Lathe-cutting of certain alloy cast irons
by Wright K Gannett

a THESIS Submitted to the Graduate Committee in partial fulfillment of the requirements for the degree of Master of Science in Mechanical Engineering
Montana State University

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This investigation was concerned with the variation of tool life and of power input with different cutting speeds.

For each composition of iron the feed and the depth of cut were kept constant at values prescribed by Mr. Deale. The purpose of this investigation was to establish empirically—under the prescribed conditions—the mathematical relationships among the variables of (1) cutting speed, (2) tool life, and (3) power input, using formulas whose general form has been well-established by F.W. Taylor 3 and confirmed by later investigators. The data gathered served merely to find the values of certain constants in those formulas.

Since little information exists on the difference between the cutting characteristics of the skin and of the clean metal1, the data for these two types of cuts were kept separately. Those data made clear the extent to which the greater hardness and abrasiveness of the skin shorten tool life.

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TABLE OF CONTENTS

Abstract

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Introduction

According to F. W. Taylor [5] there are twelve principal variables involved in the cutting of metals. Combination of these variables as made by the machine operator is empirical and is based on practice which he never thinks to question. Modern industry in its scramble for profits is constantly placing itself under a more scientific economic management. Since the cutting of metals is one of the foremost processes of industry, it is important that the optimum economic combination of the variables of cutting for any given job be known. But such knowledge can be obtained only by careful and extensive research which establishes the emperical formulas that relate those variables. For all metals these formulas are of the same general exponential type and are commonly used to relate the more important variables of (1) tool life, (2) cutting speed, (3) power input, (4) feed, and (5) depth of cut. Altho this paper is limited to reporting on only the first three of those variables, further investigations from time to time are certain to help complete the picture of the cutting of these metals

Conditions under which this Investigation was made

The analyses of the three cast irons were:

	250 (Base Iron)	262	213 M
Silicon	1.99%	1.97%	1.92%
Total carbon	3.38	3.40	3.25
Nickel	0.36	2.00	0.30
Chromium	0.28	0.51	0.40
Molybdenum	----	----	0.60
Copper	0.35	0.50	0.20

And the physical properties were:

	250 (Base Iron)	262	213 M
Transverse	2,450	2,400	3,150
Deflection	0.20	0.26	0.28
Tensile (0.505" bar)	44,520	44,720	55,590
Brinell (average)			
(a) in skin	248	264	305
(b) at 1/8" depth	205	215	270
Type of fracture in tensile test	fine grain--gray carbide network	fine grain--gray	fine grain--gray

Except for the hardness values the above information was furnished by the International Nickel Company. The 250 base iron and the 262 iron were not dissimilar enough to produce very different cutting characteristics. Both cut far more easily than the 213 M.

There was available a total of twelve sleeves: four of each composition of iron. Since all cuts were 1/8" depth, the 3/8" walls of the sleeves allowed only two passes to be taken in each: one in the skin and one in the clean metal.

Since data for skin cuts were kept separately from those for clean metal, there were two sets of data for each composition of iron or six sets of data in all. The size of the sleeves and other factors made it impossible to get in each set of data more than about a dozen readings--much too few to establish a dependable average result. Therefore, the results of this investigation are not conclusive and should be regarded only as giving the approximate cutting characteristics of these irons.

The dimensions of the sleeves were: 10 7/8" length, 5 1/2" outside diameter, and 4 3/4" inside diameter. The top end of each sleeve was thickened for about 1/4" in a collar equipped with two diametrically opposite lugs (for a positive driving grip). The bottom end of each sleeve, opposite the top (or collar) end, cooled first in the mold and as a result was chilled so hard that it had to be cut back about 1/2" before any "official" cuts could be taken. Further metal was made unavailable for cutting because of preliminary cuts. For example, a preliminary cut in the skin of sleeve 1-250-base was taken to check the approximate tool lives which the sleeves were expected to give. The tool cut the length of the sleeve without failing and showed the necessity of raising estimated speeds by more than 50%. Several tools on the last cut of a pass reached the end of the sleeve without failing. The preceding factors reduced the average length "officially" cut to considerably less than the total length of the sleeve.

Brinell hardness readings were taken in the skin and at 1/8" depth. A bolt and nut were cinched up inside the sleeves to help carry the 3,000 kg. load. No Brinell readings could be taken at 1/4" depth, because the 3,000 kg. load crushed thru, while the metal was not soft enough to be measured by the 500 kg. load. In both the skin and at 1/8" four readings equally spaced along the length "officially" cut were made. These readings were placed at random around the circumference of the sleeve. The Brinells showed a rather well-defined hardness gradient of about 20 B. H. N. units from the soft end to the hard bottom end, where the first cuts of each pass were started. No Brinells were taken in the chilled part of the hard end. This end in the 213-M sleeves was almost unmachinable with any tool softer than stellite, but the extreme hardness ended about 1/2" from the bottom end.

Cutting was done on a heavy-duty, cone-driven lathe 36" between centers and having a 26" swing (fig. 1). A 10-hp., D. C., adjustable-speed motor drove the lathe. Power input was measured by means of a voltmeter and an ammeter in the power circuit (fig. 2). The efficiency of the motor un-

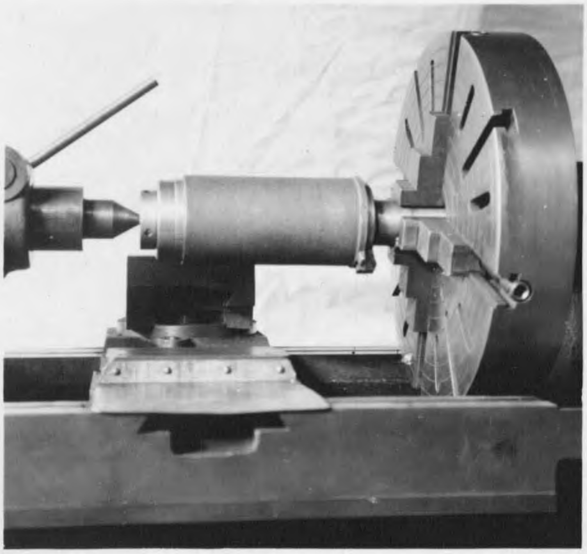

Fig. 1--Lathe with mandrel and sleeve.

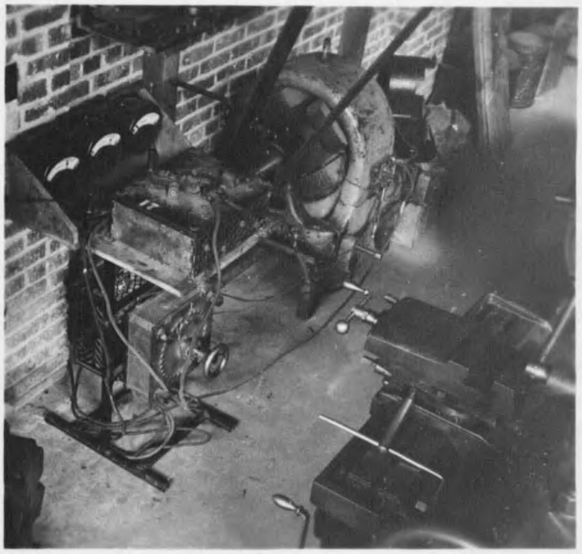

Fig. 2--D. C. motor and instruments.

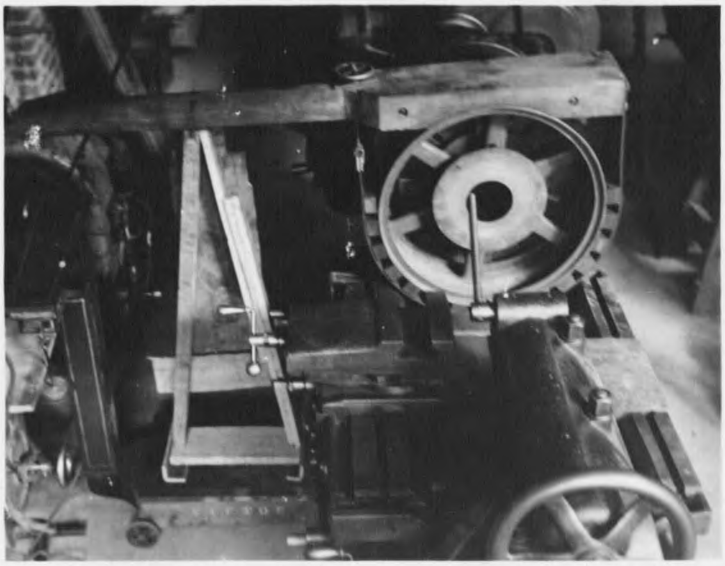

Fig. 3--Prony brake.

der various conditions of load had been determined previously with a prony brake (fig. 3), the efficiency readings including all friction losses up to the spindle of the lathe. Before any cuts were made the lathe was always allowed to run until the power readings became constant.

Cutting speed was gotten from the diameter of the work and the r. p. m. The latter was obtained in two ways: by measurement with a revolution counter and by calculation from the tool life, feed, and longitudinal length of work cut. When the two methods were not in exact agreement the greater weight was given to the revolution counter on very short cuts and to the computation method on longer cuts. The latter gave the average r. p. m. within ±1 revolution per time of tool life.

The 1/8" depth of cut, which was used both in the skin and in the clean metal for all three compositions of iron, was measured from the point of average runout for skin cuts. The feeds were as follows: for 250 base--0.0123"/rev., for 262--0.0123"/rev., and for 213 M--0.0185"/rev.

The sleeves were mounted with good concentricity and positive driving grip on a specially designed and constructed mandrel (fig. 4). Husky construction, including a 3"-diameter shaft, insured high rigidity. The mandrel is shown between centers on the lathe and holding a sleeve in fig. 1. Before the sleeves were mounted on the mandrel they were turned in a steady-rest and their inner ends were bored on a bevel so as to fit between the bevel rings on the mandrel. One ring was welded to the body of the mandrel, while the other was cinched up against the sleeve by means of a thick nut and washer. The lugs which furnish the positive driving grip can be seen in figs. 1 and 4.

Before starting skin cuts the average runout of each sleeve was measured and recorded. The average for the runouts of all sleeves was less than 1/32", while the runout of most single sleeves averaged near 1/32". The runout was partly caused by egg-shaped cross sections or by the sleeves' not being exactly straight from end to end. These same inaccuracies made it impossible to hold the sleeves for boring with perfect concentricity in the steady-rest. On all except one sleeve the runout was practically the same at all points along the length. For these sleeves the average runout was recorded. For the remaining sleeve the runouts were recorded cut by cut.

All tests were run dry, using sharp-nosed tool bits of a single shape, heat treatment, and composition. The tool blanks were heat treated by Brown & Sharpe and were of the 18-4-1 type and 5/8" square. Their analysis was: carbon 0.78-0.83%, manganese 0.20-0.25, phosphorous 0.025 max., sulphur

Fig. 4--Mandrel.

Fig. 6--Tool-holder.

0.03, chromium 3.50-4.00, tungsten 17.25-18.25, and vanadium 0.90-1.10. Their heat treatment was:

Operation	Temp. (deg. Fahr.)	Time (min.)	Atmosphere
Preheat	1,600	13	
Hardening	2,400	4 3/4	8-10% CO
Tempering	1,100	240	

The tools--of a shape approximating those in general use--were ground with no top rake, all top rake being provided by the 8-degree upslant of the tool-holder. Measured with respect to the tool shank the other angles were: 14 degrees side rake, 15 degrees front clearance, 6 degrees side clearance, 6 degrees front cutting-edge angle, and 20 degrees side cutting-edge angle (fig. 5). All tools were accurately ground on a Gisholt lathe-tool grinder and the burrs on the edges were carefully removed by honing. Care was taken not to burn the tool surfaces while grinding.

A specially built tool-holder (fig. 6) designed for rigidity and prevention of slippage was used. It was similar to the tool-holder used by H. J. French and T. G. Digges[2] in the rough turning of steel, in that a 3/8"-square trailer tool (not used in this investigation) can also be held in place if necessary. The main body of the tool-holder was a single piece of steel, to which the top piece was held by six cap screws. Between the main body and the top

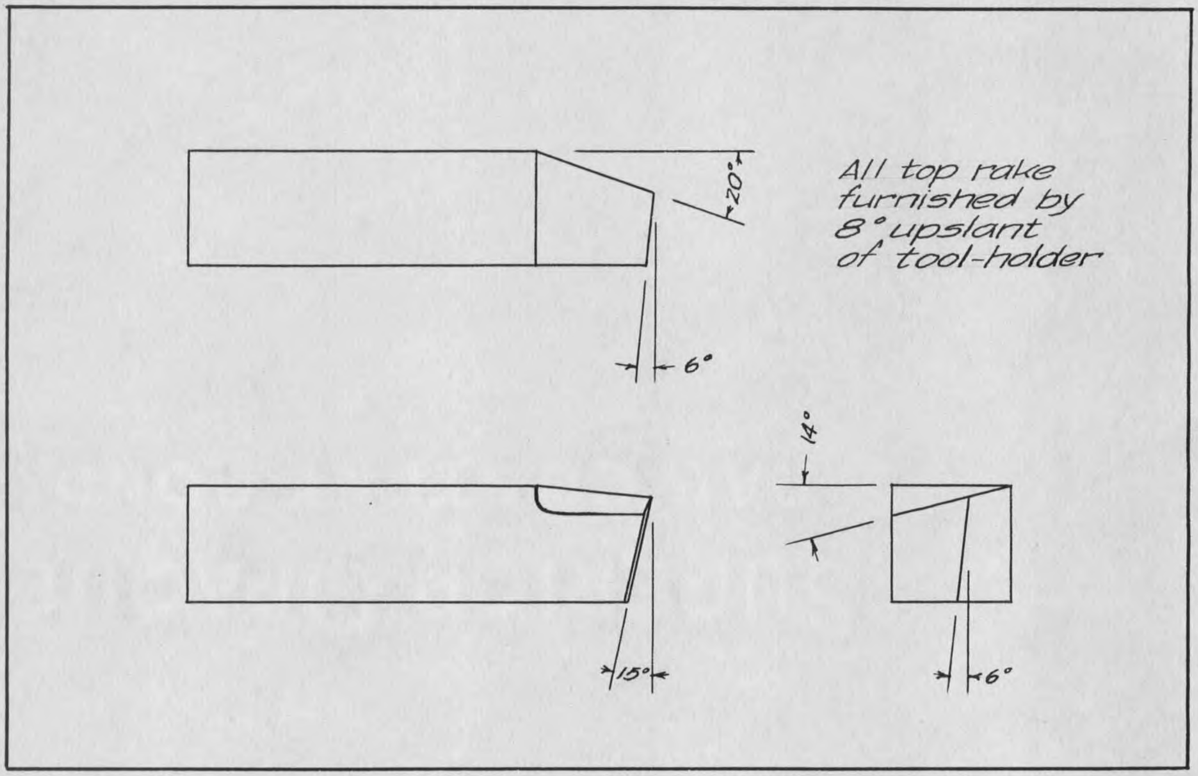

FIG. 5 — TOOL SHAPE

piece were grooves for the cutting tool and for the trailer tool. The tool bits were held in place by set screws and backed up by bolts provided with lock nuts.

Tool Failure

The exact time of tool failure was never clear-cut and had to be set somewhat arbitrarily. The type of failure was characteristic of a sharp-nosed tool, being of a slowly progressive rather than of a more "instantaneous" nature. Cutting conditions would remain constant up to the point where failure started. The first stage of the progressive failure consisted of infinitesimal specks of metal adhering to the corner of the cut. Next an almost imperceptible fuzz would appear, the corner of the cut becoming less well-defined. Then the fuzz would grow into what I called a "definite fuzz". The latter I took as the criterion of failure. Naming the instant at which the fuzz became "definite" was rather arbitrary. Certainly the accuracy could not have been much closer than ± 30 seconds for a tool life of, say, four minutes. Incidentally, the fuzzy appearance at the corner of the cut was partly illusory due to the rotation of the work.

In gathering each of the six sets of data no tool bit was used more than twice. Thus, any possible peculiarities of single tool bits were minimized.

A failed tool had a slightly rounded-off nose, while the cutting edge at contact with the periphery of the work was brightly but negligibly abraded--even for skin cuts. The top of the tool, where the chip rubbed, was burned and also slightly roughened by specks of metal welded to it. Except for the degree of rounding of the nose, a tool appeared the same whether removed shortly before or shortly after the "definite-fuzz" point. Neither the face of the cut nor the surface of the work underwent any apparent change before failure. But the "definite-fuzz" point seems a proper indication of failure, because it was there that both power input and the diameter of the work started to increase. Several times after failure a new tool was inserted and used to make a longitudinal scratch in the surface of the work. These scratches became minutely deeper in the neighborhood of the "definite-fuzz" point, revealing a small increase in the diameter of the work.

Two cuts, each of about a two-minute tool life, were run past failure. The resulting increase in fuzz was enormous. About three minutes past failure the corner of the cut, resembling iron filings clustered to a magnet, became a complete mess and power input went up abruptly. I called this the "let-go" point. The tool upon removal had a bluntly <u>flattened</u> nose, seemingly sheared off. Welded "wings" on each side of the nose and considerable burning evidenced the heat generated. Probably the failure of a round-nosed tool would correspond more closely to the "let-go" point than to the "definite-fuzz" point. Paradoxically no change in the character of the surface of the work or in the face of the cut took place between "definite fuzz" and "let go". But the increase in the diameter of the work was apparent to the naked eye, while a steel scale held longitudinally against the work showed daylight under its middle.

There were two tools which failed differently from all the others. For one the corner of the cut at failure rounded off without the appearance of any fuzz. The nose of that tool was rounded more bluntly than for the ordinary failure. The second tool failed in a manner more characteristic of a round-nosed tool. The failure was very definite, the face of the cut "mushing up" immediately. Unlike the other tool failures this one could be observed with a probable accuracy of ±10 seconds. It seems likely that peculiarities in the tool bits themselves accounted for these two singular tool failures.

Tool life was closely dependent on hardness. For example, on sleeve 1-213 M (cut in the clean metal) identical conditions yielded a tool life of 3 1/3 minutes in the hard end and 8 1/2 minutes in the soft end. Differences in hardness between two sleeves of the same composition often made the data gathered from one almost worthless in predicting tool life for the other. For that reason computation for the prediction of tool life was shelved in favor of "by guess and by gosh". A formula relating tool life, cutting speed, and hardness would greatly "iron out" many of the discrepancies in the data gathered. That relationship would probably be of the form, $VM^{0.1}H^{A} = C'$, where H is the hardness and A is a constant to be determined by experiment with the given metal. In this investigation the data were insufficient to establish such a formula. Instead, the first cut in each sleeve was run at a high enough speed to make a fairly short tool life probable. That tool life was used with the hardness gradient for estimating subsequent tool lives on the same sleeve. These estimates were generally successful in keeping the tool lives between one and ten minutes.

Occasionally a tool reached the end of the sleeve before failure. If the tool was in the "speck" stage of progressive failure the additional time necessary to reach "definite fuzz" was estimated, giving a tool life that was undoubtedly within the usual limits of error (± 30 seconds). Otherwise the reading was discarded.

Cutting speed also affected tool life greatly. Since a 7% decrease in cutting speed results in a 100% increase in tool life (by the formula, $VM^{0.1} = C$), the wisdom of calculating the r. p. m. as well as measuring it becomes apparent.

The progressive failure of these tools, while proceeding very slowly under ordinary conditions, became more rapid as the severity of the conditions increased. In one cut a double-heavy feed was erroneously used, giving a tool life of perhaps fifteen seconds and an almost instantaneous failure. Other tools making "unofficial" cuts in the chilled end failed very rapidly. But for all usual cuts the time between "definite fuzz" and "let go" is probably somewhat in excess of the actual tool life.

Results (Tool Life)

The data for the variation of tool life with cutting speed are given on the following tables and graphs:

for iron 250--Table I, data plotted on figs. 7 and 8;
for iron 262--Table II, data plotted on figs. 9 and 10;
for iron 213 M--Table III, data plotted on figs 11 and 12.

The two figures in each case give the plot of V, the cutting speed in ft./min., against M, the tool life in minutes, on log-log paper for skin and clean-metal cuts respectively.

The tables list the Brinell hardness number for each separate cut. These values were estimated by shading the average B. H. N. of the sleeve to account for the position of the cut along the hardness gradient. The hardness gradient was not noticed in time to allow separate hardness readings to be taken for each cut. However, since on the average more Brinells were taken per sleeve than cuts per sleeve, the estimated hardness of each cut should be reasonably accurate.

The tool-life formulas below, of the general type established by Taylor[5], were used in this investigation:

$VM^{0.1} = C;$

$V = K/T^{0.43}L^{237}M^{0.1}$,

where C and K are empirical constants, T is the chip thickness (= feed [cos. 20°] for the tool used), and L is the length of engagement (= depth of cut/cos. 20° for the tool used).

Mr. Deale specified the exponents in the above formulas on the basis of his experience.[1] The exponent, 0.1, in $VM^{0.1} = C$ is the negative slope of the straight-line plot on log-log paper. This slope seems well confirmed by the grouping of the points on the graphs in figs. 7 thru 12. The other exponents, in the second formula, must be taken on faith. Their accuracy could not be checked, because neither feed nor depth of cut (i. e., T and L) were varied.

If the cutting conditions for the three irons had been identical the constant, C, from the first formula would have been a criterion of machinability. The higher values of C would have indicated greater machinability and the resulting greater tool life to be expected. But the cutting conditions for the three irons were not identical, because a heavier feed (0.0185"/rev. against 0.0123"/rev.) was used for sleeves 213 M. But the constant, K, from the second formula is a true criterion of machinability, because that formula considers variations (or differences) in both feed and depth of cut. The preceding statement assumes, of course, that the remaining variables of cutting are kept constant. It is apparent that highly dependable values of K could be obtained only from data in which both feed and depth of cut are varied. However, K was calculated for both skin and clean-metal cuts for all three irons in order to show the differences in machinability between skin and clean metal and to show the relative machinability of the three irons.

It should be remembered that the values of C (from the first formula) are true only for the particular feeds and depth of cut used. If any of the remaining of the twelve variables had been different (for example, tool shape), different values of both C and K would have resulted. Since the second formula considers all the foremost variables of cutting (for a given metal) the constant, K, can be considered a fairly universal criterion of machinability.

The average values of C and K are listed below. Note how the K's emphasize the lesser machinability (and resulting shorter tool life) of the skin. The three irons listed in order of decreasing machinability are: 250 base, 262, and 213 M.

for 250 base, skin cut--C=100.7, K=14.21;
for 250 base, cut in clean metal--C=108.4, K=15.33;

for 262, skin cut--C=92.7, K=13.11;
for 262, cut in clean metal--C=98.7, K=13.93;

for 213 M, skin cut--C=50.5, K= 8.35;
for 213 M, cut in clean metal--C=56.6, K=9.36.

The heavier feed used for sleeves 213 M lowers the values of C, but does not affect K. In fig. 14 the above K's are plotted in order to bring out graphically the differences in machinability. It should be remembered that the lesser machinability and tool life characteristic of the skin was caused not only by the greater hardness and abrasiveness of the skin, but also by the runout.

Altho variations in runout were not an appreciable factor in the variation of tool life, the runout added another component to the rubbing action of the skin. Therefore, the runout contributed to the shorter tool life in the skin.

TABLE I

These data are plotted in figs. 7 and 8 (for tool life) and fig. 13 (for power input), while K is compared to 1/K' in fig. 14

Sleeves--250 base Feed--0.0123"/rev. Depth of cut--1/8"

Cut in Skin

Average runout	
	Average C = 100.7
2-250--0.030"	Average K = (average C)$T^{0.43}L^{2.37}$ = 14.21
3-250--0.023"	Average K' = 6.03
4-250--0.025"	Average B.H.N., all sleeves = 249

Cut no.	Sleeve no.	B.H.N.* at cut	Speed, V ft./min.	Life, M min.	$VM^{0.1}=C$	Kw. input	K' = P/FDV
1	2	245	88.5	6.25	106.2	0.890	6.53
2	3	264	86.4	2.25	93.7	0.868	6.52
3	3	262	82.0	3.67	93.3	0.887	7.02
4	3	256	80.0	7.75	98.2	0.811	6.59
5	4	242	91.4	3.75	104.4	0.577	4.10
6	4	238	89.3	4.17	103.1	0.762	5.54
7	4	232	92.8	3.67	105.7	0.845	5.92

Cut in Clean Metal

Average C = 108.4 Average K = (average C)$T^{0.45}L^{2.37}$ = 15.33
Average K' = 5.80 Average B.H.N., all sleeves = 205

Cut no.	Sleeve no.	B.H.N.≠ at cut	Speed, V ft./min.	Life, M min.	$VM^{0.1}=C$	Kw. input	K' = P/FDV
1	1	205	88.8	5.25	104.9	0.738	5.40
2	1	192	94.4	3.00	105.3	0.858	5.90
3	1	181	95.8	4.17	110.5	0.865	5.86
4	2	215	95.8	2.75	106.1	0.910	6.16
5	2	198	87.0	9.67	109.2	0.796	5.95
6	3	220	90.9	5.33	107.5	0.893	6.38
7	3	203	93.0	5.75	110.8	0.852	5.95
8	4	230	91.6	8.00	112.8	0.681	4.83

* in skin

≠ at 1/8" depth

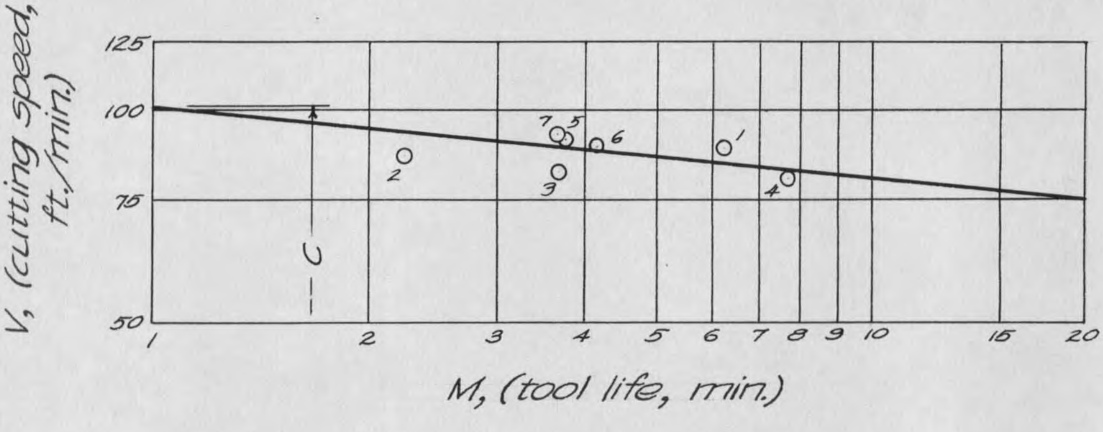

FIG. 7—CUT IN SKIN

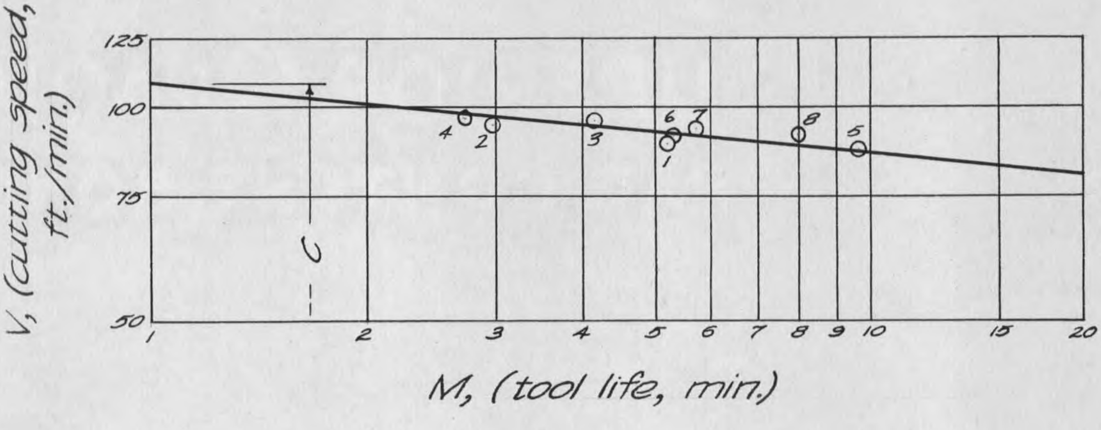

FIG. 8—CUT IN CLEAN METAL

Figs. 7 and 8--Effect of cutting speed on tool life for sleeves 250. Depth of cut 1/8", feed 0.0123"/rev., and $VM^{0.1} = C = 100.7$ (for skin) and 108.4 (for clean metal).

The small numbers refer to "Cut no." on Table I.

TABLE II

These data are plotted in figs. 9 and 10 (for tool life) and fig. 13 (for power input), while K is compared with 1/K' in fig. 14.

Sleeves—262 Feed—0.0123"/rev. Depth of cut—1/8"

Cut in Skin

Average runout
1-262—0.036"
2-262—0.032"
3-262—0.033"
4-262—0.015"

Average C = 92.7
Average K = (average C)$T^{0.43}L^{2.37}$ = 13.11
Average K' = 6.55
Average B.H.N., all sleeves = 264

Cut no.	Sleeve no.	B.H.N.* at cut	Speed, V ft./min.	Life, M min.	$VM^{0.1} = C$	Kw. input	K'=P/FDV
1	1	278	80.6	1.25	82.4	0.861	6.94
2	1	267	74.5	13.17	96.2	0.801	6.98
3	2	274	76.8	13.92	99.9	0.792	6.70
4	3	266	74.0	7.25	90.2	0.848	7.44
5	3	259	86.4	2.25	93.5	0.925	6.95
6	3	255	93.6	0.53	87.9	0.675	4.68
7	3	253	94.3	1.25	96.3	0.864	5.95
8	4	252	76.8	9.00	95.5	0.798	6.75

Cut in Clean Metal

Average C = 98.7
Average K' = 5.91

Average K = (average C)$T^{0.43}L^{2.37}$ = 13.93
Average B.H.N., all sleeves = 215

Cut no.	Sleeve no.	B.H.N.≠ at cut	Speed, V ft./min.	Life, M min.	$VM^{0.1} = C$	Kw. input	K'=P/FDV
1	1	206	90.9	1.03	91.0	0.820	5.85
2	1	204	90.2	1.33	92.9	0.985	7.09
3	1	202	87.4	3.67	99.5	0.700	5.20
4	1	197	87.4	5.08	102.9	0.861	6.39
5	2	230	91.1	2.00	97.8	0.870	6.20
6	2	224	90.1	2.75	99.6	0.772	5.56
7	2	219	87.4	4.50	101.5	0.711	5.28
8	3	225	85.0	4.75	99.0	0.858	6.56
9	3	219	84.1	6.25	101.0	0.762	5.88
10	4	228	84.5	2.75	93.5	0.607	4.66
11	4	222	86.0	9.00	107.0	0.841	6.35

* in skin
≠ at $\frac{1}{8}$" depth

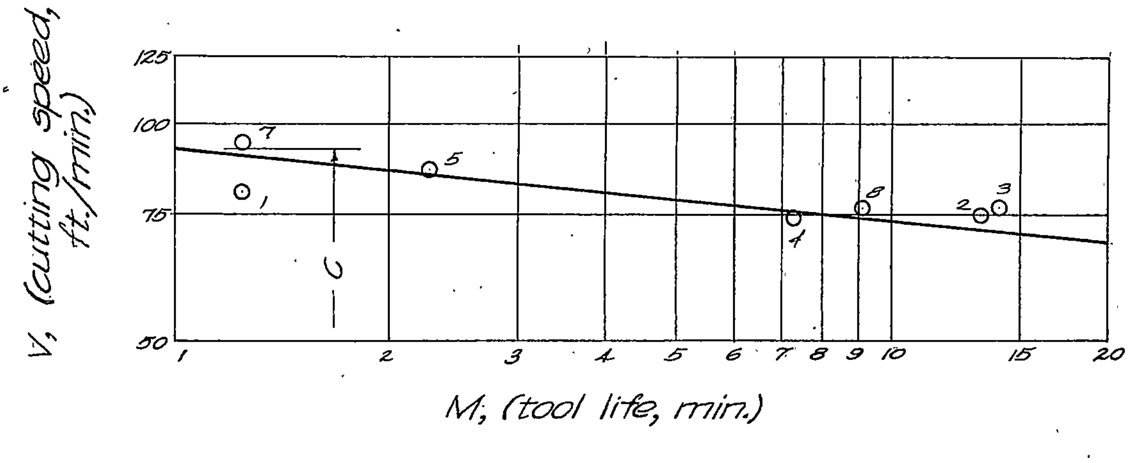

FIG. 9—CUT IN SKIN

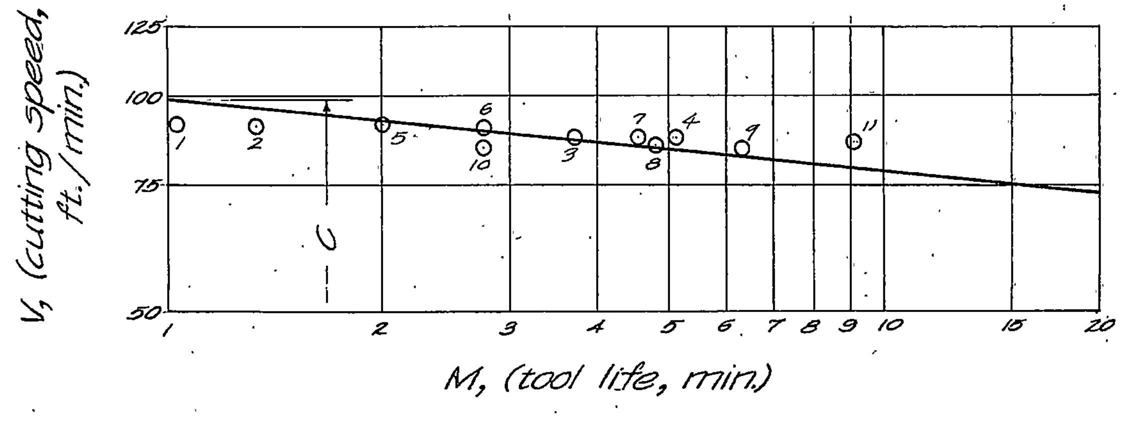

FIG. 10—CUT IN CLEAN METAL

Figs. 9 and 10-- Effect of cutting speed on tool life for sleeves 262. Depth of cut 1/8", feed 0.0123"/rev., and $VM^{0.1} = C = 92.7$ (for skin) and 98.7 (for clean metal).

The small numbers refer to "Cut no." on Table II.

TABLE III

These data are plotted in figs. 11 and 12 (for tool life) and fig. 13 (for power input), while K is compared with 1/K' in fig. 14.

Sleeves--213 M   Feed--0.0185"/rev.   Depth of cut--1/8"

Cut in Skin

Average runout
1-213 M--0.034"
2-213 M--0.032"
3-213 M--0.047", 0.055"
4-213 M--0.019"

Average C = 50.5
Average K = (average C)$T^{0.43}L^{2.37}$ = 8.35
Average K' = 7.93
Average B.H.N., all sleeves = 305

Cut no.	Sleeve no.	B.H.N.* at cut	Speed, V ft./min.	Life, M min.	$VM^{0.1}=C$	Kw. input	K'=P/FDV
1	1	326	40.3	2.75	44.6	0.741	7.95
2	1	322	38.4	3.50	43.6	0.756	8.52
3	2	313	46.8	1.83	49.7	0.841	7.77
4	2	311	51.8	1.00	51.8	0.920	7.67
5	3	310	43.2	5.25	51.0	0.833	8.34
6	3	302	44.6	11.00	56.7	0.785	7.61
7	4	284	43.2	13.75	56.1	0.763	7.63

Cut in Clean Metal

Average C = 56.6
Average K' = 6.60

Average K = (average C)$T^{0.43}L^{2.37}$ = 9.36
Average B.H.N., all sleeves = 270

Cut no.	Sleeve no.	B.H.N.‡ at cut	Speed, V ft./min.	Life, M min.	$VM^{0.1}=C$	Kw. input	K'=P/FDV
1	1	275	50.0	1.42	51.7	0.790	6.83
2	1	271	49.3	3.33	55.6	0.965	8.45
3	1	263	49.3	8.50	61.0	0.728	6.38
4	2	278	48.7	5.25	57.5	0.744	6.60
5	2	268	49.9	9.00	62.1	0.714	6.18
6	3	270	52.6	1.33	54.2	0.665	5.46
7	3	268	51.4	2.25	55.6	0.672	5.66
8	4	277	50.7	1.75	53.6	0.678	5.77
9	4	271	45.1	13.00	58.3	0.838	8.04

* in skin
‡ at $\frac{1}{8}$" depth

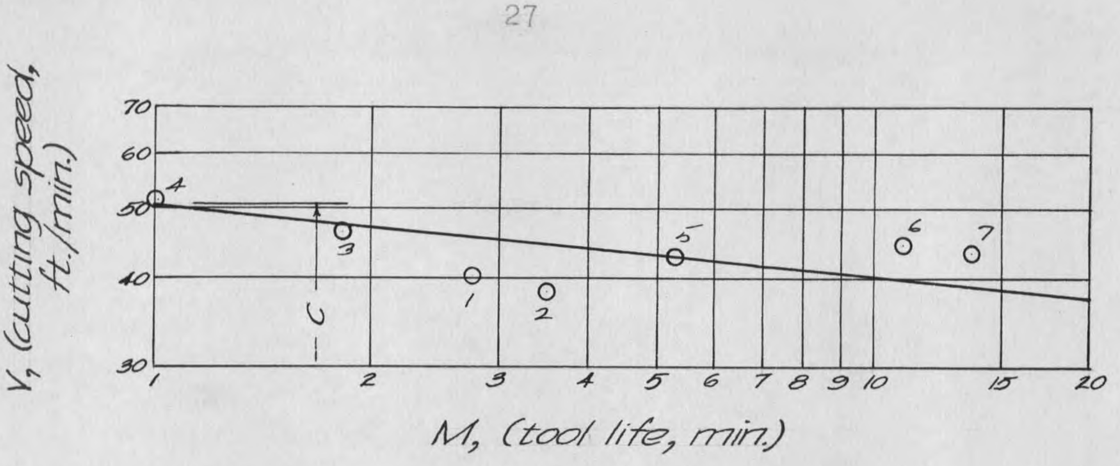

FIG. 11—CUT IN SKIN

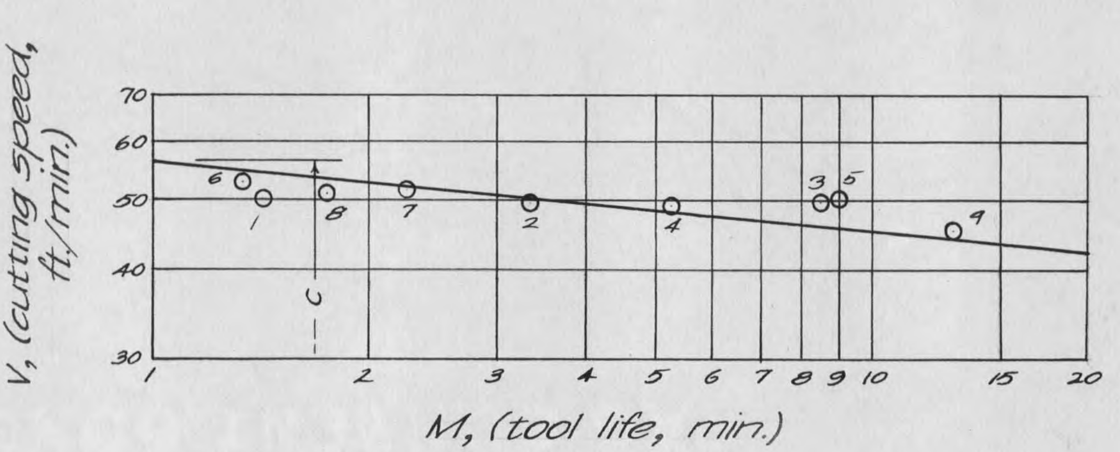

FIG. 12—CUT IN CLEAN METAL

Figs. 11 and 12--Effect of cutting speed on tool life for sleeves 213 M. Depth of cut 1/8", feed 0.0185"/rev., and $VM^{0.1} = C = 50.5$ (for skin) and 56.6 (for clean metal).

The small numbers refer to "Cut no." on Table III.

Results (Power input)

Fig. 13 shows the relationships between cutting speed and power input for all three compositions of iron. Unfortunately the power input and cutting speed both covered such small ranges that only a cluster of points on each graph was obtained. Since the plots (for tool life) on log-log paper were nearly horizontal, the desired range of tool life was covered with a corresponding very small range in speed (or power input). If the metal cut had been such that a higher value of the exponent in the formula, $VM^{0.1} = C$, had been obtained, the resulting range of cutting speed (or power input) would have been correspondingly larger.

Altho there is a straight-line relationship between cutting speed and power input, it is not apparent from the clustered points obtained from each set of data. But the fact that (0, 0) is a point on the "curve" and other factors to be discussed presently indicate that the "curve" must be a straight line (thru the origin).

The graph in fig. 13 was drawn in the following manner. The formula, $P = K'FDV$,[4] was used, where P is power input at the spindle in Kw., F is feed in inches/rev., D is depth of cut in inches, and K' is a constant depending on the metal cut. Multiplying both sides of the equation by <u>time</u>, (t), reveals that energy input, (Pt), is proportional (for given feed and depth of cut) to the weight of metal removed, (Vt = length of chip, which is proportional to the weight of metal removed). Since the preceding statement is obviously true, it becomes apparent that the original equation (without time) is also true (for given feed and depth of cut). For different feeds and depths of cut it seems reasonable that power input would be proportional to FD. The truth of that relationship would have to be determined by experiment. But whether or not that relationship holds over a wide range is of no importance to this investigation, because all D's (depths of cut) were the same and F (feed) was only slightly greater for 213 M.

Further evidence of the straight-line relationship is that power-input graphs in which a greater range of speed and power input is covered show points scattered over a fairly wide band, but, nevertheless, tracing out a well-defined straight line.

In the graph in fig. 13 the straight lines are drawn with average values of K's. The steeper the slope of the lines the more easily cut the metal is and the longer the tool lasts. Note that the clean-metal cuts (dotted lines) for each composition of iron have a steeper slope than the lines for the skin cuts. Comparison of the slopes of the lines for 213 M with the slopes for the other irons is misleading, because 213 M was cut with a heavier feed. But the discrepancy due to the different feed is eliminated in the constant, K', since the formula, P=K'FDV, accounts for differences in feed. Therefore, K' is a criterion of machinability (or tool life). Lesser values of K' indicate greater machinability. In fig. 14 the reciprocal of K' is shown on a bar graph in order to bring out graphically the differences in machinability between skin and clean metal and among the three compositions of iron. It is significant that this graph (from power input) tells about the same story of machinability as does the bar graph of K (from tool life). Both graphs are shown on the same sheet, (fig. 14).

The motor at all times operated on the early part of the efficiency curve, where the slope was large and the efficiency values not well-fixed. This fact partly accounts for the "flock-of-birds" arrangement of the points in fig. 13. The power input, P (in kw.), was taken as the power delivered to the spindle of the lathe and was corrected for variations in no-load power.

Below are the average values of K'. These values are simply averages and actually are not accurate to two decimal places.

for 250 base, skin cut--K' = 6.03;
for 250 base, cut in clean metal--K' = 5.80;

for 262, skin cut--K' = 6.55;
for 262, cut in clean metal--K' = 5.91;

for 213 M, skin cut--K' = 7.93;
for 213 M, cut in clean metal--K' = 6.60.

For a given feed, speed, and depth of cut K' is proportional to the power input. Since energy input is ultimately dissipated as heat, K' is also proportional to the amount of heat generated per second. For given cutting conditions the ratio of K' (for the skin) to K' (for the clean metal) is the ratio of the heats developed in each cut. The greater heat developed in skin cuts contributes to the shorter tool life in the skin.

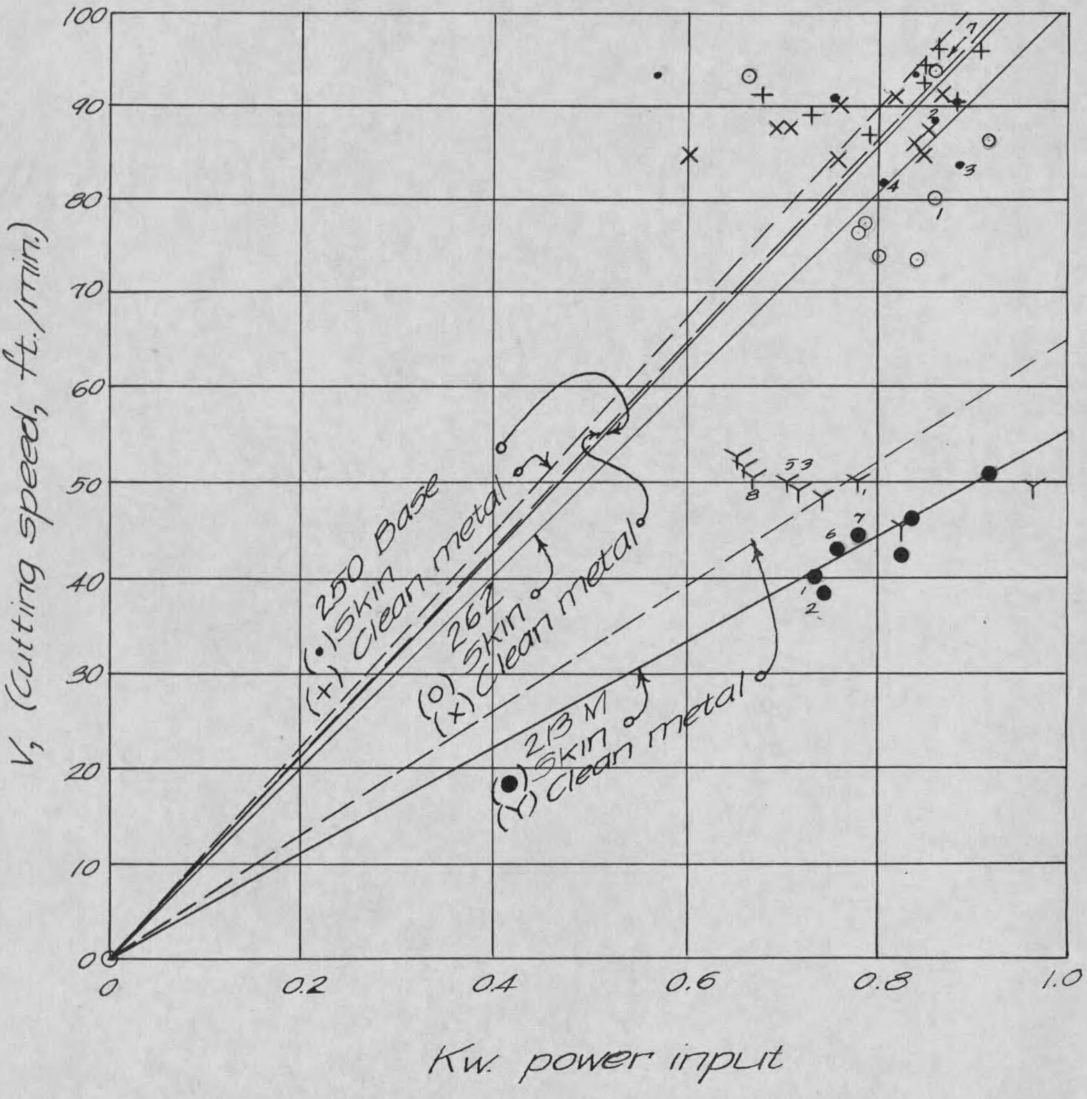

Fig. 13--Cutting speed against power input for all three irons.

The increasing slopes of the lines indicate increasing ease of cutting and, therefore, greater tool life. Note that for each iron the dotted line (for clean metal) is above the solid line (for the skin). The significance of the graph is explained in greater detail in the text. The straight lines are plots of the formula, $P = K'FDV$. The average values of K' (a criterion of machinability) are listed in the text.

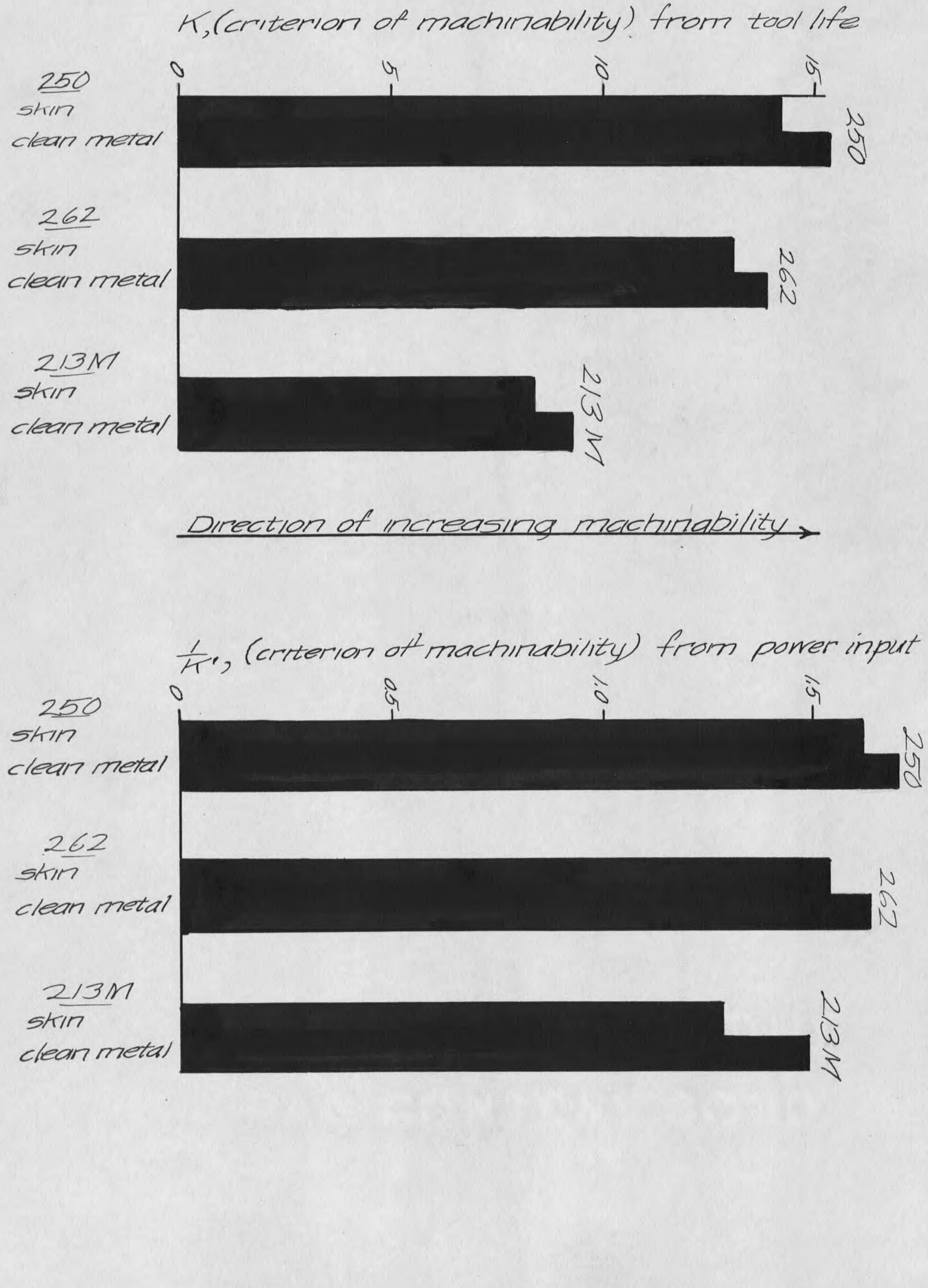

Fig. 14 – CRITERIA OF MACHINABILITY

Particular Points on the Graphs

Inspection of the tool-life graphs (figs. 7 thru 12) and of the power-input graph (fig. 13) reveals that for both a cut made in metal harder than the average should yield a point below the line--and vice versa. Inspection of a few particular points on the tool-life graphs should be instructive. In fig. 7 points 2, 3, and 4 are below the line. Table I reveals that skin cuts 2, 3, and 4 were made in the hardest metal. In fig. 9 point 1 is a considerable distance below the line. The explanation is found in Table II, which shows that cut number 1 was made in the hardest part of the sleeve. Point 7 directly above point 1 owes its position to the fact that cut number 7 was made in the softest part of the sleeve. Incidentally, cut number 3 was made in metal nearly as hard as that for number 1, but point 3 is above the line instead of below it. This fact indicates that a large number of points (say 50) per graph might very well show an exponent smaller than 0.1 to be desirable. Figs. 10 and 12 support this probability.

Fig. 11 has four very interesting points. Numbers 1 and 2 are considerably below the line, while 6 and 7 are considerably above it. At first glance the points seem to be too far from the line to be consistent. But Table III shows that cuts 1 and 2 were made in metal about 19 B.H.N units harder than the average, while cut 7 was made in metal 21 B.H.N. units softer than the average. Cut number 6 was also made in relatively soft metal. It should be noted that cuts 2 and 7 were the two singular tool failure discussed under Tool Failure. Probably because of some fault in the tool bit, cut 2 failed at the periphery of the work before failing at the nose (as the tool bits generally did). In other words, that failure was apparently too early. It can be seen in fig. 11 that if the tool life for point 2 had been longer, point 2 would have been closer to the curve. For cut 7 the tool failed without the formation of fuzz at the corner of the cut. In attempting to get fuzz it is very likely that cut 7 was run past failure, giving an over-long tool life. Fig. 11 shows that point 7 would have been closer to the line if the tool life had been less.

In fig. 12 points 1 and 8 are furthest below the line and, as shown in Table III, cuts 1 and 8 were made in the hardest metal. Points 3 and 5 are furthest above the line, cuts 3 and 5 being made in the softest metal.

Thus, it seems that the greatest discrepancies in the tool-life graphs can be accounted for by the rather large differences in hardness among many of the cuts.

If the points corresponding to the particular points (on the tool-life graphs) mentioned in the preceding paragraphs are located on the power-input graph (fig. 13), it will be found (except for two of the points) that all points above (or below) the line on the power-input graph correspond respectively to points above (or below) the line on the tool life graphs. Since, in either kind of graph, variations from the average hardness should shift the points in the same direction from the line (*above* for softer metal, *below* for harder metal), the particular points chosen are in good agreement on the two kinds of graphs. This "striking" confirmation is really fortuitous, because the impossibility of measuring power input accurately made many of the remaining points on the power-input graph contradictory as regards their location relative to the line. This "contradictoriness" makes any discussion of the location of particular points on the power-input graph almost meaningless. However, it is interesting to note that point 5 (for 250 skin, fig. 13) owes its position high above the line partly to the fact that cut 5 was made in relatively soft metal.

A formula such as that discussed on page 16 ($VM^{a'}H^{A}=C'$) could be obtained by running tool-life tests with feed, *speed*, and depth of cut constant. Such a formula would to a great extent "iron out" those discrepancies due to hardness variation.

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