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A METHOD FOR RATING THE COMPARATIVE MACHINABILITY OF WOODS

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Wood Technology

A METHOD FOR RATING THE COMPARATIVE MACHINABILITY OF WOODS

Master's Problem

By Albert R. Tegge, Jr.

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This work was planned to be primarily exploratory, seeking a method whereby any wood species might be subjected to a standard machinability test, the result of which would be expressed as a machinability rating. Pilot tests were conducted showing drilling methods to be poorly suited to the determination of machinability of woods, while more extensive work indicates the planing method to be admirably suited to the purpose. The importance of employing cutting angles suited to the planing of various wood species at given moisture contents is stressed because of its direct bearing in obtaining high quality surface finish and importance in establishing correct machinability ratings.

The purpose of this paper is the presentation of data gathered during the conduct of tests designed to investigate the possibility of eventually establishing a standard method for rating and comparing the machining properties of various wood species, these expressed in standard units. The term "machinability" then, refers to the comparative ease or difficulty involved in cutting or altering the shape of any wood material during any wood-working process, when referred to an accepted standard base. Qualification of the word machinability is realized by reference to a particular machining or wood-working operation. Thus we have the descriptive expressions "machinability in planing" and "machinability in sawing", these suggesting the need for a separate set of machinability ratings for each wood-working operation. Such may, or may not prove to be the case.

Original Working Plan Adopted

Original plans involved the conduct of drilling and planing tests and determination of the physical properties of the wood material machined, particularly those of specific gravity and hardness. No hardness data was actually obtained. However, the specific gravity of any normal wood of any species is the key to calculation of all physical properties of the material involved, hardness included. This, of course, means that all physical properties of normal wood are largely functions of specific gravity. Future work may well involve the actual determination of hardness, employing established standard testing methods for the purpose rather than by calculation, this offering the possibility of closer correlation with machining properties than offered by specific gravity.

Standard Test-piece Adopted

In accordance with the original working plan adopted, it was deemed advisable to conduct all tests on end-matched material. A test-piece fifteen inches long, for instance, could be first subjected to tangential and radial planing, this followed by longitudinal, radial and tangential drilling at both ends of the test piece. The central, unaltered portion might then be used for determination of specific gravity, hardness and for further drilling tests. A test-piece cross-section of $2\frac{1}{4}$" x $2\frac{1}{4}$" would make possible the removal of 1/4" in tangential and radial planing, leaving ample room for numerous holes, say 3/4" in diameter, to be drilled at either end of the 15" test-specimen leaving, in turn, a central, unaltered portion, 2" x 2" x 8". This is the standard test-piece size adopted for determination of several physical properties of wood by the U.S. Forest Products Laboratory.

Moisture Content of Woods for Machinability Tests

In conditioning the material for machinability tests, a constant-timperature-humidity room was available, controlled at 70° F and 65% relative humidity. Every test-piece used remained in this room for three or more months and was at absolute equilibrium moisture content when tested, or 12.5% plus or minus 1.5%. Most species stabilized within 1% or less of the theoretical 12.5% value. Machinability studies, made on woods at this particular moisture content, were appropriate in representing an intermediate moisture condition. This particular value also fulfills one of the conditions adopted for standard tests for physical properties at the U.S. Forest Products Laboratory, so that hardness and other physical properties, determined under standard conditions in connection with the machinabilityy studies, may be directly referred and compared with physical data already established.

One particular division of future studies will seek the relationship between wood moisture content and machinability for various wood-working operations. However, many other divisions for study of wood machinability may be conducted at one particular moisture content which may well be approximately 6%. Much wood ~~may~~ is worked in this condition because of the fact that lumber stored within many heated buildings (65° to 75°F) stabilizes at approximately 6%. Taking advantage of this phenomenon, use of a constant-temperature-humidity room could be avoided.

On the other hand, air-dried wood material, or kiln-dried lumber, stored for a long period out of doors, will stabilize between 12 and 18%, dependent upon season and locality. Selection of moisture content for machinability studies, therefore, may be dependent upon facilities available, but for unlimited work, the advisable conditions dictated by the wood moisture content - machinability study must be followed.

Summary of Reasons for Adopting a Test-piece of Given Standard Specifications

Selection of $2\frac{1}{4}$" x $2\frac{1}{4}$" x 15" as the standard size of test-specimens, and some of the reasons therefor, have already been mentioned. These and other of the more important reasons are summarized below:

(1) Greater chance of selecting clear and straight-grained specimens than with larger sizes.

(2) Difficulty of procuring many wood species in thicknesses exceeding $2\frac{1}{4}$ to $2\frac{1}{2}$".

(3) Small specimens make possible shorter moisture conditioning time required.

(4) Possibility of using test-pieces of small size on a bench jointer with direct motor drive, avoiding slippage and losses of the belt type drive.

(5) Multiple use of a single test specimen, providing end-matched material for each test (That is, the drilling, planing and standard tests for physical properties already mentioned).

Machinability of Metals

Professor O.W.Boston, at the University of Michigan, in his tests designed to determine the machinability of metals, has used various methods for establishment of machinability ratings, simultaneously recording Rockwell and Brinell hardness figures for each test-piece, these being excellent indices to the physical properties of the metals concerned, much the same as specific gravity of wood largely controls the physical properties of that material. Professor Boston's tests include measurement of:

(1) Torque and thrust developed in drilling.

(2) Component forces on a planer tool.

(3) Energy absorbed in milling of metals.

(4) Drill penetration under fixed load and rotation speed. (Test found to bear no constant relationship to machinability ratings as determined by other methods).

In machining woods, it is readily seen that the drill test is the only one of Professor Boston's methods for rating machinability that may be directly applied to tests on woods. However, obvious variations of his methods present themselves, these being planing, sawing and turning.

An investigation of drilling and planing, as possible methods for the rating of machinability of woods, was decided upon as advisable preliminary work, being the most simply applied for the equipment on hand, and giving greatest promise of worthwhile results.

Drilling Tests

Professor Boston's equipment for the measurement of torque and thrust developed in drilling of metals was actually used in drilling studies involving woods. Alterations were made in order that the very low torque and thrust forces set up in drilling wood might be measured and automatically graphically recorded.

Pilot tests soon revealed the use of drilling methods to be rather poorly suited to the determination of machinability ratings for many wood species. Figures I, II and III, which are fairly accurate reproductions of the original graphs automatically recorded, make many of the disadvantages evident.

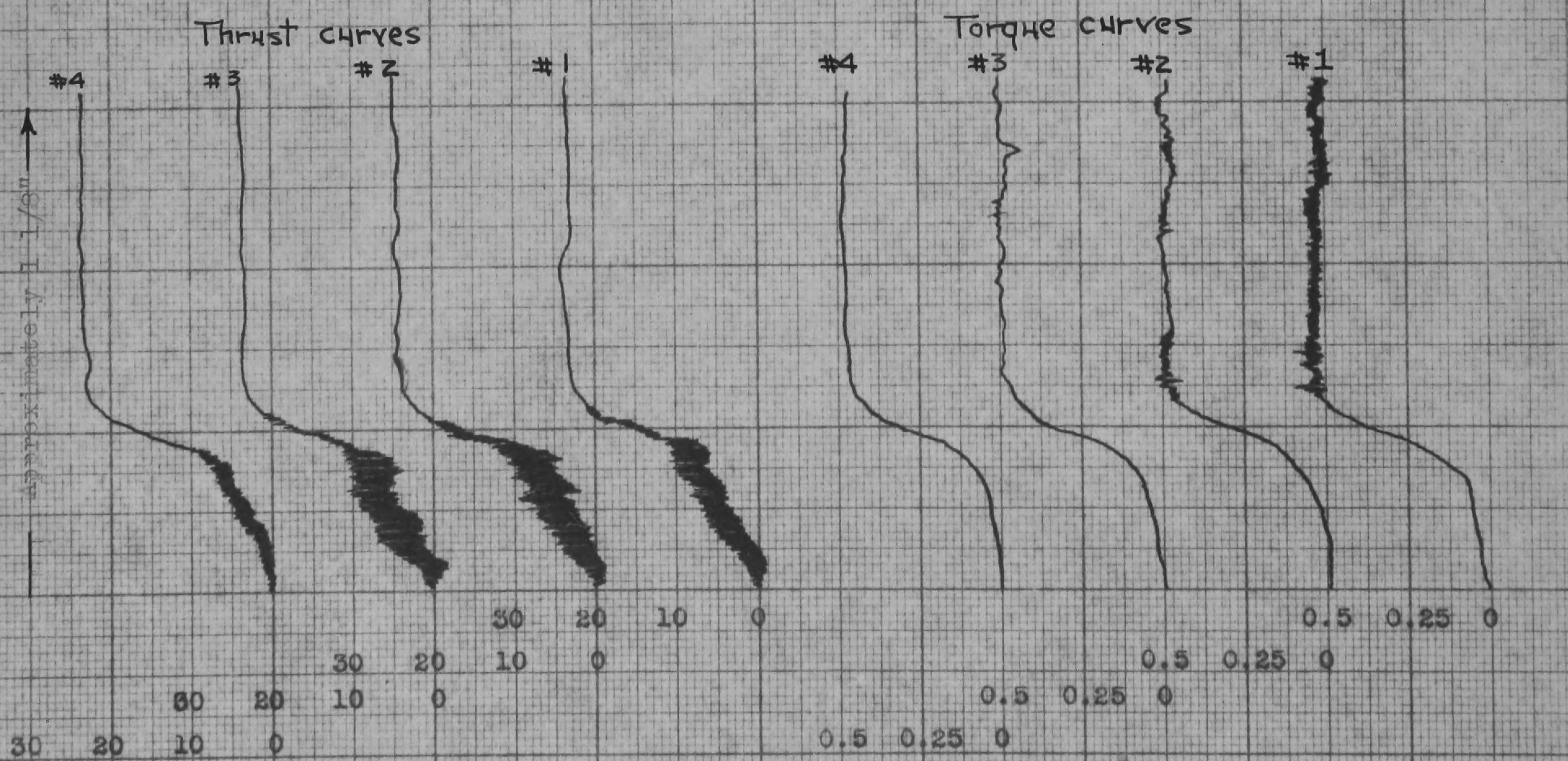
Figure I, representative of radial drilling tests made on yellow poplar, a relatively homogeneous species, illustrates the most uniform results obtained in the drilling of several homogeneous species. Presumably the average of results obtained from many identical runs of this caliber on each test-piece, would be suitable for the machinability rating. Thus the possible application of the method to tropical woods, nearly all of which are diffuse-porous, and therefore relatively homogeneous.

FIG. 1

TORQUE AND THRUST DEVELOPED IN RADIAL DRILLING OF YELLOW POPLAR

Using taper-point machine drill with sharp point angle, helix angle 67 and 7/64" web thickness.

Repeat runs using a 3/4" drill at 573 r.p.m., 0.009" / revolution feed.



Thrust in pounds (approximate).

Torque in foot-pounds (approximate).

The consideration is important since tropical species will probably be introduced in abundance within the next decade or two, and the machining qualities of nearly all are practically unknown at present.

Radial drilling must be employed if uniform results are to be secured, for tangential drilling of even the most homogeneous species introduces marked variations in torque and thrust as the drill point and cutting edges advance through wood material of varying density; that is, from growth ring to growth ring and within individual growth rings (spring and summer wood). When spring and summer wood are markedly contrasted, great variations in torque and thrust are developed in tangential drilling. The effect may be seen by referring to Figure II. When drilling a ring-porous hardwood, as white ash, the variations have an even greater amplitude than has been noted in connection with Douglas fir.

True radial penetration in drilling makes possible the elimination of extreme torque and thrust variations, this being accomplished by drilling of wood material of given average density. However, true radial penetration is possible only through a small part of the drilling stroke, and provided that the growth rings are of almost perfect uniformity.

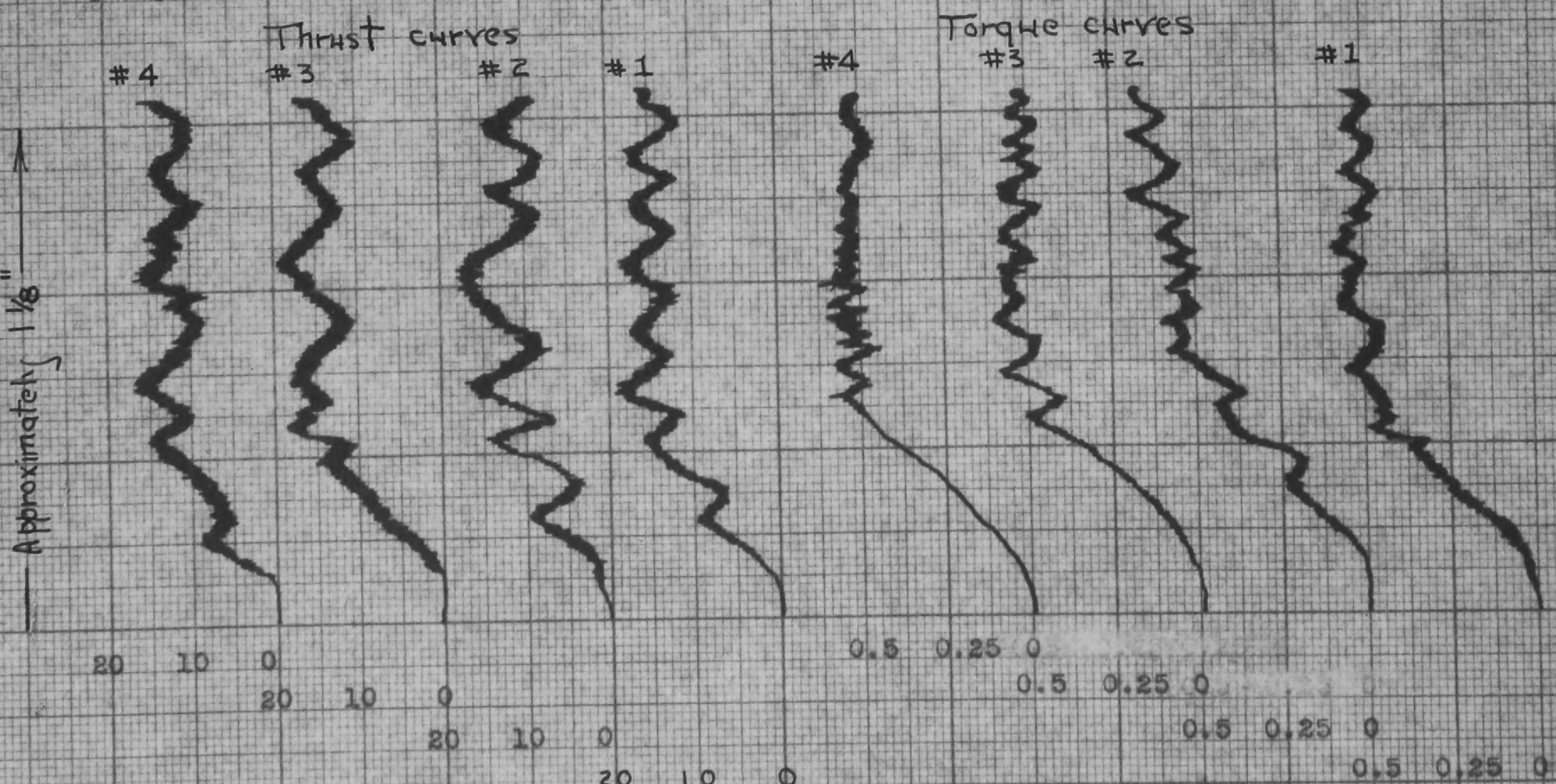
Figure III is presented in order to give an idea of the effect of increased drill penetration rate. Incidentally, the smaller deviations of regular frequency, recorded on almost every torque and thrust graph, are due to slightly off-center

FIG. 11

TORQUE AND THRUST DEVELOPED IN DRILLING DOUGLAS FIR

Drilling perpendicular to "radial" surface. Growth rings at 40° angle.

Taper-point drill used. All curves recorded at 573 r.p.m. and 0.009" / revolution of feed.



Thrust in pounds (approximate).

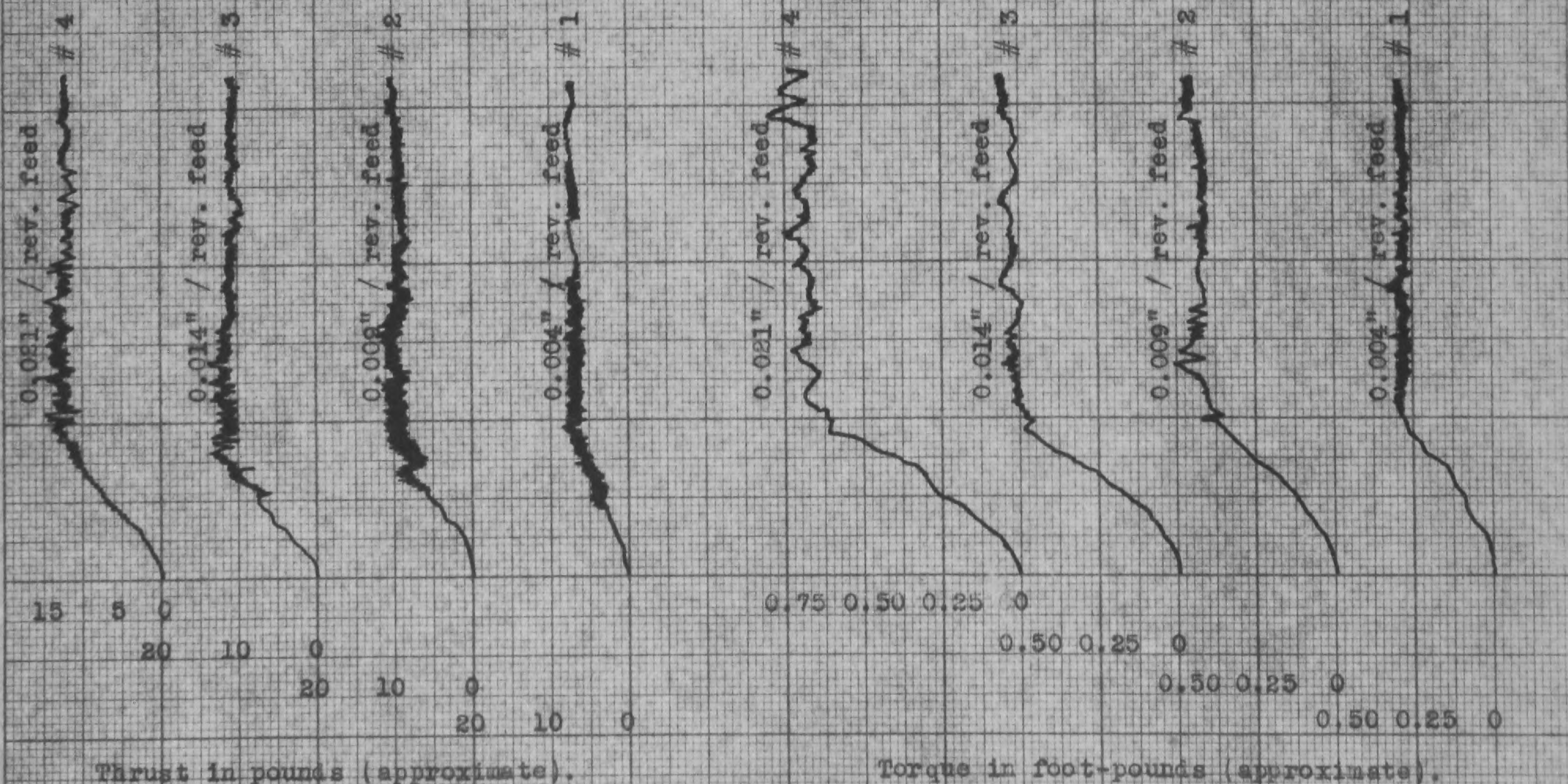
Torque in foot-pounds (app.).

FIG. III

TORQUE AND THRUST DEVELOPED IN RADIAL DRILLING OF YELLOW POPLAR

Using taper-point machine drill with sharp point angle.

573 r.p.m., 3/4" drill, helix angle 67°, 7/64" web.



rotation of the drill. The perfect centralization required to produce a line free from the effects of vibration is almost impossible to realize.

The difficulties involved in establishing machinability ratings from torque and thrust values recorded in drilling, are readily appreciated. In addition to a few of the difficulties already mentioned, grinding of drills to a standard sharpness would be especially difficult. However, the method may prove useful, especially if machinability ratings established from radial drilling data may be correlated with ratings established by other machining operations. The method is simple and fast, once the apparatus has been set up. This is also true of the planing set-up, to be described later, but use of the drilling method would probably prove most advantageous on the extremely dense tropical species, provided that sufficient accuracy is obtainable.

Drilling tests, with torque and thrust values automatically recorded, show more promise of being useful in drill-type efficiency ratings and tool-life studies. In order to investigate this possibility, graphical comparison of repeat runs were made on a single test-piece, under given rotation and feed speeds, using four different types of drills, the wood-bits being fitted with brad point to eliminate the forced and uncontrolled feed secured with the screw point:

(1) Standard machine bit with inscribing cutters (double spur).

(2) Acme machine bit designed to bore thoroughly seasoned hickory, oak, hard maple etc. Cutting edges form an inverted V, easily accessable for re-sharpening, and no inscribing cutters are present, as on the standard machine bit.
(3) Taper-head machine drill suited to the boring of shallow holes in hard and soft woods. Very similar to a standard metal-cutting twist drill, except that the point angle is more acute for purpose of free feed. The twist provides more clearance for chips and no lands are present as on the metal-cutting drill.
(4) Standard machine twist drill.

It has been observed that newly sharpened twist drills bore with much the same freedom as do sharp bits especially designed for wood-boring, and have similar thrust requirments with given speed of rotation and advance. It would appear that twist type drills would have a far greater life, before necessity of re-sharpening, than wood bits with delicate cutting edges, easily dulled and sharpened with difficulty. However, it has been suggested that continued drilling would alter the comparative drilling efficiency of bits and drills that have been observed when using newly sharpened edges. Recording of torque and thrust in drilling would probably be an excellent means for the making of such comparative drill-life studies.

The wood-bit, of course, provides a smoother bore in some cases, and minimizes the tendency of the wood to split, particularly in end-boring. Use of the wood bit also makes possible the boring of deep holes. These advantages are more important than the disadvantage of rapid drill dulling in many classes of work.

Although many test runs were made, no further time will be spent in their consideration. The drilling method seems inferior to the planing method, which is to be described, for the establishment of machinability ratings. Then too, ratings established by drilling tests, may differ from ratings derived from other wood-working operations, as by planing and sawing. As such, the drill rating is pertinent when drilling only is considered, but probably would not rank in importance with planing machinability ratings or those established in sawing tests, should a relationship be discovered.

Planing Tests

The standard test-piece size adopted as 2¼" x 2¼" x 15" makes possible planing tests on a small bench jointer. Advantages that may be claimed in using such equipment are:

(1) Direct motor drive through flexible coupling, avoiding belt slippage and reducing power losses.

(2) One-quarter horse-power motor operates at or near peak efficiency during most planing tests (0.005 to 0.01" cut at 23' / minute).

(3) Low range watt-meter (0 to 750W), of high sensitivity (5-watt scale divisions) may be used, accurately indicating power inputs to peak load when using a 1/4 h.p., 3,400 r.p.m., single phase cutterhead drive motor.

(4) cont.

Planing cuts made on practically every test-piece required power inputs ranging between 200 and 600 watts, this involving variation in motor efficiency of only plus and minus 4%. Efficiencies were considered in all calculations made for power consumption in planing.

(5) Use of a small bench jointer would be desirable for permanent set-up designed to rate the machinability of any test-piece or new species coming in. This would be particularly desirable if more than one planer was found necessary for rating the machinability of several classes of woods (To be considered later).

Disadvantages in using a small, bench type jointer:

(1) Shallow limit to depth of cut permissible in the planing of hardwoods at high feed speeds.

(2) Jointer feeding and receiving tables being short, are unable to accomodate a long test-piece.

Conditions Adopted for Planing Machinability Tests

Following are the standards adopted for the tests about to be described and some of the reasons for their selection are given:

(1) Power feed at a uniform 23' / minute.

No faster feed than 20 to 25' / min. is possible in planing the denser hardwoods when using a 1/4 h.p. cutter-head drive.

(2) Cuts of about 0.01" maximum used

No deeper cut is possible on the denser hardwoods with feed speeds at 23' / min. when a small jointer is used.

(3) An approximate 0.005" was termed to be a light cut.

(4) Wood of all species was planed at a moisture content of approximately 12.5% for reasons already explained.

(5) A cutting angle of 10° was selected as being best suited to the planing of the particular species investigated, among which hardwoods and conifers of intermediate hardness predominated. Corresponding clearance and sharpness angles were 35° and 45° for the particular knives and cutter-head used.

Cutting angle used in the planing of any wood at given moisture content is probably the most important variable in the planing operation when quality of surface finish is of importance. A method is suggested, in a section to follow, whereby machinability of any wood species is rated under conditions producing best possible surface finish. Table I is an aid in suggesting cutting angles that should be employed in the planing of certain woods at varying moisture contents. Reference to Figure IV will make the identity of the terms cutting, clearance and sharpness angles evident.

Difficulties Encountered During the Conduct of Planing Tests

Extreme difficlty was had in obtaining satisfactory empirical data for purposes of study of machinability in planing. Conditions were such that a mcuh worn bench jointer had to be used, this being the only direct drive planer available. Time for conduct of tests was also very limited after the passage of three months required in collection and conditioning of the woods used.

TABLE I - Recommended Cutting-angles [1]

Species	Manufacturer "A" [2] "Green"	Manufacturer "A" [2] "Air-dried"	Manufacturer "A" [2] "Kiln-dried"	Manufacturer "B" [3] "Wet"	Manufacturer "B" [3] "Dry"	Manufacturer "B" [3] "Bone-dry"
Ash, curly	20°	15°	10°	30°	10°	0°
Ash, plain						
Basswood	25	25	25	30	20	10
Beech	25	25	20	20	10	0
Birch, curly	25	20	15	20	10	0
Birch, plain	25	25	20			
Cherry	25	25	20			
Chestnut	25	25	25			
Cottonwood	25	25	25	30	30	20
Elm, hard	25	[illegible]	20	30	20	10
Elm, soft	25	25	25			
Gum	25	25	20	20	20	10
Hickory	25	20	15			
Mahogany, plain	25	25	20			
Mahogany, figured	25	20	15			
Maple, plain	25	25	20	20	10	0
Maple, birds-eye	20	15	10			
Oak, plain	25	25	20	30	20	10
Oak, quartered	25	20	15			
Sycamore, plain	25	20	20			
Sycamore, qtd.	25	25	20			
Walnut, black	25	25	20			
Walnut, Circassian	25	20	15			
Poplar	25	20	20	30	20	10
Cedar	25	[illegible]	20	30	30	20
Cypress	25	25	25	30	20	10
Fir	25	25	20	30	20	10
Hemlock	25	20	15	30	30	20
Larch				30	20	10
Pine, yellow	25	25	20			
Pine, white	25	25	25	30	20	20
Redwood	25	25	25	30	20	10
Spruce	25	25	25	30	30	20

Foot-notes for Table I

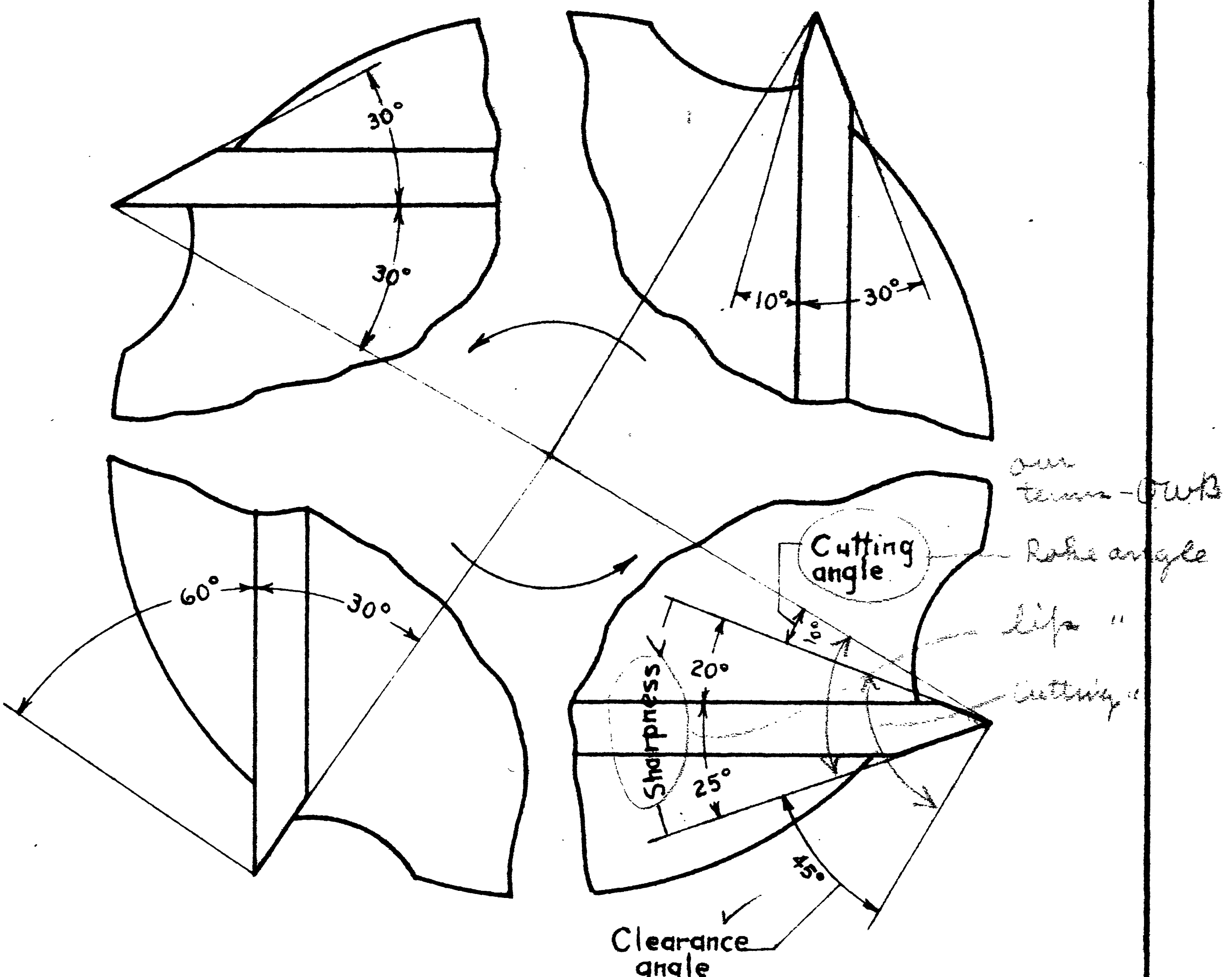
1 It has been announced that the English Forest Products Research Laboratory will release Forest Products Research Bulletin # 16 dealing with their extensive studies in the planing and sawing of woods. This bulletin should include recommended cutting angles for native and colonial timbers, which may be compared, in part, with the varying recommendations of Manufacturers "A" and "B" presented above.

2 Manufacturer "A" uses 20, 25, 30 and 35° clearance angles, and knife-bevels of 20, 15, 10 and 5° corresponding, in order, with the 5, 10, 15 and 20° cutting angles. Feed-speed varying inversely with hardness of the species being planed, is recommended in combination with the knife angles given.

3 Manufacturer "B" uses the cutting and clearence angles and k knife-bevels shown in Fig. IV. The 10° cutting angle and corresponding complimentary angles, were used in all planing studies dealt with in this paper.

FIG. IV

ALTERATION OF CUTTING ANGLES



The method of altering cutting angles by back-honing, illustrated by the two cuts at the right, is by no means ideal, altering the sharpness angle as it does. Use of extra cutter heads, holding knives at the required angle, eliminates the changing sharpness angle. A block provided with means of adjusting the knife angle would accomplish the same purpose.

Some flexibility is provided by using a reversed knife, as is seen in changing from a 30° cutting angle (upper left) to a 0° cutting angle (lower left).

Extremely desirable data concerning the dulling of cutter knives during test runs, as determined by planing of controls, was entirely lost when power consumption readings for test runs became variable toward the latter part of the work. Poor condition of the jointer made itself evident in this manner and was, in fact, the cause of all difficulty encountered. However, that data actually presented in this paper was gathered during satisfactory test runs. All doubtful data has been discarded.

It would be well to bear in mind the unavoidable limitations attatched to this particular study.

Representative Planing Test Run Series

A planing test series on a single test-specimen always involved five passes "with the grain" and five "against the grain" for a single setting at given depth of cut. For illustration see Table II.

Reaction on Test-piece During Planing Investigated as a Possible Means for Rating Machinability

The column headed "reaction" in Table II refers to the net force required to feed the test-piece into the cut at the rate of 23 feet per minute. It has been obtained by deducting the force required to feed the test-piece across the planer table (frictional resistance) from the toal force required for the feed during the planing operation. The method is unsatisfactory in many ways, most important of which are:

TABLE II - Typical planing test run series

Species: Bald cypress

Specific gravity: 0.523 (at 12% moisture content)

Planing: On a truly radial surface

Width of cut: 2.23"

Finish obtained:

With the grain: Very slightly woolly

Against the grain: Very slightly woolly

With the grain			Against the grain		
Reaction	Watt-meter reading		Reaction	Watt-meter reading	
	During run	Idle		During run	Idle
1.5#	250 watts	94	2.75#	255 watts	102
1.0	240	92	2.5	260	110
1.5	250	91	2.5	260	110
1.75	245	90	2.5	245	108
1.75	240	90	3.0	255	105
	Av. 245 watts			Av. 255 watts	

0.045" / 5 passes — 0.0385 / passes

= 0.009" av. depth of cut — = 0.0077 av. depth of cut

(1) Unsteadiness of reaction forces indicated on the spring balance used. The short duration of the test, when using a test-piece only 15" in length, does not permit stabilization of the spring balance.

(2) One-quarter pound scale divisions on the balance used were too rough for the accuracy necessary. Smaller scale divisions would aggrivate the unsteadiness of (1).

(3) Difficulty in obtaining an accurate frictional value.

Generally then, the method is unsuitable as a substitute for watt-meter readings obtained by use of such an instrument in the cutter-head drive motor circuit. A refinement of the method used in obtaining reaction values, eliminating the oscillating motion of the spring balance prior to stabilization, and indicating small force units with accuracy, may offer a solution. However, the difficulty in obtaining a true frictional value still exists. Difference in level of feed and receiving tables make the latter difficult.

Calculations for Power Consumption in Planing

Presentation of a second typical test run series, illustrating the excellence of results obtained in radial and tangential planing of the very non-homogeneous species white oak, will also serve to illustrate the method used in calculating power consumption in planing (see Table III).

TABLE III - Typical planing test run series

Species: White oak (hhartwood). Width of cut: 2.23"

Specif. grav. : 0.697 (at 12% m.c.) Rings per inch: 21

Planing: Radial minus 5°. Tangential minus 15°.

Radial Planing				Tangential Planing			
Watt-meter Readings							
With grain		Against grain		With grain		Against grain	
During run.	Idle	During run.	Idle	During run.	Idle	During run.	Idle
370	97	355	98	350	95	400	97
385	98	375	100	390	95	410	96
385	99	365	100	395	95	410	96
390	98	370	98	410	95	400	95
390	96	375	97	390	95	405	95
390	97	360	97	380	94	400	95
380	97	360	98	395	94	400	95
380	97	375	98	385	94	410	95
390	97	350	98	390	94	405	95
380	97	370	98	385	94	290	95
380	95	370	97				
375	97	360	95				
4595		4365		3870		3930	
383 watts av.		364		387		393	
31.7W/cu.in./min.		31.2		37.6		36.8	
0.1285" by 12 passes, = 0.0107" av. Finish OK		0.1250" by 12 passes, = 0.01042" av. Finish OK		0.1015" by 10 passes = 0.01015" av. Finish OK		0.1050" by 10 passes = 0.0105" av. Finish OK	

Calculation of Average Power Consumption in Planing

$$\frac{\text{Sum total wattage x efficiency (at average wattage)}}{\text{Width of cut x total depth of cut x feed speed (276"/min.)}}$$

= watts per cubic inch of material removed per minute.

From the foregoing tangential planing series; planing against grain:

$$\frac{3{,}930 \text{ watts x } 54.4\% \text{ efficiency}}{2.01" \text{ x } 0.1050" \text{ x } 276" \text{ / min.}} = 36.8 \text{ watts / cu.in. / min.}$$

Planing with the grain:

$$\frac{3{,}870 \text{ watts x } 54.6\% \text{ efficiency}}{2.01" \text{ x } 0.1015" \text{ x } 276" \text{ / min.}} = 37.6 \text{ watts / cu.in. / min.}$$

This corresponds to milling in metal cutting. OWB

Relation of Depth of Cut to Power Consumption in Planing

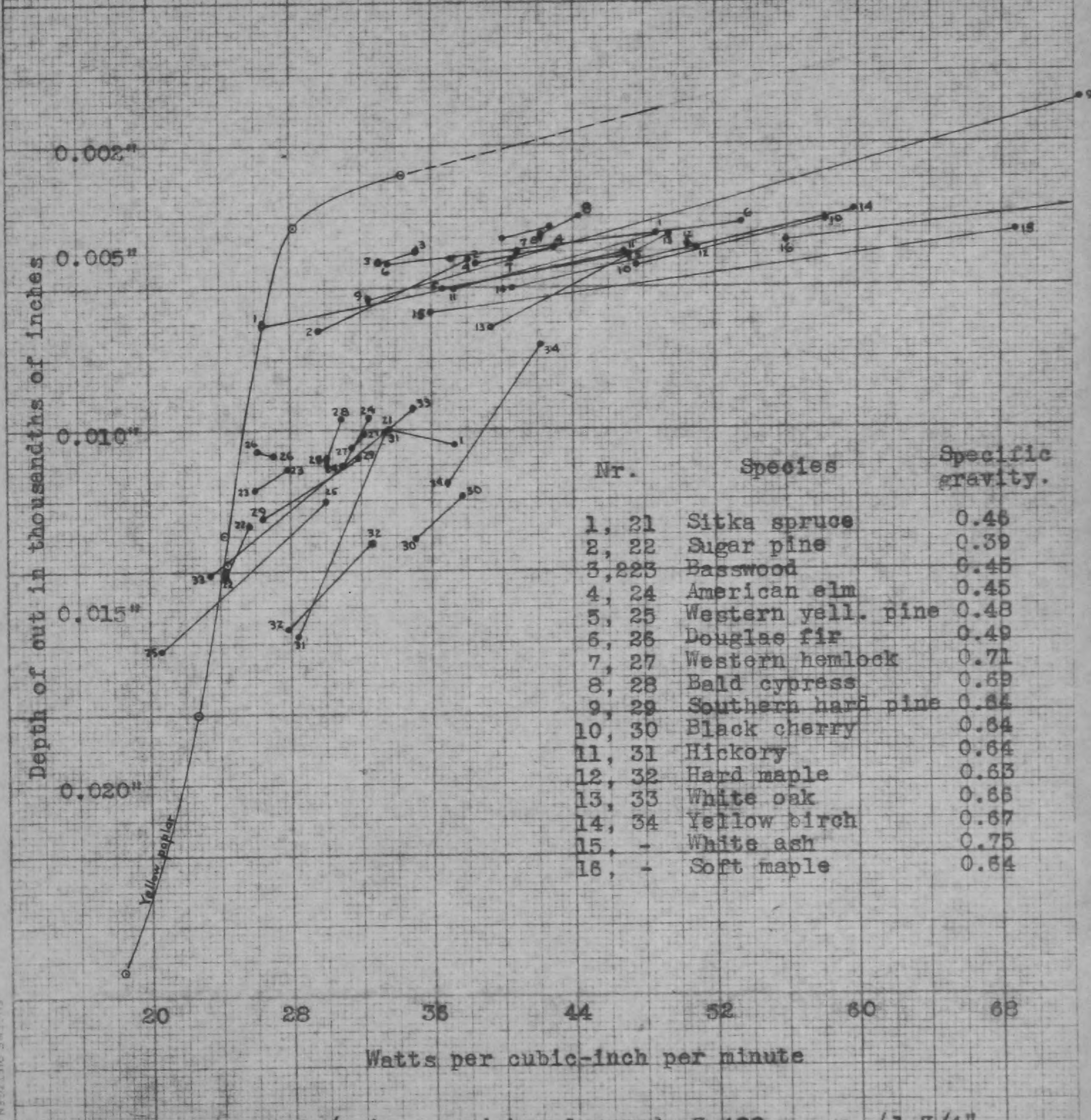
Figure V involves the plotting of data gathered during radial planing studies on a number of wood species. This data was reduced by calculation, as in the foregoing example (Table III), and power consumption with and against the grain plotted separately against their respective average depths of cut. The order in which the tests were conducted is indicated by an appropriate figure accompaning each pair of points connected by a straight line. The line is drawn between points to bring out trends and relationships and is not a true curve such as would be obtained in connecting many points involving power consumption for varying depths of cut. Such a curve is shown applying to yellow poplar and accompanies the straight lines indicative of curve trend for other species in Fig. V. This curve does not belong to this particular series and, accordingly, has not been numbered. The tests establishing the power consumption for yellow poplar were conducted prior to the planing of the other species represented in Fig. V and thus at a time when planer knives were in sharper condition.

The data graphically presented in Fig. V is significant in indicating the following:

(1) The efficiency in planing, in terms of power consumption per unit volume wood material removed, increases with depth of cut.

FIG. V

POWER REQUIREMENTS FOR THE PLANING OF VARIOUS WOOD SPECIES



Nr.	Species	Specific gravity.
1, 21	Sitka spruce	0.46
2, 22	Sugar pine	0.39
3, 23	Basswood	0.45
4, 24	American elm	0.45
5, 25	Western yell. pine	0.48
6, 26	Douglas fir	0.49
7, 27	Western hemlock	0.71
8, 28	Bald cypress	0.69
9, 29	Southern hard pine	0.64
10, 30	Black cherry	0.64
11, 31	Hickory	0.64
12, 32	Hard maple	0.63
13, 33	White oak	0.66
14, 34	Yellow birch	0.67
15, -	White ash	0.75
16, -	Soft maple	0.64

Feed speed, 23' / min.; peripheral speed, 3,400 r.p.m. (1 3/4" cutting circle).

Cutting angle, 10°; clearance angle, 35°; sharpness angle, 45°.

Width of cut, 2 to 2 1/4".

(2) Power consumption per unit volume material removed increases at a very rapid rate when depth of cut falls below 0.006", the relationship being almost a straight line of slight slope for cuts less than 0.003".

(3) Indications are that, for many species, power consumption per unit volume of material removed decreases at a less rapid rate as the depth of cut exceeds 0.010" and is less than 0.020". The rate may increase beyond the latter limit when the chip removed becomes quite thick.

(4) It is possible that power consumption per unit volume of wood removed by planing, with and against the grain, are much the same. The angle at which the grain intersects the planed surface influences the depth of cut. Thus, with any test-piece, a series of passes in planing against the grain will result in the removal of more material than an equal number of passes in the opposite direction on the same test-piece (the condition would not be so marked when deep cuts are made). Since planing efficiency increases with depth of cut (Fig. V), the planing series against the grain will yield an average figure of lower power consumption per unit volume of wood material removed. Reference to calculations for white oak in Table III will reveal power consumption figures almost equal for planing with and against the grain, this indicating that the direction of the cellular wood elements was almost parallel to the planing surface.

(5) Curves drawn, representing power consumption in planing, as those of Fig. V, tend to form a band with individual curves "parallel" to adjacent curves.*

* This is especially true over that portion of the curves representing cuts of 0.005" depth or less. In Fig. V, the lighter cuts were made with the cutter knives newly sharpened; that is, planing series numbers 1 to 19 inclusive. Deeper cuts, or series 21 to 34 inclusive, made immediately following the light cut series, do not show marked parallelism, the slope of curve segments depending upon the species considered. Note that these segments are not at all parallel to the corresponding segment of the "complete" curve for yellow poplar; the planing series for the latter species being made with very sharp knives. For dulling effect, after completion of 19 planing series on 19 species, compare the curve segment for yellow poplar, labeled 19, with the corresponding segment of the complete yellow poplar curve. The flat portion of the curve, typical of lighter cuts, is seen to be "lowered" as the knives become dull. As would be expected, power consumption per unit volume wood material removed increases simultaneously, so that the two effects cause the curves to be displaced in two directions. In the case of Fig. V, the movement is downward and to the right. Another possible effect of dulling of cutters, as suggested above, is alteration of curve slope for power consumption curves, especially those representing cuts 0.010" and deeper.

(7) That machinability of a given wood species is not entirely governed by its specific gravity. In fact, for some species, such as Douglas fir, western hemlock and black cherry, specific gravity is very misleading, and not at all indicative of machinability in planing.

(6) The relative position of each curve is representative of the comparative machinability of the wood it represents and under the particular test conditions employed. It is possible that comparative machinability ratings may be altered for different woods in respect to one another if test conditions are changed.

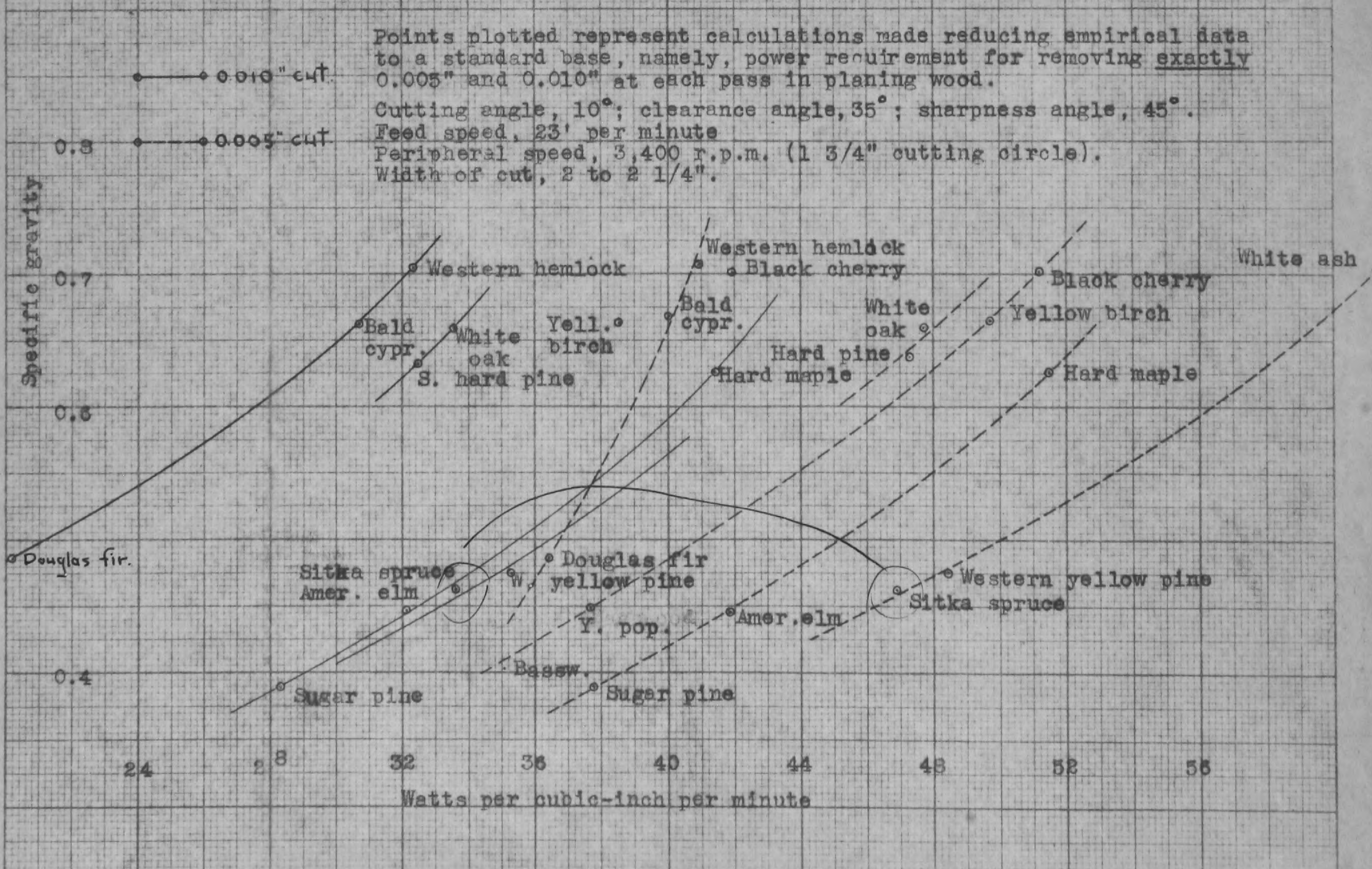
Consistency of Machinability Ratings Established at Varying Depths of Cut

Fig. VI makes use of the same data as was employed in the construction of Fig. V. Interpolations have been made to determine the power that would be required in planing test-specimens with depths of cut exactly 0.005" and 0.010".

In Fig. VI, power consumption is plotted against specific gravity and shows the partial independence of machinability in planing with respect to specific gravity of the wood. Data gathered to make possible the drawing of a complete curve, as seen for yellow poplar in Fig. V, would make for more accurate results and eliminate the necessity of using the interpolation method mentioned above. The graphs presented in Fig. VI are important in that rating of comparative machinability of woods

FIG VI

POWER REQUIREMENTS FOR THE PLANING OF VARIOUS WOOD SPECIES



is seen to be much the same when the cut is either 0.005" or 0.010", in spite of the fact that efficiency in planing for the two depths of cut is widely different.* The points plotted, representative of various species, have been connected by lines merely to indicate the possibility of relationship between specific gravity and machinability in planing, with species classed by groups, and to separate the points representative of shallow and deep cut. Classification of species by groups, according to their machinability, may be governed by one influencing factor independent of specific gravity, the latter also exerting an influence. It is also apparent that wood structure of given type does not exert a uniform influence on the machinability of given species. Both coniferous and hardwood material, forinstance, may fall into a given machinability class.

Allowance for Dulling of Cutters

While the curves and points of Figs. V and VI are representative of various wood species, they do not bear a true relationship to one another, since dulling of cutter knives has not been considered in calculations made. However, the fact that the planing of the various wood species has been conducted in the same order, for the two basic depths of cut, has preserved the relationship seen in Fig. VI. Future work must always involve the gathering of data to permit compensating for the effect of dulling of cutter knives. These data would be considered and applied to the readings from each test made.

or keep sharpness constant [illegible]

* The relationship has also held in spite of dulling of cutters.

Tangential Planing

Most test runs were made on radial surfaces in order that the effect of variations in specific gravity encountered might be minimized. Tangential test runs were made, but the observations were unsatisfactory due to the condition of the jointer used. This, together with the fact that calculation was not made to determine separately the specific gravity of the tangential test strip removed, made the power consumption data for radial and tangential planing, even though on the same test-piece, not truly comparable. It was thought that a machinability rating, established by radial or tangential planing on the same test-piece, would be the same, provided the respective specific gravity values involved were identical, but the identity, or possible relationship, remains to be established. In any case, conditions permitting, it seems advisable to conduct all planing tests for machinability ratings on radial surfaces.

Recommendations for Future Tests When Using Planing Methods for the Rating of Machinability of Woods

If it is possible to establish a relation between the power requirements in making very shallow cuts, when using the bench jointer, with power requirements encountered in commercial planing, use of the jointer will be decidedly preferable.

The advantages of using small test-pieces on the bench jointer, and operation of cutter-head drive motor at peak efficiency, when planing such test-pieces, have already been set forth.

One other advantage, not yet noted, is the small investment that will attach to the bench jointer. This consideration is particularly important when a permanent planer set-up is required for standard rating of machinability. If use of more than one planer proves advisable, consideration of investment and space requirement is still more important. Use of four planer set-ups is suggested in paragraphs to follow, this as a matter of advantage and convenience in selecting cutting angles properly suited to the planing of the species in question. The changing of cutter-heads offers an alternative but the method has its disadvantages.

Use of a bench jointer with cutter-head driven by a 1/2 to 3/4 h.p. motor will make possible depths of cut similar to those encountered in commercial planing. The jointer should be fitted with long feed and receiving tables to properly accomodate a 20" test piece, the minimum length desirable when employing feed speeds of 20' per minute. Higher feed speeds may be desirable to more closely simulate commercial planing practice, this requiring larger test-pieces and in turn, longer feed and receiving tables. An accurate device for adjustment of these table to accomodate different depths of cut is extremely desirable. Watt-meter readings are not uniform until this adjustment is properly made.

In conducting tests, the separate determination of specific gravity of wood removed in tangential and radial planing should be provided for. A fast counter-balance type scale, accurate to one gram, located near the planer, should be used for the purpose.

The effect of changing cutter knife angles is the most important consideration in any machinability study involving the planing of woods. Quality of surface finish is largely dependent upon proper selection of cutting angle according to the species and moisture content of the wood being planed. Feed speeds employed also exert an influence but are of secondary importance to proper selection of cutting angles.

In conducting tests for this particular study a 10° cutting angle was used for the planing of all species. Fig. IV and Table I, presented under a previous section entitled 'Conditions Adopted for Planing Machinability Tests', clear up the inter-relationships between cutting, clearance and sharpness angles and give an idea of the cutting angles that should be employed for the planing of various species within certain moisture content ranges. It is obvious that the 10° cutting angle, selected for these tests, is not perfectly adapted to the planing of any species but rather only to those falling into a group of particular specific gravity range and having certain structural make-up.

An ideal comparison of the machinability of various wood species would, in one sense, involve the use of one particular group of standards from which no deviation would be allowed. However, the use of such a set of rigid standards deprives a machinability rating, for certain wood species, of much significance. For instance, what would be the value of a comparative machinability rating if the test conditions involved in establishing that rating caused impossible quality of surface finish? A cutting angle suited to the planing of white pine is certainly not suited to the proper planing of white ash and other heavy species in dry condition.

For these reasons, possibly the use of four jointers, fitted with cutters involving say, 0°, 10°, 20°, and 30° cutting angles, seems advisable. Then feed-speeds and depth of cut may be varied on any one of the four jointers, making a number of combinations which should be limited to avoid undue complications, and yet serve to rate the machinability of any wood species under the conditions which should be applied in its planing.

Thus with any new tropical species coming in, the proper test procedure would be:

(1) Establishment of planing conditions best suited to the species.

(2) Rating of machinability, using proper test conditions as established in (1).

Since power consumption per unit volume of material removed serves as a standard base for comparison, the rating of machinability of various wood species, when machined under optimum conditions, seems well advised. Conversely, there can be little value in rating the machinability of a species under test conditions which, for instance, cause poor quality of surface finish or low efficiency in planing.

Thus woods of various species will fall into various groups according to their requirements in planing, or other machining operation used for comparative rating tests, and ideal requirements for the machining of the species are simultaneously established with the machinability rating.

Indications are, that planing tests carried out in the future, given excellent equipment and ample time for conduct of tests, should yield excellent results for rating the comparative machinability of woods. Steady watt-meter readings, which may be obtained during the planing of any species, indicate that the planer tables are in perfect adjustment in respect to the cutter knives, and data so obtained seems to be most reliable.

Rating of Machinability by Other than Planing Test Methods

It is conceivable that the machinability of woods may be successfully rated according to their response to sawing, turning and other wood-working operations. Sawing studies, particularly, show promise of yielding results similar in quality to those obtained during planing studies for the rating of machinability, and probably would be conducted in a similar manner. Of course, other variables and considerations are applicable to sawing studies, but basic principles are the same.

Thus we have the study of economical and proper sawing methods to consider before establishing standards, much the same as will be necessary to the standardization of planing studies designed for the rating of machinability.

The sawing problem would involve study of relation between saw-tooth shape, size and spacing, angle of hook, peripheral speed, rate of feed, set, top-bevel, resistance to feed, depth of cut and height of table above the saw axis of rotation. With these relations established, the effect of each variable upon saw life and power consumption is next in line. Rapid saw dulling, particularly on the denser species, will probably make the problem quite complicated.

Published Literature on Machinability of Woods and Proper Woodworking Methods

Data on planing and sawing relationships have been gathered by the English Forest Products Research Laboratory, and the results should now be available in the new Forest Products Research Bulletin known as Project 16. Other foreign literature, chiefly English, German and Russian, of possible assistance, is listed in the bibliography following.[2] The German work, properly translated, should be most valuable.

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Appendix

'A Method for Rating the Comparative Machinability of Woods'

Equipment Used for the Study

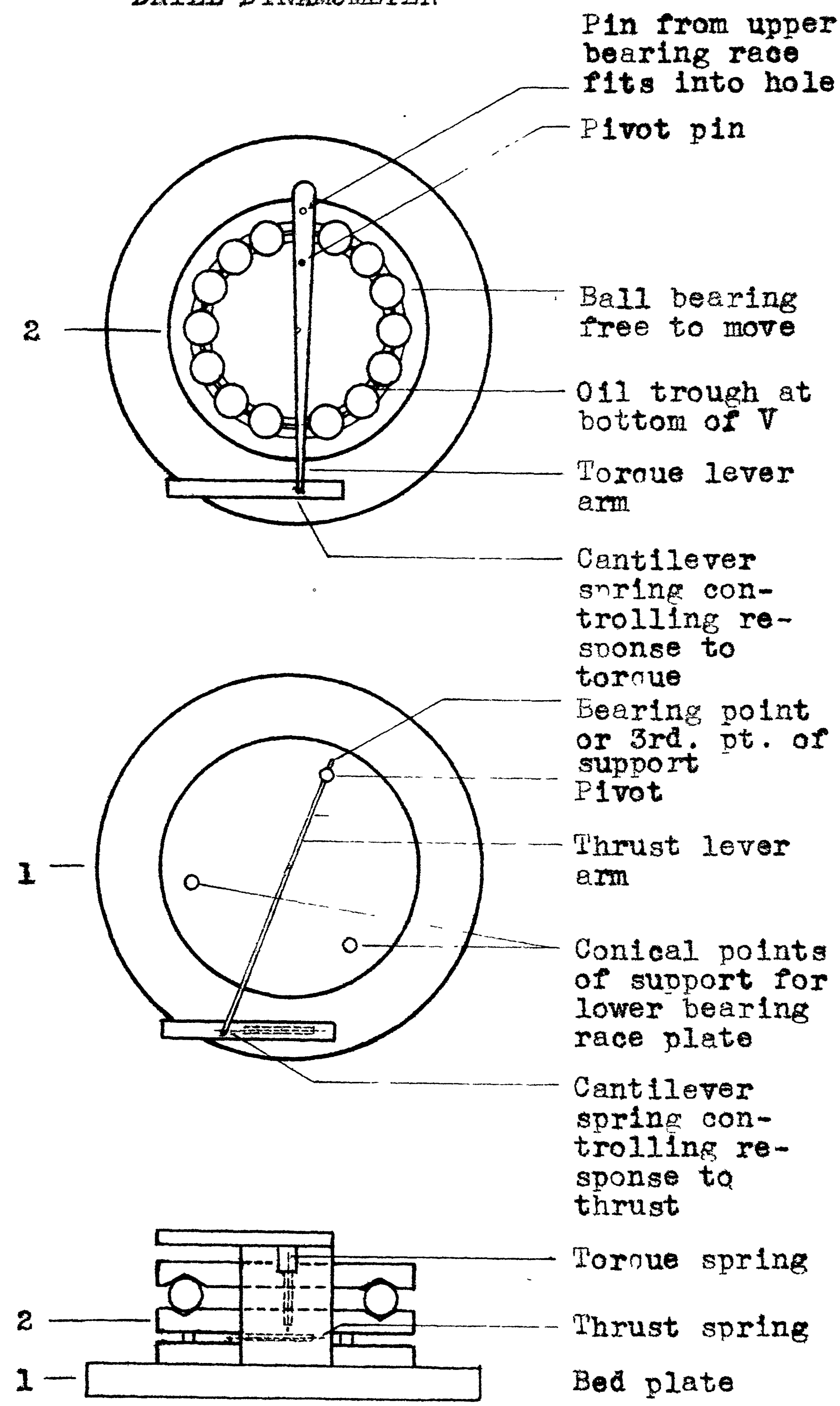
Professor O.W.Boston's* drill dynamometer, designed to simultaneously graphically record torque and thrust developed in drilling metals, when employing twist drills of small diameters,** was altered and used to record torque and thrust developed in drilling woods with 3/4" bits and drills of various designs. Before alteration, the dynamometer was capable of recording a maximum thrust of 350 pounds and maximum torque of 7 foot pounds. Changes made reduced these values to 65# and 2 foot pounds, which range was found to be suitable in obtaining reasonable results with 3/4" bits or drills rotating between 140 and 600 r.p.m. and feed of 0.004" to 0.021" per revolution. The torque and thrust range was sufficient under these conditions when drilling woods within specific gravity range of 0.40 (sugar pine) and 0.65 (hard maple). Greater torque and thrust range would probably be required in drilling native tropical species with specific gravity exceeding 0.75 if feed speed is high (5 to 10" / min.).

Torque and thrust range is readily altered on Prof. Boston's drill dynamometer by substitution of cantilever springs of varying cross-section and therefore stiffness. Reference to Plate I will make clear the control of sensitivity and range exercised by these simple springs, free to move at one end and rigidly held at the other. Ends of lever arms, transmitting

* Professor of Shop Practice, University of Michigan.
** 1/4", for instance.

Plate I

DRILL DYNAMOMETER



forces set up by torque and thrust, bear against the ends of the cantilever springs and simultaneously actuate recording pens, the mountings for which are actually lever arms with fulcrum so located that large magnification of movement is realized. Thus the drill dynamometer is nothing more than a pair of scales conveniently arranged to automatically measure and record torque and thrust forces set up in drilling. A train of magnifying lever-arms make possible automatic recording of torque and thrust values and proper selection of controlling springs determines the recording range of the instrument.

Fig. I, Plate II shows a general view of the drill dynamometer and drill press used for pilot tests investigating the possibility of using the drilling method for rating comparative machinability of woods.

Fig. II, Plate II is a view showing the drill dynamometer from rear and side. Note the wood specimen clamped to the upper, or movable plate of the dynamometer.

Plate II

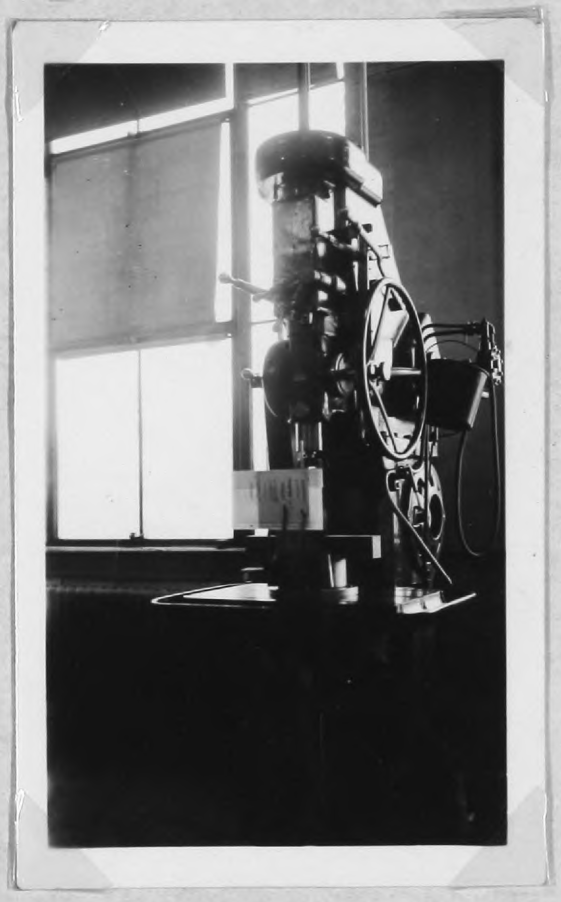


Fig. I

Drill press and dynamometer used for drilling studies

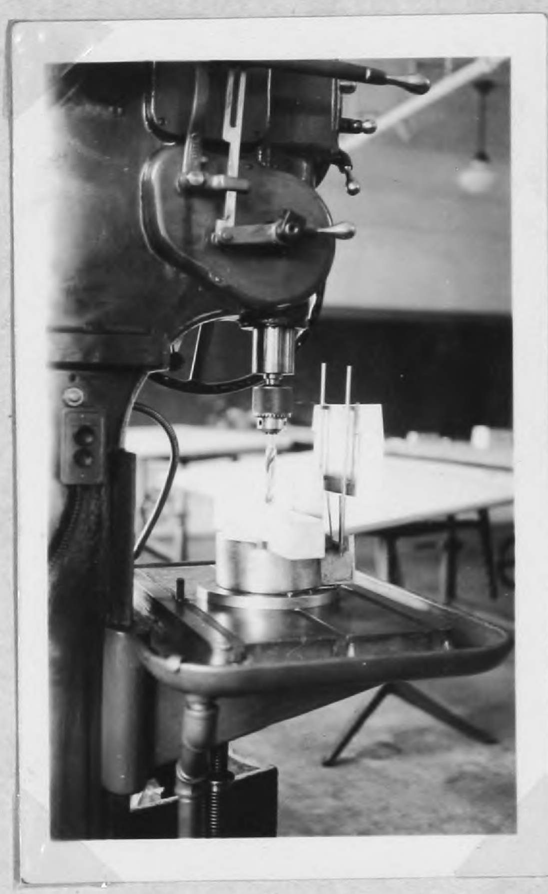


Fig. II

Drill dynamometer

Planing Dynamometer

The introduction to the section devoted to the investigation of planing as a means of rating machinability of woods, suggests that a watt-meter, inserted in the cutter-head drive motor circuit, has served as a dynamometer for planing studies. Using this method, no allowance is made for electrical and frictional losses in motor and cutter-head bearings or in the flexible coupling between drive motor and cutter-head. Allowance for these losses may be advisable in establishment of standard machinability ratings provided that they may be properly and accurately accounted for. On the other hand, inclusion of losses in machinability ratings probably would be desirable to manufacturers of planing equipment and to others who find it difficult to estimate power requirements of new machines.

Fig. I, Plate III shows the general planing set-up employed. On the right is the 4-inch bench jointer directly driven by a 1/4 h.p., 3,400 r.p.m. motor through a flexible coupling. The test specimen is shown in place at the mid-point of the planing pass,weighted from above by a simple brass bar centrally located on the test piece. At the extreme left is the worm gear speed reduction box powered by a 1/4 h.p. motor. This was used to draw the test piece across the planer tables at uniform speed. Using a 3/16" multi-strand steel cable wound about the 7/8" output axle, used as a drum, the linear speed resulting was 23' per minute, a value used for all planing tests. One end of the flexible cable was attatched to a pair of miniature tongs, convenient for grasping the end of the test piece. The horizontal position of the cable terminated at the gear box output drive,

Plate III

Fig. I

Planing set-up employed in studying the machinability of woods

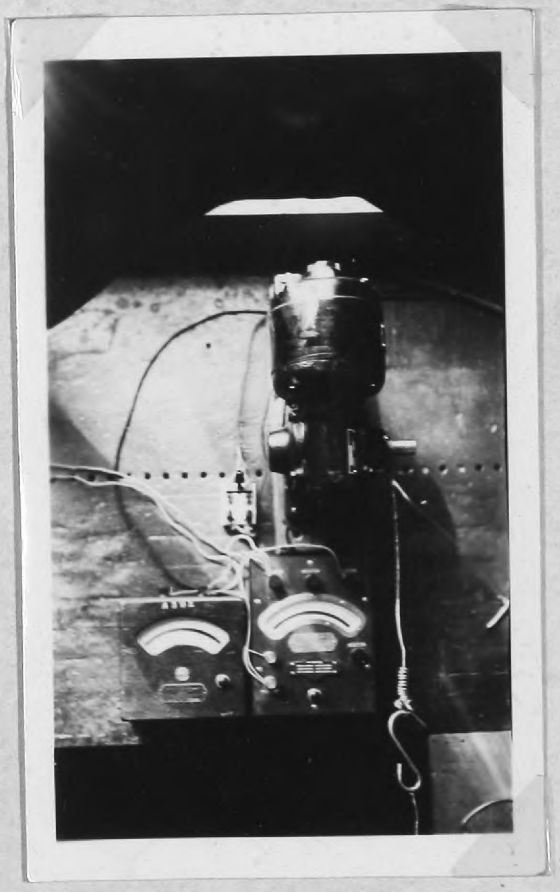


Fig. II

Mechanical planer feed, watt-meter and volt-meter

Fig. III

Bench jointer, test piece and test piece weight where it wound about this axle one and one-quarter times and or dropped vertically to a heavy weight attatched to its end. A wire was provided to pull the weight to a height exceeding the length of the test piece by 3 or 4". Allowing the weight to hang while the test piece, and therefore the cable, was held in place, caused the cable to wrap tightly about the gear box output axle. Simultaneous rotation of the axle and release of the test piece pulled the latter across the rotating planer knives at uniform speed. When the weight, oriented directly below the gear box output drive, finally reaches the floor, the tension on the cable is released and movement of cable and test piece ceases. Length of the stroke may be adjusted by limiting or extending the vertical movement of the weight attatched to the cable end. Such a device is sometimes called a "nigger-head".

Watt-meter and volt-meter may be seen between the worm gear drive and bench jointer in Fig. I, Plate III.

Figs II and III, Plate III, are self explanatory in showing views of parts of the planing set-up of Fig. I seen at various angles.

Supplementary Figures Applying to Text

Comparative Efficiency in Boring with Various Bits and Drills

Appendix Figs. Ia, Ib, Ic and Id are interesting in comparing the efficiency in drilling realized with various types of bits and drills when drilling the same test piece under identical feed and rotation speeds. Note that torque and thrust requirements are much the same, no matter which of the four types of drills are used.

Only the standard machine drill, designed for metal drilling (Fig. Id), reveals a thrust requirment differing appreciably from the other three types, this due to the very obtuse point point angle. Grinding of the drill to a more acute angle permits the drill to feed more freely and reduces thrust requirement considerably. The effect may be noted by referring to Fig. Ic, where thrust has actually been reduced to a value under that observed when using bits especially designed for wood-boring (Figs. Ia and Ib).

Data presented in Figs Ia, Ib, Ic and Id was recorded when using new drills as sharpened by the manufacturers.

Using the drill dynamometer method, drill life studies made from time to time, employing various drill types, would probably prove most informative.

Refer to the section entitled 'Drilling Tests', contained in the text, for description of drills used and for other discussion.

Appendix Fig. Ia

Appendix Fig. I a

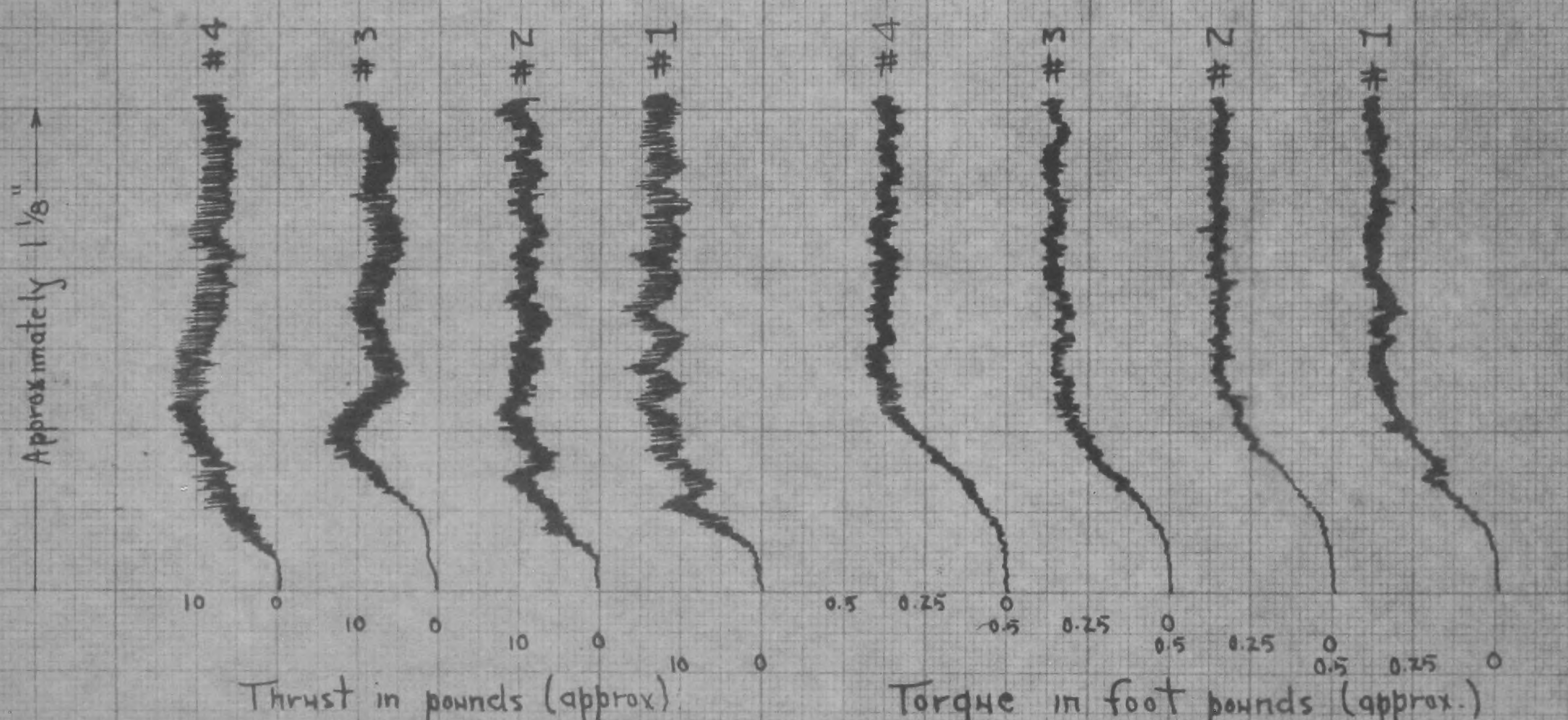
Torque and Thrust Developed in Drilling of Sugar Pine

Using Standard Machine Bit

Compare with Figs. IV-b, V-a & V-b

Wood at approx. 12 % m.c.

3/4" machine bit
573 R.P.M.
0.009"/rev. feed
} All curves



Appendix Fig. Ib

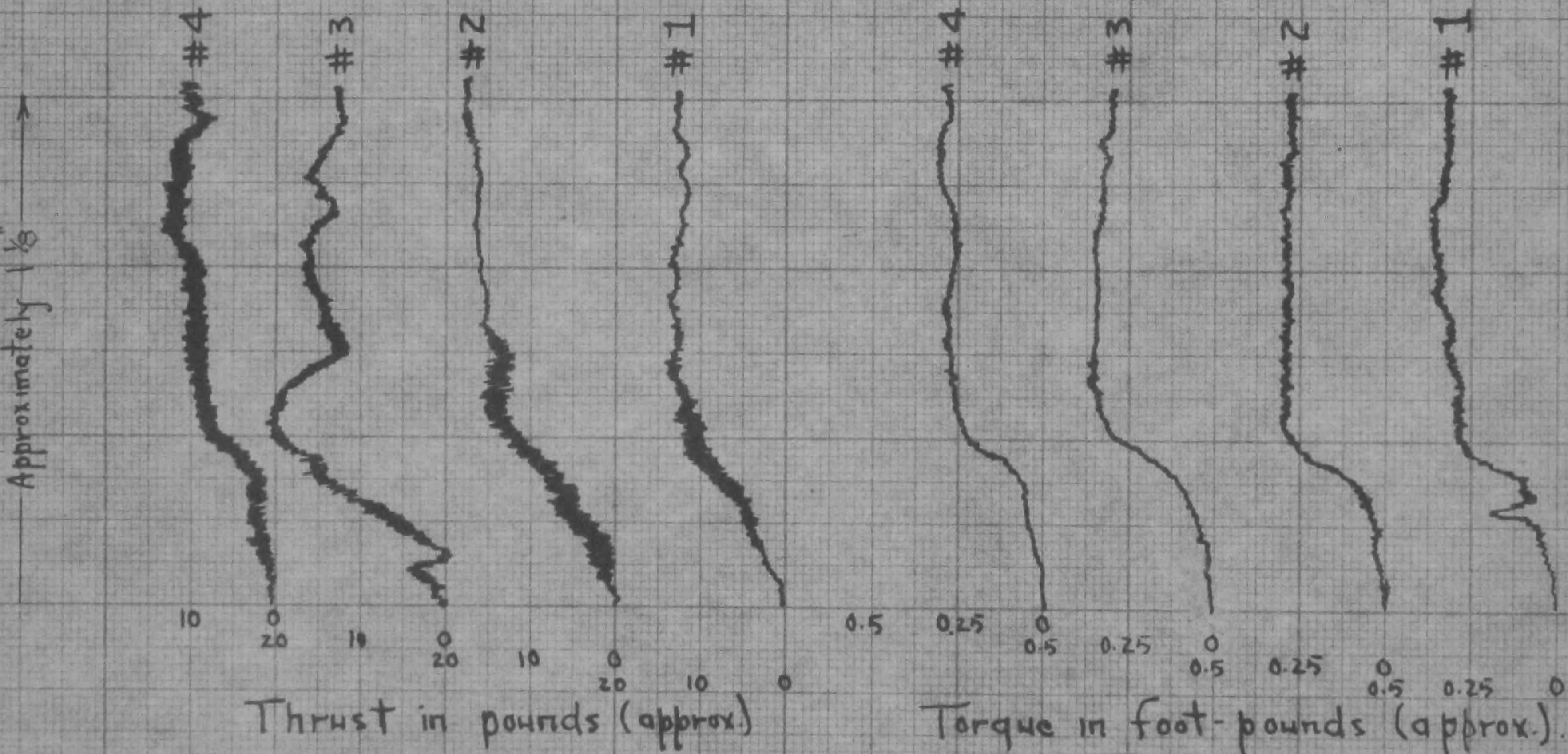
Torque and Thrust Developed in Drilling of Sugar Pine

Using Acme Machine Bit

(Compare with Figs. IV-a, V-a + V-b)

3/4" bit
573 R.P.M. } All
0.009"/rev. feed } curves

Wood at approx. 12%. m.c.



~~Fig V b~~

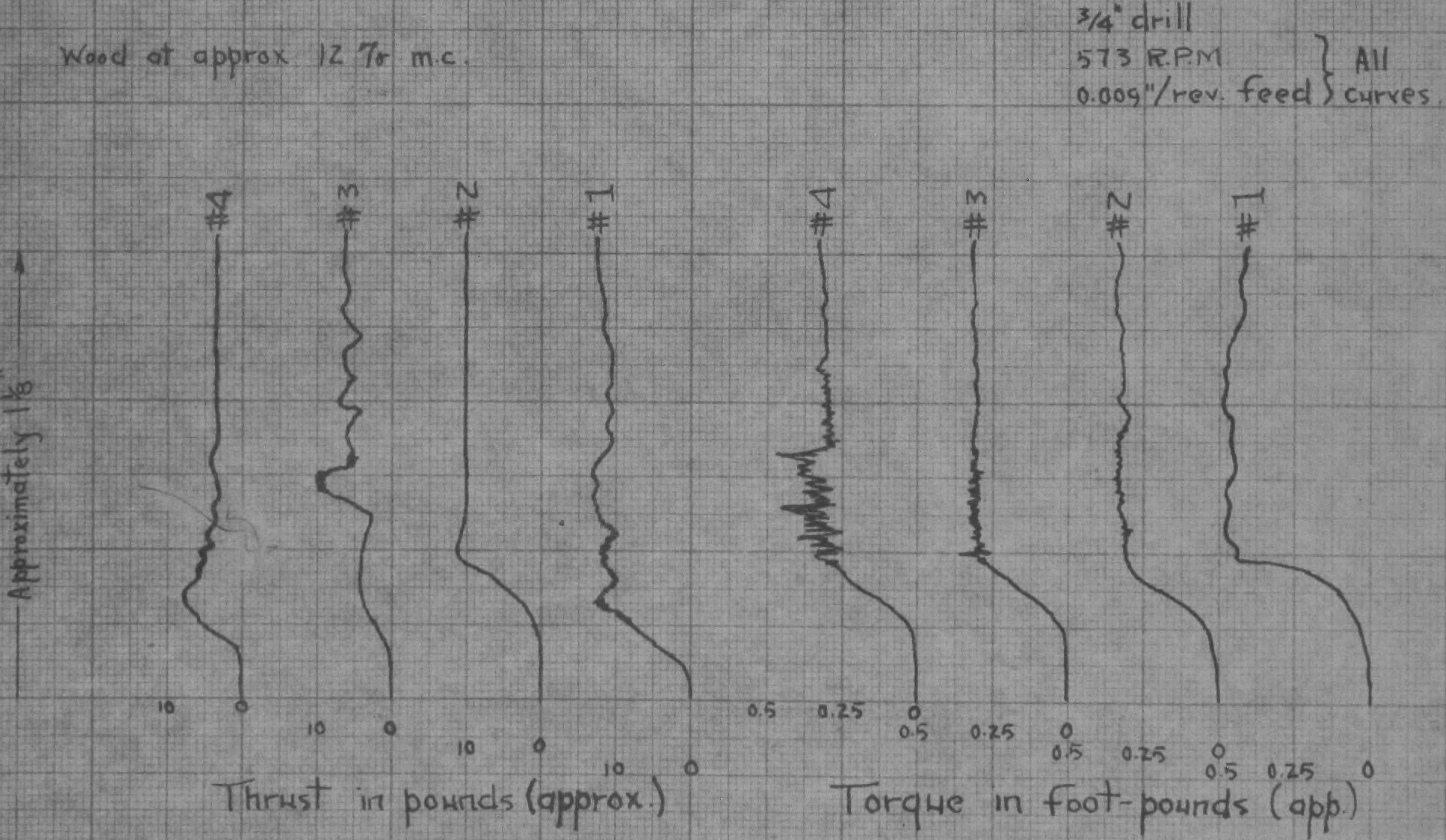
Appendix Fig. Ic.

TORQUE AND THRUST DEVELOPED IN DRILLING OF SUGAR PINE

TAPER - POINT

USING ~~STANDARD~~ MACHINE DRILL

(Compare with Figs. IV-a, IV-b + V-a).



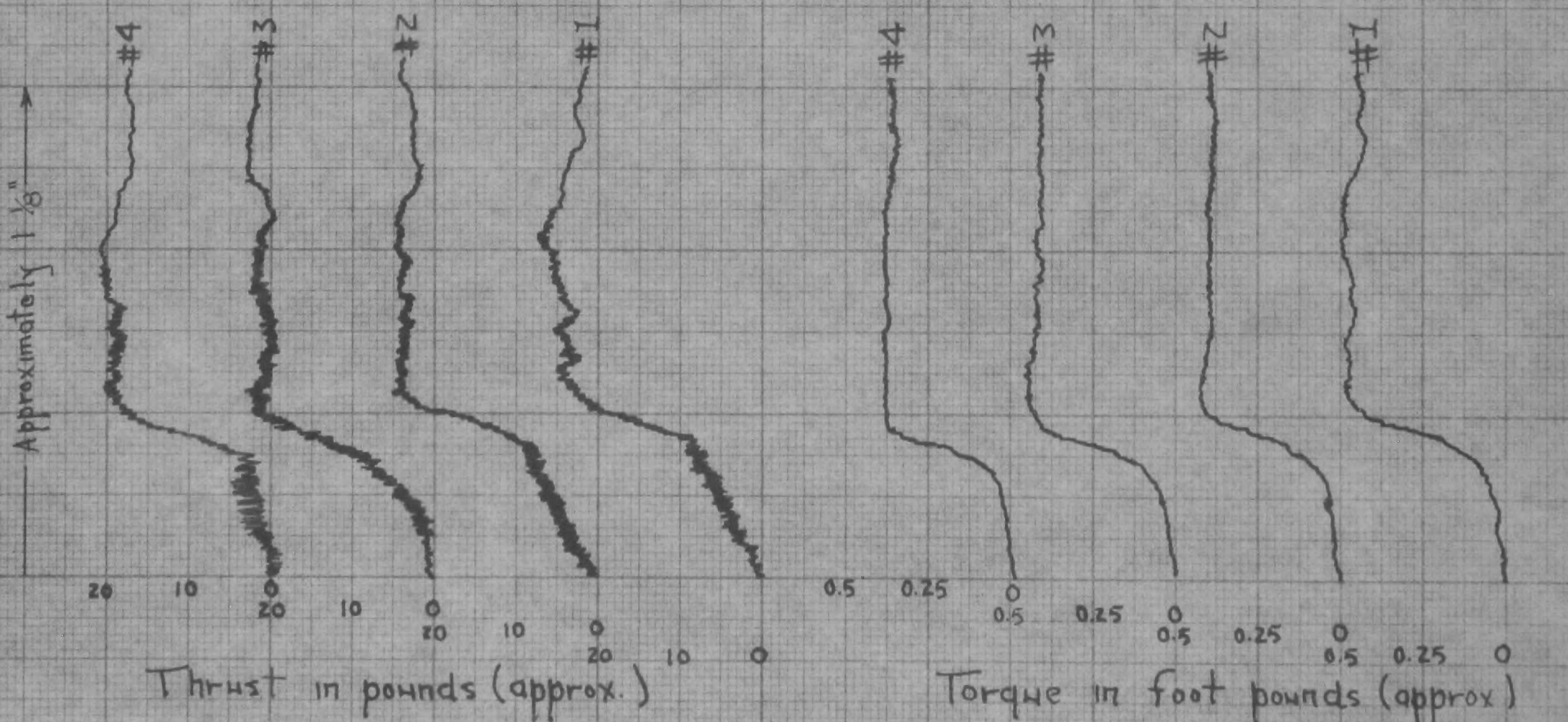
Appendix Fig. I d.
~~Fig. V-d~~

Torque and Thrust Developed in Drilling of Sugar Pine Using ~~Taper-point~~ Standard Machine Drill

(Compare with Figs. IV-a, IV-b + V-b)

All curves { 3/4" drill; 573 R.P.M.; 0.009"/rev. feed }

Wood at approx. 12% m.c



Effect of Increased Feed Speed in Drilling

The relationship between torque and thrust developed in drilling with increased feed speed at given rotation was suggested in connection with radial drilling of yellow poplar in Text Fig. III. A similar series for tangential drilling of that species is seen by referring to Appendix Fig. II. Note the variation in torque due to change in specific gravity as the drill point and cutting edges advance from growth ring to growth ring.

Efficiency Curve for Cutter-head Drive Motor

App. Fig. III represents the efficiency curve applying to the single phase, 3,400 r.p.m., 1/4 h.p. motor used in directly driving the 4" bench jointer employed for planer machinability tests. Examination will show that efficiency varied only plus and minus 4% when drawing from 200 to 600 watts. Most planing passes developed loads requiring from 300 to 500 watts input. Percentage efficiency, corresponding to average wattage drawn, was applied in all calculations involving the power consumption per cubic inch of wood material removed in planing. For examples, see Text Tables II and III and accompaning calculations.

"Knee" of Depth of Cut - Power Consumption Curve

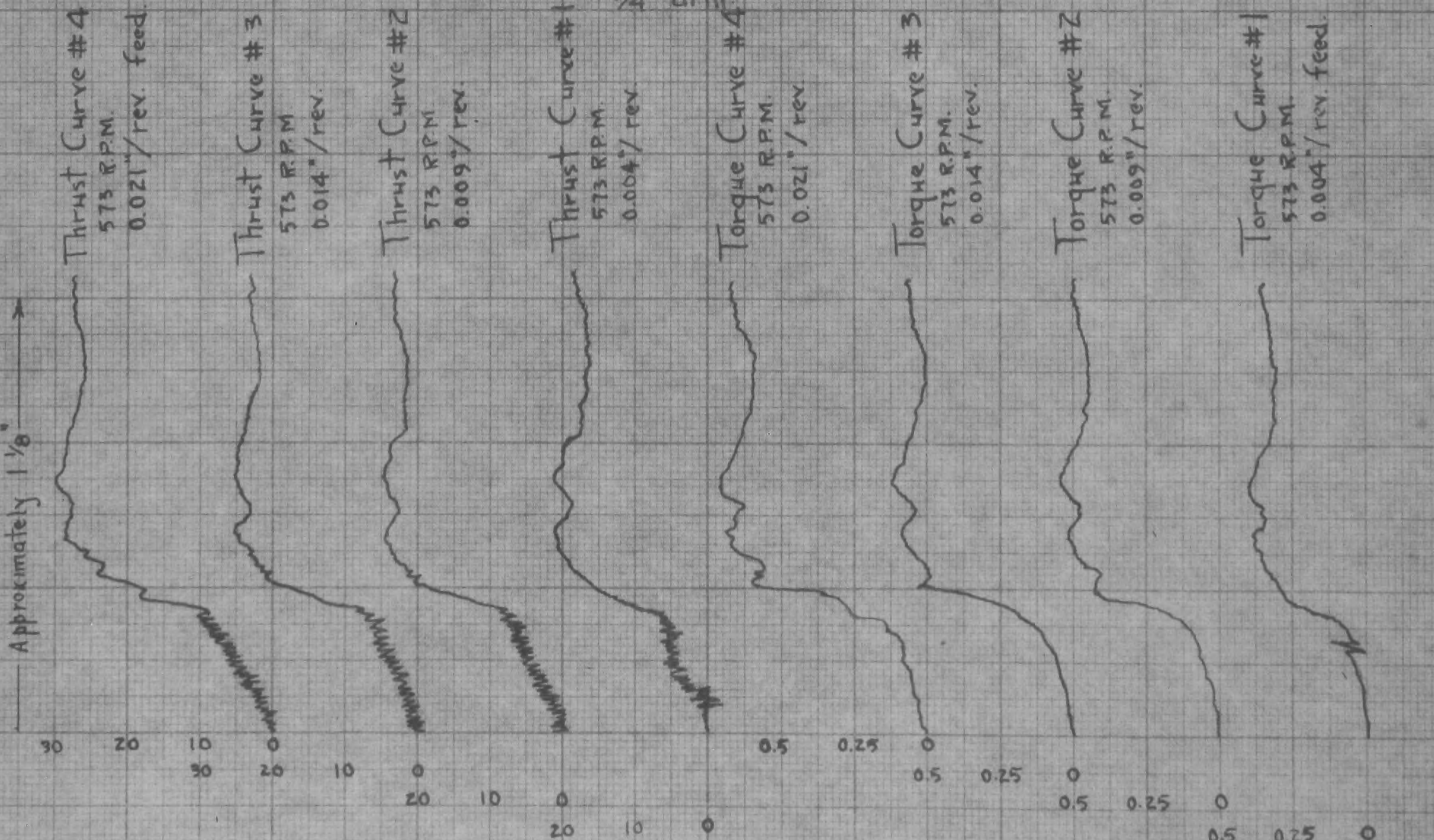
Power consumtion trend for depths of cut between 0.007" and 0.01" was conspicuously lacking in Text Fig. V. Depth of cut between these limits suggests the shape and position of the "knee" of the curve for each species, and would connect the relatively straight curve segments representative of "light" (below 0.006") and "heavy" (above 0.01") cuts. In considering the

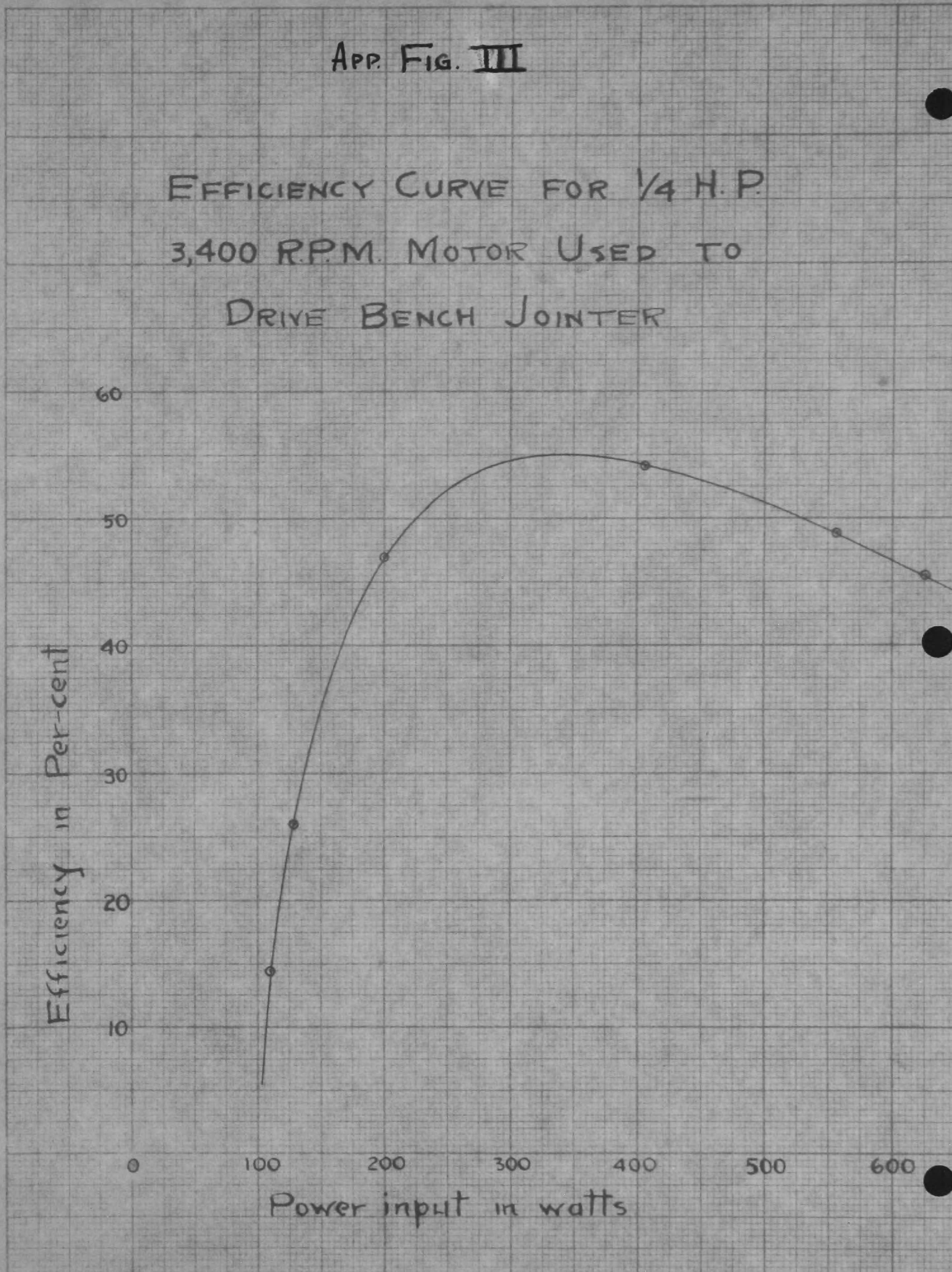
App. F[illegible]. II

Torque and Thrust Developed in Tangential Drilling of Yellow Poplar

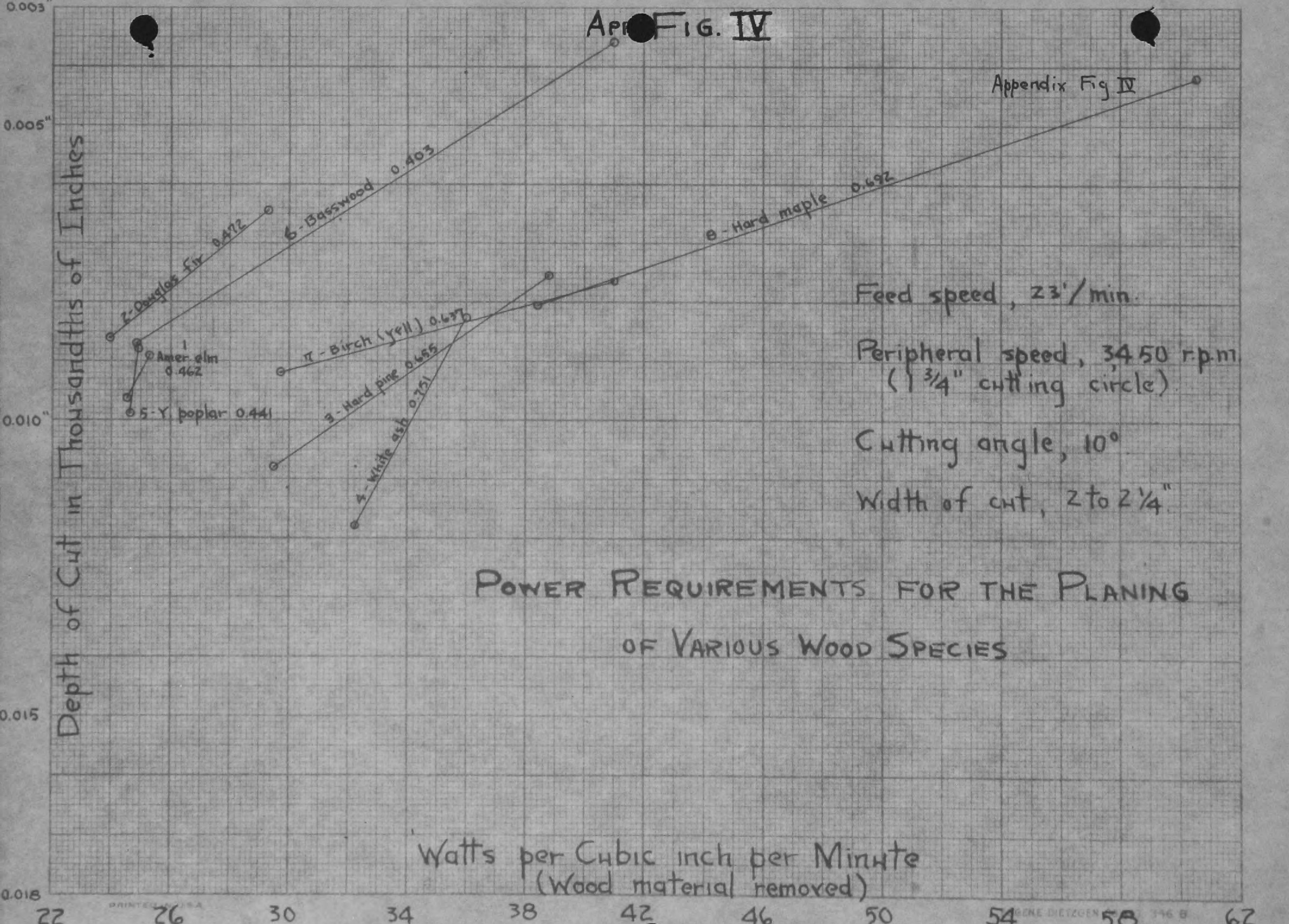
Appendix Fig II

Using taper head machine drill with sharp point angle. Helix ∠ 67°. 7/64" web. 3/4" drill




APP. FIG. III
EFFICIENCY CURVE FOR 1/4 H.P.
3,400 R.P.M. MOTOR USED TO
DRIVE BENCH JOINTER
60
50
40
30
20
10
Efficiency in Per-cent
0
100
200
300
400
500
600
Power input in watts

APP. FIG. IV


Appendix Fig IV
0.003"
0.005"
0.010"
0.015
0.018
22
26
30
34
38
42
46
50
54
58
62
Depth of Cut in Thousandths of Inches
Watts per Cubic inch per Minute
(Wood material removed)
2-Douglas fir 0.472
6-Basswood 0.403
8-Hard maple 0.692
1 Amer. elm 0.462
5-Y. poplar 0.441
7-Birch (yell) 0.637
3-Hard pine 0.655
4-White ash 0.751
Feed speed, 23'/min.
Peripheral speed, 3450 r.p.m.
(1 3/4" cutting circle)
Cutting angle, 10°
Width of cut, 2 to 2 1/4"
POWER REQUIREMENTS FOR THE PLANING
OF VARIOUS WOOD SPECIES

relation between Appendix Fig. IV, presenting results for a few "intermediate" depths of cut, and Text Fig. V, it is necessary to know that the gathering of data for the former preceded that of the latter, introducing a difference due to difference in sharpness of cutter knives. Test pieces of Appendix Fig. IV were originally selected for use as controls, but impossible behaviour of the bench jointer used made the data of later control test runs useless. Thus, data on dulling of cutters was lost.