | 50 |
| Mechanical Structure | | | 1000 |
| Miscellaneous Relays, Switches and Electrical Elements | | | 1000 |
| Total | | | $7615 |

## A PROPOSAL FOR SAW SHARPENING

One of the highest paid jobs in a sawmill is that of the filer or saw sharpener. There is an art to the work, and the competence of the filer is one of the main determinants of successful mill operation. The maintenance of a band saw blade includes three operations: sharpening, swaging, and tensioning. Sharpening is the operation of maintaining the form of the saw tooth, and it is done with files and templates. Swaging of the saw teeth provides that the cut be wider than the saw blade so that the saw can move through the wood, and is accomplished by bending alternate teeth to different sides or by flattening the face of the tooth so that it is broader than the blade. Tensioning a band saw blade is necessary to keep the blade running smoothly on the guide wheels, and is done by working the metal with a hammer. A blade must be sharpened more frequently than any of the other operations; in a large band mill the blade will be changed several times during a day's operation to provide for sharpening.

Many mills, mainly the smaller ones, use a circular saw for the first cutting. The sharpening requirements are much the same, but the problem is somewhat simplified by the use of removable teeth in many of the circular saw blades.

Could the sharpening operation be simplifed or minimized? There are several changes that might be attempted. The most desirable state would be the elimination of the

the necessity for sharpening frequency, i.e., longer blade life. Another direction which might be taken would be to simplify or somehow improve the sharpening operation.

Some possible means of accomplishing these results would be:

1. Lower the blade wear, possibly by:
    a. Better tooth design.
    b. Use of cutting agent.
    c. Better saw material.
    d. Chroming, or special maintenance of teeth.
    e. Use of optimum cutting conditions.
    f. Improving hardening methods of saws.
    g. Removal of impurities from logs.
2. Provide for continuous sharpening while saw is in operation. This might be accomplished by using two modes of cutting such that the wear would tend to cancel out or by providing an artificial wearing device which would tend to sharpen the blade.
3. Eliminate the sharpening problem by using some other means of cutting or of lumber manufacture.
4. Devise a fast-acting sharpener which could operate with the blade still on the machine.

The emphasis here has been on the "sharpening" aspect of saw maintenance, mainly because that is the most time consuming and seems the most likely to yield to mechanical solution.

There is some work being done at the present time on most of the possibilities for lowering blade wear, mainly in the metallurgical field. Some research has been done on the problem of tooth design, although the literature is rather scant. As far as I know, no formal testing of cutting agents for use with wood has been done; this is a possibility, although since wood is normally sawed under water-saturated conditions, it might be suspected that little more could be accomplished here.

Elimination of this problem is studied in other parts of this work, and the continuous sharpening scheme will be considered further here. I feel that continuous sharpening would be a better solution to the problem than an automatic filing machine, since a continuously sharp blade would lower saw power requirements, result in better sawed wood, and would probably yield better saw life.

The general feelings that I have about such a device are these:

1. It should be extremely simple, since it must operate at high speeds and should not require continuous maintenance.
2. It would not have to maintain a perfect tooth shape at all times, but it should offset the effects of wear.
3. The operation or safety of the saw must not be impaired by the machine.

This continuous sharpening will in effect be wear on the saw tooth. There are three basic requirements to be satisfied if the desired effect is to be accomplished. They are:

1. A wearing material must be provided.
2. There must be force and motion between the wearing material and the tooth.
3. The material must be guided to the correct place on the tooth.

Any material capable of removing steel from the face of the tooth would qualify as a "wearing material." A list these includes:

1. Any grit, such as emery, diamond, etc.
2. Sharp edges, such as files, knives, etc.
3. Chemicals, such as acids.
4. Flame.

Force between the tooth and material might result from:

1. Difference in velocities.
2. Difference in pressures.
3. Damping.
4. Gravity.
5. Coriolis acceleration.
6. Forces from sawing in log.

The material might be carried to the tooth by:

1. An air or liquid jet.
2. A solid binder material.
3. A mechanical device.

There are many possibilities here--an acid grease smeared on the tooth face, a hail of gritty particles striking the tooth, a plastic rod with grit embedded in it being sawn, and quite a number of other plausible cominations. In order to maintain the most mechanical accuracy in the sharpening operation, I chose a mechanical device to carry the cutting material, and since a force and velocity can be easily developed between the blade and material with such a system, a grinding action for cutting was chosen, either a grit or file surface making contact with the tooth face. The extremely high velocities of the saw blade, around 10,000 feet per minute, demand that the device be extremely simple in its operation, and the idea of a wheel of some sort seems the most likely to accomplish that end.

The proposed "wheel" would be very similar to a gear, and the action would be similar to a rack and pinion. The trouble with such a system is that the shape of the sawtooth prevents a gear-type action, and that there would be no motion of the cutting surface relative to the tooth. The solution to this condition is to incline the axis of the wheel such that the teeth would come in from the side, move across the cutting surface, and leave from the other side; all this happening while the blade and the wheel were in rapid motion. The inclination of the wheel would force the cutting surfaces to be specially shaped so that the sharpening would occur straight across the tooth face. A sketch of the proposed gadget is shown in Figure 10. The problems which would probably cause the most difficulty in the perfection of this sharpener would be:

1. The determination of the correct wheel diameter. Large diameters would require less shaping of the wearing surfaces and would tend to form a more perfect plane on the tooth face. A smaller wheel would be more easily handled, less disturbance to the sawing set-up, and cheaper.
2. Determination of the correct damping. The dynamics of the proposed device are complicated. The damping must be enough to insure the wheel meeting all the teeth, which may be slightly unevenly spaced, and it must also provide smooth, not bouncing, contact between the saw blade and the sharpening surface. Too large damping would be an unnecessary waste of energy and would cause unnecessary wear on the sharpening device.
3. Choice of the correct wearing or sharpening surface. The surface must be chosen such that the amount of wear at the saw tooth is not too great, nor too small, and the sharpener itself must withstand the wearing effect of its action.
4. Allowance for blade motion perpendicular to the sawing path must be made. During sawing the blade moves in and out on its guide wheel, and vibrates in its flat plane. Because of the flat face of the sawtooth, the in and out motion can be taken by design of the shape of the cutting surface by allowing for longer

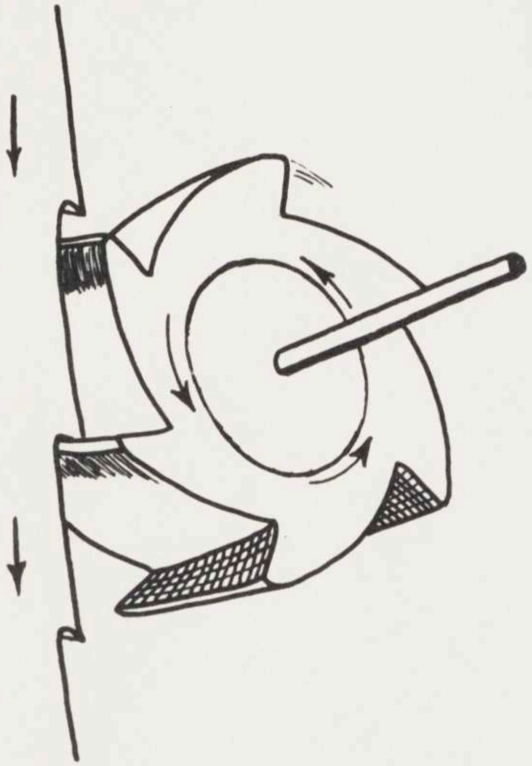
than usual blade faces. The vibration will not affect the operation.

This device might perform best with replacable sharpening surfaces, such as plastic with embedded abrasive particles.

Consideration of the extremely high velocities involved tend to cause some doubt about the practicality of the proposed sharpener. In retrospect, it seems that the use of such a device under special low speed conditions, maintained for short times, would be necessary to utilize the potential of this gadget.

FIGURE 10

THE CONTINUOUS SHARPENER



# APPENDIX

## THE PROBLEM STATEMENT

The purpose of this section is to review the original problem statement and to expand and redefine it and with the help of the new information to determine some very specific problems associated with the overall one.

From a moment's consideration it can be seen that a problem stated in "point to point" terms is a highly constrained one. One of the early realizations of this work was the recognition of that quality in the original problem statement. I had stated for a problem "Improve the conversion of logs to lumber." Now I would like to list the two other types of parallel problems and to point out the necessity in a two-point problem of giving the boundary points a reasonable degree of flexibility. The need for flexible boundaries became extremely apparent in the early work when the problem invariably reverted to "How can wood be sawn." The single point problems are:

1. Where could wood material be used?
2. From what can building material be produced?

The original problem can now be restated "How can the production of building material from wood be improved?"

A decision was necessary here between these three types of problem statement. They are equally important, and all seem suitable for this study. The two-point statement was chosen because of its similarity to the original statement and because it seemed the most likely to be involved with machinery and gadgets. The value of stating the "utilization" and "implementation" problems is simply in increasing the awareness of the problem situation.

Within the framework of the present system lie many problems whose solution would be a valid, if limited, answer to the main problem. It was in search of these problems that section C, Process of Lumber Milling, was written. The resulting problems will be explicitly stated here.

There are many transportation problems; the items involved are:

1. Logs, from forest to mill site.
2. Logs, from storage to first operation.
3. Cants and flitches, from headsaw to resaw.
4. Rough lumber, between resaw, edger, and trimmer.
5. Green lumber, from machines to sorting operation.
6. Sorted green lumber, to drying area.

Many handling problems arise in the milling process. The main ones are:

1. Stacking and unstacking logs in nonpond storage.
2. Loading the log onto the carriage.
3. Adjusting and turning the log on the carriage.
4. Stacking the lumber for drying.

The cutting of wood is necessary for the operations of:

1. Cutting off the log ends.
2. Breaking down the log.
3. Resawing.
4. Edging.
5. Trimming.

Waste occurs in many of these processes and must be disposed of, or preferably, utilized in some way. The waste consists of:

1. Sawdust.
2. Trimmings and edgings.
3. Bark and wood with bark on it.
4. Log ends.

There are several processes where decisions made by men are central in the process and are important to the efficiency of the mill. Among these are:

1. Head sawing, resawing, edging, and trimming. The operator must decide where the cut is to be made. There are more possibilities in the head sawing, while the trimming and edging involve a reasonably limited selection.
2. Grading, which is governed by a set of reasonably simple rules.
3. Sorting, in which primarily simple decisions are involved.

The maintenance of equipment provides all the usual problems; however the maintenance of saw blades is one of the most difficult problems in the mill. The men who perform this job are the most highly skilled and the highest paid of all the mill workers.

This sketch of problems does not feign to include all, or even most, of the problems concerned with sawmilling, but the majority of mechanical problems are stated.

Some of these problems are being vigorously attacked in research and developement programs, and therefore lose some of their charm for a project like this. Among these are: utilization of wastes and debarking of logs prior to cutting.

Other problems in the group, such as most of the conveying processes, have been studied in rather general terms, and better solutions already exist than are in use. I do not mean to say that even better solutions do not exist and would not be worth finding, but they might take longer to find than improvements to semi-neglected, traditionally-accepted processes.

To work on all the problems which were mentioned would be impossible. Therefore, with the general requirements of reasonable virginity, uniqueness, and personal appeal, the following statements were used while trying to cover a fairly broad range of problem levels:

1. How can the conversion of wood to lumber be improved (the original, overall problem)?
2. Could the process of wood cutting be improved?
3. How might saw blades be maintained (an outgrowth of the second problem)?

In searching for a solution to the overall problem, a possible answer to the following was stumbled upon,

4. How could the process of lumber grading be improved?

One of the most amazing results of a study of this sort is how the problems occur, disappear, and change complexion as the work goes on.

## THE STRUCTURE OF WOOD

Wood occurs as a natural resource in the form of a tree, often in a group of trees, a forest. The tree itself, in a rather approximate form, consists of a column, at one end of which is a collection apparatus, which also secures the structure to the ground, and at the other is a factory-like affair which produces the building materials for the tree. The column, or trunk, has several different parts, which correspond with its functions of supporting the top and acting as a transportation medium. If the trunk is viewed as a solid cylindrical column surrounded by concentric layers of material, the various sections can be identified as follows. The solid column at the center is composed of inactive, or dead, cells of wood and serves the single purpose of support. The wood in this part of the trunk, often containing resins gums and coloring substances, is called heartwood. The layer just outside the heartwood is also wood; however the cells are alive, and nutrients and water are moved from the roots to the factory at the top through this section. This second layer is called the sapwood and also serves the function of supporting the tree. A thin layer surrounding the sapwood, called the cambium, is the dynamic element of the trunk. It is this layer which forms the building materials made by the factory on top into the elements which make up the wood. The cambium is capable of growing as it forms new wood to the inside; and therefore, as the diameter of the tree increases, the cambium layer remains continuous about the trunk. The wood-forming action of the cambium during the two parts of the growing season is responsible for the phenomenon of growth rings. During the first part of the growing season the cambium produces relatively large, thin-walled cells with large cavities, the springwood. Later in the season when growing conditions are not quite so favorable, smaller, closer packed, thick-walled cells with smaller cavities are produced, forming the summer wood. These two types of wood form alternating vari-colored layers, which also have slightly different physical properties, and under normal conditions each pair represents one year of tree life. Just outside the cambium is the bark. The part of the bark closest to the cambium serves the tree as a transportation medium and delivers the building materials produced at the top to the cambium so that they may be used for wood construction. The very outside of the bark forms a protective layer for the trunk.

The collection system at the base of the tree, the root system, also serves the tree as a base. Its organic function, however, is to collect water and mineral nutrients from the soil. The root system is similar to the top of the tree in that it branches out into a very elaborate network, with the finest elements being root hairs which do most of the actual collection work. The hairs, as the name implies, are very fine strands about the same diameter as a heavy piece of thread.

The amazing device at the top of the tree, which I have described as a factory, is the crown. It is here that the important process of photosynthesis takes place, carbon dioxide is taken in from the atmosphere, the carbon is removed and the oxygen liberated. The carbon is used to form the basic building material of the tree, sugar. The water which carried the inorganic nutrients to the crown is evaporated in a process known as transpiration. The sugars travel back down the limbs and trunk and then are converted to cellulose and other similar products for cell construction.

Two main types of wood cells are formed. One variety, which is laid down parallel to the axis of the trunk, is by far the more numerous; an idealized model of wood might be constructed of it uniquely. The second type of cell, which occurs horizontally, is formed by the cambium into channels radiating outward within the trunk. The function of these horizontal channels is to store various materials and transport them and others to and from the cambium. In softwoods the vertical cells have a length up to four milimeters and are ninty to one hundred times longer than broad.

They have a generally tubular structure, the walls of the tube being formed by four layers. The layers of the cell wall might be compared to the cord structure of an automobile tire. The basic constituent of the wall is the cellulose molecule, which is an indefinitely long chain-like organic structure. The molecules gather into string-like groups called fibrils, and it is the general orientation of these strings within the cell wall which differentiates the layers. A binding material is deposited somewhat irregularly throughout the structure and has proven quite difficult to analyze, both chemically and mechanically. The cell walls are not solid, but contain space in which water and other foreign substances may be deposited.

To give a general idea of the size relationships involved in the cell I have computed the size of a model which uses a one-sixteenth-inch diameter piece of string to represent the cellulose molecule. One the average, the strings would be approximately eight feet in length, and the total cell would have a length of eight miles. The diameter of the cell would be over four hundred feet, and the hollow running down the center would have a diameter of three hundred fifty feet, although all these figures would exhibit large variation over any real sample of wood.

The cells are bonded together by a cement similar to the bonding material within the cell walls. This material forms a continuous honeycomb network within the wood and has been shown to be as strong or stronger than the cells which it joins. The cells are further joined by pits which allow water to move from cell to cell. The pits occur both at the ends of the cell and in the walls. They are not actual holes in the cell walls, but are instead thin spots where diffusion occur rapidly. There are many various types of pit, according to whether a valve type mechanism is included in the structure.

From the discussion it may be seen that wood may vary according to:

1. Types of cell present.
2. Sizes of the several types of cell present.
3. Thickness of the cell walls.
4. Direction of longitudinal axes of cells relative to that of trunk.
5. Relative proportions of the several cell types present.
6. Mutual arrangement of these cell types.
7. Composition of the cell walls.
8. Molecular structure of the cell walls.
9. Presence, distribution, and nature (physical and chemical) of extraneous materials.
10. Structure of the middle lamella.

An interesting sidelight on the basic element of the wood cell is the fact that the longitudinal strength of cellulose is as great as that of high quality steel.

The lumber which is produced from wood has many properties which have made it popular. The ease of making connections with lumber is one of the most important attributes, while the ease with which it may be cut into different shapes is probably equally important. The convenience of using rectangular shapes in our usually rectangular structures is obvious; the general ease of cutting wood has been solely responsible for the success of the conversion of a round log into rectangular shapes since the process is otherwise difficult. The ability of wood to take different kinds of decorative and protective finishes has been partially responsible for its popularity, while the necessity of finishing wood has been to its disadvantage. The high strength of wood relative to its weight is another of the truly remarkable features about it, and any building material which is to compete with wood should have this attribute.

Wood has several characteristics which are undesirable in a building material. Its nonhomogeniety is perhaps the most important of these. Knots, cracks, and odd grain patterns are naturally occurring defects which seriously decrease the usefulness of wood. Its susceptibility to fungus, termites and other insects, and fire make it somewhat unstable for structures of a permanent nature. The changes which wood undergoes with different moisture contents cause many problems, two of the most serious being shrinkage and warping.

## THE PROCESS OF LUMBER MANUFACTURE

There are many problems involved in the present general method of lumber manufacture which seem likely candidates for review.

Lumber manufacture is carried on at many degrees of refinement. The strong back of a man and an axe or saw still produce lumber amongst the sophistication and gadgetry of our present society, but it is the gadgetry toward which we turn in the search for the better life.

The other extreme in lumber production is the large permanent sawmill. That is the unit to be described; however, the smaller operations serve an important function, and their processes and needs will also be considered.

At a large mill the logs must be stored since their delivery is seasonal, while the mill operates continuously. During this storage period the logs must be protected from rot, and this is accomplished by keeping them wet.. The most common types of storage systems are ponds where the logs are simply floated and stacks where water is pumped to the top and sprayed over the pile.

The log must then be conveyed to the sawing area when it is to be processed. In the pond the log is handled like a poling barge and is carried from the pond into the mill on an inclined ramp with a chain drive or is simply lifted out of the pond with a cable lift. From the stack the logs are moved with a system of cables to the sawing area. This is the first of many "conveyor" problems encountered in the sawmilling process.

When the log first enters the mill, the ends are sawed off in order to produce a clean working surface. The log is temporarily stored, and then loaded on the movable carriage which will carry it back and forth past the main saw as it is being broken down into pieces which can be handled in smaller machines for the final cutting to lumber.

The process of carriage sawing is very spectacular because of the high speed, rapid handling, and large size of the machinery and log. The carriage must be equipped to rotate the log, and to move the ends toward and away from the saw blade.

The saw which is used is either a circular or a band type. It operates at cutting speeds around 10,000 feet per minute. The choice of pattern of initial breakdown of the log, a critical and difficult operation, is done by a highly skilled lumberman known as the sawyer, who controls the process through a set of hand signals to the operator of the carriage. The pieces which are cut from the log are carried on a set of rollers to the next operation. One of the largest losses of raw material occurs at the first breakdown, where approximately 10 per cent of the log is lost in sawdust, and approximately 5 per cent is lost when the very outside portion of the log, having a round edge and carrying bark, is cut away.

The cants and flitches, as the pieces cut from the log are called, are then sawn on smaller machines to lumber dimensions. This operation is done on a multibladed machine, the "resaw," which cuts the pieces to the required thickness, and the "edger," which removes remaining bark and cuts the resawn pieces to the correct width.

The boards are then sent through a machine that has movable circular saws spaced at equal intervals, usually two feet. The operator of this machine trims the ends of the boards and can remove sections with imperfections from the center by putting different saws into the path of the board.

The lumber is then graded and sorted according to grade and size. It is stacked in a special manner out-of-doors so that its moisture content will drop to that of the air. In some mills special drying ovens, known as kilns, are used to dry selected lumber to indoor humidity conditions. This kiln-dried lumber may be finished to specially smooth surfaces or to special shapes.

There are several subordinate operations necessary to the milling process. Two of these, peculiar to the sawmill industry are that the sawdust and waste wood must be disposed of and that the saw blades, which are subject to heavy wear, must be maintained.

A type of mill which is sawing a fair percentage of the total lumber cut, especially in the south, is the portable mill. The reasons for this are that much of the timber being cut is second or third growth, is relatively small, and can therefore be handled with lighter, more portable equipment and that the need for lumber has forced the utilization of small wood lots which could not economically justify a standard mill.

The portable mills have certain problems peculiar to their type of operation. All the operations of the large mill must be carried out but are on a smaller level. The equipment which is used must be small, relatively inexpensive, and convenient to move. The extreme of this type sawmill is a rubber-tired device that tows behind a truck and and which can be put in operation by four men in one day.

I have not attempted to give a detailed account of the methods of sawmilling, as my object is to look for better means of doing these jobs. The steps which have been investigated with some intensity are discussed in more detail in the appropriate chapters.

## CONDITIONS ON THE PROBLEM SOLUTION

The preparation for problem solution must include study of three quantities. They are the desired result, the conditions leading to the problem, and the conditions governing the solution of the problem. The third category is somewhat distasteful, since it limits the possibilities. These constraints might be satisfied in a number of different ways, and in recognition of this fact, it seems wise to become aware of the constraints, but not to consider them during the search for solutions. Another reason why the constraints must not be given too much consideration is that there are often an overwhelming number of them; and a complete analysis, listing, and constant recognition of them would be very narrowing and frustrating.

There are many constraints on the solution to the "log to lumber" problem. My study of them is limited simply to listing where the constraints arise and what their general nature is. The description of the basic material can be viewed as a condition on the problem, and there are others concerned with the raw material. Among them are the physical occurence of forests, the number of trees in a forest, the amount of growth per year, the seasonal variations in logging, the total amount of wood that is available, and the laws which control the utilization of the forests. This last category, the laws, is a condition imposed by society and deserves a little further consideration. The laws under which the lumber manufacturers operate are the result of consideration for future needs for wood and for the esthetic values of the forest. In general the laws provide for minimization of waste in logging operations and for the protection of certain forest areas from lumbering activity.

As with the raw material, the finished product sets certain conditions on the problem solution. These have been rather thoroughly discussed and will not be further considered here.

Next in importance is the financial structure of the problem situation. There are two main considerations here, which are that a better solution must produce lumber at a lower cost than present methods and that any new solution must be realizable within the financial resources available to the industry.

Any solution to the problem will be dependent upon certain quantities from the physical world, as the method which is in use at the present time is dependent upon power supply, manpower, transportation facilities, construction equipment and material, tools and machinery, petroleum products, and many others. It is impossible to list what the dependencies of a new process would be, but it is important to realize that they must be listed and considered when the proposed system is evaluated.

A careful study of the future lumber market was made by Stanford Research Institute for the Weyerhauser Lumber Company. The results of that study are of great interest in the consideration of this problem, since they point out how the problem might change in the next few years. In very brief form those results are:

1. The size and activity of U. S. economy will expand by 1975.
2. Construction, container production, and manufacturing--the main users of wood products will increase.
3. Increased lumber supply will be forthcoming only at greatly increased expense; the price of lumber relative to competing materials will increase.
4. The price of plywood will increase, paper and paper products will remain constant, and fibre and insulating board will decrease relative to competing products.
5. Domestic production of lumber will increase only moderately by 1975.
6. There will be a market for all lumber produced, plus increased imports.
7. Major increases in pulp products, plywood, and fibre boards are expected.
8. Fuel wood consumption will decline.
9. There will be little change in consumption for other forest products.
10. Domestic requirements for saw timber delivered to mill sites will increase only moderately by 1975.
11. The increase in all timber delivered to mill sites will increase by approximately 14 per cent, owing mainly to the increased pulp demand.

12. There will be an increased use of mill residuals in pulp production.

13. Improved pulping methods will result in greater use of hardwoods for pulping.

14. The major increases in the South will be in pulp; in the West, softwood lumber and plywood; and in the East, both categories will increase slightly.

The final constraint on the solution has been mentioned before, and its importance to the whole procedure has been emphasized. That condition is the one of values, which we try to measure in terms of money, although we cannot always accomplish it. The one overall condition that can be put on the solution is that it has greater value to man than the present solution, and we still find that a definition of value poses a more difficult problem than the one we are trying to solve, which of course is meaningless without some measure of value.

## A TRANSGRESSION ON NATURE

The several conditions of lumber manufacture which cause the greatest inefficiencies and problems are these: (1.) Rectangular shapes must be formed from essentially circular pieces. (2.) Undesirable inconsistencies, such as knots, splits and so forth occur in the raw material. (3.) The large size, great weight and water content, and the irregularity of the logs make their handling difficult.

Plastics,do not have these undesirable traits, but their cost is higher than that of lumber, and no plastic known has the combination of properties which are required of lumber. The suggestion has often been made to the lumber industry that it grind its trees into small pieces, and then synthesize a lumber material from this pulp. The stock answers in refusal of the suggestion are "It would cost too much" and "We don't know how." Perhaps a method of forming a tough, strong, lumbery material from wood grindings will be found; that would indeed eliminate the problems of manufacture which were listed.

These thoughts all lead toward the industrial synthesis of wood. Could man devise a factory to compare with nature's tree? The substitute would depend on the same operations--collection of carbon and other elemental construction of the physical "wood" elements. We suspect, and most scientists are convinced, that organic syntheses are not controlled by magical phenomenon, but are the result of chemical andphysical principles as are the actions of the inorganic universe. If that is true we can expect to understand those principles, and probably be able to control their action. That would be the beginning of the antiseptic, science fiction state of synthetic lumber production, and although the idea is revolting at the moment, significant improvements might be found in the material and the process through such effort.

The amazing capabilities of the natural wood factory (the kind with branches and shade) cause grave doubts whether it can ever be matched in industrial terms, let alone the esthetic. Even among the world of plants the tree is an awesome producer--its yield in seven years is five times the amount of cellulose produced by seven consecutive cotton crops on the same land, and much less help is required from man for the trees than for the cotton. Considering the whole process, man gets a marvelous building material with a very small amount of trouble.

But those troubles remain. Round logs and square boards, knots and bumps and splits. There are several ways, in addition to complete synthesis, which might yield a better log. These all amount to some degree of artificiality and might be looked at as cooperation with nature at a slightly different level than that of the present.

I don't think too highly of these plans; nevertheless, I will mention a few of the possibilities for the sake of the record. Work is being done on the improvement of trees for lumber production, mainly through controlled growing. A description of the work is not necessary here.

The cambium of the tree--that layer just under the bark, where the growing, or wood production takes place--knows it is in a tree because of the material being delivered to it, the pressures and temperatures about it, and so forth. If a piece of cambium were removed from a tree, mounted on a rectangularly-shaped form, and the conditions of tree life imposed on it, then we would expect it to behave as though it were within the tree. Since the cambium layer which was used could be an ideal piece, free from branches and other imperfections, the wood produced would also be clear and ideal. The layer could be held in a flat plane; therefore, the growth would occur in planes, not cylinders, and the ideal log might be produced. Some improvement in the output of the cambium might be expected, since ideal growing conditions could be maintained at all times, and the amount of spring and summer wood could be varied at will. In a system such as this, the growth material, the sugars, would be collected from standing trees, much as maple sugar is collected at the present time.

Consideration of the physical possibilities and economic aspects must be made. An immense amount of equipment would be necessary to provide the correct conditions and maintain the necessary production. The logging operation, or raw material gathering, would be greatly simplified, as would the final production of lumber. The problems of grading, nonuniformity, and mill waste would be eliminated. The final judgment of such a system should be made on a much more thorough study of the process than I, using subjective judgment only, have made. I have decided to search in other places for improvements to lumber production.

There are a few variations of this plan which might be more (or less) practical. If the ideal cambium could be left on the tree so that the whole unit continued to function (the difference being that the special section of cambium was made separate from the trunk of the tree, perhaps in a special container mounted on the trunk) we might in actuality be able to harvest two by fours.

## SAWING

When the problem of lumber manufacture is considered with the "log" as the basic raw material, a breaking down operation becomes necessary, because lumber is smaller than the log. Lumber is produced directly from the log by sawing; when the log is broken down into chips, fibres or chemicals for later synthesis to building material, the procedure becomes quite indirect. It has been mentioned elsewhere that a process of producing satisfactory "lumber" from chips, fibres, or chemicals from logs has not been developed; the pursuit of such a process would be an excellent exercise. The other choice for investigation is the process of sawing, and that is what follows. The choice was made mainly because it seemed that little thinking had been done on the operation of sawing, judging from the lack of changes over the last century; however, the choice now seems poor, since no wothwhile results were obtained, and the synthesis from log constituents has thereby developed a certain fascination.

The sawing problem is rather simply expressed by the statement, "Produce a plane surface in a solid material." Accomplishment of this feat should be done with a minimum loss of material and energy.

If a solid material such as wood is to be sawed some one or several of the components (cellulose melocules, cells, middle lamela) will have to change in form, either broken, removed, crushed, or separated from its neighbor. It is obvious that such an action will require some form of energy. Since "sawing" requires a plane surface in the sawed material, the action of the energy must be controlled to operate only at desired points in the log. These two quantities, the energy which causes failure and the control of the action of that energy, constitute the basic aspects of a sawing action; the search for a better method of sawing will be an investigation of the various means of providing these quantities in a sawing machine.

The various types of energy which might cause failure of the wood material are:

1. Mechanical.
2. Chemical.
3. Thermal.
4. Electrical.
5. Nuclear.

Mechanical energy is delivered to the wood in the form of stress and would result from the resisting of the wood to the normal action of a gas, liquid, or solid pocessed of mechanical energy. Before causing such stress, a solid might have energy due to vibration, high velocity, stress (such as spring compression,) or height above some datum. A fluid might be compressed or have energy due to flow. A gas might also be compressed or have a high velocity.

Chemical energy would cause failure of the basic structure of wood--either the cellulose cell wall material, the lignin binder between the cells, or both--and would act by removing the stess-carrying potential of certain areas of wood.

Thermal energy would not cause failure of the wood directly but would cause a chemical reaction or would change the state of some material within the wood, thereby causing a stress or a chemical failure.

Electrical energy might act upon the bonds of the individual nolecules of the wood, which, as in most organic material, are "electron pair" bonds, or might produce heat within the material and cause failure through one of the thermal channels.

Nuclear energy, such as fast-moving atomic particles, might also work on the molecules of the wood structure directly, or change its form to chemical or thermal energy before causing failure.

By now listing the possible means of controling energies, there would be an immense number of possible combinations, but many would be nonsensical, and it seems logical to choose some of the more promising failure mechanisms and consider the reasonable systems for their control.

That procedure was followed, and the resulting systems are briefly described. Some comment is made on several of the most promising.

1. A vibrating blade of high frequency driven by magnetic field. This would be difficult to drive, have friction to a high degree, but there is a possibility of a narrow cut and low waste.

2. Hi voltage arcing along guiding edge of a metal blade: It would be difficult to provide guidance due to space and material problems; the possibility of low energy use and fine cut is good.
3. Cutting flame from gas delivered through flat blade: It would be difficult to maintain regular cutting surface, prevent fires and provide for escape of combustion products.
4. A cutting chemical in liquid form delivered through blade following the cutting action: A limitation in the speed of this operation would be likely, and an auxiliary material (the chemical) would have to be supplied.
5. Thermal energy using beamed electro-magnetic energy: The developement of a sufficiently fine beam would be difficult, and cutting of thick sections would be complicated. This has good possibilities of a very clean cut.
6. High mechanical energy particles, such as bullets. Achieving a smooth cut would be difficult, as would cutting of thick sections, and reclamation of the used particles would present a problem.
7. The forced moving blade, the present saw: This should be in the list for comparison. It has high waste of raw material, and rather severe maintenance problems, but does accomplish the task rather simply.
8. Nuclear bombardment with atomic particle beam. The high energies involved would demand large equipment,

there would be safety problems, and control might be difficult. There is a possibility of high speed and low waste.

9. Razor style cutting with an extremely narrow blade.
10. Localized boiling of the water included in the cell walls, thereby exploding the cells.
11. Hi pressure liquid forced in a jet into the wood.
12. Simple mechanical shear, as in a paper cutter.
13. Heat delivered by a hot wire or blade.
14. Abrasive particles in a liquid stream.
15. Localized freezing, and subsequent failure.
16. Chemical reaction with water of cells to produce gases which would expand and break cells.

All these suggestions have at least some semblance of feasibility. Any of them could be carried further into a sophisticated design, and then to testing programs; the only reason that this course was not followed in this work was that the time and funds for the testing work were not immediately available. One possible way to contribute something to the science of wood cutting, since the unusual ideas could not be tried, was to attempt to improve the present methods.

One of the easiest means of arriving at improvements in things is to specify what improvements might accomplish, and then set out to implement the improvements. That was done, and here are some of the things that would sawing "nicer."

1. Cut other material than wood.

2. Cut lumber from poorer logs.
3. Cut lumber sections instead of only a plane.
4. Lower operating manpower requirement.
5. Lower maintenance requirement.
6. Lower power requirements.
7. Lower wastage.
8. Devise a simpler and smaller sawing machine.
9. Provide for faster operation.
10. Cut more lumber per log.
11. Cut more logs at the same time.
12. Design more attractive machine.

These, for some strange reason, are specific examples of the four criteria of a better product as outlined by a prominent machine designer; the criteria are:

1. Increased function.
2. Lower cost.
3. Higher performance level.
4. Greater saleability.

The process for accomplishing this improvement is the standard: List many possible ways and try to work the best into a feasible solution. As was mentioned at the first of this chapter, the study of sawing had no valuable results. Perhaps the reasons are mental blocks, which I should recognize and overcome, perhaps just the drabness of such commonplace considerations gave no incentive. Nevertheless, some lists were made, glowered over, and the ideas were disgustedly discarded. There is work being done in the industry on these problems; I decided to search another area for problems and new solutions.