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ANN ARBOR

REPORT NO. 4

EFFECT OF SIZE OF CUT ON TOOL LIFE IN TURNING TITANIUM

By

L. V. COLWELL

Project M993

U. S. ARMY, ORDNANCE CORPS
CONTRACT NO. DA-20-018-ORD-11918

January, 1953

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 401/109-4.

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:

Cutting speed, tool life curves were obtained with 18-4-1 high-speed steel tools at feeds of 0.003, 0.006, and 0.012 ipr. with a depth of 0.020, 0.050, 0.100, and 0.150 inch at a constant feed of 0.006 ipr. All tests were run dry. The tool shape was 0,28,6,6,6,15,0.010 for the Type 304 stainless steel and 0,32,6,6,6,15,0.010 for SAE 1045 hot-rolled steel, grade Ti 150A titanium and grade RC 130 titanium.

IX. Conclusions:

(a) The interrelationships of cutting speed, tool life, feed rate, and depth of cut for optimum tool rake angle are summarized in the exponential equations of Table V.

(b) The sensitivity of cutting speed to changes in feed, depth of cut, and tool life is less than linear.

(c) The sensitivity of the cutting speed is greatest for changes in feed rate, and least for changes in tool life.

(d) Conversely, the tool life is most sensitive to changes in cutting speed and least sensitive to changes in depth of cut.

(e) The cutting speeds for optimum rake angle should be reduced 20-25 per cent for rake angles in the range of 0 to 15 degrees (see Progress Report No. 2 for support of this conclusion).

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REPORT NO. 4

EFFECT OF SIZE OF CUT ON TOOL LIFE IN TURNING TITANIUM

This report concerns the effect of size of cut when turning titanium with high-speed-steel tools. This phase of the program, i.e., the effect of size of cut, is a continuation of the larger program discussed in Progress Report No. 3 on the effect of tool side rake angle. As before, tool life curves were obtained for cutting conditions that were held constant except for the cutting speed. Curves of this type were obtained for a range of both feed rates and depths of cut. These curves constitute the basis for evaluating the effect of size of cut for grades Ti 150A and RC 130B titanium in addition to SAE 1045 hot-rolled steel and Type 304 austenitic stainless steel.

TEST CONDITIONS

The cutting tools were 18-4-1 high-speed steel as provided under the trade name of "Blue Chip" by the Firth-Sterling Steel Company. They were in the form of 1/2-inch square by 4-inch long tool bits ground to the ASA signature 0,28,6,6,6,15,0.010 for the Type 304 stainless and 0,32,6,6,6,15,0.010 for the three other materials. It will be noted that the tools were the same except for the side rake angle; this angle was selected as the optimum for each work material as shown by the results of Progress Report No. 3.

In the variable-feed series of tests the depth of cut was held constant at 0.050 inch and the feed was held constant at 0.006 ipr during the variable-depth series. Tool life curves were obtained for feeds of 0.003, 0.006, and 0.012 ipr for each of the four work materials. The combination of 0.006-ipr feed and 0.050-inch depth was used in the series of tests for Report No. 3, but it was repeated for this series because of variation in properties of the titanium from one test bar to another.

For the same reason, the 0.050-inch depth with 0.006-ipr feed was repeated in the variable-depth series. The four depths of cut included in this series were 0.020, 0.050, 0.0100, and 0.150 inch.

TEST RESULTS

Effect of Feed Rate

Results of the variable-feed series of tests are summarized in Figs. 1-8 inclusive. The cutting speed for a 10-minute tool life (V_{10}) is plotted as a function of feed rate (f) for each of the four work materials in Figs. 1-4 inclusive. Similarly, the cutting speed for a 60-minute tool life (V_{60}) is plotted as a function of the feed rate in Figs. 5-8 inclusive.

Since all data points are well represented by straight lines on the logarithmic coordinates, the results for each work material can be represented by an equation of the type $V_x = Kf^a$. A summary of the equations of V_{10} as a function of feed rate is given in Table I.

TABLE I

V_{10} VERSUS FEED

Work Material	$*V_{10} = K_{10}f^a$		When f = .010 ipr	
	K_{10}	a	V10, fpm	V10, %
RC 130B titanium	2.51	-.608	41.5	29.3
Ti 150A titanium	3.13	-.625	55.7	39.4
304 stainless	11.85	-.437	88.7	62.6
SAE 1045 steel	7.95	-.625	141.5	100

* Depth of cut is constant at 0.050 inch

A similar summary for V_{60} as a function of feed rate is given in Table II.

TABLE II

V_{60} VERSUS FEED

Work Material	$^*V_{60} = K_{60}f^a$		When f = .010 ipr	
	K_{60}	a	V_{60}, fpm	V_{60}, %
RC 130B titanium	2.36	-.601	37.8	29.6
Ti 150A titanium	2.73	-.619	47.0	36.7
304 stainless	11.35	-.415	77.0	60
SAE 1045 steel	7.1	-.628	128.0	100

* Depth of cut = 0.050 inch

<u>Effect of Depth of Cut</u>

The cutting speed for constant tool life is also an exponential function of depth of cut. Thus the results of the variable-depth tests plotted in Figs. 9-16 inclusive are summarized in Tables III and IV.

TABLE III

V_{10} VERSUS DEPTH OF CUT

Work Material	$^*V_{10} = C_{10}d^b$		When d = .100 in.	
	C_{10}	b	V_{10}, fpm	V_{10}, %
RC 130B titanium	44.2	-.117	58	30
Ti 150A titanium	50.5	-.172	75	38.4
304 stainless	112.3	-.067	131	67
SAE 1045 steel	153.0	-.104	195	100

* Constant feed = 0.006 ipr

TABLE IV

V_{60} VERSUS DEPTH OF CUT

Work Material	$^*V_{60} = C_{60}d^b$		When d = .100 in.	
	C_{60}	b	V_{60}, fpm	V_{60}, %
RC 130B titanium	40.6	-.094	52.5	30.6
Ti 150A titanium	43.0	-.162	62.5	36.4
304 stainless	98.0	-.066	114.0	66.0
SAE 1045 steel	136.0	-.102	172.0	100

* Constant feed = 0.006 ipr

Combined Effect of Feed and Depth

The empirical equations contained in Tables I to IV inclusive can be combined and further altered to include tool life as a variable. Any such equation can represent only average performance for the particular material for which it was obtained, since it does not include the mechanical properties as variables. These equations are summarized for the four work materials in Table V.

TABLE V

EQUATIONS RELATING CUTTING SPEED, FEED, DEPTH AND TOOL LIFE

Work Material	Equation	For f = 0.010 ipr; d = .100	
		V_{60}, fpm	V_{60}, %
RC 130B titanium	$V = 1.42\ f^{-.60}\ d^{-.10}\ T^{-.075}$	38.6	30.9
Ti 150A titanium	$V = 1.18\ f^{-.62}\ d^{-.17}\ T^{-.100}$	45.6	36.5
304 stainless	$V = 7.52\ f^{-.43}\ d^{-.07}\ T^{-.085}$	91	72.9
SAE 1045 steel	$V = 4.25\ f^{-.63}\ d^{-.10}\ T^{-.061}$	125	100

The exponents of the variables are averages of those obtained from several groups of laboratory tests and although they will not predict cutting speed for tool life with a high degree of precision where the properties of the work materials vary they can at least be depended on to suggest a workable cutting speed for any particular size of cut. The exponents are a measure of the sensitivity of the cutting speed to changes in the corresponding variables.

For example, if the depth of cut and tool life are to be held constant and the feed is to be doubled, the speed will not need to be reduced to one-half its original value; instead it will be reduced to $2^{-.6}$ or 0.66 times for the RC 130B titanium. Similarly, if the depth is doubled, everything else being held constant, the cutting speed must be reduced only to $2^{-.1}$ or 0.93 times its original value. Thus the larger the absolute value of the exponent, the greater the sensitivity of cutting speed to changes in the variable.

It should be recalled that the equations given in Table V are applicable only to the optimum rake angles previously specified. If tools with rake angles in the range of 0 to 15 degrees are to be used, the cutting speeds calculated from the equations of Table V should be reduced from 20 to 25 per cent. It may be necessary to use smaller rake angles on interrupted cuts such as occur in milling, shaping, broaching, etc., in order to prevent even superficial crumbling of the cutting edge.

ORIGINAL DATA

All original data from which the specific effects of feed and depth of cut were evaluated are plotted as cutting speed, tool life curves on logarithmic coordinates in Figs. 17 to 44 inclusive.

CONCLUSIONS

(a) The interrelationships of cutting speed, tool life, feed rate, and depth of cut for optimum tool rake angle are summarized in the exponential equations of Table V.

(b) The sensitivity of cutting speed to changes in feed, depth of cut and tool life is less than linear.

(c) The sensitivity of the cutting speed is greatest for changes in feed rate, and least for changes in tool life.

(d) Conversely, the tool life is most sensitive to changes in cutting speed and least sensitive to changes in depth of cut.

(e) The cutting speeds for optimum rake angle should be reduced 20-25 per cent for rake angles in the range of 0 to 15 degrees (see Progress Report No. 2 for support of this conclusion).

CUTTING SPEED - FEED

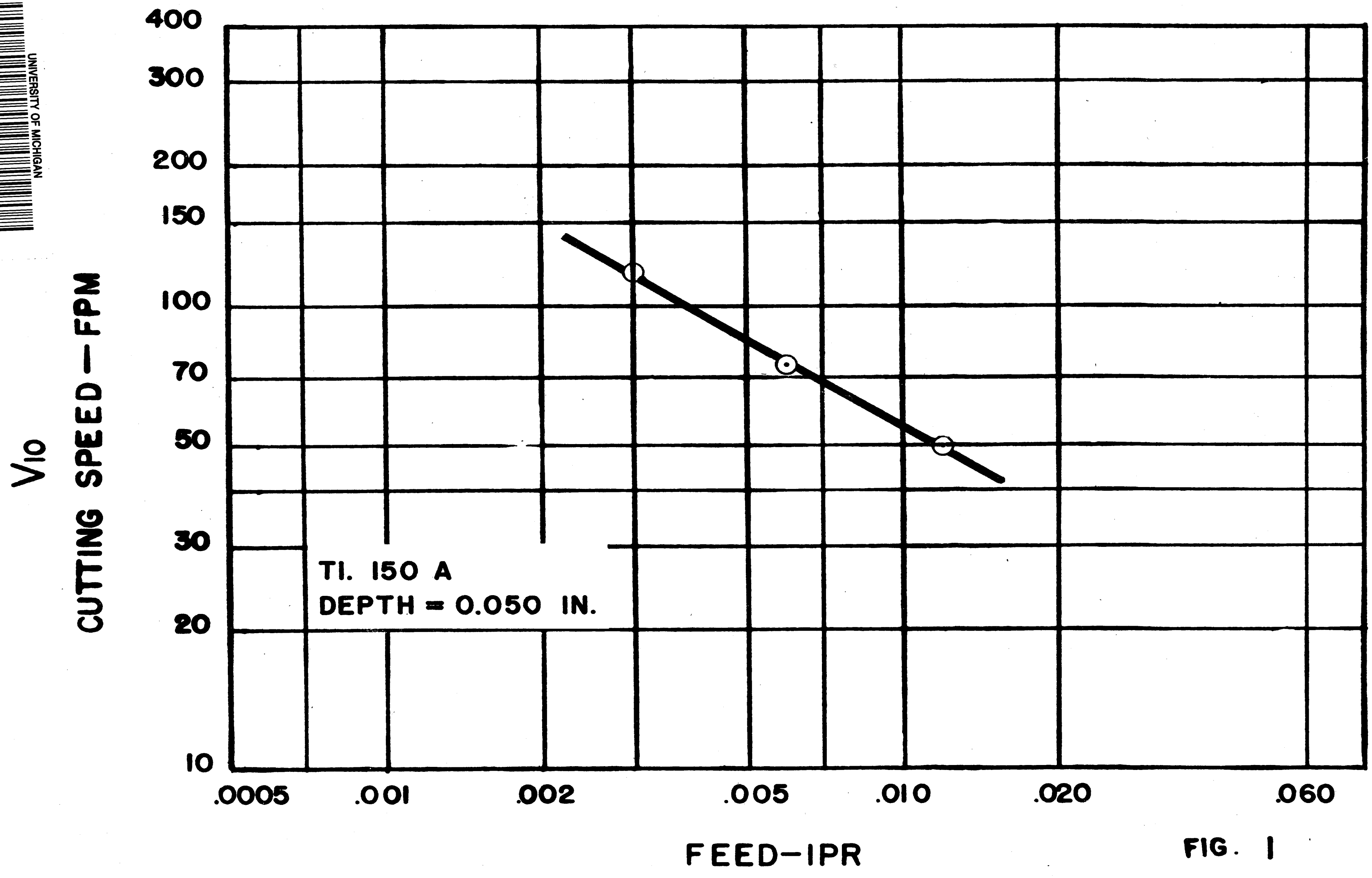


FIG. 1

CUTTING SPEED - FEED

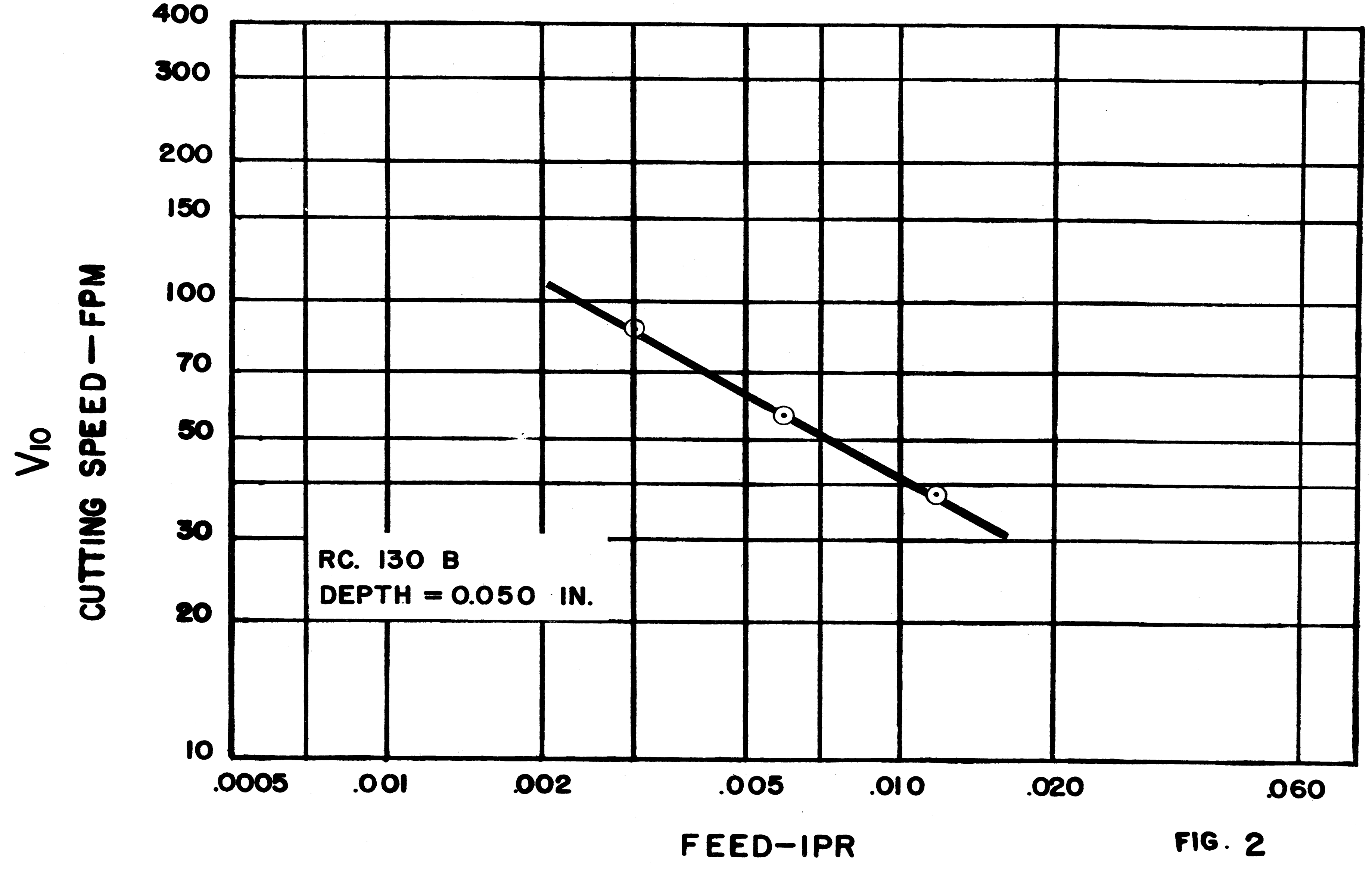


FIG. 2

CUTTING SPEED - FEED

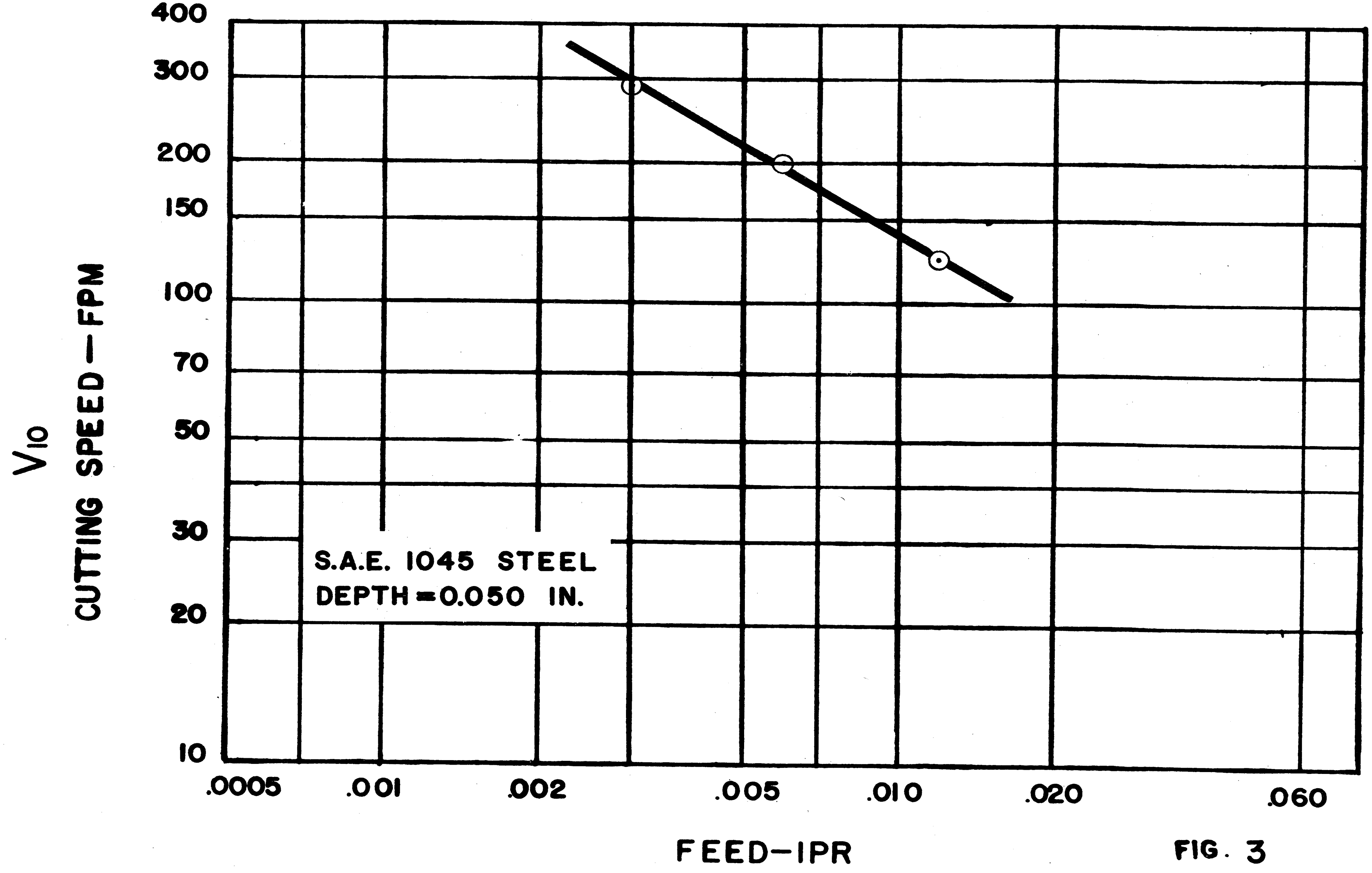


FIG. 3

CUTTING SPEED - FEED

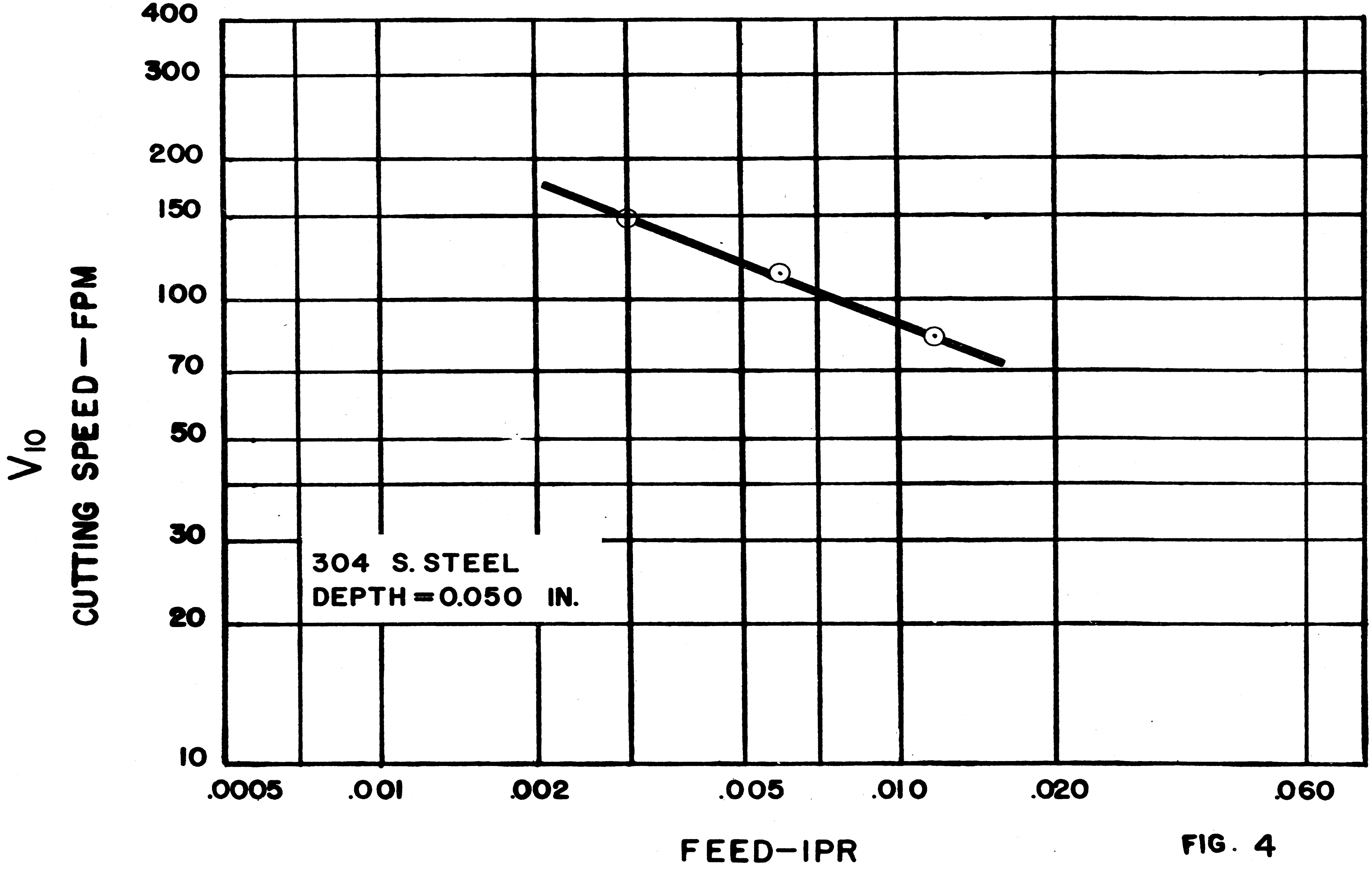


FIG. 4

CUTTING SPEED - FEED

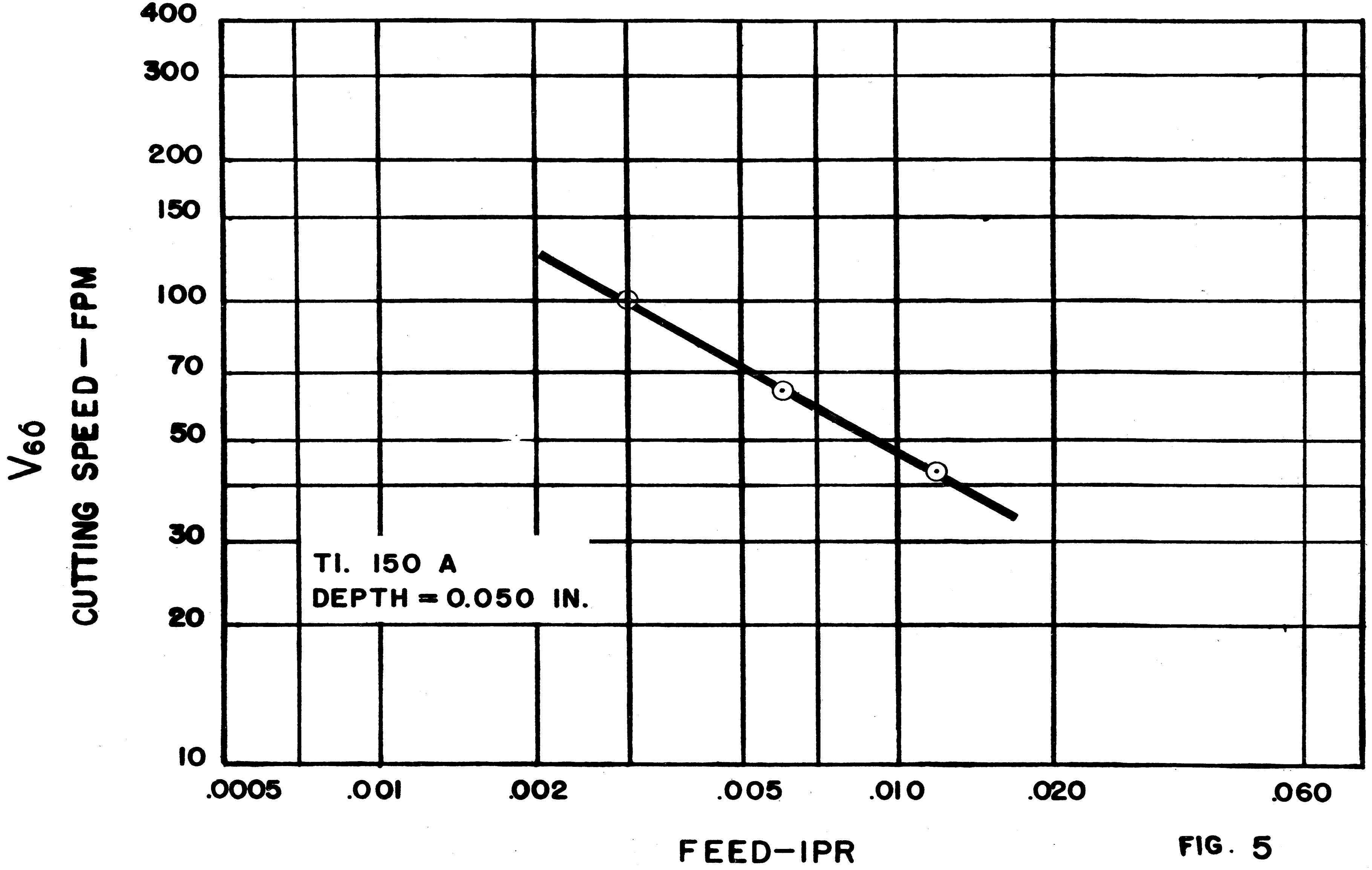


FIG. 5

CUTTING SPEED - FEED

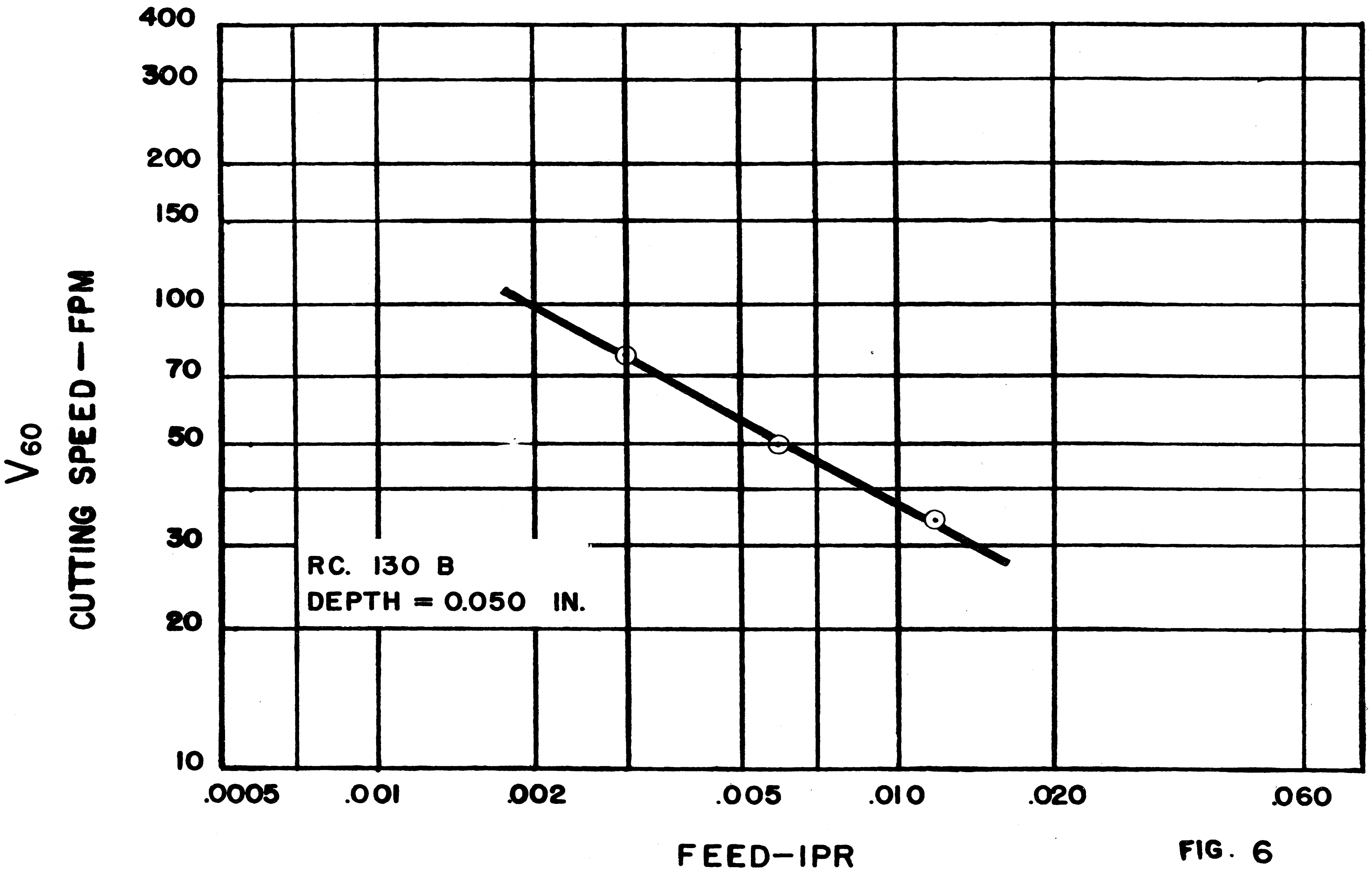


FIG. 6

CUTTING SPEED - FEED

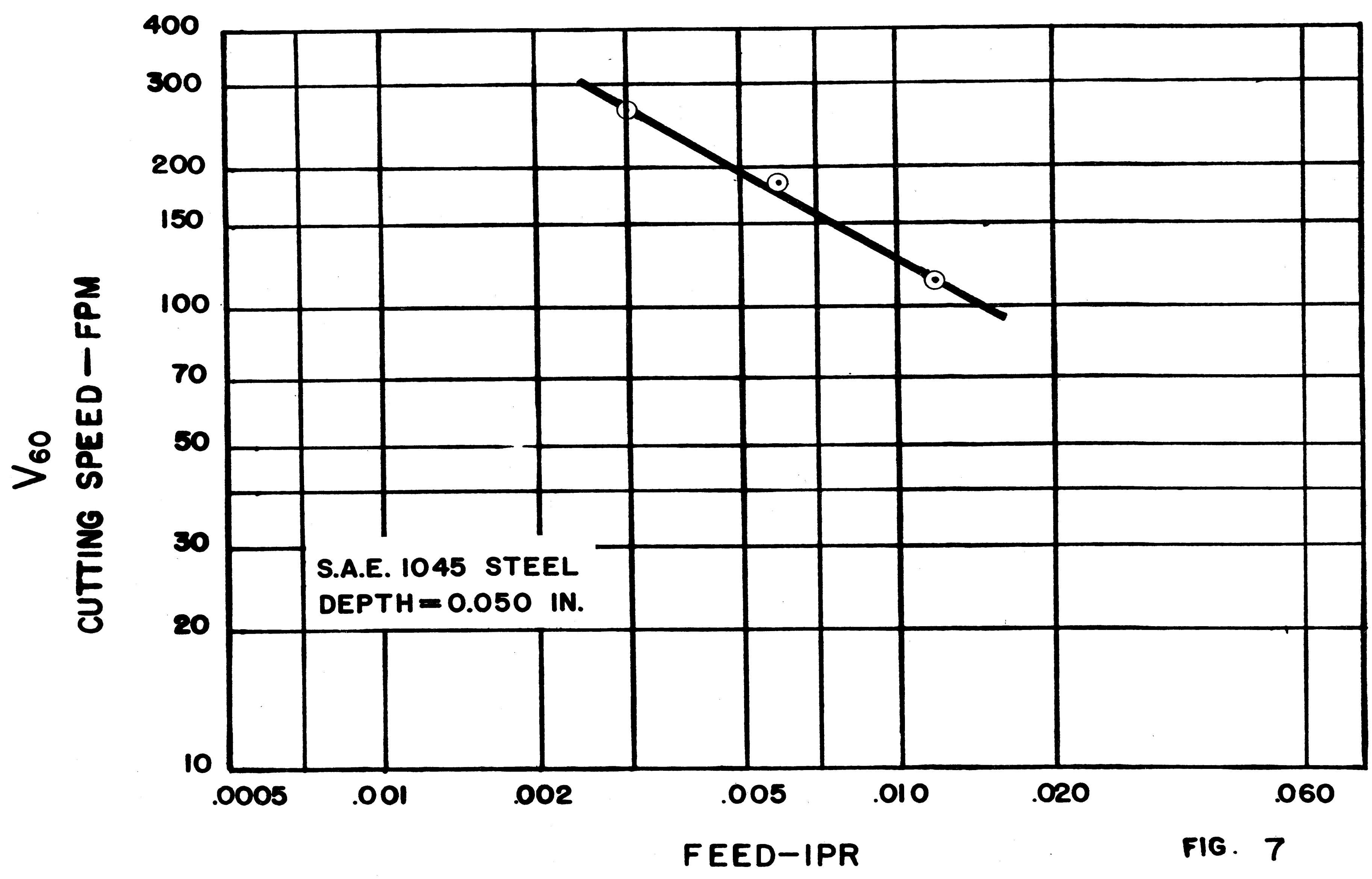


FIG. 7

CUTTING SPEED - FEED

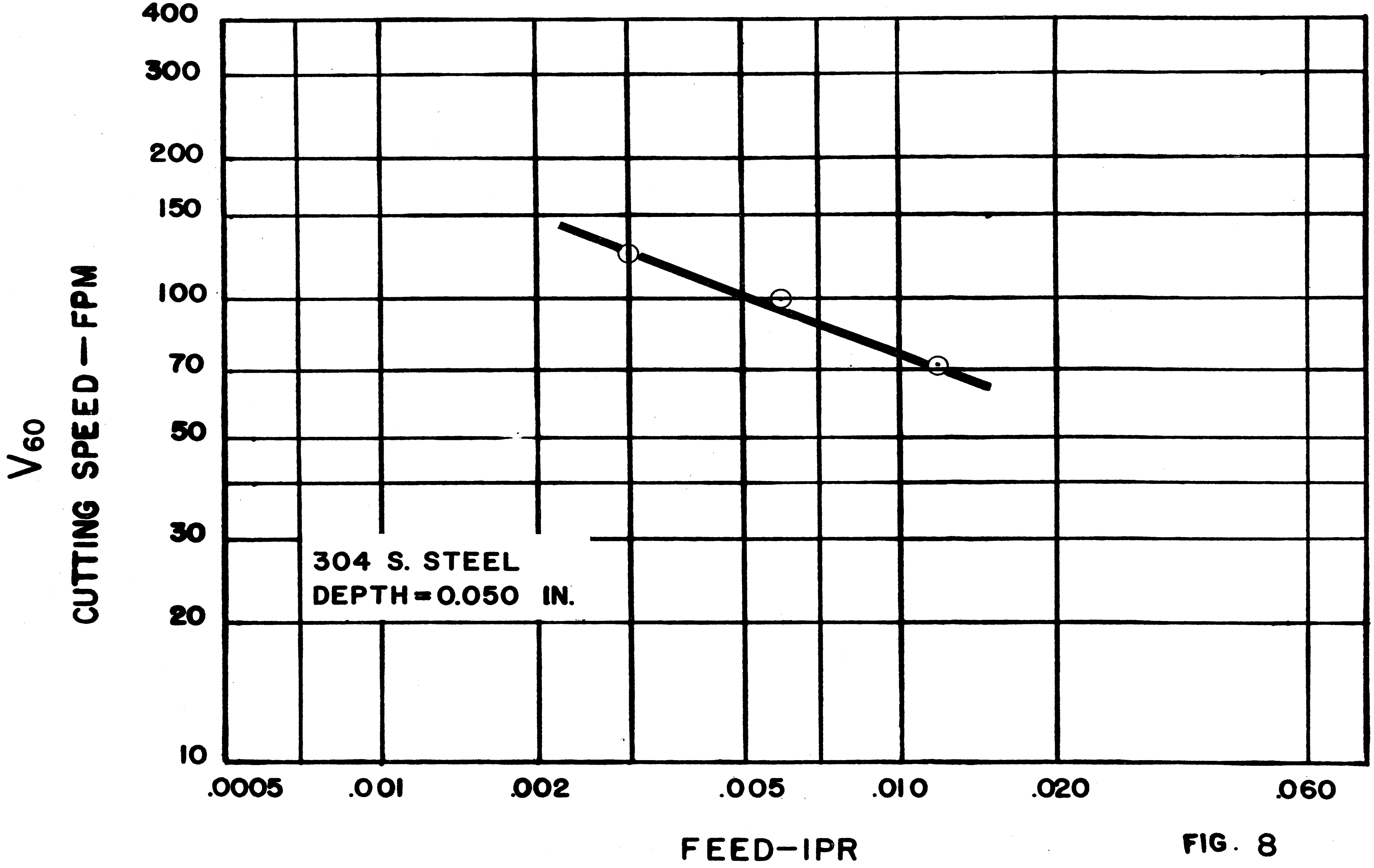


FIG. 8

CUTTING SPEED - DEPTH

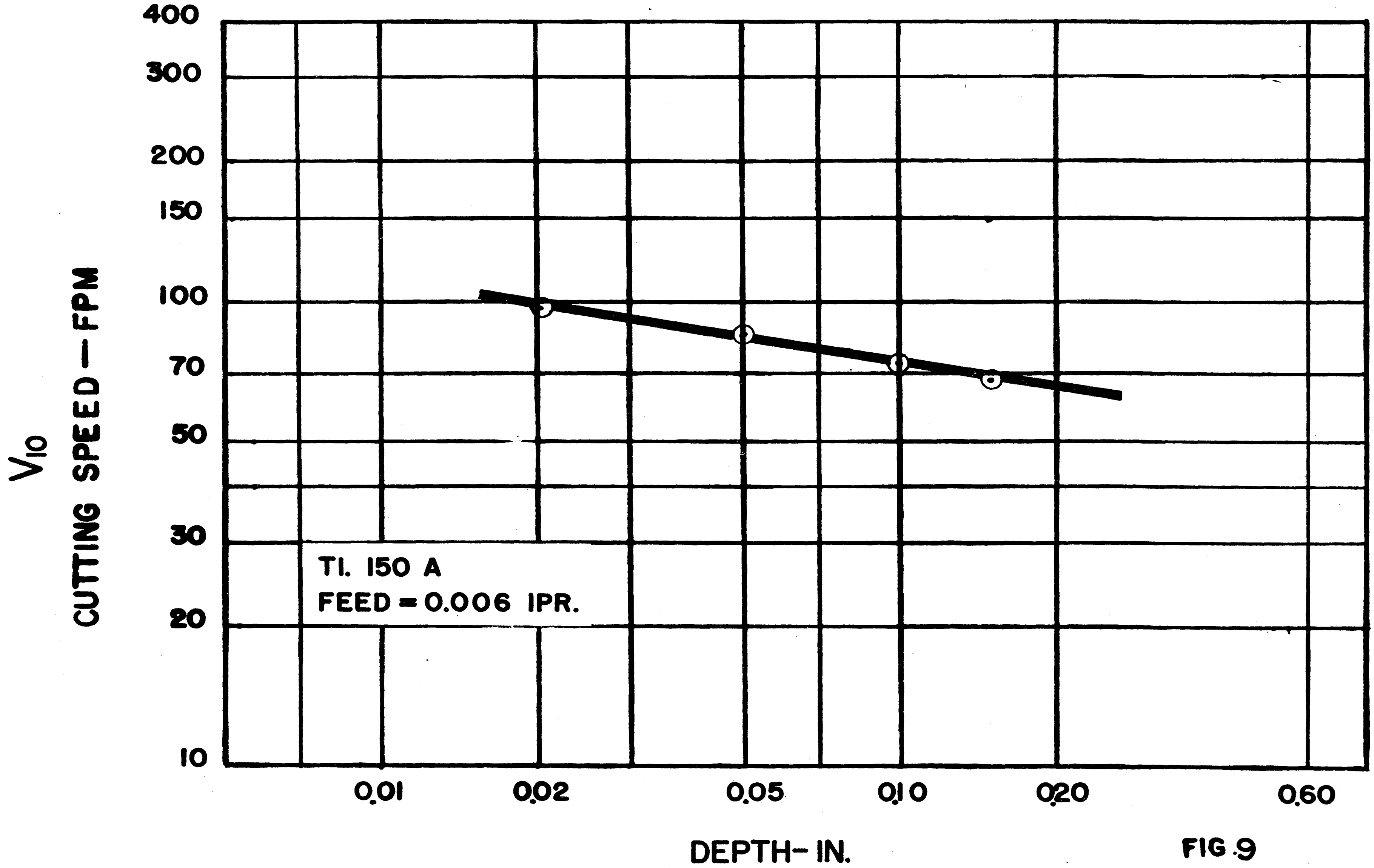


FIG. 9

CUTTING SPEED - DEPTH

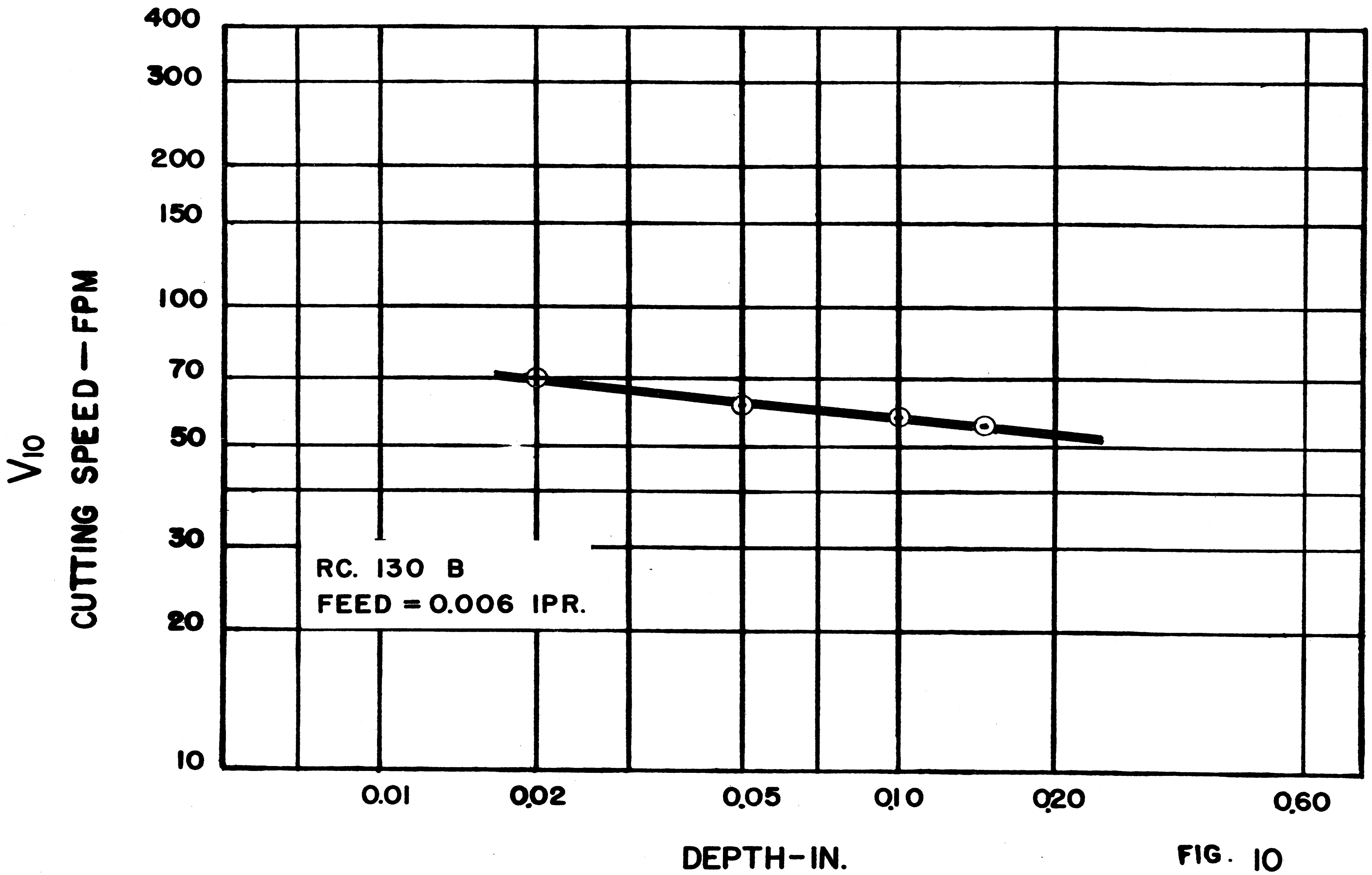


FIG. 10

CUTTING SPEED - DEPTH

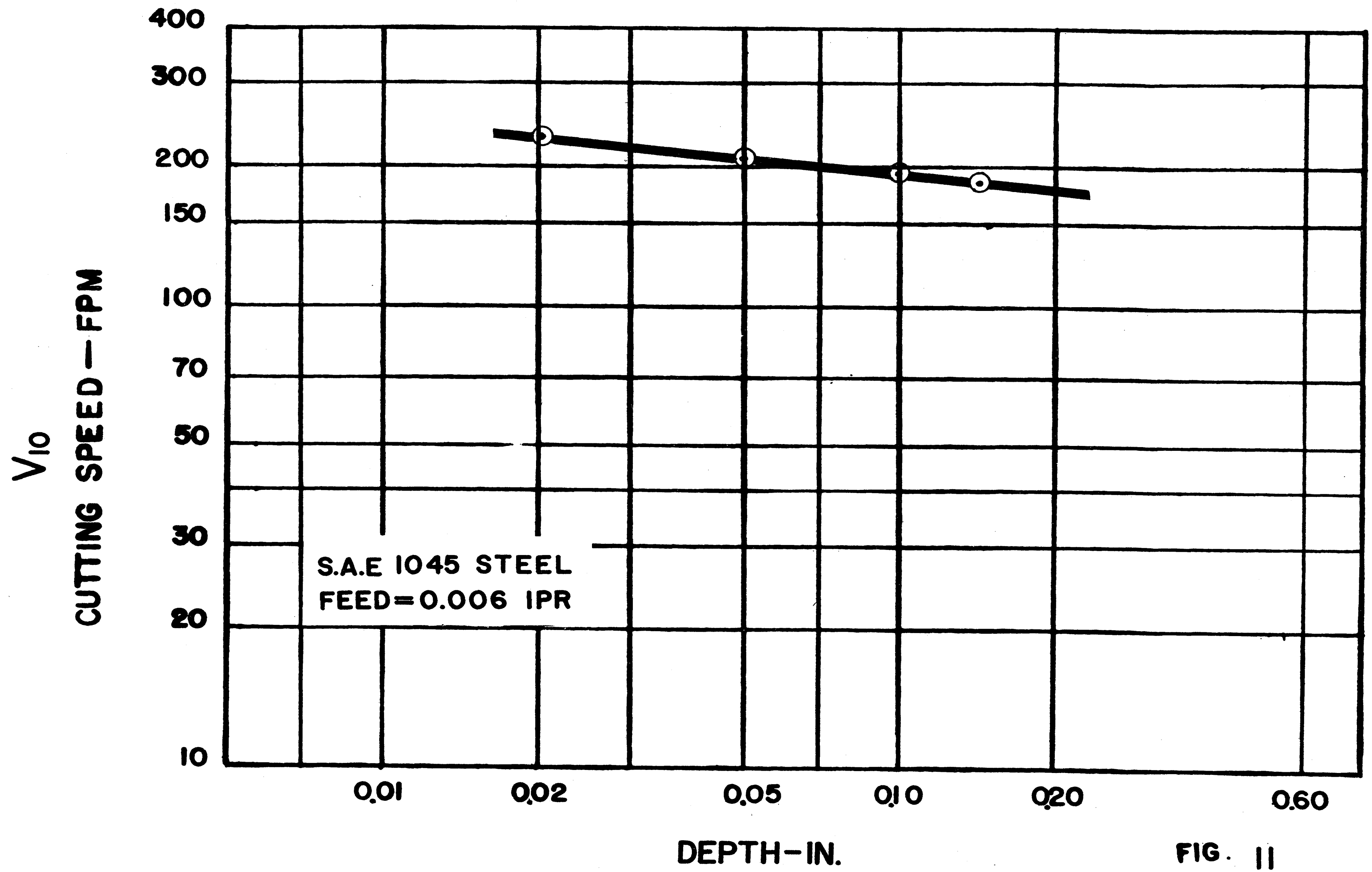


FIG. 11

CUTTING SPEED - DEPTH

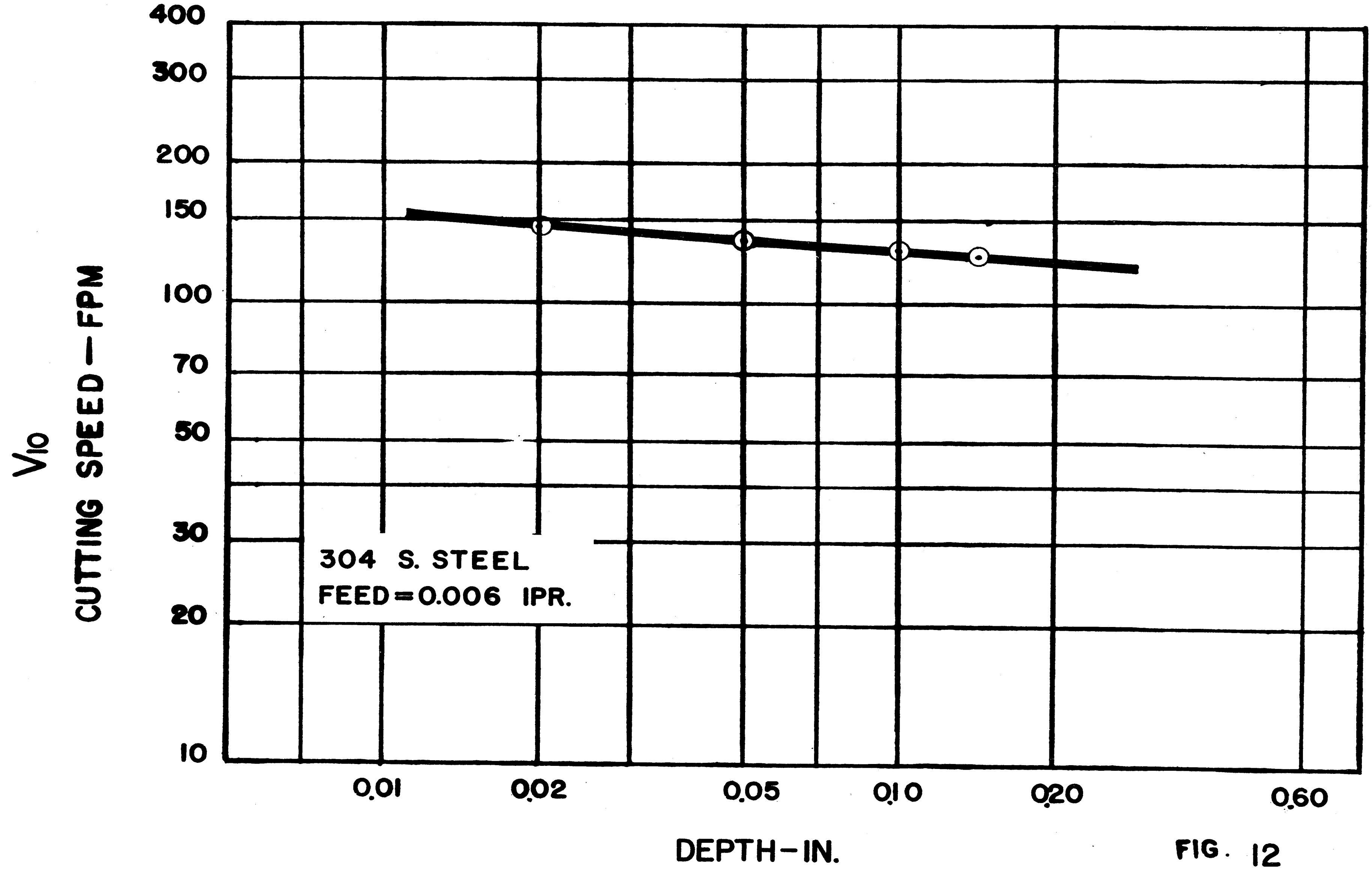


FIG. 12

CUTTING SPEED - DEPTH

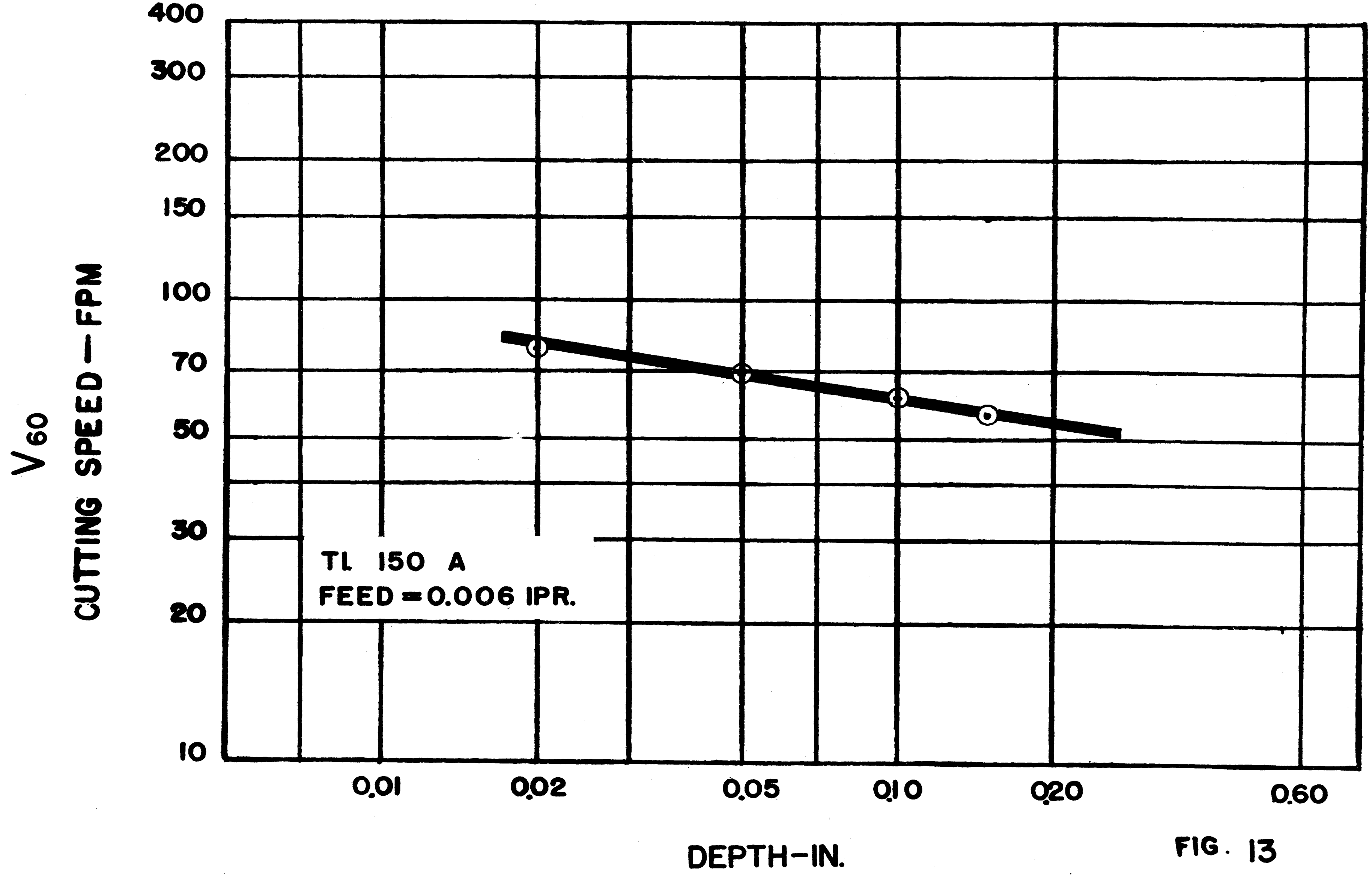


FIG. 13

CUTTING SPEED - DEPTH

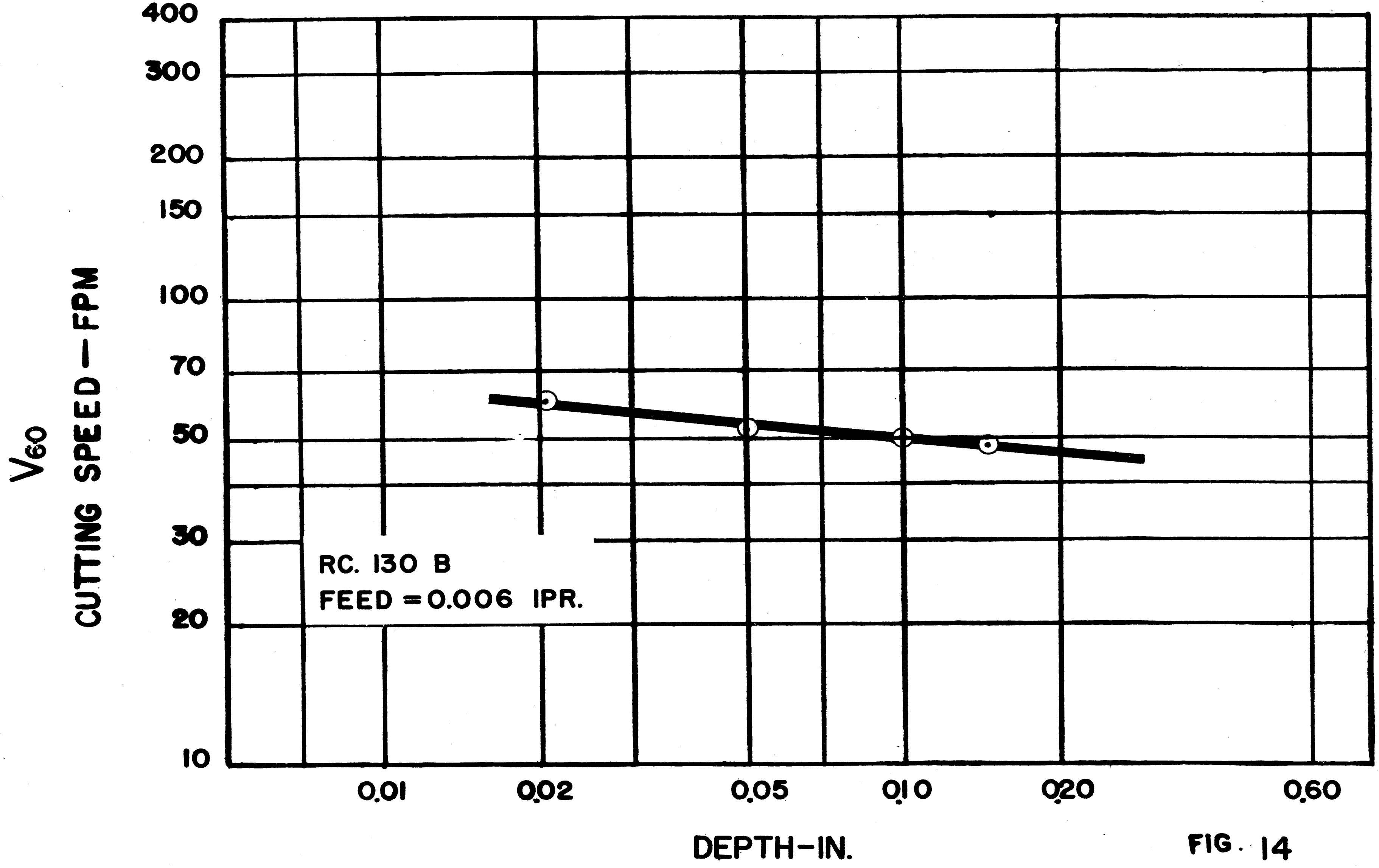
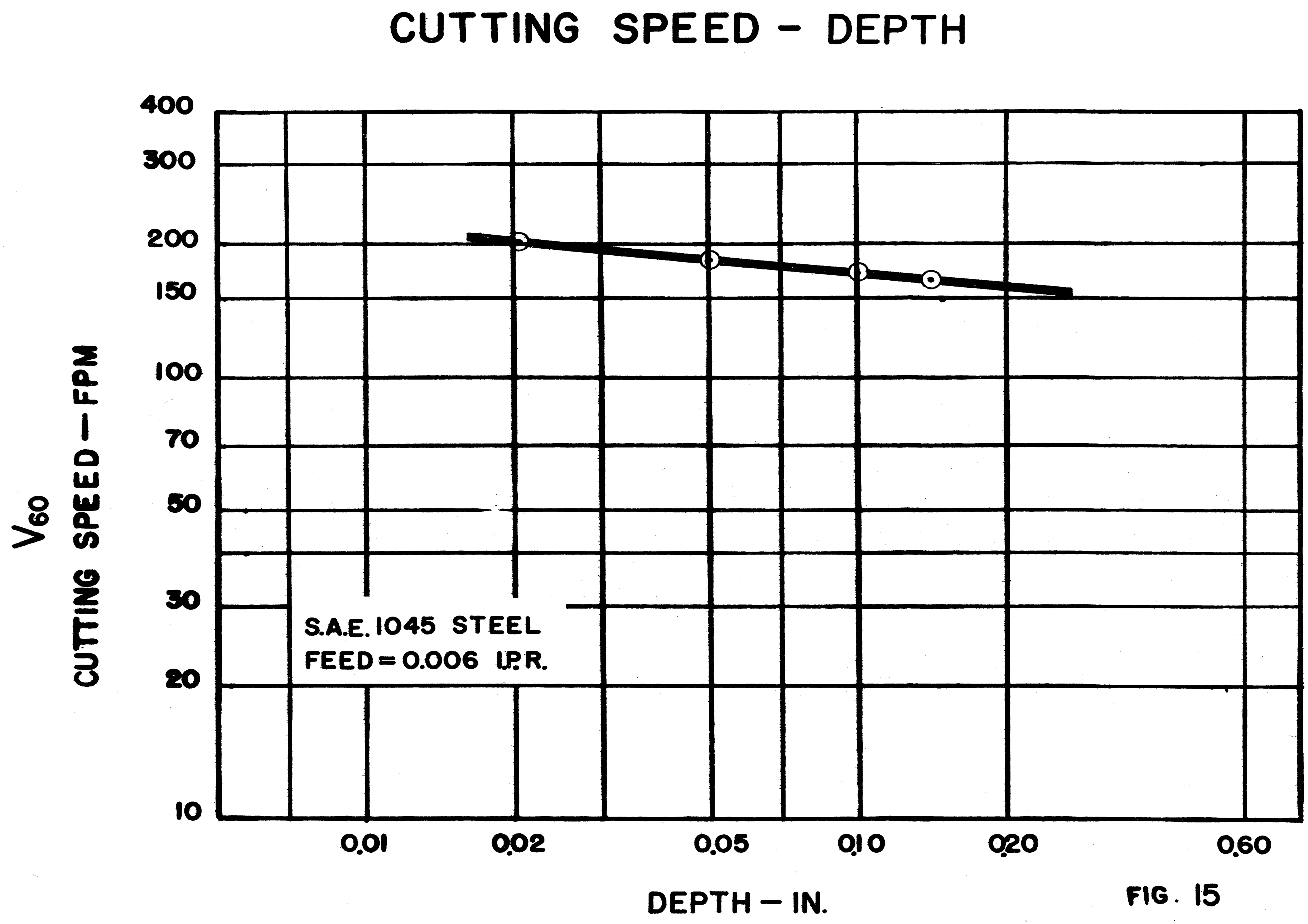


FIG. 14



CUTTING SPEED - DEPTH
400
300
200
150
100
70
50
30
20
10
V60
CUTTING SPEED — FPM
S.A.E. 1045 STEEL
FEED = 0.006 I.P.R.
0.01
0.02
0.05
0.10
0.20
0.60
DEPTH — IN.

FIG. 15

CUTTING SPEED - DEPTH

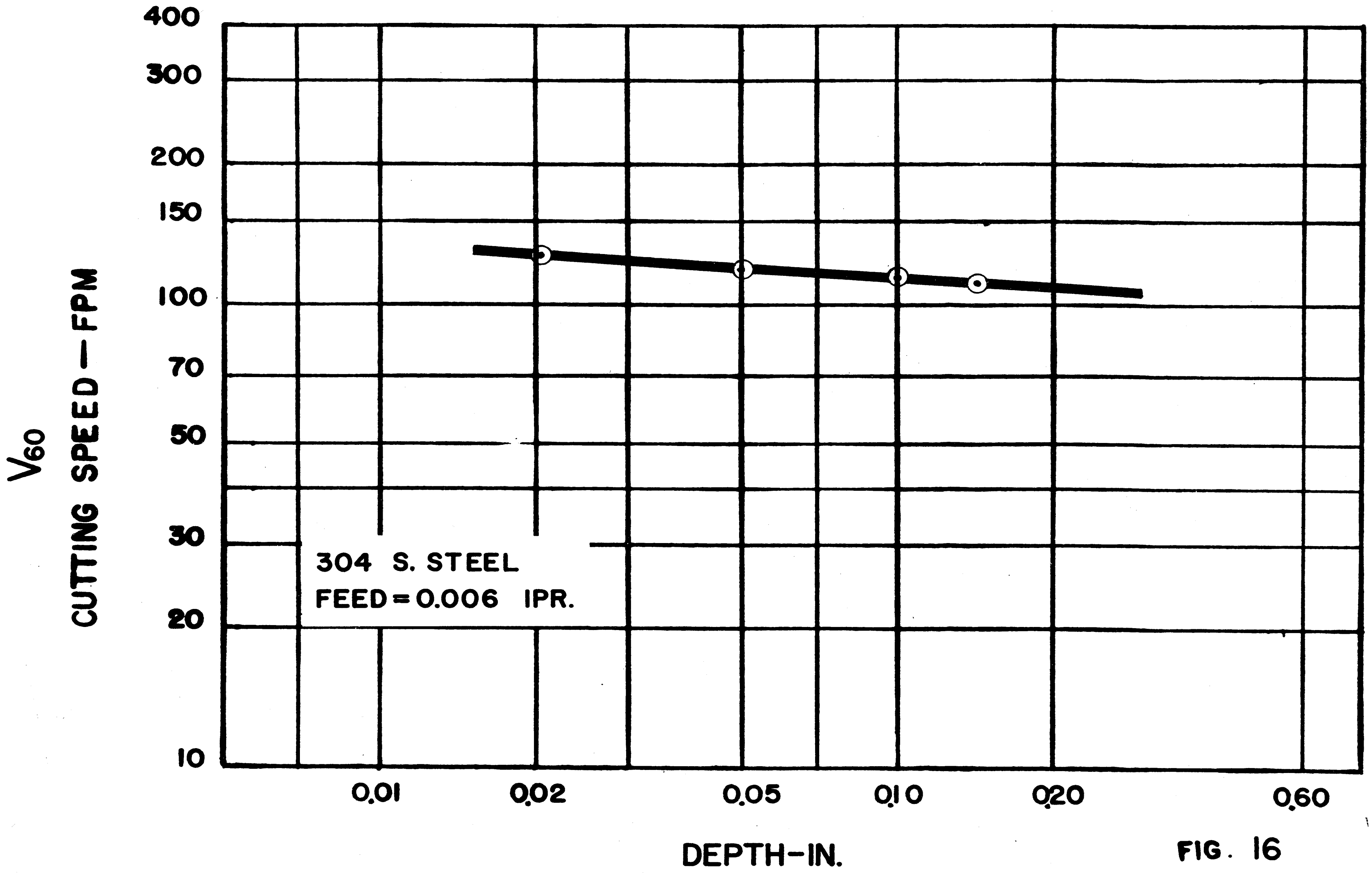


FIG. 16

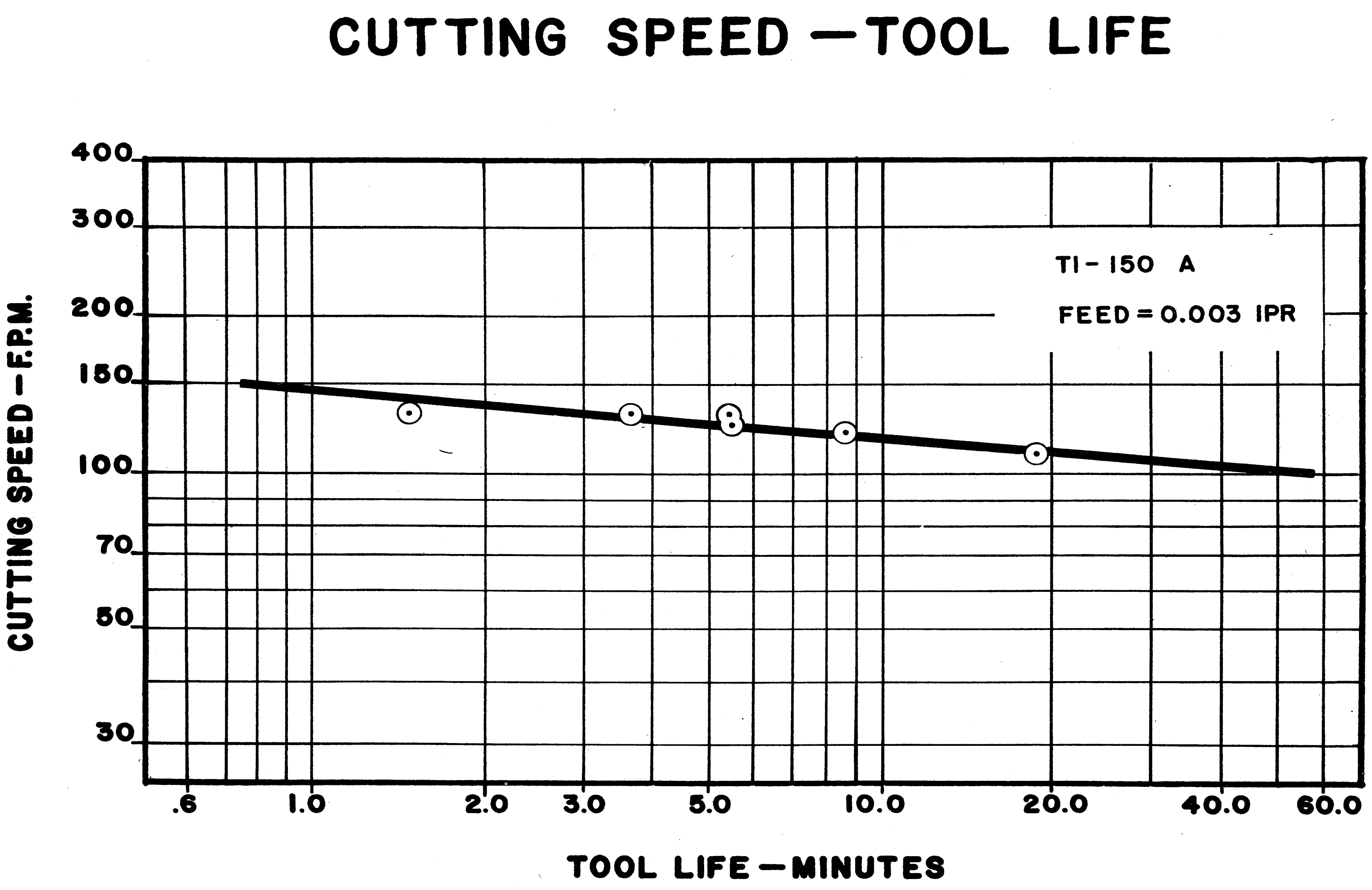

CUTTING SPEED — TOOL LIFE
CUTTING SPEED — F.P.M.
400
300
200
150
100
70
50
30
.6
1.0
2.0
3.0
5.0
10.0
20.0
40.0
60.0
TOOL LIFE — MINUTES
TI-150 A
FEED = 0.003 IPR

FIG. 17

CUTTING SPEED — TOOL LIFE

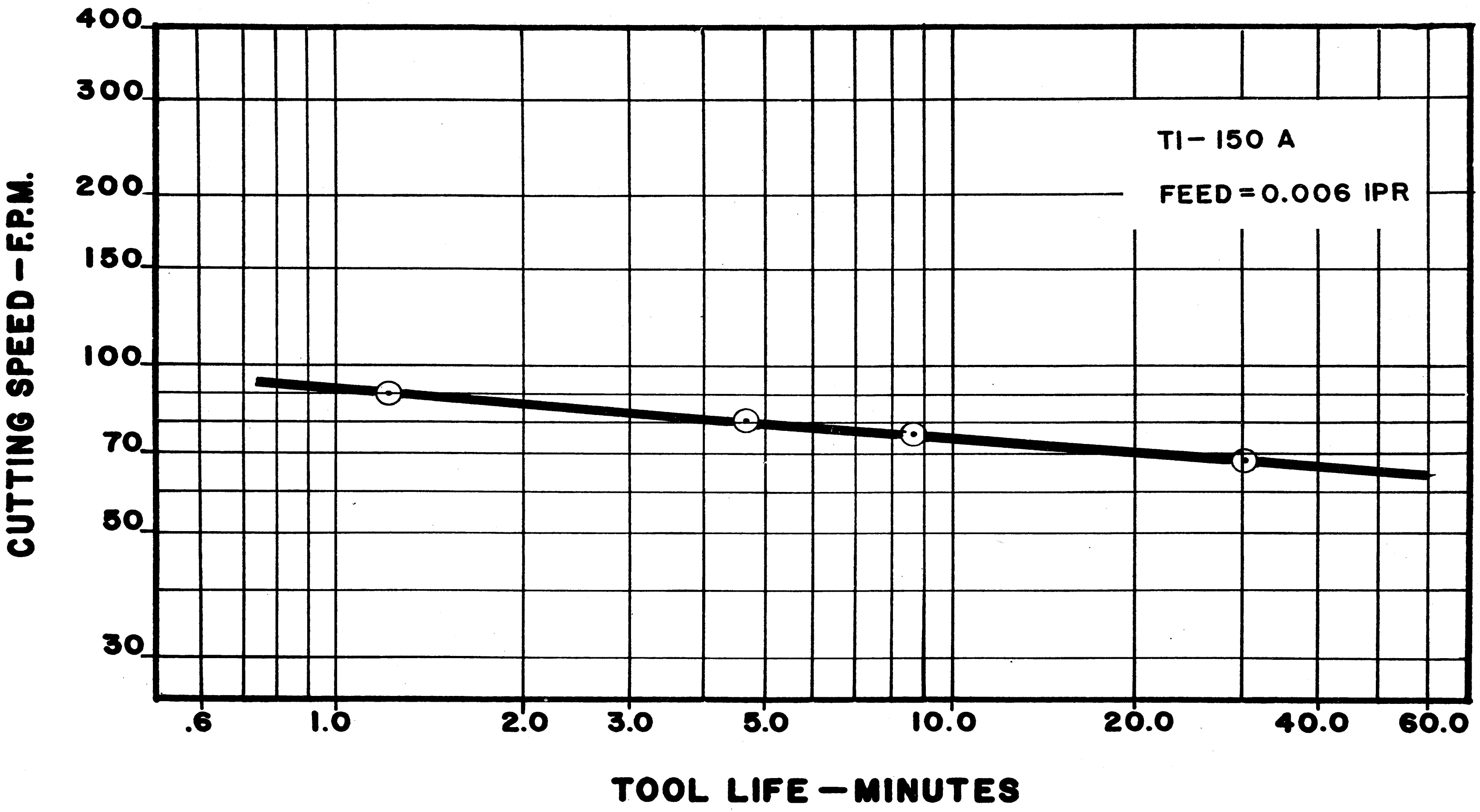
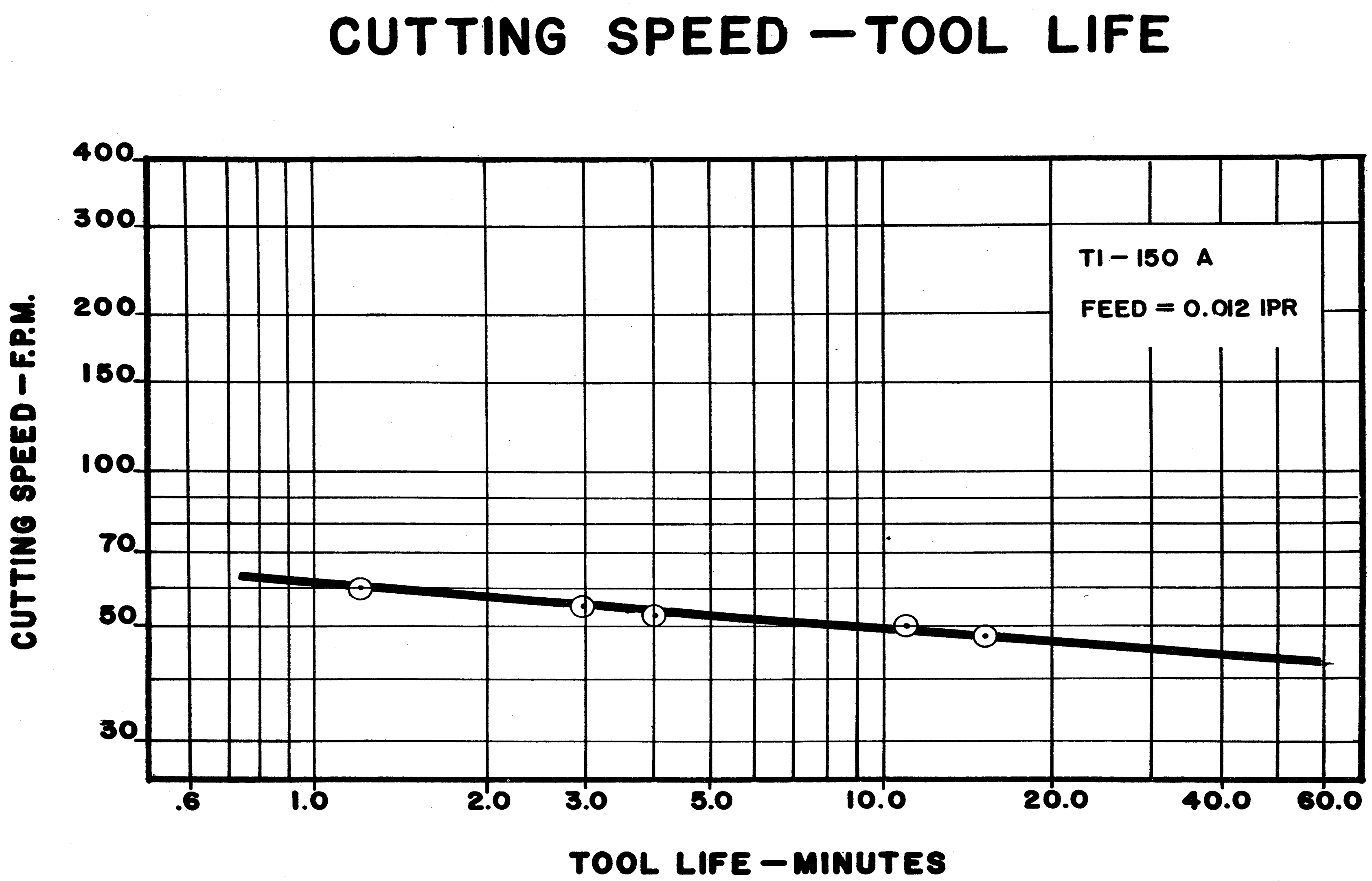


FIG. 18



CUTTING SPEED — TOOL LIFE
CUTTING SPEED — F.P.M.
400
300
200
150
100
70
50
30
TI — 150 A
FEED = 0.012 IPR
.6
1.0
2.0
3.0
5.0
10.0
20.0
40.0
60.0
TOOL LIFE — MINUTES

FIG. 19

CUTTING SPEED — TOOL LIFE

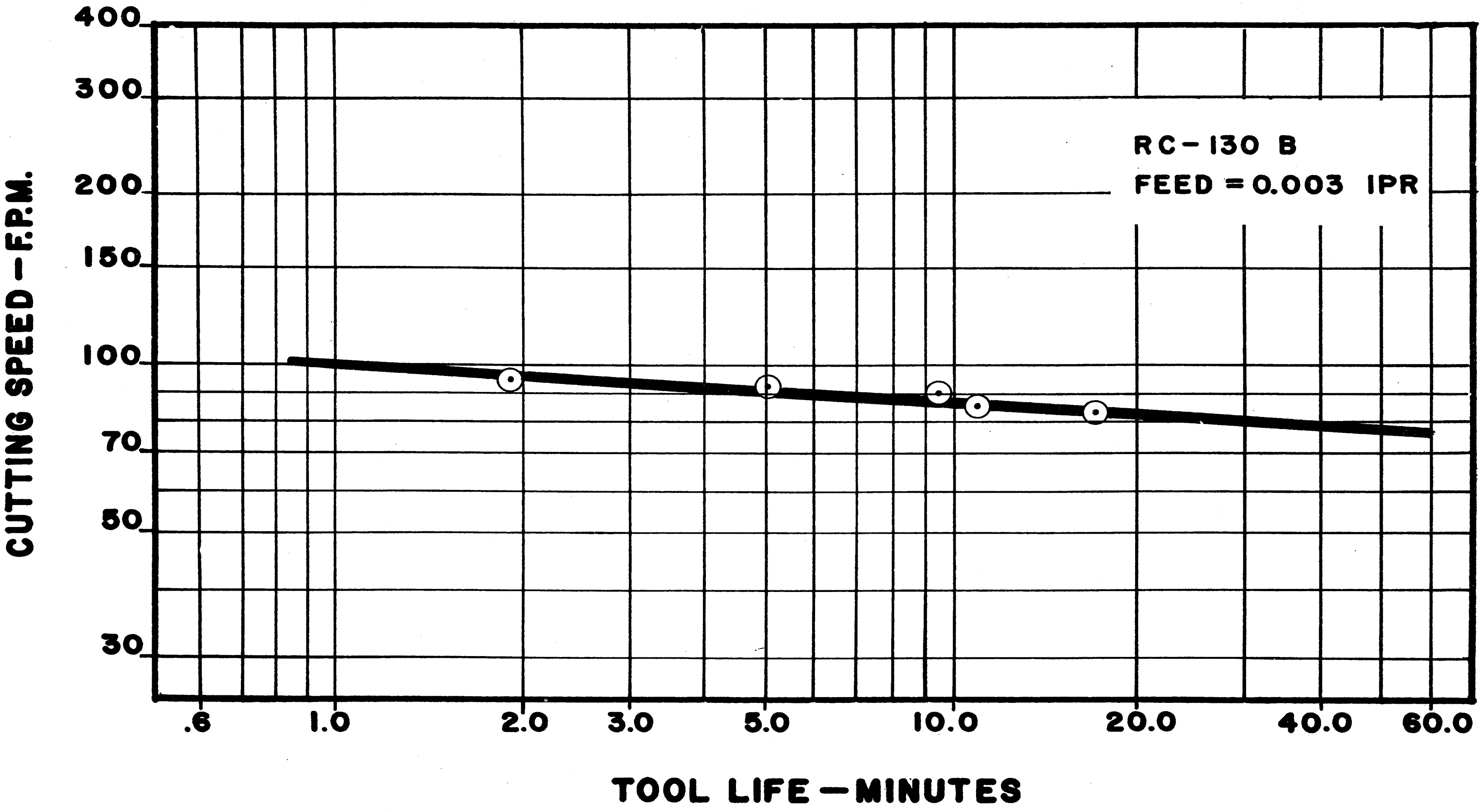


FIG. 20

CUTTING SPEED — TOOL LIFE

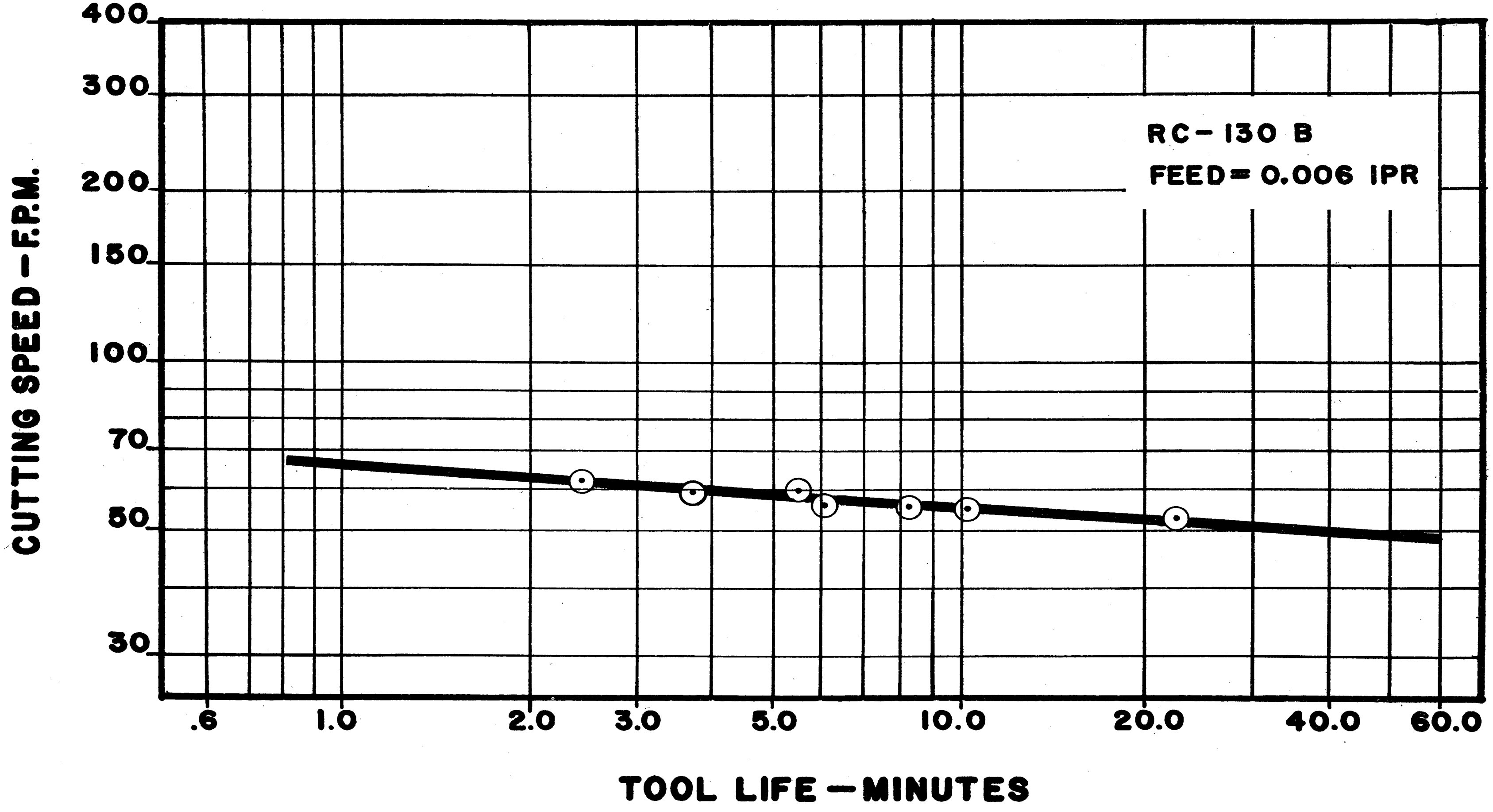


FIG. 21

CUTTING SPEED — TOOL LIFE

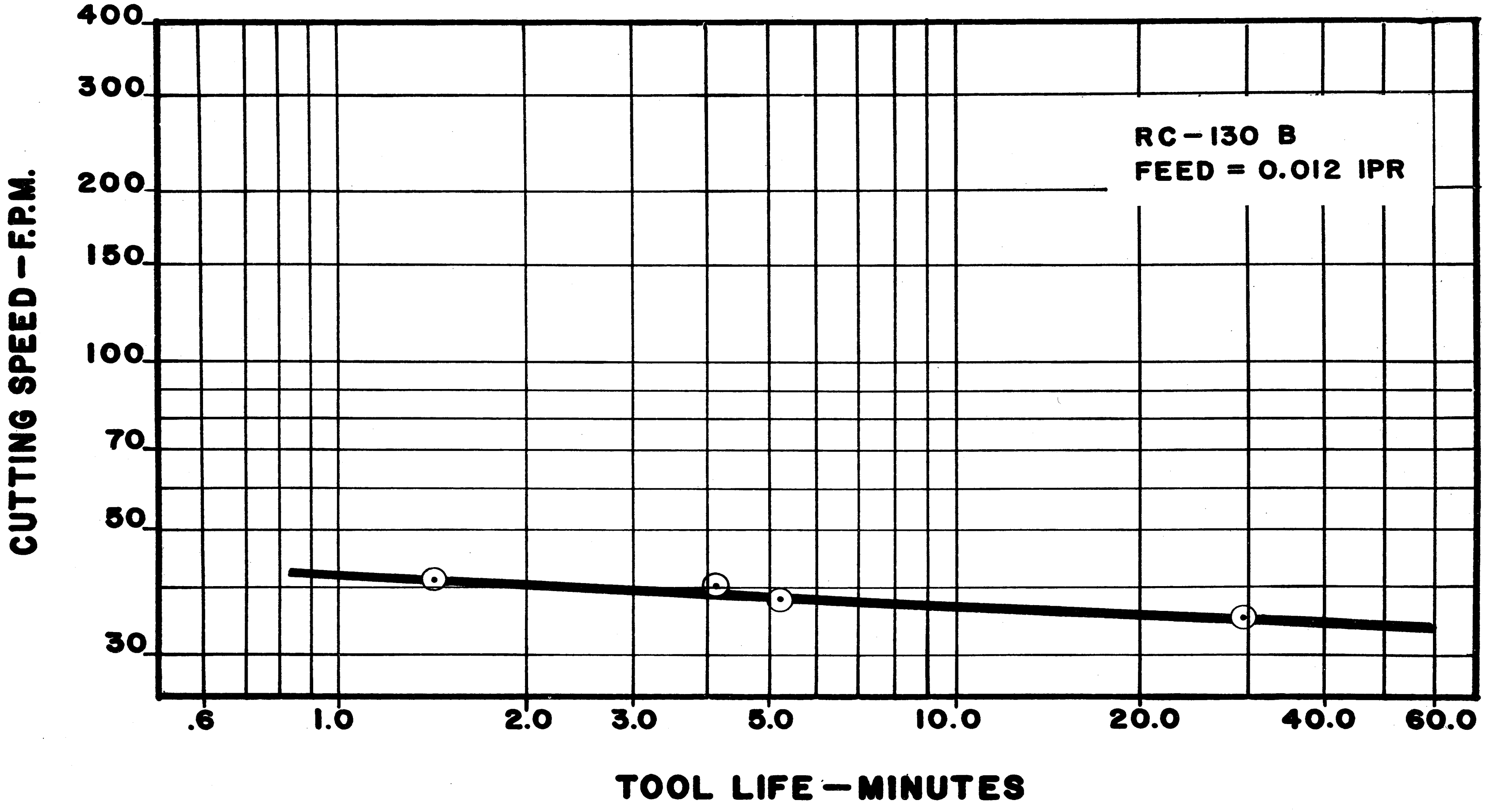


FIG. 22

CUTTING SPEED — TOOL LIFE

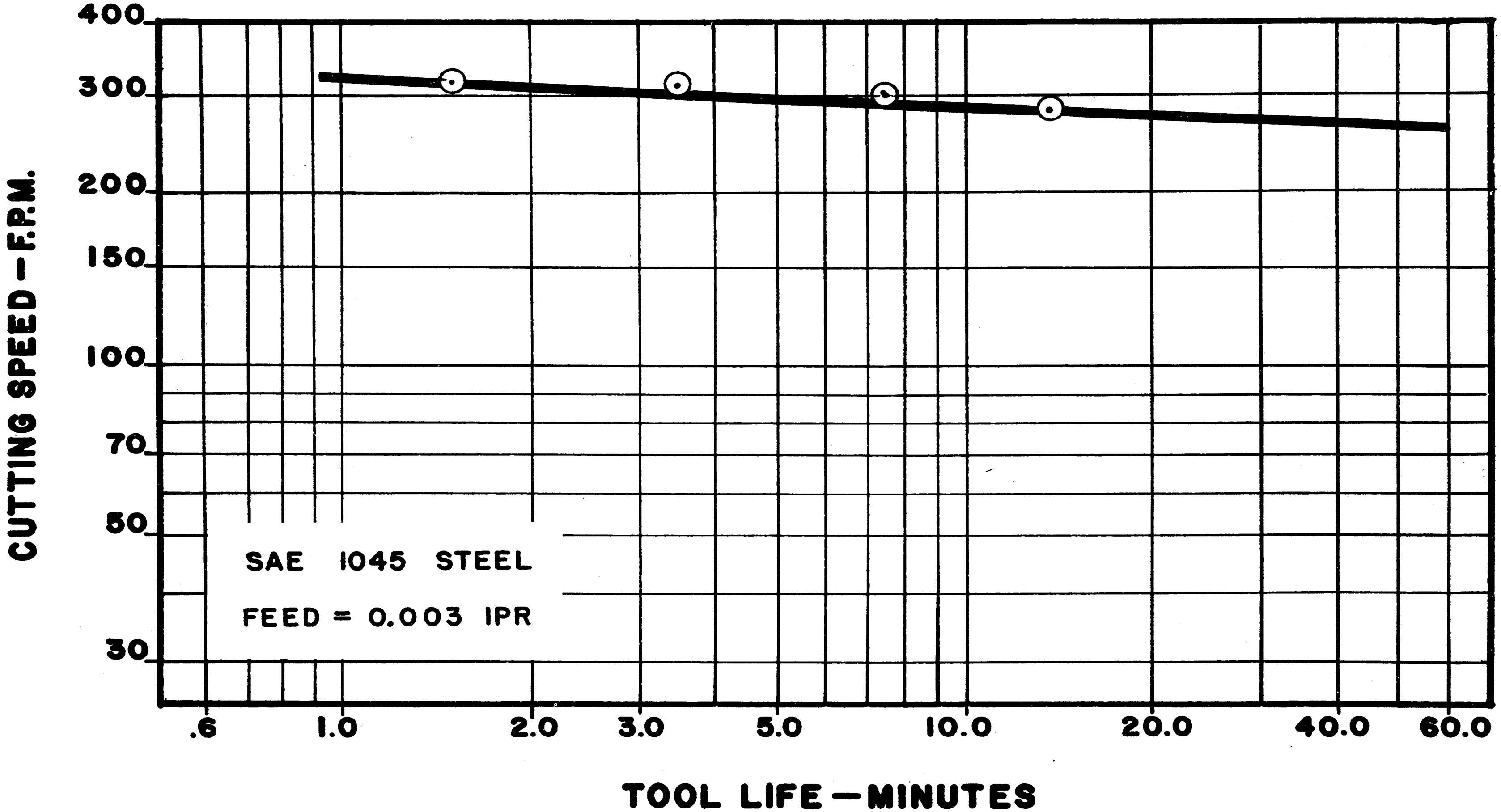


FIG. 23

CUTTING SPEED — TOOL LIFE

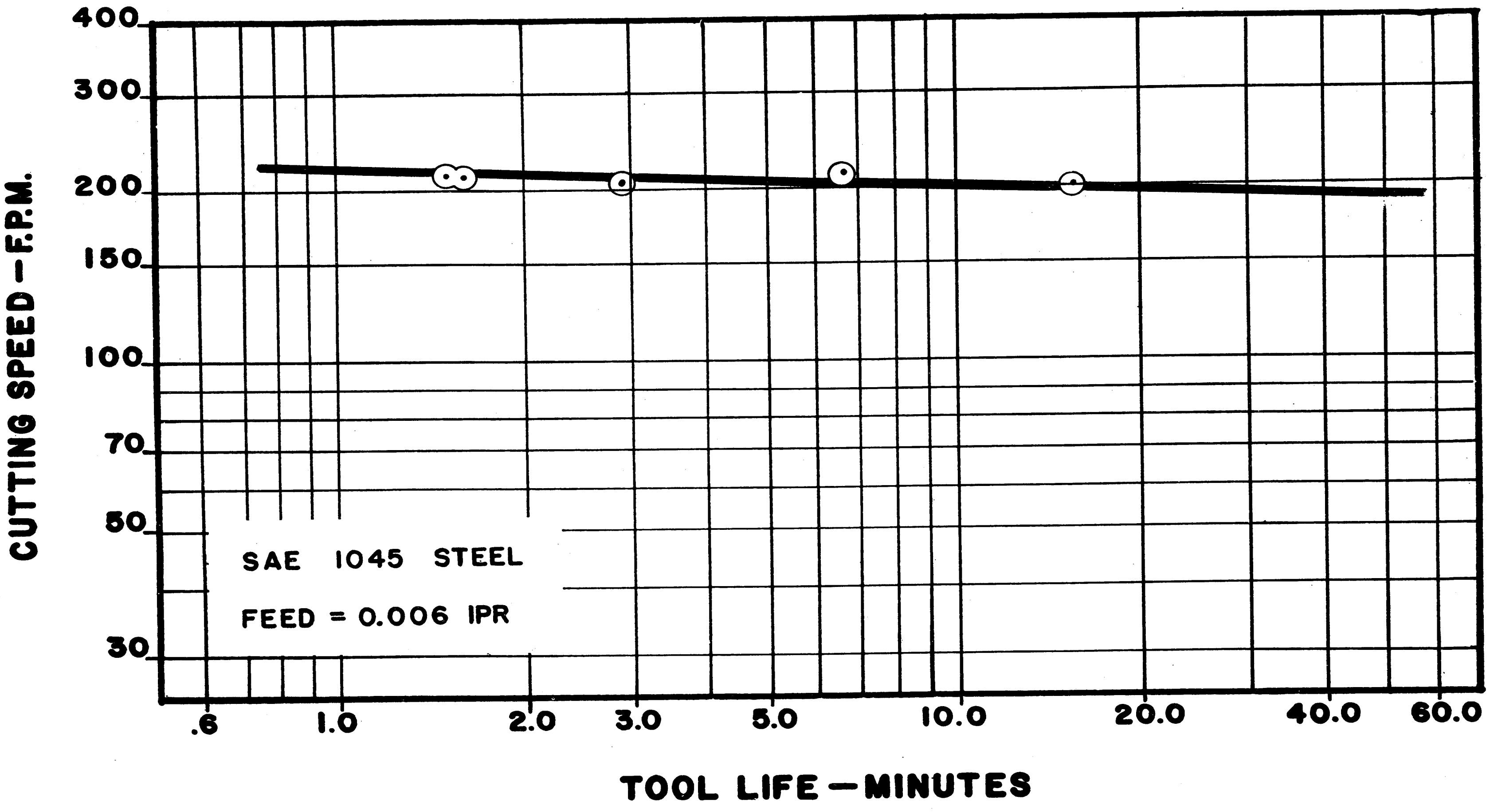


FIG. 24

CUTTING SPEED — TOOL LIFE

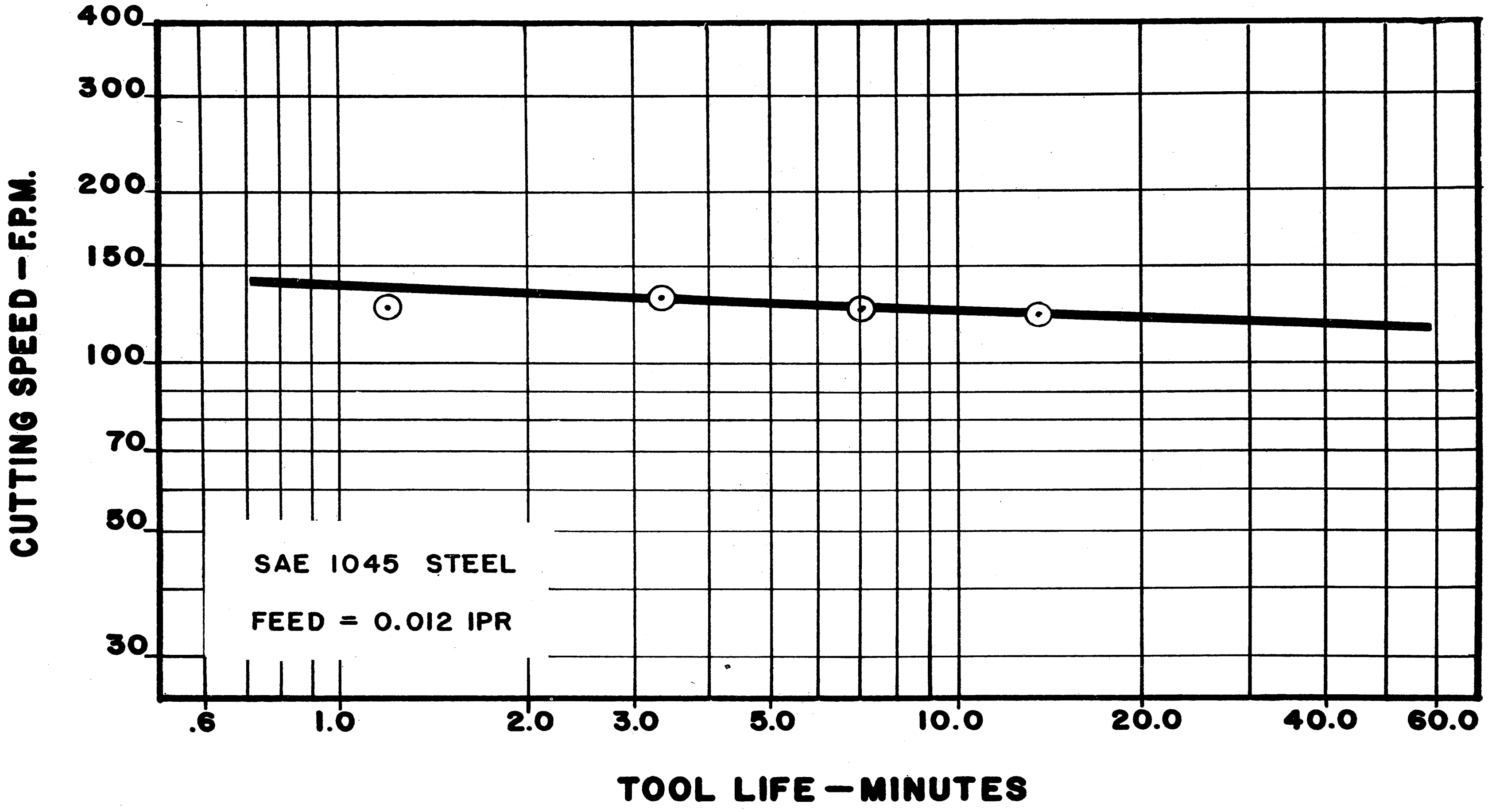


FIG. 25

CUTTING SPEED — TOOL LIFE

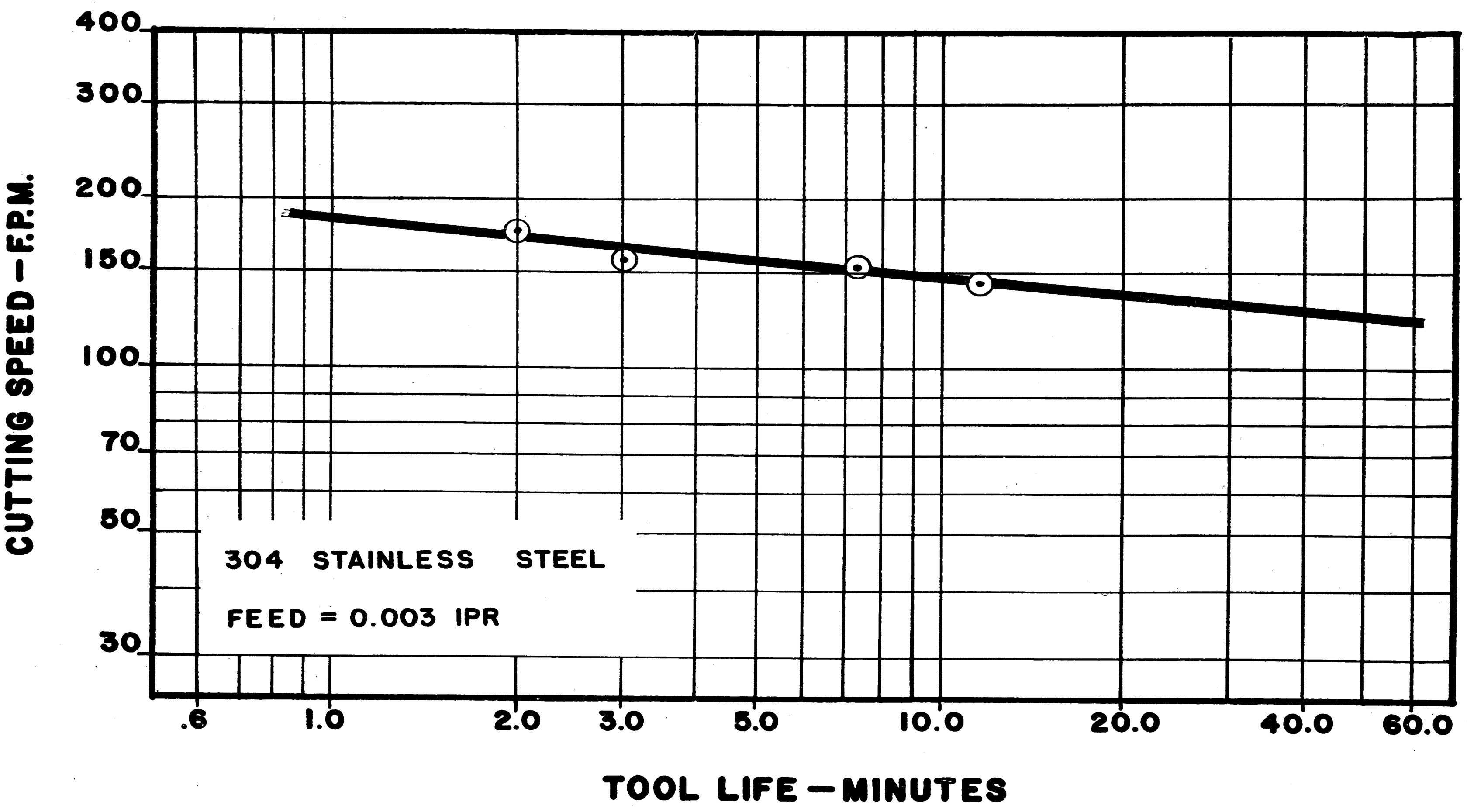


FIG. 26

CUTTING SPEED — TOOL LIFE

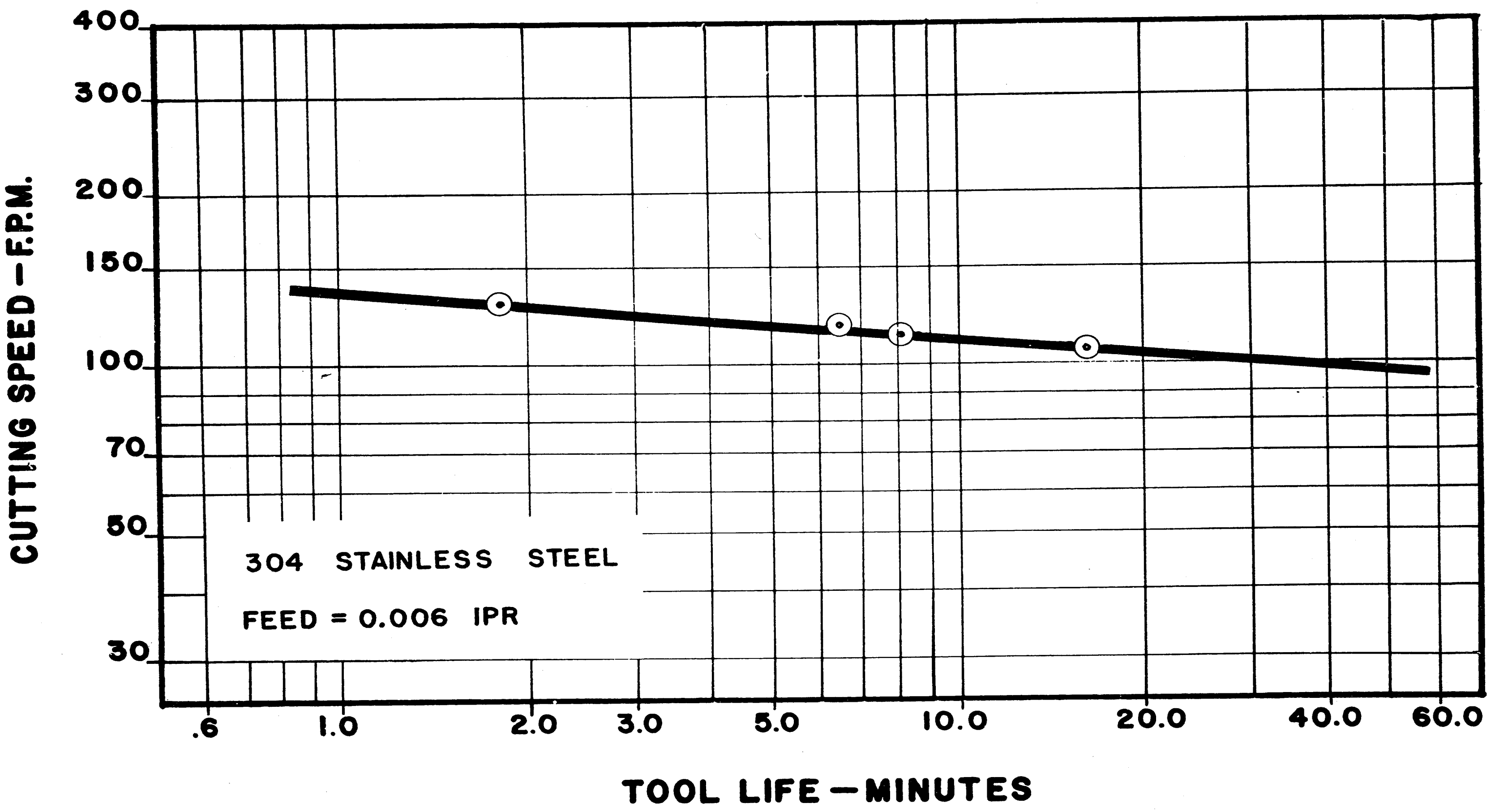


FIG. 27

CUTTING SPEED — TOOL LIFE

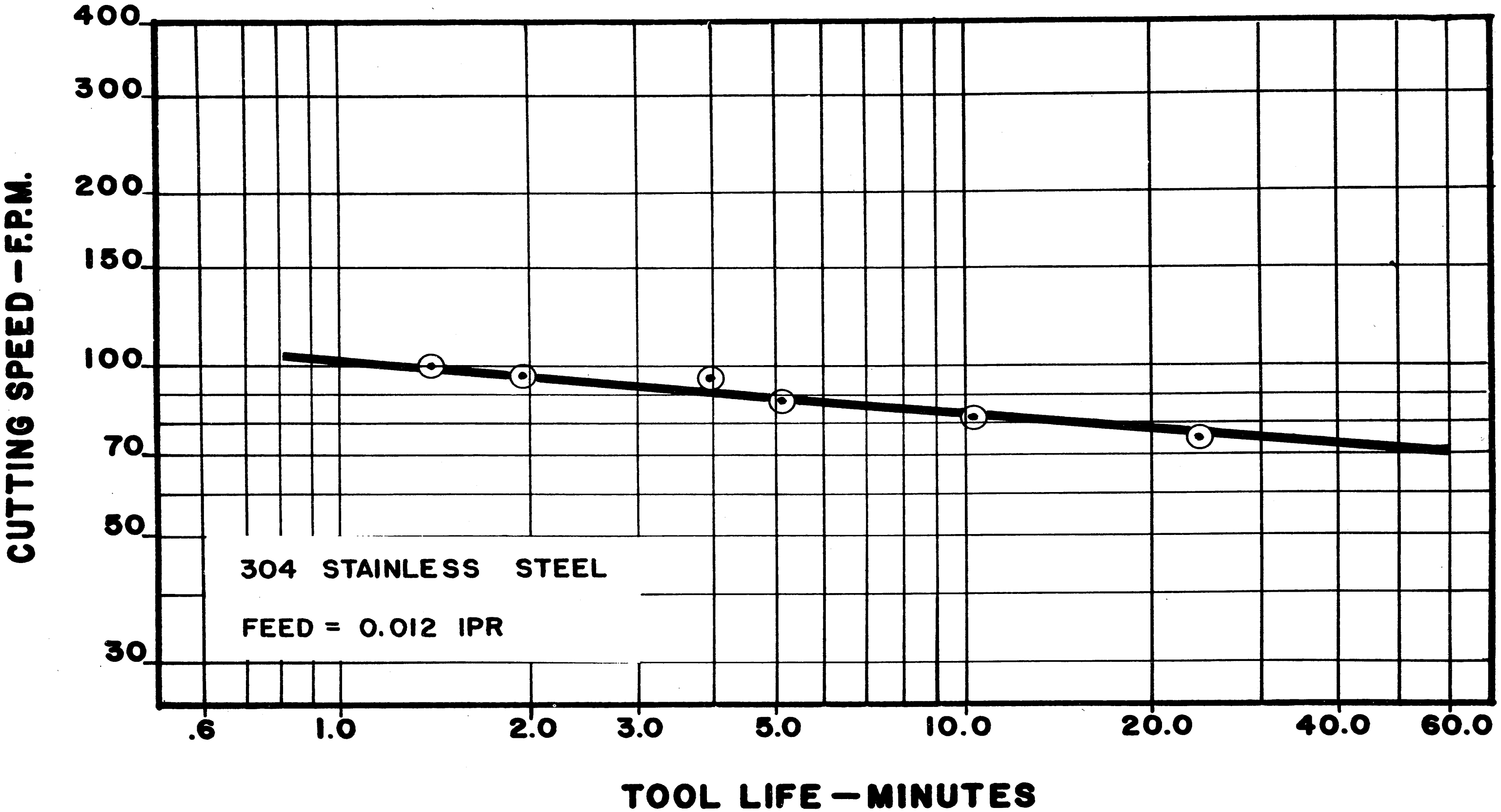


FIG. 28

CUTTING SPEED — TOOL LIFE

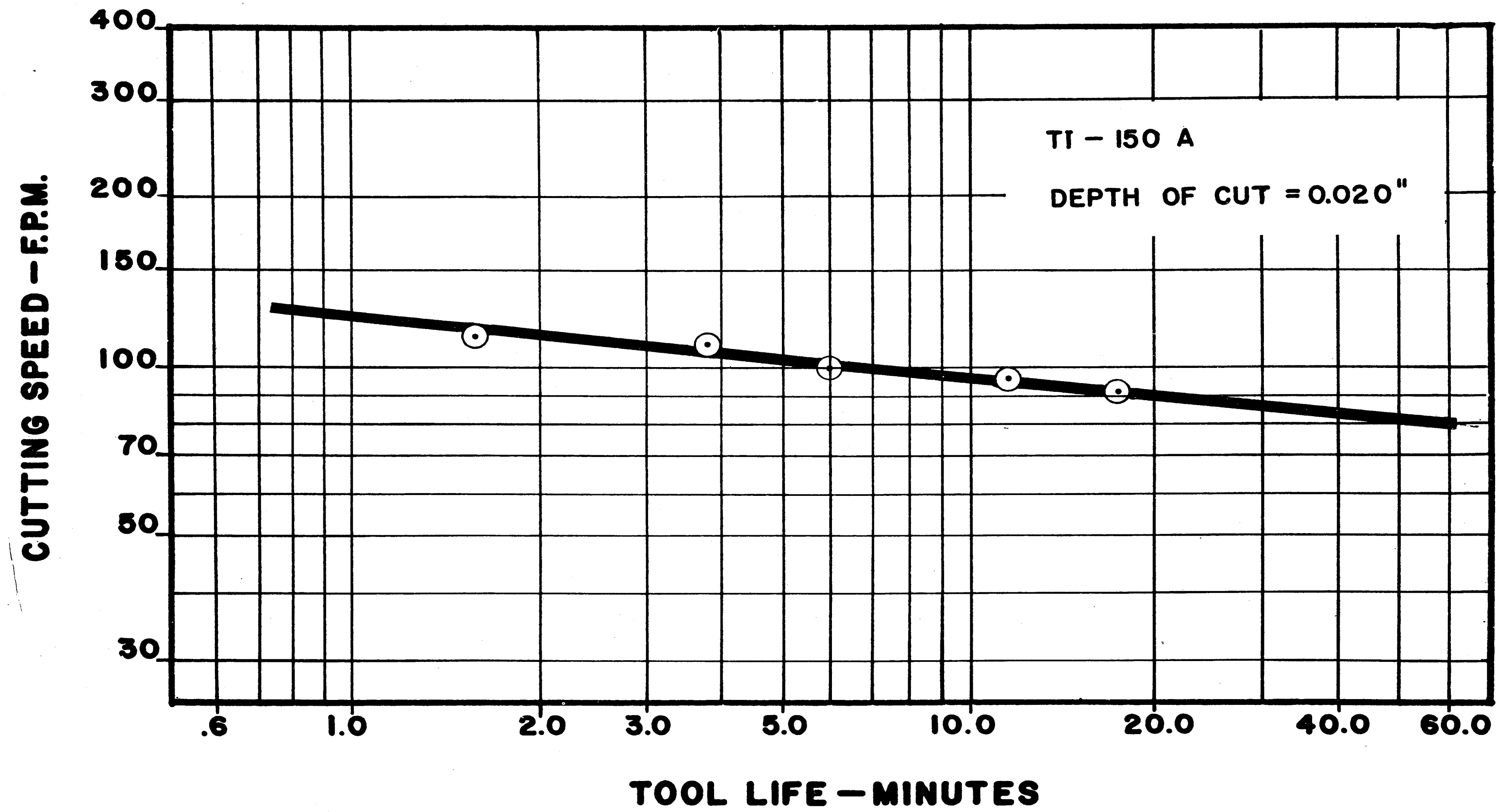


FIG. 29

CUTTING SPEED — TOOL LIFE

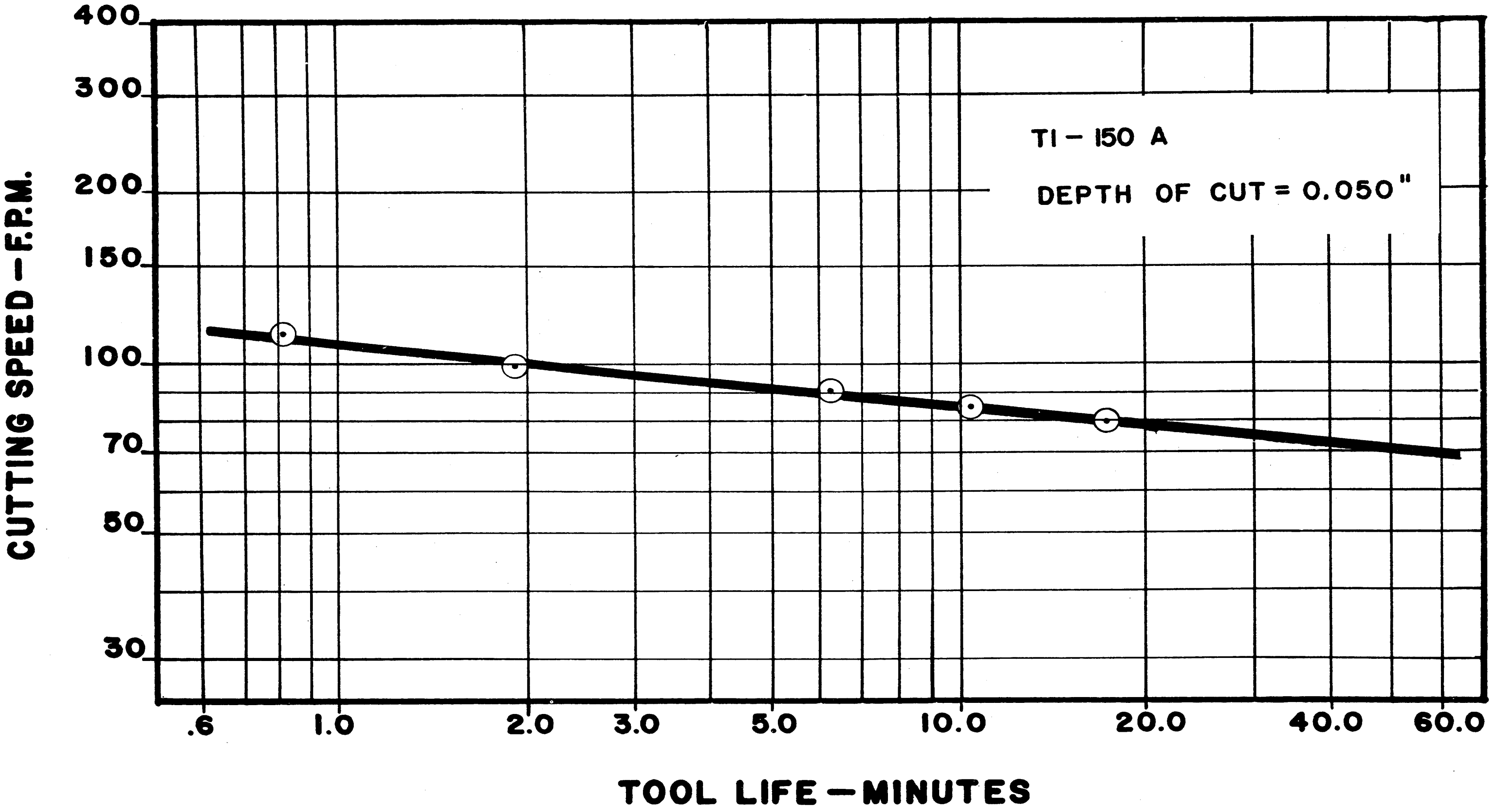


FIG. 30

CUTTING SPEED — TOOL LIFE

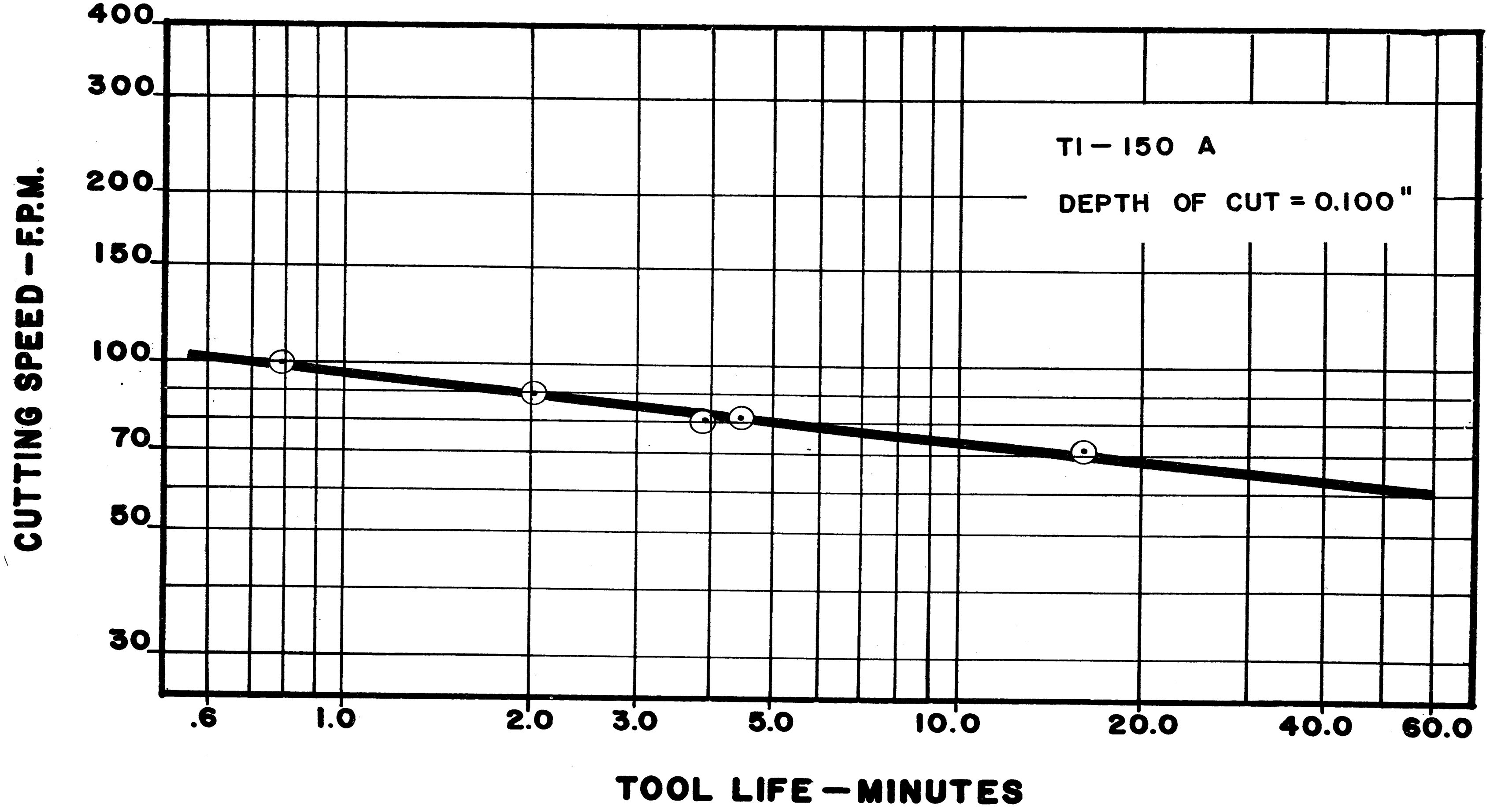


FIG. 31

CUTTING SPEED — TOOL LIFE

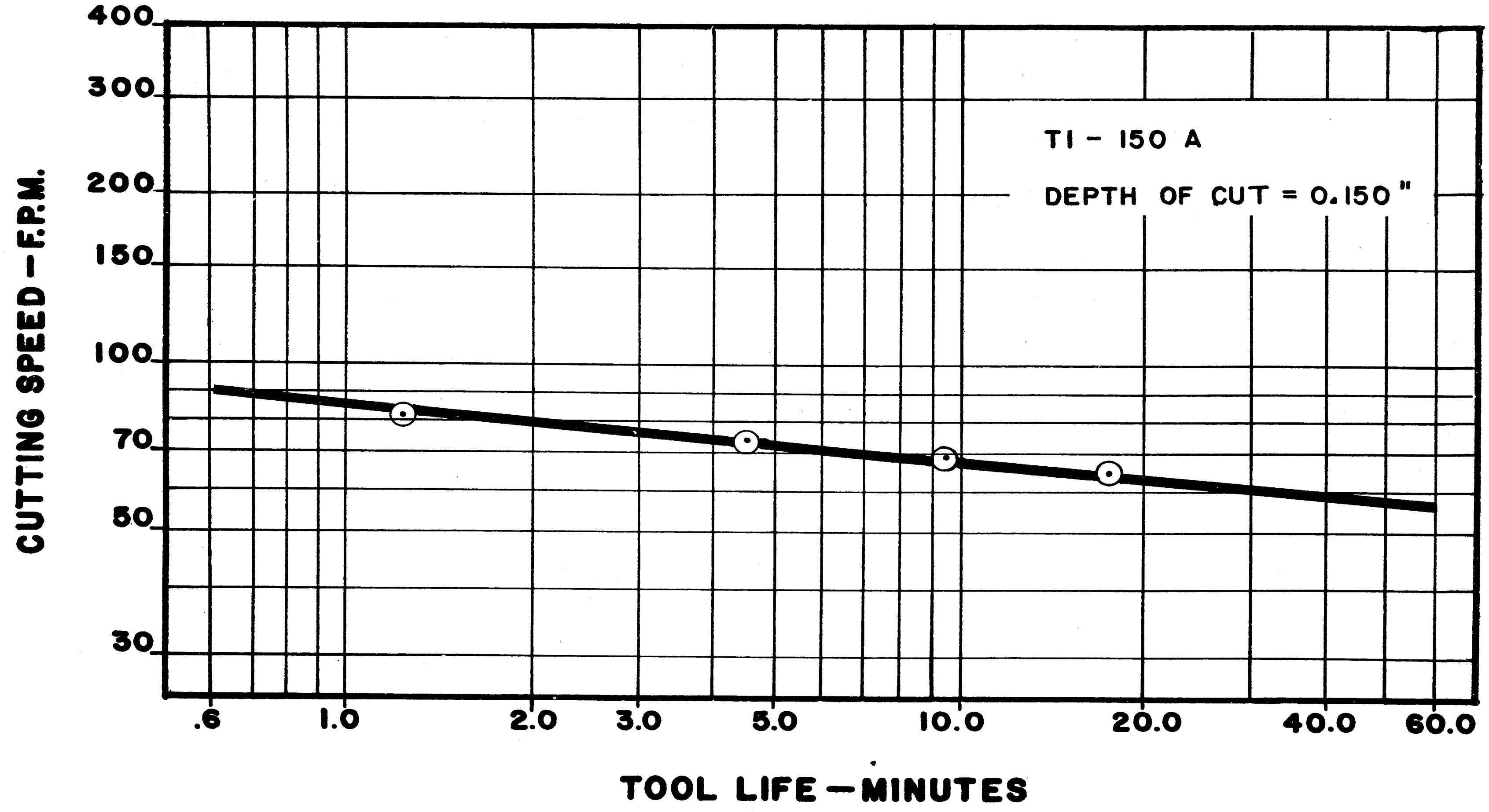


FIG. 32

CUTTING SPEED — TOOL LIFE

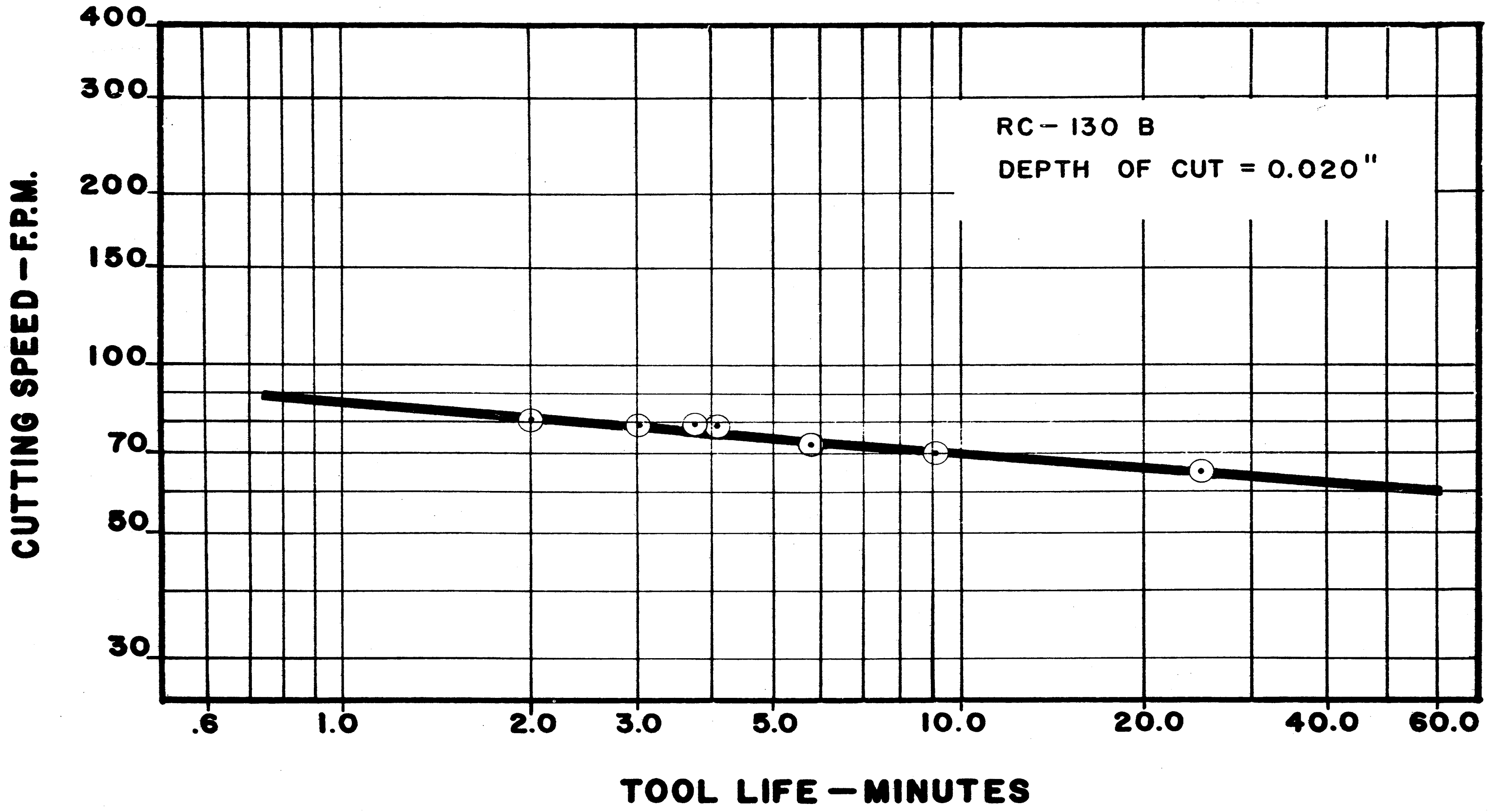


FIG. 33

CUTTING SPEED — TOOL LIFE

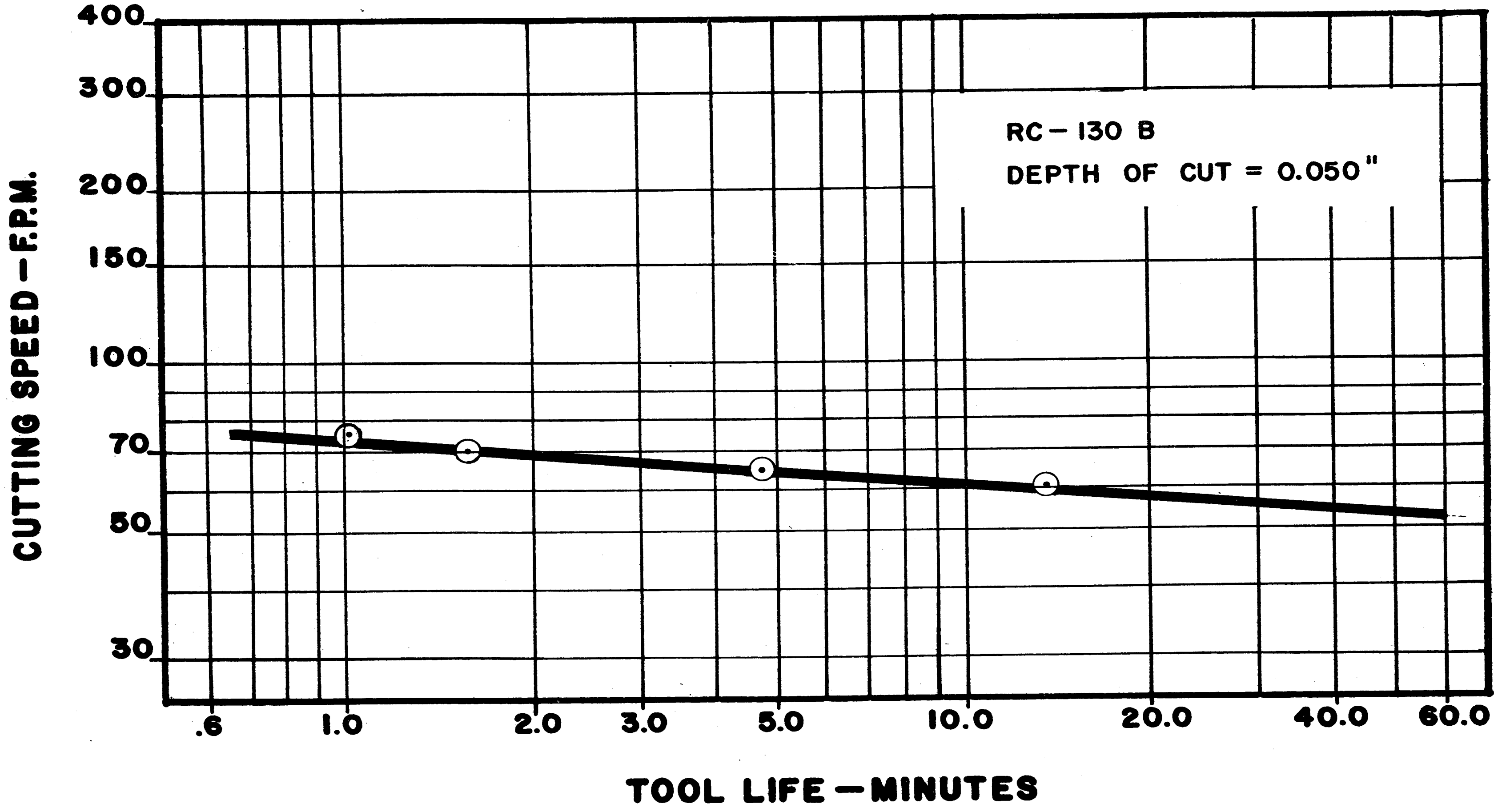


FIG. 34

CUTTING SPEED — TOOL LIFE

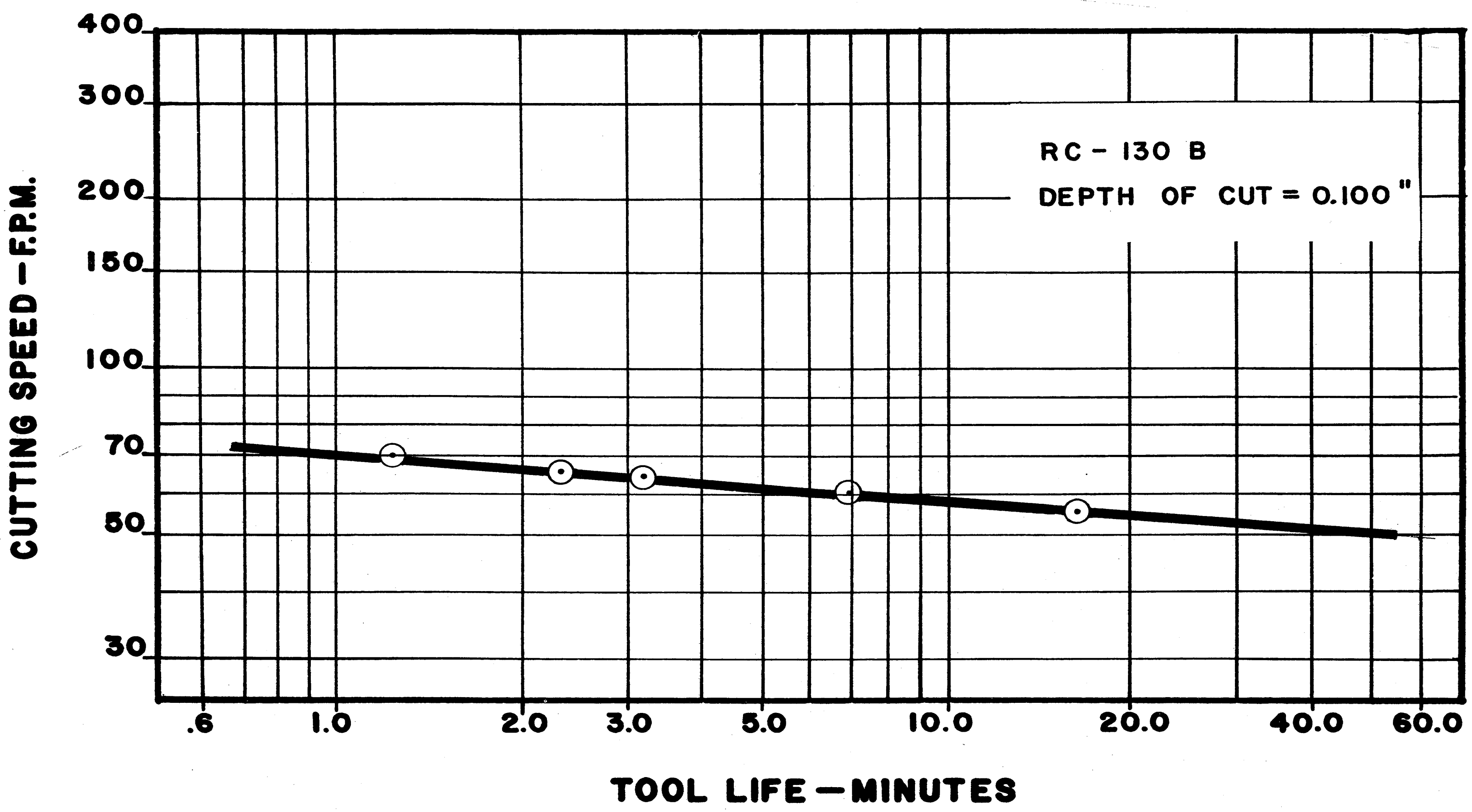


FIG. 35

CUTTING SPEED — TOOL LIFE

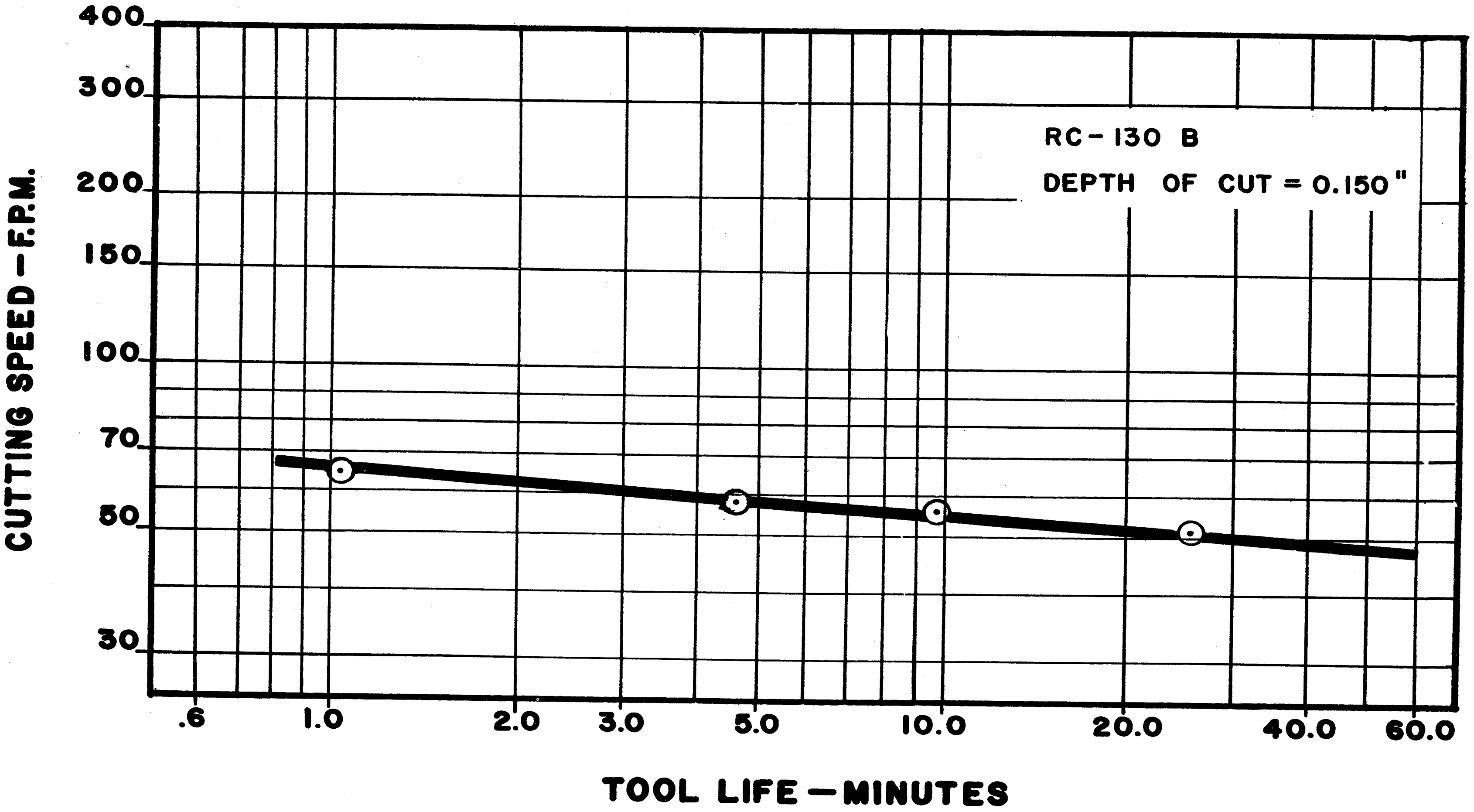


FIG. 36

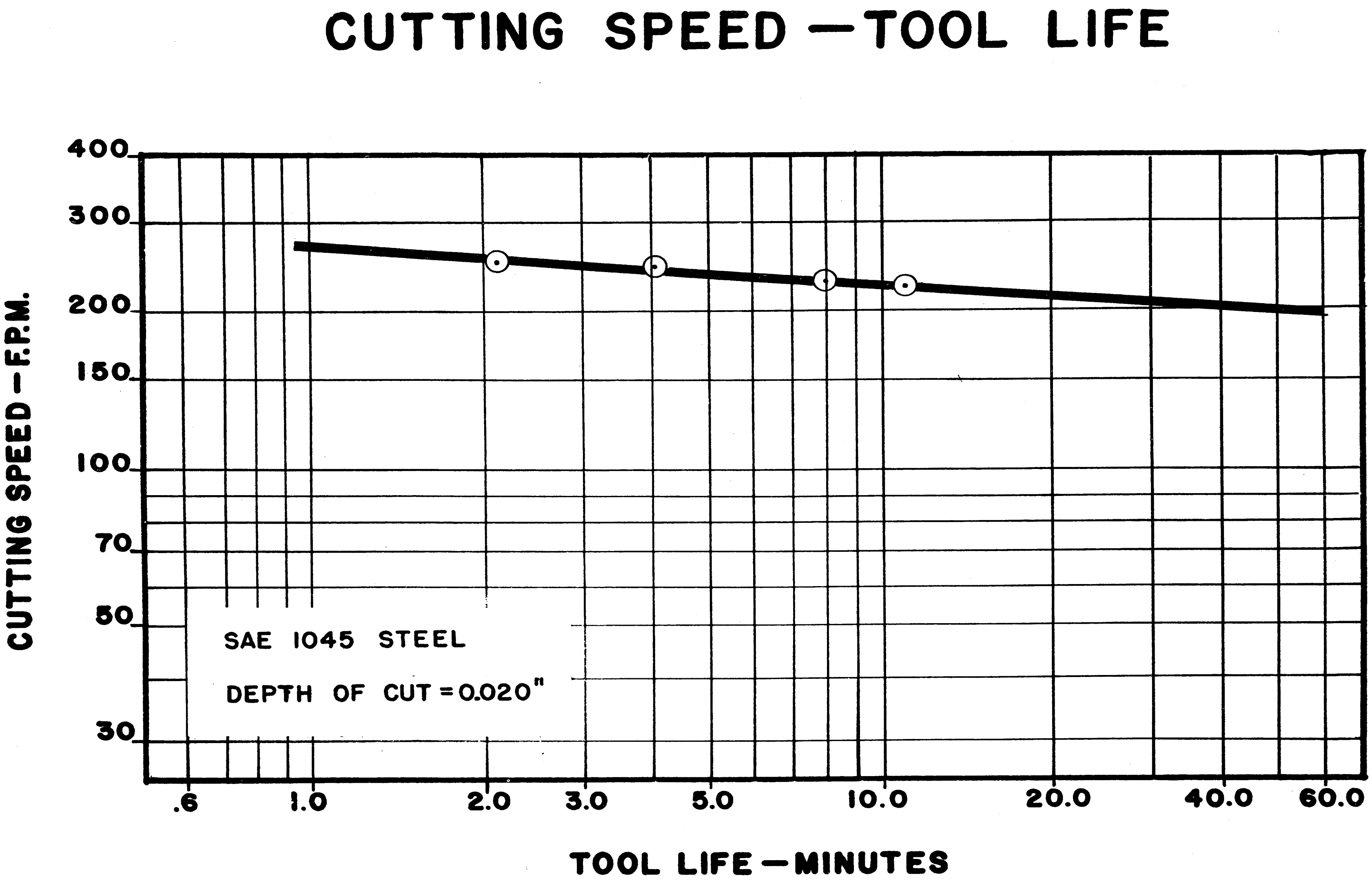

CUTTING SPEED — TOOL LIFE
CUTTING SPEED — F.P.M.
400
300
200
150
100
70
50
30
SAE 1045 STEEL
DEPTH OF CUT = 0.020"
.6
1.0
2.0
3.0
5.0
10.0
20.0
40.0
60.0
TOOL LIFE — MINUTES

FIG. 37

CUTTING SPEED — TOOL LIFE

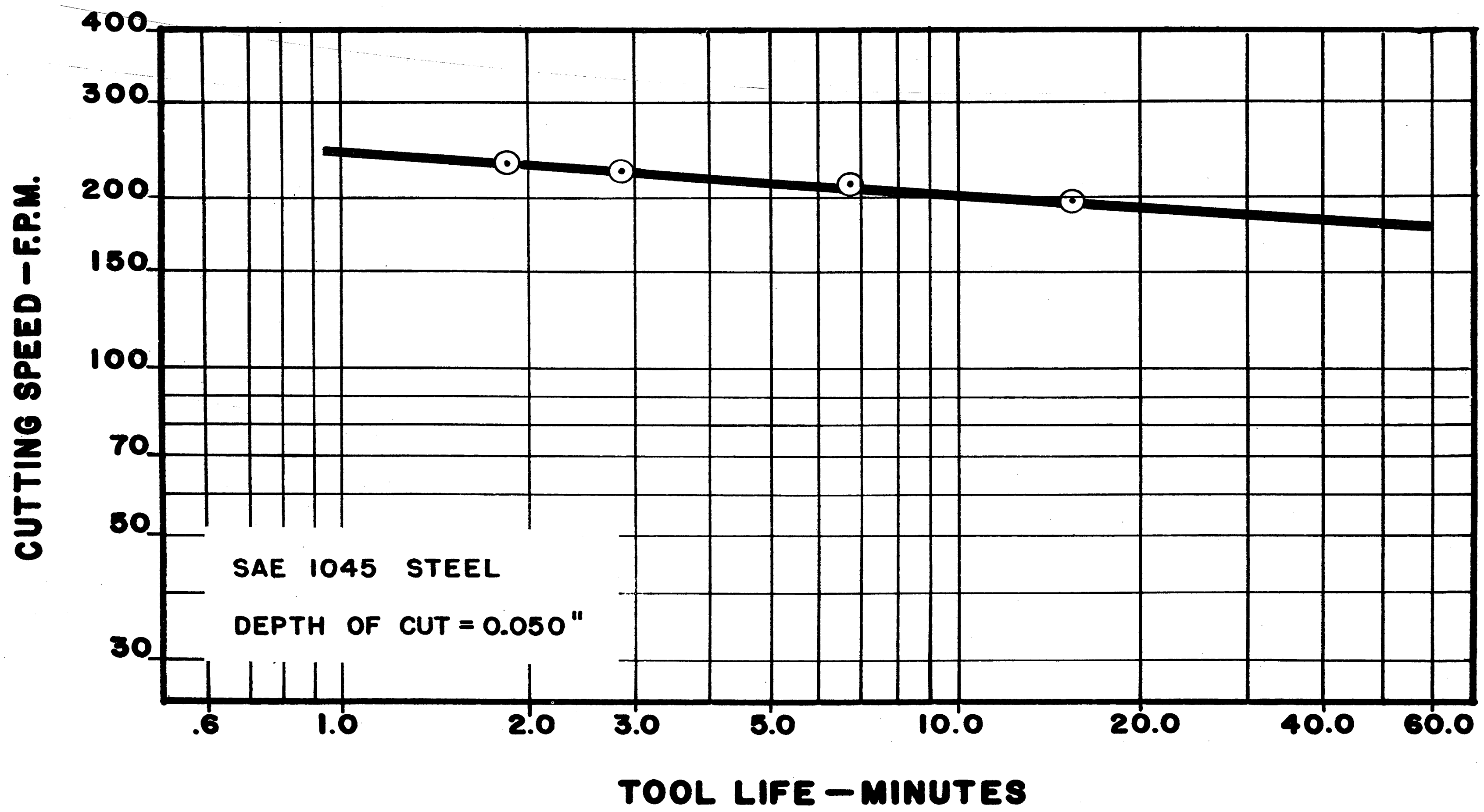


FIG. 38

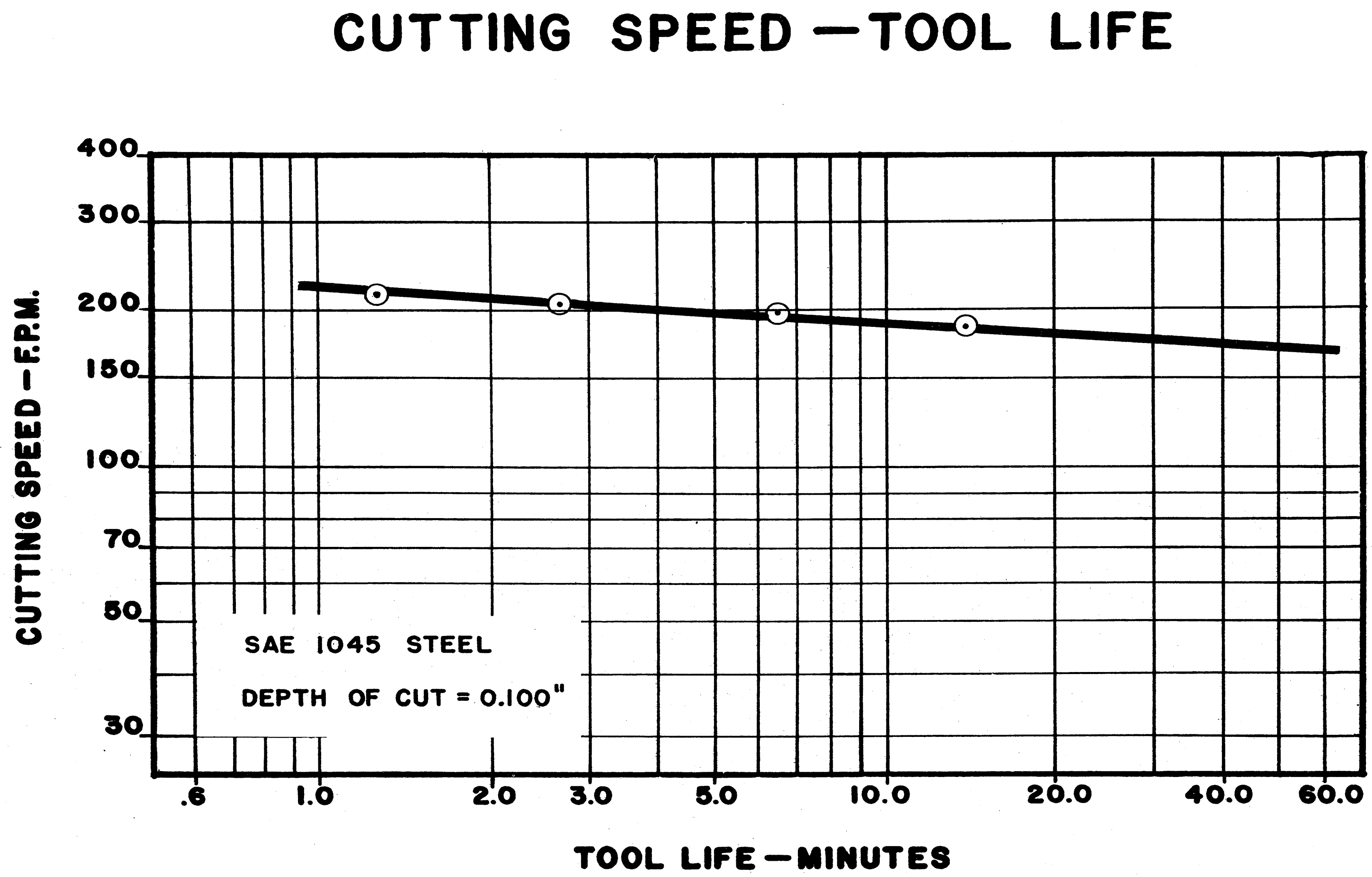

CUTTING SPEED — TOOL LIFE
400
300
200
150
100
70
50
30
CUTTING SPEED — F.P.M.
SAE 1045 STEEL
DEPTH OF CUT = 0.100"
.6
1.0
2.0
3.0
5.0
10.0
20.0
40.0
60.0
TOOL LIFE — MINUTES

FIG. 39

CUTTING SPEED — TOOL LIFE

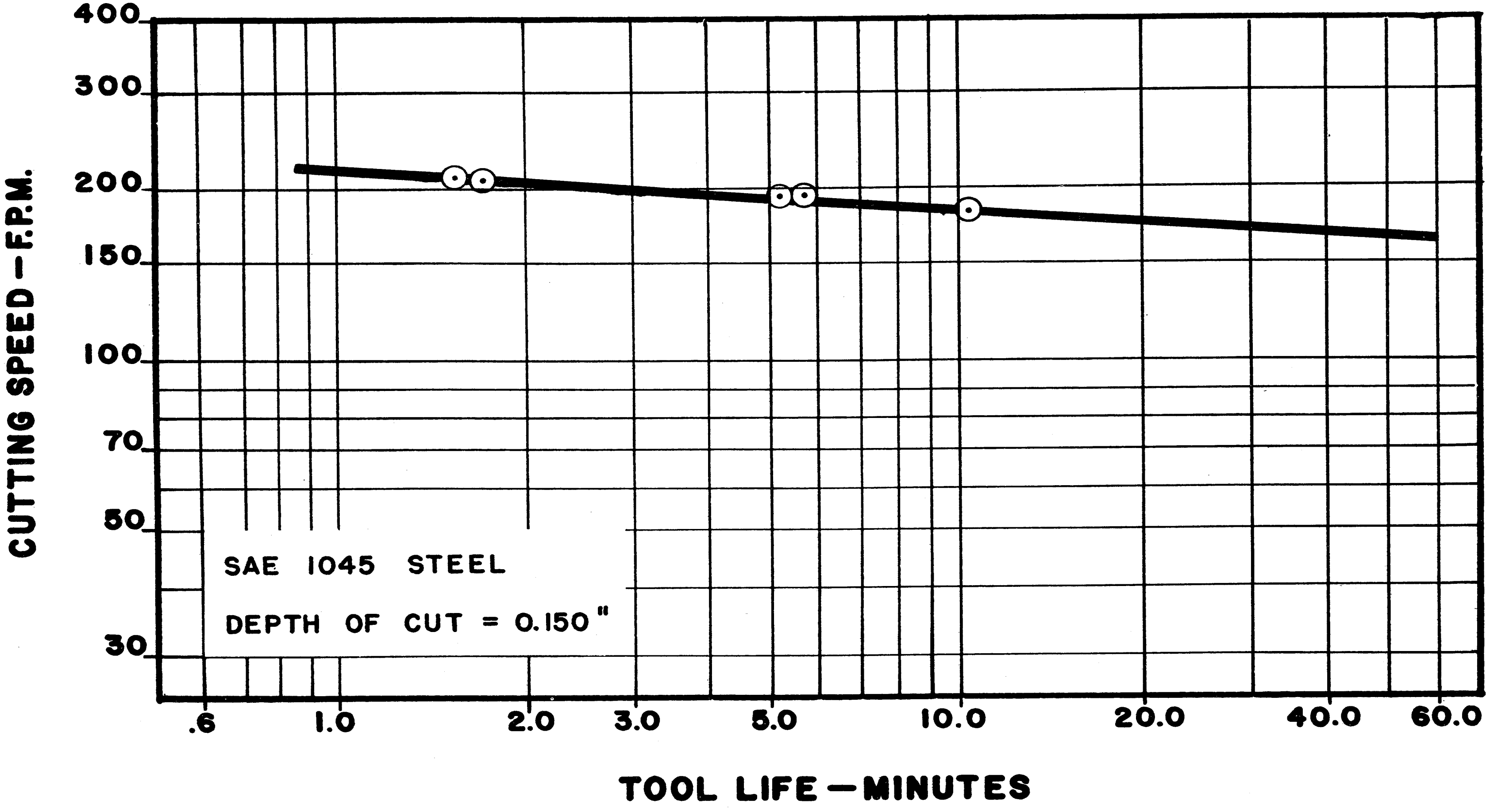


FIG. 40

CUTTING SPEED — TOOL LIFE

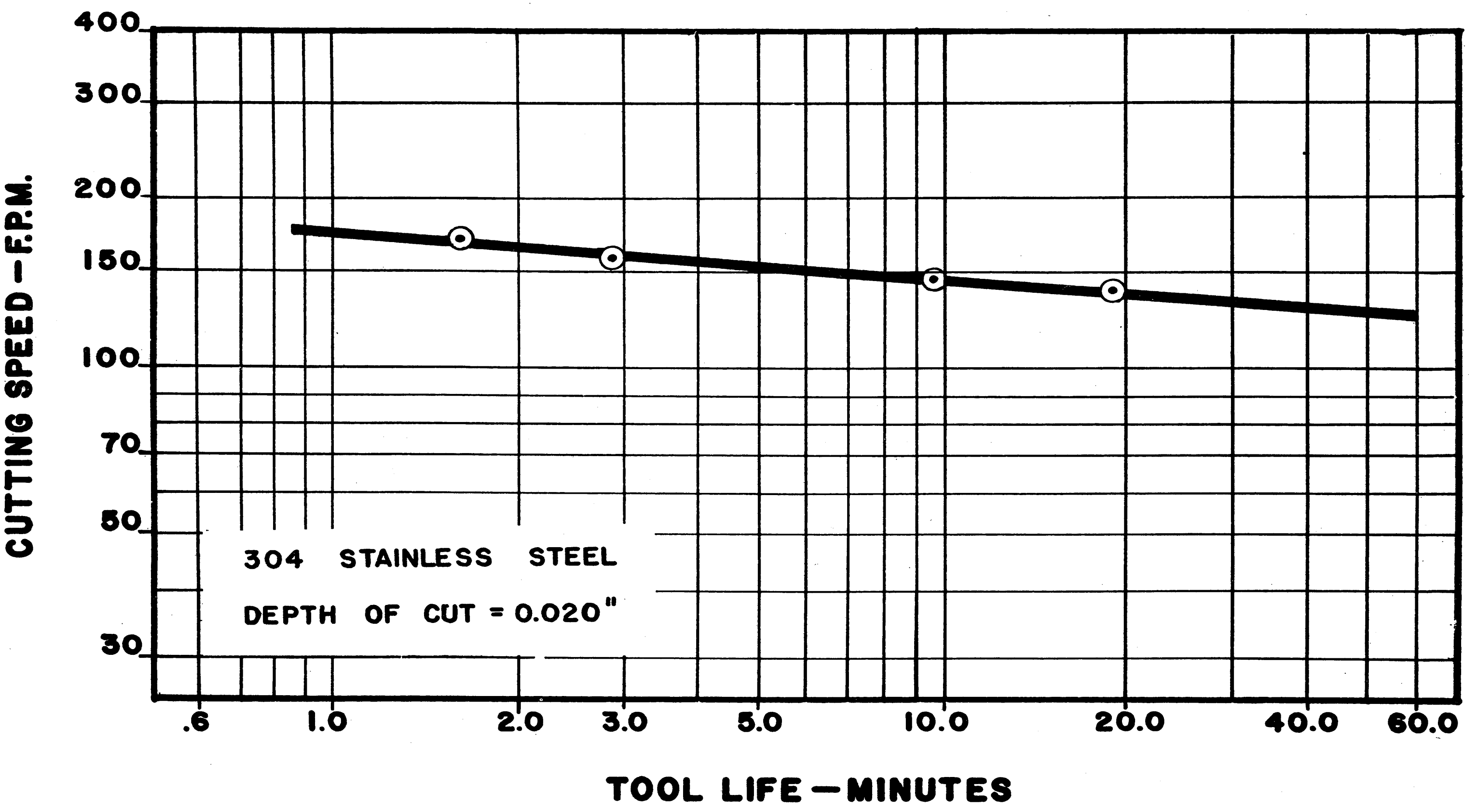


FIG. 41

CUTTING SPEED — TOOL LIFE

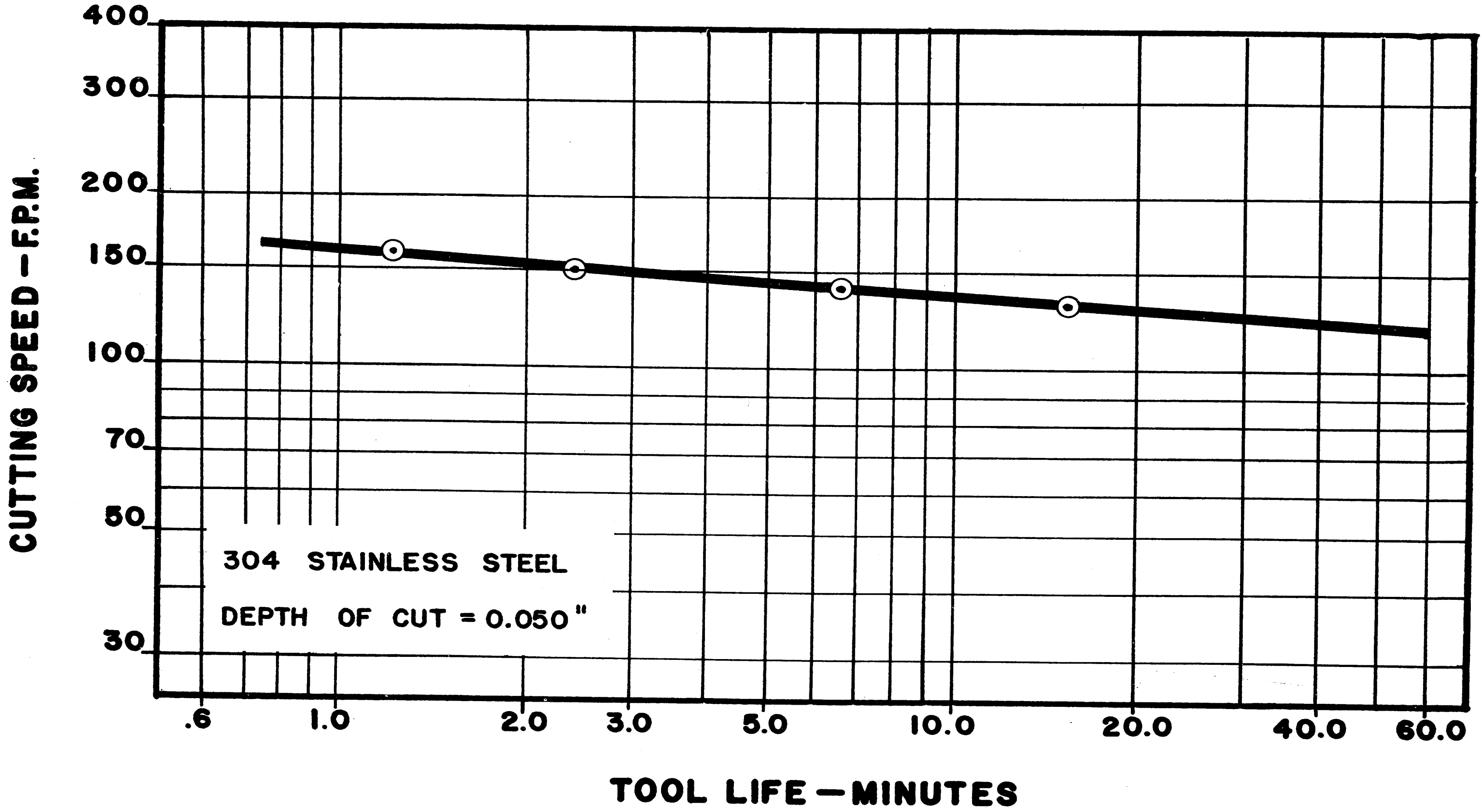


FIG. 42

CUTTING SPEED — TOOL LIFE

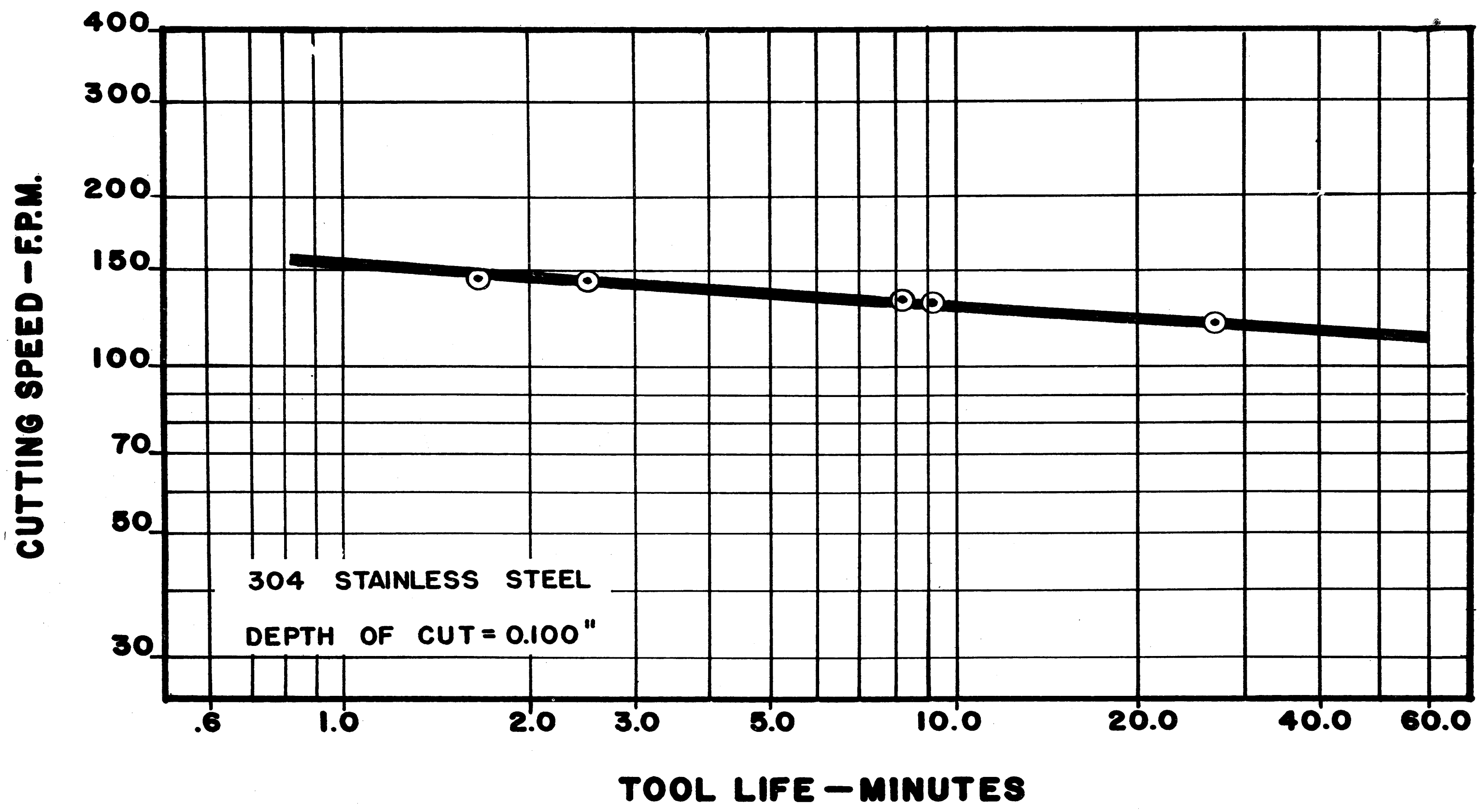


FIG. 43

CUTTING SPEED — TOOL LIFE

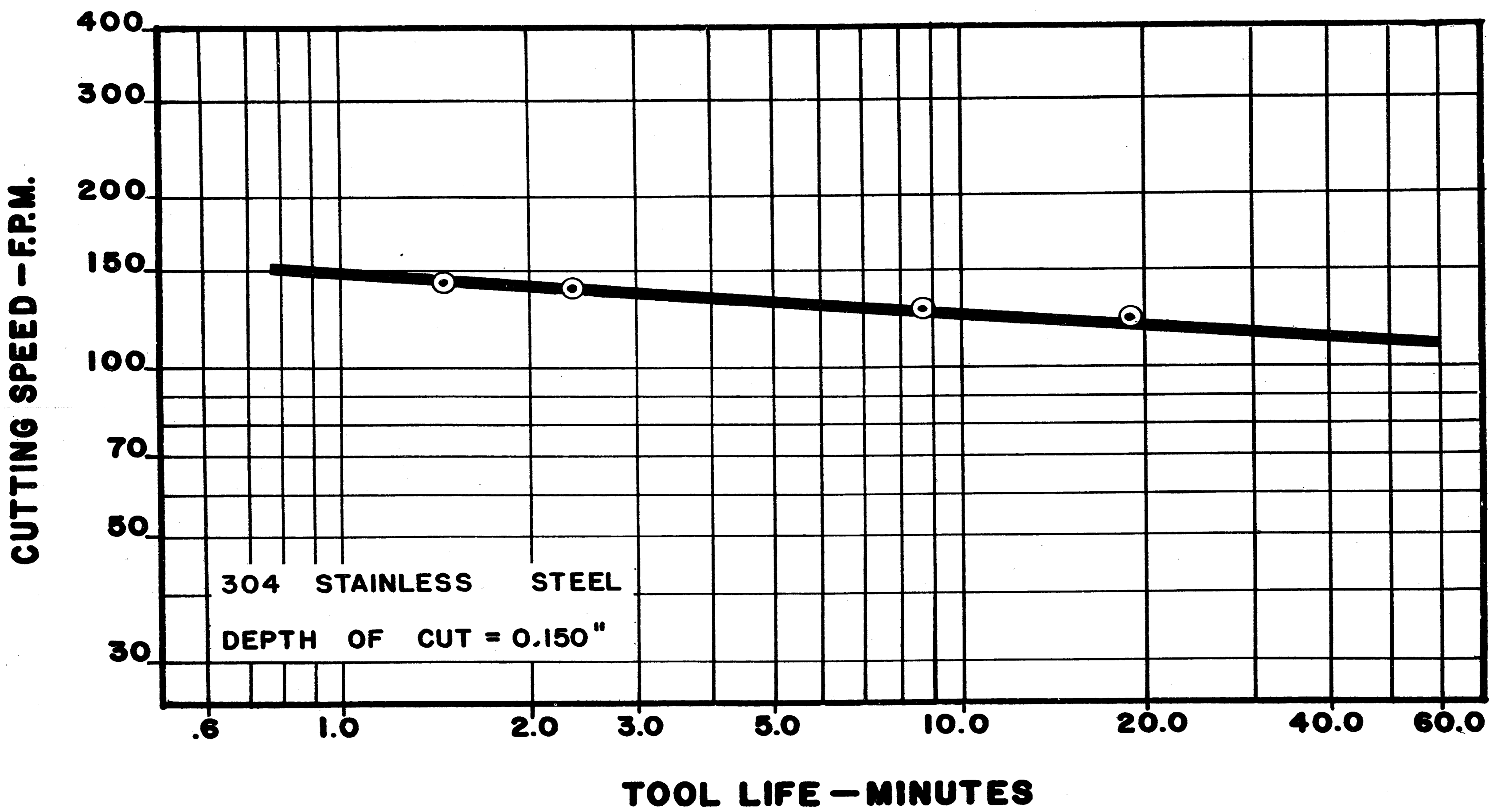


FIG. 44