FACTORS INFLUENCING THE MACHINING OF METALS

BY

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1934

Submitted in Partial Fulfillment of the Requirements for the Degree of

MASTER OF SCIENCE

From the

Massachusetts Institute of Technology

1940

Signature of Author . . . .
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Committee on Graduate Students

ACKNOWLEDGEMENT

The author wishes to express his appreciation for the help and advice of Professor A. L. Townsend, under whose supervision this thesis was carried out. Sincere thanks are due to Mr. A. B. English for giving so generously of his time and advice, especially after the untimely death of Mr. A. W. Lawson, designer of the dynamometer.

To Professor G. B. Wilkes and Mr. L. R. Vianey of the Heat Measurements Laboratory and to Professor P. E. Kyle of the Metals Processing Laboratory, the author wishes to express his appreciation for valuable advice and the loan of equipment from their respective departments.

The entire staff of the Machine Tool Laboratory proved to be of great assistance in the completion of this thesis. The work of R. J. Bowley, Mr. George Harkins and Mr. Earl Luther deserves special mention.

Finally, to Mr. E. M. Ferguson of the Horton Manufacturing Company, Minneapolis, Minnesota, the author expresses his sincere appreciation and thanks for the gift of a Horton Variable Speed Pulley which greatly simplified the procedure and technique of this thesis.

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I

INTRODUCTION AND PURPOSE

A great many investigations have been made and pages of literature have been written on the machining of metals and yet it seems as though only the surface of this subject has been scratched. Taylor, Herbert, Woxen, Klopstock, Ernst, Boston and many others have carried on thorough investigations on the physics of cutting and machinability in general. All agree that cutting is a shearing failure in the plastic region, but besides this point there is little general agreement, and this thesis is no exception.

This lack of agreement is due largely to the various individual definitions of machinability and the use of widely different materials and cutting conditions. It was hoped at the beginning of this thesis that this would be the first of a long line of theses at M.I.T. devoted to the study of all of the factors influencing machining, and that the results obtained could be applied to any material under any set of conditions after a series of standard tests had been made to determine material constants. These theses should also be so planned as to include all of the various definitions of machinability.

At the present time the machinability of a metal is defined in three ways. First, machinability may be a measure of the power required to remove a chip; second, it may be an index of the abrasiveness of the metal, that is, the influence that a particular metal has on the tool life; and third, it may be an index to the quality of surface finish that may be obtained. In this investigation, the power criterion was used to define machinability.

Before starting the actual experimental work, it was necessary to pick out a few variables from a rather awe inspiring list of possible variables. This list of possible factors which may affect machining includes, surface speed of the billet, feed, depth, side rake angle, back rake angle, side cutting edge angle, front cutting edge angle, side and front clearance and relief angles, nose radius of tool, height of tool with respect to centers, temperature of the tool, temperature of the billet, physical properties of the billet (hardness, tensile strength, yield point, etc.), microstructure of billet (microconstituents, grains size, etc.), physical properties of the cutting tool, use of cutting fluids, chemical analysis of the billet, etc. I chose the first four variables on the list for this investigation, namely, surface speed, feed, depth and side rake angle, as I felt that these were probably the most important and should be investigated first. As a side line to the main investigation, I chose the temperature of the billet as another possible variable and did a little investigation into it's influence on machining.

A statement of the main purpose of the thesis would be as follows: (1) to observe the influence of certain variables, namely speed, depth, feed and side rake angle, on the power required to remove metal, changing one variable at a time and holding the others constant; (2) to set up an equation for power consumed which would include on the right hand side the above variables raised to known powers and a constant K, this constant to be largely dependent on the material being cut, although it may also be affected by certain supressed variables; and (3) if it appears that this equation may hold for different materials, the only change in the equation being in the constant K, a standard test will be devised to determine this constant, the value of the constant will then be an index to machinability based on power consumption.

II

DESCRIPTION OF APPARATUS

The lathe used in this investigation was a fourteen inch Reed-Prentise with a five foot bed. It was driven by a $7\frac{1}{2}$ horse-power motor through a Horton Variable Speed Pulley. (Fig. #1) By means of the change gears and the Horton Pulley, it was possible to obtain any desired surface speed irrespective of the diameter of the billet.

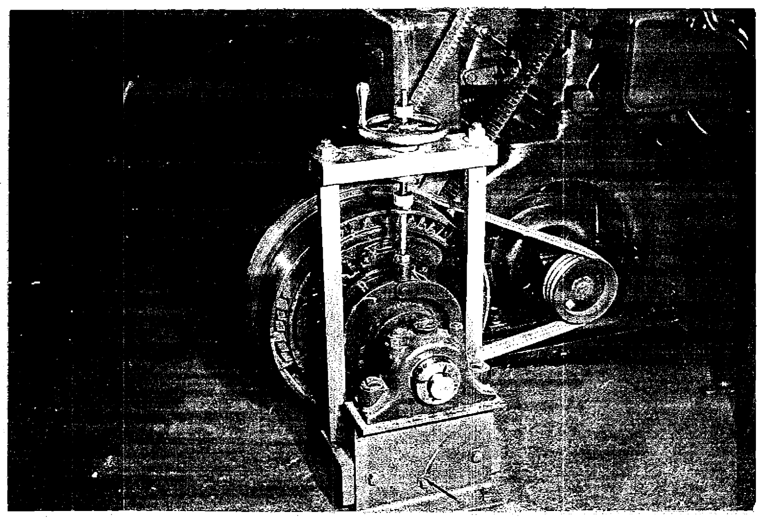


Fig. I

To measure the forces on the cutting tool, a three component lathe tool dynamometer was employed. This dynamometer (Fig. #2) was designed by the late Mr. A. W. Lawson, instructor in the Machine Tool Laboratory at Massachusetts Institute of Technology. Rex AA high speed steel tools (see Appendix G for composition and heat

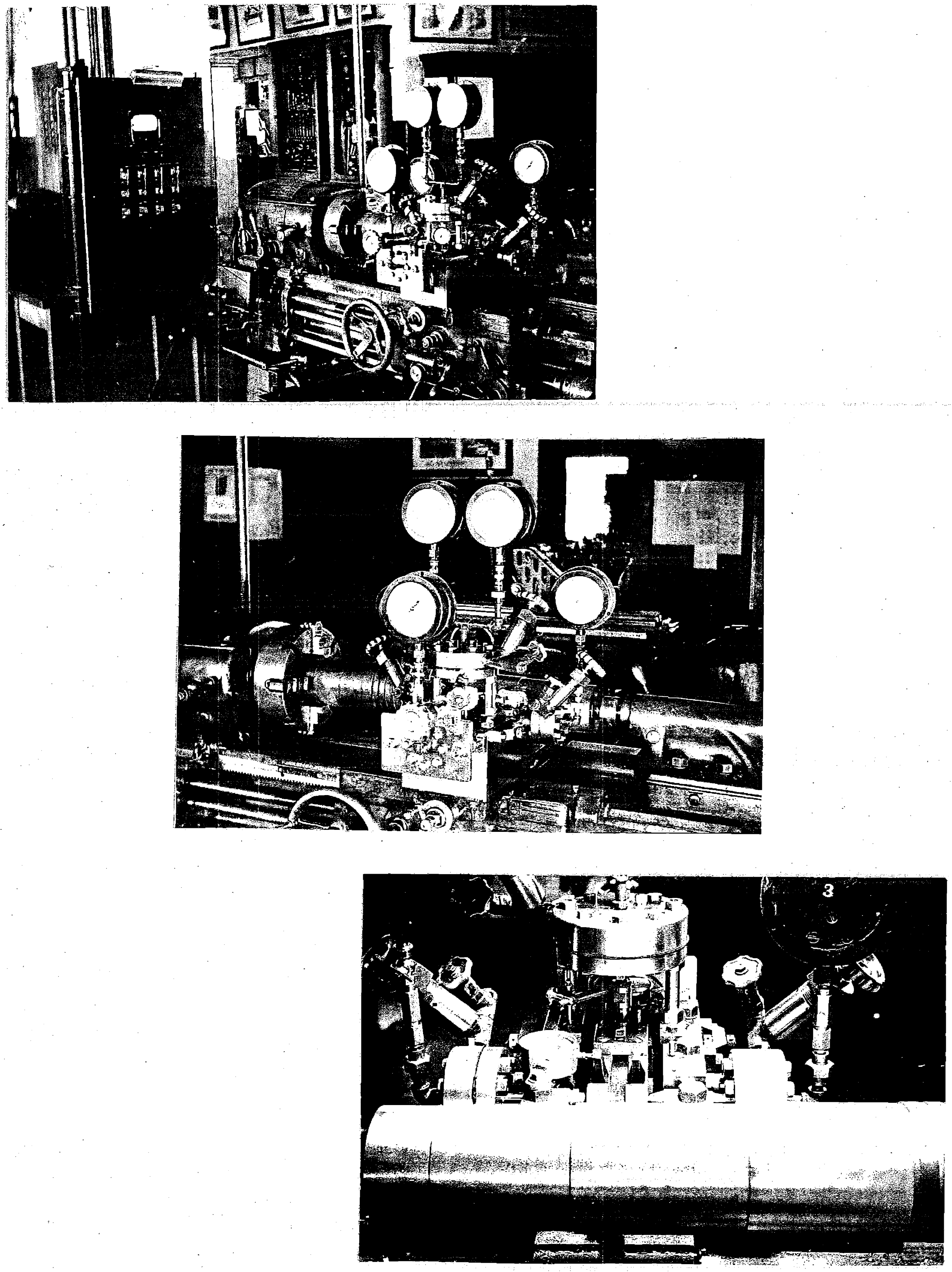
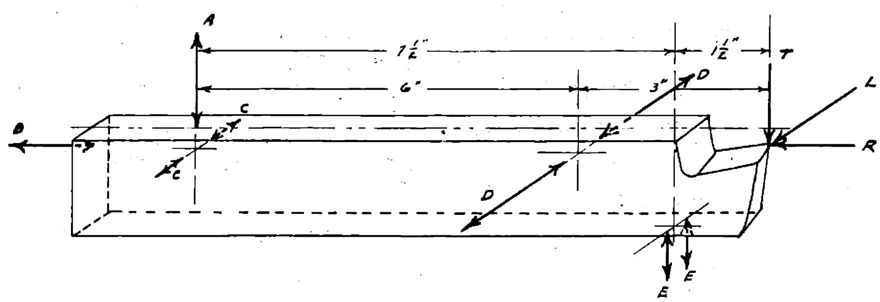


Fig. 2

treatment) were clamped into a floating tool holder. The tool holder had been machined out of a solid piece of steel and was so counter-balanced that it remained perfectly level when supported by only two steel struts at the forward end. These struts (E in Fig. 3) were adjustable so that the point of the tool could be placed at or above the height of centers. All the pivots and struts used in this dynamometer were ball pointed and acted on hardened steel sockets in order to eliminate as much friction as possible.



FORCES ON TOOL

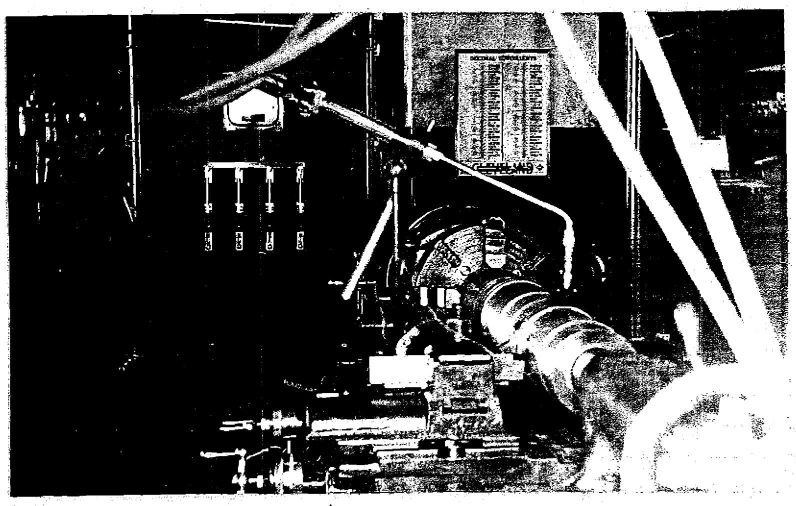
A-STRUT TO TANG. DIAPHRAMS AND GAUGES
B-STRUT TO RADIAL DIAPHRAM AND GAUGE
C-LONGITUDINAL FORCE FULCRUMS
D-STRUTS TO LONG. DIAPHRAMS AND GAUGES
E-TANGENTIAL FORCE FULCRUMS
T-TANGENTIAL FORCE
L-LONGITUDINAL FORCE
R-RADIAL FORCE

Fig. 3

At the top and to the rear of the tool holder, a strut (A in Fig. 3) transmitted the tangential or downward force T on the tool point to a large diaphram, the pressure being recorded on a Crosby Bourdon gage. Another strut (B in Fig. 3) at the rear of the tool holder, approximately at the height of the cutting edge of the tool, connected the tool holder to another diaphram and gage. This gage measured the radial force R on the tool. At the front end of the tool holder and at the approximate height of the cutting edge, two struts were placed (D in Fig. 3), one on either side, to transmit the longitudinal force L to two diphrams and gages.

The technique used in the operation of the dynamometer was such that the tool holder was always maintained in its original level position. Hydraulic plungers on the gage side of each diaphram were used to set up a force equal and opposite to the mechanical force delivered by the strut. Dial gages were placed so as to measure any change in the position of the tool holder. All the dials were set at zero when the tool was balancing and unloaded. As the load was applied to the tool, the oil pressure on the gage side of the diaphram was increased so as to maintain the dial gage at zero. Pressure readings were only made when all of the dial gages were at their original or zero position.

For the experiments on the cutting at elevated temperatures, the dynamometer could not be used. The cutting tools were, therefore, held in the regular tool post and all the power measurements were made with the wattmeter. The setup for heating and cutting the billet is shown below in Fig. 4.



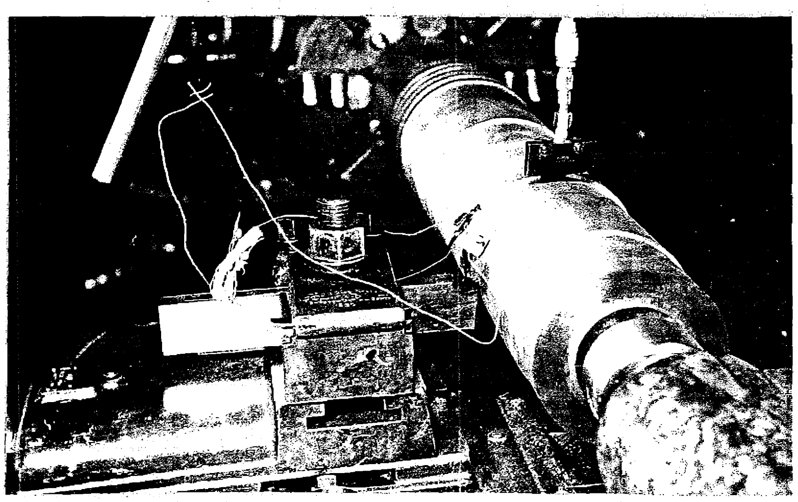


Fig. 4

A two inch oxy-acetylene descaling tip was used to apply the heat to the billet. The application of the flame was about three inches ahead of the tool.

The measurement of the temperature of the billet presented quite a problem. The tool-work thermocouple method as employed by Herbert, Woxen, Boston and others was considered but finally discarded as it was felt that this method would not give the temperature of the billet but rather the temperature at the point of the tool. This temperature would, of course, be considerably higher than the billet temperature due to the heat evolved in the rupturing of the metal and the frictional heat caused by the chip rubbing on the tool point.

A thermocouple as illustrated below in Fig. 5 was finally made and mounted so as to rub on the surface of the billet just ahead of the cutting tool, between the tool and the flame.

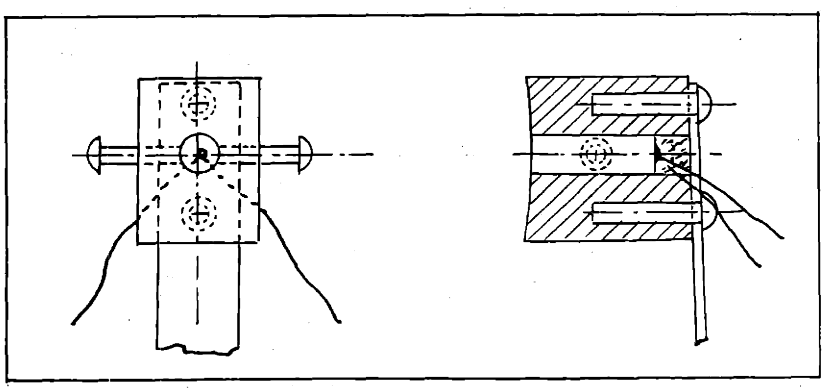


Fig. 5

A copper-constantine thermocouple (calabration chart in appendix G) was silver soldered to a short piece of copper rod. This rod was held in a piece of asbestos wood with two steel set screws. The end of the rod to which the thermocouple was soldered was insulated from the room temperature by a packing of asbestos fibre. The surface of the asbestos wood was ground to a radius of six inches. A piece of spring steel held the block against the billet with a constant normal force. The thermo-electric force was measured with a Wilson-Maeulen Millivoltmeter.

III

PROCEDURE

A - Calibration of Lathe and Horton Pulley.

In order to use the wattmeter reading of the power input as a check on the power output as given by the dynamometer, it was necessary to determine very carefully the efficiency of the lathe and Horton Pulley for the different sets of change gears that might be used and for different percentages of slip in the Horton Pulley.

A prony brake was mounted on a shaft held in the lathe chuck and a platform scales were used in this calibration. The necessary tables of data and the efficiency charts are included in the appendices A and B respectively.

B - Calibration of Diaphrams and Gages.

The diaphrams and gages had been calibrated by Albert Musschoot and James Stewart in 1936, using a Riehle testing machine, and their calibration data appears in Appendix G. This calibration was checked in 1937 by R. W. Vose using a 3000 pound Moorehouse proving ring. Since the two calibrations checked very closely, it was felt that further calibration was not necessary. The figures obtained by Musschoot and Stewart are used in the calculations.

C - Cutting at Room Temperature.

In order to obtain the necessary data for this investigation, it was necessary to make a great many runs. Each of the four variables had to be varied over a certain range while the other three were held constant. Four values of surface speed were used, 30, 40, 50 and 60 feet per minute; seven values of feed were chosen, $3\frac{1}{2}$, 7, 14, 28, 21, $10\frac{1}{2}$, and $5\frac{1}{4}$ thousandths of an inch per revolution; three values of depth, 1/32", 1/16" and 1/8"; and four values of the side rake angle, 15, 20, 25, and 30 degrees.

All the tools were ground on a special grinding wheel equipped with a tilting protractor table and a protractor guide so that all the angles of the tool could be easily reproduced. All the angles of the tools were kept constant except the side rake angle. (See Appendix G for tool dimensions) Eight tools were used. Tools 1 and 2 had a 15° side rake angle; 3 and 4, a 20° angle; 5 and 6, a 25° angle; and 7 and 8, a 30° angle.

The technique used in handling the dynamometer is very important and considerable time was spent in developing a suitable technique. For the sake of future investigators, I will try to explain the procedure very closely so that unnecessary time in their investigations need not be wasted.

The tool is first placed in the tool holder and adjusted with the gage provided so that it extends just the right amount from the tool holder. It is then clamped firmly in position. The two front struts are then adjusted to bring the cutting point at the right height. In this thesis all of the cuts were made with the tool at the height of centers. Next check with a small bench level to see that the tool is level and square with the billet. When the tool is perfectly level set the temperary stop at the bottom and rear of the tool holder to the correct height. This stop is only used to adjust the tangential and radial struts and must be screwed out of the way when the actual cuts are made.

The longitudinal, tangential and radial stuts are then adjusted so that a small pressure is recorded on their respective gages. It was found that the best results were obtained when the struts were adjusted so that the longitudinal and radial gages carried an initial pressure of five pounds per square inch and the tangential gage recorded an initial pressure of one pound per square inch. The dial gages are now placed in position and their scales so adjusted that the indicators are in the zero position. If the dial gages are clamped tightly in position and the struts are locked with the lock nuts provided, this one initial adjustment may be all that is necessary. Frequent checks should be made, however, to be sure that there has been no change in the zero position.

Before making the runs, the lathe should be allowed to run idle for approximately one half hour to insure that the motor is at the normal operating temperature.

The tool is now brought up until it just touches the surface of the billet and the reading on the micrometer dial of the cross-feed screw is noted. With the tool carraige at the end of the billet, the tool is screwed into the desired depth of cut. The surface speed of the billet is then adjusted with the Horton Pulley and accurately checked with a hand tachometer.

Before engaging the feed clutch, an additional pressure was applied to the longitudinal strut by means of the plunger on the longitudinal diaphram. As the tool begins to cut, the plungers for the tangential and radial diaphrams were adjusted simultaneously so as to keep their respective dial gages at the zero position. With these two gages at zero and the full cut being made, the longitudinal plunger is readjusted so as to bring its dial gage to zero. When all of the dial gages were at zero and the billet was turning at the right speed, the pressure gages and the wattmeter were read and their values recorded. Of course, it was impossible for one man to make four simultaneous readings. A certain amount of error, therefore, was unavoidable. The pressure gages remained fairly constant throughout a cut but the wattmeter fluctuated considerably, which made it very difficult to read and added to the probable error. It is for the above reasons that too much weight is not to be placed on the percentage errors between the mechanical and electrical measures of power consumption as shown in the charts in Appendix C.

As a rule, fourteen runs were made with each tool before resharpening. These cuts averaged a didtance of about 3/4" along the surface of the billet, and the approximate cutting time before resharpening was 15 minutes. With only two exceptions (on the 1/4" cuts) the tool was always in good cutting condition when it was removed from the holder for resharpening.

The actual depth of the cut was determined by measuring the diameter of the billet with a micrometer before and after the cut was made.

Photographs were taken with a microscope attachment of all the cuts in an attempt to get some measure of surface conditions. Some of these pictures will be found in Appendix I.

D - Cutting at Elevated Temperatures.

The procedure of cutting at elevated billet temperatures was quite different from that above. The tool was held in the regular tool post, all power measurements being made with the wattmeter. A few runs were made with no heat applied to determine the amount of fritional heat developed by the rubbing of the thermocouple over the surface of the billet. These results are included in Appendix G. The actual cut was then started, and after it had progressed a short distance the heating torch was ignited and the temperature of the billet began to rise. Frequent reading of the wattmeter and the millivoltmeter were recorded. The cut continued until the cutting edge of the tool broke down. The billet was then allowed to cool and a second run was made.

IV

DISCUSSION OF THEORIES AND RESULTS

A - Cutting at Room Temperature.

In the introduction it was stated that power consumption was probably a function of feed, depth, tool angle and speed, or an equation of the following sort

(1) $$P = K\, F^{w}\, D^{x}\, A^{y}\, S^{z}$$

where F is feed in thousandths of an inch per revolution, D is depth in thousandths of an inch, A is the side rake angle in degrees and S is the surface speed in feet per minute. K is a constant whose dimensions are rather complicated, but since K is to be an index of machinability, its dimensions are unimportant. P is power consumption measured in horse-power.

It is assumed that K is a constant of the material being cut and is dependent only on the material. This, however, need not be true since a large number of variables that were listed in the introduction were suppressed in this investigation. That is, it is very possible that power may also be a function of back rake angle, cutting edge angles, nose radius, etc. We will not know this definitely, however, until future investigations have been made to determine the influence of these other variables on machining.

For the time being, therefore, we will assume that K is a material constant and its value will be influenced only by the microstructure and physical and chemical properties of the material being cut. The proof of this assumption would be very helpful, for then it might be possible to predict K, or in other words machinability, by means of hardness, grain size, tensile strength, etc.

The values of the exponents w, x, y and z in equation (1) were determined by plotting one variable at a time versus power, for example

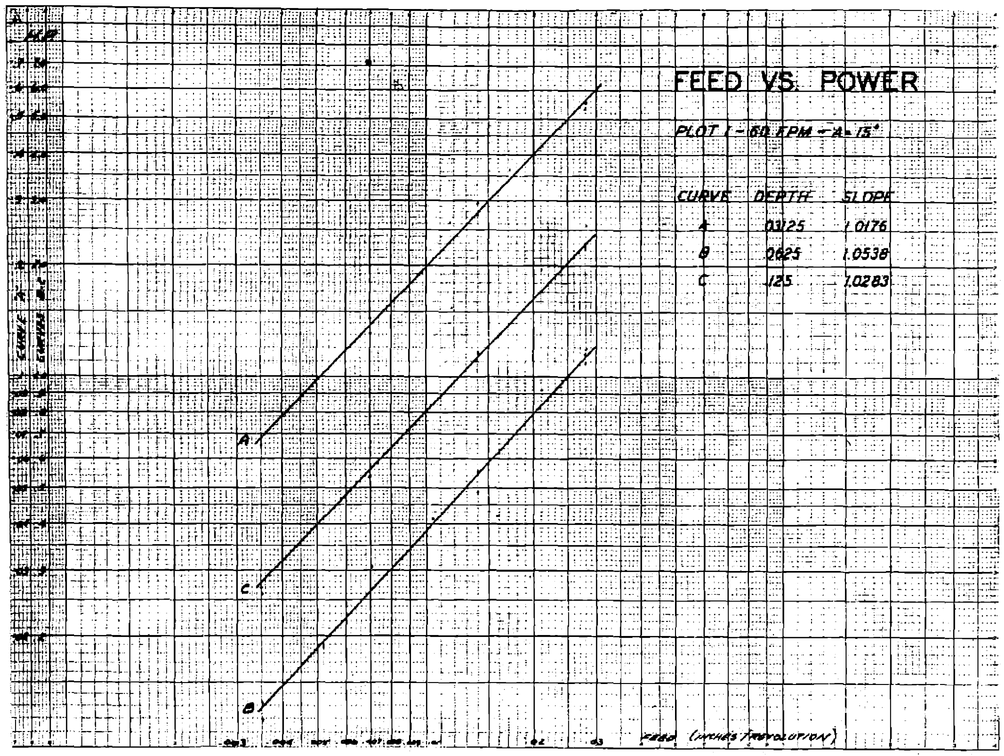
(2) $\log P = [\log K + x \log D + y \log A + z \log S] + w \log F$

but the part of equation (2) in brackets may be combined to form a new variable Q and the equation then becomes

(3) $\log P = \log Q + w \log F$, or

(4) $\log P - \log Q = w \log F$

If we, therefore, plot feed versus power on log log paper, the average slope of the resulting set of curves will be the value of w. Plot I, below, is a typical Feed vs. Power graph. (See Appendix D for



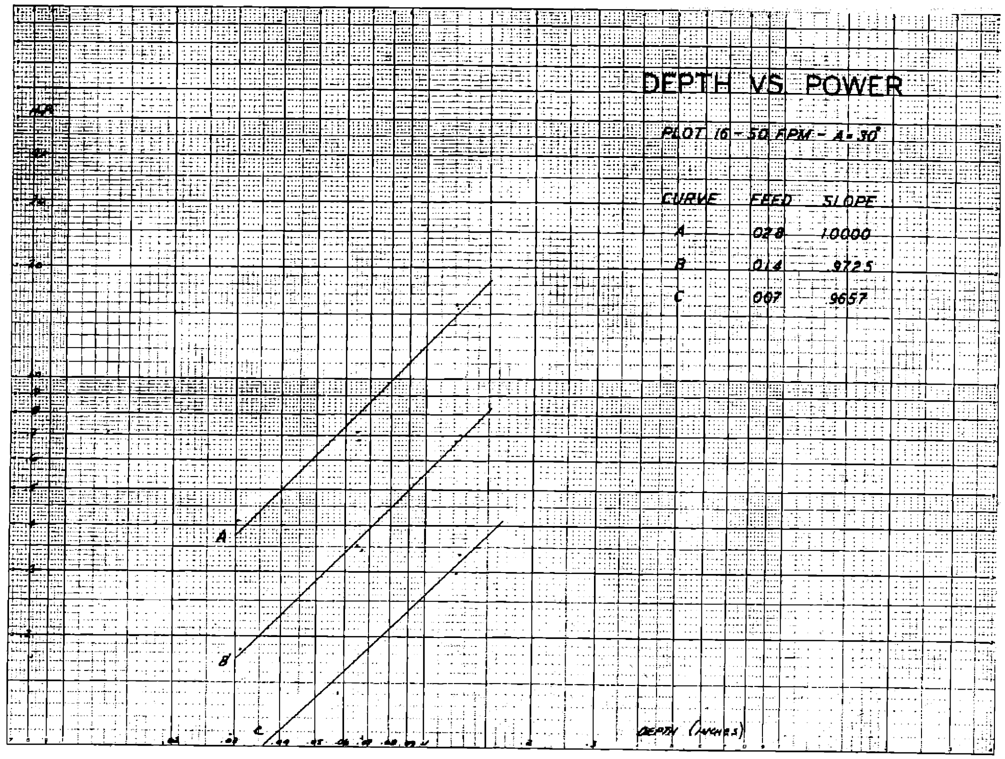
other Charts). The average value of the 24 curves of Feed vs. Power was 1.1048.

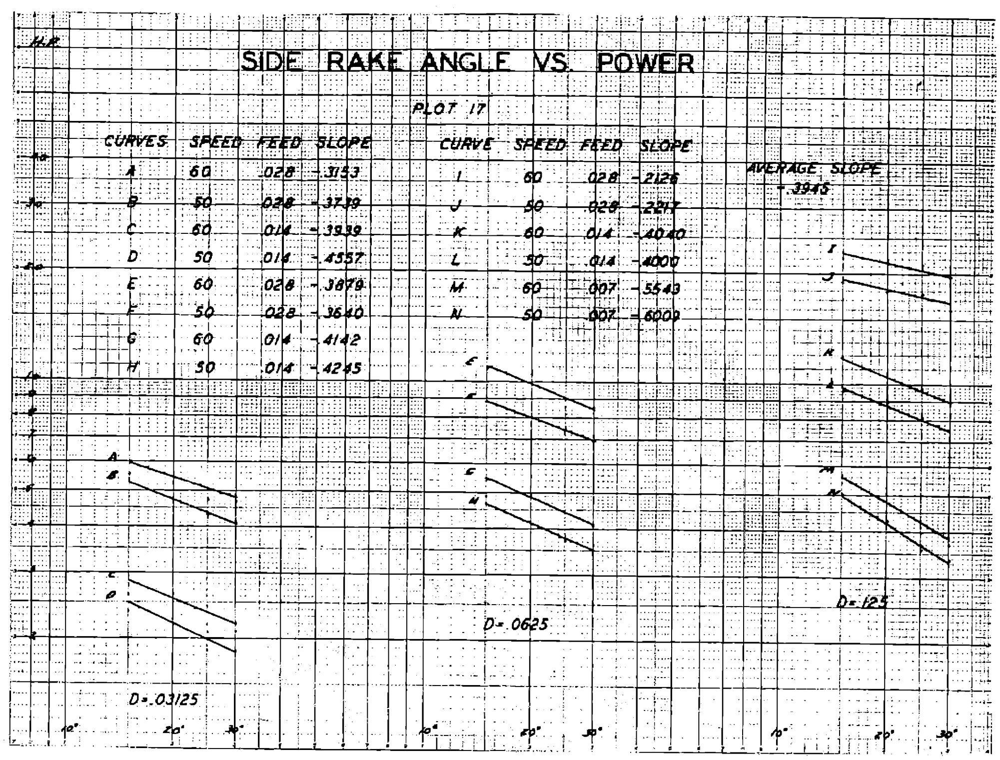
Plot 16 is typical of the curves obtained by plotting Depth vs. Power. The average slope in this case being 1.0000.

Plot 17 is the entire set of curves for Side Rake Angle vs. Power, the average slope being -.3945.

Substituting the above values of w, x and y into equation (1) we have

(5) $$P = K \ F^{1.1048} \ D \ A^{-.3945} \ S^{z}$$


DEPTH VS. POWER
PLOT 16 - 50 FPM - A = 30°
CURVE FEED SLOPE
A .028 1.0000
B .014 .9725
C .007 .9657
H.P.
DEPTH (INCHES)
A
B
C


H.P.
SIDE RAKE ANGLE VS. POWER
PLOT 17
CURVES SPEED FEED SLOPE
A 60 .028 -.3153
B 50 .028 -.3739
C 60 .014 -.3939
D 50 .014 -.4557
E 60 .028 -.3879
F 50 .028 -.3640
G 60 .014 -.4142
H 50 .014 -.4245
CURVE SPEED FEED SLOPE
I 60 .028 -.2126
J 50 .028 -.2217
K 60 .014 -.4040
L 50 .014 -.4000
M 60 .007 -.5543
N 50 .007 -.6009
AVERAGE SLOPE
-.3945
D = .03125
D = .0625
D = .125
10°
20°
30°

leaving z the only unknown exponent. Unfortunately, the runs, numbers 1 through 350, which contained the data for the surface speed variable were not consistent with the reruns, numbers 351 through 542. It seemed after the runs had been made that the first billet was not as homogeneous as the second. All data available, however, on the affect of speed of loading on the power to rupture metals seemed to indicate that the range of speeds here tested would have no affect on power consumption. It is , therefore, assumed that S appears in the equation to the first power, and the final equation is

$$(6) \qquad P = K \ F^{1.1048} \ D \ A^{-.3945} S$$

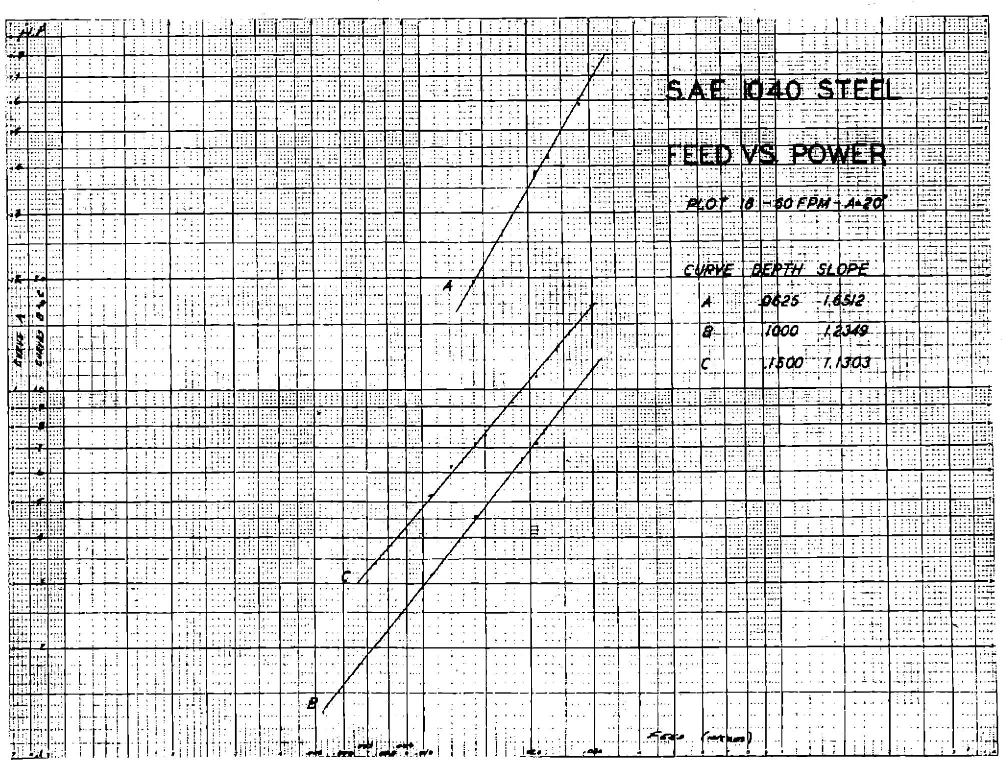
In order to determine the value of K, the equation would be written

$$(7) \qquad K = \frac{P \cdot A^{.3945}}{D \cdot S \cdot F^{1.1048}}$$

The accompaning nomographic chart was set up for the rapid calculation of equations (6) and (7), and is the basis for the proposed standard test to determine machinability.

In order to check the validity of the assumption that equation (6) should hold for all similar metals (steels, for example) a series of runs were made on a billet of S.A.E. 1040 steel (see Appendix G for properties). Plot 18, below, is the Feed vs. Power curve for the series of runs. In all cases the data from the light cuts seemed to be somewhat erratic, and for this reason, too much weight should not be placed on the slope of curve A in this plot. The slopes of curves B and C come close to the average value of the slope for feed as determined on the Vanadium "D" stock. The deviation of slope B from this average was only 11.8%, and the deviation of slope C only 2.36%.

It seems very likely, therefore, that the original assumption is correct and the equation is valid. Time



did not permit making more tests on other materials, but these, of course, should be made as further and more absolute proof of the equation.

The average value of K for the Vanadium "D" stock was $.237 \times 10^{-4}$, the largest deviation from this value being but 5.5%.

The value of K for the S.A.E. 1040 stock as determined from slope C Plot 18 was $.153 \times 10^{-4}$. This, I believe, is very close to the real value of K for this material as curve C is the closest of the three curves to the curves found for the Vanadium "D" stock. The average value of K as determined from curves B and C was $.160 \times 10^{-4}$, deviating only 4.57% from the value of K as determined from curve C alone. The average value of K as determined from all three curves was $.137 \times 10^{-4}$, a deviation of 10.46% from what I believe to be the better value.

From these values of K it would seem that the Vanadium "D" stock was 55% harder to machine than the S.A.E. 1040 steel. This is on the basis of power consumption.

On the basis of the results of this thesis, the following standard test for determining machinability is proposed.

The tool to be used in the standard test for machinability shall be made of high speed steel of the 18-4-1 type of composition. It shall have the following dimensions; front cutting edge angle, 11°; side cutting edge angle, 30°; side and front clearance angles, 6°; back rake angle, 6°; side rake angle, 20°; and nose radius, 3/64".

Nine cuts shall be made, three each at the following depths, 100, 125 and 150 thousandths of an inch, using all of the following values of feed during each cut, 7, 10.5, 14, 21 and 28 thousandths of an inch per revolution.

The data obtained from these cuts will then be plotted on log log paper, Feed vs. Power. The value of K for each of the three curves will be computed using the nomographic chart, and the average value of K obtained will be the index of machinability for that material. This index is based on the power consumption definition of machinability.

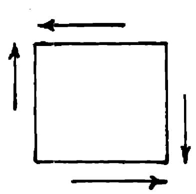
B - Cutting at Elevated Temperatures.

The investigation on the affect of billet temperature on machining was started after reading a paper by Hans Ernst of the Cincinatti Milling Machine Company on some experiments he had carried out on aluminum bars. He used dry ice and boiling water for controlling the billet temperature. He found a decided improvement in surface finish at temperatures of 60° below zero.

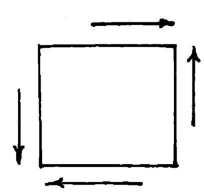
At first it was thought that by raising the temperature of the billet, the work-hardening effect of machining would be greatly reduced and consequently a lower power consumption would be observed. This theory was quickly exploded as soon as the runs were made. Instead of noting a decrease in power as the temperature of the billet increased, it was observed that the power also increased.

This increase in power is probably due to three things. First of all, the thermal expansion of the billet may affect the power consumption in two ways, an increase in the radius would cause a corresponding increase in the depth of cut, and the increase in the length of the billet would result in an increased pressure on the tail-stock center. The increase in power, however, due to the thermal expansion was practically negligable since the increase in radius was of the magnitude of a few thousandths of an inch. By using a ballbearing tail-stock center, the increase in frictional drag, due to the increased pressure on the center, was not of great importance.

A second factor which led to an increase in power was the setting up of high internal stresses by the uneven temperature distribution throughout the billet. This factor is probably of much greater importance than the first. Very rough calculations showed that with a surface temperature of 650 degrees Fahrenheit there was a tangential compressive stress of 40,000 psi. (exact calculations were impossible with the data available.) This stress would result in a negative shear stress of approximately 20,000 psi. Being a negative shear, it was in the opposite direction from the shear stress necessary to remove the metal.



Shear due to Temperature distribution.



Shear to Remove Metal.

This factor, undoubtably, caused a large increase in the power consumption. The cutting tool had to overcome this large internal shear stress before it could start cutting the chip from the billet.

The third factor, and by far the most important of the three, lies in the physical properties of the metal itself. Although no tensile tests were made on the Vanadium "D" stock at elevated temperatures, sufficient data has been published to show that steels of similar composition show an increase in tensile strength up to a certain point and then a rapid falling off as the temperature is increased from room tempeaature on up. The maximum tensile strength is observed between 650 and 700 degrees Fahrenheit.

Taking everything into consideration, the cutting at elevated temperatures was not a very satisfactory experiment. At the elevated temperatures, tool life was reduced to practically nothing and power consumption was materially increased. Just opposite of Ernst's results on aluminum, a noticably finer finish was observed when machining at the higher temperatures.

V

SUMMARY OF RESULTS AND RECOMMENDATIONS

At the beginning of this thesis, an equation with four unknown exponents was set up. This equation was

$$P = K \; F^{w} \; D^{x} \; A^{y} \; S^{z}$$

By using conventional type high speed cutting tools and varying the side rake angle as well as the feed, depth and cutting speed, the exponents in the above equation were determined.

$$w = 1.1048$$
$$x = 1.0000$$
$$y = -.3945$$
$$z = 1.0000$$

The equation for power consumption then becomes

$$P = K \; F^{1.1048} \; D \; A^{-.3945} \; S$$

where feed and depth are in thousandths of an inch, A is the side rake angle in degrees, S is the surface speed in feet per minute and P is the power consuption in HP.

The value of K is assumed to be an index of machinability, with machinability, in this case, defined by power consumption. The value of K for the Vanadium "D" stock was $.237 \times 10^{-4}$, and for the S.A.E. 1040 $.153 \times 10^{-4}$.

A proposed standard test for determining machinability was set up as follows:

> The tool to be used in the standard test for machinability shall be made of high speed steel of the 18-4-1 type of composition. It shall have the following dimensions; front cutting edge angle, 11°; side cutting edge angle, 30°; side and front clearance angles, 6°; back rake angle, 6°; side rake angle, 20°; and nose radius, 3/64".
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> Nine cuts shall be made, three each at the following depths, 100, 125 abd 150 thousandths of an inch, using all of the following values of feed during each cut, 7, 10.5, 14, 21 and 28 thousandths of an inch per revolution.
>
> The data obtained from these cuts will then be plotted on log log paper, Feed vs. Power. The value of K for each of the three curves will be computed using the nomographic chart, and the average value of K obtained will be the index of machinability for that material. This index is based on the power consumption definition of machinability.

A few of the pictures of the billet surface are included in Appendix I. It was almost impossible to tell, either with the naked eye or from the pictures, any difference in the surface finish obtained when the surface speed, depth of cut and side rake angle were changed. Increasing the feed, of course, increased the roughness of the finish. In general, the finish obtained under all conditions was very good.

The results of machining at elevated billet temperatures showed that power consumption rose as the temperature of the billet was increased. Tool life was reduced to but a few minutes of cutting, but surface finish was greatly improved at the higher temperatures.

RECOMMENDATIONS

(I) It is recommended that for undergraduate research, further work should be carried out to check the validity of the Power equation and the accuracy of the Standard Test. The check on the equation should be made, if possible, using Vanadium "D" stock, otherwise S.A.E. 1040 stock. After the equation has been checked and a suitable technique established, the Standard Test should be applied to as many samples of steel that can be obtained.

(2) For graduate research, it is suggested that some of the other possible variables be investigated to see what influence they have on power and the constant K. Some of these variables might be side cutting edge angle, back rake angle and the use of cutting fluids. It may be found that the equation proposed in this thesis is too simple and that some more terms must be added to make the equation more general. When the present equation or a more general equation has been established and the contant K has been proven to be dependent only on the material itself for its value, it is suggested that an investigation be made to determine the influence of the micro-structure and the physical and chemical properties of the material on K. It is very possible that the value of K could be predicted knowing the chemical analysis, hardness, tensile strength and grain size of a certain piece of steel.

(3) It is further suggested for graduate research, that an attempt be made to find a relationship between the established equation for power consumption and an equation for tool life similar to that of Woxen. It is very possible, however, that no direct relationship exists, and in that case, we would have two different constant terms, each one being an index to machinability, but based on different definitions.

APPENDICES

APPENDIX A

Data on Calibration of Lathe and

Horton Pulley

CALIBRATION OF LATHE
AND HORTON PULLEY

GEAR TRAIN No. 47

Spindle speed 43.5 rpm — 0 % Slip

Net Load on Brake	HP Output	Kw. Output	Kw. Input	Eff. %
6.5	.132	.099	.99	9.96
11.5	.234	.174	1.06	16.4
16.5	.336	.250	1.15	21.7
21.5	.437	.326	1.21	27.0
25.5	.540	.402	1.31	30.7
31.5	.641	.478	1.40	34.4
36.5	.743	.554	1.48	37.4
41.5	.845	.630	1.56	40.4
51.5	1.10	.820	1.75	46.7
61.5	1.25	.931	1.91	48.7
71.5	1.45	1.08	2.08	52.0
81.5	1.66	1.23	2.30	53.7
91.5	1886	1.38	2.48	55.9
101.5	2.06	1.53	2.70	56.7
111.5	2.27	1.69	2.85	59.4
121.5	2.47	1.84	3.00	61.4
131.5	2.68	1.99	3.15	63.2
141.5	2.88	2.14	3.37	63.5
151.5	3.08	2.29	3.52	65.0

GEAR TRAIN No. 47

Spindle speed 30 rpm 31 % Slip

Net Load on Bake	HP Output	Kw. Output	Kw. Input	Eff. %
11.5	.176	.131	.95	13.7
21.5	.329	.245	1.15	21.3
31.5	.479	.356	1.30	27.4
41.5	.635	.473	1.55	30.5
51.5	.789	.588	1.65	35.6
61.5	.942	.702	1.85	38.0
71.5	1.10	.816	2.05	39.8
81.5	1.25	.932	2.25	41.4
91.5	1.40	1.04	2.45	42.5
101.5	1.55	1.15	2.65	43.6
111.5	1.71	1.27	2.85	44.6
121.5	1.86	1.39	3.00	46.2
131.5	2.01	1.50	3.20	46.9
141.5	2.17	1.62	3.40	47.7
151.5	2.32	1.73	3.60	48.0

GEAR TRAIN No. 47

Spindle speed 20 rpm 54 % Slip

11.5	.117	.087	.95	9.2
21.5	.218	.163	1.10	14.8
31.5	.320	.238	1.30	18.3
41.5	.422	.314	1.45	21.6

Net Load on Brake	HP Output	Kw. Output	Kw. Input	Eff. %
51.5	.524	.391	1.65	23.7
61.5	.625	.466	1.85	25.2
71.5	.726	.557	2.00	27.8
81.5	.829	.635	2.20	28.8
91.5	.930	.714	2.35	30.4
101.5	1.03	.790	2.65	29.8
111.5	1.13	.878	2.75	31.9
121.5	1.24	.948	2.95	32.1
131.5	1.34	1.03	3.15	32.6
141.5	1.44	1.10	3.35	32.9
151.5	1.54	1.18	3.50	33.8

GEAR TRAIN No. 73

Spindle speed 65.5 rpm — 0 % Slip

11.5	.383	.286	1.20	23.8
26.5	.882	.658	1.60	41.1
41.5	1.38	1.03	2.10	49.0
56.5	1.88	1.40	2.50	56.0
71.5	2.38	1.78	2.95	60.2
86.5	2.88	2.15	3.40	63.2
101.5	3.38	2.52	3.80	66.4
116.5	3.82	2.85	4.30	66.0
131.5	4.27	3.19	4.70	67.9
146.5	4.62	3.45	5.20	66.4
161.5	5.10	3.80	5.60	67.9

GEAR TRAIN No. 73

Spindle speed 55 rpm 15.4% Slip

Net Load on Brake	HP Output	Kw. Output	Kw. Input	Eff. %
11.5	.343	.256	1.00	25.6
26.5	.606	.452	1.45	31.1
41.5	.950	.710	1.95	36.1
56.5	1.29	.964	2.40	40.0
71.5	1.64	1.22	2.85	42.7
86.5	1.98	1.48	3.30	44.7
101.5	2.33	1.74	3.80	45.7
116.5	2.67	1.99	4.20	47.4
131.5	3.02	2.25	4.60	48.9
146.5	3.36	2.50	5.10	49.0
161.5	3.70	2.76	5.50	50.2

GEAR TRAIN No. 73

Spindle speed 38.5 rpm 40.8% Slip

11.5	.225	.168	1.00	16.8
26.5	.518	.386	1.40	27.6
41.5	.813	.606	1.90	31.9
56.5	1.11	.829	2.35	35.2
71.5	1.40	1.05	2.80	37.3
86.5	1.70	1.26	3.20	39.4
101.5	1.99	1.49	3.70	40.1
116.5	2.28	1.70	4.10	41.5

Net Load on Brake	HP Output	Kw. Output	Kw. Input	Eff. %
131.5	2.58	1.92	4.60	41.7
146.5	2.87	2.14	5.10	42.0
161.5	3.16	2.52	5.50	45.8

GEAR TRAIN No. 110

Spindle speed 100 rpm 0 % Slip

11.5	.584	.435	1.40	31.0
26.5	1.34	.995	2.05	48.5
41.5	2.09	1.56	2.70	57.8
56.5	2.84	2.12	3.35	63.3
71.5	3.60	2.68	4.00	67.0
86.5	4.36	3.25	4.70	69.1
101.5	5.06	3.77	5.40	69.9
116.5	5.56	4.15	6.10	68.0

GEAR TRAIN No. 110

Spindle speed 91 rpm 9 % Slip

11.5	.533	.390	1.30	30.0
26.5	1.23	.918	2.10	43.7
41.5	1.92	1.43	2.70	53.0
56.5	2.62	1.95	3.30	59.1
71.6	3.31	2.47	4.00	61.8
86.5	4.00	2.98	4.80	62.1
101.5	4.70	3.50	5.50	63.6

Spindle speed 82 rpm 18 % Slip

Net Load on Brake	HP Output	Kw. Output	Kw. Input	Eff. %
11.5	.479	.357	1.30	27.4
26.5	1.11	.824	2.00	41.2
41.5	1.73	1.29	2.70	47.8
56.5	2.36	1.76	3.30	53.4
71.5	2.98	2.22	4.00	55.5
86.5	3.60	2.68	4.70	57.0
101.5	4.23	3.16	5.40	58.5
116.5	4.85	3.62	6.20	58.4

Spindle speed 73 rpm 27 % Slip

11.5	.427	.318	1.30	24.4
26.5	.985	.735	2.00	36.9
41.5	1.54	1.15	2.60	44.3
56.5	2.10	1.57	3.30	47.4
71.5	2.65	1.98	3.90	50.8
86.5	3.21	2.39	4.70	50.8
101.5	3.76	2.80	5.40	51.9

Spindle speed 64 rpm 36 % Slip

11.5	.374	.279	1.20	23.2
26.5	.860	.641	2.00	32.0
41.5	1.35	1.01	2.60	38.6
56.5	1.84	1.37	3.20	42.7

Net Load on Brake	HP Output	Kw. Output	Kw. Input	Eff. %
71.5	2.32	1.73	3.90	44.4
86.5	2.81	2.10	4.60	45.7
101.5	3.30	2.46	5.30	46.4
Spindle speed 54.5 rpm				45 % Slip
11.5	.319	.238	1.20	19.8
26.5	.735	.548	1.90	28.8
41.5	1.15	.857	2.60	33.0
56.5	1.57	1.17	3.20	36.4
71.5	1.98	1.48	3.90	37.8
86.5	2.40	1.79	4.60	38.9
101.5	2.81	2.10	5.30	39.6
Spindle speed 46 rpm				54 % Slip
11.5	.266	.198	1.20	16.5
26.5	.612	.456	1.90	24.0
41.5	.958	.714	2.60	27.4
56.5	1.31	.973	3.20	30.4
71.5	1.65	1.23	3.90	31.6
86.5	2.00	1.49	4.60	32.4
101.5	2.35	1.75	5.30	33.0
Spindle speed 37 rpm				63 % Slip
11.5	.213	.159	1.20	13.3
26.5	.491	.366	1.90	19.3

Net Load on Brake	HP Output	Kw. Output	Kw. Input	Eff. %
41.5	.770	.574	2.60	22.1
56.5	1.05	.783	3.20	24.4
71.5	1.33	.992	3.90	25.4
86.5	1.60	1.19	4.60	26.0
101.5	1.88	1.40	5.30	26.4

GEAR TRAIN No. 171

Spindle speed 156 rpm — 0 % Slip

11.5	.912	.68	1.80	37.8
26.5	2.10	1.57	2.75	57.1
41.5	3.25	2.43	3.80	64.0
56.5	4.36	3.26	4.80	68.0
71.5	5.02	3.74	6.00	62.4

Spindle speed 128 rpm — 18 % Slip

11.5	.747	.558	1.70	32.9
26.5	1.72	1.29	2.70	47.6
41.5	2.70	2.02	3.70	54.6
56.5	3.67	2.74	4.70	58.3
71.5	4.65	3.47	5.80	59.8

Spindle speed 106 rpm — 32 % Slip

11.5	.679	.506	1.60	31.6
26.5	1.56	1.17	2.70	43.1
41.5	2.45	1.83	3.65	50.1
56.5	3.33	2.48	4.70	52.7
71.5	4.22	3.15	5.75	54.8

Spindle speed 85 rpm 46 % Slip

Net Load on Brake	HP Output	Kw. Output	Kw. Input	Eff. %
11.5	.497	.371	1.60	23.2
26.5	1.14	.851	2.65	32.0
41.5	1.79	1.34	3.65	36.6
56.5	2.44	1.82	4.65	38.2
71.5	3.09	2.30	5.75	40.0

Spindle speed 64 rpm 59 % Slip

11.5	.374	.279	1.60	17.4
26.5	.861	.644	2.60	24.7
41.5	1.35	1.01	3.60	27.9
56.5	1.84	1.38	4.60	29.9
71.5	2.32	1.73	5.70	30.4

GEAR TRAIN No. 276

Spindle speed 252 rpm 0 % Slip

6.5	.835	.622	1.80	34.5
11.6	1.48	1.10	2.40	45.8
16.5	2.12	1.58	2.95	53.6
21.5	2.73	2.04	3.50	58.4
26.5	3.34	2.49	4.00	62.2
31.5	3.97	2.96	4.50	65.8
36.5	4.57	3.41	5.00	68.2
41.5	5.19	3.87	5.60	69.1
51.5	6.35	4.73	6.70	70.7
61.5	7.51	5.60	8.40	66.8

Spindle speed 206 rpm 18.3 % Slip

Net Load on Brake	HP Output	Kw. Output	Kw. Input	Eff. %
6.5	.683	.476	1.70	28.0
11.5	1.21	.904	2.30	39.2
16.5	1.73	1.29	2.80	46.2
21.5	2.26	1.69	3.40	49.6
26.5	2.78	2.07	4.10	50.5
31.5	3.31	2.47	4.50	54.9
41.5	4.36	3.25	5.60	58.0
51.5	5.41	4.04	6.80	59.5
61.5	6.46	4.82	8.10	59.5

Spindle speed 160 rpm 37 % Slip

6.5	.528	.394	1.60	24.6
11.5	.935	.696	2.20	31.6
16.5	1.34	1.00	2.80	35.7
21.5	1.75	1.30	3.35	38.8
26.5	2.15	1.60	3.80	43.1
31.5	2.66	1.98	4.50	44.1
41.5	3.37	2.51	5.60	44.7
51.5	4.18	3.12	6.80	45.9
61.5	5.00	3.73	8.00	46.6

Spindle speed 115 rpm 54.5 % Slip

6.5	.379	.282	1.60	17.6
11.5	.671	.500	2.20	22.7

Net Load on Brake	HP Output	Kw. Output	Kw. Input	Eff. %
16.5	.963	.718	2.70	26.6
21.5	1.25	.935	3.20	29.2
26.5	1.55	1.15	3.80	30.3
31.5	1.84	1.37	4.35	31.5
41.5	2.42	1.81	5.50	32.9
51.5	3.00	2.24	6.75	33.2
61.5	3.58	2.67	8.10	33.0

GEAR TRAIN No. 432

Spindle speed 393 rpm 0 % Slip

6.5	1.30	.97	2.55	36.6
11.5	2.29	1.71	3.40	50.4
16.5	3.23	2.41	4.20	57.4
21.5	4.20	3.13	5.00	62.6
26.5	5.15	3.84	5.90	65.2
31.5	6.02	4.50	7.00	64.3
41.5	7.85	5.85	9.10	64.3

Spindle speed 322 rpm 15.5 % Slip

6.5	1.07	.799	2.45	32.6
11.5	1.89	1.41	3.30	42.7
16.5	2.71	2.02	4.15	48.7
21.5	3.53	2.63	5.10	51.5
26.5	4.35	3.24	6.00	54.0
31.5	5.17	3.86	7.00	55.2
41.5	6.81	5.08	9.10	55.9

Spindle speed 250 rpm — 36 % Slip

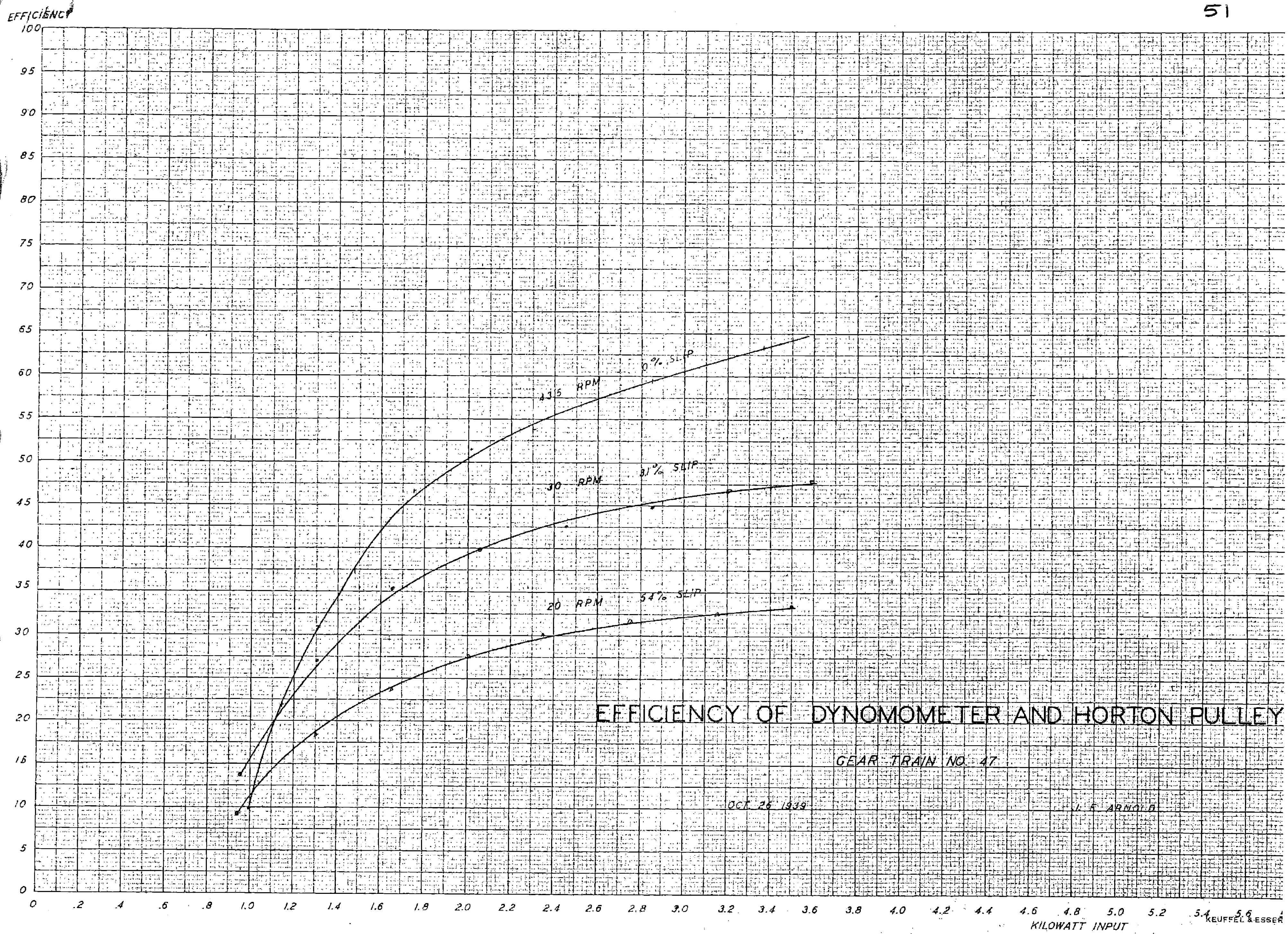
Net Load on Brake	HP Output	Kw. Output	Kw. Input	Eff. %
6.5	.826	.616	2.30	26.8
11.5	1.46	1.09	3.20	34.1
16.5	2.10	1.57	4.00	39.2
21.5	2.73	2.04	4.90	41.6
26.5	3.37	2.51	5.80	43.2
31.5	4.00	2.98	6.80	43.8
41.5	5.27	3.93	9.00	43.7

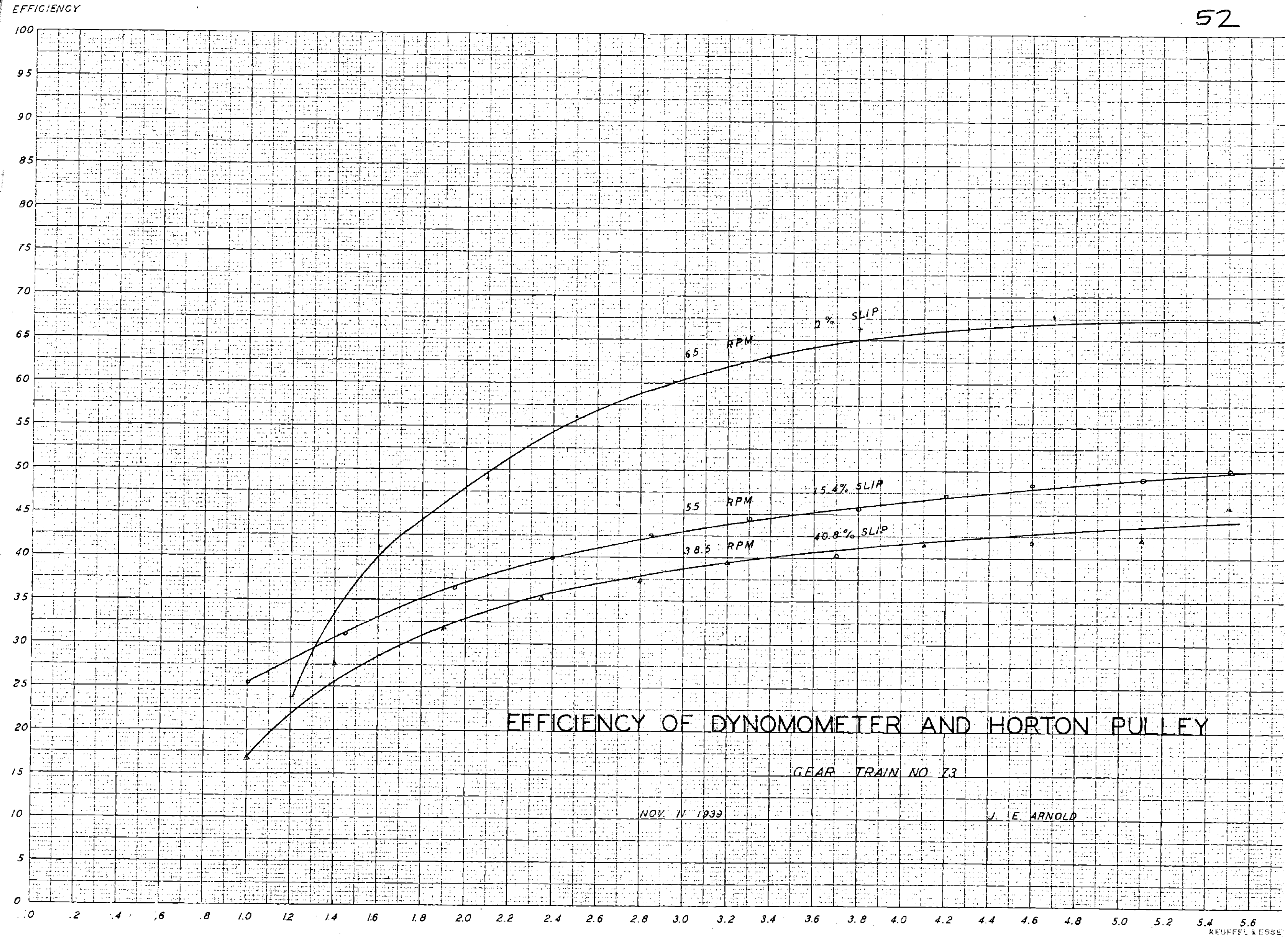
Spindle speed 178 rpm — 55 % Slip

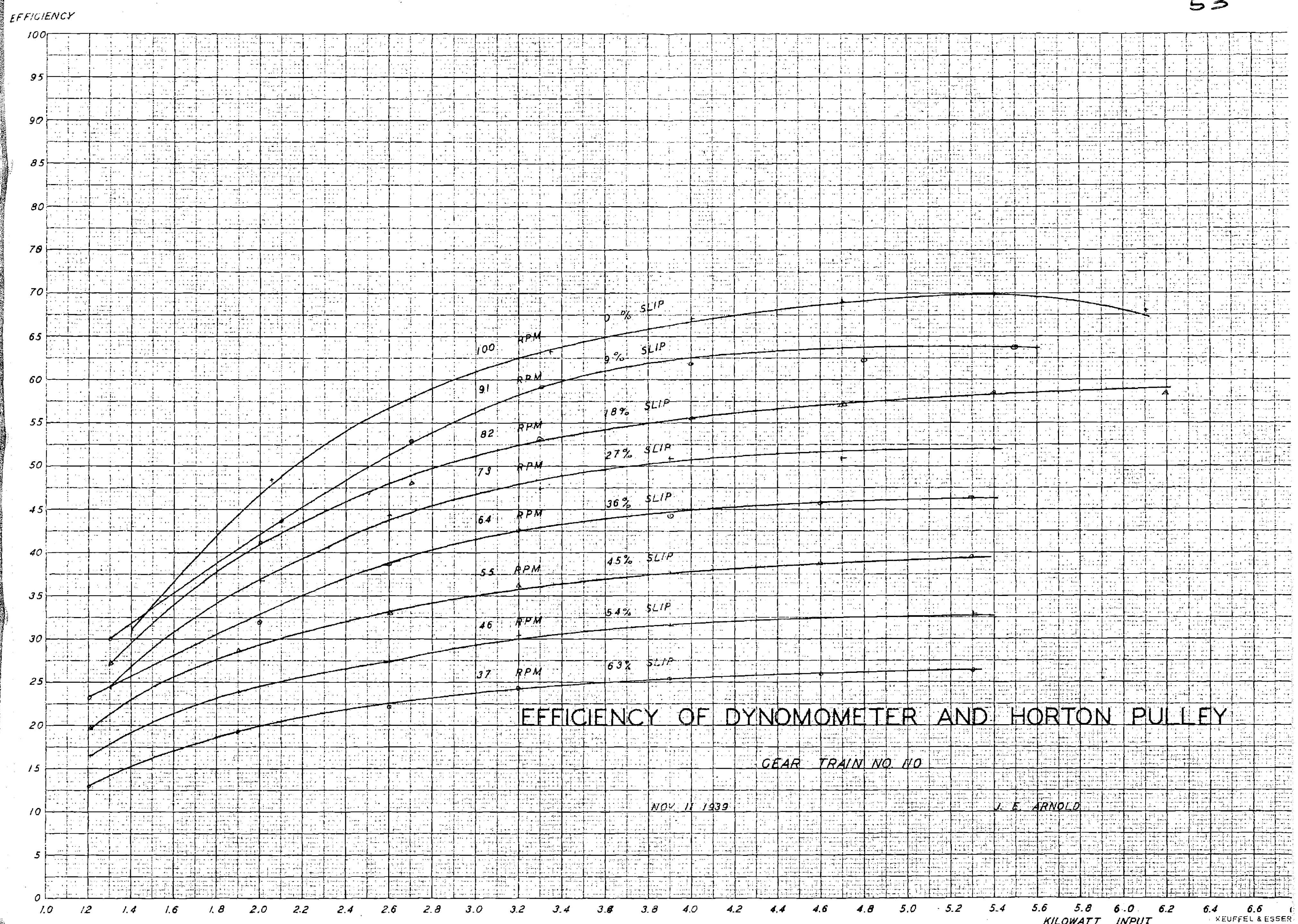
6.5	.590	.440	2.20	20.0
11.5	1.04	.778	3.10	25.1
16.5	1.50	1.12	4.00	28.0
21.5	1.95	1.46	4.95	29.4
26.5	2.40	1.79	5.80	30.9
31.5	2.86	2.14	6.80	31.4
41.5	3.76	2.80	8.80	31.8

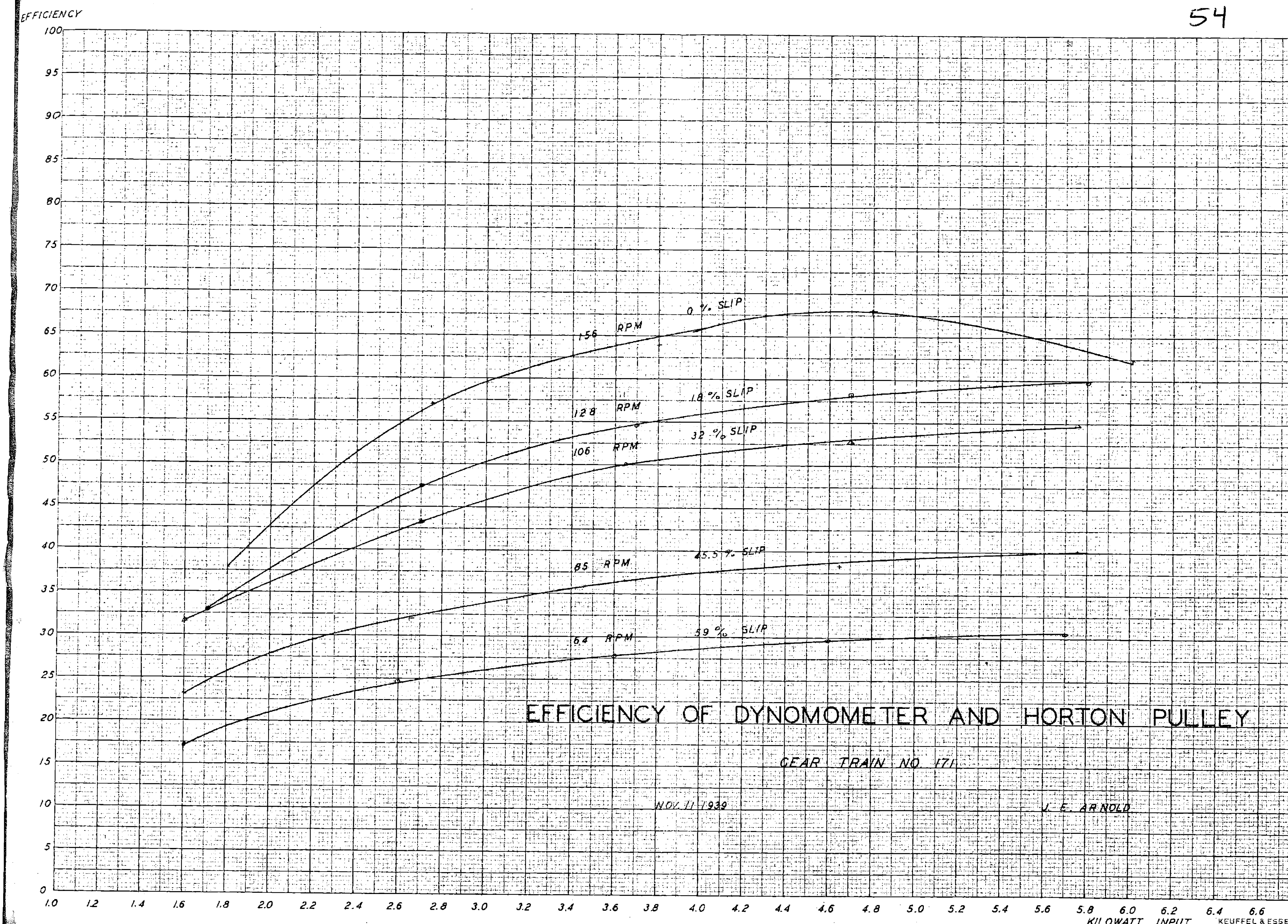
APPENDIX B

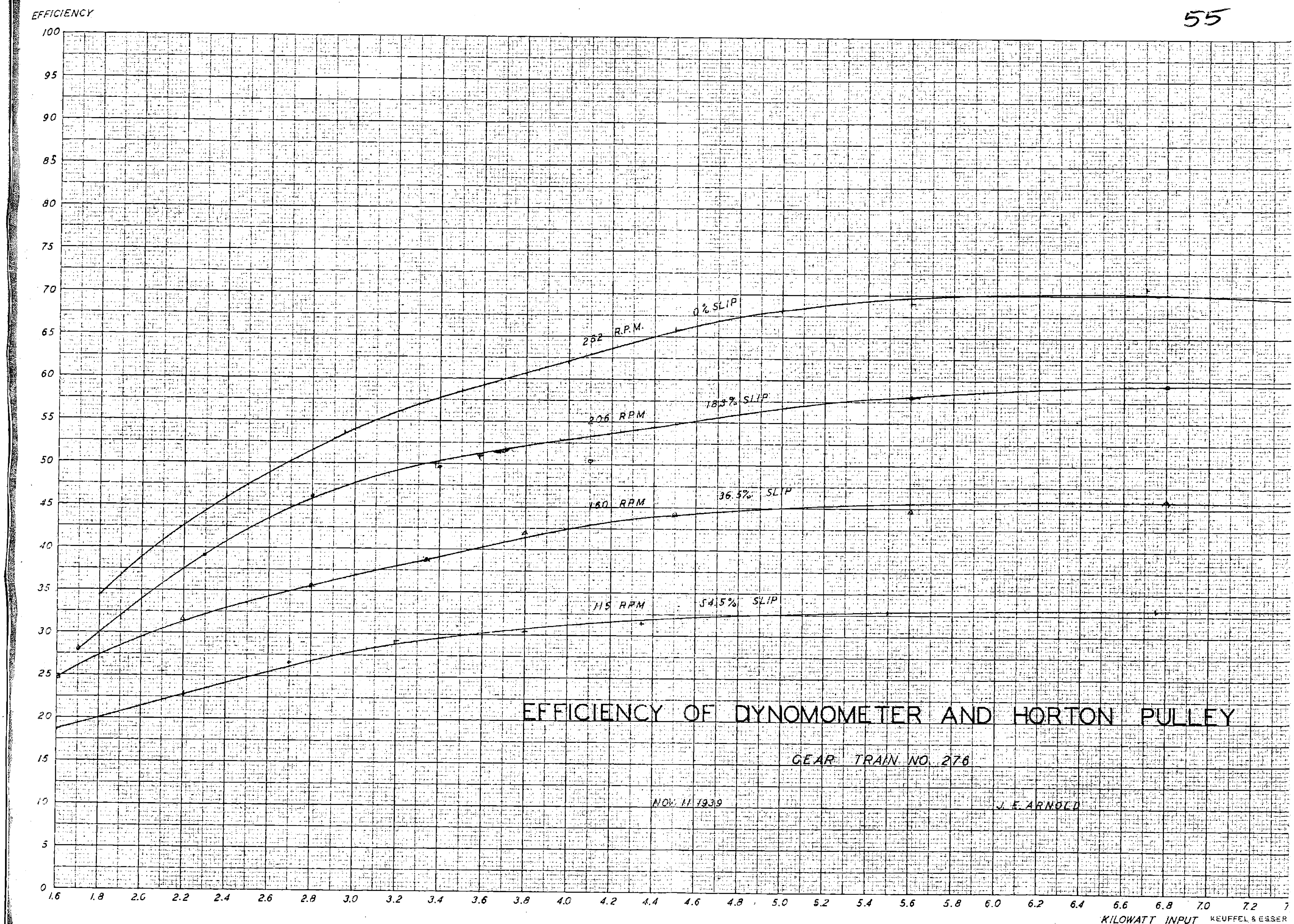
Efficiency Charts for Lathe and Horton Pulley

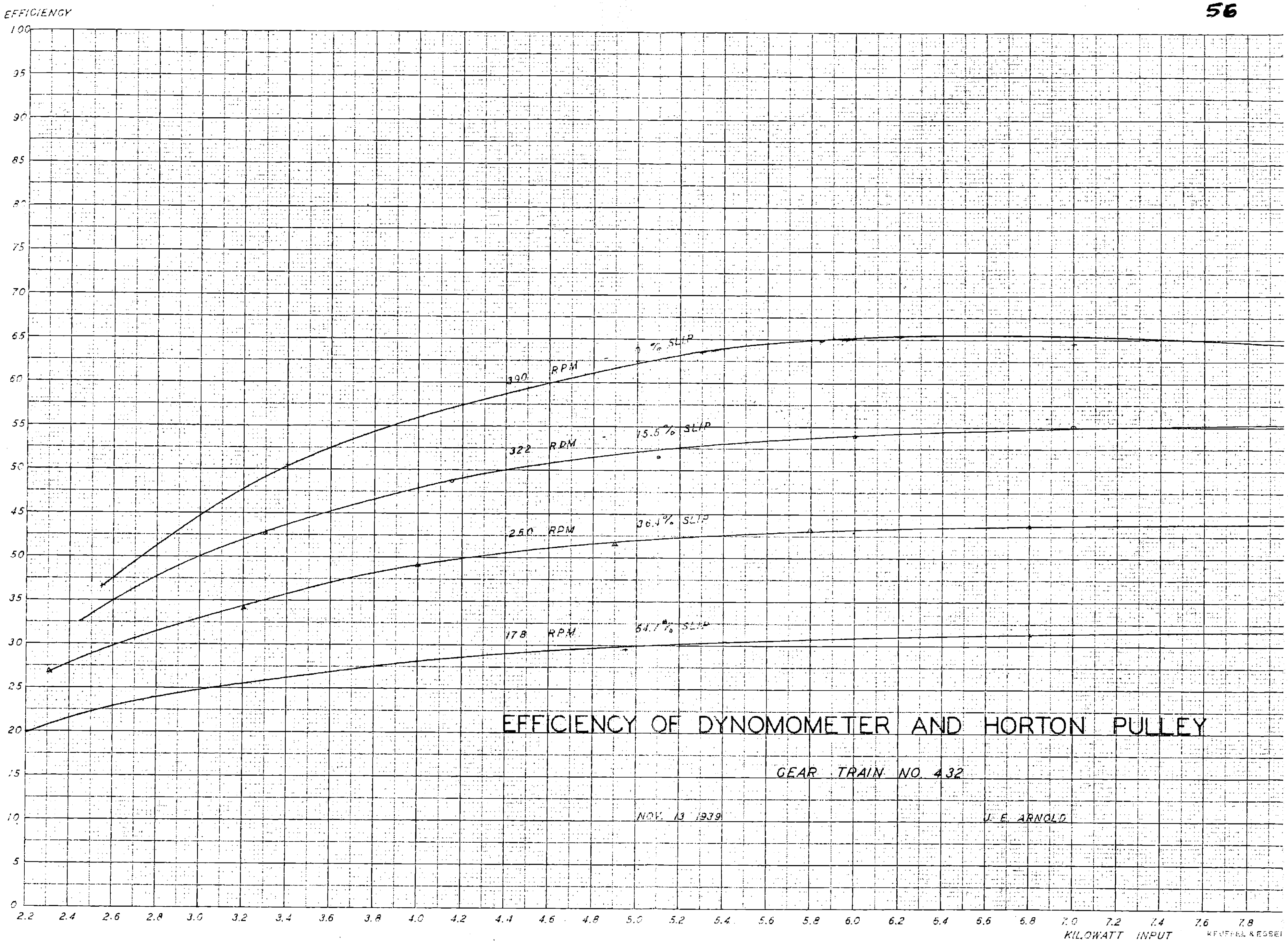

EFFICIENCY OF DYNOMOMETER AND HORTON PULLEY
GEAR TRAIN NO. 47
OCT. 26 1939
J. F. ARNOLD
EFFICIENCY
KILOWATT INPUT
43.5 RPM
0% SLIP
30 RPM
31% SLIP
20 RPM
54% SLIP
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
.2
.4
.6
.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
3.0
3.2
3.4
3.6
3.8
4.0
4.2
4.4
4.6
4.8
5.0
5.2
5.4
5.6
KEUFFEL & ESSER


EFFICIENCY
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
.0 .2 .4 .6 .8 1.0 1.2 1.4 1.6 1.8 2.0 2.2 2.4 2.6 2.8 3.0 3.2 3.4 3.6 3.8 4.0 4.2 4.4 4.6 4.8 5.0 5.2 5.4 5.6
65 RPM 0% SLIP
55 RPM 15.4% SLIP
38.5 RPM 40.8% SLIP
EFFICIENCY OF DYNOMOMETER AND HORTON PULLEY
GEAR TRAIN NO 73
NOV. 11 1939
J. E. ARNOLD
KEUFFEL & ESSE


EFFICIENCY
100
95
90
85
80
78
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
1.0
12
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
3.0
3.2
3.4
3.6
3.8
4.0
4.2
4.4
4.6
4.8
5.0
5.2
5.4
5.6
5.8
6.0
6.2
6.4
6.6
KILOWATT INPUT
100 RPM
0 % SLIP
91 RPM
9 % SLIP
82 RPM
18% SLIP
73 RPM
27% SLIP
64 RPM
36% SLIP
55 RPM
45% SLIP
46 RPM
54% SLIP
37 RPM
63% SLIP
EFFICIENCY OF DYNOMOMETER AND HORTON PULLEY
GEAR TRAIN NO 110
NOV. 11 1939
J. E. ARNOLD
KEUFFEL & ESSER


EFFICIENCY
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
3.0
3.2
3.4
3.6
3.8
4.0
4.2
4.4
4.6
4.8
5.0
5.2
5.4
5.6
5.8
6.0
6.2
6.4
6.6
KILOWATT INPUT
156 RPM
0 % SLIP
128 RPM
18 % SLIP
106 RPM
32 % SLIP
85 RPM
45.5 % SLIP
64 RPM
59 % SLIP
EFFICIENCY OF DYNOMOMETER AND HORTON PULLEY
GEAR TRAIN NO 171
NOV. 11 1939
J. E. ARNOLD
KEUFFEL & ESSER


EFFICIENCY
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
0% SLIP
252 R.P.M.
18.3% SLIP
206 RPM
36.5% SLIP
160 RPM
54.5% SLIP
115 RPM
EFFICIENCY OF DYNOMOMETER AND HORTON PULLEY
GEAR TRAIN NO. 276
NOV. 11 1939
J. E. ARNOLD
1.6
1.8
2.0
2.2
2.4
2.6
2.8
3.0
3.2
3.4
3.6
3.8
4.0
4.2
4.4
4.6
4.8
5.0
5.2
5.4
5.6
5.8
6.0
6.2
6.4
6.6
6.8
7.0
7.2
KILOWATT INPUT
KEUFFEL & ESSER



EFFICIENCY
390 RPM
% SLIP
322 RPM
15.5 % SLIP
250 RPM
36.4 % SLIP
178 RPM
54.7 % SLIP
EFFICIENCY OF DYNOMOMETER AND HORTON PULLEY
GEAR TRAIN NO. 432
NOV. 13 1939
J. E. ARNOLD
KILOWATT INPUT

APPENDIX C

Data on Machining Vanadium "D"

Stock

DATA ON VANADIUM "D" STOCK

RUN	TOOL	FPM	DEPTH	FEED	GAUGE PRESSURES RADIAL	LONG.	TANG.	KW.in
1	1	50	.031	.0035	-7 -	20.0	1.4	.85
2	1	50	.032	.007	---	22.0	3.0	.90
3	1	50	.030	.014	7.5	29.0	5.0	1.00
4	1	50	.0325	.028	29.0	27.0	10.0	1.25
5	1	50	.029	.021	16.0	27.0	7.3	1.15
6	1	50	.031	.0105	----	22.0	3.5	.95
7	1	50	.031	.00525	----	19.0	2.0	.86
8	1	60	.0315	.00525	14.0	12.0	4.8	.95
9	1	60	.031	.0105	17.0	12.0	6.2	1.00
10	1	60	.030	.021	28.0	18.0	8.8	1.20
11	1	60	.032	.0035	7.0	8.0	3.0	.88
12	1	60	.0315	.007	13.0	15.0	5.0	.95
13	2	60	.029	.014	10.0	14.0	4.0	1.05
14	2	60	.029	.028	37.0	22.0	8.8	1.35
15	2	30	.0335	.0035	----	9.0	1.0	.83
16	2	30	.0335	.007	3.0	12.0	2.5	.87
17	2	30	.034	.014	6.0	15.0	4.0	1.00
18	2	30	.034	.028	27.0	20.0	8.5	1.27
19	2	30	.034	.021	15.0	20.0	6.2	1.15
20	2	30	.034	.0105	8.0	15.0	3.7	.95
21	2	30	.034	.00525	----	11.0	1.5	.86
22	2	40	.034	.00525	----	12.0	1.3	.89

RUN	TOOL	FPM	DEPTH	FEED	RADIAL	LONG.	TANG.	KW. in
23	2	40	.0345	.0105	4.0	15.0	3.0	.89
24	2	40	.0345	.021	17.0	19.0	6.8	.98
25	2	40	.0345	.028	25.0	19.0	9.0	1.28
26	2	40	.035	.014	13.0	17.0	5.0	1.05
27	2	40	.035	.007	4.0	13.0	2.7	.93
28	2	40	.035	.0035	----	10.0	1.2	.85
29	3	30	.0335	.00525	2.0	15.0	.9	.83
30	3	30	.0335	.0105	5.0	20.0	2.0	.92
31	3	30	.033	.021	15.0	23.0	5.2	1.10
32	3	30	.0325	.028	24.0	25.0	7.5	1.20
33	3	30	.033	.014	8.0	17.0	3.0	1.00
34	3	30	.0335	.007	1.0	15.0	1.0	.90
35	3	30	.0345	.0035	.5	15.0	.5	.80
36	3	40	.0345	.0035	.5	6.0	.5	.82
37	3	40	.0345	.007	.5	10.0	1.0	.90
38	3	40	.0345	.014	5.0	15.0	3.5	1.00
39	3	40	.0335	.028	23.0	14.0	8.0	1.25
40	3	40	.034	.021	13.0	16.0	5.5	1.15
41	3	40	.0345	.0105	2.0	14.0	2.6	.96
42	3	40	.0345	.00525	----	13.0	1.0	.86
43	3	50	.035	.00525	----	14.0	1.0	.88
44	3	50	.035	.0105	3.0	15.0	2.9	.97
45	3	50	.0345	.021	14.0	17.0	6.1	1.15
46	3	50	.0345	.028	32.0	27.0	9.1	1.30

RUN	TOOL	FPM	DEPTH	FEED	RADIAL	LONG.	TANG.	KW. in
47	3	50	.035	.014	11.0	19.0	4.5	1.02
48	3	50	.036	.007	4.0	15.0	2.1	.92
49	3	50	.0365	.0035	----	13.0	----	.83
50	4	60	.033	.0035	----	9.0	1.5	.90
51	4	60	.0325	.007	----	9.0	2.1	.98
52	4	60	.032	.014	9.0	15.0	4.2	1.07
53	4	60	.030	.028	35.0	20.0	9.9	1.35
54	4	60	.032	.021	17.0	12.0	6.3	1.20
55	4	60	.034	.0105	4.0	9.0	3.5	1.01
56	4	60	.034	.00525	----	7.0	1.9	.92
57	5	60	.0335	.00525	2.0	2.0	2.8	.91
58	5	60	.0335	.0105	5.0	4.0	3.3	1.00
59	5	60	.0325	.021	20.0	8.0	7.0	1.19
60	5	60	.031	.28	40.0	16.0	10.5	1.35
61	5	60	.0335	.014	14.0	5.0	5.2	1.15
62	5	60	.0345	.007	4.0	4.0	3.1	1.00
63	5	60	.0345	.0035	2.0	----	1.9	.90
64	5	50	.034	.0035	----	----	2.0	.87
65	5	50	.345	.007	6.0	4.0	3.8	.92
66	5	50	.034	.014	10.0	5.0	5.0	1.08
67	5	50	.033	.028	34.0	12.0	10.2	1.32
68	5	50	.0345	.021	20.0	7.0	7.2	1.20
69	5	50	.035	.0105	11.0	6.0	4.5	1.00
70	5	50	.0345	.00525	6.0	5.0	2.8	.88

RUN	TOOL	FPM	DEPTH	FEED	RADIAL	LONG.	TANG.	KW.in
71	6	40	.033	.00525	2.0	3.0	1.5	.85
72	6	40	.0325	.0105	18.0	5.0	2.3	.95
73	6	40	.031	.021	50.0	9.0	5.2	1.10
74	6	40	.030	.028	28.0	7.0	6.5	1.20
75	6	40	.033	.014	14.0	6.0	3.7	1.00
76	6	40	.0335	.007	6.0	6.0	1.5	.90
77	6	40	.0335	.0035	1.0	3.0	0.5	.80
78	6	30	.0335	.0035	1.0	2.0	0.8	.78
79	6	30	.0335	.007	5.0	3.0	2.0	.82
80	6	30	.0335	.014	9.0	5.0	3.4	.95
81	6	30	.0315	.028	27.0	7.0	7.0	1.20
82	6	30	.033	.021	17.0	5.0	5.1	1.05
83	6	30	.034	.0105	4.0	5.0	2.2	.91
84	6	30	.034	.00525	----	1.0	0.5	.81
85	7	30	.034	.00525	----	1.0	0.5	.81
86	7	30	.0335	.0105	4.0	2.0	2.2	.90
87	7	30	.031	.021	13.0	4.0	4.4	1.04
88	7	30	.0305	.028	30.0	5.0	7.0	1.20
89	7	30	.032	.014	12.0	3.0	3.8	.95
90	7	30	.0325	.007	4.0	1.0	1.5	.81
91	7	30	.0325	.0035	----	0.5	0.5	.79
92	7	40	.0325	.0035	----	1.0	1.0	.80
93	7	40	.0325	.007	1.0	3.0	1.3	.87
94	7	40	.032	.014	12.0	4.0	3.5	.98

RUN	TOOL	FPM	DEPTH	FEED	RADIAL	LONG.	TANG.	KW.in
95	7	40	.0305	.028	40.0	6.0	7.1	1.25
96	7	40	.032	.021	25.0	5.0	5.5	1.10
97	7	40	.0325	.0105	10.0	5.0	2.6	.92
98	7	40	.033	.00525	3.0	2.0	1.0	.83
99	8	50	.0325	.00525	6.0	2.0	1.0	.91
100	8	50	.0325	.0105	14.0	4.5	2.5	1.00
101	8	50	.0315	.021	29.0	6.0	4.8	1.15
102	8	50	.0305	.028	40.0	6.0	7.0	1.25
103	8	50	.0325	.014	18.0	5.0	3.2	1.05
104	8	50	.0335	.007	4.0	3.0	1.0	.93
105	8	50	.034	.0035	1.0	0.5	0.5	.87
106	8	60	.034	.0035	1.0	0.5	0.5	.88
107	8	60	.0335	.007	8.0	2.0	1.5	.93
108	8	60	.0335	.014	13.0	4.0	3.5	1.03
109	8	60	.0031	.028	48.0	10.0	7.2	1.30
110	8	60	.033	.021	18.0	5.0	4.8	1.17
111	8	60	.034	.0105	10.0	4.0	2.0	1.00
112	8	60	.0345	.00525	----	1.0	0.5	.90
113	1	30	.0655	.00525	11.0	22.0	3.9	1.00
114	1	30	.0665	.0105	23.0	40.0	7.1	1.20
115	1	30	.0665	.021	47.0	52.0	13.0	1.50
116	1	30	.068	.028	61.0	52.0	17.0	1.70
117	1	30	.0675	.014	27.0	37.0	9.0	1.30
118	1	30	.0675	.007	8.0	25.0	4.0	1.02
119	1	30	.0675	.0035	----	20.0	2.0	.91

RUN	TOOL	FPM	DEPTH	FEED	RADIAL	LONG.	TANG.	KW. in
120	1	40	.067	.0035	----	19.0	2.1	.92
121	1	40	.0675	.007	6.0	28.0	3.8	1.06
122	1	40	.068	.014	23.0	40.0	8.5	1.29
123	1	40	.064	.028	80.0	90.0	20.0	1.85
124	1	40	.067	.021	45.0	65.0	13.0	1.50
125	1	40	.067	.0105	16.0	52.0	6.0	1.18
126	1	40	.0675	.00525	2.0	36.0	2.2	.98
127	2	50	.0625	.00525	----	22.0	1.8	.98
128	2	50	.0615	.0105	8.0	37.0	4.6	1.13
129	2	50	.0645	.021	43.0	65.0	12.5	1.55
130	2	50	.0635	.028	65.0	90.0	17.0	1.85
131	2	50	.0655	.014	18.0	48.0	7.0	1.25
132	2	50	.0675	.007	5.0	45.0	3.0	1.05
133	2	50	.0675	.0035	----	36.0	1.5	.92
134	2	60	.0615	.00525	4.0	31.0	2.8	1.05
135	2	60	.0615	.0105	22.0	35.0	6.5	1.22
136	2	60	.059	.021	60.0	75.0	14.0	1.56
137	2	60	.0565	.028	105.0	85.0	18.0	1.77
138	2	60	.062	.014	22.0	35.0	7.2	1.38
139	2	60	.0645	.007	3.0	30.0	3.0	1.07
140	2	60	.0645	.0035	----	21.0	1.2	.95
141	3	60	.0645	.0035	-2.0	15.0	0.8	.95
142	3	60	.064	.007	2.0	23.0	2.5	1.06
143	3	60	.064	.014	17.0	35.0	6.8	1.25

RUN	TOOL	FPM	DEPTH	FEED	RADIAL	LONG.	TANG.	KW.in
144	3	60	.0625	.028	65.0	70.0	18.0	1.77
145	3	60	.0645	.021	45.0	60.0	13.2	1.57
146	3	60	.0665	.0105	12.0	37.0	5.1	1.19
147	3	60	.0675	.00525	-3.0	30.0	1.8	1.00
148	3	50	.0685	.00525	-3.0	30.0	1.8	1.00
149	3	50	.0675	.0105	11.0	40.0	5.2	1.15
150	3	50	.067	.021	48.0	60.0	13.0	1.50
151	3	50	.0655	.028	74.0	73.0	18.2	1.75
152	3	50	.0685	.014	19.0	42.0	7.2	1.20
153	3	50	.0695	.007	7.0	30.0	3.2	1.05
154	3	50	.069	.0035	-3.0	25.0	1.5	.93
155	4	40	.0615	.00525	----	22.0	3.8	1.00
156	4	40	.062	.0105	14.0	25.0	8.2	1.13
157	4	40	.061	.021	32.0	25.0	13.8	1.38
158	4	40	.061	.028	54.0	35.0	17.2	1.55
159	4	40	.0635	.014	12.0	23.0	7.5	1.21
160	4	40	.0645	.007	2.0	21.0	3.8	1.00
161	4	40	.0645	.0035	-3.0	14.0	1.0	.90
162	4	30	.065	.0035	-4.0	13.0	1.1	.89
163	4	30	.0645	.007	10.0	21.0	3.0	.98
164	4	30	.0645	.014	12.0	27.0	7.1	1.12
165	4	30	.0625	.028	45.0	30.0	15.2	1.45
166	4	30	.064	.021	30.0	30.0	12.0	1.32
167	4	30	.064	.0105	7.0	22.0	6.0	1.05
168	4	30	.0655	.00525	-2.0	16.0	2.8	.92

RUN	TOOL	FPM	DEPTH	FEED	RADIAL	LONG.	TANG.	KW.in
169	5	30	.0645	.00525	----	12.0	3.0	.98
170	5	30	.0635	.0105	14.0	15.0	6.8	1.16
171	5	30	.0635	.021	28.0	15.0	14.0	1.48
172	5	30	.0625	.028	45.0	22.0	18.0	1.65
173	5	30	.064	.014	17.0	22.0	9.0	1.25
174	5	30	.0645	.007	4.0	17.0	4.2	1.05
175	5	30	.0655	.0035	----	7.0	1.7	.90
176	5	40	.0655	.0035	-1.0	9.0	1.8	.93
177	5	40	.0645	.007	4.0	15.0	4.0	1.07
178	5	40	.0635	.014	20.0	18.0	9.2	1.27
179	5	40	.061	.028	65.0	50.0	20.0	1.83
180	5	40	.0635	.021	30.0	19.0	13.2	1.48
181	5	40	.0645	.0105	13.0	15.0	6.8	1.18
182	5	40	.0655	.00525	1.0	8.0	2.8	.98
183	6	50	.0635	.00525	1.0	11.0	2.6	.98
184	6	50	.063	.0105	15.0	14.0	6.2	1.16
185	6	50	.062	.021	50.0	32.0	13.2	1.50
186	6	50	.061	.028	57.0	35.0	18.5	1.72
187	6	50	.065	.014	21.0	19.0	8.2	1.25
188	6	50	.0655	.007	3.0	10.0	3.8	1.02
189	6	50	.0665	.0035	----	4.0	1.1	.92
190	6	60	.0655	.0035	-1.0	4.0	1.2	.97
191	6	60	.065	.007	4.0	14.0	3.8	1.08
192	6	60	.0645	.014	27.0	25.0	9.2	1.42
193	6	60	.061	.028	69.0	50.0	18.3	1.91

RUN	TOOL	FPM	DEPTH	FEED	RADIAL	LONG.	TANG.	KW.in
194	6	60	.062	.021	42.0	35.0	13.5	1.62
195	6	60	.065	.0105	11.0	20.0	5.8	1.25
196	6	60	.0655	.00525	-2.0	11.0	2.1	1.10
197	7	60	.062	.00525	2.0	10.0	2.5	1.04
198	7	60	.060	.0105	20.0	18.0	7.1	1.22
199	7	60	.0605	.021	67.0	33.0	16.0	1.80
200	7	60	.059	.028	90.0	35.0	20.5	2.02
201	7	60	.065	.014	32.0	21.0	9.8	1.48
202	7	60	.067	.007	12.0	15.0	4.8	1.12
203	7	60	.0685	.0035	-3.0	7.5	1.3	.98
204	7	50	.068	.0035	-4.0	7.0	1.0	.96
205	7	50	.0675	.007	9.0	16.0	4.2	1.10
206	7	50	.066	.014	30.0	20.0	9.3	1.30
207	7	50	.061	.028	86.0	43.0	20.2	1.85
208	7	50	.0655	.021	57.0	25.0	15.0	1.60
209	7	50	.0675	.0105	24.0	19.0	7.5	1.22
210	7	50	.070	.00525	2.5	12.0	2.5	1.05
211	8	40	.0695	.00525	-1.0	10.0	2.7	1.00
212	8	40	.069	.0105	12.0	15.0	6.5	1.15
213	8	40	.0685	.021	35.0	22.0	14.0	1.55
214	8	40	.0665	.028	68.0	40.0	20.5	1.80
215	8	40	.070	.014	20.0	15.0	8.8	1.28
216	8	40	.0705	.007	3.0	15.0	3.9	1.03
217	8	40	.071	.0035	-2.0	7.0	1.0	.95
218	8	30	.0695	.0035	-2.0	7.0	1.0	.90

RUN	TOOL	FPM	DEPTH	FEED	RADIAL	LONG.	TANG.	KW.in
219	8	30	.0685	.007	6.0	15.0	4.1	1.01
220	8	30	.0685	.014	18.0	18.0	8.4	1.23
221	8	30	.0675	.028	56.0	27.0	17.0	1.65
222	8	30	.068	.021	34.0	18.0	12.8	1.42
223	8	30	.070	.0105	13.0	13.0	6.2	1.15
224	8	30	.070	.00525	2.0	9.0	2.8	.97
225	1	30	.1225	.00525	12.5	38.0	6.5	1.15
226	1	30	.120	.0105	33.0	65.0	15.5	1.45
227	1	30	.1135	.021	100.0	135.0	30.0	2.08
228	1	30	.1095	.028	122.0	185.0	37.0	2.55
229	1	30	.1165	.014	40.0	110.0	17.0	1.60
230	1	30	.1185	.007	28.0	85.0	9.5	1.27
231	1	30	.119	.0035	3.0	27.0	3.8	1.00
232	1	40	.118	.0035	3.0	24.0	3.8	1.00
233	1	40	.117	.007	25.0	55.0	10.0	1.28
234	1	40	.1165	.014	47.0	90.0	18.0	1.68
235	1	40	.112	.028	130.0	170.0	36.0	2.50
236	1	40	.1145	.021	120.0	130.0	28.5	2.18
237	1	40	.1195	.0105	40.0	70.0	13.5	1.47
238	1	40	.1205	.00525	13.0	32.0	6.5	1.17
239	2	50	.1265	.00525	17.0	58.0	6.5	1.20
240	2	50	.129	.0105	60.0	82.0	14.0	1.50
241	2	50	.1245	.021	115.0	160.0	31.0	2.25
242	2	50	.1255	.028	125.0	180.0	38.0	2.60
243	2	50	.129	.014	73.0	120.0	22.0	1.82

RUN	TOOL	FPM	DEPTH	FEED	RADIAL	LONG.	TANG.	KW. in
244	2	50	.1305	.007	25.0	77.0	10.0	1.35
245	2	50	.1325	.0035	5.0	62.0	3.8	1.09
246	2	60	.1315	.0035	5.0	70.0	3.8	1.25
247	2	60	.1305	.007	27.0	87.0	10.0	1.60
248	2	60	.1285	.014	67.0	132.0	22.5	2.40
249	2	60	.1255	.028	135.0	200.0	38.0	3.45
250	2	60	.130	.021	94.0	151.0	29.0	2.95
251	2	60	.1335	.0105	38.0	75.0	15.0	1.98
252	2	60	.133	.00525	15.0	75.0	7.5	1.48
253	3	60	.1265	.00525	9.0	35.0	9.2	1.37
254	3	60	.127	.0105	38.0	75.0	17.5	1.80
255	3	60	.127	.021	130.0	165.0	39.0	2.90
256	3	60	.1235	.028	130.0	170.0	43.5	3.15
257	3	60	.1325	.014	51.0	130.0	25.0	2.10
258	3	60	.134	.007	27.0	97.0	15.0	1.55
259	3	60	.135	.0035	5.0	71.0	6.0	1.25
260	3	50	.134	.0035	5.0	75.0	5.8	1.20
261	3	50	.1335	.007	22.0	90.0	15.0	1.50
262	3	50	.1335	.014	50.0	110.0	22.0	2.00
263	3	50	.129	.028	117.0	165.0	41.5	3.12
264	3	50	.1335	.021	90.0	140.0	32.0	2.55
265	3	50	.136	.0105	34.0	95.0	17.2	1.75
266	3	50	.136	.00525	15.0	80.0	10.0	1.35
267	4	40	.1235	.00525	6.0	31.0	5.2	1.10
268	4	40	.1235	.0105	27.0	65.0	14.0	1.35

RUN	TOOL	FPM	DEPTH	FEED	RADIAL	LONG.	TANG.	KW.in
269	4	40	.120	.021	73.0	98.0	26.0	1.86
270	4	40	.1145	.028	112.0	140.0	33.0	2.15
271	4	40	.121	.014	35.0	95.0	16.5	1.45
272	4	40	.122	.007	13.0	75.0	8.0	1.17
273	4	40	.1225	.0035	5.0	60.0	4.0	.98
274	4	30	.122	.0035	2.0	60.0	3.8	.95
275	4	30	.1215	.007	18.0	80.0	8.8	1.12
276	4	30	.121	.014	35.0	91.0	16.5	1.40
277	4	30	.120	.028	90.0	115.0	30.0	1.96
278	4	30	.122	.021	60.0	110.0	22.0	1.72
279	4	30	.1245	.0105	25.0	65.0	11.0	1.25
280	4	30	.1255	.00525	6.0	32.0	6.2	1.05
281	5	30	.123	.00525	10.0	31.0	5.0	.98
282	5	30	.124	.0105	27.0	52.0	11.5	1.22
283	5	30	.123	.021	47.0	65.0	20.0	1.55
284	5	30	.1225	.028	68.0	75.0	27.0	1.80
285	5	30	.1245	.014	35.0	60.0	15.0	1.35
286	5	30	.125	.007	16.0	40.0	7.2	1.05
287	5	30	.1265	.0035	3.0	30.0	3.2	.91
288	5	40	.1245	.0035	3.0	33.0	3.1	.95
289	5	40	.1245	.007	20.0	40.0	8.2	1.15
290	5	40	.1245	.014	40.0	60.0	15.0	1.40
291	5	40	.121	.028	90.0	110.0	31.0	1.95
292	5	40	.124	.021	50.0	70.0	19.0	1.60
293	5	40	.124	.0105	24.0	60.0	10.0	1.05

RUN	TOOL	FPM	DEPTH	FEED	RADIAL	LONG.	TANG.	KW.in
294	5	40	.124	.00525	10.0	35.0	6.0	1.55
295	6	50	.127	.00525	10.0	32.0	6.0	1.70
296	6	50	.126	.0105	24.0	40.0	11.0	----
297	6	50	.126	.021	62.0	100.0	22.0	2.45
298	6	50	.118	.028	125.0	160.0	36.0	3.45
299	6	50	.125	.014	35.0	75.0	14.0	1.95
300	6	50	.1265	.007	13.0	55.0	8.0	1.45
301	6	50	.127	.0035	3.0	45.0	3.2	1.18
302	6	60	.1275	.0035	2.0	45.0	3.2	1.20
303	6	60	.127	.007	19.0	65.0	8.2	1.50
304	6	60	.1265	.014	35.0	76.0	15.8	2.05
305	6	60	.1215	.028	140.0	160.0	33.0	3.50
306	6	60	.1255	.021	72.0	90.0	23.5	2.65
307	6	60	.129	.0105	29.0	70.0	11.0	1.70
308	6	60	.129	.00525	10.0	60.0	6.0	1.35
309	7	60	.125	.00525	13.0	25.0	6.0	1.35
310	7	60	.125	.0105	32.0	60.0	12.0	1.75
311	7	60	.124	.021	95.0	110.0	26.0	2.62
312	7	60	.1215	.028	135.0	145.0	33.0	3.35
313	7	60	.1285	.014	20.0	65.0	13.0	1.85
314	7	60	.129	.007	10.0	55.0	7.0	1.38
315	7	60	.129	.0035	1.0	45.0	2.8	1.15
316	7	50	.1265	.0035	----	25.0	4.2	1.15
317	7	50	.1265	.007	12.0	41.0	9.5	1.42
318	7	50	.127	.014	30.0	50.0	15.0	1.80

RUN	TOOL	FPM	DEPTH	FEED	RADIAL	LONG.	TANG.	KW.in
319	7	50	.125	.028	95.0	95.0	32.0	2.85
320	7	50	.1275	.021	40.0	60.0	21.0	2.25
321	7	50	.1295	.0105	22.0	40.0	12.0	1.60
322	7	50	.1295	.00525	7.0	30.0	5.5	1.28
323	8	40	.123	.00525	15.0	27.0	6.8	1.12
324	8	40	.1235	.0105	30.0	45.0	13.0	1.35
325	8	40	.1235	.021	50.0	50.0	22.5	1.70
326	8	40	.123	.028	65.0	70.0	28.0	1.90
327	8	40	.124	.014	35.0	60.0	16.0	1.45
328	8	40	.1255	.007	15.0	42.0	7.5	1.15
329	8	40	.126	.0035	9.0	30.0	3.8	1.00
330	8	30	.125	.0035	9.0	30.0	3.7	.96
331	8	30	.1245	.007	13.0	45.0	7.8	1.12
332	8	30	.124	.014	35.0	50.0	15.0	1.35
333	8	30	.1235	.028	60.0	60.0	27.0	1.85
334	8	30	.1255	.021	50.0	56.0	20.5	1.65
335	8	30	.126	.0105	27.0	40.0	12.5	1.25
336	8	30	.1275	.00525	7.5	35.0	6.5	1.05
337	1	30	.247	.00525	52.0	100.0	21.0	1.65
338	1	30	.245	.0105	87.0	165.0	37.0	2.20
339	1	30	.236	.021	175.0	300.0	55.0	3.30
340	1	30	----	.028	----	----	----	----
341	1	30	.234	.014	141.0	235.0	47.0	2.80
342	1	30	.238	.007	55.0	125.0	23.0	1.90
343	1	30	.242	.0035	22.0	55.0	13.0	1.30

RUN	TOOL	FPM	DEPTH	FEED	RADIAL	LONG.	TANG.	KW.in
344	I	40	.242	.0035	25.0	60.0	13.5	1.40
345	I	40	.241	.007	55.9	130.0	24.5	2.10
346	I	40	.2375	.014	150.0	245.0	55.0	2.60
347	I	40	----	.028	----	----	----	----
348	I	40	----	.021	----	----	----	----
349	I	40	.238	.0105	135.0	200.0	41.0	2.40
350	I	40	.2415	.00525	52.0	120.0	22.0	1.70

RERUNS ON VANADIUM "D" STOCK

RUN	TOOL	FPM	DEPTH	FEED	RADIAL	LONG.	TANG.	KW.in
351	1	50	.031	.0035	3.0	7.0	0.9	.85
352	1	50	.031	.007	7.0	12.0	2.1	.90
353	1	50	.031	.014	17.0	20.0	4.3	1.02
354	1	50	.0305	.028	47.0	29.0	9.8	1.25
355	1	50	.0345	.0035	4.0	7.0	1.0	.85
356	1	50	.0345	.007	7.0	15.0	2.0	.93
357	1	50	.033	.014	14.0	25.0	4.8	1.03
358	1	50	.032	.028	28.0	49.0	9.7	1.25
359	2	60	.0315	.0035	5.0	6.0	1.0	.90
360	2	60	.0315	.007	12.0	10.0	2.0	.99
361	2	60	.032	.014	29.0	17.0	4.2	1.15
362	2	60	.031	.028	62.0	30.0	8.2	1.50
363	2	60	.0355	.0035	7.0	6.0	1.0	.91
364	2	60	.0355	.007	14.0	32.0	2.2	1.00
365	2	60	.0335	.014	32.0	22.0	4.5	----
366	2	60	.032	.028	57.0	22.0	8.5	----
367	3	60	.0335	.0035	7.0	3.0	1.1	.93
368	3	60	.032	.007	14.0	5.0	2.8	1.05
369	3	60	.032	.014	28.0	10.0	4.5	1.18
370	3	60	.032	.028	47.0	20.0	8.8	1.48
371	3	60	.0325	.0035	10.0	3.0	1.0	.93
372	3	60	.0325	.007	12.0	5.0	2.5	1.00
373	3	60	.0325	.014	26.0	10.0	4.0	1.17
374	3	60	.032	.028	57.0	----	8.0	1.55
375	4	50	.031	.0035	5.0	4.0	1.0	.86

RUN	TOOL	FPM	DEPTH	FEED	RADIAL	LONG.	TANG.	KW.in
376	4	50	.031	.007	10.0	6.0	1.9	.90
377	4	50	.031	.014	20.0	8.0	4.0	1.00
378	4	50	.0295	.028	51.0	15.0	7.5	1.15
379	4	50	.033	.0035	9.0	7.0	1.0	.89
380	4	50	.0315	.007	17.0	13.0	2.2	.92
381	4	50	.0315	.014	44.0	17.0	4.1	1.00
382	4	50	.0305	.028	64.0	18.0	7.5	1.15
383	5	50	.0325	.0035	12.0	2.0	0.5	.85
384	5	50	.0325	.007	9.0	3.0	1.4	.90
385	5	50	.0325	.014	12.0	7.0	3.4	.99
386	5	50	.031	.028	35.0	13.0	8.0	1.20
387	5	50	.0335	.0035	6.0	4.0	0.5	.85
388	5	50	.0335	.007	10.0	12.0	1.5	.90
389	5	50	.0325	.014	29.0	15.0	4.0	1.01
390	5	50	.033	.028	53.0	15.0	7.9	1.15
391	6	60	.029	.0035	5.0	3.0	0.5	.95
392	6	60	.029	.007	14.0	4.0	1.5	1.02
393	6	60	.0285	.014	21.0	7.0	3.2	1.15
394	6	60	.0285	.028	47.0	8.0	7.2	1.40
395	6	60	.032	.0035	6.0	3.0	0.4	.94
396	6	60	.0295	.007	17.0	5.0	1.5	1.03
397	6	60	.030	.014	20.0	7.0	3.7	1.15
398	6	60	.0295	.028	45.0	12.0	7.1	1.40
399	7	60	.030	.0035	3.0	4.0	0.4	.96
400	7	60	.030	.007	15.0	7.0	2.3	1.05

RUN	TOOL	FPM	DEPTH	FEED	RADIAL	LONG.	TANG.	KW.in
401	7	60	.030	.014	22.0	3.0	4.0	1.15
402	7	60	.0295	.028	47.0	4.0	9.2	1.42
403	7	60	.033	.0035	14.0	3.0	1.0	.98
404	7	60	.032	.007	16.0	9.0	1.8	1.05
405	7	60	.0315	.014	25.0	15.0	3.0	1.15
406	7	60	.0315	.028	31.0	6.0	7.1	1.40
407	8	50	.029	.0035	9.0	2.0	1.0	.93
408	8	50	.029	.007	17.0	3.0	2.0	1.00
409	8	50	.029	.014	30.0	4.0	3.3	1.05
410	8	50	.0285	.028	49.0	4.0	7.6	1.38
411	8	50	.031	.0035	14.0	2.0	1.0	.92
412	8	50	.031	.007	20.0	2.5	1.7	1.00
413	8	50	.031	.014	32.0	2.0	3.4	1.12
414	8	50	.0305	.028	45.0	2.0	7.6	1.38
415	1	50	.060	.0035	32.0	18.0	3.0	1.12
416	1	50	.060	.007	42.0	30.0	5.0	1.30
417	1	50	.060	.014	62.0	35.0	9.0	1.60
418	1	50	.058	.028	180.0	80.0	16.5	2.25
419	1	50	.059	.0035	35.0	15.0	3.0	1.15
420	1	50	.059	.007	42.0	24.0	5.0	1.30
421	1	50	.059	.014	77.0	40.0	8.9	1.55
422	1	50	.0585	.028	110.0	75.0	16.0	2.18
423	2	60	.0645	.0035	23.0	15.0	1.8	1.02
424	2	60	.0645	.007	25.0	30.0	4.6	1.20
425	2	60	.065	.014	47.0	52.0	8.3	1.50

RUN	TOOL	FPM	DEPTH	FEED	RADIAL	LONG.	TANG.	KW.in
426	2	60	.0595	.028	105.0	105.0	17.2	2.20
427	2	60	.0655	.0035	37.0	22.0	2.0	1.05
428	2	60	.0655	.007	44.0	30.0	4.0	1.18
429	2	60	.0655	.014	57.0	65.0	8.2	1.45
430	2	60	.061	.028	118.0	120.0	16.5	2.20
431	3	60	.065	.0035	7.0	16.0	1.0	1.08
432	3	60	.065	.007	15.0	24.0	3.0	1.22
433	3	60	.065	.014	26.0	42.0	7.5	1.52
434	3	60	.0625	.028	82.0	85.0	16.0	2.15
435	3	60	.0685	.0035	10.0	12.0	1.0	1.08
436	3	60	.0675	.007	24.0	22.0	3.2	1.25
437	3	60	.0675	.014	25.0	30.0	7.5	1.50
438	3	60	.0635	.028	82.0	85.0	16.5	2.25
439	4	50	.061	.0035	4.0	11.0	0.8	.98
440	4	50	.061	.007	21.0	17.0	3.0	1.13
441	4	50	.061	.014	40.0	29.0	7.0	1.49
442	4	50	.0585	.028	64.0	60.0	14.0	1.85
443	4	50	.063	.0035	12.0	15.0	1.2	1.00
444	4	50	.063	.007	18.0	25.0	3.2	1.20
445	4	50	.063	.014	32.0	33.0	7.1	1.40
446	4	50	.0615	.028	52.0	60.0	14.0	1.90
447	5	50	.061	.0035	12.0	12.0	1.0	.98
448	5	50	.061	.007	16.0	18.0	2.0	1.10
449	5	50	.061	.014	23.0	23.0	7.0	1.35
450	5	50	.060	.028	40.0	45.0	13.0	1.80

RUN	TOOL	FPM	DEPTH	FEED	RADIAL	LONG.	TANG.	KW.in
451	5	50	.063	.0035	8.0	15.0	1.0	.95
452	5	50	.063	.007	18.0	20.0	2.0	1.10
453	5	50	.063	.014	27.0	25.0	6.8	1.35
454	5	50	.062	.028	45.0	38.0	13.2	1.75
455	6	60	.0625	.0035	7.0	7.0	1.0	1.05
456	6	60	.0625	.007	23.0	15.0	2.8	1.22
457	6	60	.0625	.014	35.0	20.0	6.0	1.60
458	6	60	.0615	.028	52.0	50.0	13.5	2.15
459	6	60	.065	.0035	12.0	12.0	1.0	1.05
460	6	60	.065	.007	18.0	17.0	2.8	1.20
461	6	60	.065	.014	27.0	23.0	6.0	1.50
462	6	60	.0635	.028	53.0	50.0	12.8	2.10
463	7	60	.063	.0035	3.0	5.0	0.5	1.00
464	7	60	.063	.007	9.0	9.0	2.3	1.15
465	7	60	.063	.014	22.0	21.0	6.1	1.45
466	7	60	.062	.028	53.0	45.0	13.0	1.95
467	7	60	.064	.0035	5.0	5.0	1.0	1.01
468	7	60	.064	.007	9.0	10.0	2.0	1.17
469	7	60	.064	.014	17.0	20.0	5.5	1.40
470	7	60	.062	.028	46.0	45.0	12.5	1.95
471	8	50	.065	.0035	6.0	9.0	0.8	.98
472	8	50	.065	.007	12.0	14.0	1.8	1.16
473	8	50	.065	.014	25.0	21.0	6.4	1.38
474	8	50	.065	.028	36.0	35.0	12.5	1.95
475	8	50	.0685	.0035	7.0	13.0	1.0	1.00

RUN	TOOL	FPM	DEPTH	FEED	RADIAL	LONG.	TANG.	KW. In
476	8	50	.068	.007	10.0	20.0	1.9	1.15
477	8	50	.067	.014	14.0	22.0	6.2	1.42
478	8	50	.065	.028	45.0	35.0	13.0	2.05
479	1	50	.125	.0035	13.0	37.0	4.5	1.29
480	1	50	.125	.007	29.0	52.0	9.0	1.60
481	1	50	.1245	.014	59.0	95.0	17.0	2.30
482	1	50	.115	.028	170.0	240.0	35.0	3.80
483	1	50	.1235	.0035	28.0	40.0	4.7	1.32
484	1	50	.1235	.007	57.0	60.0	9.0	1.65
485	1	50	.123	.014	65.0	115.0	17.5	2.35
486	1	50	.1155	.028	160.0	210.0	34.0	3.75
487	2	60	.128	.0035	35.0	30.0	4.0	1.30
488	2	60	.128	.007	40.0	60.0	8.0	1.65
489	2	60	.127	.014	85.0	115.0	17.5	2.40
490	2	60	.1215	.028	125.0	220.0	34.0	3.80
491	2	60	.130	.0035	37.0	----	4.0	1.38
492	2	60	.130	.007	50.0	----	8.5	1.70
493	2	60	.1295	.014	75.0	----	17.5	2.45
494	2	60	.1255	.028	125.0	----	33.0	3.70
495	3	60	.1225	.0035	20.0	----	3.8	1.25
496	3	60	.1225	.007	41.0	----	7.5	1.45
497	3	60	.1225	.014	57.0	----	16.0	2.00
498	3	60	.1135	.028	115.0	----	32.0	3.45
499	3	60	.123	.0035	20.0	----	3.8	1.25
500	3	60	.123	.007	46.0	----	7.7	1.50

RUN	TOOL	FPM	DEPTH	FEED	RADIAL	LONG.	TANG.	KW.in
501	3	60	.123	.014	55.0	----	16.0	2.05
502	3	60	.114	.028	120.0	----	32.5	3.45
503	4	50	.128	.0035	40.0	30.0	3.7	1.20
504	4	50	.128	.007	50.0	49.0	7.6	1.45
505	4	50	.128	.014	110.0	83.0	16.0	2.00
506	4	50	.125	.028	118.0	150.0	32.0	3.35
507	4	50	.129	.0035	39.0	32.0	3.8	1.20
508	4	50	.129	.007	43.0	48.0	7.5	1.45
509	4	50	.129	.014	85.0	95.0	16.2	2.00
510	4	50	.127	.028	115.0	160.0	32.5	3.30
511	5	50	.130	.0035	39.0	26.0	1.2	1.20
512	5	50	.130	.007	47.0	40.0	5.2	1.50
513	5	50	.130	.014	115.0	75.0	15.0	2.05
514	5	50	.1285	.028	185.0	145.0	31.0	3.40
515	5	50	.132	.0035	27.0	30.0	2.5	1.25
516	5	50	.132	.007	50.0	48.0	6.5	1.55
517	5	50	.132	.014	75.0	70.0	14.5	2.05
518	5	50	.1285	.028	125.0	130.0	31.5	3.45
519	6	60	.126	.0035	30.0	27.0	2.0	1.25
520	6	60	.126	.007	45.0	45.0	5.8	1.55
521	6	60	.126	.014	100.0	75.0	14.5	2.10
522	6	60	.124	.028	160.0	135.0	31.0	3.60
523	6	60	.1255	.0035	32.0	30.0	2.0	1.25
524	6	60	.1255	.007	47.0	42.0	6.0	1.55
525	6	60	.1255	.014	80.0	80.0	14.5	2.08

RUN	TOOL	FPM	DEPTH	FEED	RADIAL	LONG.	TANG.	KW.In
526	6	60	.123	.028	150.0	130.0	31.5	3.50
527	7	60	.124	.0035	12.0	15.0	1.5	1.15
528	7	60	.124	.007	26.0	25.0	5.5	1.50
529	7	60	.124	.014	65.0	50.0	12.0	1.95
530	7	60	.122	.028	100.0	95.0	28.0	3.10
531	7	60	.1235	.0035	14.0	17.0	1.8	1.15
532	7	60	.1235	.007	26.0	22.0	5.9	1.55
533	7	60	.1235	.014	55.0	47.0	12.0	2.00
534	7	60	.1215	.028	95.0	100.0	28.0	3.20
535	8	50	.123	.0035	9.0	15.0	1.0	1.10
536	8	50	.123	.007	25.0	22.0	5.2	1.45
537	8	50	.123	.014	45.0	45.0	12.0	1.88
538	8	50	.1205	.028	90.0	100.0	28.0	2.95
539	8	50	.125	.0035	18.0	17.0	2.2	1.20
540	8	50	.125	.007	27.0	27.0	6.0	1.45
541	8	50	.125	.014	85.0	60.0	12.5	1.88
542	8	50	.122	.028	120.0	95.0	27.5	2.90

ADDITIONAL DATA ON VANADIUM "D" STOCK

RUN	RPM	KW.in	EFF.	KW.out	HPout	Mech.HP	% ERROR
1	32.8	.85	8.5	.072	.097	.076	28.0
2	32.8	.90	11.0	.099	.133	.162	21.6
3	32.8	1.00	15.5	.155	.208	.269	22.7
4	32.8	1.25	24.5	.333	.442	.537	17.7
5	32.8	1.15	21.5	.247	.331	.392	15.5
6	32.8	.95	13.5	.128	.172	.188	9.4
7	32.8	.86	9.0	.078	.104	.100	4.0
8	39.4	.95	13.5	.128	.172	.310	44.5
9	39.4	1.00	15.5	.155	.208	.400	48.0
10	39.4	1.20	23.5	.282	.378	.566	33.2
11	39.4	.88	10.0	.088	.118	.193	38.8
12	39.4	.95	13.5	.128	.172	.323	46.5
13	39.4	1.05	17.5	.184	.246	.258	4.7
14	39.4	1.35	28.5	.385	.515	.566	9.0
15	19.8	.83	2.5	.020	.028	.032	12.1
16	19.8	.87	4.0	.035	.047	.081	42.3
17	19.8	1.00	10.0	.100	.134	.129	3.9
18	19.5	1.27	16.5	.210	.281	.274	2.7
19	19.5	1.15	14.0	.161	.216	.200	8.0
20	19.5	.95	8.0	.076	.102	.119	14.3
21	19.5	.86	4.0	.034	.046	.049	5.2
22	26.6	.89	8.0	.071	.095	.056	69.0
23	26.6	.98	11.5	.113	.151	.129	17.0
24	26.6	1.17	17.0	.198	.265	.293	9.5
25	26.6	1.28	18.5	.250	.334	.387	13.7

RUN	RPM	KW.in	EFF.	KW.out	HPout	Mech.HP	% ERROR
26	26.6	1.05	13.5	.142	.190	.215	11.6
27	26.6	.93	9.5	.088	.118	.116	1.7
28	26.6	.85	6.0	.051	.068	.052	32.2
29	20.2	.83	2.5	.021	.028	.029	4.1
30	20.2	.92	7.0	.065	.086	.065	33.9
31	20.2	1.10	13.0	.143	.191	.198	13.7
32	20.2	1.20	15.5	.186	.249	.242	2.9
33	20.2	1.00	10.0	.100	.134	.097	38.5
34	20.2	.90	6.5	.059	.078	.032	143.0
35	20.2	.80	1.5	.012	.016	.016	0.0
36	27.0	.82	5.5	.045	.060	.022	180.0
37	27.0	.90	8.5	.077	.103	.043	138.0
38	27.0	1.00	12.0	.120	.161	.151	6.7
39	27.0	1.25	19.0	.238	.318	.344	7.6
40	27.0	1.15	16.5	.190	.245	.236	7.6
41	27.0	.96	10.0	.096	.129	.113	13.7
42	27.0	.86	3.0	.026	.035	.044	20.4
43	33.7	.88	6.0	.053	.071	.054	30.4
44	33.7	.97	15.7	.131	.175	.157	11.5
45	33.7	1.15	22.0	.253	.339	.331	2.4
46	33.7	1.30	27.0	.352	.472	.494	4.5
47	33.7	1.02	16.5	.169	.227	.244	6.9
48	33.7	.92	8.5	.078	.105	.114	7.9
49	33.7	.83	2.0	.017	.022	----	----
50	41.0	.90	8.0	.072	.097	.098	1.3

RUN	RPM	KW.in	EFF.	KW.out	HPout	Mech.HP	% ERROR
51	41.0	.98	13.0	.127	.170	.137	24.0
52	41.0	1.07	18.5	.198	.266	.274	2.9
53	41.0	1.35	31.5	.425	.570	.645	11.6
54	41.0	1.20	24.5	.294	.394	.410	3.9
55	41.0	1.01	14.0	.141	.189	.228	17.1
56	41.0	.92	8.0	.074	.099	.124	20.6
57	41.0	.91	7.5	.068	.091	.182	49.9
58	41.0	1.00	16.0	.160	.215	.215	0.0
59	41.0	1.19	25.0	.298	.400	.456	12.3
60	41.0	1.35	32.0	.432	.579	.684	15.3
61	41.0	1.15	22.5	.259	.347	.339	2.4
62	41.0	1.00	16.0	.160	.215	.202	6.3
63	41.0	.90	7.5	.068	.091	.124	27.0
64	34.2	.87	7.0	.061	.082	.108	24.5
65	34.2	.92	8.5	.078	.105	.206	49.0
66	34.2	1.08	19.0	.205	.275	.272	1.1
67	34.2	1.32	28.5	.377	.505	.554	8.8
68	34.2	1.20	24.0	.288	.386	.393	1.8
69	34.2	1.00	16.0	.160	.215	.244	11.9
70	34.2	.88	7.5	.066	.089	.152	41.8
71	27.7	.85	5.5	.047	.063	.065	4.0
72	27.7	.95	9.0	.086	.114	.100	14.0
73	27.7	1.10	18.5	.202	.271	.226	19.9
74	27.7	1.20	22.0	.264	.354	.283	25.1
75	27.7	1.00	14.0	.140	.187	.161	16.1

RUN	RPM	KW.in	EFF.	KW.out	HPout	Mech.HP	% ERROR
76	27.7	.90	6.5	.058	.078	.065	20.3
77	27.7	.80	2.5	.020	.027	.022	23.5
78	20.8	.80	2.0	.016	.021	.026	19.2
79	20.8	.82	5.0	.041	.055	.065	15.5
80	20.8	.95	8.0	.076	.102	.111	8.1
81	20.8	1.20	16.5	.198	.263	.228	15.3
82	20.8	1.05	13.0	.137	.181	.166	9.3
83	20.8	.91	6.5	.059	.078	.072	9.3
84	20.8	.81	1.5	.012	.016	.016	0.0
85	20.8	.81	1.5	.012	.016	.016	0.0
86	20.8	.90	6.5	.059	.078	.072	7.9
87	20.8	1.04	12.5	.130	.172	.143	20.3
88	20.8	1.20	16.5	.198	.263	.228	15.3
89	20.8	.95	9.6	.090	.121	.124	3.4
90	20.8	.81	1.5	.012	.016	.049	67.0
91	20.8	.79	1.0	.008	.011	.016	35.0
92	27.7	.80	3.5	.028	.037	.044	14.5
93	27.7	.87	5.0	.044	.058	.057	2.3
94	27.7	.98	12.0	.117	.156	.152	2.5
95	27.7	1.25	23.0	.288	.382	.309	23.6
96	27.7	1.10	17.0	.187	.248	.239	3.8
97	27.7	.92	10.0	.092	.123	.113	8.9
98	27.7	.83	4.0	.033	.044	.044	0.0
99	35.1	.91	4.5	.041	.055	.054	0.4
100	35.1	1.00	10.0	.100	.134	.136	2.2

RUN	RPM	KW.in	EFF.	KW.out	HPout	Mech.HP	% ERROR
101	35.1	1.15	22.0	.253	.336	.261	28.7
102	35.1	1.25	26.5	.332	.441	.380	16.0
103	35.1	1.05	15.0	.168	.223	.174	28.1
104	35.1	.93	5.0	.047	.062	.055	13.2
105	35.1	.87	2.0	.017	.023	.027	15.1
106	42.1	.88	2.0	.018	.023	.033	28.4
107	42.1	.93	5.5	.051	.068	.098	29.6
108	42.1	1.03	14.0	.144	.192	.228	15.8
109	42.1	1.30	30.0	.390	.518	.471	10.0
110	42.1	1.17	23.0	.269	.356	.314	13.4
111	42.1	1.00	10.0	.100	.134	.131	1.5
112	42.1	.90	2.5	.023	.030	.033	8.6
113	21.4	1.00	10.0	.100	.134	.132	0.7
114	21.4	1.20	17.0	.204	.271	.241	12.5
115	21.4	1.50	22.5	.337	.447	.440	1.6
116	21.4	1.70	25.0	.425	.565	.576	1.9
117	21.4	1.30	19.5	.254	.337	.305	10.5
118	21.4	1.02	11.5	.117	.155	.136	14.0
119	21.4	.91	5.5	.050	.067	.068	1.5
120	28.6	.92	6.5	.060	.080	.095	14.7
121	28.6	1.06	15.0	.159	.213	.168	26.8
122	28.6	1.29	20.5	.265	.355	.375	5.1
123	28.6	1.85	30.0	.555	.743	.880	16.8
124	28.6	1.50	25.0	.375	.503	.572	12.0
125	28.6	1.18	18.0	.212	.282	.264	6.8

RUN	RPM	KW.in	EFF.	KW.out	HPout	Mech.HP	% ERROR
126	28.6	.98	8.5	.083	.111	.097	14.4
127	35.7	.98	8.5	.083	.111	.099	12.1
128	35.7	1.13	20.5	.231	.309	.253	22.1
129	35.7	1.55	32.5	.504	.675	.689	2.0
130	35.7	1.85	37.5	.695	.931	.934	0.3
131	35.7	1.25	25.0	.312	.416	.385	8.0
132	35.7	1.05	15.0	.157	.210	.165	27.3
133	35.7	.92	7.5	.069	.092	.082	12.0
134	43.9	1.05	15.0	.157	.210	.185	13.5
135	43.9	1.22	25.0	.305	.408	.429	4.9
136	43.9	1.56	36.5	.571	.766	.926	17.2
137	43.9	1.77	42.5	.760	1.020	1.190	14.3
138	43.9	1.38	31.0	.428	.573	.475	20.6
139	43.9	1.07	15.0	.161	.215	.198	8.6
140	43.9	.95	5.0	.047	.064	.079	19.7
141	43.9	.95	5.0	.047	.064	.053	20.1
142	43.9	1.06	14.0	.148	.198	.165	20.0
143	43.9	1.25	26.0	.326	.436	.449	2.9
144	43.9	1.77	42.5	.760	1.020	1.190	14.3
145	43.9	1.57	36.5	.574	.769	.871	11.6
146	43.9	1.19	23.5	.280	.374	.337	11.0
147	43.9	1.00	10.0	.100	.134	.119	12.6
148	36.6	1.00	9.5	.095	.127	.099	28.3
149	36.6	1.15	21.0	.230	.308	.286	7.8
150	36.6	1.50	31.5	.473	.633	.715	11.4

RUN	RPM	KW.in	EFF.	KW.out	HPout	Mech.HP	% ERROR
151	36.6	1.75	36.0	.630	.844	1.000	15.6
152	36.6	1.20	23.0	.276	.370	.396	6.6
153	36.6	1.05	15.0	.157	.210	.176	19.3
154	36.6	.93	7.0	.065	.087	.083	4.8
155	30.3	1.00	10.0	.100	.134	.167	19.7
156	30.3	1.13	19.0	.215	.288	.361	20.2
157	30.3	1.38	24.5	.338	.453	.606	25.2
158	30.3	1.55	30.0	.466	.624	.756	17.4
159	30.3	1.21	19.0	.230	.308	.330	6.7
160	30.3	1.00	11.0	.110	.147	.169	12.5
161	30.3	.90	5.5	.045	.060	.045	33.4
162	22.7	.89	3.0	.027	.036	.037	2.8
163	22.7	.98	9.5	.093	.124	.102	21.6
164	22.7	1.12	15.0	.168	.225	.241	6.6
165	22.7	1.45	24.5	.370	.496	.515	3.7
166	22.7	1.32	21.5	.284	.380	.407	6.6
167	22.7	1.05	13.5	.142	.190	.203	6.4
168	22.7	.92	9.5	.087	.117	.095	23.2
169	19.9	.98	10.0	.098	.131	.102	28.4
170	19.9	1.16	16.0	.181	.242	.231	4.7
171	19.9	1.48	21.5	.318	.427	.475	10.1
172	19.9	1.65	24.0	.396	.530	.611	13.2
173	19.9	1.25	18.0	.225	.302	.305	0.9
174	19.9	1.05	13.0	.136	.195	.143	36.5
175	19.9	.90	4.5	.041	.054	.058	5.7

RUN	RPM	KW.in	EFF.	KW.out	HPout	Mech.HP	% ERROR
176	26.6	.93	8.5	.079	.106	.081	30.2
177	26.6	1.07	15.5	.166	.222	.181	22.6
178	26.6	1.27	23.5	.298	.399	.416	4.1
179	26.6	1.83	34.0	.623	.835	.904	7.6
180	26.6	1.48	27.5	.407	.545	.597	8.7
181	26.6	1.18	20.0	.236	.316	.307	2.7
182	26.6	.98	10.0	.098	.131	.127	3.2
183	34.2	.98	12.0	.117	.157	.147	6.8
184	34.2	1.16	22.5	.261	.350	.351	0.2
185	34.2	1.50	33.5	.502	.674	.746	9.6
186	34.2	1.72	40.0	.689	.923	1.045	11.7
187	34.2	1.25	26.0	.326	.437	.464	5.8
188	34.2	1.02	16.0	.164	.220	.214	2.8
189	34.2	.92	6.0	.055	.074	.062	19.3
190	41.1	.97	8.0	.078	.104	.081	27.8
191	41.1	1.08	18.0	.195	.261	.258	1.2
192	41.1	1.42	34.5	.490	.656	.624	5.1
193	41.1	1.91	49.0	.936	1.255	1.240	1.2
194	41.1	1.62	42.5	.689	.923	.916	0.8
195	41.1	1.25	28.0	.350	.468	.393	29.4
196	41.1	1.10	20.0	.220	.294	.104	107.0
197	42.3	1.04	16.0	.166	.222	.169	31.2
198	42.3	1.22	27.0	.330	.442	.480	7.9
199	42.3	1.80	44.5	.801	1.075	1.082	0.6
200	42.3	2.02	51.0	1.030	1.380	1.390	0.7

RUN	RPM	KW. in	EFF.	KW. out	HPout	Mech. HP	% ERROR
201	42.3	1.48	38.0	.562	.752	.664	13.2
202	42.3	1.12	20.5	.230	.308	.326	5.5
203	42.3	.98	8.0	.078	.105	.088	19.3
204	35.2	.96	6.0	.058	.077	.057	36.3
205	35.2	1.10	19.0	.209	.280	.237	18.1
206	35.2	1.30	23.5	.306	.410	.526	22.1
207	35.2	1.85	43.0	.796	1.070	1.140	6.1
208	35.2	1.60	37.5	.600	.804	.847	5.1
209	35.2	1.22	25.0	.305	.407	.424	4.0
210	35.2	1.05	15.0	.157	.210	.141	49.0
211	29.0	1.00	10.0	.100	.134	.122	9.9
212	29.0	1.15	21.0	.241	.322	.294	9.5
213	29.0	1.55	32.5	.504	.675	.634	6.6
214	29.0	1.80	37.0	.666	.893	.926	3.6
215	29.0	1.28	25.5	.326	.436	.398	9.6
216	29.0	1.03	14.5	.149	.199	.176	13.1
217	29.0	.95	6.0	.057	.076	.045	77.5
218	21.8	.90	3.0	.027	.036	.034	6.5
219	21.8	1.01	11.0	.111	.148	.139	6.5
220	21.8	1.23	18.0	.221	.296	.285	3.9
221	21.8	1.65	26.0	.429	.574	.577	0.5
222	21.8	1.42	22.5	.319	.427	.434	1.6
223	21.8	1.15	17.0	.196	.262	.210	24.8
224	21.8	.97	8.0	.078	.104	.095	9.5
225	22.5	1.15	17.5	.201	.269	.220	22.2

RUN	RPM	KW. in	EFF.	KW.out	HPout	Mech.HP	% ERROR
226	22.5	1.45	24.0	.348	.466	.525	11.2
227	22.5	2.08	31.0	.645	.864	1.020	15.2
228	22.5	2.55	33.5	.856	1.150	1.250	8.0
229	22.5	1.60	26.0	.416	.557	.576	3.3
230	22.5	1.27	19.5	.248	.332	.322	3.1
231	22.5	1.00	10.0	.100	.134	.129	3.9
232	30.0	1.00	11.5	.117	.157	.172	8.7
233	30.0	1.28	25.5	.326	.437	.452	3.3
234	30.0	1.68	35.0	.589	.789	.815	3.2
235	30.0	2.50	43.5	1.090	1.460	1.630	10.4
236	30.0	2.18	41.0	.894	1.200	1.290	6.9
237	30.0	1.47	31.0	.456	.611	.611	0.0
238	30.0	1.17	22.0	.258	.345	.294	17.3
239	39.6	1.20	25.5	.306	.409	.367	11.5
240	39.6	1.50	38.0	.764	.570	.791	3.5
241	39.6	2.25	51.5	1.160	1.550	1.750	11.4
242	39.6	3.60	55.0	1.430	1.920	2.140	10.3
243	39.6	1.82	46.0	.838	1.120	1.240	9.7
244	39.6	1.35	31.5	.425	.570	.566	0.7
245	39.6	1.09	18.0	.196	.263	.215	22.3
246	47.6	1.25	22.5	.281	.376	.258	45.7
247	47.6	1.60	30.5	.488	.654	.678	3.5
248	47.6	2.40	38.0	.912	1.220	1.520	19.7
249	47.6	3.45	42.5	1.470	1.970	2.570	23.4
250	47.6	2.95	40.5	1.200	1.610	1.970	18.3

RUN	RPM	KW. in	EFF.	KW.out	HPout	Mech.HP	% ERROR
251	47.6	1.98	34.0	.684	.902	1.020	11.5
252	47.6	1.48	29.0	.429	.575	.509	13.0
253	47.6	1.37	30.0	.411	.550	.624	11.8
254	50.4	1.80	34.5	.622	.834	1.190	29.9
255	50.4	2.90	42.0	1.220	1.640	2.640	37.9
256	50.4	3.15	43.0	1.360	1.820	2.940	37.1
257	50.4	2.10	37.0	.778	1.040	1.700	38.9
258	50.4	1.55	31.5	.489	.655	1.020	35.8
259	50.4	1.25	28.0	.350	.469	.407	15.2
260	42.0	1.20	23.0	.276	.370	.328	12.8
261	42.0	1.50	28.5	.428	.574	.848	32.3
262	42.0	2.00	34.0	.680	.910	1.240	26.6
263	42.0	3.12	40.5	1.270	1.700	2.340	27.6
264	42.0	2.55	38.0	.970	1.300	1.810	28.2
265	42.0	1.75	31.5	.552	.740	.974	24.0
266	42.0	1.35	26.5	.358	.480	.565	15.0
267	35.8	1.10	19.5	.214	.287	.235	22.1
268	35.8	1.35	29.5	.398	.533	.633	15.8
269	35.8	1.85	42.0	.778	1.040	1.175	11.5
270	35.8	2.15	45.0	.970	1.300	1.490	12.8
271	35.8	1.45	32.0	.464	.622	.749	17.0
272	35.8	1.17	23.0	.269	.360	.362	0.6
273	35.8	.98	13.0	.127	.170	.181	6.1
274	26.9	.95	10.5	.100	,134	.129	3.9
275	26.9	1.12	19.0	.213	.285	.298	4.4

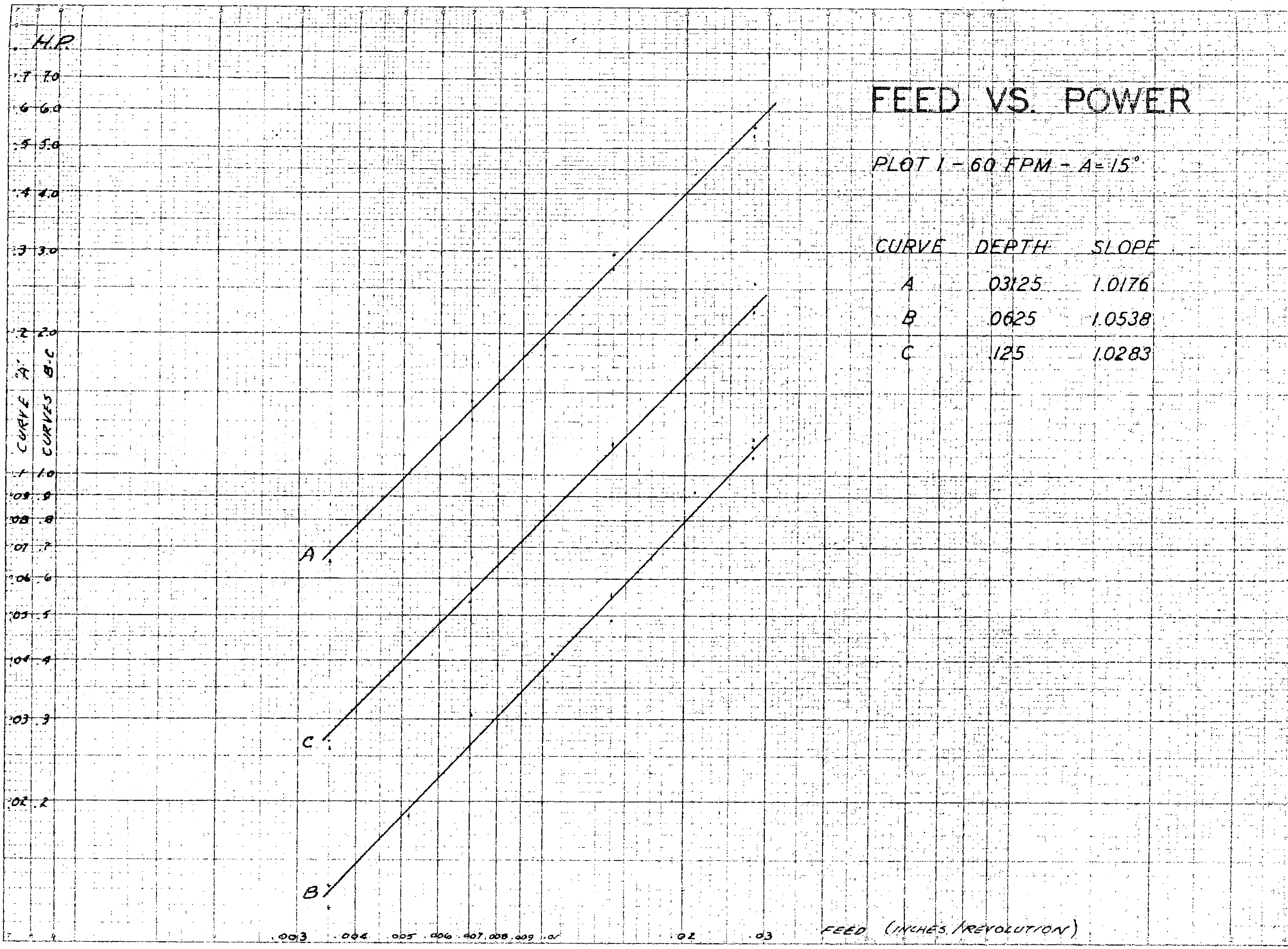
RUN	RPM	KW. in	EFF.	KW. out	HPout	Mech. HP	% ERROR
276	26.9	1.40	27.5	.385	.515	.560	8.0
277	26.9	1.96	36.0	.706	.947	1.020	7.2
278	26.9	1.72	33.0	.568	.761	.746	2.0
279	26.9	1.25	23.0	.288	.386	.373	3.5
280	26.9	1.05	13.0	.136	.182	.142	28.2
281	28.6	.98	12.0	.118	.158	.170	7.1
282	28.6	1.22	23.0	.280	.375	.390	3.8
283	28.6	1.55	31.5	.489	.655	.677	3.3
284	28.6	1.80	36.0	.648	.860	.916	5.1
285	28.6	1.35	26.5	.357	.487	.509	6.1
286	28.6	1.05	16.5	.173	.232	.244	4.9
287	28.6	.91	7.5	.121	.162	.109	48.6
288	38.2	.95	8.5	.112	.150	.140	7.1
289	38.2	1.15	22.0	.253	.339	.371	8.4
290	38.2	1.40	32.5	.456	.611	.679	10.0
291	38.2	1.95	45.5	.888	1.190	1.400	15.0
292	38.2	1.60	39.0	.624	.836	.859	2.7
293	38.2	1.05	16.5	.173	.232	.452	48.7
294	38.2	1.55	37.0	.573	.767	.271	183.0
295	39.1	1.70	30.5	.518	.644	.339	105.0
296	39.1	----	----	----	----	.621	----
297	39.1	2.45	37.0	.906	1.215	1.240	2.0
298	39.1	3.45	41.0	1.420	1.900	2.040	6.9
299	39.1	1.95	33.0	.644	.862	.790	9.1
300	39.1	1.45	27.0	.392	.525	.452	16.1

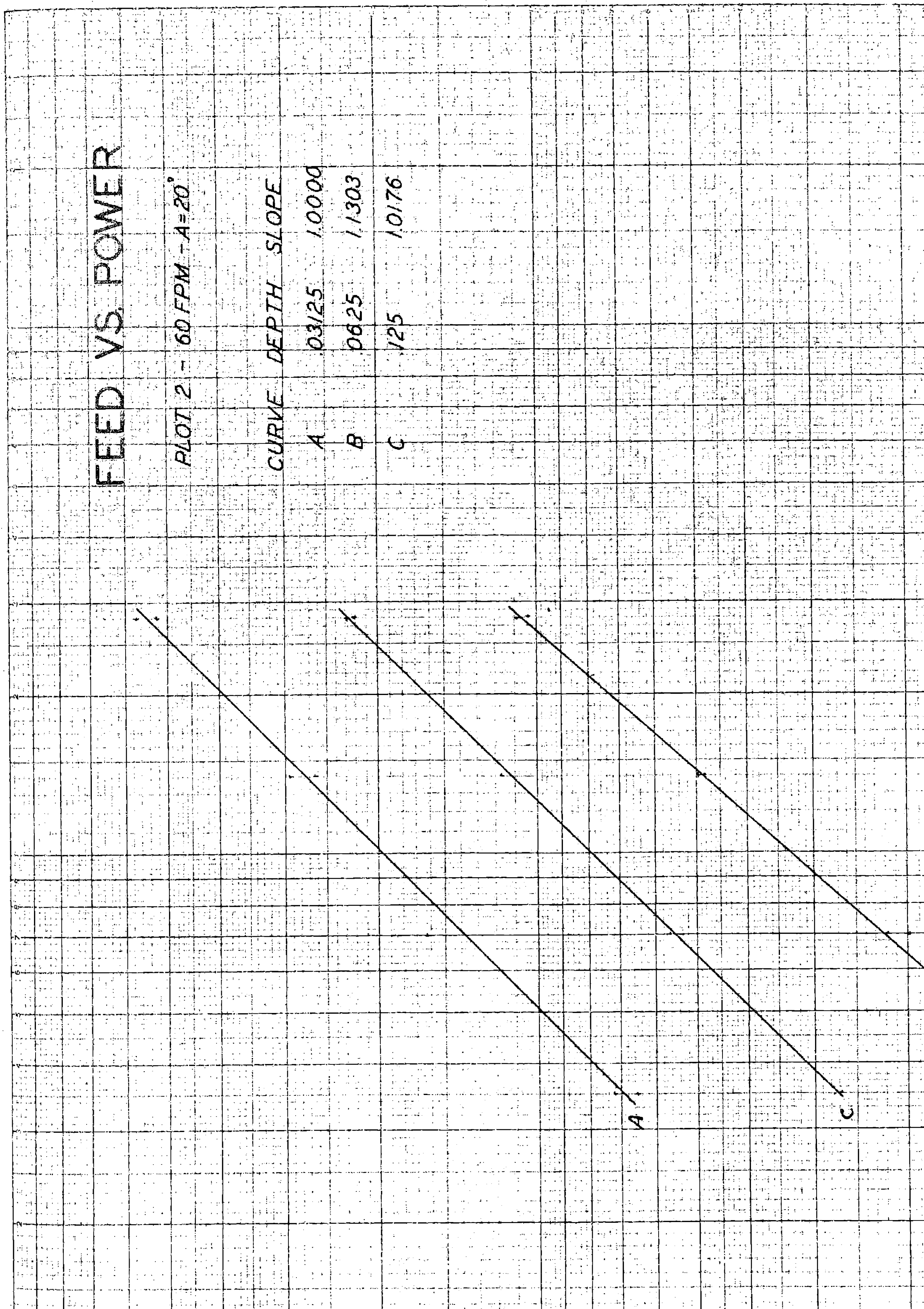
RUN	RPM	KW.in	EFF.	KW.out	HPout	Mech.HP	% ERROR
301	39.1	1.18	20.0	.236	.316	.181	74.6
302	46.9	1.20	25.0	.300	.402	.217	85.0
303	46.9	1.50	29.0	.435	.582	.556	5.7
304	46.9	2.00	35.0	.700	.938	1.070	12.3
305	46.9	3.50	42.5	1.490	2.000	2.240	10.7
306	46.9	2.65	39.0	1.035	1.385	1.590	12.6
307	46.9	1.70	32.0	.544	.729	.746	2.3
308	46.9	1.35	26.5	.358	.479	.407	17.7
309	50.3	1.35	27.0	.365	.487	.407	19.6
310	50.3	1.75	33.5	.586	.785	.815	3.7
311	50.3	2.62	40.0	1.050	1.410	1.760	19.9
312	50.3	3.35	43.5	1.460	1.960	2.240	12.5
313	50.3	1.85	34.0	.629	.842	.882	4.5
314	50.3	1.38	28.0	.386	.517	.475	8.9
315	50.3	1.15	25.0	.287	.384	.190	102.0
316	42.0	1.15	21.5	.247	.331	.238	39.1
317	42.0	1.42	27.0	.384	.514	.536	4.1
318	42.0	1.80	32.0	.576	.773	.848	8.9
319	42.0	2.85	39.0	1.110	1.490	1.810	17.7
320	42.0	2.25	36.0	.811	1.090	1.190	8.4
321	42.0	1.60	30.0	.480	.644	.678	5.0
322	42.0	1.28	24.0	.307	.411	.311	32.2
323	35.7	1.12	20.4	.229	.307	.307	0.0
324	35.7	1.35	30.0	.405	.543	.587	7.5
325	35.7	1.70	40.0	.680	.911	1.020	11.7

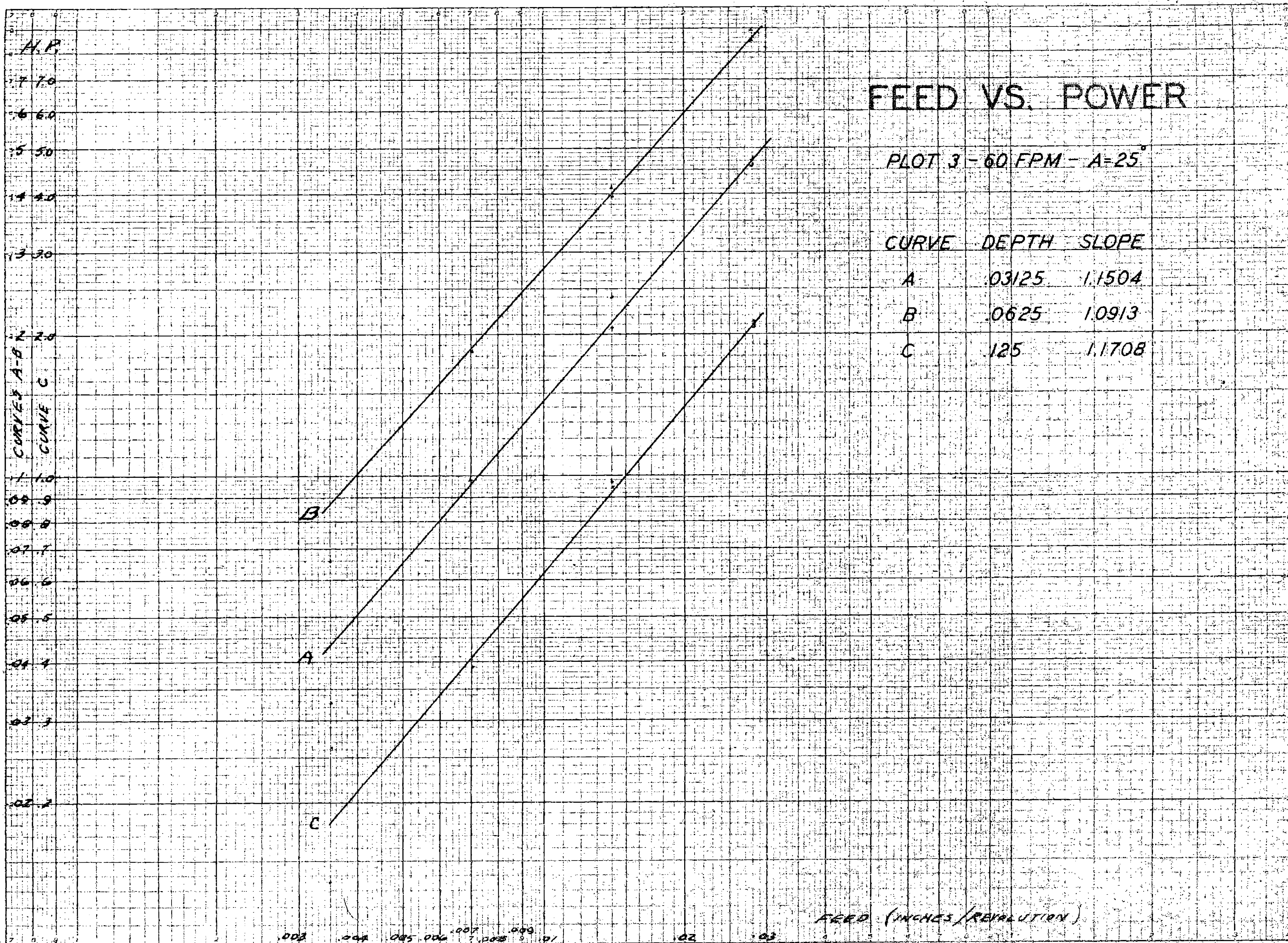
RUN	RPM	KW.in	EFF.	KW.out	HPout	Mech.HP	% ERROR
326	35.7	1.90	43.5	.828	1.110	1.270	12.6
327	35.7	1.45	33.5	.486	.651	.724	10.1
328	35.7	1.15	22.0	.253	.339	.339	0.0
329	35.7	1.00	13.5	.135	.181	.172	5.2
330	26.8	.96	8.0	.077	.103	.126	18.2
331	26.8	1.12	17.5	.196	.263	.264	0.4
332	26.8	1.35	24.0	.324	.435	.508	14.3
333	26.8	1.85	34.0	.630	.844	.933	9.5
334	26.8	1.65	29.5	.487	.652	.695	6.2
335	26.8	1.25	21.5	.269	.360	.424	15.1
336	26.8	1.05	14.5	.152	.204	.220	7.3
337	23.3	1.65	27.5	.454	.608	.740	17.8
338	23.3	2.20	35.0	.770	1.030	1.300	20.7
339	23.3	3.30	38.0	1.255	1.680	1.940	13.4
340	23.3	----	----	----	----	----	----
341	23.3	2.80	36.0	1.010	1.355	1.650	17.6
342	23.3	1.90	30.0	.570	.764	.811	5.8
343	23.3	1.30	21.0	.274	.367	.458	19.8
344	31.0	1.40	23.5	.329	.441	.476	7.4
345	31.0	2.10	31.5	.662	.886	.863	2.7
346	31.0	2.60	35.5	.924	1.240	1.940	36.1
347	31.0	----	----	----	----	----	----
348	31.0	----	----	----	----	----	----
349	31.0	2.40	33.5	.805	1.080	1.440	25.0
350	31.0	1.70	27.5	.468	.627	.774	19.0

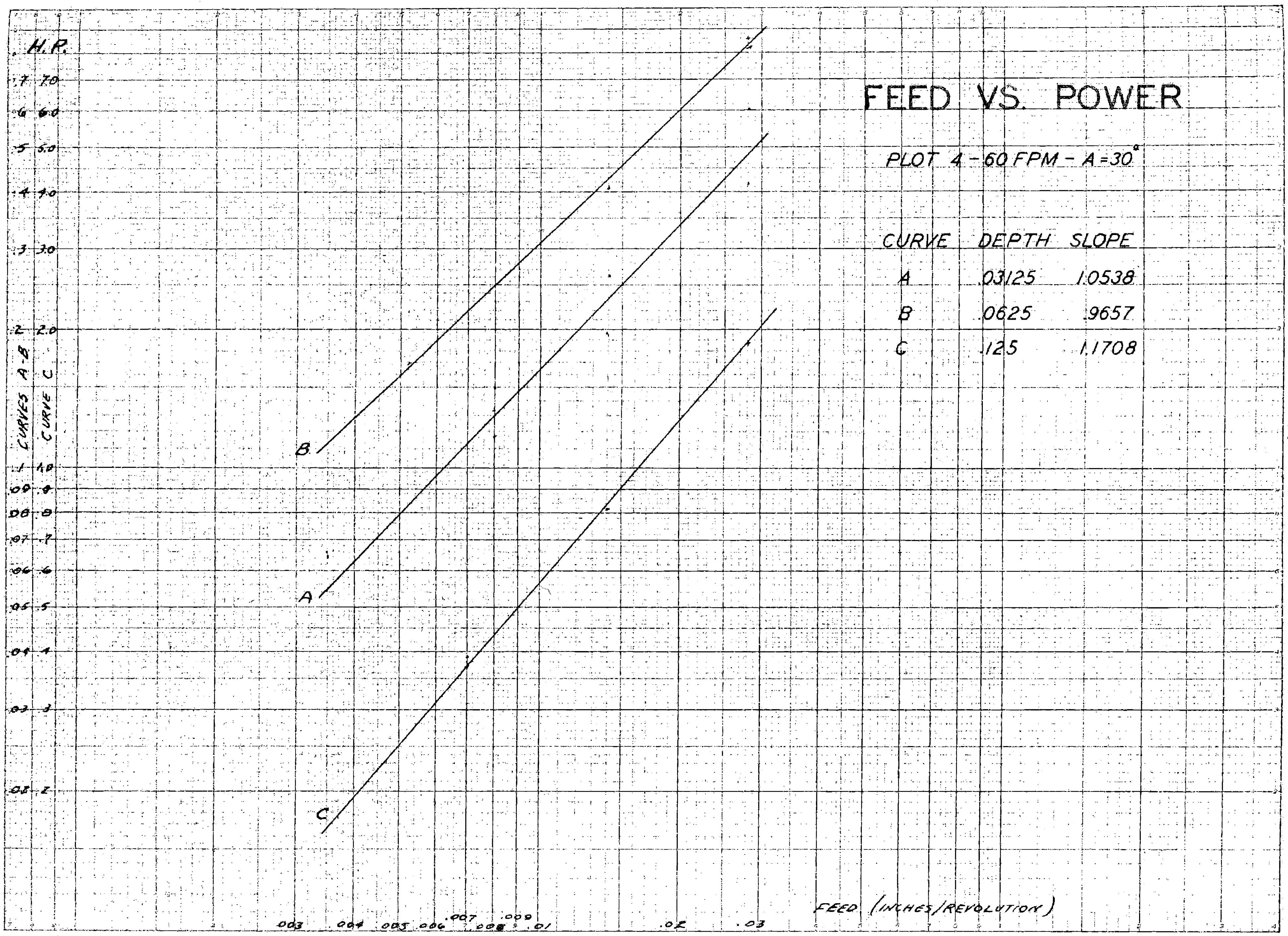
APPENDIX D

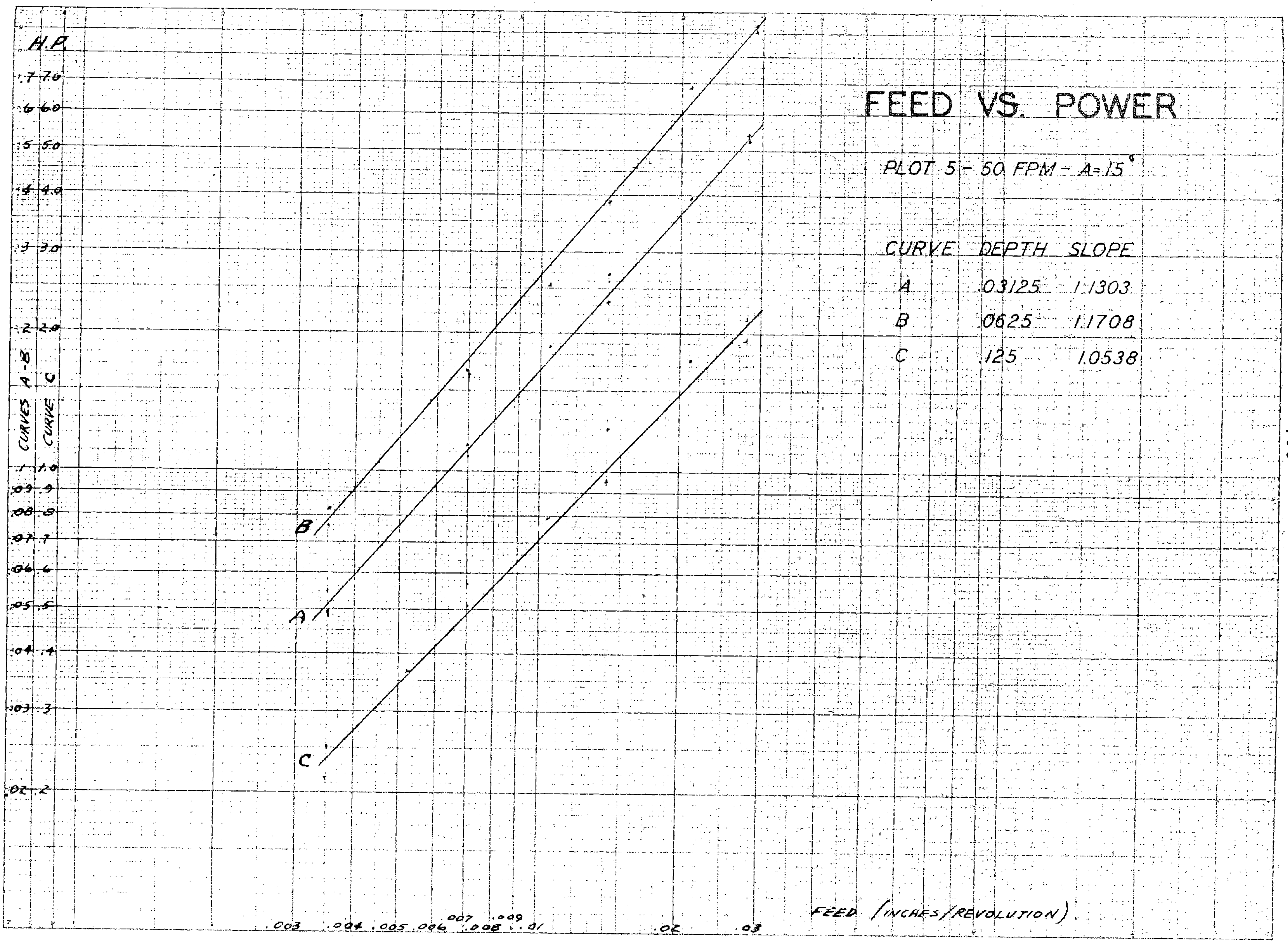
Charts on Vanadium "D" Stock

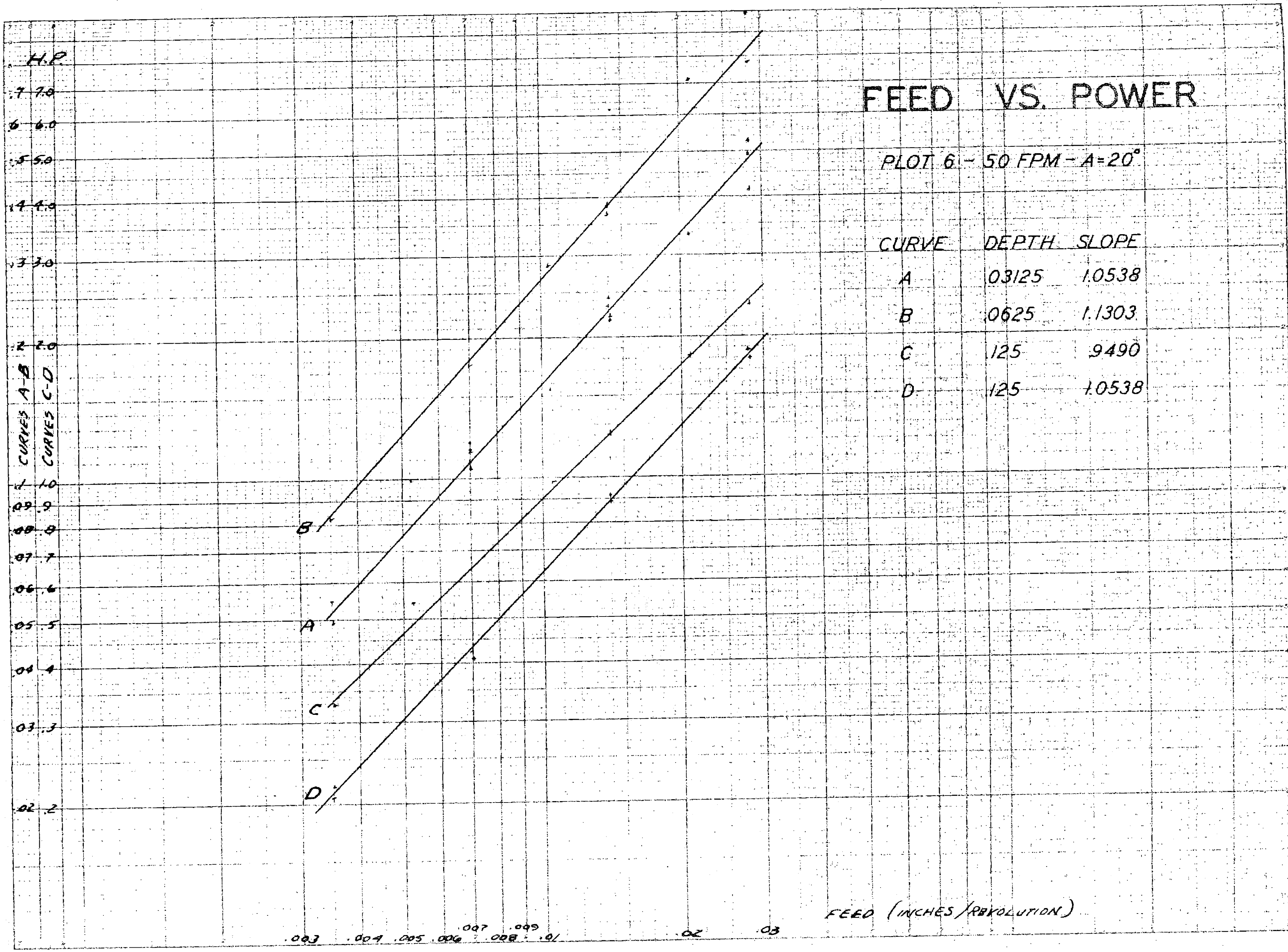

FEED VS. POWER
PLOT I - 60 FPM - A=15°
CURVE DEPTH SLOPE
A 03125 1.0176
B 0625 1.0538
C 125 1.0283
H.P.
CURVE "A"
CURVES B-C
A
B
C
.003 .004 .005 .006 .007 .008 .009 .01 .02 .03
FEED (INCHES/REVOLUTION)

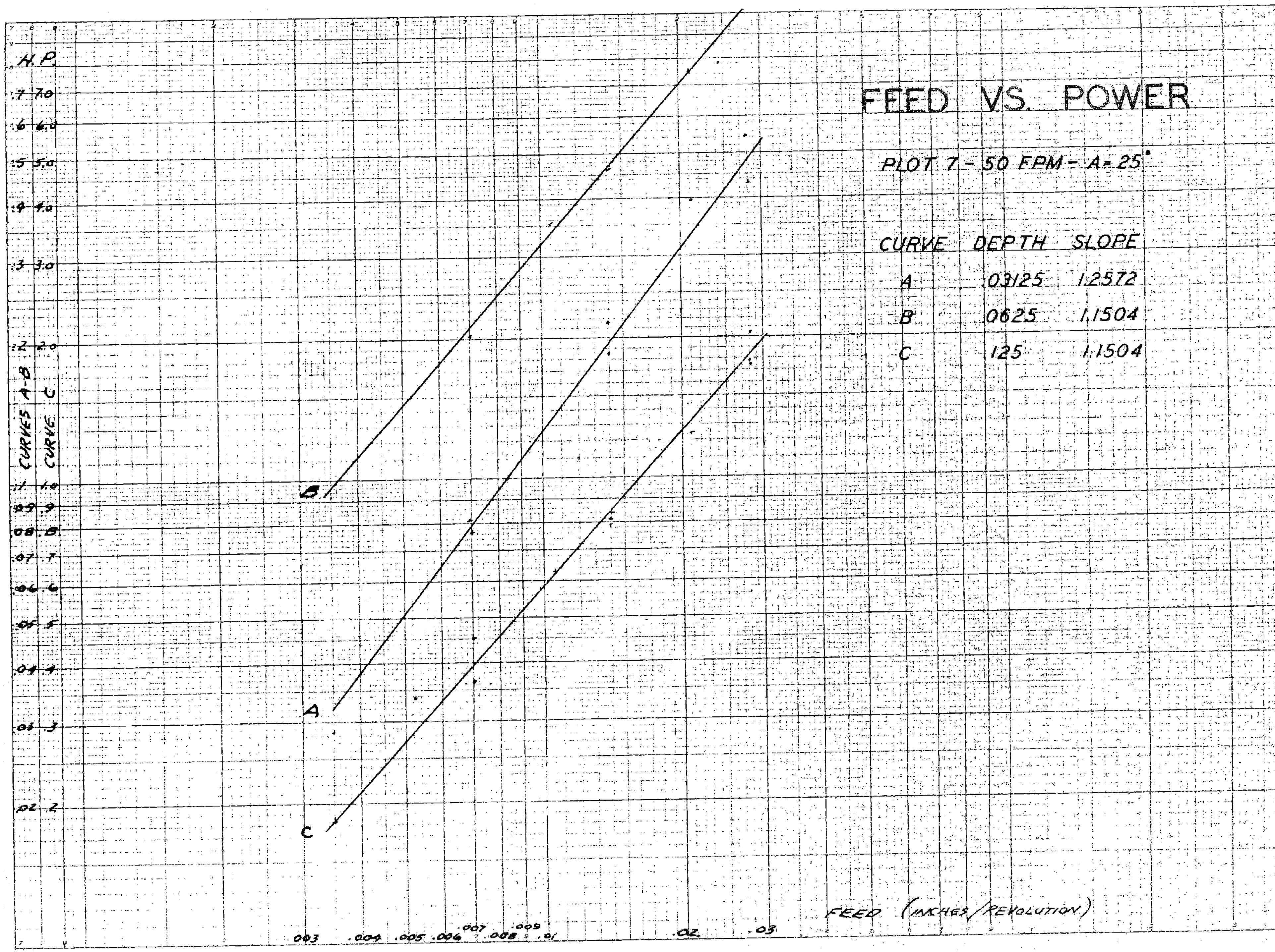

FEED VS. POWER
PLOT 2 - 60 FPM - A=20°
CURVE DEPTH SLOPE
A .03125 1.0000
B .0625 1.1303
C .125 1.0176
FEED (INCHES/REVOLUTION)
H.P.
CURVE A
CURVES B-C
A
B
C

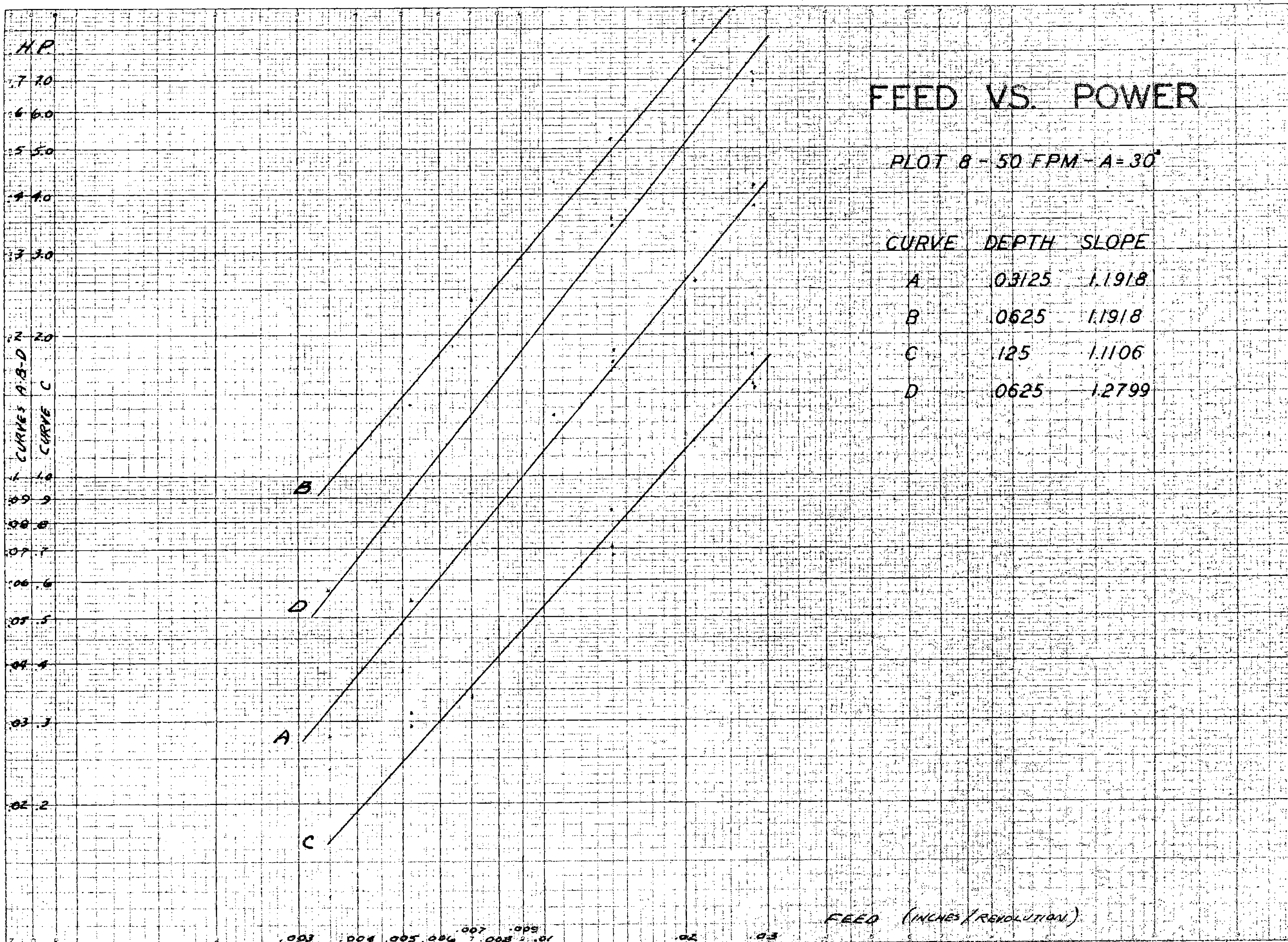

FEED VS. POWER
PLOT 3 - 60 FPM - A=25°
CURVE DEPTH SLOPE
A .03125 1.1504
B .0625 1.0913
C .125 1.1708
H.P.
CURVES A-B
CURVE C
FEED (INCHES/REVOLUTION)
.003 .004 .005 .006 .007 .008 .009 .01 .02 .03
7.0 6.0 5.0 4.0 3.0 2.0 1.0 .9 .8 .7 .6 .5 .4 .3 .2
A
B
C


FEED VS. POWER
PLOT 4 - 60 FPM - A = 30°
CURVE DEPTH SLOPE
A .03125 1.0538
B .0625 .9657
C .125 1.1708
H.P.
CURVES A-B
CURVE C
FEED (INCHES/REVOLUTION)
A
B
C

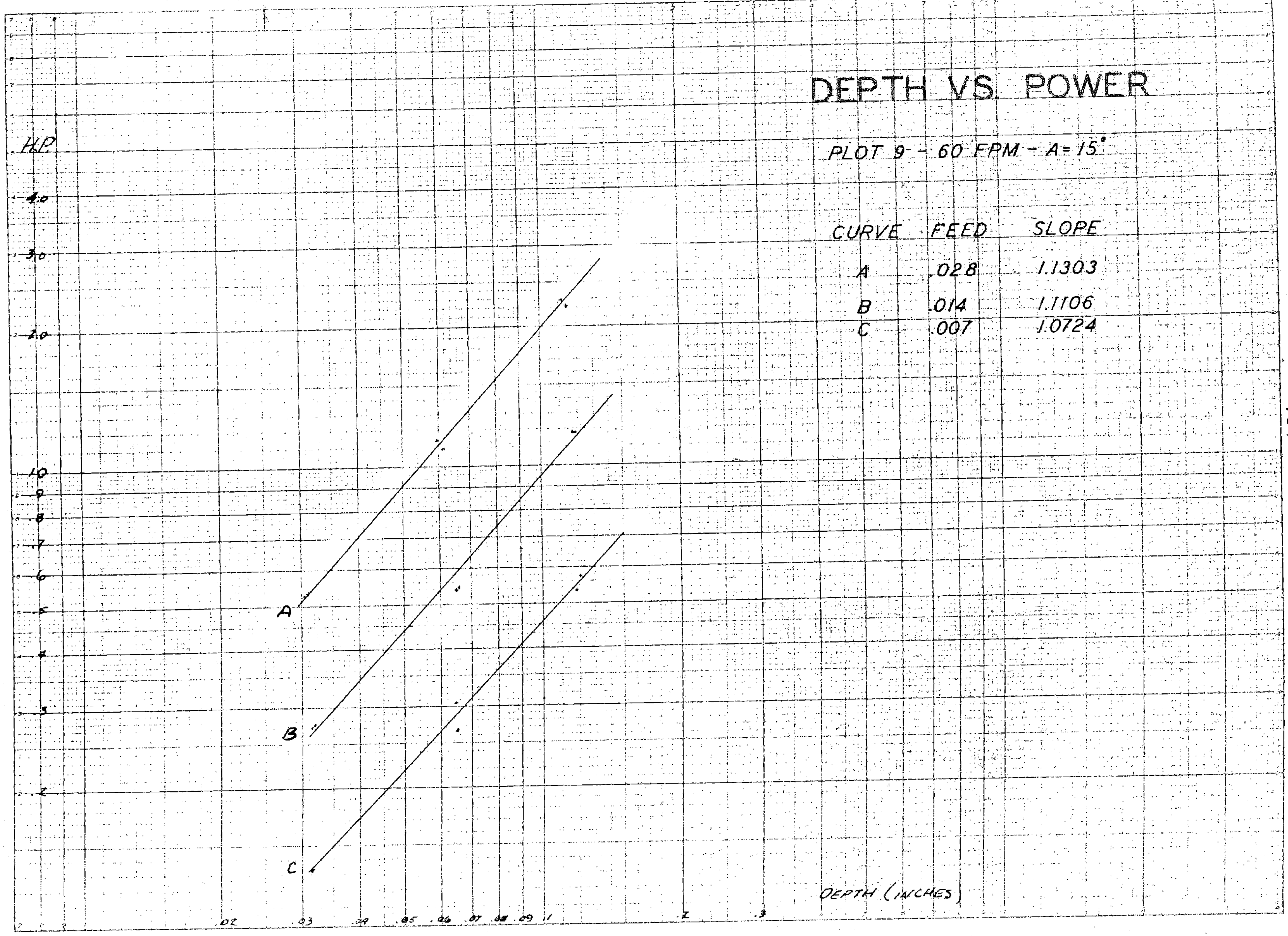

FEED VS. POWER
PLOT 5 - 50 FPM - A=15°
CURVE DEPTH SLOPE
A .03125 1.1303
B .0625 1.1708
C .125 1.0538
H.P.
CURVES A-B
CURVE C
FEED (INCHES/REVOLUTION)
.003 .004 .005 .006 .007 .008 .009 .01 .02 .03
A
B
C

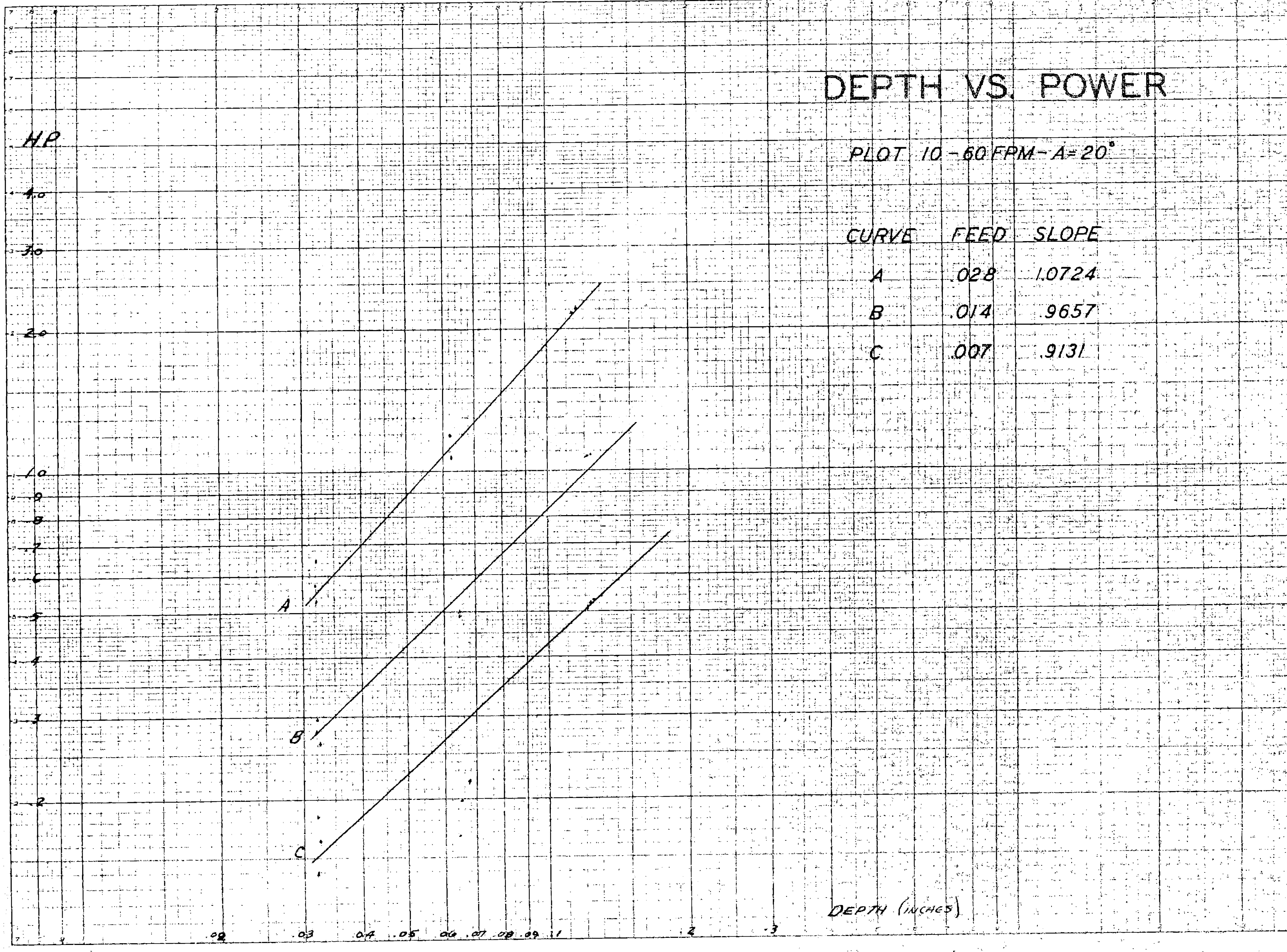

FEED VS. POWER
PLOT 6 - 50 FPM - A=20°
CURVE DEPTH SLOPE
A .03125 1.0538
B .0625 1.1303
C .125 .9490
D .125 1.0538
H.P.
CURVES A-B
CURVES C-D
FEED (INCHES/REVOLUTION)
A
B
C
D
.003 .004 .005 .006 .007 .008 .009 .01 .02 .03
.02 .03 .04 .05 .06 .07 .08 .09 .1 .2 .3 .4 .5 .6 .7
.2 .3 .4 .5 .6 .7 .8 .9 1.0 2.0 3.0 4.0 5.0 6.0 7.0

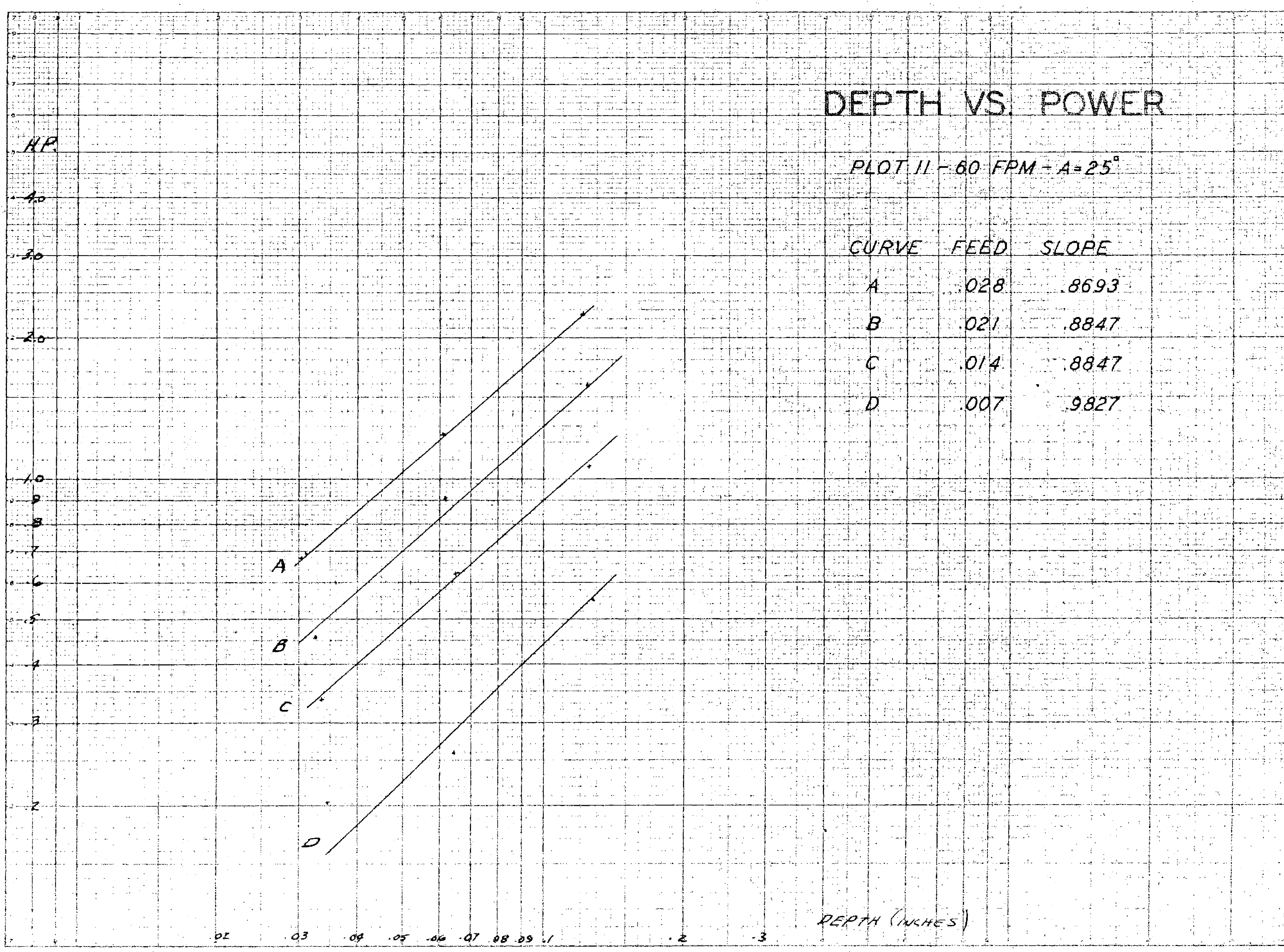

FEED VS. POWER
PLOT 7 - 50 FPM - A = 25°
CURVE DEPTH SLOPE
A .03125 1.2572
B .0625 1.1504
C .125 1.1504
H.P.
CURVES A-B
CURVE C
FEED (INCHES/REVOLUTION)
.003 .004 .005 .006 .007 .008 .009 .01 .02 .03
B
A
C

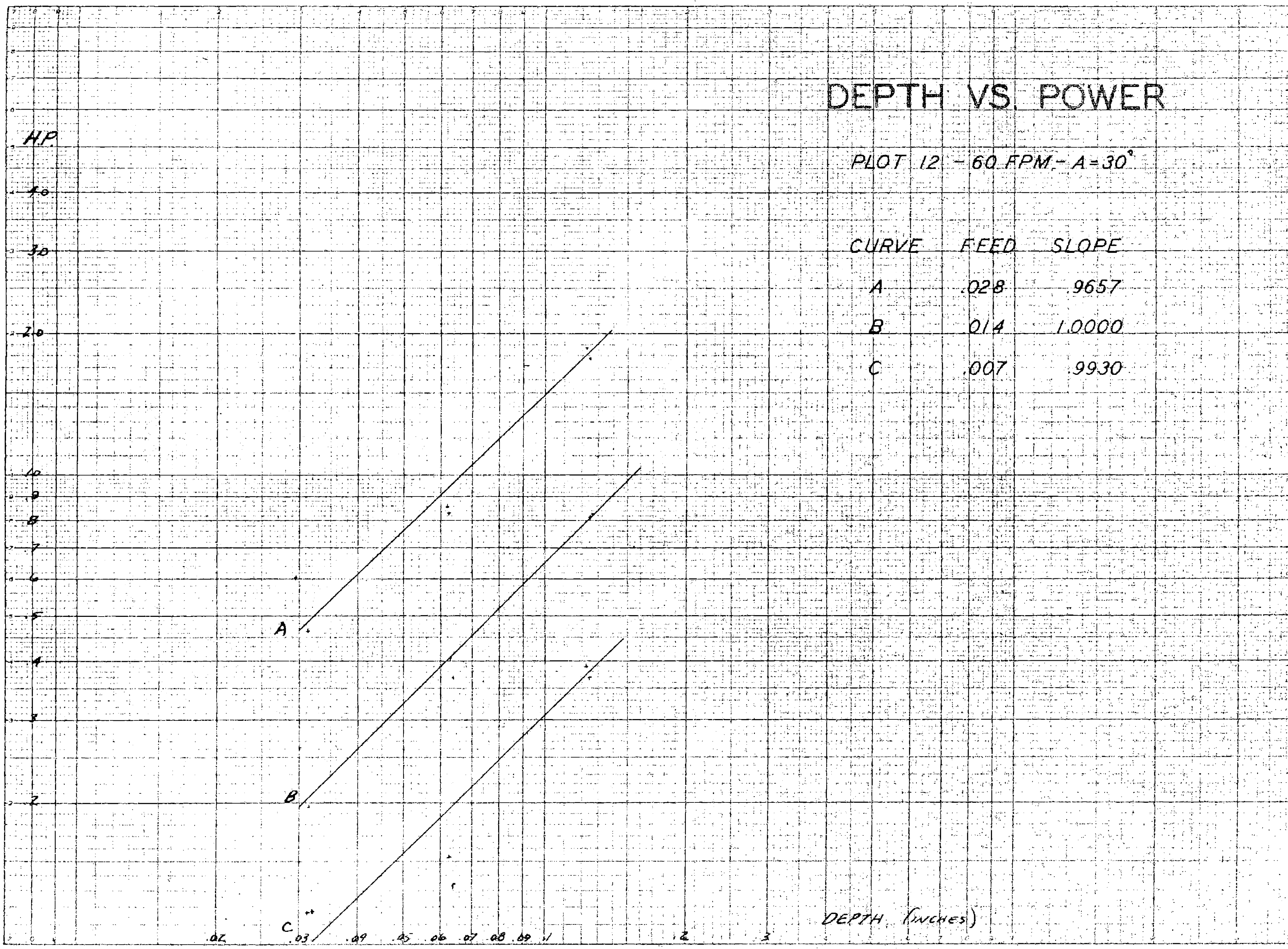


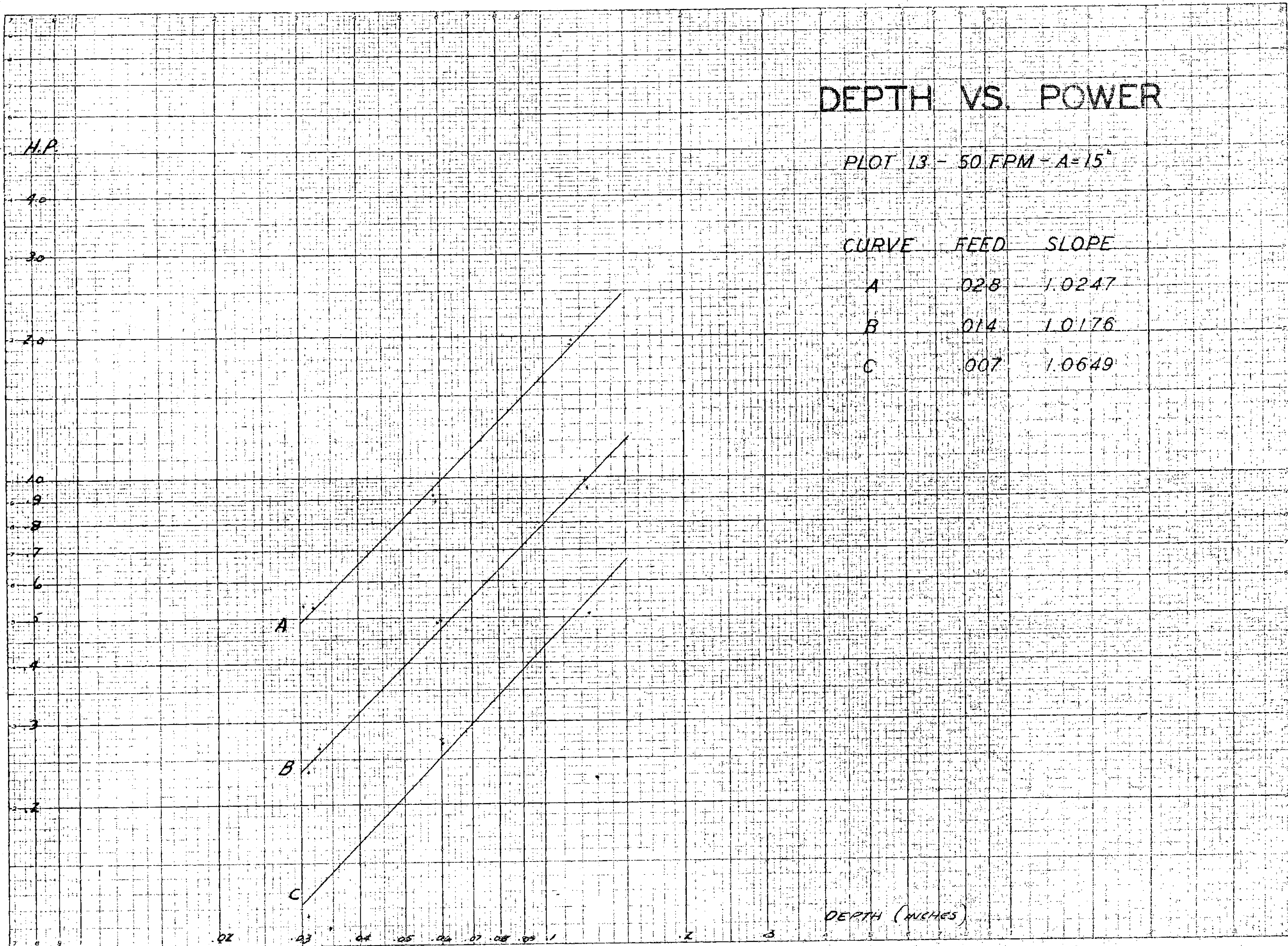
FEED VS. POWER
PLOT 8 - 50 FPM - A = 30°
CURVE DEPTH SLOPE
A .03125 1.1918
B .0625 1.1918
C .125 1.1106
D .0625 1.2799
H.P.
CURVES A-B-D
CURVE C
FEED (INCHES/REVOLUTION)
B
D
A
C

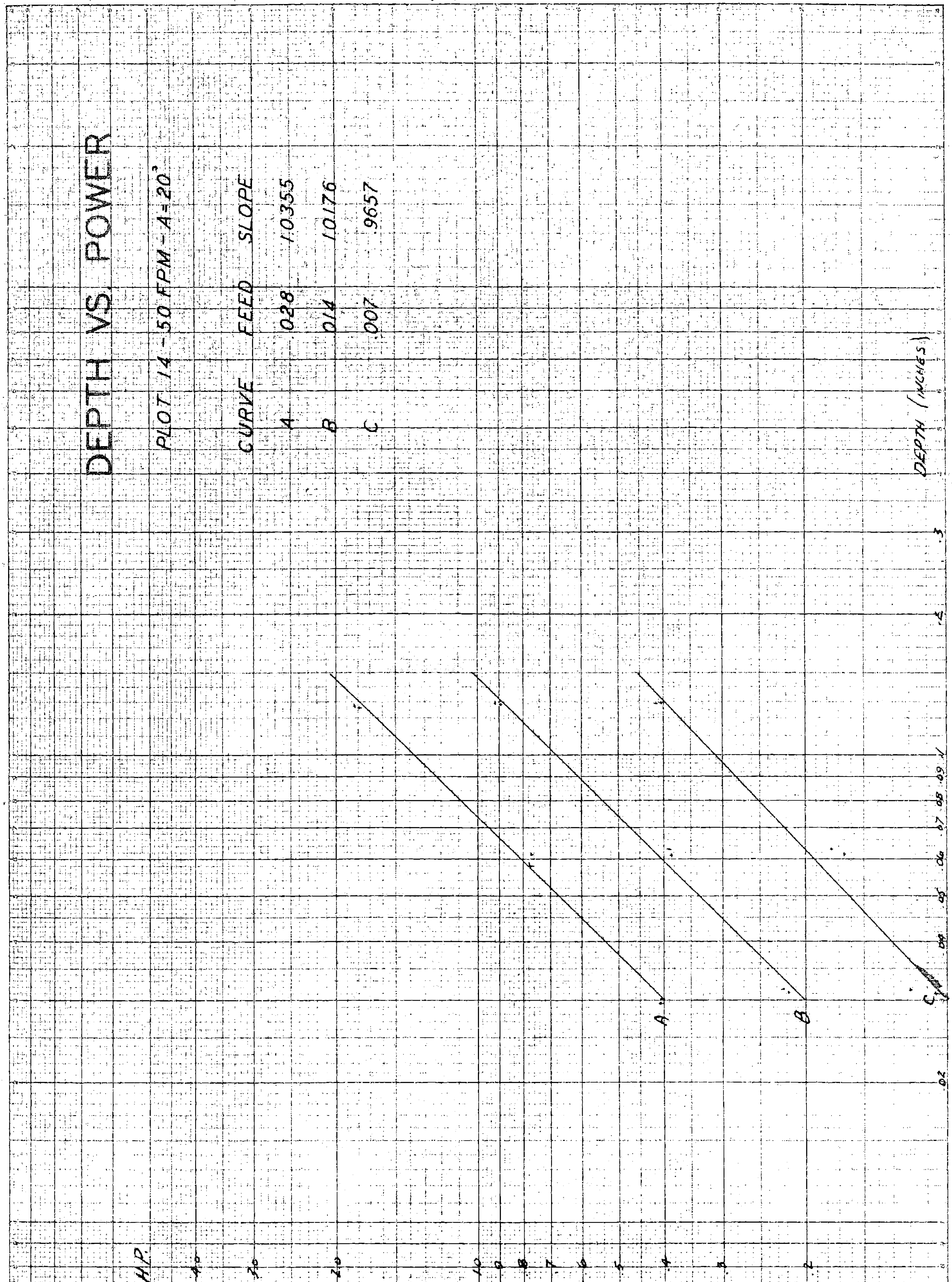

DEPTH VS. POWER
PLOT 9 - 60 FPM - A=15°
CURVE FEED SLOPE
A .028 1.1303
B .014 1.1106
C .007 1.0724
H.P.
4.0
3.0
2.0
10
9
8
7
6
5
4
3
2
A
B
C
.02
.03
.04
.05
.06
.07
.08
.09
.1
.2
.3
DEPTH (INCHES)

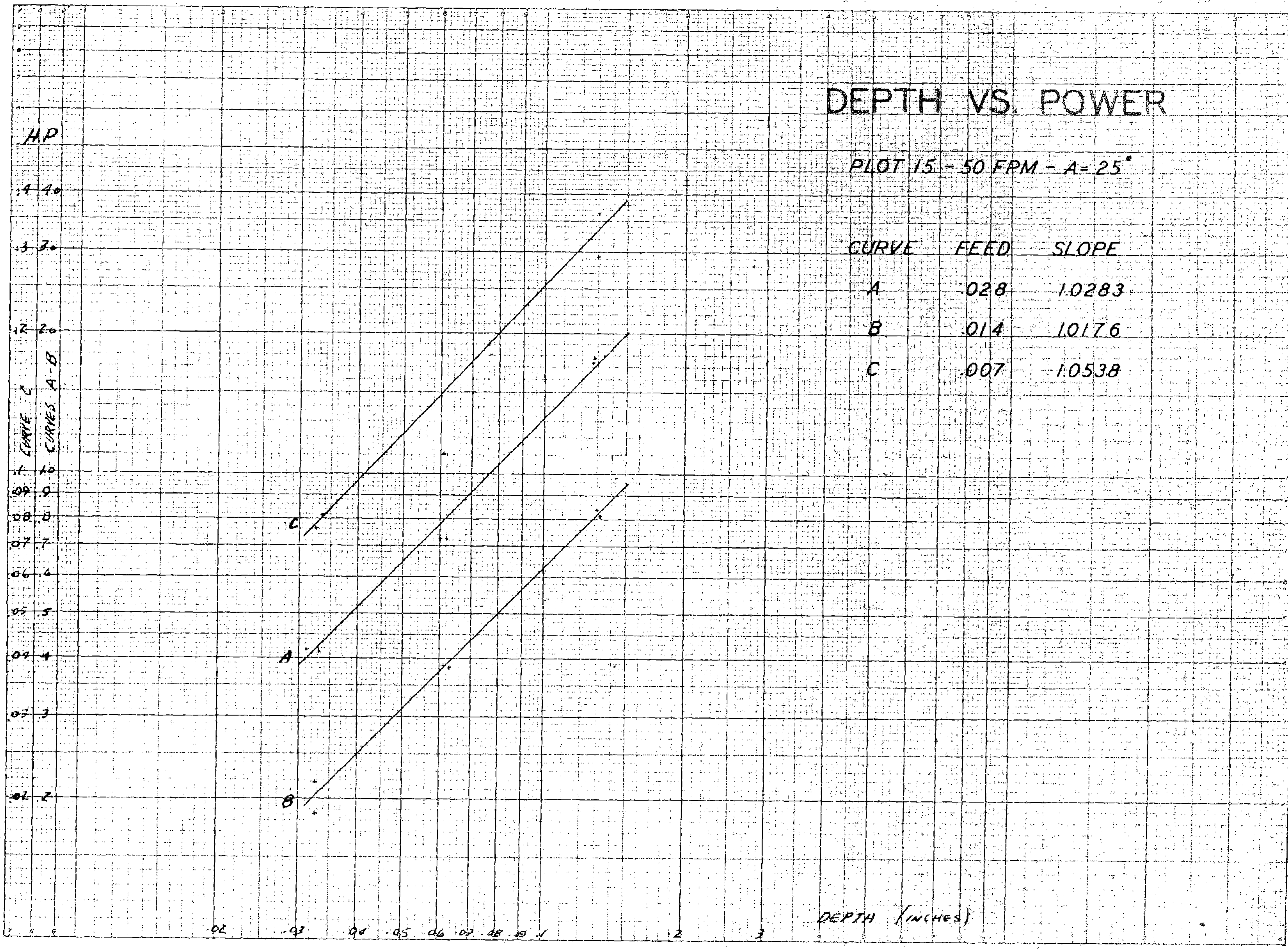

DEPTH VS. POWER
PLOT 10-60 FPM - A = 20°
CURVE FEED SLOPE
A .028 1.0724
B .014 .9657
C .007 .9131
HP
4.0
3.0
2.0
1.0
.9
.8
.7
.6
.5
.4
.3
.2
A
B
C
DEPTH (INCHES)
.02
.03
.04
.05
.06
.07
.08
.09
.1
.2
.3

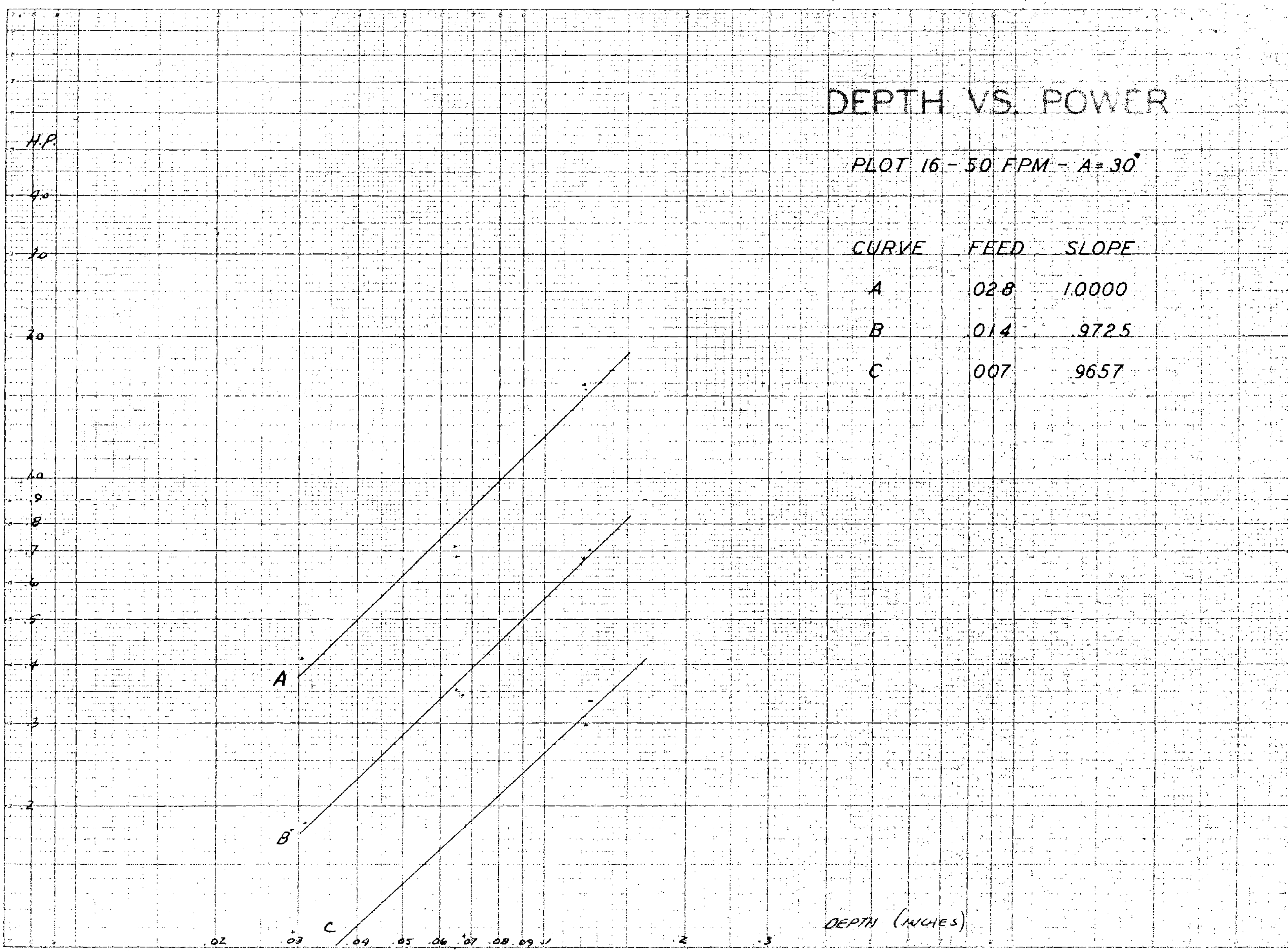

DEPTH VS. POWER
PLOT 11 - 60 FPM - A=25°
CURVE FEED SLOPE
A .028 .8693
B .021 .8847
C .014 .8847
D .007 .9827
H.P.
4.0
3.0
2.0
1.0
.9
.8
.7
.6
.5
.4
.3
.2
A
B
C
D
.02
.03
.04
.05
.06
.07
.08
.09
.1
.2
.3
DEPTH (INCHES)


DEPTH VS. POWER
PLOT 12 - 60 FPM - A=30°
CURVE FEED SLOPE
A .028 .9657
B .014 1.0000
C .007 .9930
H.P.
40
30
20
10
9
8
7
6
5
4
3
2
A
B
C
DEPTH (INCHES)
.02
.03
.05
.06
.07
.08
.09
.1
.2
.3


DEPTH VS. POWER
PLOT 13 - 50 FPM - A=15°
CURVE FEED SLOPE
A .028 1.0247
B .014 1.0176
C .007 1.0649
H.P.
4.0
3.0
2.0
1.0
.9
.8
.7
.6
.5
.4
.3
.2
A
B
C
.02
.03
.04
.05
.06
.07
.08
.09
.1
.2
.3
DEPTH (INCHES)


DEPTH VS. POWER
PLOT 14 - 50 FPM - A=20°
CURVE FEED SLOPE
A .028 1.0355
B .014 1.0176
C .007 .9657
DEPTH (INCHES)
H.P.
A
B
C


DEPTH VS. POWER
PLOT 15 - 50 FPM - A=25°
CURVE FEED SLOPE
A .028 1.0283
B .014 1.0176
C .007 1.0538
HP
CURVE C
CURVES A-B
C
A
B
DEPTH (INCHES)


DEPTH VS. POWER
PLOT 16 - 50 FPM - A = 30°
CURVE FEED SLOPE
A .028 1.0000
B .014 .9725
C .007 .9657
H.P.
40
30
20
10
9
8
7
6
5
4
3
2
A
B
C
.02
.03
.04
.05
.06
.07
.08
.09
.1
.2
.3
DEPTH (INCHES)

H.P.

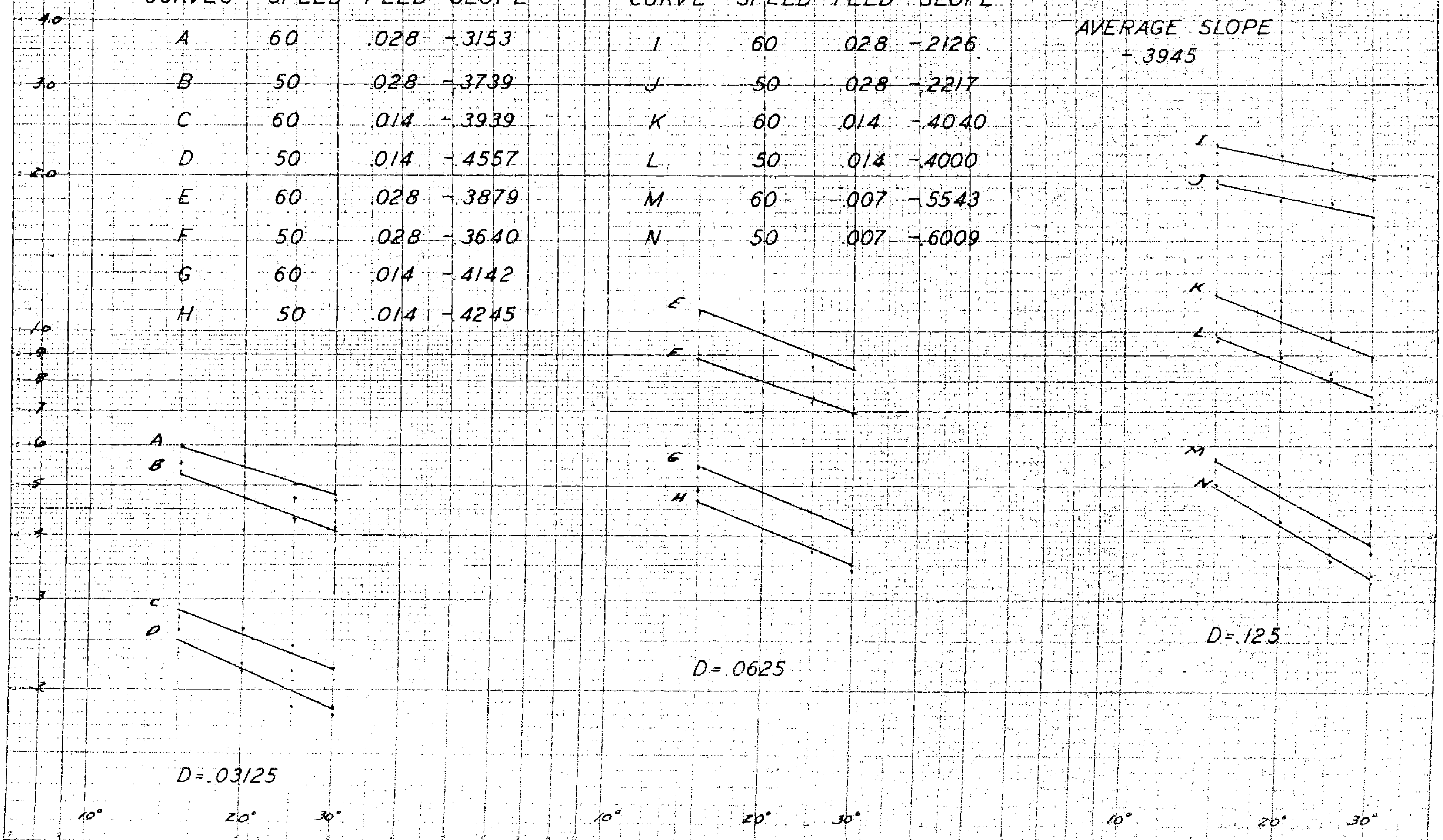
SIDE RAKE ANGLE VS. POWER

PLOT 17

CURVES	SPEED	FEED	SLOPE
A	60	.028	-.3153
B	50	.028	-.3739
C	60	.014	-.3939
D	50	.014	-.4557
E	60	.028	-.3879
F	50	.028	-.3640
G	60	.014	-.4142
H	50	.014	-.4245

CURVE	SPEED	FEED	SLOPE
I	60	.028	-.2126
J	50	.028	-.2217
K	60	.014	-.4040
L	50	.014	-.4000
M	60	.007	-.5543
N	50	.007	-.6009

AVERAGE SLOPE
-.3945



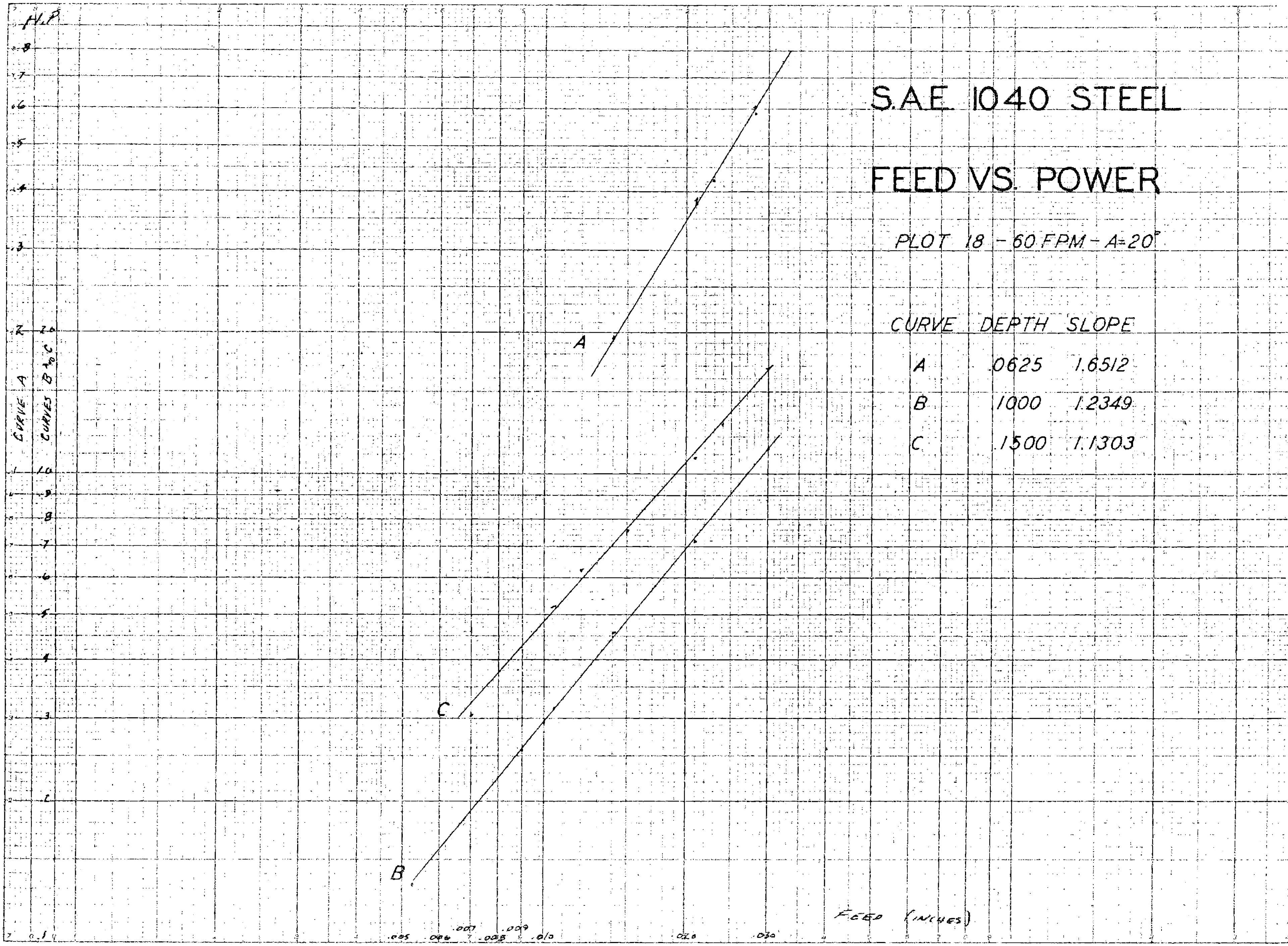
APPENDIX E

Data and Charts on Machining

S.A.E. 1040 Stock

DATA ON SAE 1040 STEEL

RUN	TOOL	FPM	DEPTH	FEED	RADIAL	LONG.	TANG.	KW.in
543	4	60	.0625	.007	2.0	15.0	----	1.05
544	4	60	.0625	.014	10.0	23.0	3.0	1.35
545	4	60	.0615	.028	29.0	37.0	9.0	1.75
546	4	60	.063	.007	3.0	20.0	----	1.10
547	4	60	.063	.014	15.0	27.0	3.0	1.32
548	4	60	.0625	.028	48.0	30.0	9.2	1.85
549	4	60	.0635	.021	32.0	25.0	5.8	1.55
550	4	60	.064	.0105	7.0	25.0	1.1	1.25
551	4	60	.064	.021	33.0	27.0	5.9	1.55
552	6	60	.101	.00525	4.0	15.0	----	1.15
553	6	60	.101	.0105	15.0	22.0	4.8	1.48
554	6	60	.101	.021	53.0	34.0	11.0	2.00
555	6	60	.1005	.028	55.0	35.0	16.0	2.40
556	6	60	.1025	.014	47.0	35.0	7.0	1.62
557	6	60	.1035	.007	9.0	25.0	2.0	1.35
558	6	60	.1025	.0065	5.0	22.0	1.4	1.22
559	6	60	.1025	.013	27.0	32.0	6.2	1.60
560	6	60	.1025	.026	65.0	40.0	14.6	2.27
561	7	60	.1505	.006	13.0	21.0	3.0	1.40
562	7	60	.1505	.012	55.0	30.0	9.5	1.90
563	7	60	.1505	.024	62.0	35.0	19.5	2.85
564	7	60	.150	.028	80.0	30.0	23.5	3.15
565	7	60	.153	.014	52.0	32.0	10.8	2.07
566	7	60	.1535	.007	32.0	38.0	4.7	1.50
567	7	60	.1535	.00525	15.0	30.0	2.0	1.35
568	7	60	.1535	.0105	36.0	27.0	8.0	1.80
569	7	60	.153	.021	60.0	20.0	16.5	2.55


S.A.E. 1040 STEEL
FEED VS. POWER
PLOT 18 - 60 FPM - A=20°
CURVE DEPTH SLOPE
A .0625 1.6512
B .1000 1.2349
C .1500 1.1303
H.P.
CURVE A
CURVES B & C
FEED (INCHES)
A
B
C

APPENDIX F

Tables for the Determination

of the Slope of Curves

CHART FOR THE DETERMINATION OF EXPONENT w

CURVE	SPEED	DEPTH	ANGLE	SLOPE	DEVIATION	% ERROR
1-A	60	1/32	15	1.0176	-.0872	- 7.89
1-B	60	1/16	15	1.0538	-.0510	- 4.62
1-C	60	1/8	15	1.0283	-.0765	- 6.92
2-A	60	1/32	20	1.0000	-.1048	-10.48
2-B	60	1/16	20	1.1303	+.0255	+ 2.31
2-C	60	1/8	20	1.0176	-.0872	- 7.90
3-A	60	1/32	25	1.1504	+.0456	+ 4.13
3-B	60	1/16	25	1.0913	-.0135	- 1.22
3-C	60	1/8	25	1.1708	+.0660	+ 5.97
4-A	60	1/32	30	1.0538	-.0510	- 4.62
4-B	60	1/16	30	.9657	-.1392	-12.60
4-C	60	1/8	30	1.1708	+.0660	+ 5.97
5-A	50	1/32	15	1.1303	+.0255	+ 2.31
5-B	50	1/16	15	1.1708	+.0660	+ 5.97
5-C	50	1/8	15	1.0538	-.0510	- 4.62
6-A	50	1/32	20	1.0538	-.0510	- 4.62
6-B	50	1/16	20	1.1303	+.0255	+ 2.31
6-C	50	1/8	20	.9490	-.1558	-14.10
6-D	50	1/8	20R	1.0538	-.0510	- 4.62

CURVE	SPEED	DEPTH	ANGLE	SLOPE	DEVIATION	% ERROR
7-A	50	1/32	25	1.2572	+.1524	+13.80
7-B	50	1/16	25	1.1504	+.0456	+ 4.13
7-C	50	1/8	25	1.1504	+.0456	+ 4.13
8-A	50	1/32	30	1.1918	+.0870	+ 7.87
8-B	50	1/16	30	1.1918	+.0870	+ 7.87
8-C	50	1/8	30	1.1106	+.0058	+ 0.53
8-D	50	1/16R	30	1.2799	+.1751	+15.90
			TOTAL	28.7243		

28.7243 ÷ 26 equals 1.1048, the average slope.

CHART FOR THE DETERMINATION OF EXPONENT x

CURVE	SPEED	FEED	ANGLE	SLOPE	DEVIATION	% ERROR
9-A	60	.028	15	1.1303	+.1303	+13.03
9-B	60	.014	15	1.1106	+.1106	+11.06
9-C	60	.007	15	1.0724	+.0724	+ 7.24
10-A	60	.028	20	1.0724	+.0724	+ 7.24
10-B	60	.014	20	.9657	-.0343	- 3.43
10-C	60	.007	20	.9131	-.0869	- 8.69
11-A	60	.028	25	.8693	-.1307	-13.07
11-B	60	.021	25	.8847	-.1153	-11.53
11-C	60	.014	25	.8847	-.1153	-11.53
11-D	60	.007	25	.9827	-.0173	- 1.73
12-A	60	.028	30	.9657	-.0343	- 3.43
12-B	60	.014	30	1.0000	-----	0.00
12-C	60	.007	30	.9930	-.0070	- 0.70
13-A	50	.028	15	1.0247	+.0247	+ 2.47
13-B	50	.014	15	1.0176	+.0176	+ 1.76
13-C	50	.007	15	1.0649	+.0649	+ 6.49
14-A	50	.028	20	1.0355	+.0355	+ 3.55
14-B	50	.014	20	1.0176	+.0176	+ 1.76
14-C	50	.007	20	.9657	-.0343	- 3.43

CURVE	SPEED	FEED	ANGLE	SLOPE	DEVIATION	% ERROR
15-A	50	.028	25	1.0283	+.0283	+ 2.83
15-B	50	.014	25	1.0176	+.0176	+ 1.76
15-C	50	.007	25	1.0538	+.0538	+ 5.38
16-A	50	.028	30	1.0000	-----	0.00
16-B	50	.014	30	.9725	-.0275	- 2.75
16-C	50	.007	30	.9657	-.0343	- 3.43
			TOTAL	24.9985		

24.9985 + 25 equals approximately 1.0000, the average slope.

CHART FOR THE DETERMINATION OF EXPONENT y

CURVE	SPEED	DEPTH	FEED	SLOPE	DEVIATION	%ERROR
A	60	1/32	.028	-.3153	-.0792	-20.00
B	50	1/32	.028	-.3739	-.0206	- 5.20
C	60	1/32	.014	-.3939	-.0006	- 0.15
D	50	1/32	.014	-.4557	+.0612	+15.50
E	60	1/16	.028	-.3879	-.0066	- 1.67
F	50	1/16	.028	-.3640	-.0305	- 7.73
G	60	1/16	.014	-.4142	+.0197	+ 5.00
H	50	1/16	.014	-.4245	+.0300	+ 7.60
I	60	1/8	.028	-.2126	-.1819	-45.70
J	50	1/8	.028	-.2217	-.1728	-43.70
K	60	1/8	.014	-.4040	+.0095	+ 2.41
L	50	1/8	.014	-.4000	+.0055	+ 1.39
M	60	1/8	.007	-.5543	+.1598	+40.40
N	50	1/8	.007	-.6009	+.2064	+52.20

AVERAGE SLOPE EQUALS -.3945

APPENDIX G

Miscellaneous Data and Charts

CALIBRATION OF DIAPHRAMS **

#1

INITIAL LOAD	FINAL LOAD	DELTA LOAD	GAGE POUNDS	INCREMENT LOAD DIVIDED BY GAGE EQUALS RATIO
22	341	319	85	3.75
22	424	402	105	3.83
22	590	568	145	3.91
22	675	653	165	3.95
22	593	571	145	3.94
				19.38

19.38 5 equals 3.88 for #1 diaphram.

#2

35	434	399	105	3.80
35	510	475	125	3.80
39	368	327	85	3.85
31	355	324	85	3.81
31	509	478	125	3.82
31	587	556	145	3.84
				22.92

22.92 6 equals 3.82 for #2 diaphram.

#3

22	484	462	65	7.11
22	1050	1028	145	7.10
22	624	602	85	7.10
22	1049	1027	145	7.09
				28.40

28.40 4 equals 7.10 for diaphram #3.

** Calibration by Musschoot and Stewart, 1936.

PHYSICAL AND CHEMICAL ANALYSIS OF

VANADIUM "D" STOCK

CHEMICAL ANALYSIS: C-.54%, MN-.35%, Cr-.55%,
V-.25%, Si-.30%, Ni-.00%.

PHYSICAL PROPERTIES:

Gage Length . . . . 2.01"

Dimension of Cross Section . . . . 0.505"

Load at Yield Point . . . . 16,950 lb.

Maximum Load . . . . 25,500 lb.

Dimension of Fractured Section. . . . . 0.34"

Extension in Two Inches . . . . 0.38"

Area of Original Section 0.2003

Area of Fractured Section 0.0908

Reduction of Area 54.8%

Elongation 18.9%

Yield Point . . . . 84,800 psi

Tensile Strength . . . . .127,500 psi

Ratio of Yield Point to Tensile
Strength . . . 0.665

Position and Appearance of Fracture:

Cup and Cone, in middle third of gage length.

Average Hardness: 265 Brinell

LATHE TOOL DIMENSIONS

Side Cutting Edge Angle	30°
Front Cutting Edge Angle	11°
Side Clearance Angle	6°
Front Clearance Angle	6°
Back Rake Angle	6°
Nose Radius	3/64"
Side Rake Angle	
Tools 1 and 2	15°
Tools 3 and 4	20°
Tools 5 and 6	25°
Tools 7 and 8	30°

HEAT TREATMENT OF TOOLS

TOOL MATERIAL, Rex AA Steel - 18 Tungsten
4 Chromium
1 Vanadium

TREATMENT FOR TOOL:

Preheat - 1550°F, for about 20 minutes per inch of thickness of the tool. Furnace atmosphere is not particularly important, although it is desirable to have a slightly reducing atmosphere, if possible.

Hardening Temperature - 2400°F for a time long enough to bring the tool to furnace atmosphere plus a soaking time of one minute.

Atmosphere of Furnace for Hardening Operation - 8-12% CO. It should never, at any time, be oxidizing, as an oxidizing atmosphere apparently sets up an exothermic reaction which gives a tool temperature, at least on the surface, higher than the furnace temperature.

Quenching Medium - Any good quenching oil. Quench then withdraw after bringing it to a black heat, then requench, to avoid brittleness.

Tempering - 120-240 minutes at a temperature of 1075 F. Keep atmosphere slightly reducing to prevent oxidation, but the exact composition is not particularly important. Air cool, being careful not to cool too rapidly, as by cooling on an iron plate, or in water.

Musschoot and Stewart.

PROPERTIES OF S.A.E. 1040 STEEL

S.A.E. 1040 Rytense AA

- .40 Carbon
- .95 Manganese
- .12 Sulphur
- .04 Phosphorous
- .60 Silicon

Tensile Strength

100,000 - 110,000

Hardness - 210 Vickers

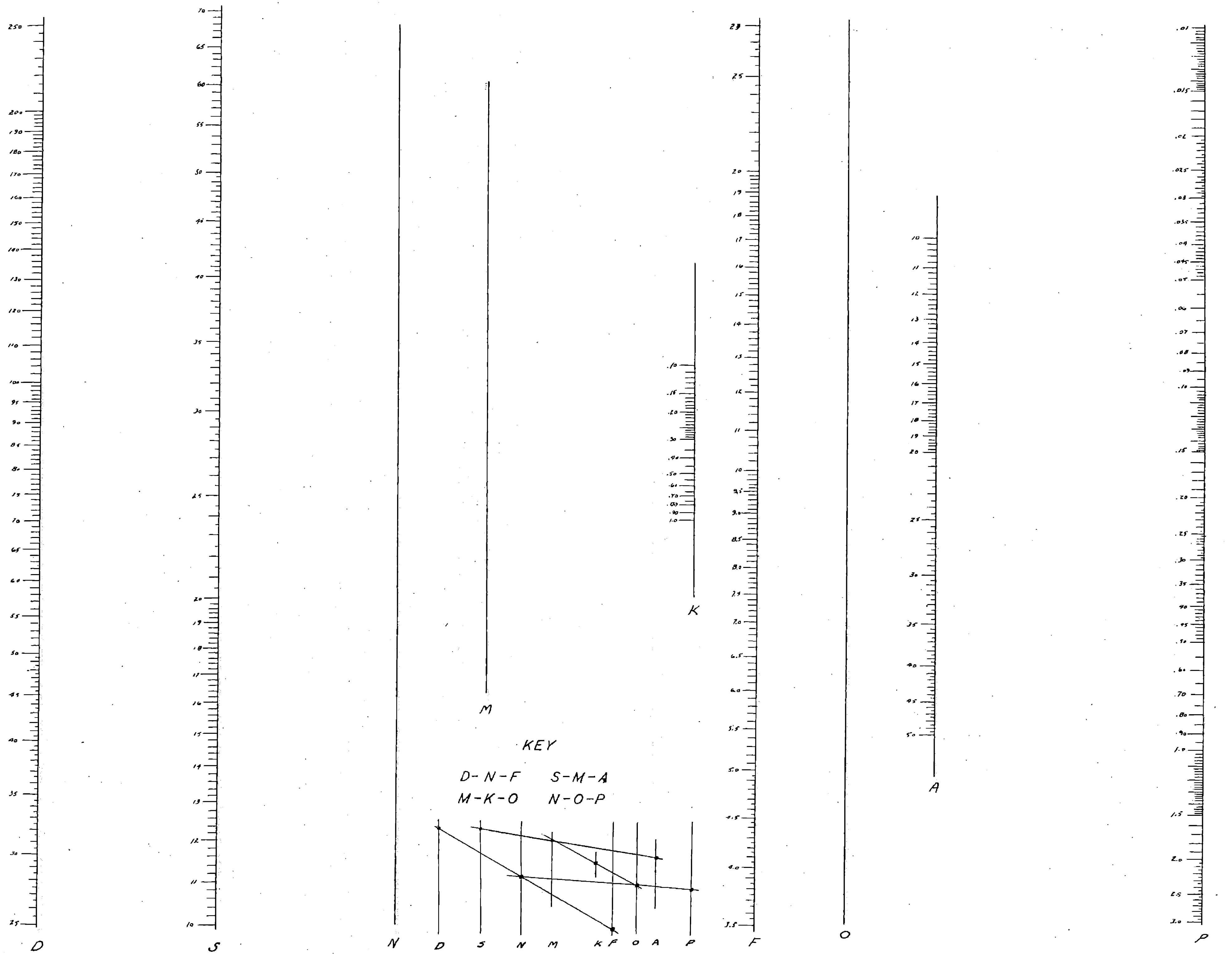
ELEVATED TEMPERATURE DATA

RUN	SPEED	DEPTH	FEED	KW. in	EFF.	KW. out	EMF
1	45	.031	.00525	.88	.04	.035	1.0
2	45	.031	.00525	.85	.035	.030	2.0
3	45	.031	.00525	.90	.05	.045	4.0
4	45	.0275	.00525	.90	.05	.045	6.0
5	45	.026	.00525	.94	.10	.094	12.0
6	45	.0225	.00525	.91	.065	.058	15.5
7	45	.0175	.00525	.88	.04	.035	17.5
8	45	.0155	.00525	1.00	.185	.185	19.5
9	45	.0105	.00525	1.10	.20	.220	21.5

- -

RUN	EMF	LESS EMF FRICTION	LESS EMF DIVIATION	CORRECTED EMF	°C	°F PLUS ROOM T.
1	1.0	.2	.13	.67	12	123.6
2	2.0	.2	.15	1.65	30	156.0
3	4.0	.2	.20	3.60	65	219.0
4	6.0	.2	.24	5.56	100	282.0
5	12.0	.2	.48	11.32	205	471.0
6	15.5	.2	.69	14.61	264	577.0
7	17.5	.2	.79	16.51	295	632.0
8	19.5	.2	.88	18.42	328	692.0
9	21.5	.2	.92	20.38	363	757.0

RUN	BILLET TEMP.	HPout	TANG. FORCE	CHIP AREA	TANG. PRESSURE
1	126.6	.047	34.4	.000163	211,000
2	156.0	.040	29.3	.000163	180,000
3	219.0	.060	44.0	.000163	270,000
4	282.0	.060	44.0	.000155	284,000
5	471.0	.126	92.5	.000136	680,000
6	577.0	.079	58.0	.000118	491,000
7	632.0	.047	34.4	.000092	378,000
8	692.0	.248	182.0	.000082	2,220,000
9	757.0	.295	217.0	.000055	3,940,000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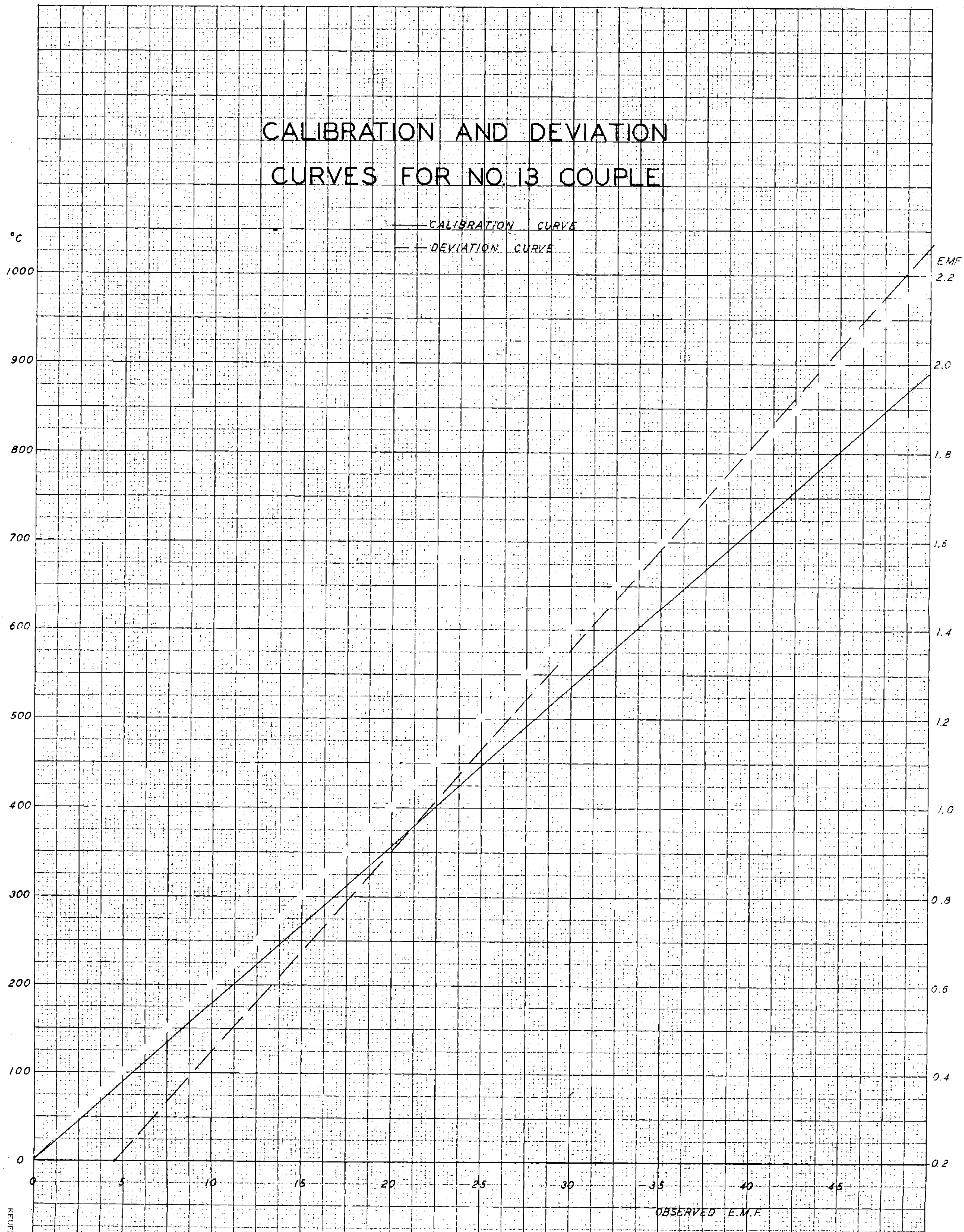

CALIBRATION AND DEVIATION
CURVES FOR NO. 13 COUPLE
CALIBRATION CURVE
DEVIATION CURVE
°C
1000
900
800
700
600
500
400
300
200
100
0
EMF
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
5
10
15
20
25
30
35
40
45
OBSERVED E.M.F.
KEUFF

APPENDIX H

Calculations

POWER CALCULATIONS

$$\text{HP (consumed)} = \frac{\text{Tangential Force X Surface Speed}}{33{,}000}$$

Tangential Force = Lever Ratio X Gage Constant X Gage Reading

Assuming that the Force acts at one-half the depth of the cut

$$\text{Lever Ratio} = 7.5/1.5-\frac{D}{2} = 15/3-D$$

Gage Constant (Diaphram #3) = 7.10

Therefore,

$$\text{Tangential Force} = 15/3-D \text{ X } 7.1 \text{ X } G$$

and,

$$\text{HP} = \frac{15/3-D \text{ X } 7.1 \text{ X } G \text{ X } S}{33{,}000}$$

TABLES FOR THE DETERMINATION OF K

VANADIUM "D" STOCK

Plot 12 - 60 fpm - A 30

Curve A - Slope = .9657

Point	Feed	Depth	Power	K
1	.028	.030	.468	$.245 \times 10^{-4}$
2	.028	.040	.620	.245
3	.028	.050	.760	.245
4	.028	.060	.905	.245
5	.028	.070	1.050	.245
6	.028	.080	1.200	.245
7	.028	.090	1.340	.245
8	.028	.100	1.490	.245

Curve B - Slope = 1.0000

Point	Feed	Depth	Power	K
1	.014	.030	.197	$.230 \times 10^{-4}$
2	.014	.040	.260	.230
3	.014	.050	.324	.230
4	.014	.060	.390	.230
5	.014	.070	.455	.230
6	.014	.080	.520	.230
7	.014	.090	.585	.230
8	.014	.100	.650	.230

Curve C - Slope = .9930

Point	Feed	Depth	Power	K
1	.007	.040	.126	$.235 \times 10^{-4}$
2	.007	.050	.157	.235
3	.007	.060	.188	.235
4	.007	.070	.218	.235
5	.007	.080	.248	.235
6	.007	.090	.278	.235
7	.007	.100	.310	.235
8	.007	.120	.368	.235

<u>Plot 13 - 50 fpm - A 15</u>

Curve A - Slope = 1.0247

1	.028	.030	.490	$.230 \times 10^{-4}$
2	.028	.040	.650	.230
3	.028	.050	.820	.230
4	.028	.060	.985	.230
5	.028	.070	1.14	.230
6	.028	.080	1.31	.230
7	.028	.090	1.49	.230
8	.028	.100	2.00	.230

Curve B - Slope = 1.0176

Point	Feed	Depth	Power	K
1	.014	.030	.236	$.230 \times 10^{-4}$
2	.014	.040	.314	.230
3	.014	.050	.393	.230
4	.014	.060	.472	.230
5	.014	.070	.550	.230
6	.014	.080	.630	.230
7	.014	.090	.710	.230
8	.014	.100	.790	.230

Curve C - Slope = 1.0649

1	.007	.030	.124	$.250 \times 10^{-4}$
2	.007	.040	.166	.250
3	.007	.050	.208	.250
4	.007	.060	.251	.250
5	.007	.070	.295	.250
6	.007	.080	.340	.250
7	.007	.090	.388	.250
8	.007	.100	.432	.250

Sum of the six values of K = 1.420×10^{-4}

$1.420 \times 10^{-4} \div 6 = .237 \times 10^{-4}$, Average K

TABLES FOR THE DETERMINATION OF K

S.A.E. 1040 STOCK

Point	Angle	Depth	Feed	Power	K
1	20	.0625	.006	.036	$.055 \times 10^{-4}$
2	20	.0625	.007	.063	.074
3	20	.0625	.008	.078	.080
4	20	.0625	.009	.094	.081
5	20	.0625	.010	.111	.085
6	20	.0625	.015	.218	.103
7	20	.0625	.020	.345	.115
8	20	.0625	.025	.498	.155
				TOTAL	.748

$.748 \times 10^{-4} \div 8 = .093$ Average K

- - - - - - - - - - - -

Point	Angle	Depth	Feed	Power	K
1	25	.100	.006	.158	$.157 \times 10^{-4}$
2	25	.100	.007	.190	.157
3	25	.100	.008	.223	.160
4	25	.100	.009	.258	.160
5	25	.100	.010	.292	.163
6	25	.100	.015	.482	.175
7	25	.100	.020	.685	.180
8	25	.100	.025	.900	.185
				TOTAL	1.337×10^{-4}

$1.337 \times 10^{-4} \div 8 = .167 \times 10^{-4}$, Average K

Point	Angle	Depth	Feed	Power	K
1	30	.150	.006	.270	$.153 \times 10^{-4}$
2	30	.150	.007	.325	.153
3	30	.150	.008	.375	.153
4	30	.150	.009	.430	.153
5	30	.150	.010	.485	.153
6	30	.150	.015	.760	.153
7	30	.150	.020	1.05	.153
8	30	.150	.025	1.37	.153
9	30	.150	.030	1.68	.153

Value of K (from Curve C) . . . . . $.153 \times 10^{-4}$

Av. K (from Curves B and C). . . . . . $.160 \times 10^{-4}$

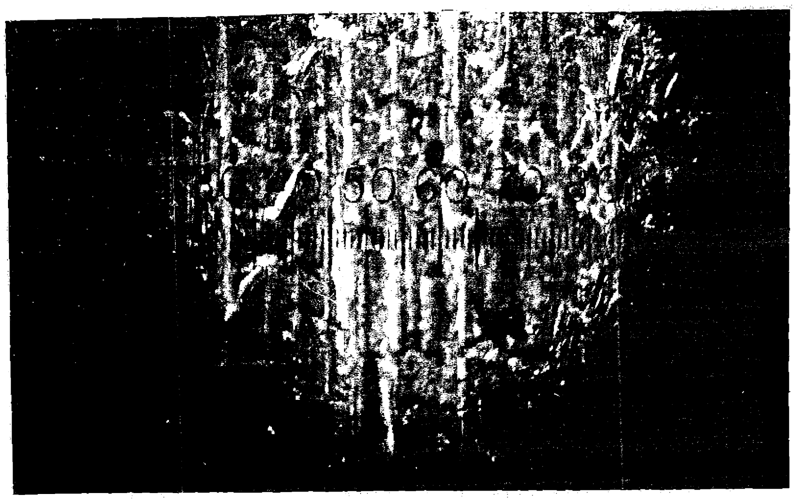
Av. K (Curves A, B and C) . . . . . . $.137 \times 10^{-4}$

APPENDIX I

Surface Condition Pictures

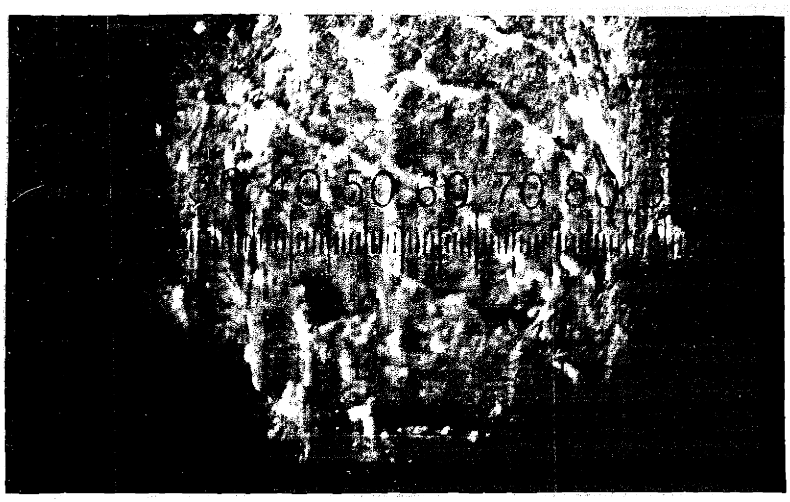
SURFACE FINISH

Tool No. 5 - Speed 60 fpm - Depth .0325"



Cut 57 - Feed .00525"

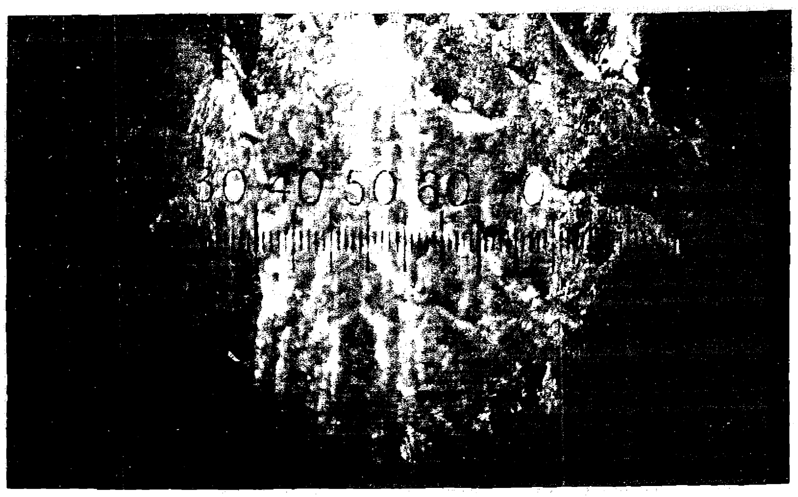
Cut 58 - Feed .0105"



Cut 61 - Feed .014"

Cut 62 - Feed .007"

Cut 59 - Feed .021"



Cut 60 - Feed .028"

VII

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