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REPORT NO. 5

CUTTING SPEED VERSUS TOOL LIFE WHEN SHAPING TITANIUM WITH HIGH-SPEED-STEEL TOOLS

By

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Project M993

U. S. ARMY, ORDNANCE CORPS
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SUMMARY SHEET

I. Engineering Research Institute, University of Michigan, Ann Arbor, Michigan.

II. U. S. Army Ordnance Corps.

III. Project No. TB4-15.
Contract DA-20-018 ORD-11918, RAD No. ORDTB-1-12045.

IV. Report No. WAL 401/109-5.

V. Priority No. - None

VI. Investigation of machinability of titanium-base alloys.

VII. Object:

The object is to investigate the machinability of commercially pure titanium and three alloys of titanium.

VIII. Summary:

Tool life tests were run on a shaper with 18-4-1 high speed steel tools at a constant depth of cut of 0.050 inch and a feed of 0.010 inches per stroke. All cuts were made dry. The work materials studied were SAE 1045 hot-rolled steel, and titanium grades Ti 75A, RC 130B, and Ti 150A.

IX. Conclusions:

1. The machining of Ti 75A, RC 130B, and Ti 150A has been successfully performed with single-point tools in a shaper. The dependence of tool life on cutting speed is orderly and predictable.

2. The results obtained in these tests indicate a reasonable degree of similarity in performance as compared to the single-point tool turning of these materials.

3. The speeds used for a given tool life favor the Ti 75A over the Ti 150A and the RC 130B.

4. The slopes of the tool life lines obtained in these tests favor the alloy materials as compared to the commercially pure Ti 75A titanium.

5. Results of the cutting speed, tool life tests with HSS tools, under the conditions of cut used for this report, indicate the following speed ranges for a tool life (actual cutting time) of 1-40 minutes or total elapsed time of 2.6 to 195 minutes depending on length of stroke: Ti 75A, 76 to 160 fpm; Ti 150A, 60 to 79 fpm; RC 130B, 34 to 45 fpm.

6. Maximum rigidity in the machine, cutting tool, and work-holding device is a necessity in the successful machining of the titanium materials covered in this report.

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CUTTING SPEED VERSUS TOOL LIFE WHEN SHAPING TITANIUM WITH HIGH-SPEED-STEEL TOOLS

This report presents the results of the initial phases of the investigation of cutting titanium on a shaper. This part of the program was devoted to the development of test procedure and interpretation of results in the absence of any established precedent for machinability studies of this type. Thus, one of the initial objectives was to determine whether an orderly relationship exists between tool life and shaping speed such as has been established in turning, for example. It was determined that an orderly relationship does exist and that it can be used not only to obtain relative machinability ratings but also to evaluate various practices that can be used in shaping.

Only one combination of size of cut and tool shape was used with the 18-4-1 high-speed-steel tools in this initial investigation. Details are described elsewhere in this report. The four work materials used in the study were SAE 1045 steel (hot-rolled) and three grades of titanium, Ti 75A, RC 130B, and Ti 150A.

SUMMARY OF TEST RESULTS

Figure 1 presents the results of the cutting speed, tool life tests made with single-point high-speed-steel tools in a shaping operation. The results indicate that the cutting speed for a given tool life is higher for SAE 1045 steel than for any of the titanium materials included in this series of tests. Ti 75A closely approaches the steel, when considering the high side of the speed range shown by the cross-hatch lines, but from the standpoint of safe prediction the lower line should be used both in the case of this material and RC 130B.

The velocity in fpm is used as ordinate and the tool life in minutes is used as abscissa. The velocity (V_{max}) is the maximum velocity computed at the center of a shaper stroke, considering that each mechanical shaper cutting stroke has a continuous change in speed from 0 to maximum to 0. The maximum velocity used in this research is higher than the average velocity which is normally established in setting a job on a shaper in a plant. The maximum velocity is emphasized in these tests because of the great sensitivity of tool life to speed.

The tool life in minutes represents actual cutting time (contact time of tool with work piece). This actual time is 20.5 to 38.4 per cent of the total elapsed time in minutes, depending on the length of stroke for a given setup.

Table I shows the values of C (velocity for a 1-minute tool life), n (slope of the tool life curve, V_{60} (velocity for a 60-minute tool life), and per cent V_{60} (based on SAE 1045 steel).

TABLE I

CUTTING SPEED VERSUS TOOL LIFE
EQUATION $VT^n = C$

Material	C	n	V_{60}	Per Cent V_{60}
SAE 1045	175	.061	136	100
Ti 75A	164	.097	110	81
	*136	.1615	70	51.5
Ti 150A	79	.077	57.7	42.5
RC 130B	45.6	.044	38.2	28.2
	*39.4	.044	32.9	24.2

*Best values based on safe prediction when cut must be made through oxidized surface.

The results show that SAE 1045 can be cut at the highest speeds, with Ti 75A, Ti 150A, and RC 130B following in descending order. The value of n (slope of the curve, established by the tangent of the angle formed with the horizontal axis) favors the RC 130B, with SAE 1045, Ti 150A, and Ti 75A in descending order. The lower value of slope is normally accepted as a favorable performance characteristic.

The last column (per cent of V_{60} for steel) shows SAE 1045 steel at 100 per cent, Ti 75A at 51.5 per cent, Ti 150A at 42.5 per cent, and RC 130B at 24.2 per cent. This provides an index to the cutting speed relationships of the various titanium materials based on SAE 1045 steel.

ORIGINAL DATA AND COMPUTATIONS

Figure 2 shows the results of shaping a hot-rolled SAE 1045 steel with Firth Sterling (Blue Chip) 18-4-1 type HSS tools of the following signature: 0° back rake, 28° side rake, 6° end relief, 6° side relief, 6° end cutting edge angle, 15° side cutting edge angle, and 0.010-inch nose radius.

The data fit a straight line with a negative slope on logarithmic coordinates. The empirical equation $VT^n = C$ represents the straight line, where

V = maximum velocity,

T = tool life in minutes (actual cutting time),

n = slope of the curve, and

C = velocity for a 1-minute tool life.

This equation might be used in the following manner:

$$V_1 T_1^n = C = V_2 T_2^n = V_3 T_3^n = \ldots\ldots\ldots\ldots\ldots$$

Using data from the curve,

$$170 \times 1.7^n = 150 \times 13^n$$

$$\frac{170}{150} = \frac{13^n}{1.7^n} = \left(\frac{13}{1.7}\right)^n$$

$$1.132 = 7.65^n$$

$$\therefore \; n = .061 \,.$$

Since $$VT^n = C,$$

$$150 \times 13^{.061} = C = 150 \times 1.169 = 175$$

$\therefore$ C = 175 fpm for a 1-minute tool life and

$$V_{10}\ 10^{.061} = 175$$

$$V_{10} = \frac{175}{1.151} = 152 \text{ fpm for a 10-minute tool life.}$$

With an equation of this type, a velocity for any desired tool life or the tool life at any velocity may be determined.

These data were obtained under the following constant conditions:

Tool Shape - 0°,28°,6°,6°,6°,15°,0.010
Tool Holder - Armstrong, 0°, straight
Machine - Gould and Eberhardt, 32 inch, Industrial Shaper
Work feed - 0.010 inch per stroke
Depth of Cut - 0.050 inch
Cutting fluid - None (dry cut)
Size of work piece - 2 inches thick by 4 inches wide by 8 inches long. original 8 inch length remained constant.

Figure 3 shows data obtained under the same conditions of cut listed for Fig. 2 except that the work material was Ti 75A. The lower curve represents data obtained near the outside surface of the bar and the top curve represents the data secured near the center of the bar.

Using the equation $VT^n = C$, the following data are derived:

	C	n	V_{10}
near center of work	164	.097	131
near outside of work	136	.1615	93.8

Since a range of results is shown for this material, the area is cross-hatched to indicate a range of performance.

Figure 4 shows the results obtained for Ti 150A, which yielded the most consistent data of all the titanium materials used in this investigation. In cutting the Ti 150A there was a manifestation of tool failure on the shoulder of the work piece that was more pronounced than a similar indication on Ti 75A. It was very evident in this material that the failure of a tool would produce either a work-hardening or an impregnation of tool material on the shoulder of the work piece, with the result that a subsequent cut using a newly ground tool would experience an immediate failure if the affected material was not removed with a clean-up cut.

The equation $VT^n = C$ for the Ti 150A gives the following results:

$$V_1 T_1^n = V_2 T_2^n$$

$$\frac{V_1}{V_2} = \left(\frac{T_2}{T_1}\right)^n$$

$$\frac{80}{70} = \left(\frac{4.7}{.83}\right)^n$$

$$1.143 = 566^n$$

$$n = 0.77$$

$$70 \text{ fpm} \times 4.7^{.077} = C$$

$$70 \times 1.127 = C$$

$C = \underline{79}$ fpm for 1 minute tool life

$$V_{10}\, 10^{.077} = 79$$

$$V_{10} = \frac{79}{10^{.077}} = \frac{79}{1.194}$$

$V_{10} = \underline{66.1}$ fpm for 10 minute tool life

Figure 5 indicates a narrow range of cutting speeds for a given tool life and a spread of data between the curves that have been drawn to represent boundary conditions of the RC 130B cutting speed vs tool life curves. The data covers a range represented by parallel boundaries.

The equation $VT^n = C$ for RC 130B indicates the following results:

	C	n	V_{10}
high boundary	45.6	.044	41.3
low boundary	39.4	.044	35.6

The variation that occurs in V_{10} is of the order of a 16 per cent increase, whereas the variation in V_{10} for the Ti 75A is a 39 per cent increase.

TEST CONDITIONS

Machine Tool

The machine used in these tests is a 32 inch Gould and Eberhardt Industrial Shaper, shown in Fig 6. It is considered a heavy-duty type of machine.

In the preliminary work done with the titanium work materials, it was found necessary to check the tightness of all gibs, ways, and clamps. Rigidity in the machine setup is of utmost importance in the successful machining of these materials. In the early stages of this investigation, considerable difficulty was encountered in machining the 130B and 150A, as compared to the cutting of most other materials, i.e., steel, cast iron, etc. A conditioning of the machine to a level of reasonable tightness and reduction of tool overhang aided in eliminating the difficulties encountered in the preliminary tests.

Cutting Tools

The tools used in these tests were Firth Sterling (Blue Chip) 18-4-1 high-speed-steel 1/2 inch square, tool bits.

The grinding of the tools was performed on a Cincinnati No. 2 tool and cutter grinder with 38A 46J 5VBE wheels for roughing cuts and subsequently finished on a Pratt and Whitney Keller-cutter grinder equipped with a special tool-holding fixture.

The signature of 0° back rake, 28° side rake, 6° end relief, 6° side relief, 6° end cutting edge angle, 15° side cutting edge angle, and 0.010-inch nose radius was selected on the basis of results obtained from the single-point tool tests in turning.

Derivation of Maximum Velocity

Figure 7 shows a diagram of the crank-arm and bull gear mechanism in the shaper and the critical dimensions affecting the velocity at the middle of the stroke. The maximum velocity was derived as follows:

For stroke lengths of 9 to 16 inches used in tests:

$H = 18.75$ inches (measured value).

L = 34.8 inches (measured value).

D = diameter of contact circle of crank arm and bull gear.

ϕ = angle defined by centerline and position of crank arm for a given length of stroke.

$$\sin \phi = \frac{S/2}{L} = \frac{S}{2L} ;$$

also

$$\therefore \frac{S}{2L} = \frac{D}{2H} \text{ or } \frac{S}{L} = \frac{D}{2H}.$$

$$V_1 = \frac{\pi Dn}{12}, \text{ where } n = \text{rpm of bull gear (measured value),}$$

and

$$V_{max} = V_1 \frac{L}{H + D/2} \text{ fpm at center of stroke.}$$

The stroke of the ram carrying the tool head was positioned in each setup, so the cut was exactly centered on the work.

Determination of Cutting Time

A Sanborn 2-channel recording oscillograph with a time recording attachment was used to determine the precise amount of time of tool contact in ratio to the total time per stroke. An electrical circuit was made to react to tool contact by insulating the work piece from the vise and connecting lead-in wires to the tool and the work piece. A recording of time in cycles per second was indicated for the total stroke and the cutting phase of the stroke. It was found that a range of 20.5 per cent to 38.4 per cent, representing the ratio of contact time to total time per stroke, could be used in determining the actual cutting time in strokes varying in length from 9 to 16 inches on a piece of metal 8 inches long.

Test Procedure

All work pieces were squared to the following dimensions prior to testing: 2 inches thick by 4 inches wide by 8 inches long. All machine setup conditions remained constant during the tests except the cutting speed. Tool failure was determined by recording tool wear, as measured on a Binocular microscope equipped with a Filar lens. The measurements of tool wear were made at given intervals of time until the wear land was approximately 0.030 inch wide. Under this condition of 0.030-inch flank wear, the useful tool life expired. A flank wear of 0.030 inch is generally accepted as a practical limit for tool wear where total breakdown failure does not occur at a smaller value of tool wear.

The position and overhang of the tool in the tool holder was carefully gaged after each inspection in the microscope.

Time of the tests was measured by a stop watch to an accuracy of 1/100 minute.

CONCLUSIONS

1. The machining of Ti 75A, RC 130B, and Ti 150A has been successfully performed with single-point tools in a shaper. The dependence of tool life on cutting speed is orderly and predictable.

2. The results obtained in these tests indicate a reasonable degree of similarity in performance as compared to the single-point tool turning of these materials.

3. The speeds used for a given tool life favor the Ti 75A over the Ti 150A and the RC 130B.

4. The slopes of the tool life lines obtained in these tests favor the alloy materials as compared to the commercially pure Ti 75A titanium.

5. Results of the cutting speed, tool life tests with HSS tools, under the conditions of cut used for this report, indicate the following speed ranges for a tool life (actual cutting time) of 1-40 minutes or total elapsed time of 2.6 to 195 minutes depending on length of stroke:

Ti 75A, 76 to 160 fpm

Ti 150A, 60 to 79 fpm

RC 130B, 34 to 45 fpm.

6. Maximum rigidity in the machine, cutting tool, and work-holding device is a necessity in the successful machining of the titanium materials covered in this report.

32" G & E SHAPER

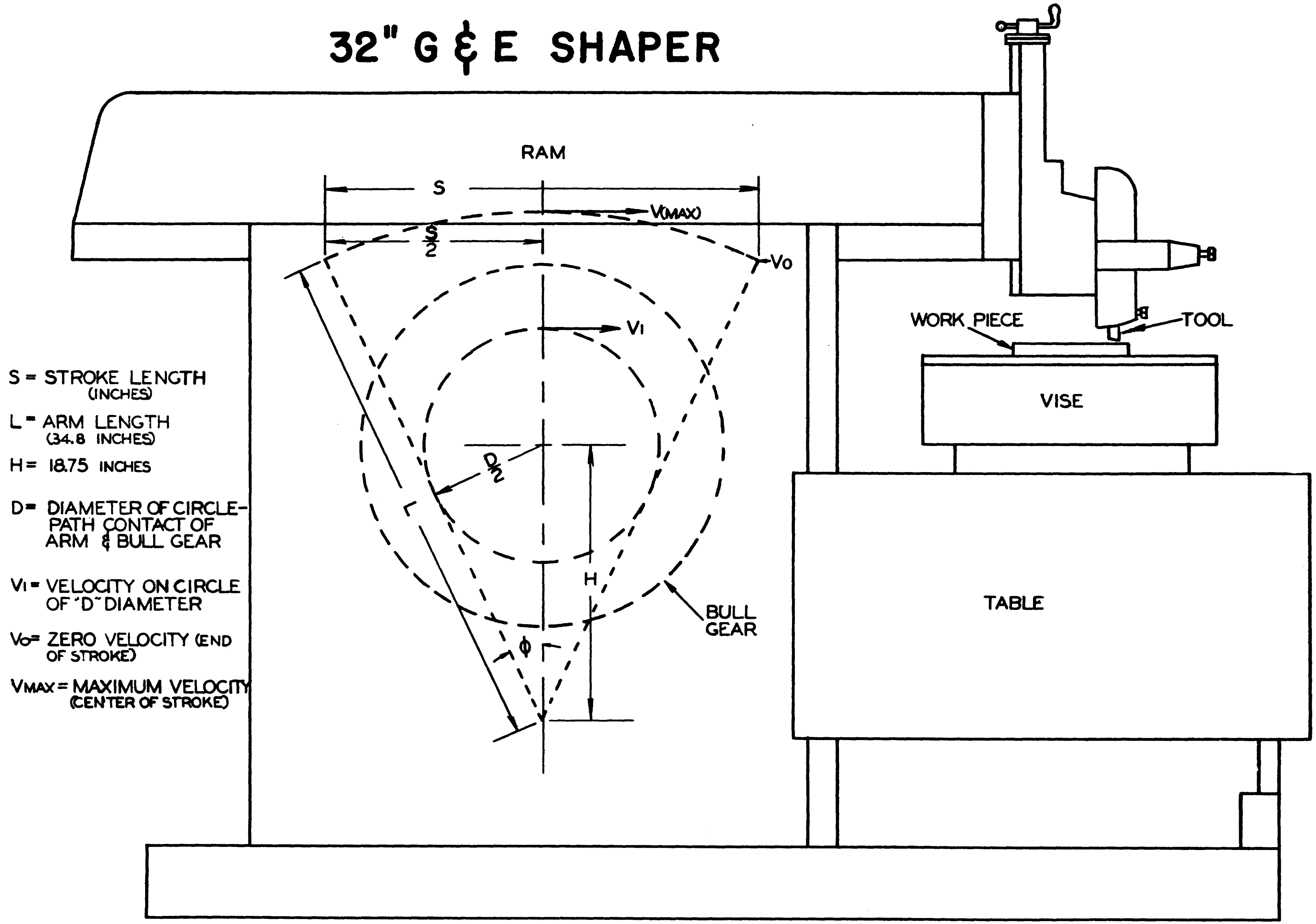

FIG. 7

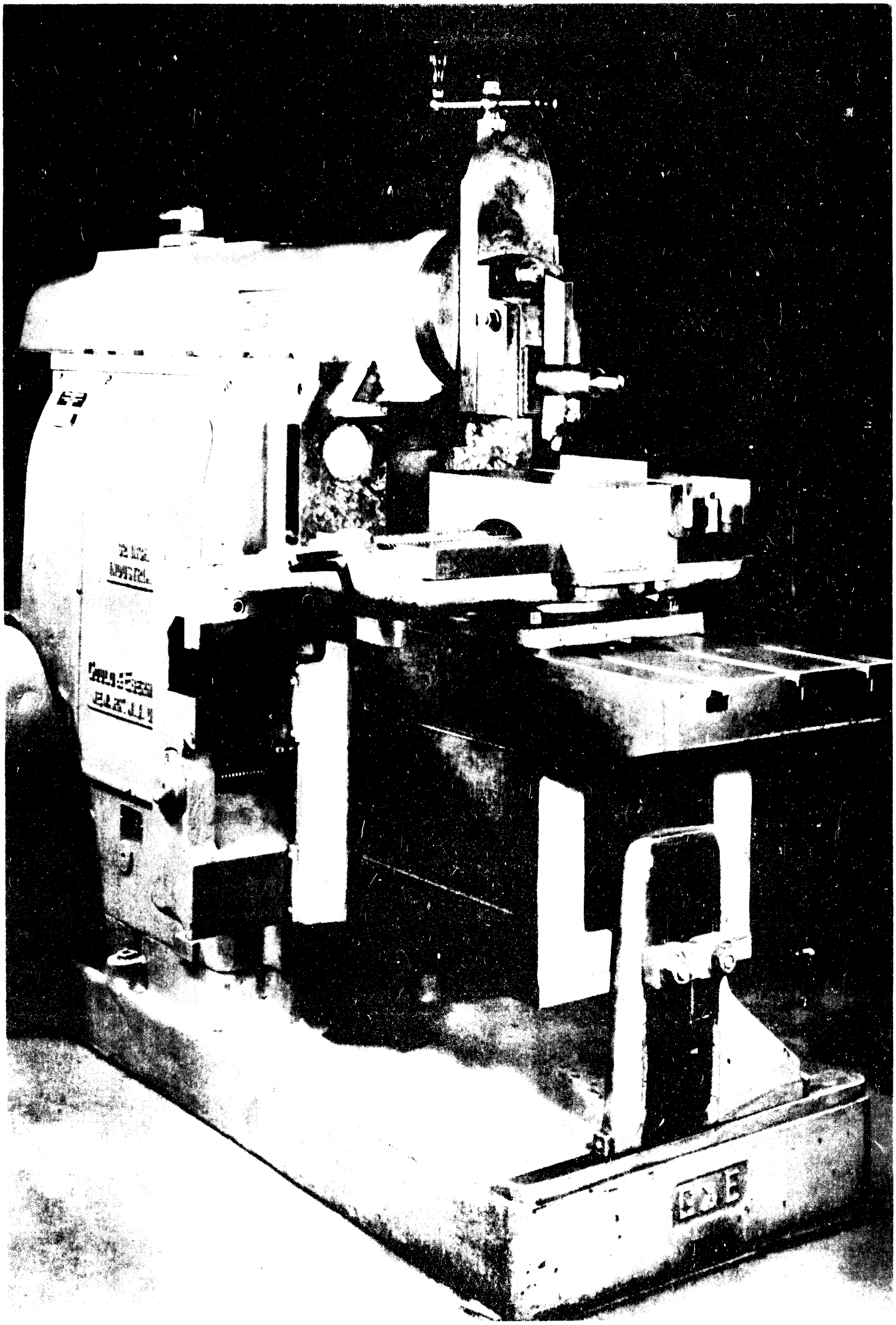

FIG.6

SHAPING

CUTTING SPEED — TOOL LIFE

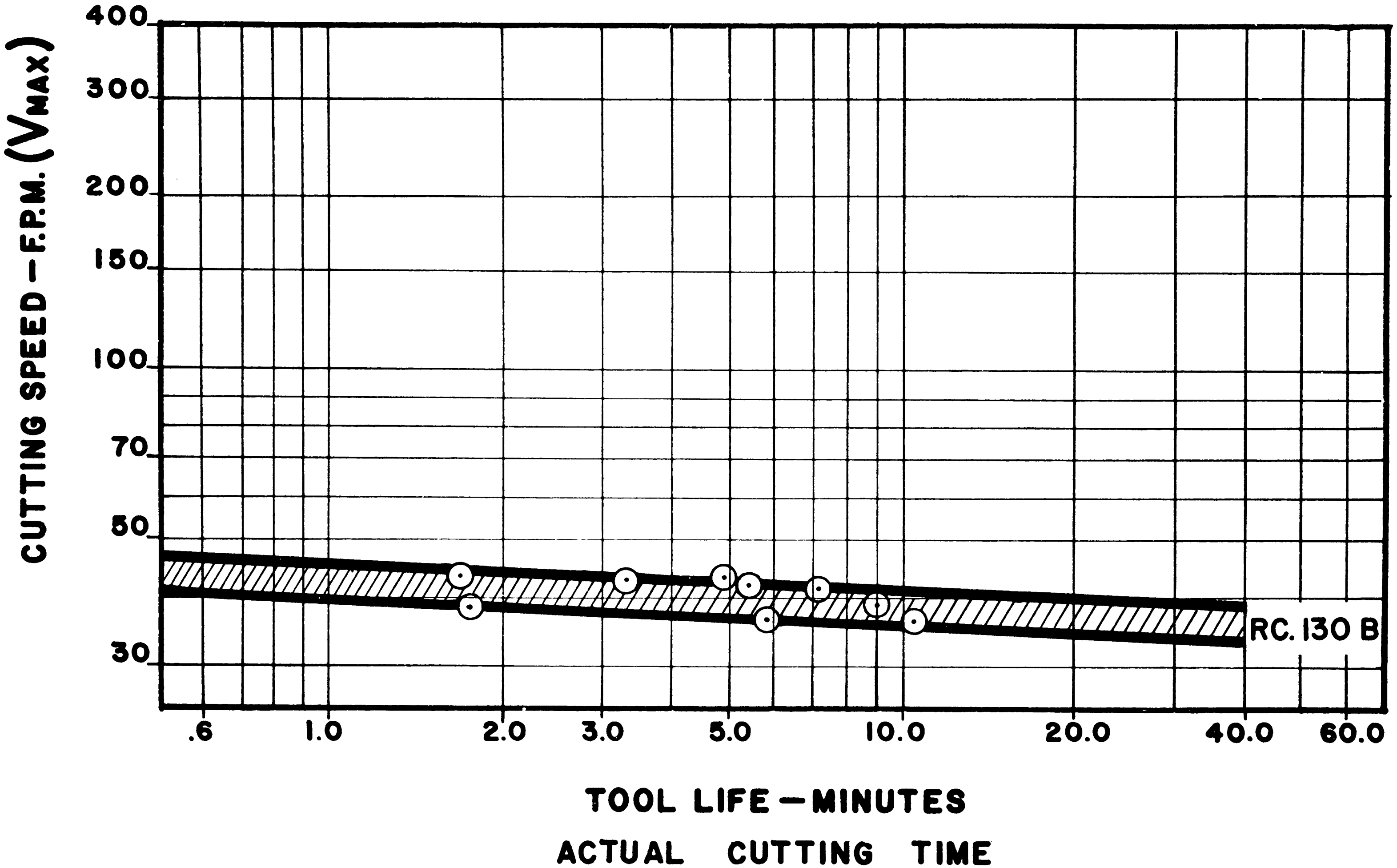

FIG. 5

SHAPING
CUTTING SPEED — TOOL LIFE

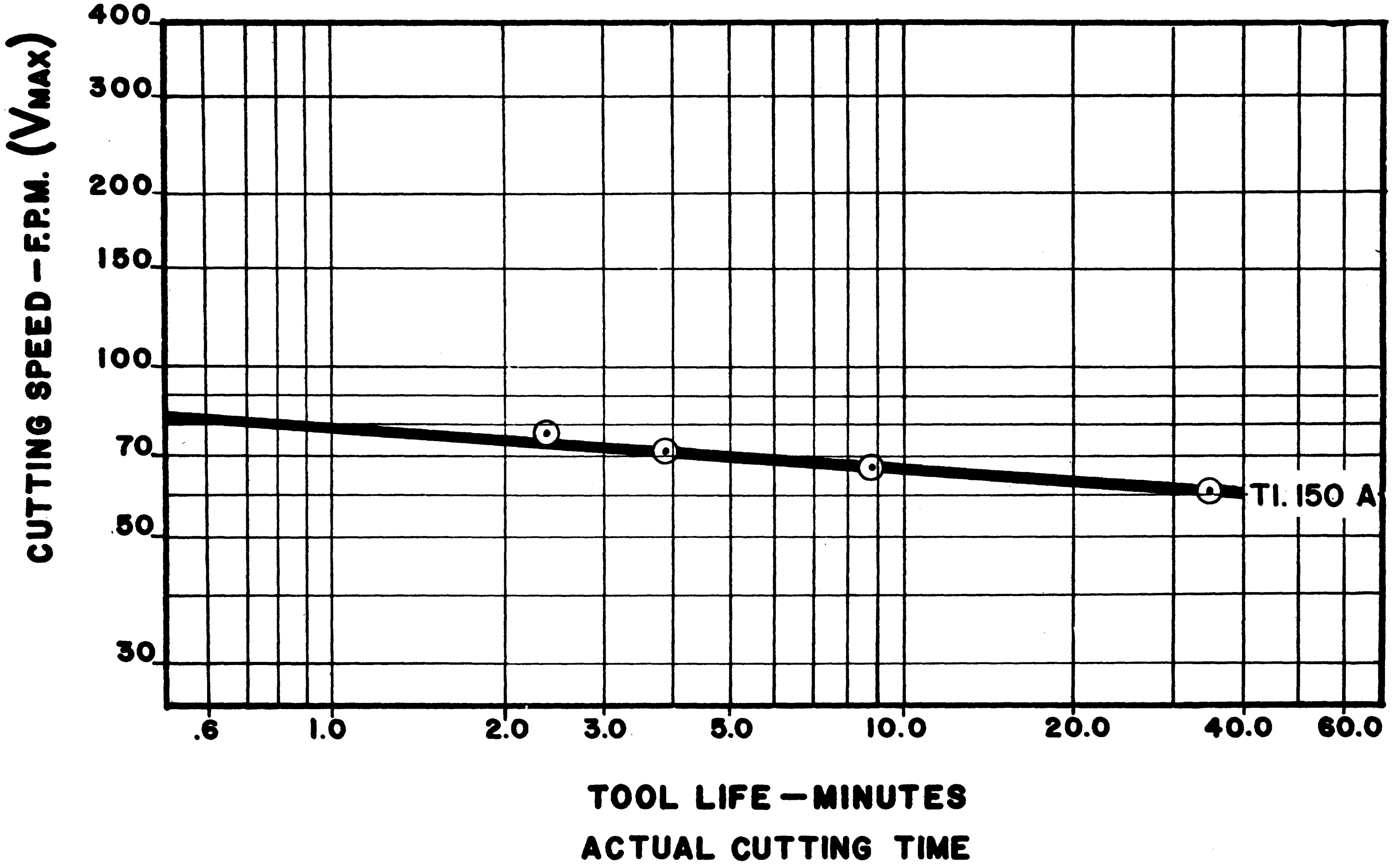

FIG. 4

SHAPING
CUTTING SPEED — TOOL LIFE

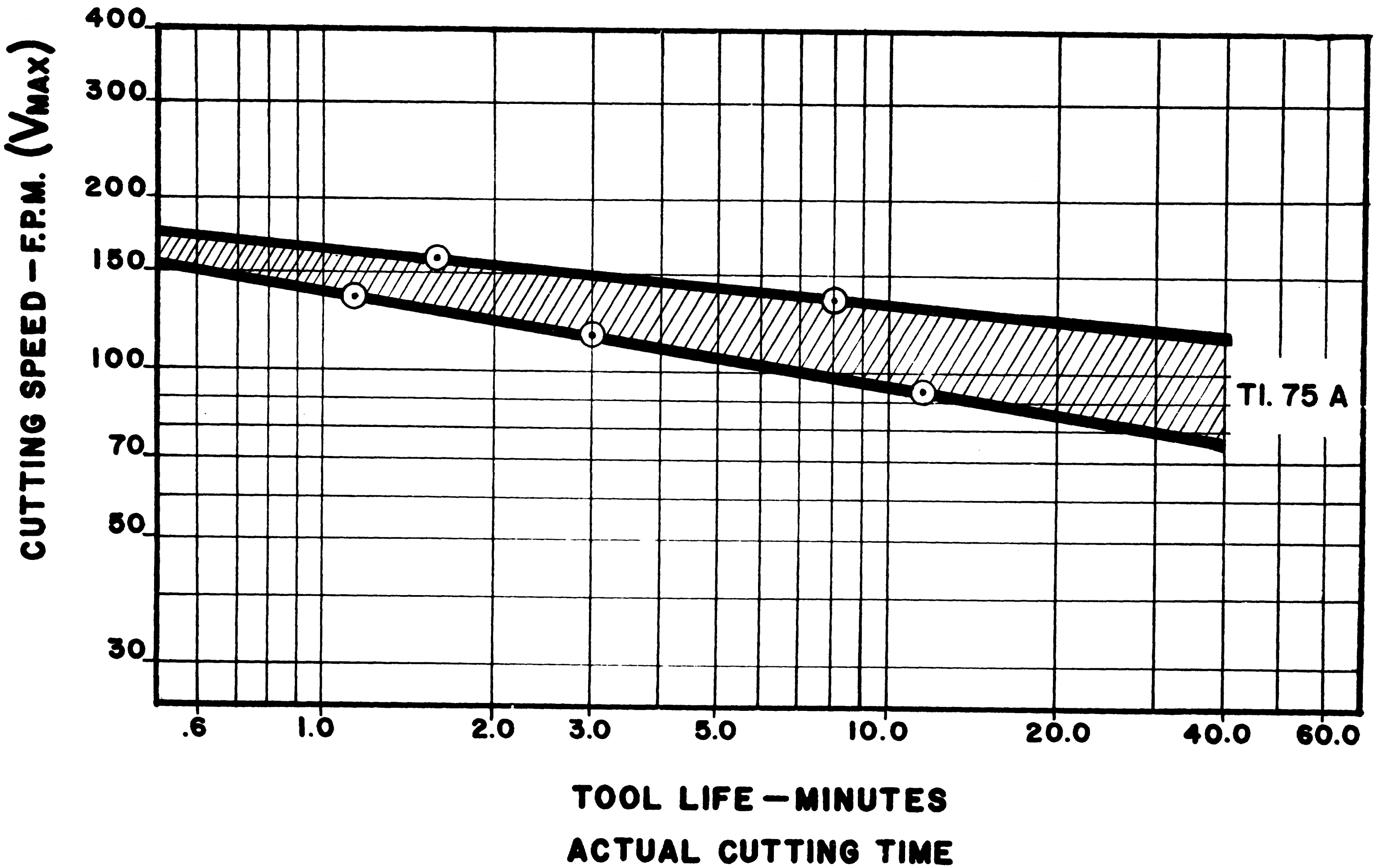

FIG. 3

SHAPING
CUTTING SPEED — TOOL LIFE

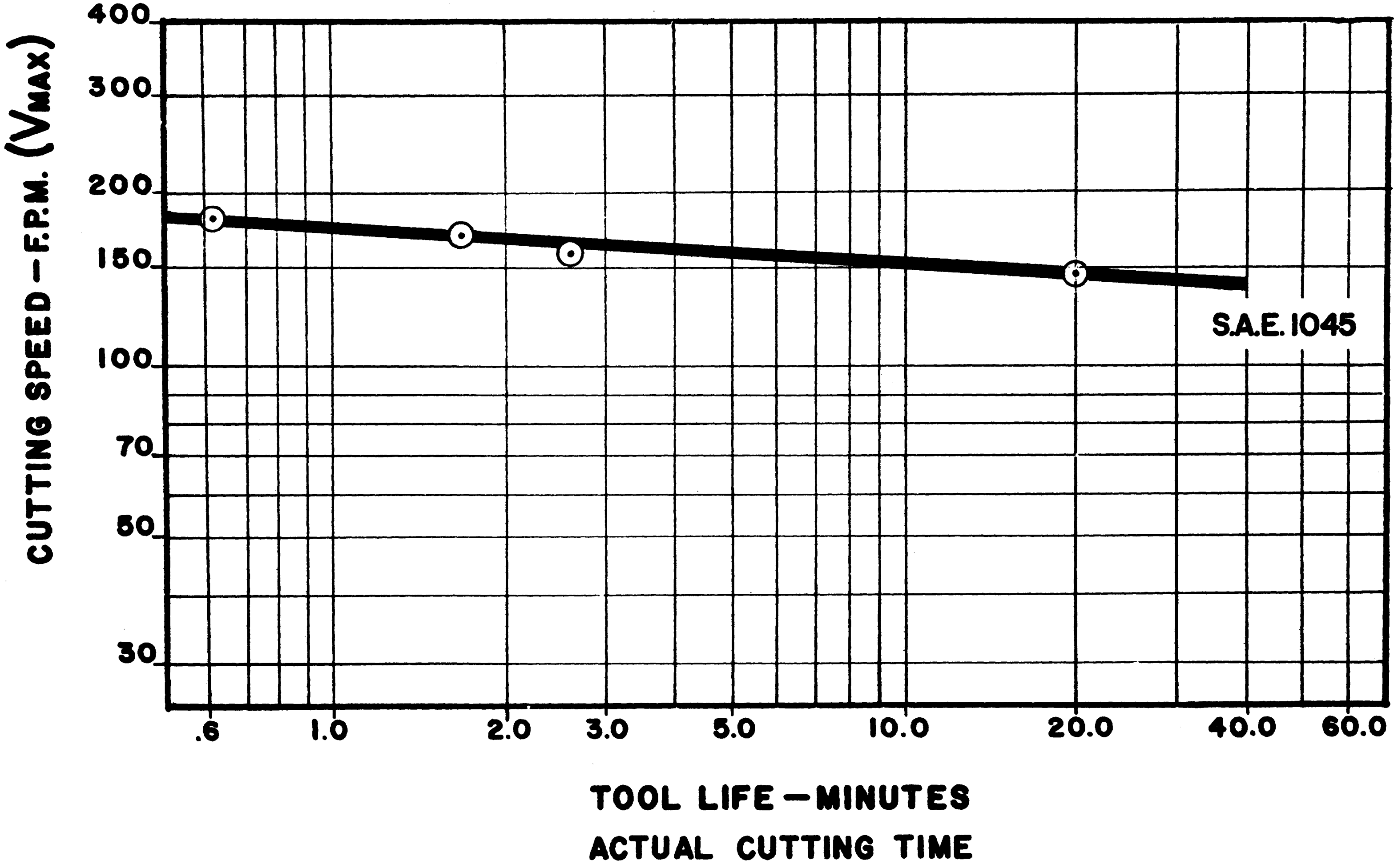

FIG. 2

SHAPING
CUTTING SPEED — TOOL LIFE

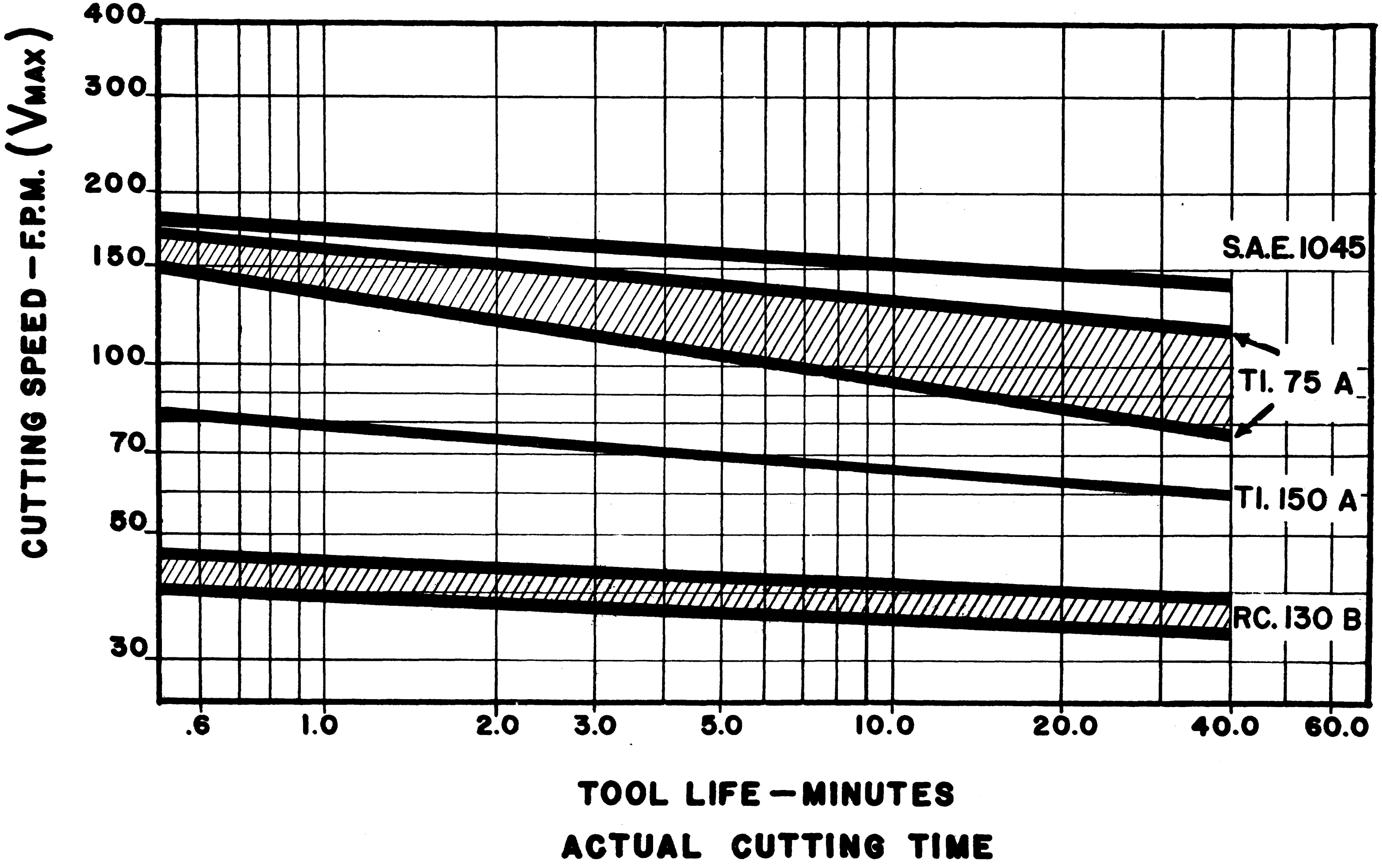

FIG. 1

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