CHAMBERLAIN MANUFACTURING Corporation

FINAL ENGINEERING REPORT

PHASE II
PRODUCTION EVALUATION
OF
NEW SAWING CONCEPT

CONTRACT DAAA25-70-C-0353

DOCUMENT NO. C7933-ED-002

Submitted 25 August 1971

Submitted To
Commanding Officer Frankford Arsenal
SMUFA-J4400
Philadelphia, Pennsylvania 19137

RESEARCH and DEVELOPMENT DIVISION

This Document Is Unclassified

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WATERLOO, IOWA

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Submitted By: John J. Bergstrom
General Manager
Research and Development

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CHAMBERLAIN MANUFACTURING CORPORATION

CONTRACT DAAA25-70-C-0353 (PHASE II)

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CHAMBERLAIN MANUFACTURING CORPORATION

CONTRACT DAAA25-70-C-0353 (PHASE II)

ABSTRACT

Using the new METALCUT XII bar-cutoff machine, approximately 1,540,000 square inches of 1561 and 1546 steel were cut in a Phase II Program to verify its productivity as a billet-separator in the manufacture of large caliber projectiles. Operation of the saw in Chamberlain operated Scranton Army Ammunition Plant resulted in cutting 19,300 to 23,100 square inches per single blade sharpening. These results represent the mean blade life for 1561 and 1546 steel respectively.

Cost comparison with the Nick-and-Break method of separation shows the saw to be competitive. Tooling costs are higher but are compensated for by reduced labor costs. The significant advantage of the clean, square-ended sawed billet is evidenced in fewer forging rejects resulting in less labor cost for reclaim and ultimately, a better quality shell.

On the success of this program, including the previous Phase I Feasibility Study, it is recommended that bar-cutoff machines of the METALCUT XII type be utilized in the production of large caliber projectiles

1. INTRODUCTION

This final engineering report documents services rendered by Chamberlain Manufacturing Corporation under Contract DAAA25-70-C-0353 per Modification No. P00001, "Phase II - Production Evaluation of New Sawing Concept," under the technical supervision of Frankford Arsenal. The new concept references the Goellner bar-cutoff saw and associated tooling. The manufacturers are Metalcut, Division of Paramount Textile Machinery Company for the saw and Heineman Saw Corporation for the blade tooling. Features of the new sawing concept include rapid billet parting and long blade life as compared to conventional cold sawing. Also, cutoff interfaces were of superior quality as compared to billets from other parting methods.

Phase I of this contract consisted of the preliminary evaluation of a prototype Goellner saw to prove feasibility of operation as a billet separator. Documentation of this successful effort was submitted to Frankford Arsenal on 29 May 1970 as a technical report entitled, "Investigation of New Sawing Concept." The currently completed Phase II program consisted of evaluating a production model of the saw, METALCUT XII, operating under production conditions in a plant manufacturing large caliber projectiles.

2. PURPOSE

The purpose of the Phase II Program was to confirm the production cutting application of the Goellner bar-cutoff saw by actual operation in a shell production plant. It is anticipated that the results of this evaluation may lead to large scale implementation of this billet-separation method in the manufacture of large caliber shell. To this end it was endeavored to optimize actual operation of the saw, to determine the effect of sawed billets upon subsequent shell fabrication and to establish a realistic production cost for the new method of billet separation.

Specific objectives of the program are listed below:

2.1 Optimization of Operation

a) Determine production rates - the number of partings per hour over extended period of operation.
b) Determine weight control of the billet through control of billet length.
c) Determine tool life - the number of partings per blade sharpenings and the number of sharpenings per blade before retipping.
d) Establish the criteria governing the required change of a worn blade.

2.2 Effect on Shell Fabrication Processes

a) Determine the reduction in material scrap rates normally occuring from inaccuracies of billet length, poor quality of parted surface and cambered bar stock.

b) Determine the effect on forging quality with respect to concentricities of metal flow and to external and internal surface finishes.

c) Determine the effect on forge tooling with respect to scoring or erosion.

d) Determine the effect on shell machining.

2.3 Establishment of Production Cost

Determine costs for a direct comparison with the nick and break method of billet separation. Consideration was given to the following:

a) Operating labor required, type and degree of skill.
b) Capital equipment, initial and sustained tooling.
c) Maintenance labor, type and degree of skill.
d) Supporting facilities as for material handling and chip removal.
e) Machine downtime for retooling and preventive maintenance.
f) Operating utilities and floor space.
g) Indirect costs (savings) attributable to the effect on process control during subsequent shell fabrication.

3. CONCLUSIONS AND RECOMMENDATIONS

3.1 Conclusions

Enumerated in this section are ten points in conclusion to the test program for production evaluation of the Goellner Saw under the conditions specified in Section 5, Procedure. It is reiterated here for qualification that bar stock of two types of steel, only, were cut and only one saw was evaluated. In general, the Goellner METALCUT XII saw was shown to be competitive as a bar separation tool in the manufacture of large caliber shells.

1. The cost per cut for the sawed billet is competitive with the cost for the broken billet. Billet-feeding operations considered for comparison included both line-dependent and centralized installations.
2. The general quality of the forgings from sawed billets is superior to that of forgings fabricated from broken billets. Rejection rates for inspected forgings may be reducible by 40 to 46%. Emphasis is placed on the surface finishes; particularly in the forging cavity.
3. Compared with the broken billets, the sawed billets with their clean, square ends cause less wear in the forge tooling. Also, the sawed billets are easier and more economical to handle during heat treatment.

4. Sawing facilitates closer control of the billet length and, consequently, closer control of the billet weight than in the nick-and-break method. Accuracy of billet weight is ± 1/2 pound when cutting 6-inch RCS steel bar. Variations in cross-sections of bars negates closer control. Another result is reduced trim scrap at the center-and-cutoff machining station.

5. Data on machine operation which yielded the best performance are shown below:

STEEL GRADE AND SIZE	BLADE FEED (rpm)	SURFACE FEED (fpm)	BLADE FEED (ipm)	CHIP LOAD (Inch)
1561, 6" RCS	50	340	12½	.00833
1546, 5¼" RCS	60	408	12½	.00833

For minimum blade cost per cut, a 60-tooth, 18° negative rake blade is best suited for the 1561 bar stock and a 50-tooth, 18° negative rake blade, for the 1546 stock.

6. Production rates to be expected with the above machine operations, assuming 100% efficiency on cycle times actually achieved, are as follows:

TYPE OF STEEL	RATE (Pc/Hr)	CYCLE TIME (Minute)
1561	89.6	.67
1546	92.3	.65

7. Blade life per grind (before resharpening) can be expected to exceed 667 cuts (23,339 square inches) and 949 cuts (25,613 square inches) for the 1561 and 1546 steels, respectively.

8. Though the maximum number of grinds per blade before retipping was not determined during this program, an estimated eight grinds can be expected based on the results obtained.

9. The loading of the saw motor (amperage drawn) is a monitor of blade wear. Loads can be expected to rise 20% to 39% before a change of saw blades becomes necessary. This corresponds to the conditions described in Item 1 above.

10. The occurrence of a chipped tooth during the early life of the blade does not warrant an immediate change of blades. Such a blade may be used economically until the general wear level is reached with respect to motor load.

3.2 Recommendations

Further evaluation of the parting capabilities and the production capacities of the METALCUT XII saw is recommended. Though it has shown to be competitive with the nick-and-break method of cutting two specific grades of steel while operating in a shell production plant, complete exploitation of the machine is yet to be achieved. Chamberlain, therefore, makes the following recommendations:

1. The specific saw which was evaluated during the current Phase II Program should remain at the Scranton Army Ammunition Plant. This saw would serve as a reliable back-up billet separator to the existing nick-and-break presses during the interim period prior to completion of plant modernization. Besides being employed to assist in meeting jeopardized production schedules, this saw would be used to cut heats of steel which were too soft to separate by nicking and breaking. Such steel occasionally is received at the Scranton facility. In addition, this saw would be available for the convenience of Frankford Arsenal to cut special steel grades and sizes for particular evaluation.

2. Encouragement should be given to industry-wide use of the METALCUT XII saw in shell-producing plants. However, studies are in order as to how the saws should best be operated because indications are that more than one saw is required in a given production installation for maximum efficiency. Questions to be answered include: Should each saw feed a forge line directly or should several saws feed a central stockpile? What type of billet conveyor system is best; gravity or powered; overhead or floor level? How are the scrap chips to be removed from one machine or a bank of machines? Can both right and left-hand models of this saw be used to advantage? What type of scramble table and bar feed system is best for a given installation of saws?

4. MACHINE DESCRIPTION

The Goellner Saw evaluated in this program is a production model METALCUT XII. Reference photographs on the following pages. Compared with the prototype model evaluated during the Phase I study, the new machine is approximately 50% bigger and heavier, weighing 24,000 pounds. A 50 horsepower spindle motor is used instead of the 25 horsepower unit in the older saw. Castings are incorporated in the new saw whereas machined weldments were necessary for the prototype. With the exception of the above and other minor refinements, the METALCUT XII is identical in features to the prototype model.

Following is a brief description of those features. The Goellner Saw uses carbide-tipped circular blades which rotate downward through a rigid workpiece support. A hydraulic clamp-down system restrains the workpiece with 14,000 pounds force. A gib system of special design on the moving saw head reduces vibration to improve saw performance and thus prolong blade life. A power screw system activates the head to reduce erratic feeding and breakthrough problems generally associated with the more common hydraulic feed systems. An anti-backlash feature is incorporated in the gear drive, a necessity with carbide blade usage.

The saw blades are ground with alternately positioned primary and secondary teeth. The former removes a center-of-the-cut chip of approximately .150 inch width while the latter removes smaller chips of about .050 inch width from each side of the primary cut. Figures 1 and 2 illustrate the teeth configurations as ground. Characteristic of this grind is the negative rake angle, uncommon with conventional cold-saw tooling. Negative rake requires greater power from the drive unit which is supplied by the aforementioned 50 horsepower motor.

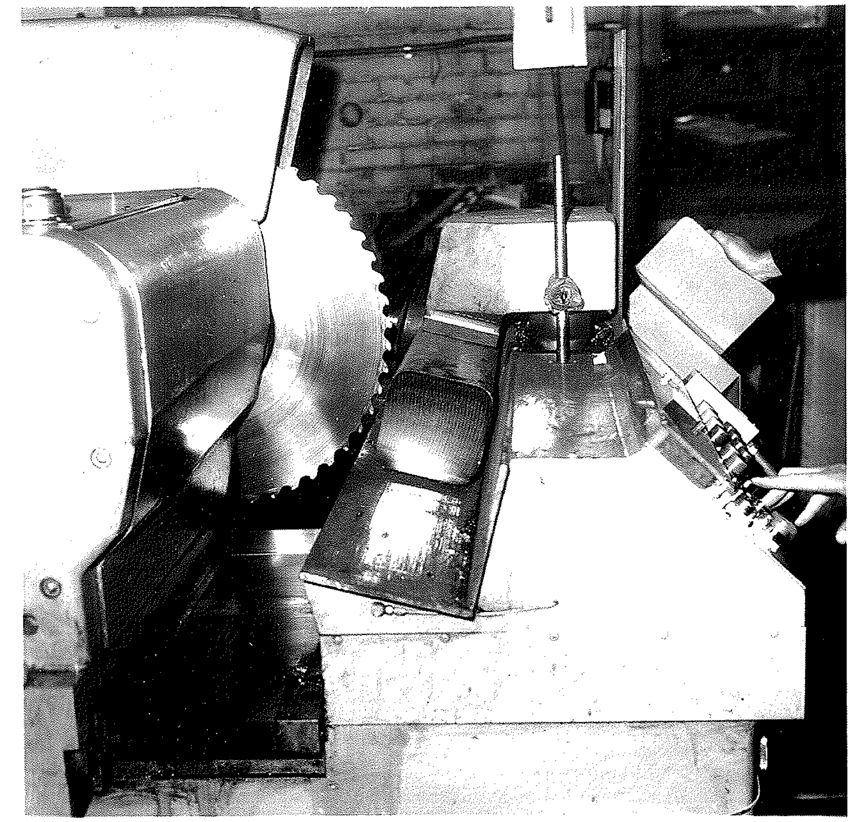
4.2 Several shortcomings with respect to operator safety are present in the METALCUT XII machine. Safety personnel at the Scranton plant advised that certain modifications should be made before a continuous operation began. These were:

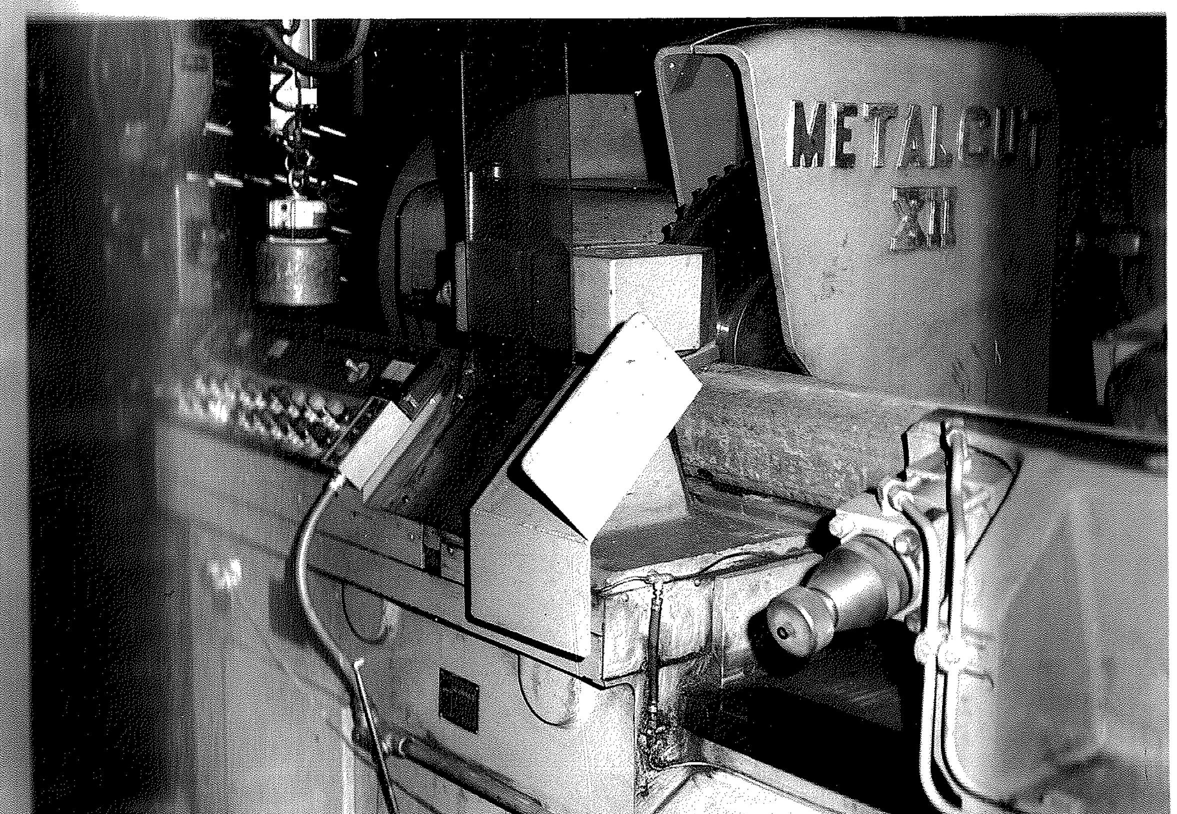
1. Modification of metal guard which extends out over the indexing mechanism as the bar is indexed into position. Additional guards were attached to the existing guard to eliminate the possibility of the operator placing his hand at a pinch point.

2. Extending of the existing Plexi-glass shield over the center of the clamping system to protect the operator from possible flying chips, scale, or broken saw teeth.

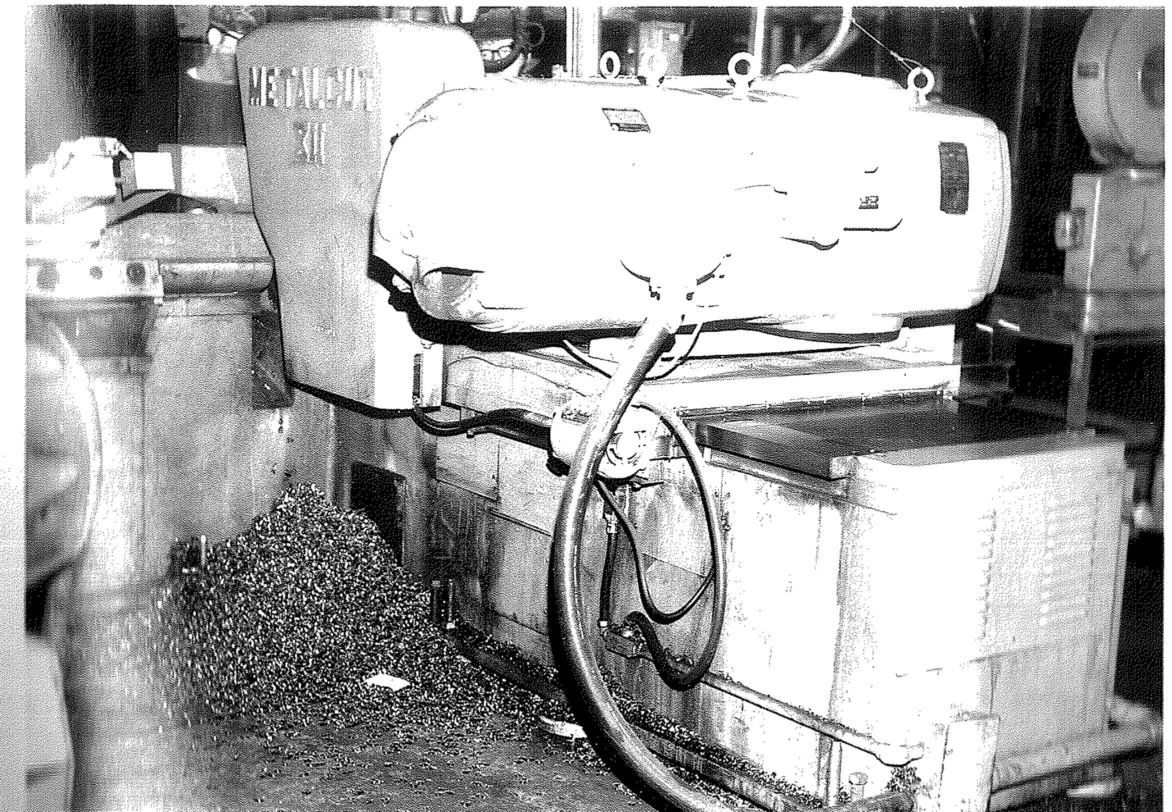
Strong emphasis was placed on having an improved method of side dressing the blade when drifting occurs. A semi-automatic or automatic method is recommended for future saws to eliminate the potential hazard existing in the present machine.

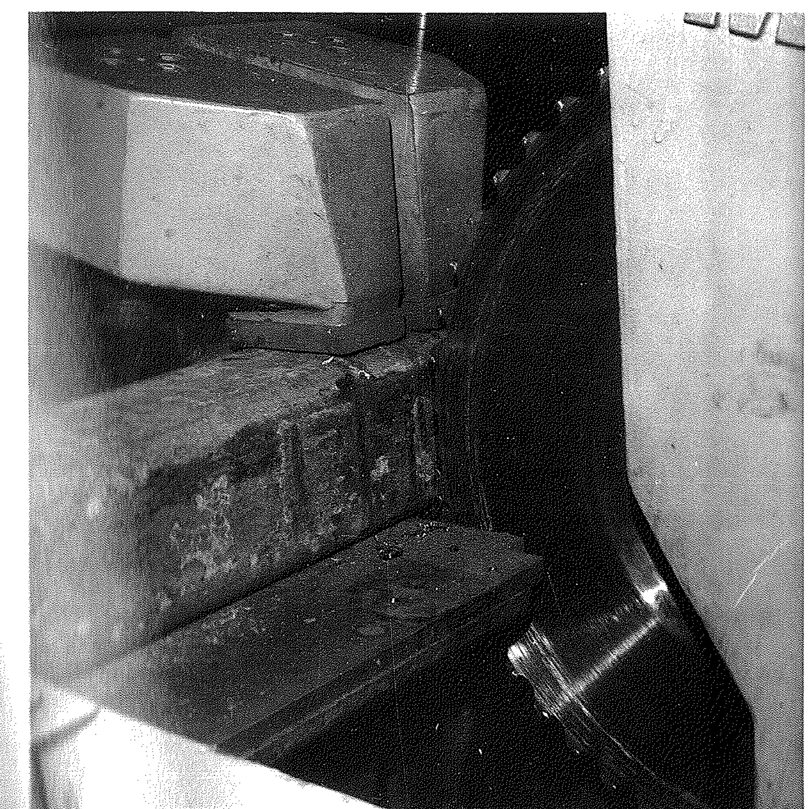
Chamberlain





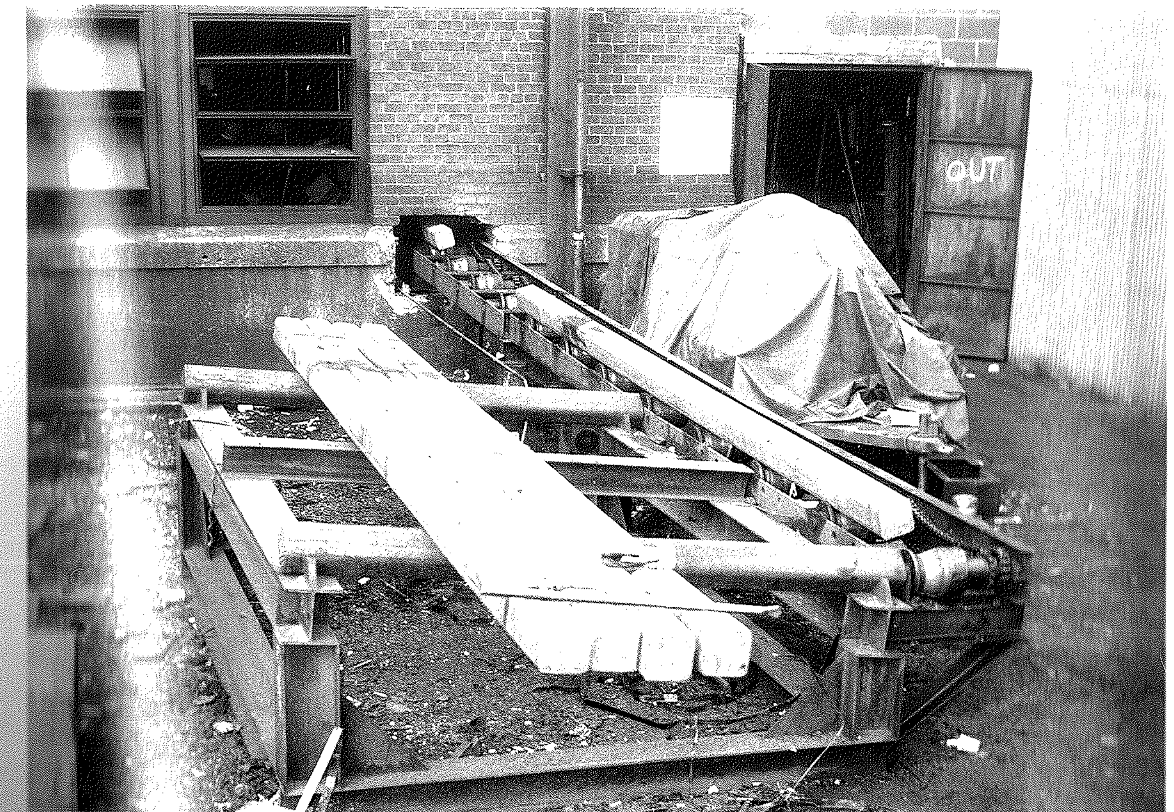
METALCUT XII BAR — CUTOFF MACHINE





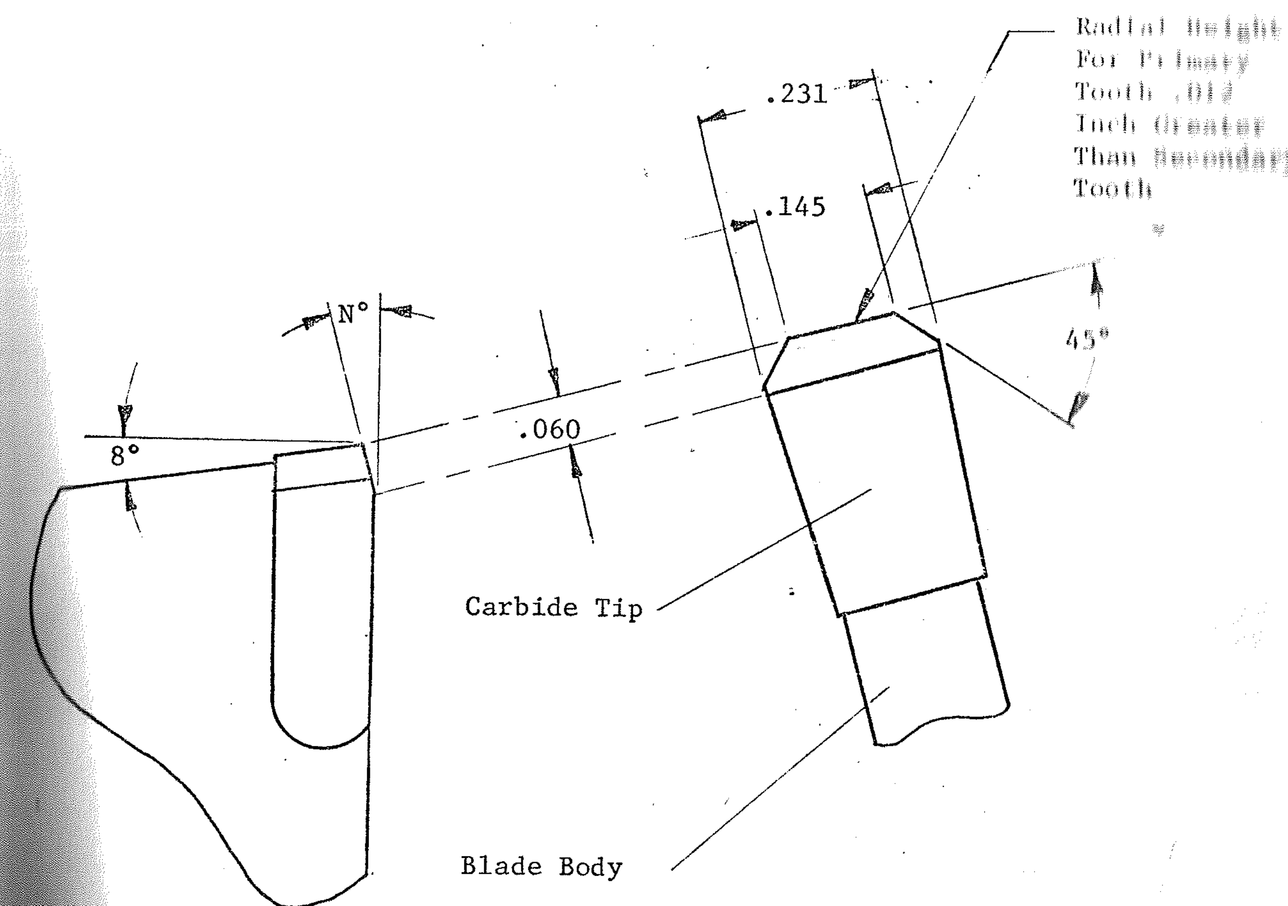
TOP: VIEW SHOWING 50hp MOTOR

BOTTOM: BEGINNING CUT — NOTE DOUBLE-JAW CLAMP SYSTEM



TOP: RACK AND CONVEYOR — BAR FEED SYSTEM

BOTTOM: BAR INDEXING MECHANISM



N = Negative Rake Angle

FIGURE 1

DETAIL - PRIMARY TOOTH

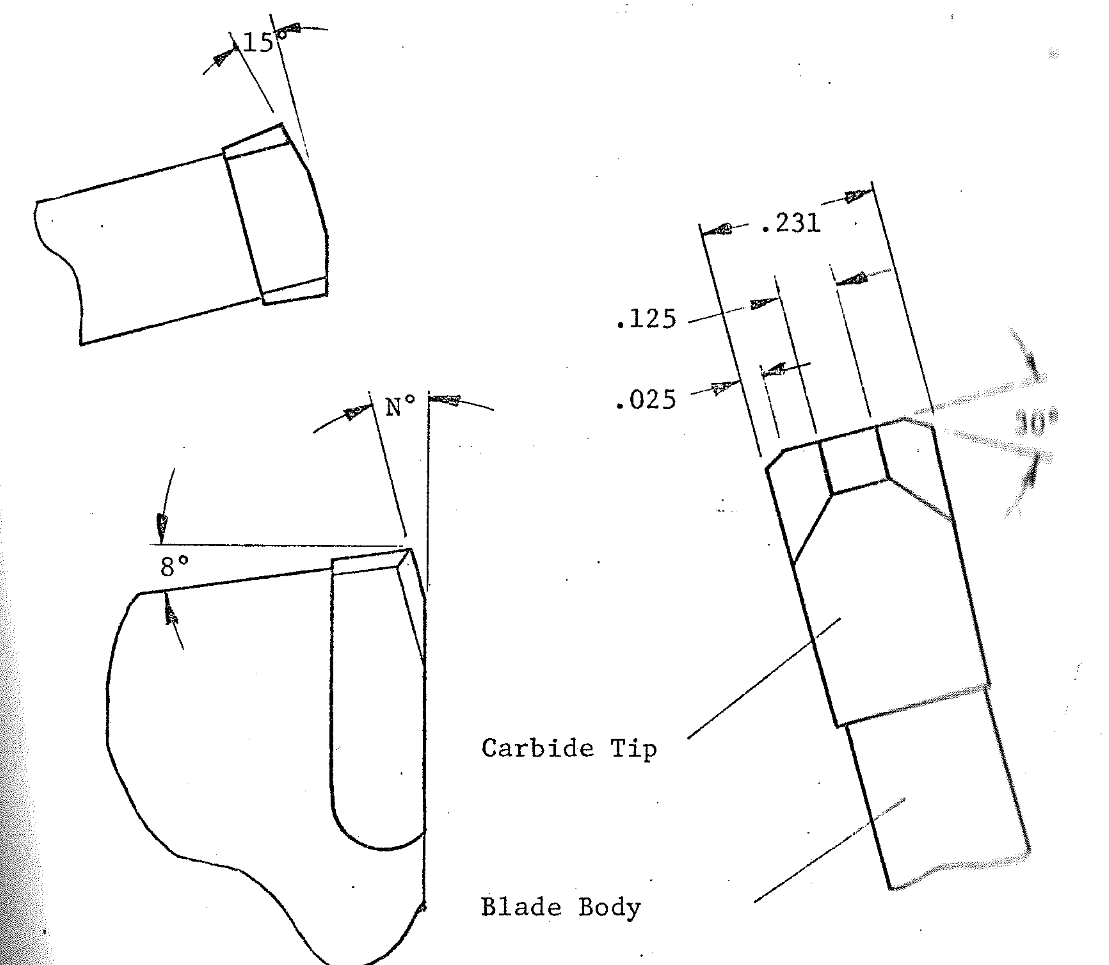


FIGURE 2
DETAIL - SECONDARY TOOTH

5. PROCEDURE

5.1 General

The testing program began with the installation of a METALCUT XII Bar-Cutoff Saw at the Scranton Army Ammunition Plant (SAAP), Scranton, Pennsylvania. During the period 23 February through 18 June, a total of 50,636 cuts (1,542,978 square inches) were made on both 1561 6-inch round corner square (R.C.S.) and 1546 5-1/4-inch R.C.S. steels, using a total of 76 sharpenings on 30 saw blades. These steels are used in the fabrication of the M437, 175-mm and the M107, 155-mm projectiles, respectively. Various machine speeds and feeds were tried using 50 and 60 tooth blades having teeth ground with negative rake angles of 12°, 15° or 18°. To evaluate the performance of the saw in a production environment, a two-shift operation was started on 19 April and extending through the end of the program. In total, 13 heats (23,000 billets) of 1561 steel and 11 heats (30,000 billets) of 1546 steel were sawed. These billets were monitored while being processed through subsequent forging and machining operations to determine improvements over the present nick and break process of billet separation.

5.2 Test Variables

The grade of carbide used for the blade teeth was universal for all blades in the test program. The carbide was a hybrid having the analysis of a standard grade C5 but the hardness of a C70.

This carbide resists impact failure or chipping because of its high rating of transverse rupture strength. The choice of carbide was the strong recommendation of both Heinemann Saw Company, the manufacturer and Metalcut, the saw manufacturer. Consequently, carbide grade did not enter into the program as a variable though it is felt by Chamberlain personnel that future exploitation may be worthwhile. Of the 30 blades used in the program, all were 26 inches in diameter, 15 each of 50 and 60 teeth. Negative rake angles ground on the 60 tooth blades were 12° (5 blades), 15° (5) and 18° (5); for 50 tooth blades, 12° (11 blades) and 18° (5). One blade was reground with a different rake angle than initially ground. Rake angles greater than -18° were not tried because of the limitations of the specialized machine used to grind the teeth. The variables investigated were those directly affecting tooth wear, as follows:

1. Grade and size of steel sawed (1561, 6-inch RCS and 1546, 5-1/4-inch RCS)
2. Spindle speed (RPM)
3. Surface feed (feet per minute) and saw feed (inches per minute)
4. Tooth load (inches per tooth)

Documentation

A record was kept by the saw operator to include the following items listed on the Daily Log Form. Reference Figure 3.

1. Weight of second billet cut of every bar, using a Toledo Model 2481 scale.

[illegible] ______________________

HEAT NUMBER ______________________

BLADE NUMBER ______________________

No. Of Teeth ____________ Blade Dia. ______________

No. Of Effective Teeth ____________ Tooth Angle ______________

Bar & Billet No.	Date	Diameter Or Cross Section	R P M	S F M	Chip Load	In/Min Feed	WEIGHT	AMPS	Length	End Piece	R E M A R K S

F I G U R E 3

SAMPLE DAILY LOG FORM

2. Rotational speed of blade as indicated by the spindle RPM indicator mounted on the machine control panel.
3. Feed rate of the blade as indicated by the feed indicator mounted on the machine control panel.
4. Spindle motor load (amps) obtained from an Amprobe AC Ammeter Recorder, Model LAA82, monitoring the motor line load.
5. Piece to piece cycle time recorded with a stopwatch for each machine setting.
6. Length of the last billet of each bar measured with a standard tape measure.

5.4 Sequence of Testing

Installation involved not only the saw itself but also the support equipment needed to handle the raw bar stock up to the saw and the sawed billets leaving the saw. The saw was positioned near the controlled-atmosphere Selas Furnace which serves the 175-mm Verson Press Line, and also near Scranton's No. 7 Hagan Furnace which is part of a 155-mm line. A power conveyor and scramble table were located outside in the steel yard and a three foot square portion of the existing building wall was removed to allow the 2300 pound bar to feed onto the bar handling and indexing mechanism of the saw. After sawing, billets were picked up manually with an air cylinder hoist utilizing a magnet head and were placed on steel pallets. Loaded pallets were stored in an area next to the Selas Furnace until ready for forging (See photographs following this section).

After installation, a Metalcut service engineer was on hand to assist in final hook-up of the hydraulic components and to familiarize necessary personnel in the operation and maintenance of the saw. Operation of the saw then was performed by actual production labor under the direct supervision of Scranton's production management.

Selection of initial machine settings and tooling were dictated by the recommendations of the Phase I study. Changes thereafter were made as deemed advisable by Chamberlain's Research and Development engineer in charge. Generally, after selection of a specific blade and machine setting, the blade was used until considered dull, with periodic checks for visual chipping of teeth and amount of tooth wear. The motor load was monitored visually using the machine ammeter while the blade was in use.

The first four blades were expended debugging the saw, training the operator and establishing procedures. The results obtained from these blades are not included in the tabulations in this report.

The sequential elements of operation to saw one complete bar were as follows:

1. With a bar in position on the power conveyor, the operator would bring the bar forward onto the indexing system of the saw.
2. The bar was clamped in the index slide and the slide was advanced until the bar was positioned for the required length of billet.
3. The index slide was released and the hold-down jaws were activated, thus completing the manual cycle. The saw then was ready for automatic operation.

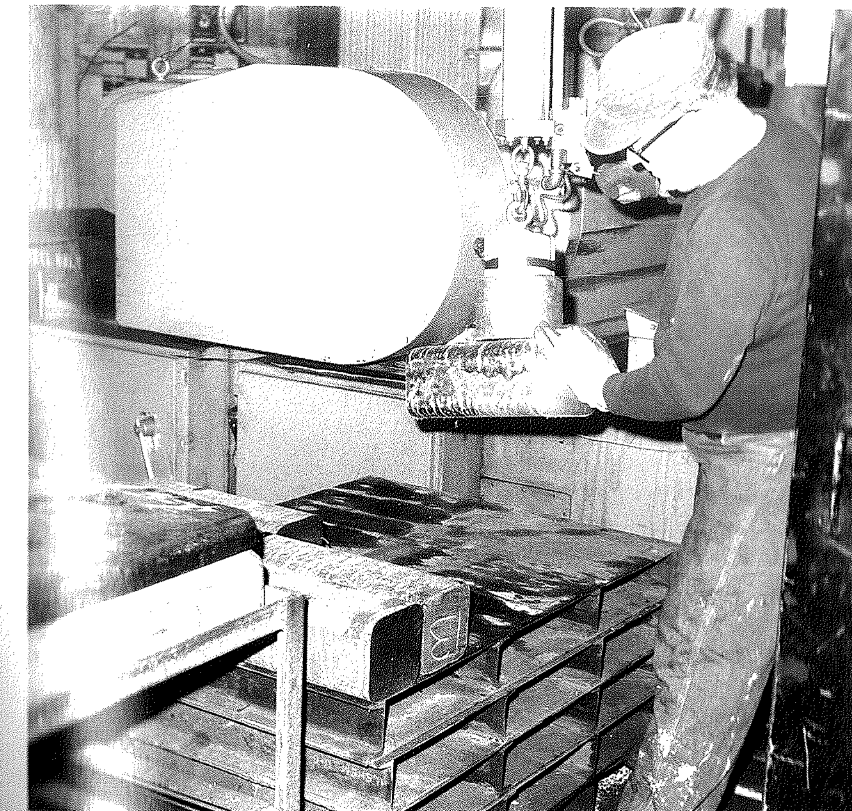
4. After pushing the "Auto" button, the machine would cycle automatically and cut the barstock into billet lengths as preset on the index control.
5. The operator weighed the second billet sawed and recorded same. This billet was the first that was measured automatically by the indexing mechanism.
6. While the machine was on automatic operation, the operator was free to monitor blade drifting and motor load and to bring the next bar into position with the power conveyor.
7. As the second to the last billet was cut, the operator measured and recorded the length of the end piece to determine if a trim cut was required. If necessary, a trim cut then was made.

Process Monitoring

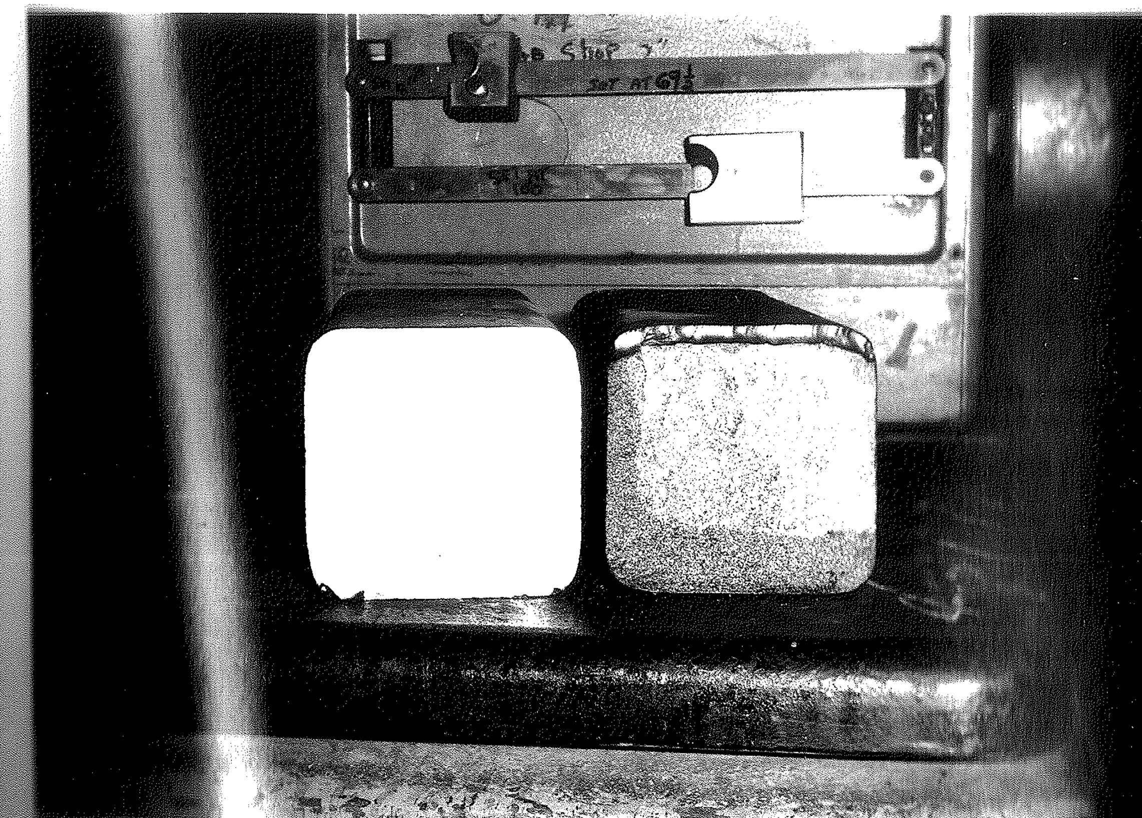
After sawing and stacking a complete heat of steel (approximately 1800 billets for the 6-inch RCS stock and 3000 billets for the 5-1/4-inch RCS stock) the billets were loaded manually into the furnaces for heat treatment. After forging and cooling, the forged cans were shot-blasted inside and out and inspected 100% for the following defects:

1. Shorts (heavy base, light weight, dog ears).
2. Internal surface defects (scale, base and wall laminations, burrs and tool marks).
3. External surface defects (burrs, tool marks, scale).

Records of the inspection operation were kept for the sawed billets as well as for an equivalent number of broken billets which were selected at random for purposes of direct comparison.

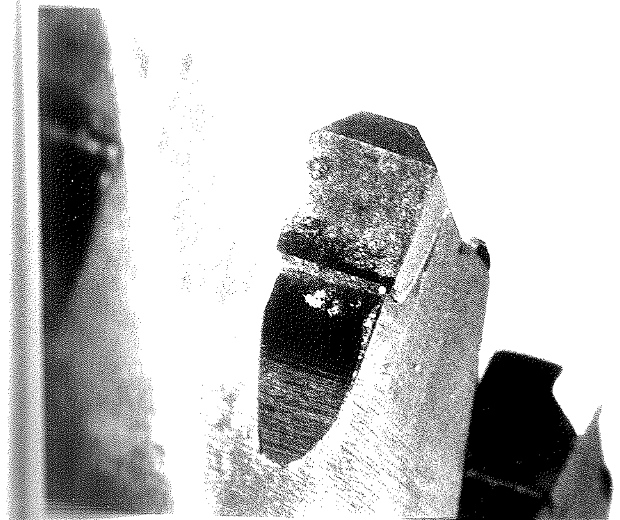


STACKING SAWED BILLETS

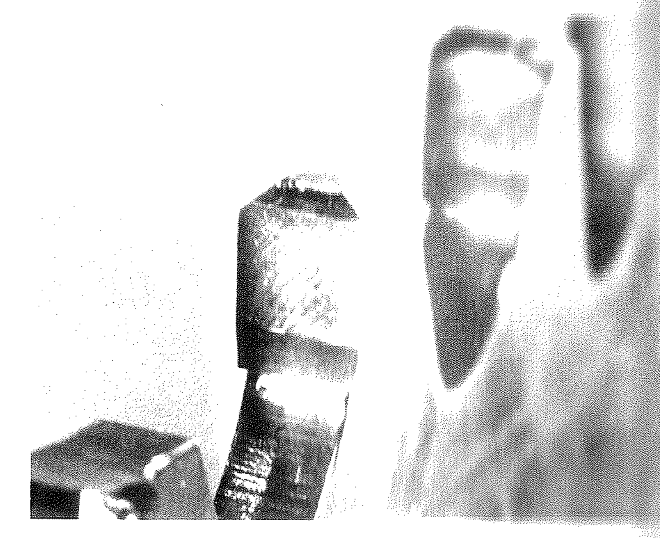


TOP: BILLET ENDS — SAWED VS. BROKEN

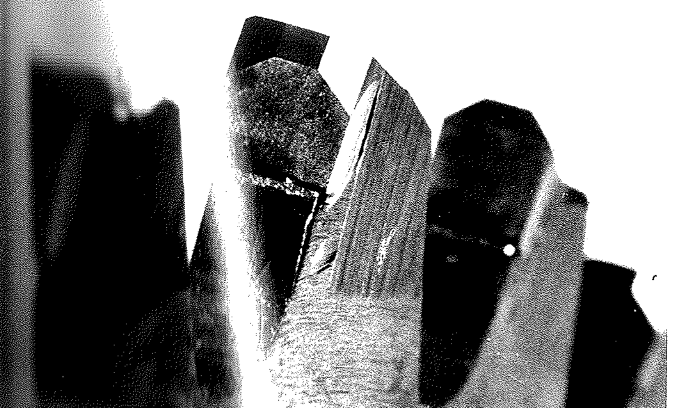
BOTTOM: SAWED BILLET AFTER ATMOSPHERICALLY-CONTROLLED HEAT TREAT — NOTE MINIMUM SCALE



PRIMARY TOOTH – NEWLY SHARPENED



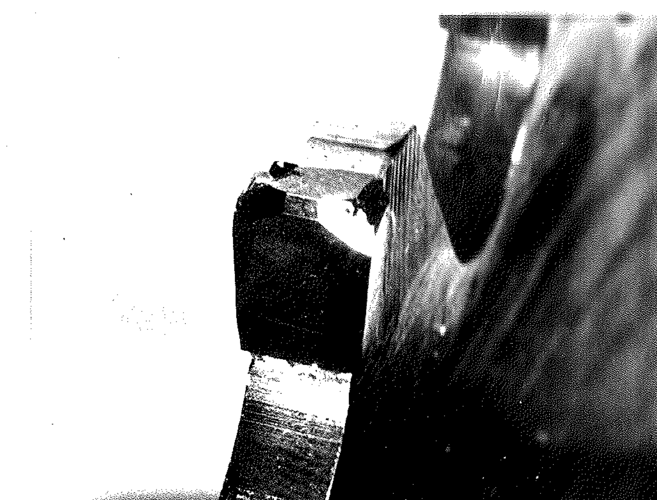
PRIMARY TOOTH – SHOWING WEAR



SECONDARY TOOTH – NEWLY SHARPENED

SECONDARY TOOTH – EROSIVE WEAR

PRIMARY TOOTH – EROSIVE WEAR PLUS FATIGUE CHIP (TIP REAR)



SECONDARY TOOTH – EROSIVE WEAR PLUS FATIGUE CHIP (OPP. REAR)

PHOTOGRAPH NO. [illegible]

CARBIDE TEETH (BEFORE AND AFTER)

RESULTS

A total of 50,636 cuts, equivalent to 1,542,978 square inches of sawed area, were made on two grades of steel - 1561, 6-inch round corner square (RCS) bar stock and 1546, 5-1/4 inch RCS bar stock. These steels are used in the manufacture of the M437, 155-mm shell and the M107, 155-mm shell respectively. A breakdown of the number of cuts, sawed area, number of blades used, blade life, production rate and blade cost per cut is shown on Table I, "Performance Summary by Blade Type and Steel Sawed". This table summarizes the performance data from Tables A1 through A10 compiled in the appendix of this report. In addition, Tables A1 through A10 list the test parameters for machine operation and blade grind for each individual saw blade used in the program. A specification of "1st" grind means that the saw blade was used after its original sharpening on the original set of carbide tips (teeth). A designation of "2nd grind" refers to the first regrind, etc. The projected blade cost per cut assumes all direct tooling costs amortized over the expected life of 40 grinds, based on eight (8) grinds through each of five (5) blade retippings.

Costs include the original blade cost, the cost for each regrind at 52.5 cents per tooth, $9.60 for the replacement of three teeth (average) at each regrind and a per tooth cost of $1.85 for the complete retipping of the blade.

The blade speed refers to the rotational speed of the saw blade which, along with the known blade diameter, determines the surface feed of the blade against the workpiece. Blade speed and feed plus the number of effective teeth on the blade determine the tooth load which is the amount of material removed by each "effective" tooth. Because each blade is comprised of two types of teeth (primary and secondary as described earlier), a 50 or 60 tooth blade has 25 or 30 "effective" teeth, respectively considering that the load is on both tooth types at the same time.

Tables II and III list the weekly results for the cutting of the 1561 and 1546 steels respectively. These tabulations show the progress attained in improving blade life, increasing production rate and lowering blade cost per cut. Note that the overall blade life values are averages per week over the cutting program and, therefore, are not contradictions of the true averages presented in Table I.

Table IV shows how blade cost per cut is affected by the number of grinds possible before complete retipping of the blade becomes necessary. Costs are given for each blade type and are based on the results of average life from Table I.

Table V gives the recommended settings for operation of the saw cutting the 1546 and 1561 steels and using the various blade types investigated during the Phase II program. The last column gives a wide range for the motor load increase before blade removal becomes necessary. The quoted ranges represent all test data for each blade type.

Table VI records the nominal lengths of the scrap ring cut off the base of 100 consecutive forgings fabricated from sawed billets. Measurements were taken at the center-and-cutoff machining station on one M437, 175-mm shell line. The length of 2.27 inches for an average ring is approximately one-third of that normally resulting from the broken billet forging.

The results of the inspection of forgings are shown in Tables VII and VIII, for the 175-mm and 155-mm shell, respectively. Data are recorded for both sawed and broken billets. Defects were categorized according to the type of "shorts" and observed surface defects, the latter primarily in the forging cavity. The last column lists the number of forgings reclaimed by removal of defects through grinding. With the exception of the shorts, most rejects were reclaimed.

The amperage drawn by the spindle motor and the cycle time for each cut were recorded on real-time charting tape. Graphs illustrating motor load versus blade life through the number of cuts (or square inches of sawed steel) for thirty-five representative test blades are compiled in the Appendix as Figures A1 through A35. A table of contents prefacing the Appendix gives reference to each particular blade usage.

TABLE I

PERFORMANCE SUMMARY BY BLADE TYPE & STEEL SAWED *

BLADE TYPE	STEEL	NO. OF CUTS	SAWED AREA (SQ.IN)	NO. OF BLADES	BLADE LIFE PER GRIND: MINIMUM NO. OF CUTS	MINIMUM SAWED AREA	MAXIMUM NO. OF CUTS	MAXIMUM SAWED AREA	AVERAGE NO. OF CUTS	AVERAGE SAWED AREA	AVERAGE PROD. RATE (@ 100% psc/hr)	AVERAGE BLADE COST PER CUT
50-12	1561	2355	82,425	6.44	222	7,770	474	16,590	370	12,950	78.0	$.1274
50-18	1561	3160	110,600	6.62	264	9,246	697	24,395	466	16,306	82.2	.1012
60-12	1561	4112	143,920	7.00	361	12,635	734	25,690	587	20,560	87.1	.0919
60-15	1561	4135	144,725	7.00	325	11,340	763	26,705	591	20,675	89.3	.0912
**60-18	1561	7543	264,005	11.58	456	15,960	990	34,650	667	23,339	87.0	.0808
TOTAL FOR	1561	21,305	745,675	38.64	OVERALL AVERAGE FOR 1561 Steel				536	18,766	84.7	.0985 ***
50-12	1546	9137	246,699	10.56	549	14,815	1129	30,483	853	23,026	100.1	.0553
50-18	1546	3926	106,002	4.38	342	9,235	1026	27,702	949	25,613	92.3	.0497
60-12	1546	3758	101,466	5.00	480	12,960	1248	33,696	752	20,293	113.7	.0717
60-15	1546	4639	125,253	5.00	496	13,392	1190	32,130	928	25,051	108.3	.0581
60-18	1546	7104	191,808	8.42	436	11,772	1052	28,404	857	23,133	112.9	.0629
TOTAL FOR	1546	28,564	771,228	33,36	OVERALL AVERAGE FOR 1546 Steel				868	23,423	105.5	.0595 ***
TOTAL ALL STEEL		49,869	1,516,903	72.00								

* Data for each blade type are taken from individual blade test data, Tables A1 through A10 in Appendix

** This group contains one blade grind still usable at 541 cuts or 18,935 square inches.

*** These values are averages per blade type of the five cost figures above each. These costs represent costs associated with both 50 and 60 tooth blades. The assumed total costs per blade are $1,885.55 and $2,156.90, for 50 and 60 tooth blades respectively.

TABLE II

WEEKLY PERFORMANCE CUTTING 1561 STEEL, 6-INCH RCS

FOR WEEK ENDING	NO. OF CUTS	SAWED AREA (SQ.IN.)	NO. OF BLADES USED*	BLADE LIFE PER GRIND: MINIMUM NO. OF CUTS	MINIMUM SAWED AREA	MAXIMUM NO. OF CUTS	MAXIMUM SAWED AREA	AVERAGE NO. OF CUTS	AVERAGE SAWED AREA	AVERAGE PRODUCTION RATE (@ 100% Hour)	BLADE *** COST/CUT
3/12	1196	41,860	2.44	456	15,960	552	19,320	490	17,156	81.7	$.1031
3/19	1748	61,180	4.62	307	10,745	473	16,555	378	13,242	86.6	.1337
3/26	1734	60,690	5.00	222	7,770	490	17,150	347	12,138	81.4	.1456
4/2	2153	75,355	4.00	396	13,860	637	22,295	538	18,839	82.4	.0939
4/8	1674	58,590	3.00	516	18,060	618	21,630	558	19,530	83.7	.0906
4/16	851	29,785	2.00	377	13,796	474	16,590	426	14,893	83.9	.1186
5/21	697	24,395	1.00	697	24,395	697	24,395	697	24,395	76.9	.0725
5/28	2842	99,470	5.00	374	13,090	678	23,730	568	19,894	84.1	.0890
6/4	2030	71,050	2.58	660	23,100	902	31,570	786	27,539	89.6	.0643
6/11	3450	120,750	5.00	602	21,070	763	26,705	690	24,150	89.6	.0732
6/18	2930	102,550	4.00	541**	18,935**	990	34,650	733	25,638	89.6	.0689
TOTALS	21,305	745,675	38.64	LIFE OVERALL: 222	7,770	990	34,650	551	19,298		

* Includes only blades fully worn through 1 grind during week. Decimals indicate that a portion of a blade worn out on 1561 steel, the remainder being worn out on 1546 steel during same week.

** Last blade of program was still usable at 18,935 square inches.

*** Assumes a $2,021.23 total blade cost, an average of $2,156.90 for a 60-tooth blade and $1,885.55 for a 50-tooth blade. This figure represents the initial blade cost plus 4 complete blade retippings with 8 grinds before retipping and including the replacement of 3 teeth at each time of regrinding.

TABLE III

WEEKLY PERFORMANCE CUTTING 1546 STEEL, 5-1/4-INCH RCS

FOR WEEK ENDING	NO. OF CUTS	SAWED AREA (SQ.IN)	NO. OF BLADES USED*	BLADE LIFE PER GRIND — MINIMUM — NO. OF CUTS	MINIMUM — SAWED AREA	MAXIMUM — NO. OF CUTS	MAXIMUM — SAWED AREA	AVERAGE — NO. OF CUTS	AVERAGE — SAWED AREA	AVERAGE PRODUCTION RATE (@ 100% Hour)	BLADE ** COST/CUT
3/12	2,715	73,305	5.56	436	11,772	512	13,824	488	13,184	124.7	$.1035
3/19	131	3,537	.38	345	9,308	345	9,308	345	9,308	120.0	.1465
4/16	1,219	32,913	2.00	605	16,335	614	15,578	610	16,457	101.	.0828
4/23	4,234	114,318	5.00	719	19,413	955	25,785	847	22,864	100.	.0597
4/30	4,914	132,678	5.00	903	24,381	1,026	27,702	983	26,536	98.	.0514
5/7	5,519	149,013	5.00	1,020	27,540	1,190	32,130	1,104	29,803	105.	.0458
5/14	3,568	96,336	4.00	735	19,845	1,047	28,269	892	24,084	105.3	.0566
5/21	3,751	101,277	4.00	561	15,147	1,129	30,483	938	25,319	99.5	.0539
5/28	2,082	56,214	2.00	834	22,518	1,248	33,696	1,041	26,107	99.7	.0485
6/4	432	11,664	.42	1,038	28,044	1,038	28,044	1,038	28,044	105.	.0487
	TOTALS			LIFE OVER ALL							
	28,564	771,228	33.36	345	9,308	1,248	33,696	856	23,118		

* Includes only blades fully worn (through 1 grind) during week. Decimals indicate that a portion of a blade worn out on 1546 steel, the remainder being worn out on 1561 steel during the same week.

** Assumes a $2,021.23 total blade cost, an average of $2,156.90 for a 60-tooth blade and $1,885.55 for a 50-tooth blade. This figure represents the initial blade cost plus 4 complete blade retippings with 8 grinds before retipping and including the replacement of 3 teeth at each time of regrinding.

TABLE IV

BLADE COST PER CUT* VERSUS NUMBER OF GRINDS BEFORE RETIPPING

BLADE TYPE (No. Teeth-Rake)	AVERAGE NO. OF CUTS PER GRIND	STEEL (RCS BAR)	NUMBER OF GRINDS				
			8	7	6	5	4
			$	$	$	$	$
50-12	853	1546,5-1/4"	.0553	.0572	.0597	.0632	.0685
50-18	949	1546,5-1/4"	.0497	.0514	.0536	.0568	.0616
60-12	752	1546,5-1/4"	.0717	.0741	.0774	.0819	.0888
60-15	928	1546,5-1/4"	.0581	.0601	.0627	.0664	.0719
60-18	857	1546,5-1/4"	.0629	.0651	.0679	.0719	.0779
50-12	370	1561,6"	.1274	.1318	.1376	.1457	.1579
50-18	466	1561,6"	.1012	.1046	.1092	.1157	.1254
60-12	587	1561,6"	.0919	.0950	.0991	.1050	.1137
60-15	591	1561,6"	.0912	.0943	.0985	.1043	.1129
60-18	667	1561,6"	.0808	.0836	.0873	.0924	.1001

* Assumes initial blade cost with original tipping plus four (4) complete retippings, with indicated number of grinds before retipping, and with three (3) teeth replaced at each regrind.

TABLE V

RECOMMENDED SAW OPERATION *

BLADE TYPE (NO. TEETH/RAKE)	STEEL GRADE & SIZE	BLADE SPEED (rpm)	SURFACE FEED (f/m)	BLADE FEED (ipm)	TOOTH LOAD (inch)	INCREASE IN MOTOR LOAD BEFORE BLADE REMOVAL (%)
50 - 12	1546,5-1/4"RCS	57	408	12 1/2	.00877	17 - 33
50 - 18**	1546,5-1/4"RCS	60	408	12 1/2	.00833	20 - 39
60 - 12	1546,5-1/4"RCS	57	388	14	.00818	13 - 29
60 - 15	1546,5-1/4"RCS	57	388	14	.00818	23 - 31
60 - 18	1546,5-1/4"RCS	60	408	14 1/2	.00805	19 - 36
50 - 12	1561,6" RCS	50	340	11	.00880	25 - 33
50 - 18	1561,6" RCS	50	340	11	.00880	21 - 33
60 - 12	1561,6" RCS	50	340	12 1/2	.00833	22 - 33
60 - 15	1561,6" RCS	50	340	12 1/2	.00833	25 - 38
60 - 18**	1561,6" RCS	50	340	12 1/2	.00833	20 - 36

* Based on results of program. Refer Tables A1 through A10 in Appendix.

** These blades tested best for greatest economy of cutting the respective steels.

TABLE VI

LENGTH OF SCRAP RING
(Center And Cutoff Station)
FOR SAWED BILLETS

HEAT NO. J65 SAMPLE: 100 Consecutive Pieces

NO.	LENGTH (Inches)	NO.	LENGTH (Inches)	NO.	LENGTH (Inches)
1	2-1/4	34	1-3/4	67	2
2	2-3/8	35	2-3/8	68	2-1/8
3	4-1/2	36	2-1/4	69	2-1/4
4	2-1/2	37	2-1/8	70	2-3/8
5	2	38	1-7/8	71	2-1/4
6	2-3/8	39	2-3/8	72	2
7	2-3/8	40	2-1/2	73	2
8	2-3/4	41	2-3/8	74	2-3/8
9	3-1/2	42	2-1/4	75	2-3/8
10	2-3/4	43	2-3/8	76	1-3/8
11	2-3/4	44	2-3/8	77	1-7/8
12	2	45	1-7/8	78	2-1/8
13	2-5/8	46	2-3/4	79	2-1/2
14	3-3/4	47	2-5/8	80	2-7/8
15	1-3/8	48	2-1/4	81	2-1/4
16	2-1/8	49	2	82	2-1/8
17	1-7/8	50	2-1/4	83	2-1/2
18	2-5/8	51	2-1/4	84	1-3/8
19	1-5/8	52	2-3/4	85	1-3/4
20	2-3/8	53	1-7/8	86	2-1/8
21	2-3/8	54	3	87	2-3/8
22	2-5/8	55	2-3/8	88	1-7/8
23	2-1/8	56	2-1/8	89	1-1/2
24	2-1/4	57	2-1/2	90	2-3/8
25	2	58	2-1/8	91	2-5/8
26	1-7/8	59	2-1/4	92	2-3/8
27	1-7/8	60	2-3/8	93	2
28	1-1/4	61	1-1/2	94	2-1/8
29	2	62	1-7/8	95	2-3/8
30	2-1/8	63	1-1/8	96	2-1/4
31	2-1/2	64	2-3/8	97	2-1/2
32	3	65	2-1/4	98	2-7/8
33	2-3/8	66	2-1/2	99	2-1/4
				100	2-3/8

AVERAGE LENGTH	MAXIMUM	MINIMUM	AVG. $+3\sigma$	AVG. -3σ
2.27	4.50	1.13	3.68	.86

TABLE [illegible]

INSPECTION OF FORGINGS

(175-mm, M437 - 1561 6-Inch RCS)

HEAT NO.	SHORTS: HEAVY BASE	SHORTS: LIGHT-WEIGHTS	SHORTS: DOG EARS	SURFACE DEFECTS: BASE LAMIN.	SURFACE DEFECTS: WALL LAMIN.	SURFACE DEFECTS: SCALE	SURFACE DEFECTS: HOLES	SURFACE DEFECTS: POROSITY	SURFACE DEFECTS: BURRS	TOTAL INSPECTED	TOTAL REJECTED	NO. OF RECLAIMS (GRINDS)
(Sawed Billets)												
J65	3	9			8	15				1,865	35	23
J66 & J81	4	6		9	16	12	3	2	1	3,087	53	43
J67				2	18	13	4	2		1,642	39	39
J74			3		27	16		1	2	1,774	49	46
K20		1		1	21	72	16	9	5	1,823	125	124
K21	2		2	3	15	17	8	2	2	2,002	51	47
K22				1	10	9				1,776	20	20
K23				1	19	21	14			1,801	55	55
K32				3	30	29	5	3	4	2,024	74	74
K33					20	17	4	3		1,604	42	42
K36			2	3	50	26	11	16	3	1,762	111	109
TOTAL	9	16	7	23	234	247	65	36	17	21,160	654	622
(PERCENT)	(.04)	(.08)	(.03)	(.10)	(1.11)	(1.17)	(.30)	(.17)	(.08)	(100.0)	(3.1)	(2.94)
(Broken Billets)												
TOTAL	10	14	14	54	974	477	255	110	65	23,105	1,973	1,935
(PERCENT)	(.04)	(.06)	(.06)	(.23)	(4.21)	(2.06)	(1.10)	(.47)	(.28)	(100.0)	(8.53)	(8.38)

HEAT NOS. K-8, 9, 10, 11, 12, 13, 15, 16, 17, 25, 26, 27, 28, 29, 36, 31, 34, 35, 37

HEAT NO.	SHORTS HEAVY BASE	LIGHT-WEIGHTS	DOG EARS	SURFACE DEFECTS BASE LAMIN.	LAMIN.	SCALE	HOLES	POROSITY	BURRS	TOTAL INSPECTED	TOTAL REJECTED	NO. OF RECLAIMS (GRINDS)
(Sawed Billets)												
N87		16		5	17	41				3,020	79	63
R38	7	5		10	42	72	2		1	3,088	139	127
R39		5		11	39	64	2			3,078	121	116
R46	7			9	47	59	3		1	2,892	126	119
R47	15	10		17	19	41			3	2,261	105	80
R48	6			13	41	56	3		3	2,917	122	116
R54	10	3		4	41	55	9		1	2,715	123	110
R55	7	3	2	18	53	94			1	2,837	178	166
R56	6	2		4	62	74	1			2,812	149	141
R51	3	1	1	5	19	28				1,818	57	52
R62	6	3	—	3	37	54	—	—	—	2,638	103	94
TOTAL	67	48	3	99	417	638	20	0	10	30,076	1,302	1,184
(PERCENT)	(.22)	(.16)	-	(.32)	(1.38)	(2.12)	(.06)	(0)	(.03)	(100.0)	(4.33)	(3.93)
(Broken Billets) TOTAL	55	14	6	360	1,579	1,326	12	1	20	46,824	3,373	3,298
(PERCENT)	(.12)	(.03)	(.01)	(.76)	(3.37)	(2.83)	(.02)	-	(.04)	(100.0)	(7.21)	(7.04)

HEAT NOS. R-57, 53, 58, 59, 45, 50, 44, 43, 40, 78, 77, 79, 76, 75, 74

7. DISCUSSION OF RESULTS

This section discusses the documented results of the preceeding section. For better correlation, the discussion will follow in the order of the program objectives as listed in Section 2.

7.1 Reference Objective 2.1 - Optimization of Saw Operation

7.1.1 The production rates, as shown in the various tables in this report, were based on piece-to-piece cycle times. Measurements were made with a stop watch and the times converted to pieces-per-hour at 100% efficiency. The cycle times were recorded on the Daily Log Form after the establishment of the saw operation accompanying each change of saw blades. The number of partings per hour actually achieved in the program was somewhat less because of the manual indexing of the first billet to be sawed. The quoted production rates reflect the completely automatic operation as would be expected in a production installation.

One shortcoming of the saw affecting cycle time is the dwell time involved while the saw head moves the distance (approximately one inch) from the normal returned position of the blade to the work-piece. A solution is the incorporation into the saw of a three-stage feed system to reduce the overall cycle time significantly. The first stage would be a rapid advance of the blade to the work-piece and then a reduced rate for cutting for the second stage. As now, the third stage would be the rapid retraction after the cut.

7.1.2 Data were recorded in the Phase I study to conclude that accuracy of the indexing mechanism was adequate to produce billets well within the weight range produced by the nick and break method. Therefore, no precise measurements were recorded with respect to billet length or the capability of the indexing mechanism to repeat accurately. However, the weights recorded on the Daily Log Forms show that the 175-mm billets all weighed between 169 and 170 pounds, and that the 155-mm billets ranged between 109-3/4 and 110-3/4 pounds. It was concluded that $\pm$ 1/2 pound was a reasonable tolerance at this time considering the variation of cross-sectional area prevailing in bar stock presently purchased according to total weight rather than length.

Some "drifting" of the indexing control mechanism did occur which tended to increase the billet length approximately .010 to .050 inch over an extended period of saw operation. Indexing is effected with a hydraulic cylinder that is cushioned on the forward stroke but not on the return stroke. Speculation was that, on the return stroke, the carriage tends to "slam" against the adjustable brass block on the measuring screw causing a slight movement in the screw. An apparent correction of this problem is simply to cushion the hydraulic cylinder on both ends.

7.1.3 Optimization of operation of the saw with respect to speeds and feeds was not known when testing began; however, knowledge increased with each blade tested. The general procedure throughout testing was to decrease surface speed progressively to gain tool life. A marked tendency of the secondary teeth to chip at the leading corners was observed at high surface speeds, above 375 fpm for 1561 and 410 fpm for 1546. Chip load, or load per tooth, was maintained in a range between .0059 and .0100 inch as recommended by various manufacturers of carbides and cutters for the types of steel being sawed.

Tables I, II and III summarize the blade life achieved during the program. Scrutiny of the latter two shows that knowledge gained each week did result in improved blade life the following week. Note that all estimates of blade cost per cut are based on obtaining eight grinds per set of teeth before retipping becomes necessary. This expectation was not verified because of the duration of "turn-around" time required to resharpen worn blades combined with the relatively short testing schedule. Table IV compares the cost per cut for each blade type as the number of available grinds decreases from eight to four, before retipping. Note that the cost per cut increases roughly 0.2 to 0.8 of a cent for each regrind less than eight. The increase is least, however, between 8 and 7. It should be noted that the quoted number of grinds is an assumed average throughout the life of the blade. In reality, a given blade could vary in number of regrinds from one set of carbide tips to the next.

7.1.4 Table V shows the speeds and feeds determined to be optimum at this time for each blade type to cut both the 1561 and 1546 steels. The values reported for increase in motor load are necessarily in a wide range because of the wide range of results in blade life achieved from all blades operating with the same quoted set of speeds and feeds. It was felt by Chamberlain personnel that sustained production operation of the recommended "best" blades would yield greatest economy of cutting with motor load increases in the narrow range between 30 and 35 percent.

Following are some observations of the test engineer while monitoring saw operation:

1. In cutting 1561 steel, a blade having an 18° negative rake exhibited less tendency to chip than a blade having 12° or 15° negative rakes. It is recommended that a 12° negative rake blade not be used on 1561 steel at all because of excessive chipping. Photograph 8942 in Section 5, Page 24, shows typical tooth chipping and wear characteristics.
2. Chip loads in the .0080 to .0090 inch range were best for the type blades used and steels cut. A 50 tooth blade is capable of cutting a slightly heavier chip than a 60 tooth blade because of the larger gullet size which permits unhindered chip formation.
3. A blade speed of 60 rpm cutting 1546 steel seemed borderline with respect to tooth chipping. A 12° and 15° negative rake blade would chip slightly at this speed while an 18° negative blade would not. A small reduction in blade speed from 60 rpm to 57 rpm for operation of blades with the lesser two rake angles (12° and 15°) yielded slightly longer life and eliminated chipping.

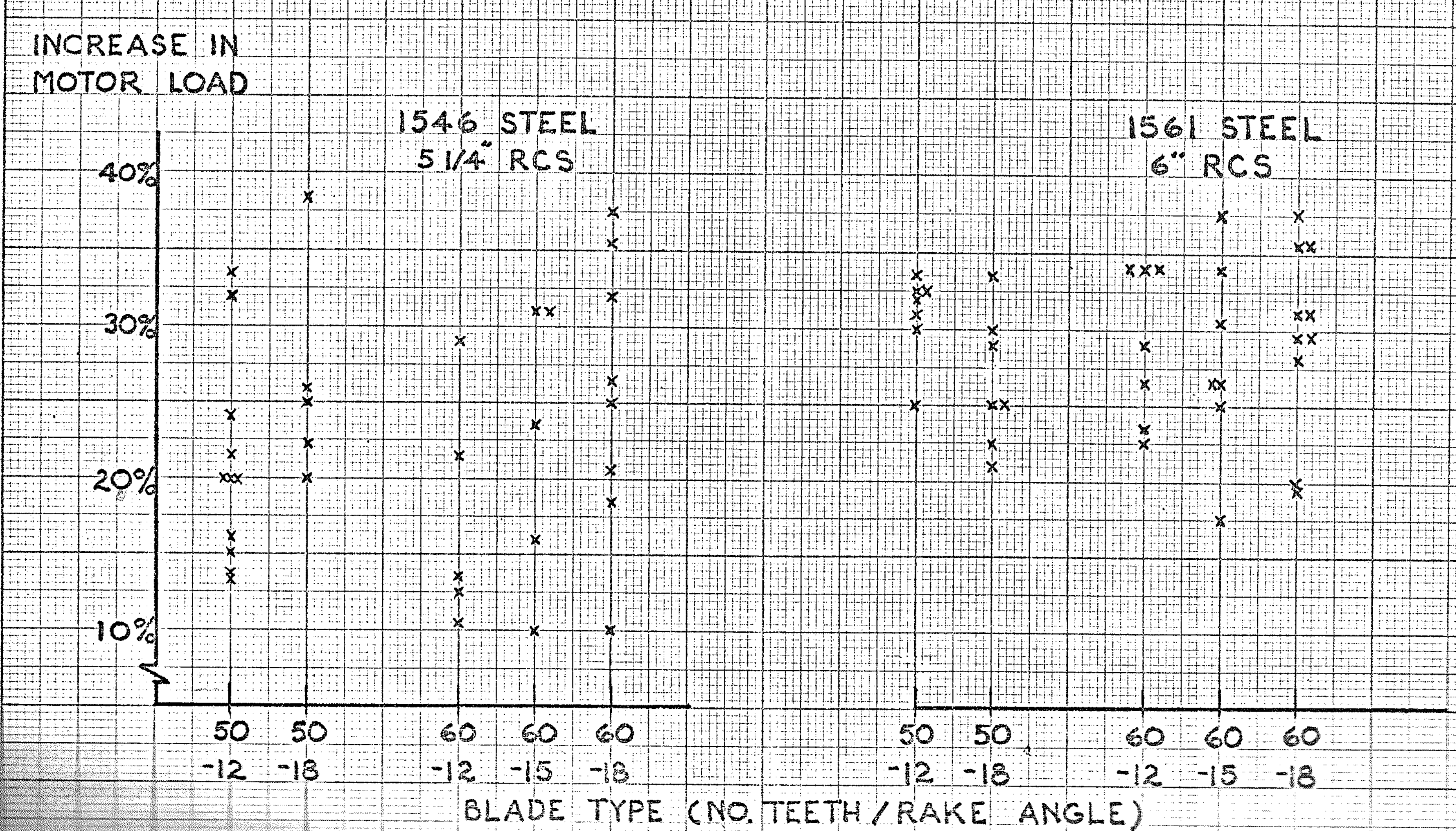
4. Because of the greater hardness of the 1561 steel, speeds of 55 rpm or more produced excessive chipping in all blades used.

7.1.5 Figures A1 through A35 in the Appendix are graphs of the number of cuts versus motor load for individual blades. Data were originally recorded on the continuously recording ammeter. Points on each graph are plotted for every seventh cut for the 1546 steel and every fifth cut for the 1561 steel. The graphs shown are only for blade usages thought to be of significance in showing a trend that depicts increased blade life with respect to reduction of surface speed. Because the feed rate of the saw head remains constant as set throughout the operation (power screw system), blade dulling or wear is reflected in the increased amperage drawn by the spindle motor. The same pattern of amperage increase resulting from Phase I testing also was evident in the Phase II graphs. This was a tendency for the increase to occur in a plateau manner, that is, a nearly constant motor load as the number of cuts progressed until the occurrence of an abrupt load increase which again remained somewhat constant until the next increase.

7.1.6 Figure 7 shows a percent increase in motor load with respect to the type of blade. Data were taken from Tables A1 through A10 in the Appendix. Each point represents a single blade used to the point of resharpening. Because of the different speeds and feeds used in determining optimum blade life there is a wide spread in motor load increase for each blade type. In a production application, using a fixed machine setting for best blade

FIGURE 7

INCREASE IN MOTOR LOAD vs. TYPE OF BLADE



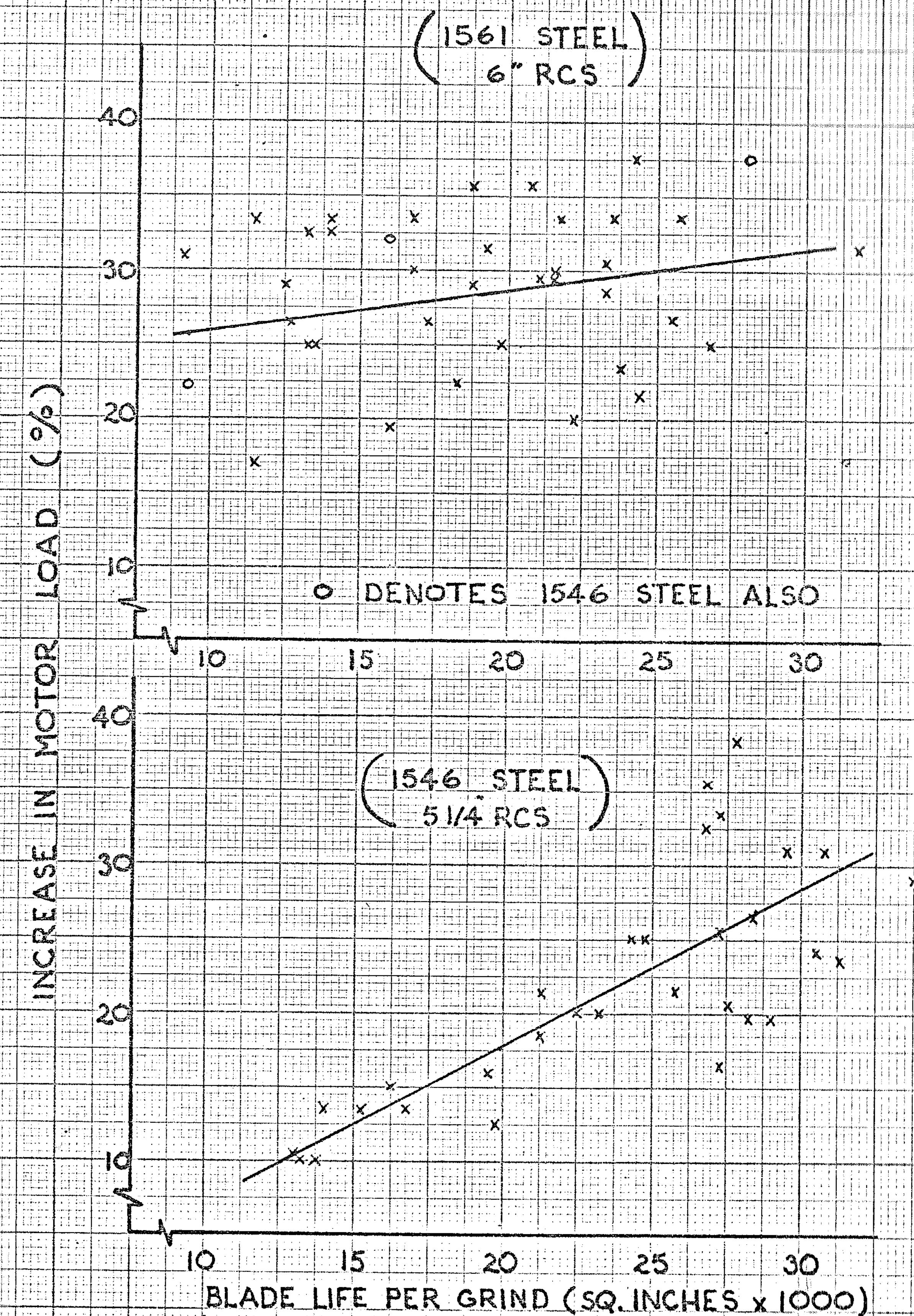


FIGURE 8

INCREASE IN MOTOR LOAD vs. BLADE LIFE

life and cutting the same type steel in a continuous operation, a more predictable increase in motor load as a criteria for blade change can be assumed. Figure 8 shows two graphs plotting percent increase in motor load against the number of square inches cut per blade for both types of steel. As would be expected, there was a rise in the increase in motor load with a corresponding increase in square inches cut. Here, as in Figure 7, the data seem to be "scattered" and it should be noted that with constant machine settings, a more clearly defined relationship would result.

7.2 Reference Objective 2.2 - Effect on Shell Fabrication Processes

7.2.1 Though the indexing accuracy of the saw makes possible the cutting of a minimum weight billet with reliability, cutting during the current program resulted in the same number of billets per bar length as from the nick and break method. However, assuming a full production installation, it is conceivable that a shorter billet could be cut with a resultant savings in material. This would enable the purchasing of bar stock of shorter length for the same number of billets or of even longer length if one more billet per bar is desired.

Billets were cut longer than necessary because they were stockpiled on skids and heat-treated subsequently in either one of two different furnaces. Scranton's Selas furnace is atmospherically controlled and, hence, little material is lost due to scaling.

(Reference photograph following Section 5, Procedure). Therefore, a minimum length billet may be heat-treated and a good shell forged and machined. However, this is not the case with Scranton's other furnaces, one of which was used to heat-treat some of the sawed billets. These furnaces permit oxidation with resultant scale losses as much as 2½ pounds for a 170 pound billet. Because operations of the overall program did not allow pre-selection of furnaces for different length billets, all billets were cut to the same length to assure a minimum weight after heat-treatment.

Because sawing in Phase II testing resulted in the same number of billets per bar as from the breaking method, a convenient item of comparison was the material converted into scrap. The total pounds of scrap per bar had to be the same for either parting method. The difference was in the kind of scrap and where it occurred in the processing of a shell between the raw bar stock and the finished product. Sawing produced chip scrap at the time of billet separation. Consequently, there was less solid scrap at the center-and-cutoff station later during the machining of the shell. Nick-and-breaking produced little or no billet separation scrap, but yielded a large scrap ring at the center-and-cutoff station. Reference Table VI which shows the average scrap ring from sawed billets to have measured 2.27 inches. This compares to a nominal 6 inch ring occurring during normal shell production from broken billets. Therefore, because chip scrap is salvagable at about $7.00 a ton less than solids, sawing during the current program caused a more expensive shell amounting to 0.8 of a cent for the 175-mm shell and 0.62 of a cent for the 155-mm shell.

Cambered bar stock occurs infrequently and presents no insurmountable cutting problems when it does. However, the bar must be oriented properly on the indexing mechanism of the saw; otherwise, the bar clamping is not rigid and damage to the blade teeth may result from the blade breakthrough at the end of the cut. To eliminate this occasional problem, the cambered bar simply is oriented to curve upward or outward when positioned on the rack and feed conveyor.

7.2.2 Forging concentricities were checked hot immediately after the last press operation as a normal inspection procedure. No significant differences were noted between sawed and broken billets. The characteristics of metal flow could possibly be improved in the sawed forging, but this would be conjecture without an analysis of the microstructure of the cross-sectional areas.

Tables VII and VIII show the results of inspection of surface conditions for forgings from both sawed and broken billets. There were differences in the number of shorts between both types of billets, however, the only characteristic attributable to the parting method was the number referenced as dog-ears. These were reducible by 50% using sawed billets. Forgings too short because of a heavy base were traceable only to the forge tooling. The types of surface defects were subdivided into six categories. Sawed billets reduced the number of rejects in all categories for an overall reduction of 40 to 46%. The importance of fewer rejects is exemplified in the time spent for inspection, handling and reclaim. Note that most all surface defects are removable through grinding using a hand-held power tool. Halving the number of rejects, therefore, accordingly reduces the labor expended for reclaim.

7.2.3 The sawed billets with their smooth, square ends are easier to handle during heat treating and cause less wear in the forge tooling than broken billets with their rough, irregular parting surfaces. Though no comprehensive analysis with an accumulation of tooling measurements was possible within the scope of the current program, the above conclusion was derivable from the knowledgeable opinions of the production personnel (billet handlers, press operators, forge shop foremen and inspectors) at Scranton. Some comparative situations were obvious as, for example, the stacking of billets on the rotating table inside the furnaces. A broken billet tends to fall over while the sawed billet will stand on end. The result was that more billets could be loaded in the furnace, they were more uniformly heated and they were more easily picked-up for removal after heat-treatment. Another obvious difference concerns the scoring or wear on the punch head due to the surface condition of the billet end. Obviously, the comparatively rough end of a broken billet must result in greater abrasive wear than from the sawed billet.

7.3 Reference Objective 2.3 - Establishment of Production Cost

7.3.1 The cost-of-operation comparison between the METALCUT XII saw and the nick-and-break method of billet separation probably is the most important objective of this Phase II production evaluation.

Table IX shows the costs involved for both methods in each of two systems of operation, line-dependent and centralized (relatively independent of shell line operation). Annotations following the table qualify the individual cost figures with explanations of the assumptions made. Reference to the nick-and-break installations necessarily imply operation at Chamberlain's Scranton Army Ammunition Plant. And reference to the saw installations are based on the current saw performance at Scranton. However, this Phase II installation and operation of the saw must not be construed as fully production-oriented. Efficiency was necessarily less than maximum for several reasons. Only one saw was operated and two are needed to feed billets adequately to one shell-processing line. Two saws, however, would produce more than enough. Hence, the sawed billets required stacking and storing until they could be incorporated into the production line as a complete heat or heats. Both the billet-handling and the scrap-removal operations were nearly all manual because of the necessary cost limitations of the evaluation program. Consequently, more manpower was actually used than is anticipated for the proposed installation systems as assumed in the cost comparisons of Table IX.

7.3.2 Analysis of comparative cost estimates show the METALCUT XII bar-cutoff saw to be competitive with the nick-and-break method of bar separation in the manufacture of large-caliber shell. Prevailing cost differences are minimal and negligible considering that small changes in the governing assumptions could easily reverse an increased cost into a decrease. This leaves forging quality and, subsequently, shell quality as the major deciding factor between sawing and breaking as the desired method for billet-separation.

It is most difficult to attach a realistic dollar value to the improvement of forging quality other than the labor savings for the reclaim grinding as estimated in Table IX. However, the cleaner forging cavities resulting from the smooth ends of sawed billets do require less time for inspection. Another advantage is less labor expended for handling of the shell throughout the process line because there are fewer rejects attributable to forging defects. Obviously affected would be the standards for inspection which could be up-graded for a better percentage of acceptable shell. Perhaps a factor of even greater significance is safety. Most of the aforementioned cavity defects now are reclaimed by grinding. This means material is removed with possible weakening of the shell wall resulting. Or, because grinding removes only the visually-observed surface defect, the actual defect still may be hidden beneath the surface such as in an obscured wall lamination. Just how this adversely affects the safe handling and final usage of the projectile is only conjecture. Certainly, hidden defects cannot enhance the safe handling of high explosive shell.

The following notes will facilitate greater understanding of Table IX by qualifying the assumptions used to determine the subject cost estimates:

1. No major capital equipment is considered.

TABLE IX

PER BILLET COST COMPARISONS

	(LINE DEPENDENT INSTALLATION)				(CENTRAL CUTTING)		
	BREAKER		METALCUT SAW		BREAKER	METALCUT SAW	
SHELL LINES	175-MM	155-MM	175-MM	155-MM	BOTH	175-MM	155-MM
No. Of Machines	2	4	4	8	3	4	8
Manpower	2-1/2 Per Breaker		1 Per Saw		2-1/2 Per Breaker	1 Per 2 Saws	
Production Rate (pcs/hr)	300	720	261	677	900	261	677
Tooling Cost	$.0428	$.0428	$.0808	$.0629	$.0428	$.0808	$.0629
Labor Cost	.1682	.1401	.1546	.1192	.0842	.0773	.0596
Subtotal	.2110	.1829	.2354	.1821	.1270	.1581	.1225
Indirect Labor Savings	--	--	(.0262)	(.0262)	--	(.0262)	(.0262)
Additional Scrap Cost	--	--	.0080	.0062	--	.0080	.0062
Total Cost	$.2110	$.1829	$.2172	$.1639	$.1270	$.1399	$.1043

2. Two types of installations are considered. The line dependent system employs one breaker or two (2) saws to feed each shell line directly. The current modernization schedule at Scranton plans for two (2) 175-mm lines and four (4) 155-mm lines. The central system utilizes all breakers or saws in one centralized location from which the billets are fed by conveyor to each shell line as needed. It is generally acknowledged that this system is most convenient because bar separation is nearly independent of the downtime of the individual forge presses, furnaces and any other line dependent shell operation.
3. Tooling costs are for expendable items and regular tool maintenance only.
4. Tooling costs for the breaker system are best estimates derived from actual production operations at SAAP. The \$.0428 figure includes \$.0128 representing the cost of consumable electrodes used for nicking the bar stock. This number reflects the yearly costs for electrodes divided by the yearly shell output. The remainder represents other tooling and its maintenance estimated at \$.020 per billet for welder repair plus another \$.010 for press tooling and maintenance such as for the anvil, ram, etc.
5. Tooling costs for the saw are blade costs only. No significant maintenance costs were incurred on the test saw itself during the brief evaluation period at SAAP and, according to the saw manufacturer, none are expected because routine maintenance is easily performed daily by the saw operator without detriment to production.

6. Blade costs are taken from Table I for the blade type of best performance during the current evaluation program. A 60 tooth, 18° negative rake blade was best for the 1561 steel and a 50 tooth, 18° negative rake blade was most economical for the 1546 steel. Cost comparisons with other blade types are shown in Figures 4 and 5. These costs represent custom sharpening by an outside blade vendor; actual production costs would be less because volume blade usage would justify an in-house sharpening capability.
7. Labor costs are for direct labor only. No indirect labor such as material handlers (yardmen, crane operators or inspectors) are included. A labor rate of $3.67 per hour and a burden rate of 175% is assumed for all jobs. Labor for one nick-and-break system requires 2-1/2 men; one press operator, one nicker and one bar marker, the latter being used only 1/2 time. This applies to either type of installation as described in Note 1 above. Labor for one saw in a line-dependent operation requires 2 men, each used only 1/2 time for a total of 1 man per saw. One saw operating in a centralized bank of saws requires 2 men, each used only 1/4 time for a total of 1/2 man per saw. One suggested saw arrangement for production is illustrated in Figure 6.
8. All production rates are figured at 75% efficiency. The rates quoted for the saw are based on those actually achieved during the evaluation program. They correspond with the associated blade costs from Table I as referenced in Note 4 above. No distinction is made between line-dependent and centralized operation at this time although the resultant rate in the latter mode should be higher with subsequent lower cost per billet.

9. Production rates for the breakers in a line-dependent operation assume maximum rates expected for the updated shell lines using modernization equipment. Antiquated equipment presently in operation at SAAP produce at rates that are approximately half of those quoted here. Production rates for the breakers operating in a centralized bank assume maximum press operation unhindered by line dependency. Again, the quoted rate is at 75% efficiency.
10. Indirect labor savings refers to the reduction by 1/2 of the labor required at SAAP to reclaim rejects through hand-grinding of forging cavities. Results from the inspection of forgings in both Phase I and Phase II saw evaluations show that reclaimable rejects are reduced by approximately 50%. Refer to Tables VII and VIII.
11. Additional scrap cost refers to the difference in salable steel scrap between chips and solids. The less desirable chips sell for $.0035 less per pound. Saw separation results in the same number of billets per bar as from the breaker method; however, the type of scrap differs. The blade kerf for saw separation yields chip scrap while this same material from broken billets scraps out as a solid ring at the center-and-cutoff machining station. Refer to Table VI.

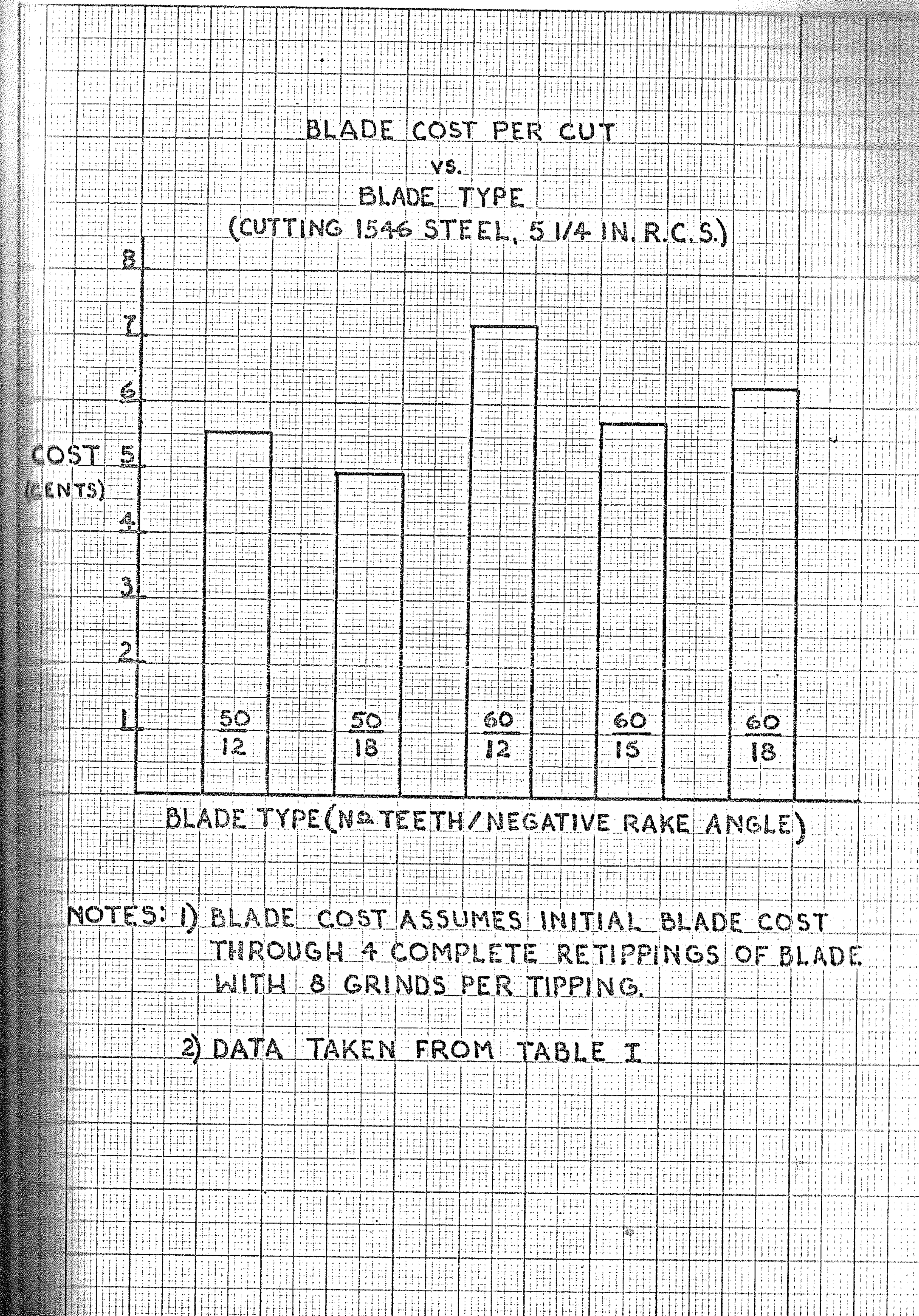

BLADE COST PER CUT
VS.
BLADE TYPE
(CUTTING 1546 STEEL, 5 1/4 IN. R.C.S.)
COST
(CENTS)
8
7
6
5
4
3
2
1
50/12
50/18
60/12
60/15
60/18
BLADE TYPE (No TEETH/NEGATIVE RAKE ANGLE)
NOTES: 1) BLADE COST ASSUMES INITIAL BLADE COST THROUGH 4 COMPLETE RETIPPINGS OF BLADE WITH 8 GRINDS PER TIPPING.
2) DATA TAKEN FROM TABLE I

FIGURE 4

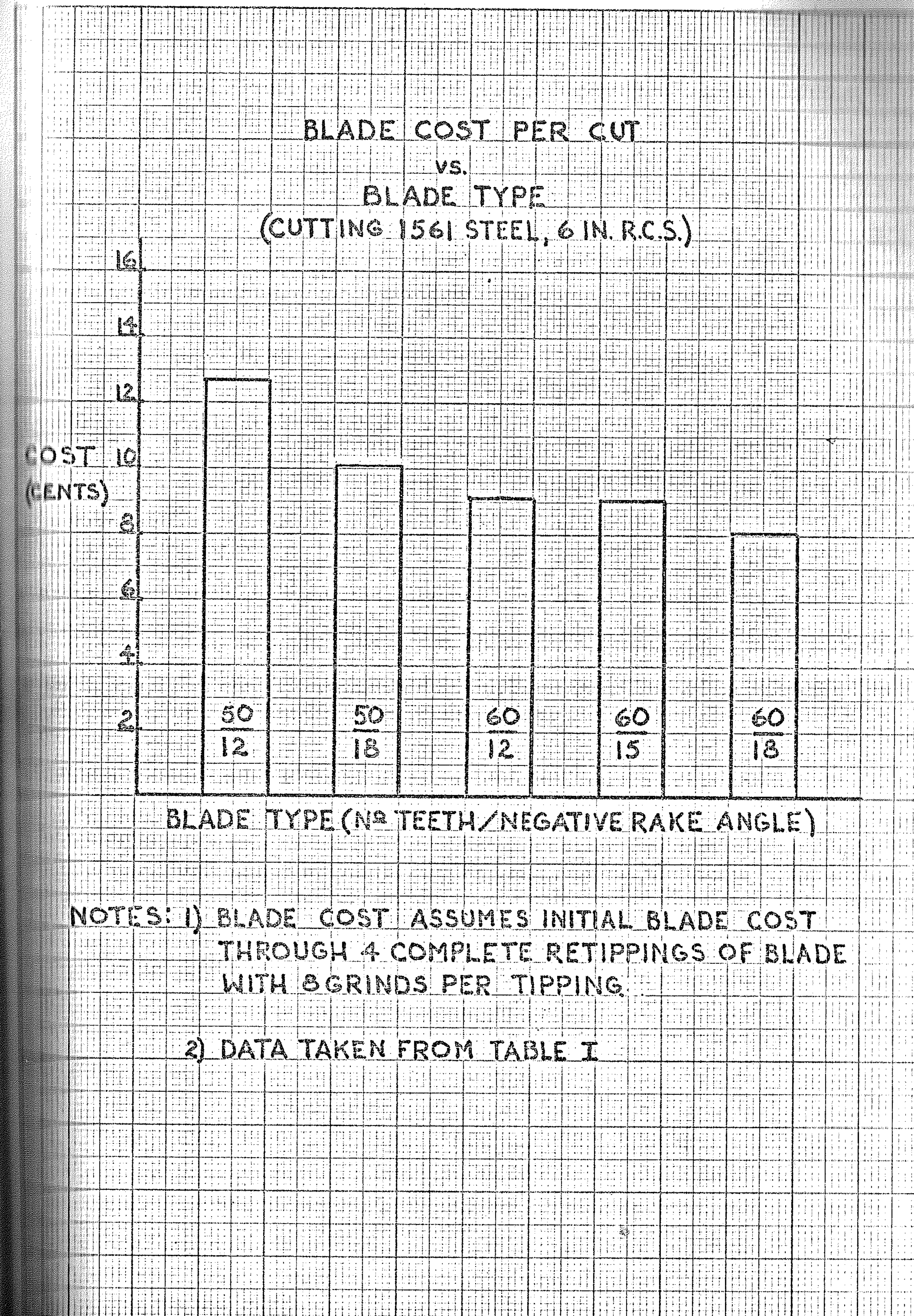
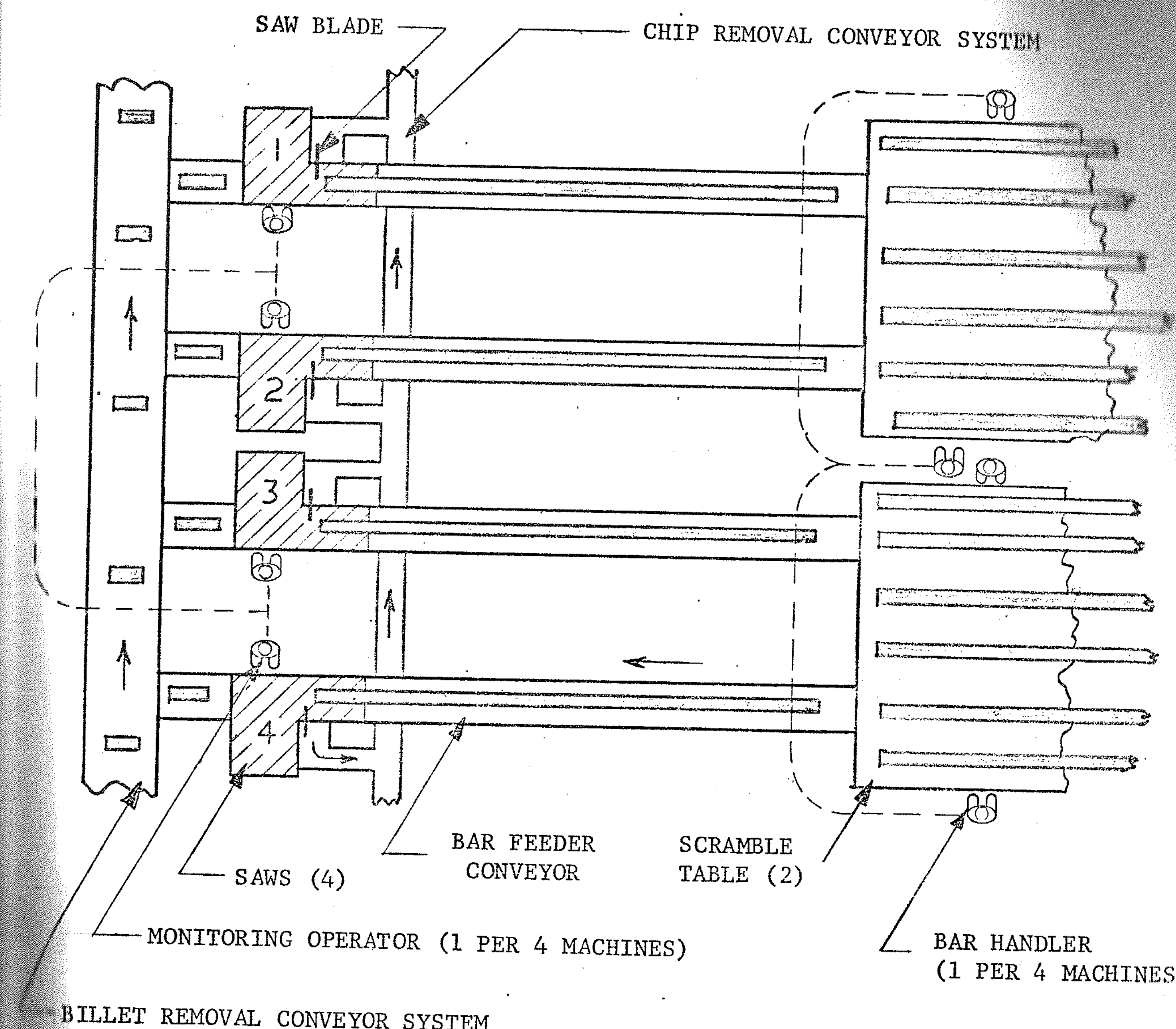

BLADE COST PER CUT
VS.
BLADE TYPE
(CUTTING 1561 STEEL, 6 IN. R.C.S.)
COST (CENTS)
16
14
12
10
8
6
4
2
50/12
50/18
60/12
60/15
60/18
BLADE TYPE (Nº TEETH/NEGATIVE RAKE ANGLE)
NOTES: 1) BLADE COST ASSUMES INITIAL BLADE COST THROUGH 4 COMPLETE RETIPPINGS OF BLADE WITH 8 GRINDS PER TIPPING.
2) DATA TAKEN FROM TABLE I

FIGURE 5



LAYOUT OF SUGGESTED
SAW ARRANGEMENT
FOR PRODUCTION

FIGURE 6

CHAMBERLAIN MANUFACTURING CORPORATION

WATERLOO, IOWA

APPENDIX

TABLES AND GRAPHS

APPENDIX

INDIVIDUAL BLADE TEST DATA

TABLE A1	50 teeth -12° Rake	1546 Steel
A2	-18°	1546
A3	60 teeth -12°	1546
A4	-15°	1546
A5	-18°	1546
A6	50 teeth -12°	1561
A7	-18°	1561
A8	60 teeth -12°	1561
A9	-15°	1561
A10	-18°	1561

LOAD VERSUS BLADE LIFE (GRAPHS)

BLADE NO.	GRIND	REFERENCE TABLE	FIGURE	BLADE NO.	GRIND	REFERENCE TABLE
53C4	2nd	A1	A19	31C4	3rd	A5
46C4	2nd	A1	A20	55C4	1st	A6
46C4	3rd	A1	A21	42C4	1st	A6
39C4	2nd	A1	A22	45C4	1st	A6
55C4	2nd	A1	A23	41C4	2nd	A6
64C4	2nd	A1	A24	49C4	1st	A7
50C4	1st	A1	A25	45C4	2nd	A7
49C4	2nd	A2	A26	79C4	1st	A8
48C4	2nd	A2	A27	85C4	1st	A8
87C4	1st	A3	A28	85C4	2nd	A8
86C4	1st	A3	A29	26C4	1st	A9
84C4	2nd	A3	A30	80C4	3rd	A9
81C4	1st	A4	A31	83C4	3rd	A9
26C4	2nd	A4	A32	27C4	1st	A10
82C4	2nd	A4	A33	30C4	1st	A10
29C4	1st	A5	A34	30C4	4th	A10
31C4	1st	A5	A35	27C4	5th	A10
30C4	3rd	A5				

TABLE A-1

INDIVIDUAL BLADE TEST DATA

No. Teeth 50
Rake -12°
Steel 1546 5-1/4 Inch RCS

		TEST PARAMETERS				BLADE PERFORMANCE					
BLADE NO.	GRIND	BLADE SPEED (rpm)	SURFACE FEED (f/m)	BLADE FEED (ipm)	CHIP LOAD (Inch)	NO. OF CUTS	AREA CUT (Sq.In.)	MOTOR LOAD INC.	CYCLE TIME (MIN)	PROD. RATE @ 100% (Pcs/Hour)	PROJECTED BLADE COST/CUT **
F700 46C4	1st	74	504	15	.00810	305*	8,235*	32.1%*	.57	105.3	$.0859
F700 53C4 A1	2nd	70	476	14-1/2	.00828	605	16,335	15.1	.57	105.3	.0779
F700 46C4 A2	2nd	65	442	13-1/2	.00830	614	16,578	13.8	.61	98.4	.0768
F700 39C4 A4	2nd	60	408	12-1/2	.00833	955	25,785	21.4	.65	92.3	.0494
F700 64C4 A6	2nd	57	388	14	.00982	1,075	29,025	20.0	.57	105.3	.0439
F700 55C4 A5	2nd	57	388	14	.00982	1,003	27,081	16.6	.57	105.3	.0470
F700 43C4	2nd	57	388	14	.00982	1,047	28,269	20.0	.57	105.3	.0450
F700 42C4	2nd	60	408	13	.00866	561	15,147	13.3	.62	96.8	.0840
F700 50C4 A7	1st	60	408	13	.00866	1,009	27,243	33.3	.62	96.8	.0467
F700 52C4	1st	60	408	13	.00866	1,129	30,483	24.1	.61	98.4	.0418
F700 46C4 A3	3rd	57	408	12-1/2	.00877	834	22,518	20.0	.65	92.3	.0565
		Average for Blade Type				853	23,026	--	--	100.1	$.0553

* This blade also used to cut 1561 steel, another 188 cuts and 6,580 square inches. Column averages consider above data as 55.6% of the blade life for this grind. Increase in Motor Load considers life through both steels.

** Assumes $1,885.55 as total blade cost through 4 complete blade retippings with 8 grinds per tipping. Average cost is based on 853 cuts per grind.

TABLE A-2

INDIVIDUAL BLADE TEST DATA

No. Teeth 50
Rake -18°
Steel 1546 5-1/4 Inch RCS

BLADE NO.	GRIND	TEST PARAMETERS: BLADE SPEED (rpm)	SURFACE FEED (f/m)	BLADE FEED (ipm)	CHIP LOAD (Inch)	BLADE PERFORMANCE: NO. OF CUTS	AREA CUT (Sq.In.)	MOTOR LOAD INC.	CYCLE TIME (MIN)	PROD. RATE @ 100% (Pcs/Hour)	PROJECTED BLADE COST/CUT **
F700 59C4	1st	88	599	17-1/2	.00795	131*	3,537*	22.2%*	.50	120.0	$.1378
F700 59C4	2nd	60	408	12-1/2	.00833	863	23,301	20.0	.65	92.3	.0546
F700 58C4	2nd	60	408	12-1/2	.00833	902	24,354	25.0	.65	92.3	.0523
F700 49C4 A8	2nd	60	408	12-1/2	.00833	1,004	27,108	25.9	.65	92.3	.0470
F700 48C4 A9	2nd	60	408	12-1/2	.00833	1,026	27,702	38.5	.65	92.3	.0459
		Average for Blade Type ***				949	25,613	--	--	92.3	$.0497

* This blade also used to cut 1561 steel, another 163 cuts and 5,705 square inches.
Above data is considered as 38.3% of the blade life for this grind. Increase in Motor Load considers life through both steels.

** Assumes 1,885.55 as total blade cost through 4 complete blade retippings with 8 grinds per tipping.
Average cost is based on 949 cuts per grind.

*** Discounts results of first blade.

TABLE A-3

INDIVIDUAL BLADE TEST DATA

No. Teeth 60
Rake -12°
Steel 1546 5-1/4 Inch RCS

		TEST PARAMETERS				BLADE PERFORMANCE					
BLADE NO.	GRIND	BLADE SPEED (rpm)	SURFACE FEED (f/m)	BLADE FEED (ipm)	CHIP LOAD (Inch)	NO. OF CUTS	AREA CUT (Sq.In.)	MOTOR LOAD INC.	CYCLE TIME (MIN)	PROD. RATE @ 100% (Pcs/Hour)	PROJECTED BLADE COST/CUT *
H700 87C4 A10	1st	80	545	19	.00791	480	12,960	10.5%	.49	122.4	$.1123
H700 86C4 A11	1st	74	504	20	.00900	512	13,824	13.1	.46	130.4	.1053
H700 79C4	2nd	57	388	14	.00818	735	19,845	12.5	.57	105.3	.0734
H700 85C4	2nd	57	388	14	.00818	783	21,141	21.4	.57	105.3	.0689
H700 84C4 A12	2nd	57	388	14	.00818	1,248	33,696	29.0	.57	105.3	.0432
		Average for Blade Type				752	20,293	--	--	113.7	$.0717

* Assumes 2,156.90 as total blade cost through 4 complete blade retippings with 8 grinds per tipping. Average cost is based on 752 cuts per grind.

TABLE A-4

INDIVIDUAL BLADE TEST DATA

No. Teeth 60
Rake -15°
Steel 1546 5-1/4 Inch RCS

BLADE NO.	GRIND	TEST PARAMETERS: BLADE SPEED (rpm)	SURFACE FEED (f/m)	BLADE FEED (ipm)	CHIP LOAD (Inch)	BLADE PERFORMANCE: NO. OF CUTS	AREA CUT (Sq.In.)	MOTOR LOAD INC.	CYCLE TIME (Min)	PROD. RATE @ 100% (Pcs/Hour)	PROJECTED BLADE COST/CUT *
H700 81C4 A13	1st	80	545	19	.00791	496	13,392	10.0%	.49	122.4	$.1087
M700 26C4 A14	2nd	60	408	14-1/2	.00805	719	19,413	16.1	.56	107.1	.0750
H700 83C4	2nd	57	388	14	.00818	1,145	30,915	31.0	.58	103.4	.0471
H700 82C4 A15	2nd	57	388	14	.00818	1,190	32,130	23.3	.58	103.4	.0453
H700 80C4	2nd	57	388	14	.00818	1,089	29,403	31.0	.57	105.3	.0445
Average for Blade Type						928	25,051	--	--	108.3	$.0581

* Assumes 2,156.90 as total blade cost through 4 complete blade retippings with 8 grinds per tipping.

Average cost is based on 928 cuts per grind.

TABLE A-5

INDIVIDUAL BLADE TEST DATA

No. Teeth 60
Rake -18°
Steel 1546 5-1/4 Inch RCS

BLADE NO.	GRIND	TEST PARAMETERS: BLADE SPEED (rpm)	SURFACE FEED (f/m)	BLADE FEED (ipm)	CHIP LOAD (Inch)	BLADE PERFORMANCE: NO. OF CUTS	AREA CUT (Sq.In.)	MOTOR LOAD INC.	CYCLE TIME (MIN)	PROD. RATE @ 100% (Pcs/Hour)	PROJECTED BLADE COST/CUT ***
M700 29C4 A16	1st	80	545	19	.00791	486	13,122	10.0%	.46	130.4	$.1109
M700 31C4 A17	1st	74	504	20	.00900	224	6,048	7.3	.46	130.4	.1237
		(92)*	(626)	(20)	(.00724)	(212)	(5,724)	8.7	(.45)	(133.3)	
M700 31C4	2nd	60	408	14-1/2	.00805	783	21,141	18.7	.56	107.1	.0689
M700 29C4	2nd	60	408	14-1/2	.00805	914	24,678	25.0	.55	109.1	.0590
M700 27C4	3rd	60	408	14-1/2	.00805	996	26,892	35.7	.55	109.1	.0541
M700 28C4	3rd	60	408	14-1/2	.00805	985	26,595	32.1	.55	109.1	.0547
M700 30C4 A18	3rd	60	408	14-1/2	.00805	1,020	27,540	20.7	.55	109.1	.0529
M700 31C4 A19	3rd	57	388	14	.00818	1,052	28,404	26.7	.57	105.3	.0513
M700 28C4	4th	57	388	14	.00818	432**	11,664*	37.5**	.57	105.3	.0519
		Average for Blade Type				857	23,133	--	--	112.9	$.0629

* This blade operated under different conditions for the results also shown in parentheses, all during the life of the 1st grind of this blade.

** This blade also used cutting 1561 steel, another 468 cuts and 16,380 square inches. Column averages consider above data as 41.59% of the blade life for this grind. Increase in Motor Load considers life through both steels.

*** Assumes 2,156.90 as total blade cost through 4 complete blade retippings with 8 grings per tipping. Average cost is based on 857 cuts per grind.

TABLE A-6

INDIVIDUAL BLADE TEST DATA

No. Teeth	50
Rake	-12°
Steel	1561 6-Inch RCS

		TEST PARAMETERS				BLADE PERFORMANCE					
BLADE NO.	GRIND	BLADE SPEED (rpm)	SURFACE FEED (f/m)	BLADE FEED (ipm)	CHIP LOAD (Inch)	NO. OF CUTS	AREA CUT (Sq.In.)	MOTOR LOAD INC.	CYCLE TIME (Min)	PROD. RATE @ 100% (Pcs/Hour)	PROJECTED BLADE COST/CUT **
F700 46C4	1st	60	408	12	.00800	188*	6,580*	32.1%*	.78	76.9	$.1114
F700 55C4 A20	1st	60	408	12	.00800	324	11,340	33.3	.73	82.2	.1455
F700 43C4	1st	58	395	11	.00758	374	13,090	32.1	.82	73.2	.1260
F700 42C4 A21	1st	75	511	11	.00586	222	7,770	31.0	.82	73.2	.2123
F700 64C4	1st	50	340	11	.00880	396	13,860	32.1	.81	74.1	.1190
F700 45C4 A22	1st	50	340	12-1/2	.01000	377	13,195	25.0	.72	83.3	.1250
F700 41C4 A23	2nd	55	374	12	.00872	474	16,590	30.0	.72	83.3	.0995
		Average for Blade Type				370	12,950	--	--	78.0	$.1274

* This blade also used to cut 1546 steel, another 305 cuts and 8,235 square inches. Column averages consider above data as 44.4% of the blade life for this grind.

** Assumes 1,885.55 as total blade cost through 4 complete retippings with 8 grinds per tipping. Average cost is based on 370 cuts per grind. Increase in Motor Load considers life through both steels.

TABLE A-7

INDIVIDUAL BLADE TEST DATA

No. Teeth 50
Rake -18°
Steel 1561 6-Inch RCS

		TEST PARAMETERS				BLADE PERFORMANCE					
BLADE NO.	GRIND	BLADE SPEED (rpm)	SURFACE FEED (f/m)	BLADE FEED (ipm)	CHIP LOAD (Inch)	NO. OF CUTS	AREA CUT (Sq.In.)	MOTOR LOAD INC.	CYCLE TIME (Min)	PROD. RATE @ 100% (Pcs/Hour)	PROJECTED BLADE COST/CUT ***
F700 49C4 A24	1st	65	442	13	.00800	396	13,860	33.3%	.71	84.5	$.1190
F700 58C4	1st	60	408	12	.00800	116	4,060		.75	80.0	.1328
		(63)*	(429)	(12)	(.00761)	(239)	(8,365)	29.0			
F700 59C4	1st	70	476	14	.00800	163**	5,705**	22.2**	.64	93.7	.1786
F700 59C4	3rd	50	340	11	.00880	697	24,395	21.2	.78	76.9	.0676
F700 45C4 A25	2nd	50	340	11	.00880	613	21,455	30.0	.75	80.0	.0769
F700 58C4	3rd	50	340	11	.00880	562	19,670	25.0	.75	80.0	.0839
F700 49C4	3rd	50	340	11	.00880	374	13,090	25.0	.75	80.0	.1260
		Average for Blade Type				466	16,306	--	--	82.2	$.1012

* This blade operated under different conditions for the results as also shown in parentheses, all during the life of the 1st grind of this blade.

** This blade also used to cut 1546 steel, another 131 cuts and 3537 square inches. Column averages consider above data as 61.7% of the blade life for this grind.

*** Assumes 1,885.55 as total balde cost through 4 complete retippings with 8 grinds per tipping. Average cost is based on 466 cuts per grind. Increase in Motor Load considers life through both steels.

TABLE A-8

INDIVIDUAL BLADE TEST DATA

No. Teeth 60
Rake -12°
Steel 1561 6-Inch RCS

BLADE NO.	GRIND	TEST PARAMETERS: BLADE SPEED (rpm)	TEST PARAMETERS: SURFACE FEED (f/m)	TEST PARAMETERS: BLADE FEED (ipm)	TEST PARAMETERS: CHIP LOAD (Inch)	BLADE PERFORMANCE: NO. OF CUTS	BLADE PERFORMANCE: AREA CUT (Sq.In.)	BLADE PERFORMANCE: MOTOR LOAD INC.	BLADE PERFORMANCE: CYCLE TIME (Min)	BLADE PERFORMANCE: PROD. RATE @ 100% (Pcs/Hour)	PROJECTED BLADE COST/CUT *
H700 79C4 A26	1st	60	408	14	.00777	361	12,635	26.5%	.67	89.5	$.1494
H700 85C4 A27	1st	50	340	12-1/2	.00833	540	18,900	29.0	.72	83.3	.0999
H700 84C4	1st	50	340	12-1/2	.00833	618	21,630	33.3	.72	83.3	.0872
H700 87C4	2nd	50	340	12-1/2	.00833	516	18,060	22.6	.71	84.5	.1045
H700 87C4	3rd	50	340	12-1/2	.00833	678	23,730	23.5	.67	89.6	.0795
H700 79C4	3rd	50	340	12-1/2	.00833	665	23,275	33.3	.67	89.6	.0811
H700 85C4 A28	1st	50	340	12-1/2	.00833	734	25,690	33.3	.67	89.6	.0735
Average for Blade Type						587	20,560	--	--	87.1	$.0919

* Assumes $2,156.90 as total blade cost through 4 complete blade retippings with 8 grinds per tipping. Average cost is based on 587 cuts per grind.

TABLE A-9

INDIVIDUAL BLADE TEST DATA

No. Teeth 60
Rake -15°
Steel 1561 6-Inch RCS

		TEST PARAMETERS				BLADE PERFORMANCE					
BLADE NO.	GRIND	BLADE SPEED (rpm)	SURFACE FEED (f/m)	BLADE FEED (ipm)	CHIP LOAD (Inch)	NO. OF CUTS	AREA CUT (Sq.In.)	MOTOR LOAD INC.	CYCLE TIME (Min)	PROD. RATE @ 100% (Pcs/Hour)	PROJECTED BLADE COST/CUT *
M700 26C4 A29	1st	60	408	14	.00777	473	16,555	33.3%	.67	89.5	$.1140
H700 80C4	1st	60	408	14	.00777	324	11,340	17.6	.65	92.3	.1664
H700 82C4	1st	50	340	12-1/2	.00833	490	17,150	26.7	.70	85.7	.1100
H700 82C4	3rd	50	340	12-1/2	.00833	692	24,220	37.5	.67	89.5	.0779
H700 80C4 A30	3rd	50	340	12-1/2	.00833	667	23,345	30.3	.67	89.5	.0808
H700 83C4 A31	3rd	50	340	12-1/2	.00833	726	25,410	26.6	.67	89.5	.0743
H700 81C4	2nd	50	340	12-1/2	.00833	763	26,705	25.0	.67	89.5	.0707
		Average for Blade Type				591	20,675	--	--	89.3	$.0912

* Assumes $2,156.90 as total blade cost through 4 complete blade retippings with 8 grinds total per tipping. Average cost is based on 591 cuts per grind.

TABLE A-10

INDIVIDUAL BLADE TEST DATA

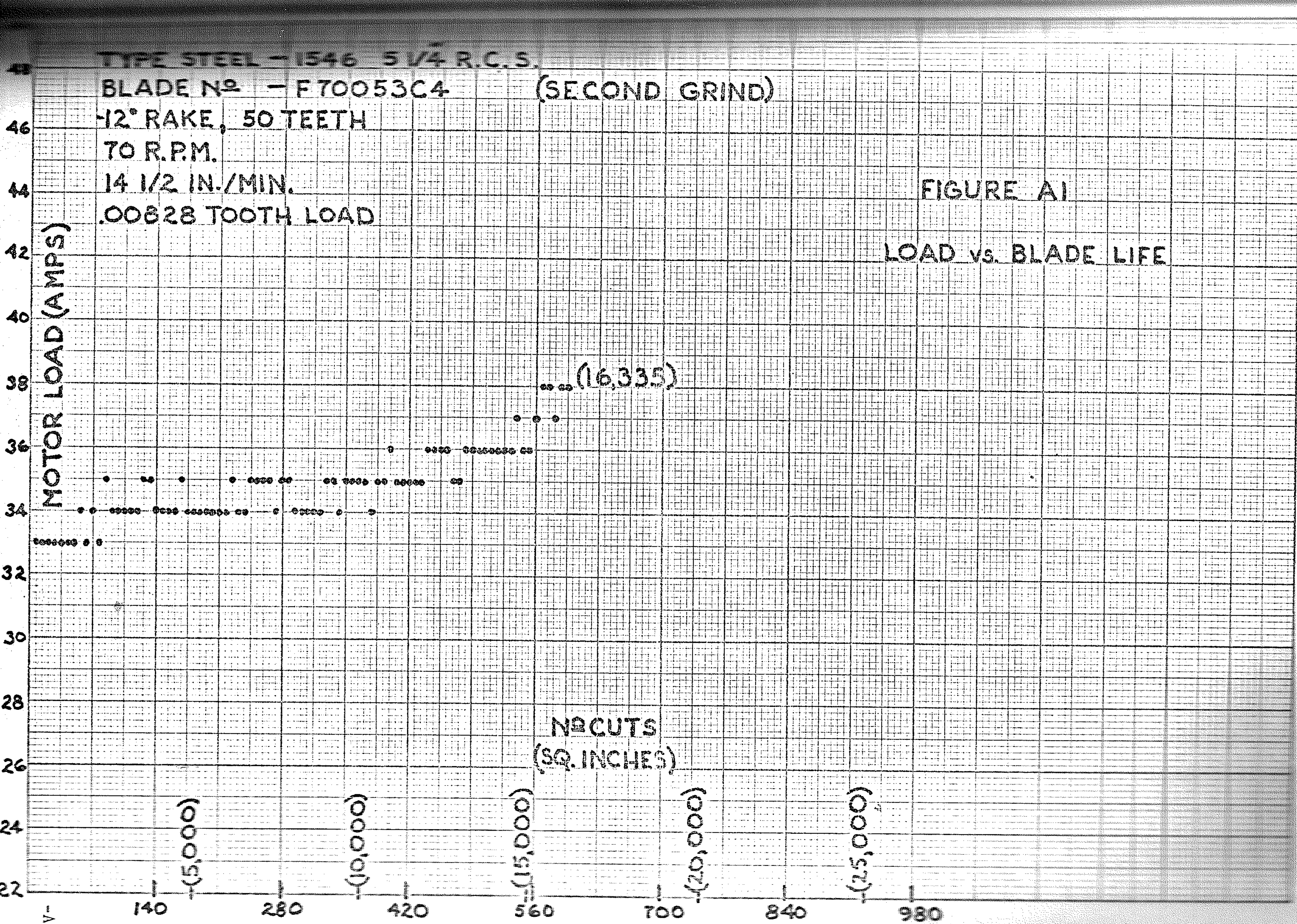
No. Teeth 60
Rake -18°
Steel 1561 6-Inch RCS

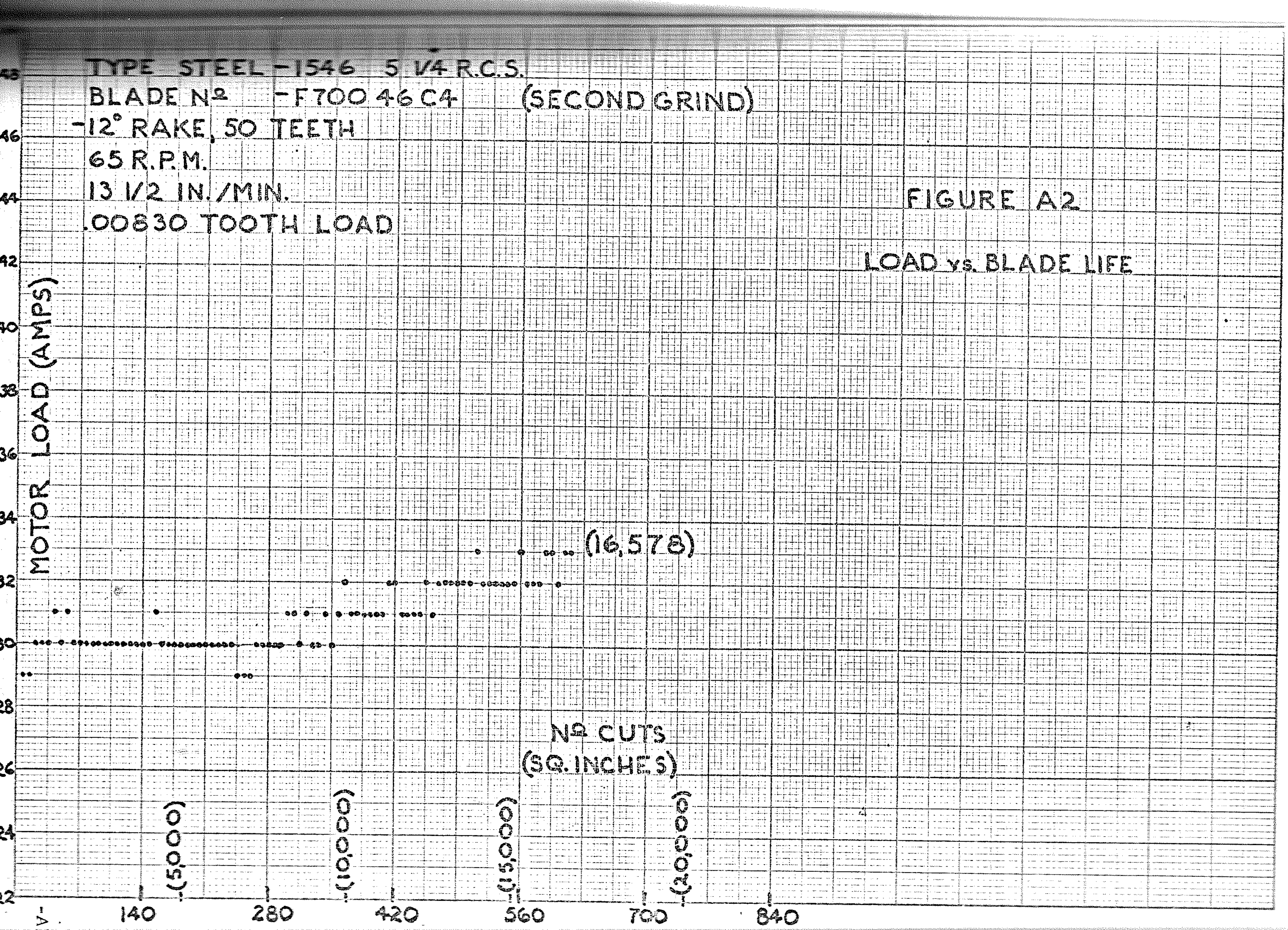
		TEST PARAMETERS				BLADE PERFORMANCE					
BLADE NO.	GRIND	BLADE SPEED (rpm)	SURFACE FEED (f/m)	BLADE FEED (ipm)	CHIP LOAD (Inch)	NO. OF CUTS	AREA CUT (Sq.In.)	MOTOR LOAD INC.	CYCLE TIME (Min)	PROD. RATE @ 100% (Pcs/Hour)	PROJECTED BLADE COST/CUT ***
M700 27C4 A32	1st	60	408	14	.00777	456	15,960	19.4%	.72	83.3	$.1182
M700 30C4 A33	1st	55	374	13	.00787	552	19,320	31.2	.73	82.2	.0977
M700 28C4	2nd	50	340	12-1/2	.00833	637	22,295	20.0	.70	85.7	.0846
M700 27C4	2nd	50	340	12-1/2	.00833	532	18,620	35.7	.72	83.3	.1014
M700 30C4	2nd	50	340	12-1/2	.00833	588	20,580	35.7	.71	84.5	.0917
M700 29C4	3rd	50	340	12-1/2	.00833	615	21,525	29.4	.67	89.6	.0877
M700 28C4	4th	50	340	12-1/2	.00833	468*	16,480*	37.5	.67	89.6	.0673
M700 30C4 A34	4th	50	340	12-1/2	.00833	660	23,100	28.1	.67	89.6	.0817
M700 27C4	4th	50	340	12-1/2	.00833	902	31,570	31.2	.67	89.6	.0598
H700 86C4	2nd	50	340	12-1/2	.00833	602	21,070	29.4	.67	89.6	.0896
M700 27C4 A35	5th	50	340	12-1/2	.00833	990	34,650	71.4	.67	89.6	.0545
M700 30C4	5th	50	340	12-1/2	.00833	541**	18,935**	--	.67	89.6	--
		Average for Blade Type				667	23,339	--	--	87.0	$.0808

* This blade also used to cut 1546 steel, another 432 cuts and 11,664 square inches. Column averages consider above data as 58.41% of the blade life for this grind. Increase in Motor Load considers life through both steels.

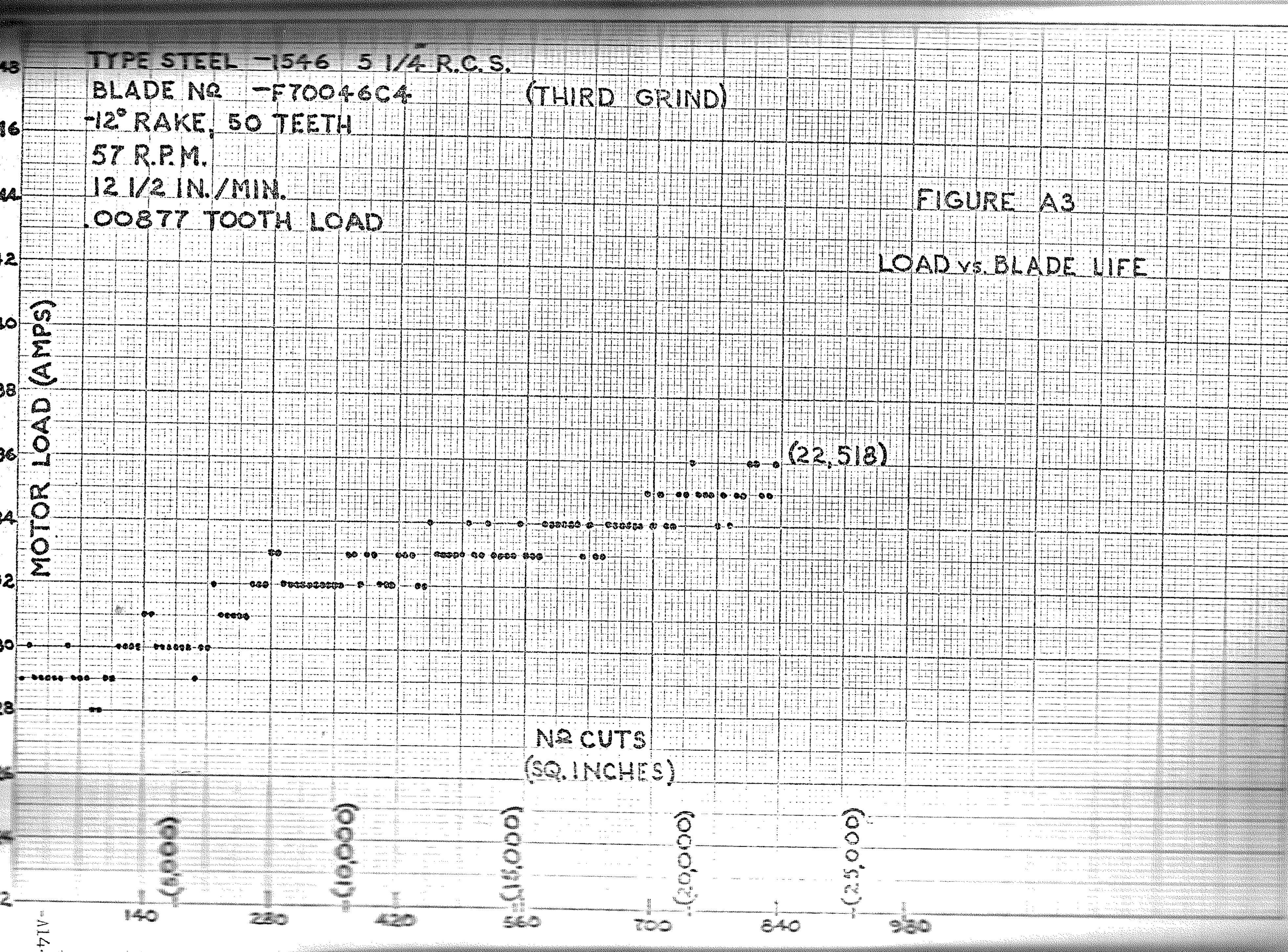
** Last blade still usable at end of test program. Data is not considered in column average.

*** Assumes $2,156.90 as total balde cost through 4 complete retippings with 8 grinds per tipping.
Average cost is based on 667 cuts per grind.

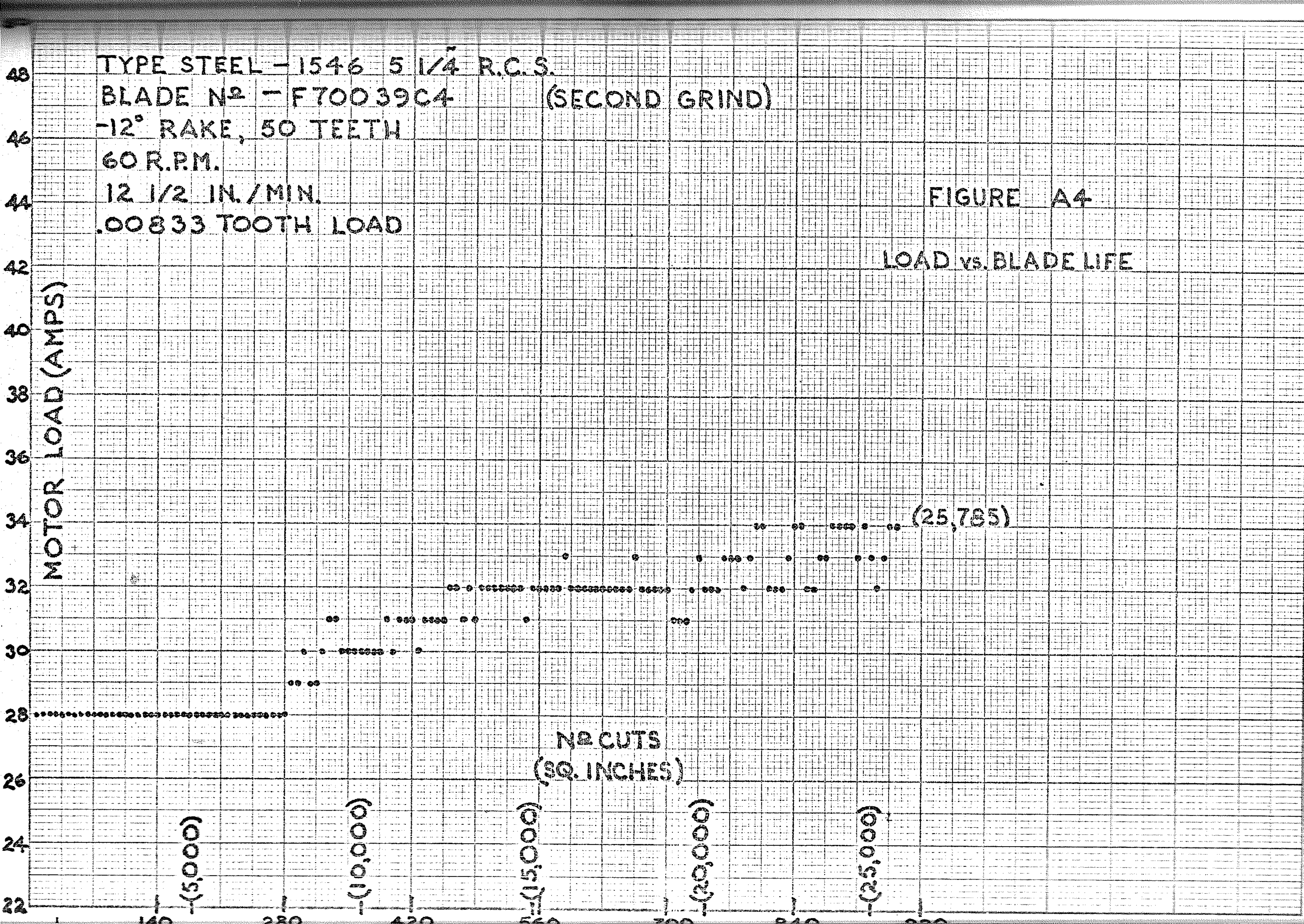

TYPE STEEL - 1546 5 1/4 R.C.S.
BLADE Nº - F70053C4
(SECOND GRIND)
-12° RAKE, 50 TEETH
70 R.P.M.
14 1/2 IN./MIN.
.00828 TOOTH LOAD
FIGURE A1
LOAD vs. BLADE LIFE
MOTOR LOAD (AMPS)
48
46
44
42
40
38
36
34
32
30
28
26
24
22
(16,335)
Nº CUTS
(SQ. INCHES)
(5,000)
(10,000)
(15,000)
(20,000)
(25,000)
140
280
420
560
700
840
980



TYPE STEEL -1546 5 1/4 R.C.S.
BLADE Nº -F700 46 C4 (SECOND GRIND)
-12° RAKE, 50 TEETH
65 R.P.M.
13 1/2 IN./MIN.
.00830 TOOTH LOAD
FIGURE A2
LOAD vs. BLADE LIFE
MOTOR LOAD (AMPS)
48
46
44
42
40
38
36
34
32
30
28
26
24
22
(16,578)
Nº CUTS
(SQ. INCHES)
140
280
420
560
700
840
(5,000)
(10,000)
(15,000)
(20,000)



TYPE STEEL -1546 5 1/4 R.C.S.
BLADE Nº -F70046C4
(THIRD GRIND)
-12° RAKE, 50 TEETH
57 R.P.M.
12 1/2 IN./MIN.
.00877 TOOTH LOAD
FIGURE A3
LOAD vs. BLADE LIFE
MOTOR LOAD (AMPS)
(22,518)
Nº CUTS
(SQ. INCHES)
48
46
44
42
40
38
36
34
32
30
28
26
24
22
140
280
420
560
700
840
980
(5,000)
(10,000)
(15,000)
(20,000)
(25,000)


TYPE STEEL - 1546 5 1/4" R.C.S.
BLADE № - F70039C4
(SECOND GRIND)
-12° RAKE, 50 TEETH
60 R.P.M.
12 1/2 IN./MIN.
.00833 TOOTH LOAD
FIGURE A4
LOAD vs. BLADE LIFE
MOTOR LOAD (AMPS)
№ CUTS
(SQ. INCHES)
(5,000)
(10,000)
(15,000)
(20,000)
(25,000)
(25,785)
48
46
44
42
40
38
36
34
32
30
28
26
24
22
140
280
420
560
700
840

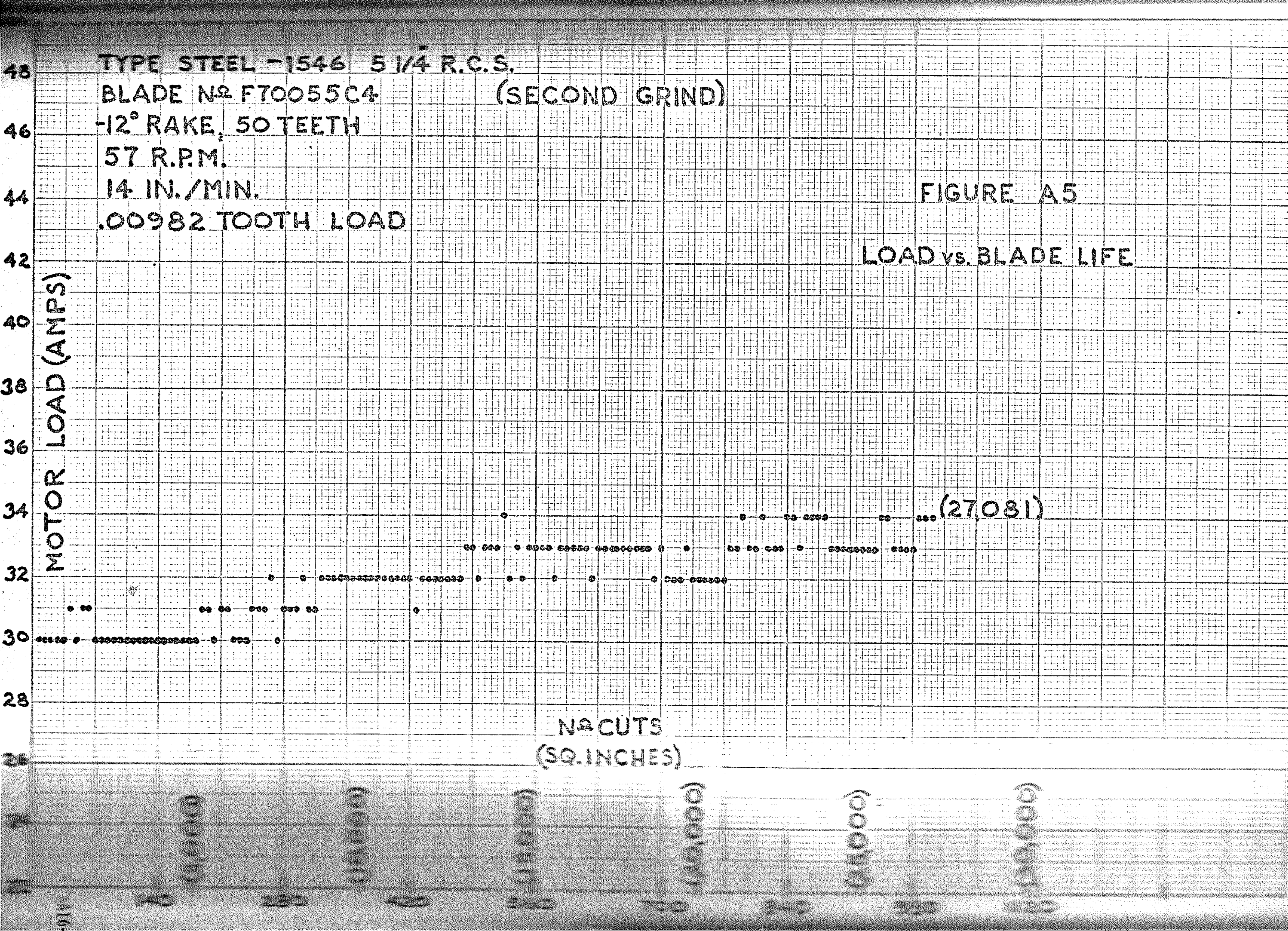
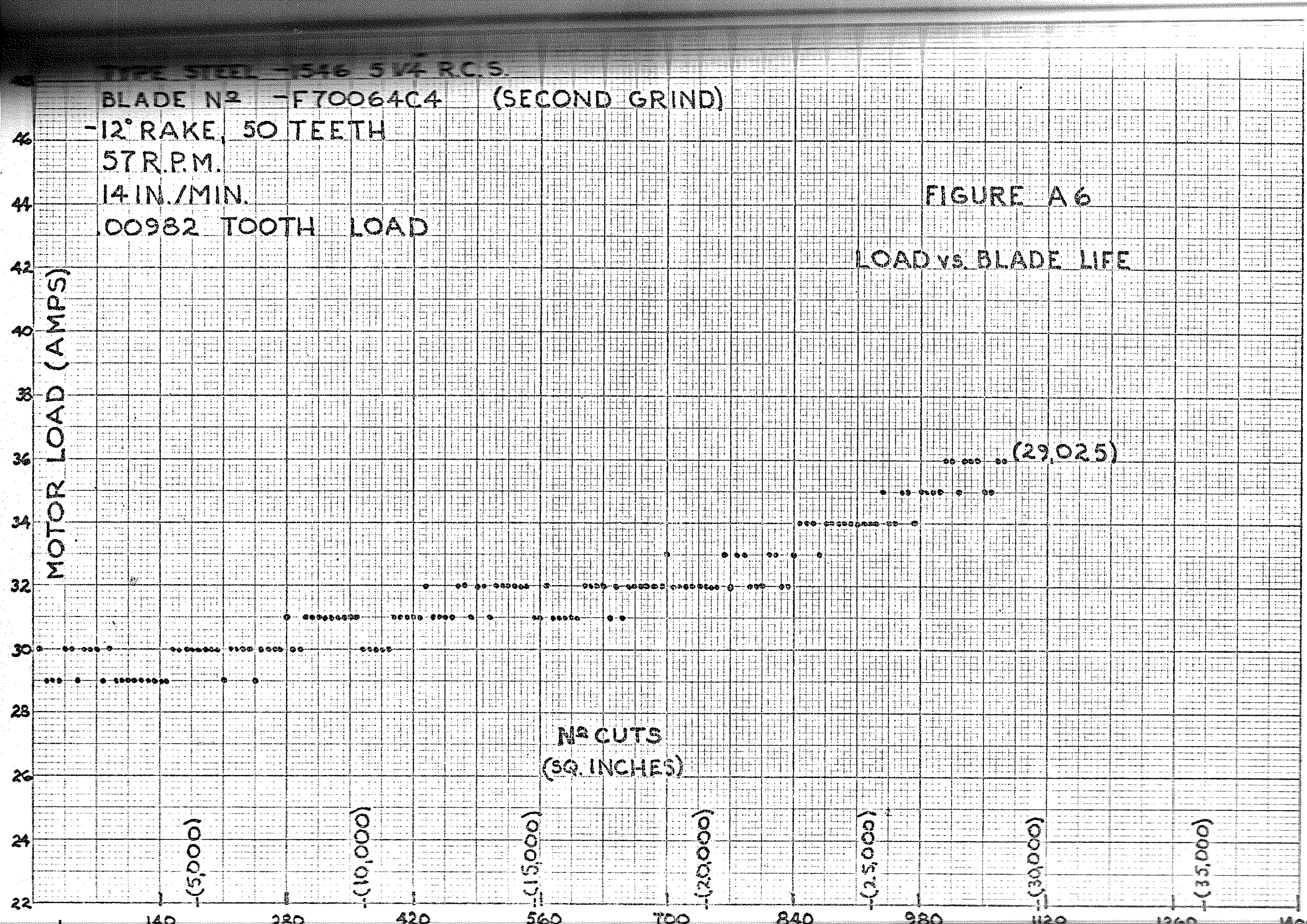
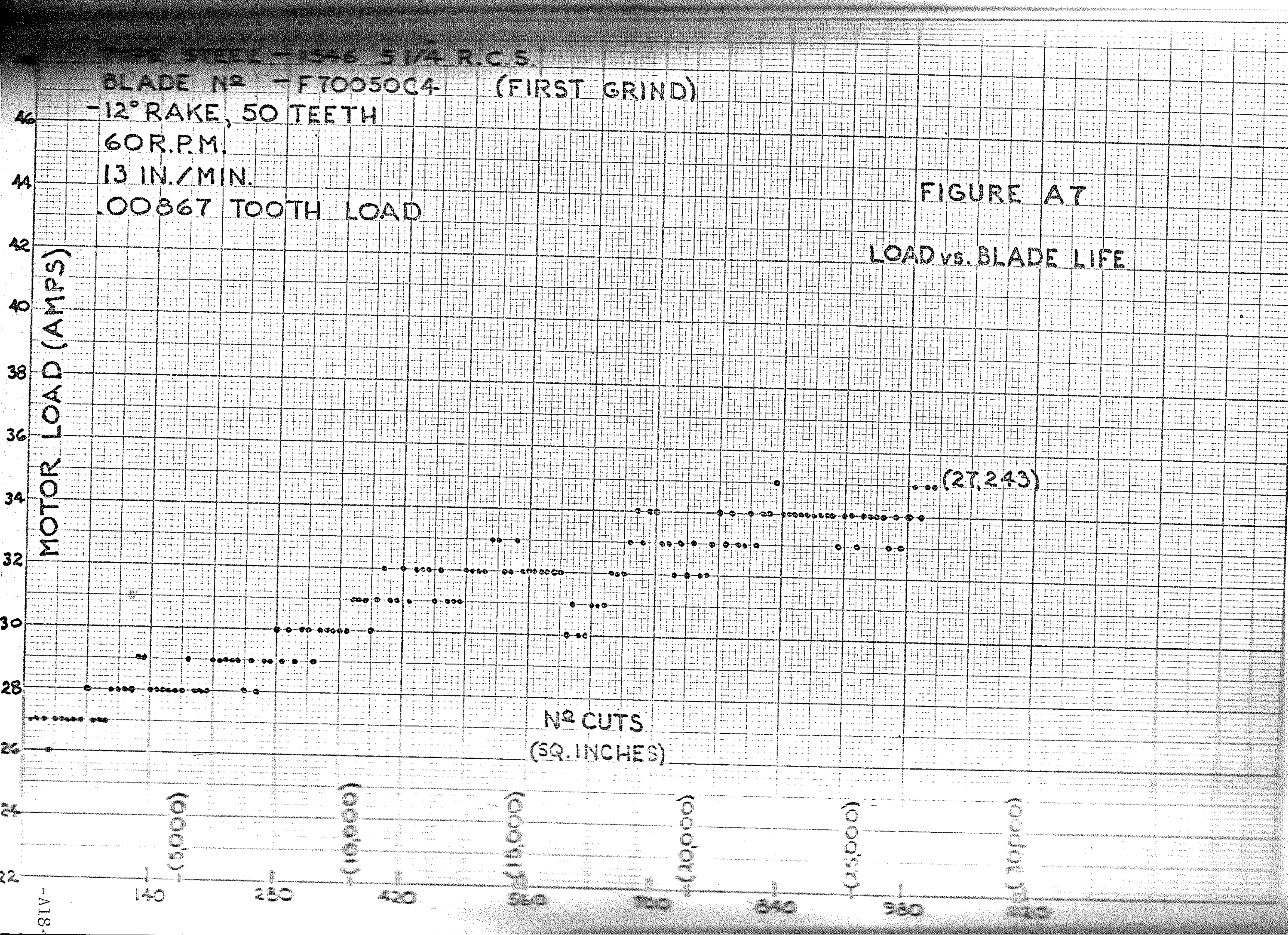


FIGURE A5

LOAD vs. BLADE LIFE


TYPE STEEL -1546 5 1/4 R.C.S.
BLADE Nº -F70064C4 (SECOND GRIND)
-12° RAKE, 50 TEETH
57 R.P.M.
14 IN./MIN.
.00982 TOOTH LOAD
FIGURE A6
LOAD vs. BLADE LIFE
MOTOR LOAD (AMPS)
(29,025)
Nº CUTS
(SQ. INCHES)
(5,000)
(10,000)
(15,000)
(20,000)
(25,000)
(30,000)
(35,000)
140
280
420
560
700
840
980
46
44
42
40
38
36
34
32
30
28
26
24
22


TYPE STEEL — 1546 5 1/4 R.C.S.
BLADE Nº — F70050C4 (FIRST GRIND)
12° RAKE, 50 TEETH
60 R.P.M.
13 IN./MIN.
.00867 TOOTH LOAD
FIGURE A7
LOAD vs. BLADE LIFE
MOTOR LOAD (AMPS)
Nº CUTS
(SQ. INCHES)
(27,243)
(5,000)
(10,000)
(15,000)
(20,000)
(25,000)
(30,000)

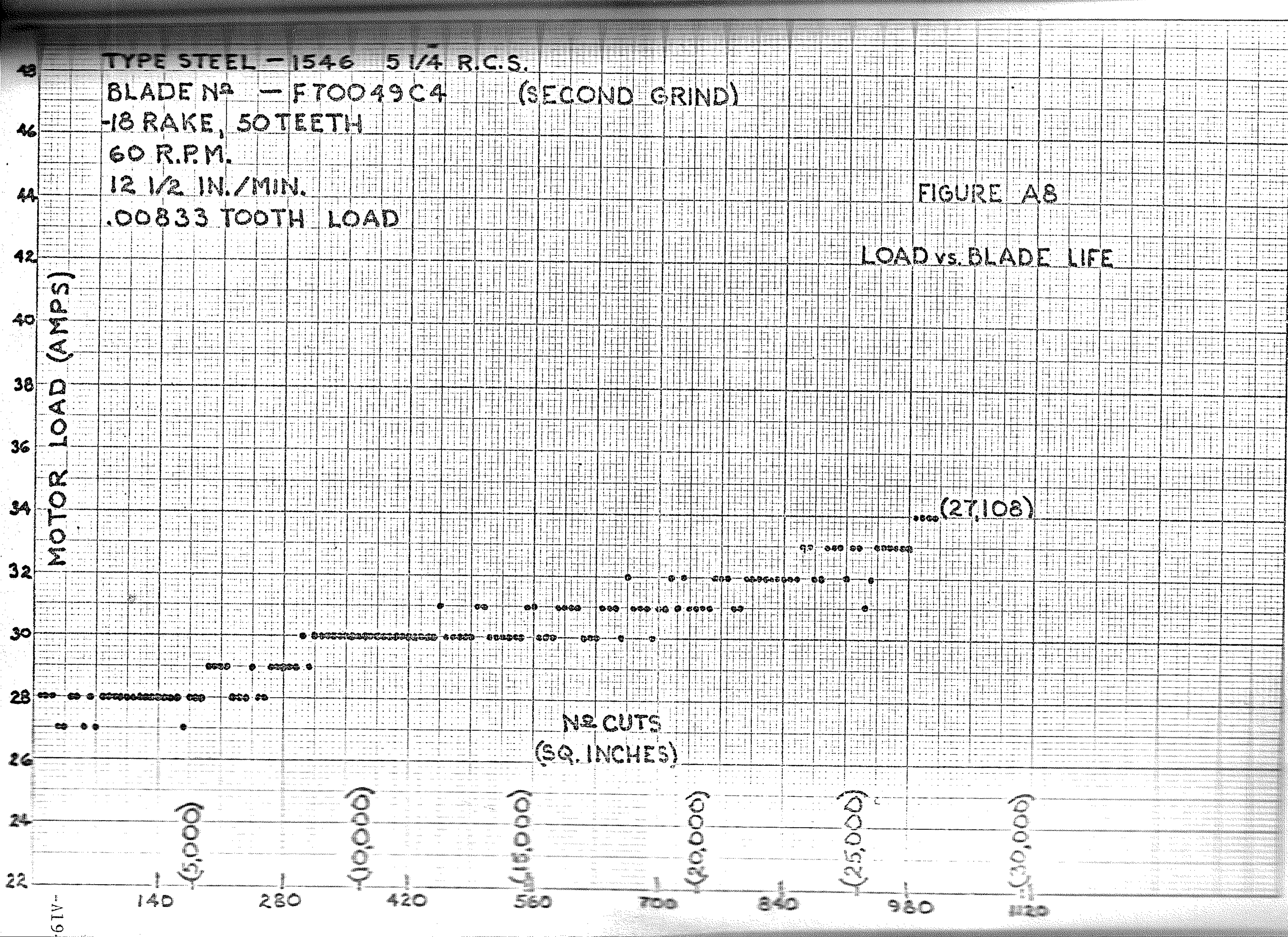
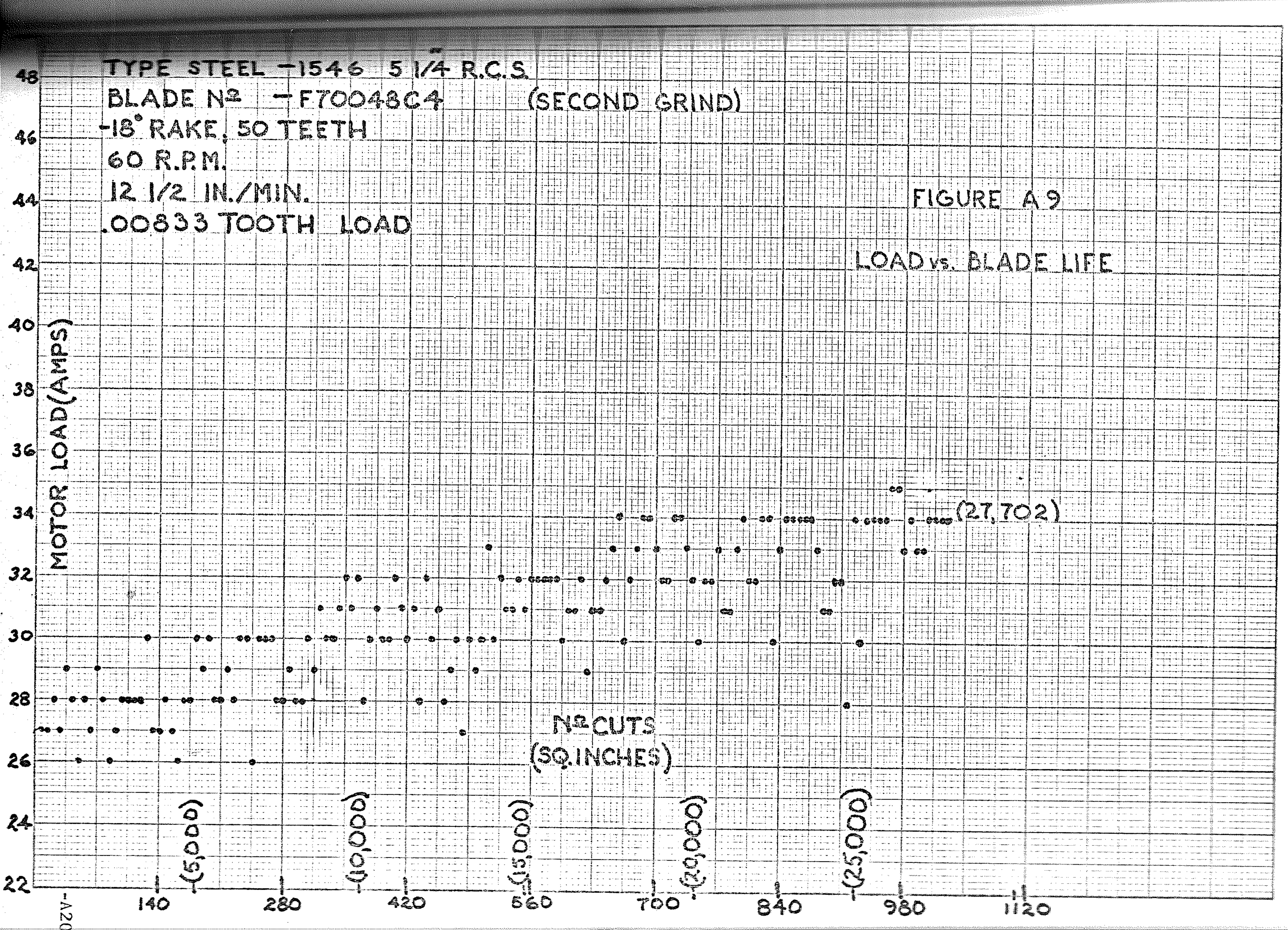
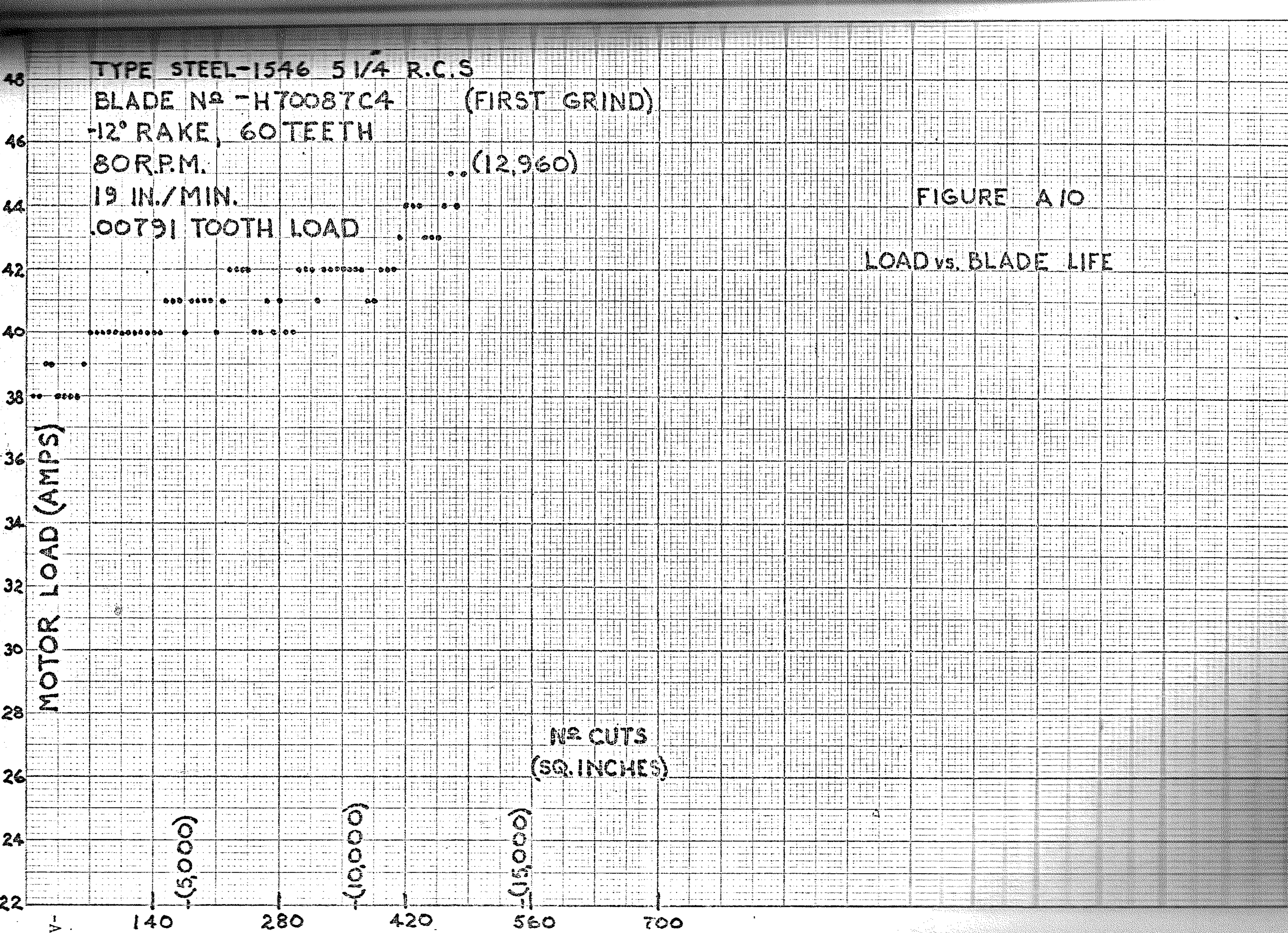


FIGURE A8

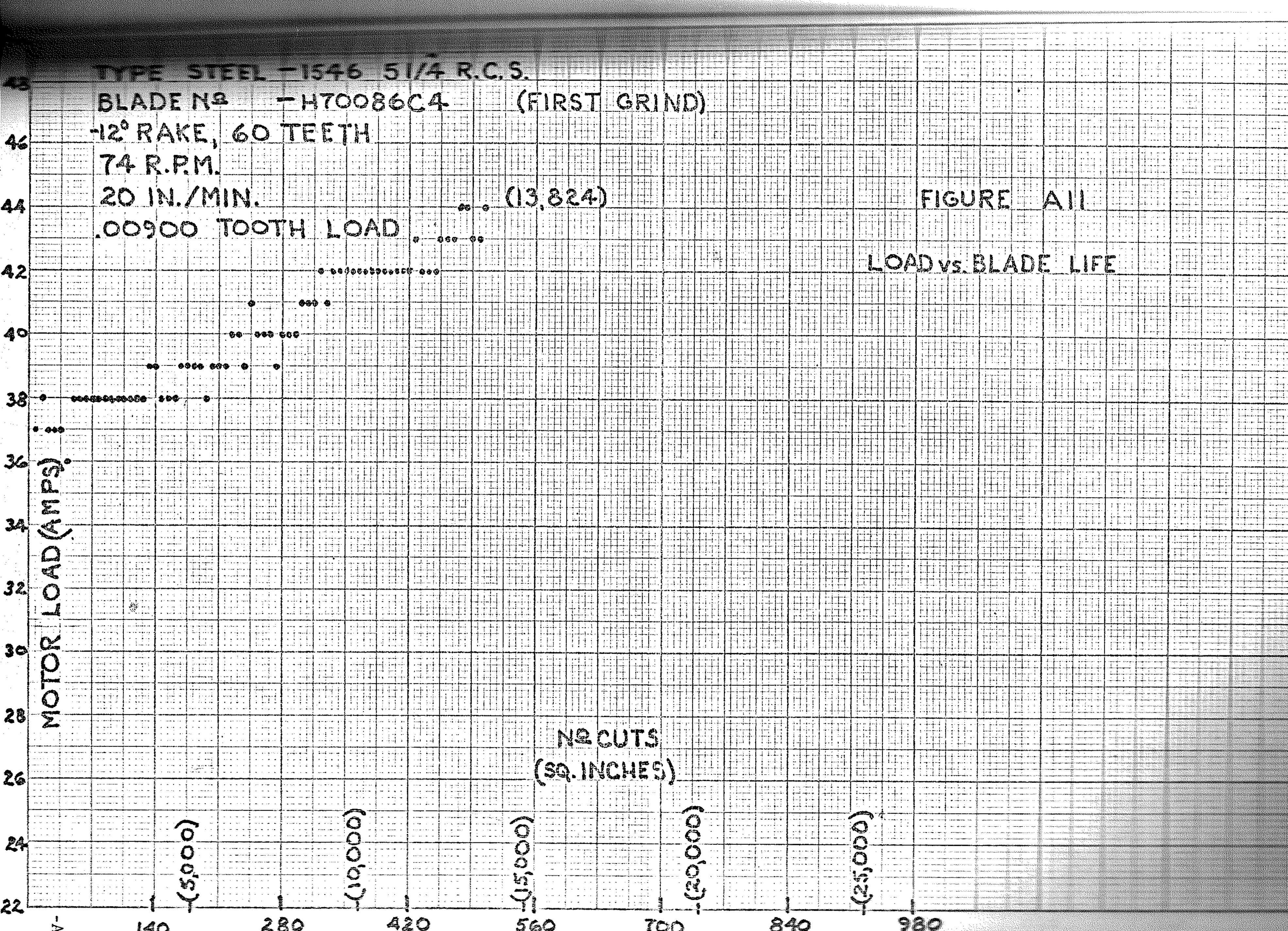
LOAD vs. BLADE LIFE

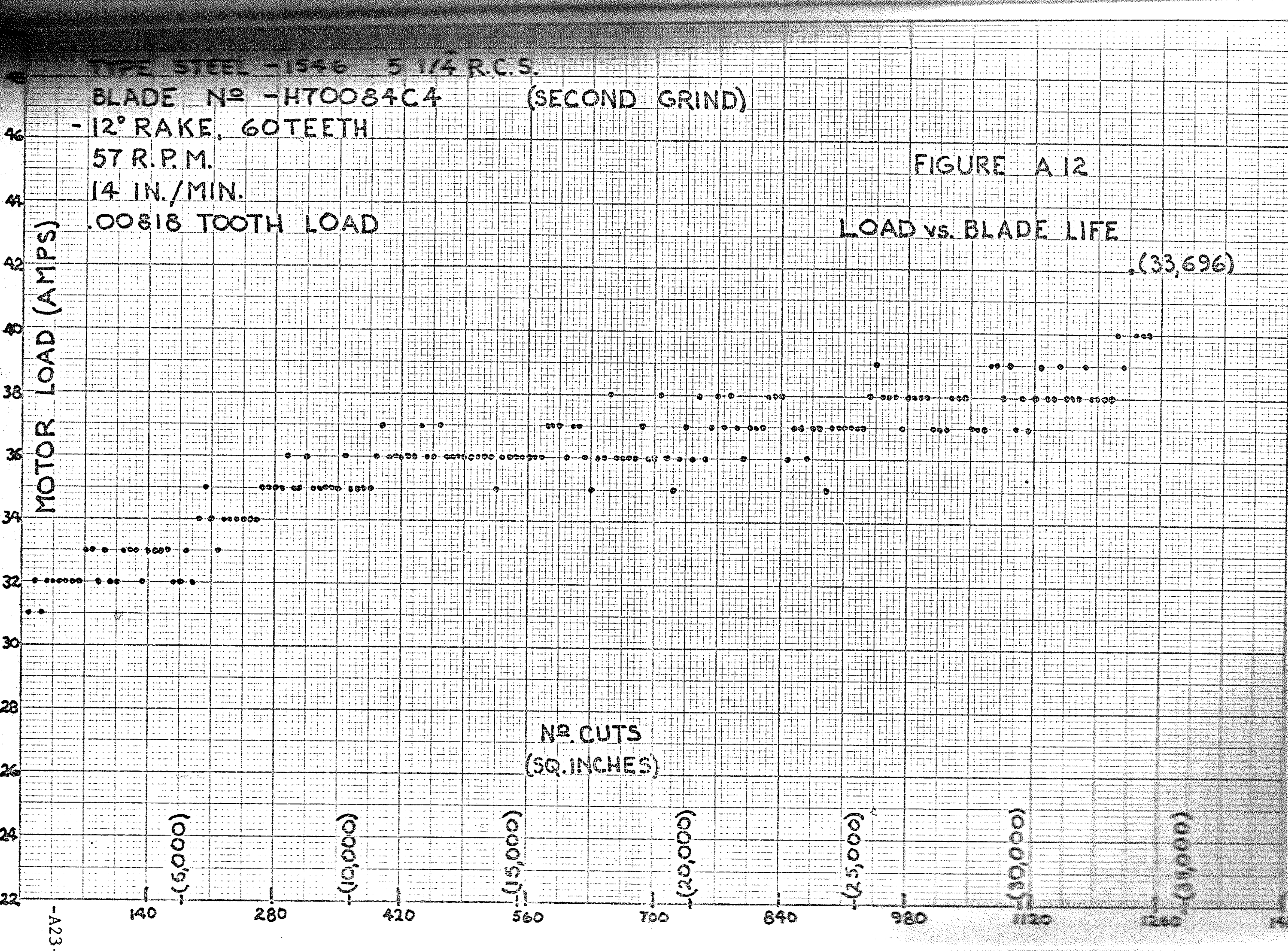


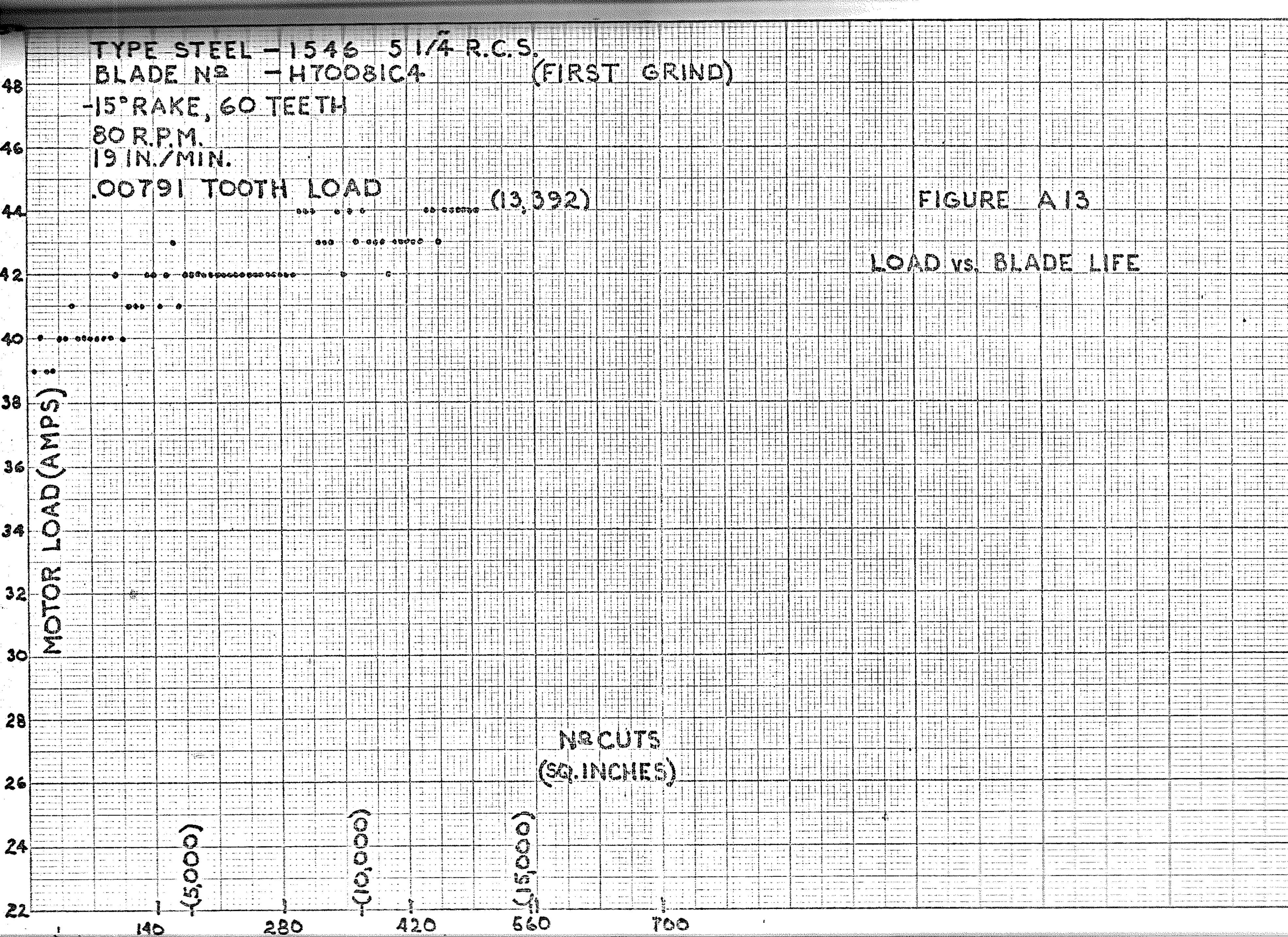
TYPE STEEL -1546 5 1/4" R.C.S.
BLADE Nº - F70048C4 (SECOND GRIND)
-18° RAKE, 50 TEETH
60 R.P.M.
12 1/2 IN./MIN.
.00833 TOOTH LOAD
FIGURE A9
LOAD vs. BLADE LIFE
MOTOR LOAD (AMPS)
Nº CUTS
(SQ. INCHES)
(27,702)
(5,000)
(10,000)
(15,000)
(20,000)
(25,000)
48
46
44
42
40
38
36
34
32
30
28
26
24
22
140
280
420
560
700
840
980
1120

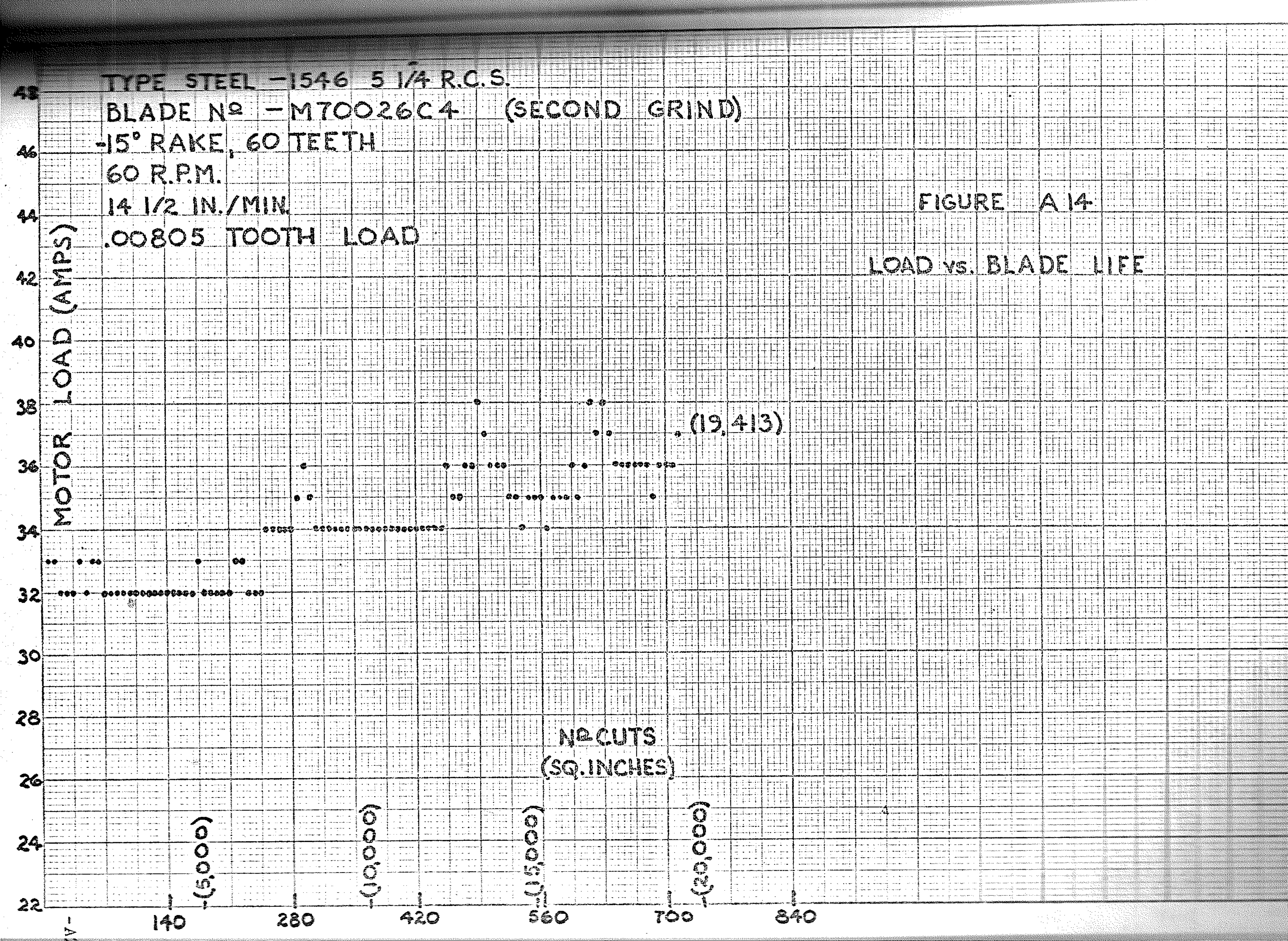


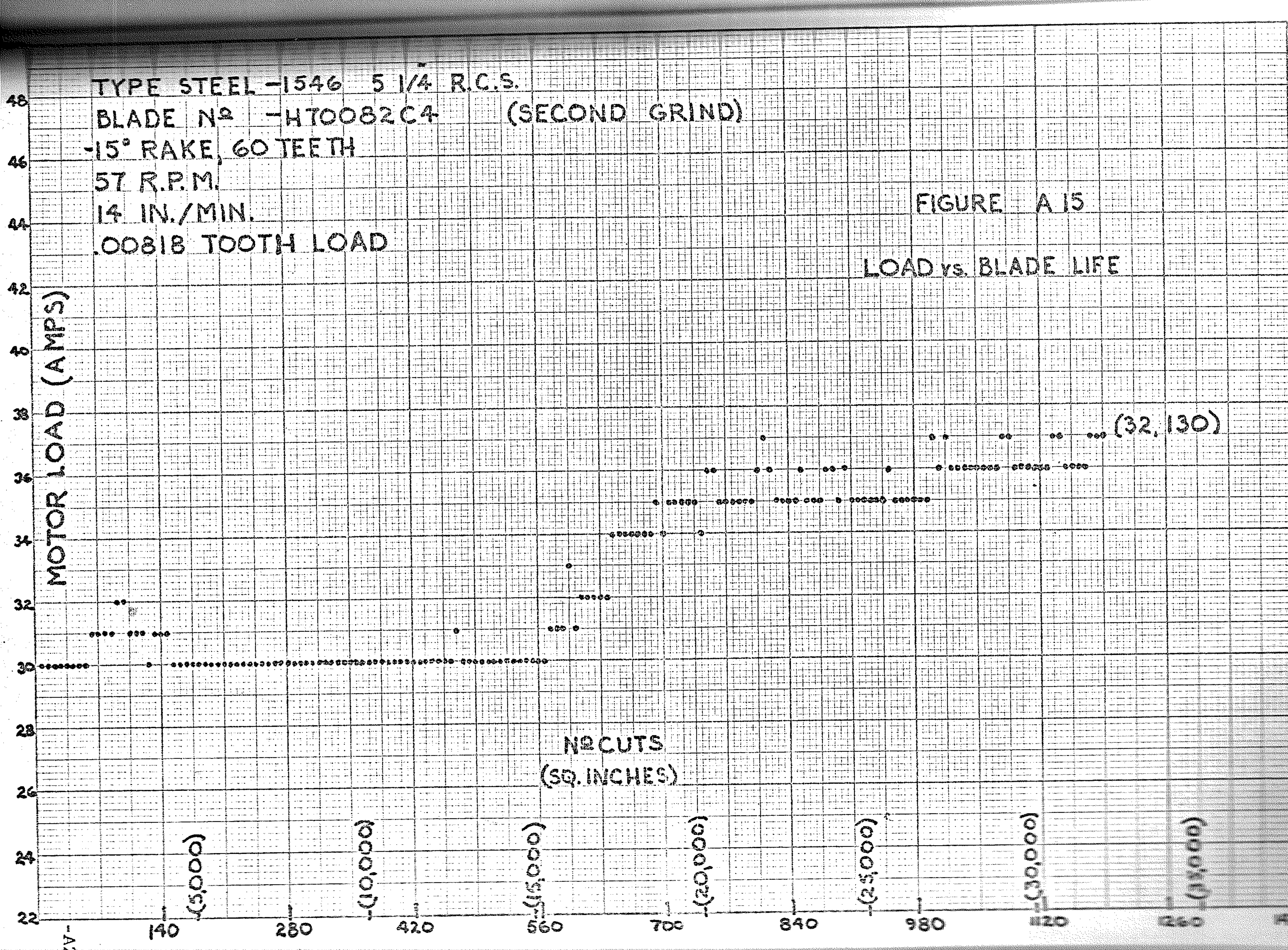
TYPE STEEL-1546 5 1/4 R.C.S
BLADE Nº -H70087C4 (FIRST GRIND)
-12° RAKE, 60 TEETH
80 R.P.M.
19 IN./MIN.
.00791 TOOTH LOAD
(12,960)
FIGURE A10
LOAD vs. BLADE LIFE
MOTOR LOAD (AMPS)
48
46
44
42
40
38
36
34
32
30
28
26
24
22
Nº CUTS
(SQ. INCHES)
(5,000)
(10,000)
(15,000)
140
280
420
560
700


TYPE STEEL -1546 5 1/4 R.C.S.
BLADE № -H70086C4 (FIRST GRIND)
-12° RAKE, 60 TEETH
74 R.P.M.
20 IN./MIN.
.00900 TOOTH LOAD
(13,824)
FIGURE A11
LOAD vs. BLADE LIFE
MOTOR LOAD (AMPS)
48
46
44
42
40
38
36
34
32
30
28
26
24
22
№ CUTS
(SQ. INCHES)
140
280
420
560
700
840
980
(5,000)
(10,000)
(15,000)
(20,000)
(25,000)


TYPE STEEL -1546 5 1/4 R.C.S.
BLADE № -H70084C4 (SECOND GRIND)
-12° RAKE, 60 TEETH
57 R.P.M.
14 IN./MIN.
.00818 TOOTH LOAD
FIGURE A 12
LOAD vs. BLADE LIFE
(33,696)
MOTOR LOAD (AMPS)
№ CUTS
(SQ. INCHES)
22
24
26
28
30
32
34
36
38
40
42
44
46
140
280
420
560
700
840
980
1120
1260
1400
(5,000)
(10,000)
(15,000)
(20,000)
(25,000)
(30,000)
(35,000)


TYPE STEEL — 1546 5 1/4 R.C.S.
BLADE Nº — H70081C4 (FIRST GRIND)
-15° RAKE, 60 TEETH
80 R.P.M.
19 IN./MIN.
.00791 TOOTH LOAD
(13,392)
FIGURE A 13
LOAD vs. BLADE LIFE
MOTOR LOAD (AMPS)
Nº CUTS
(SQ. INCHES)
(5,000)
(10,000)
(15,000)
48
46
44
42
40
38
36
34
32
30
28
26
24
22
140
280
420
560
700


TYPE STEEL -1546 5 1/4 R.C.S.
BLADE Nº - M70026C4 (SECOND GRIND)
-15° RAKE, 60 TEETH
60 R.P.M.
14 1/2 IN./MIN.
.00805 TOOTH LOAD
FIGURE A 14
LOAD vs. BLADE LIFE
MOTOR LOAD (AMPS)
(19,413)
Nº CUTS
(SQ. INCHES)
(5,000)
(10,000)
(15,000)
(20,000)
48
46
44
42
40
38
36
34
32
30
28
26
24
22
140
280
420
560
700
840



TYPE STEEL -1546 5 1/4 R.C.S.
BLADE Nº -H70082C4 (SECOND GRIND)
-15° RAKE, 60 TEETH
57 R.P.M.
14 IN./MIN.
.00818 TOOTH LOAD
FIGURE A15
LOAD vs. BLADE LIFE
MOTOR LOAD (AMPS)
Nº CUTS
(SQ. INCHES)
(32,130)
48
46
44
42
40
38
36
34
32
30
28
26
24
22
140
280
420
560
700
840
980
1120
1260
1400
(5,000)
(10,000)
(15,000)
(20,000)
(25,000)
(30,000)
(35,000)

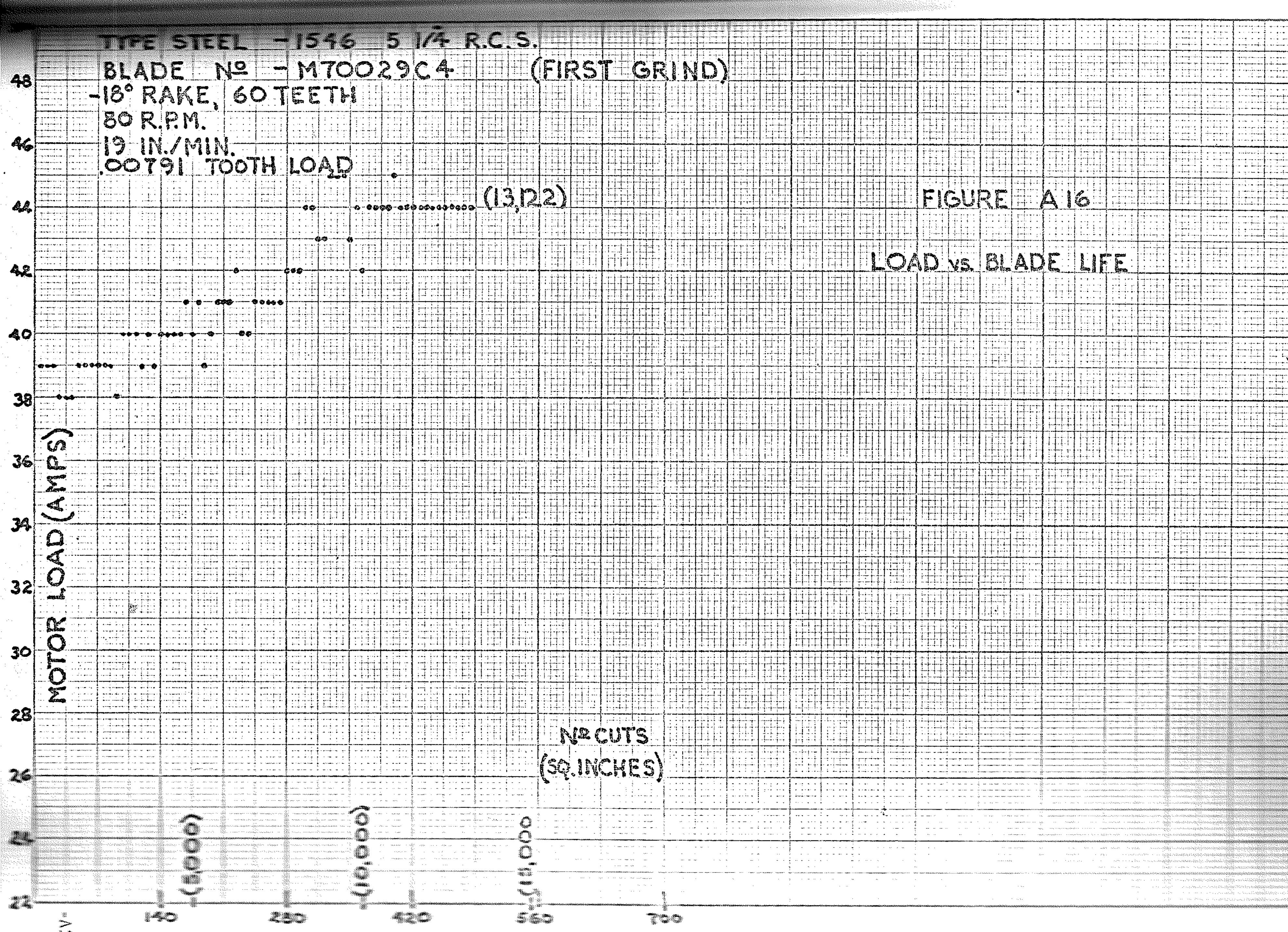


FIGURE A 16

LOAD vs. BLADE LIFE

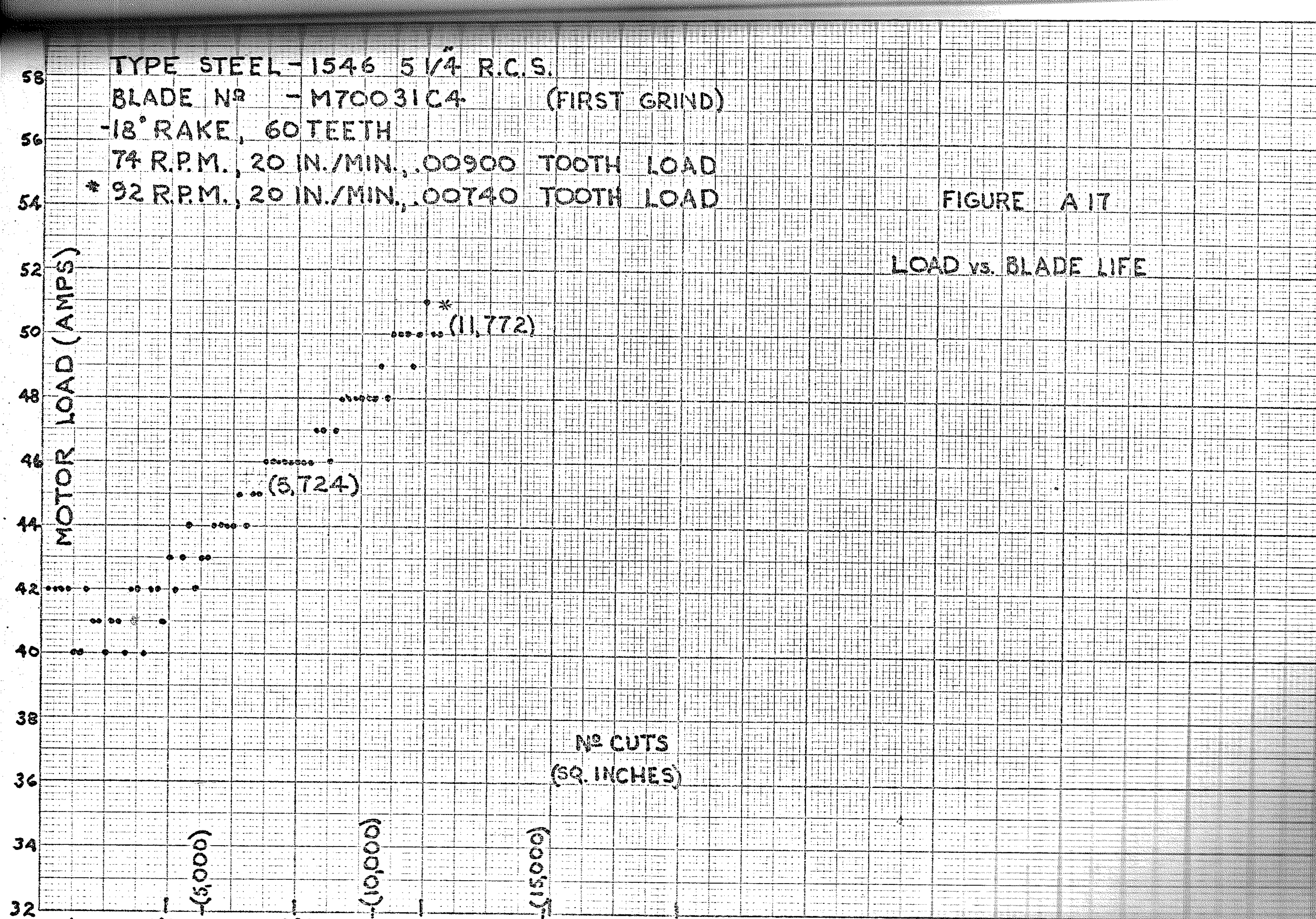
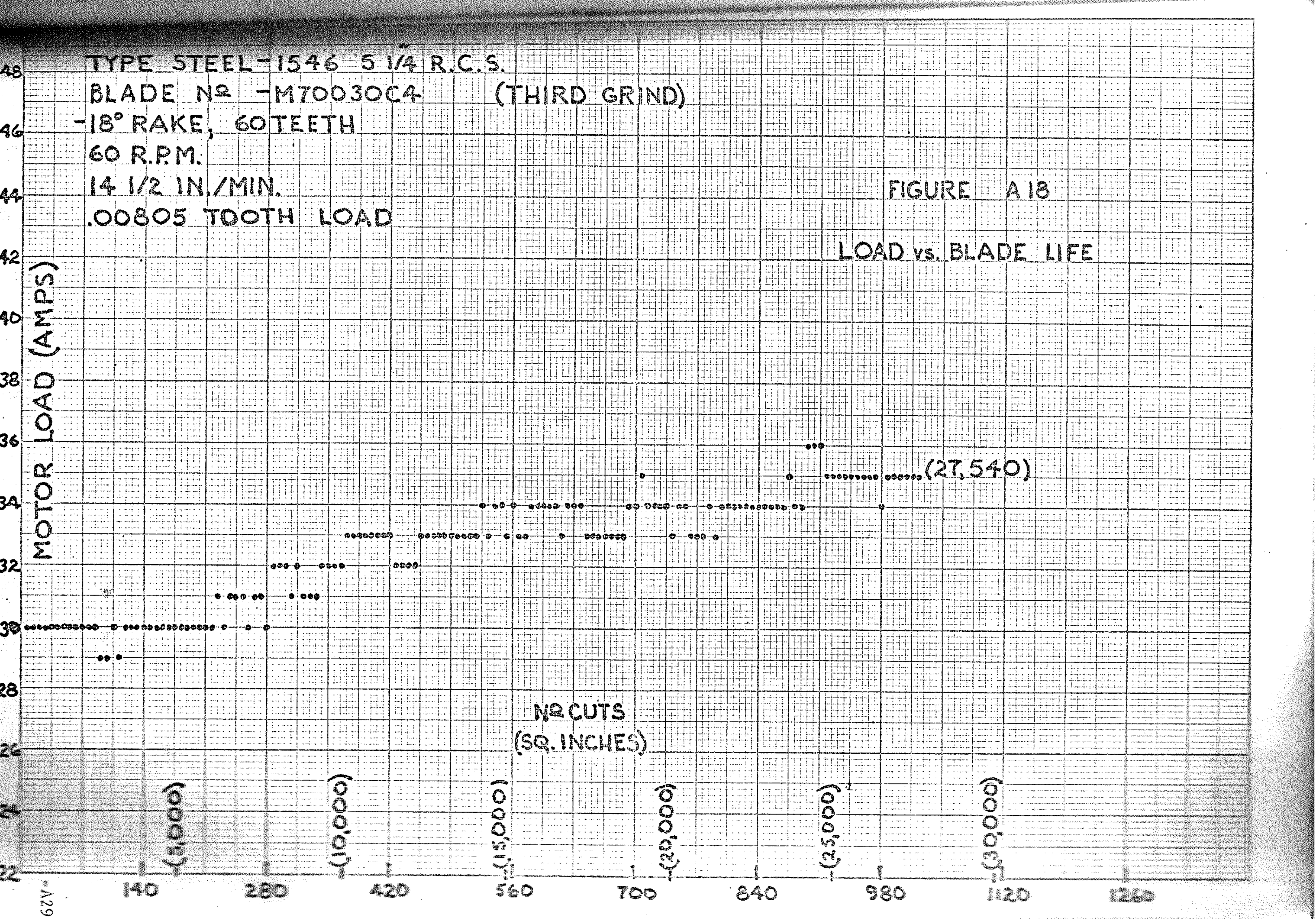
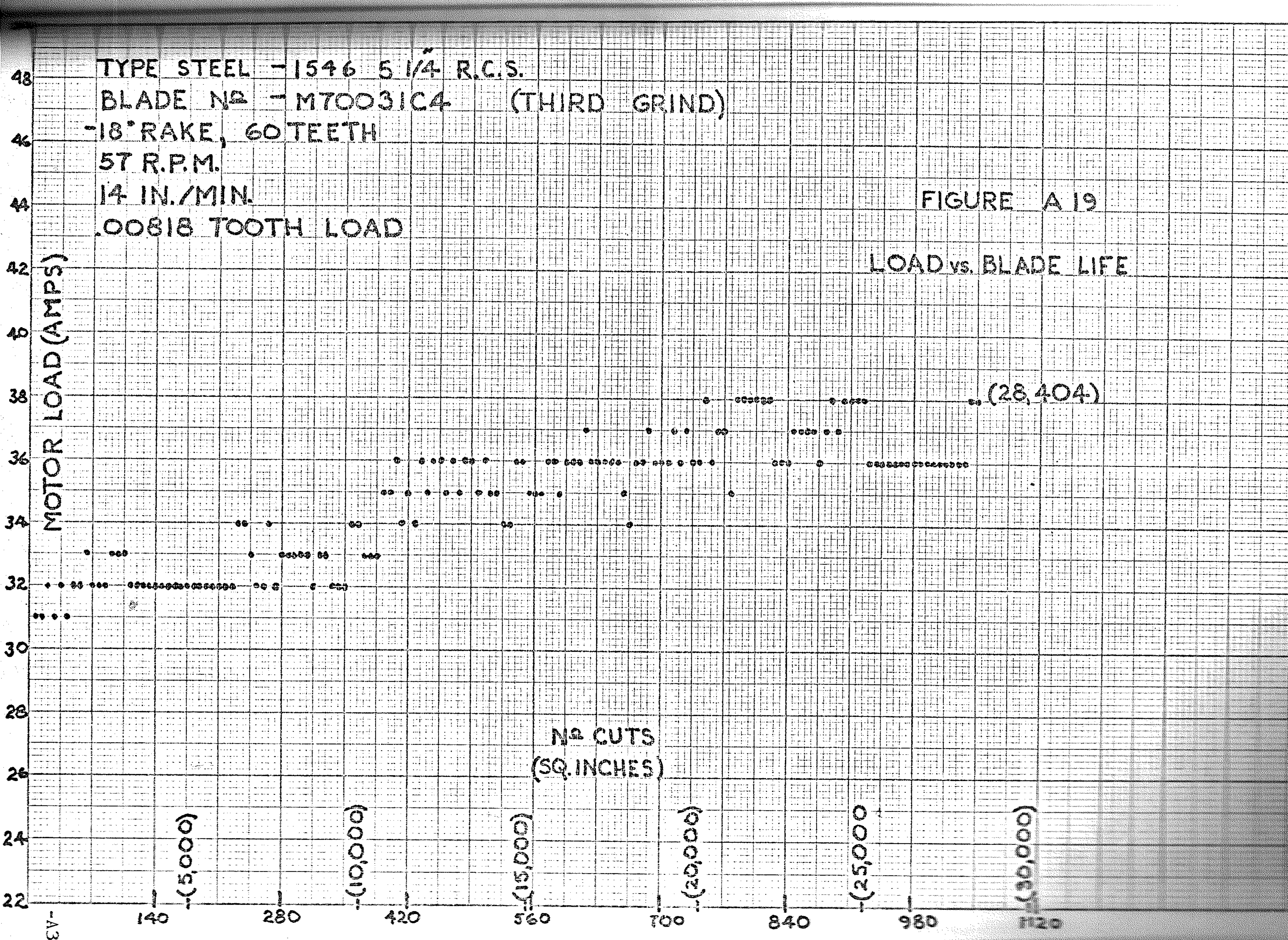


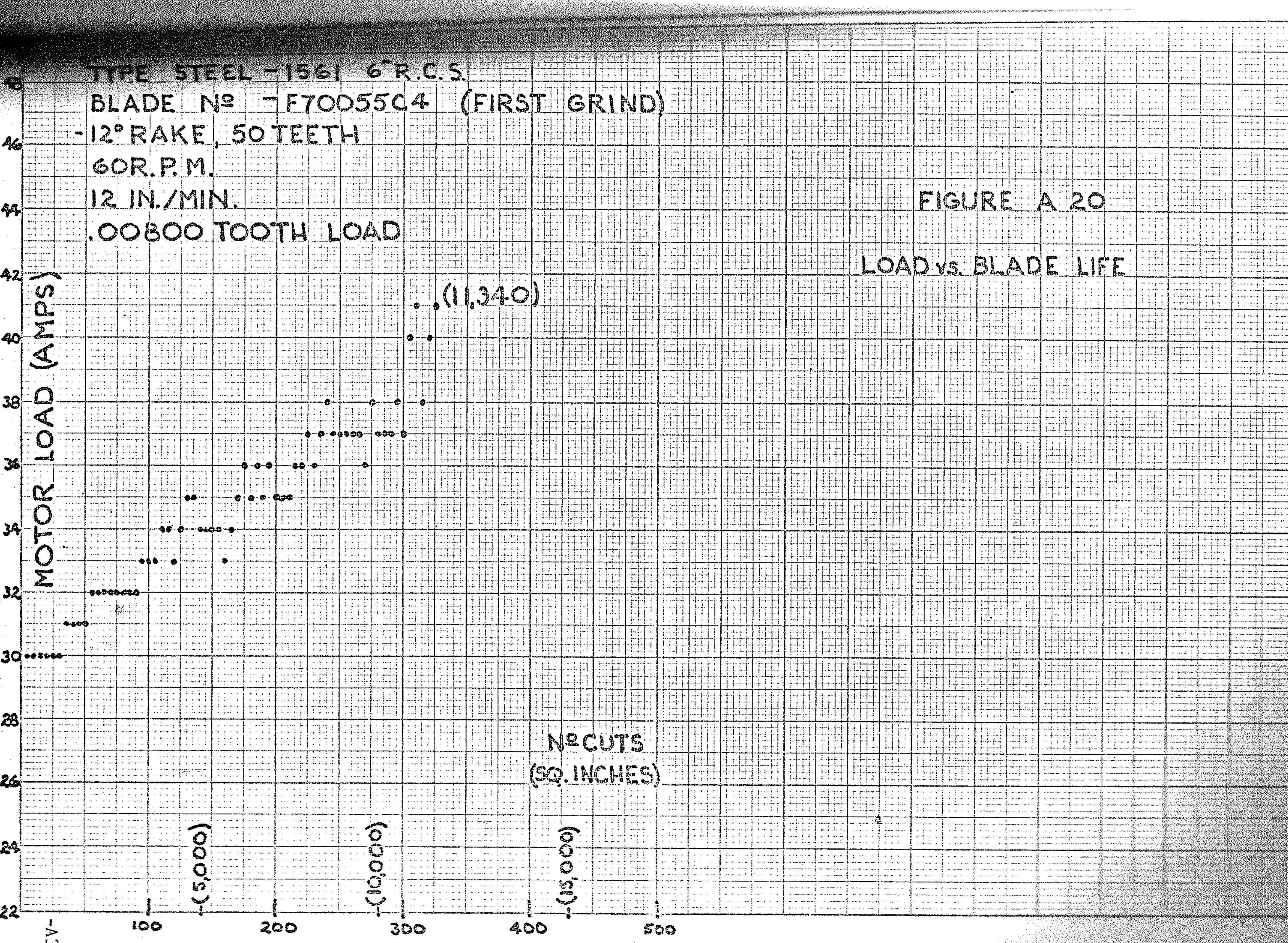
FIGURE A 17

LOAD vs. BLADE LIFE



TYPE STEEL-1546 5 1/4 R.C.S.
BLADE № -M70030C4 (THIRD GRIND)
-18° RAKE, 60 TEETH
60 R.P.M.
14 1/2 IN./MIN.
.00805 TOOTH LOAD
FIGURE A18
LOAD vs. BLADE LIFE
MOTOR LOAD (AMPS)
№ CUTS
(SQ. INCHES)
(27,540)
(5,000)
(10,000)
(15,000)
(20,000)
(25,000)
(30,000)
48
46
44
42
40
38
36
34
32
30
28
26
24
22
140
280
420
560
700
840
980
1120
1260


TYPE STEEL - 1546 5 1/4" R.C.S.
BLADE No - M70031C4 (THIRD GRIND)
-18° RAKE, 60 TEETH
57 R.P.M.
14 IN./MIN.
.00818 TOOTH LOAD
FIGURE A 19
LOAD vs. BLADE LIFE
MOTOR LOAD (AMPS)
No CUTS
(SQ. INCHES)
(28,404)
48
46
44
42
40
38
36
34
32
30
28
26
24
22
140
280
420
560
700
840
980
1120
(5,000)
(10,000)
(15,000)
(20,000)
(25,000)
(30,000)


TYPE STEEL - 1561 6" R.C.S.
BLADE № - F70055C4 (FIRST GRIND)
-12° RAKE, 50 TEETH
60 R.P.M.
12 IN./MIN.
.00800 TOOTH LOAD
FIGURE A 20
LOAD vs. BLADE LIFE
(11,340)
MOTOR LOAD (AMPS)
№ CUTS
(SQ. INCHES)
(5,000)
(10,000)
(15,000)
22
24
26
28
30
32
34
36
38
40
42
44
46
48
100
200
300
400
500

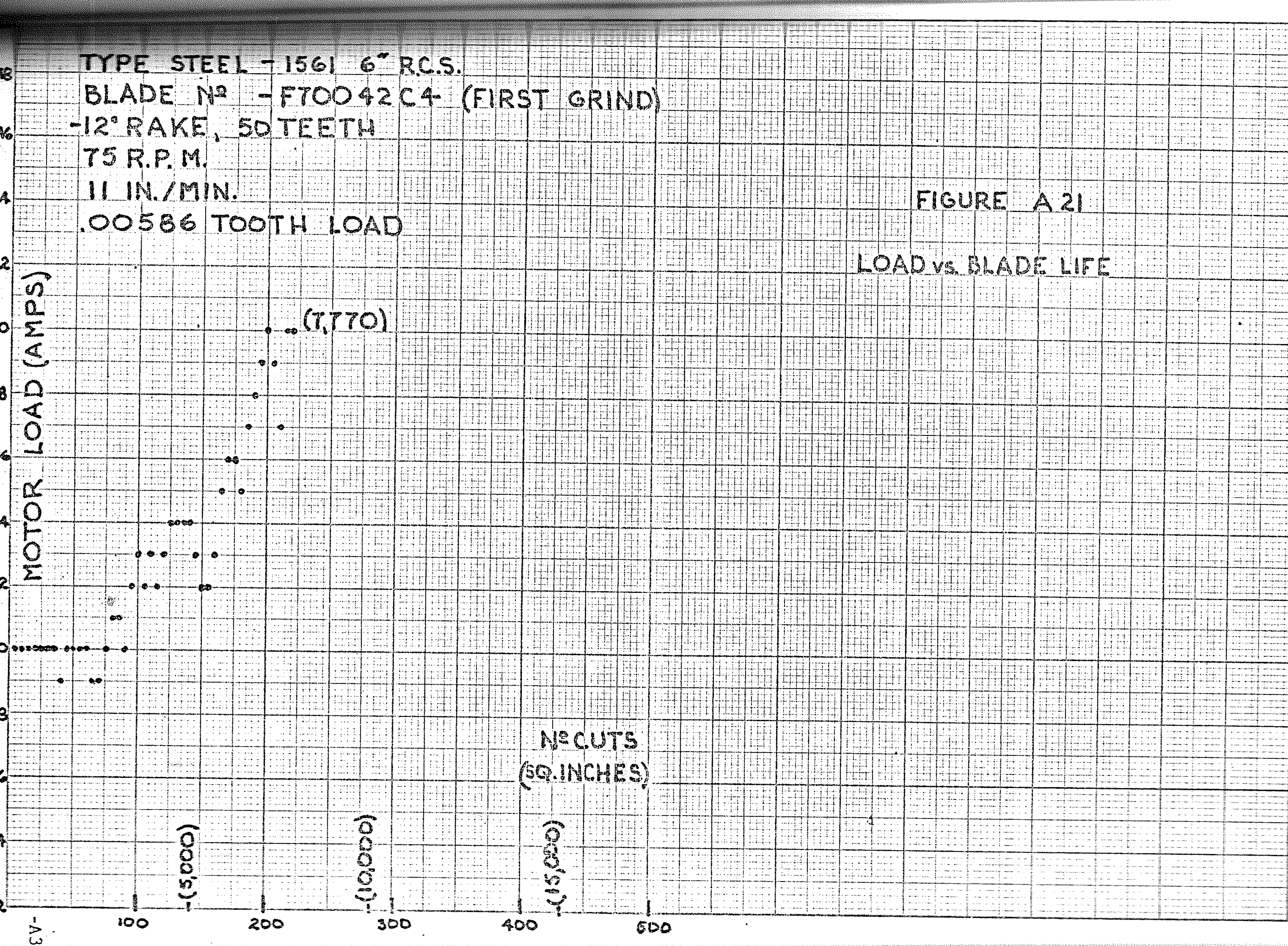


FIGURE A 21

LOAD vs. BLADE LIFE

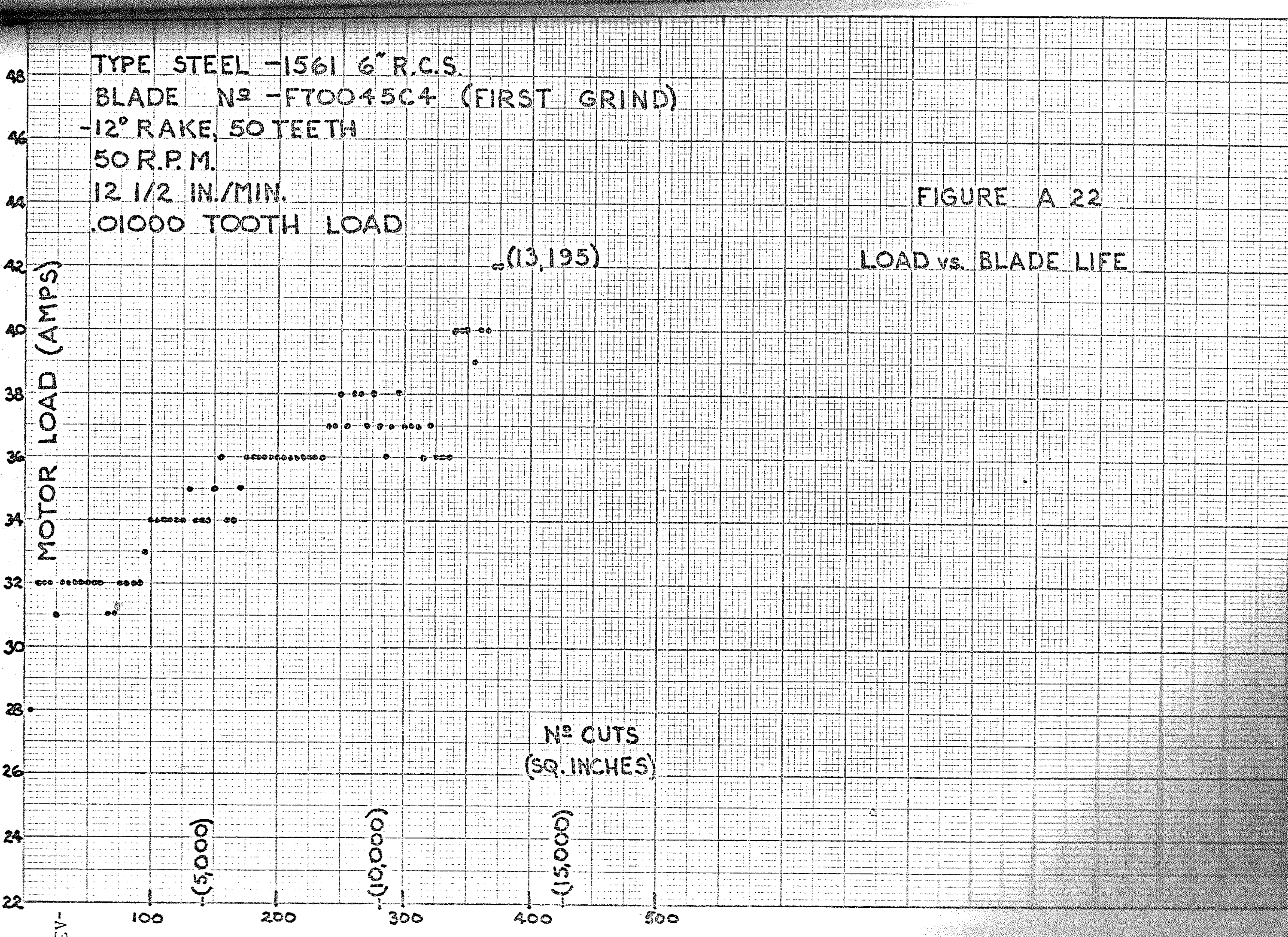
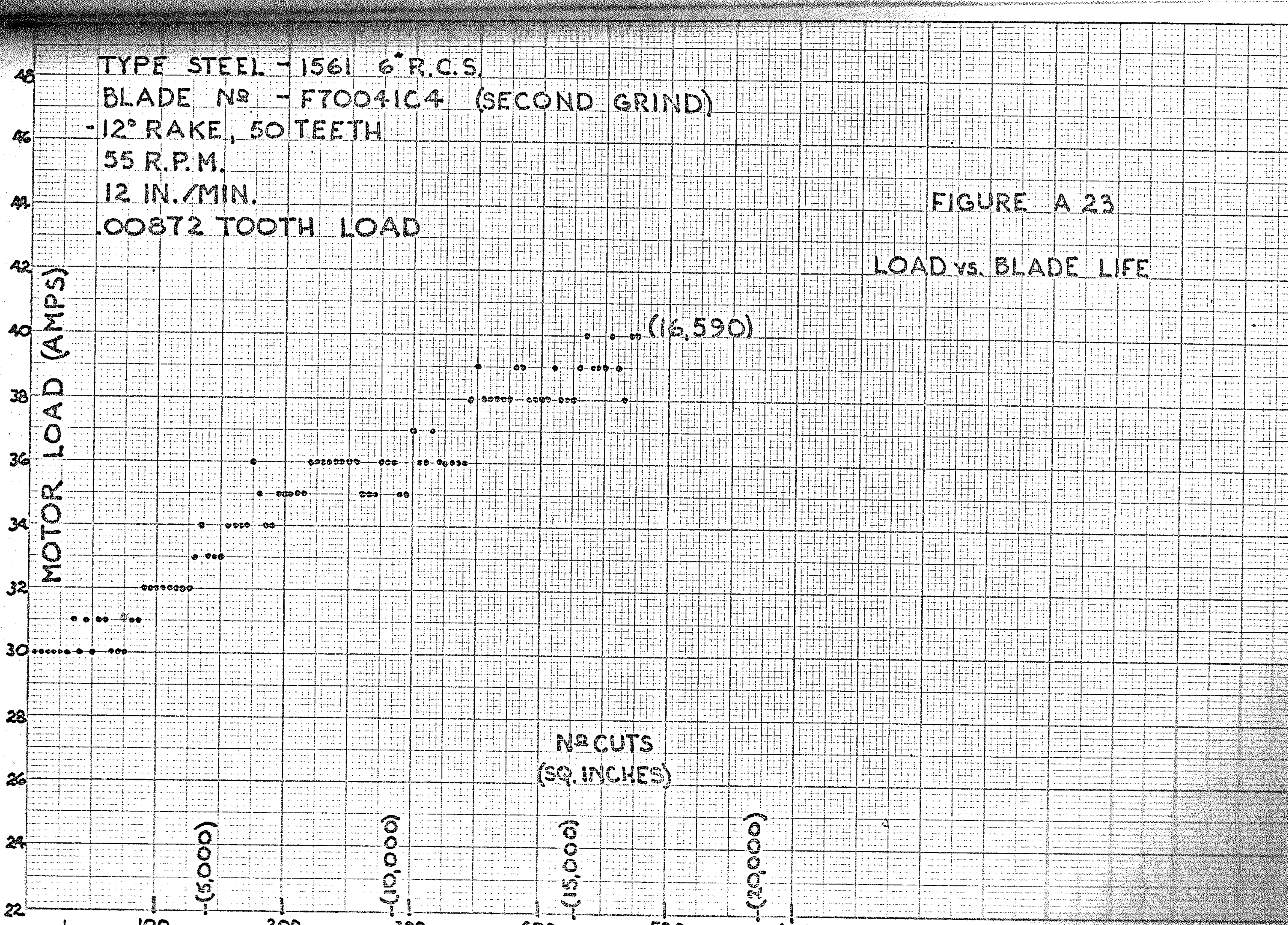
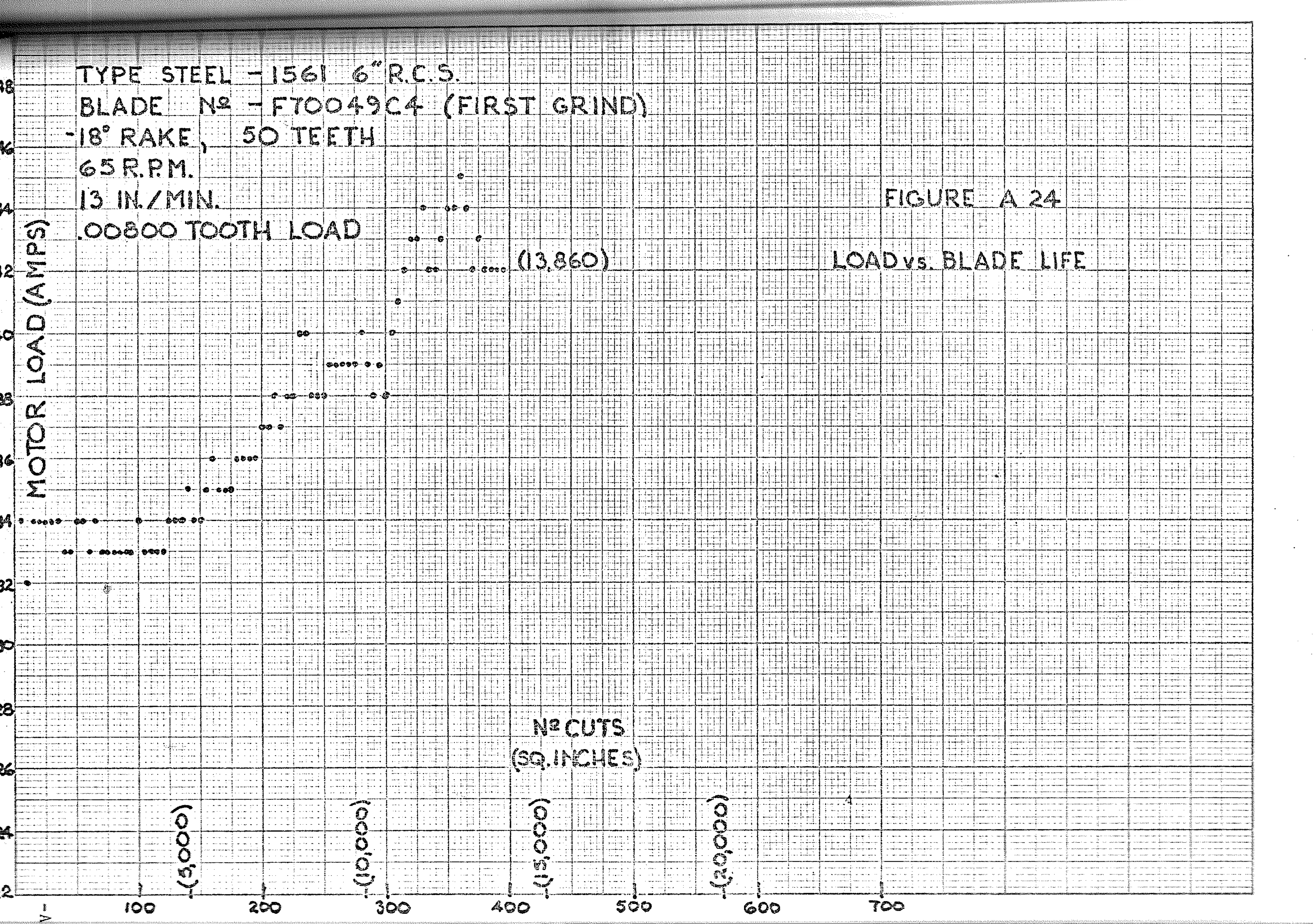


FIGURE A 22

LOAD vs. BLADE LIFE


TYPE STEEL - 1561 6" R.C.S.
BLADE № - F7004IC4 (SECOND GRIND)
- 12° RAKE, 50 TEETH
55 R.P.M.
12 IN./MIN.
.00872 TOOTH LOAD
FIGURE A 23
LOAD vs. BLADE LIFE
MOTOR LOAD (AMPS)
(16,590)
№ CUTS
(SQ. INCHES)
(5,000)
(10,000)
(15,000)
(20,000)
48
46
44
42
40
38
36
34
32
30
28
26
24
22
100
200
300
400
500
600


TYPE STEEL - 1561 6" R.C.S.
BLADE № - F70049C4 (FIRST GRIND)
-18° RAKE, 50 TEETH
65 R.P.M.
13 IN./MIN.
.00800 TOOTH LOAD
FIGURE A 24
LOAD vs. BLADE LIFE
MOTOR LOAD (AMPS)
№ CUTS
(SQ. INCHES)
(13,860)
(5,000)
(10,000)
(15,000)
(20,000)
48
46
44
42
40
38
36
34
32
30
28
26
24
22
100
200
300
400
500
600
700

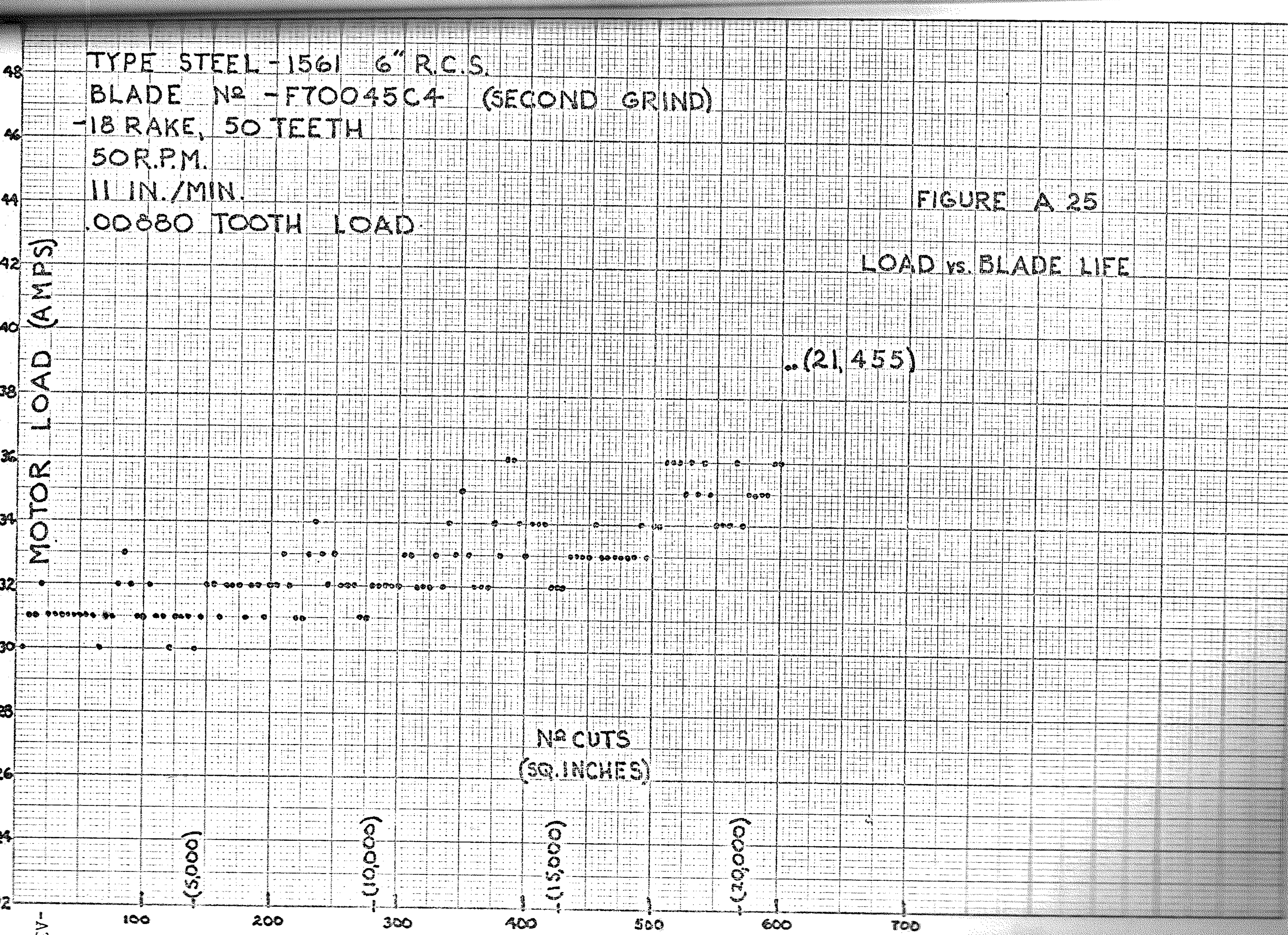
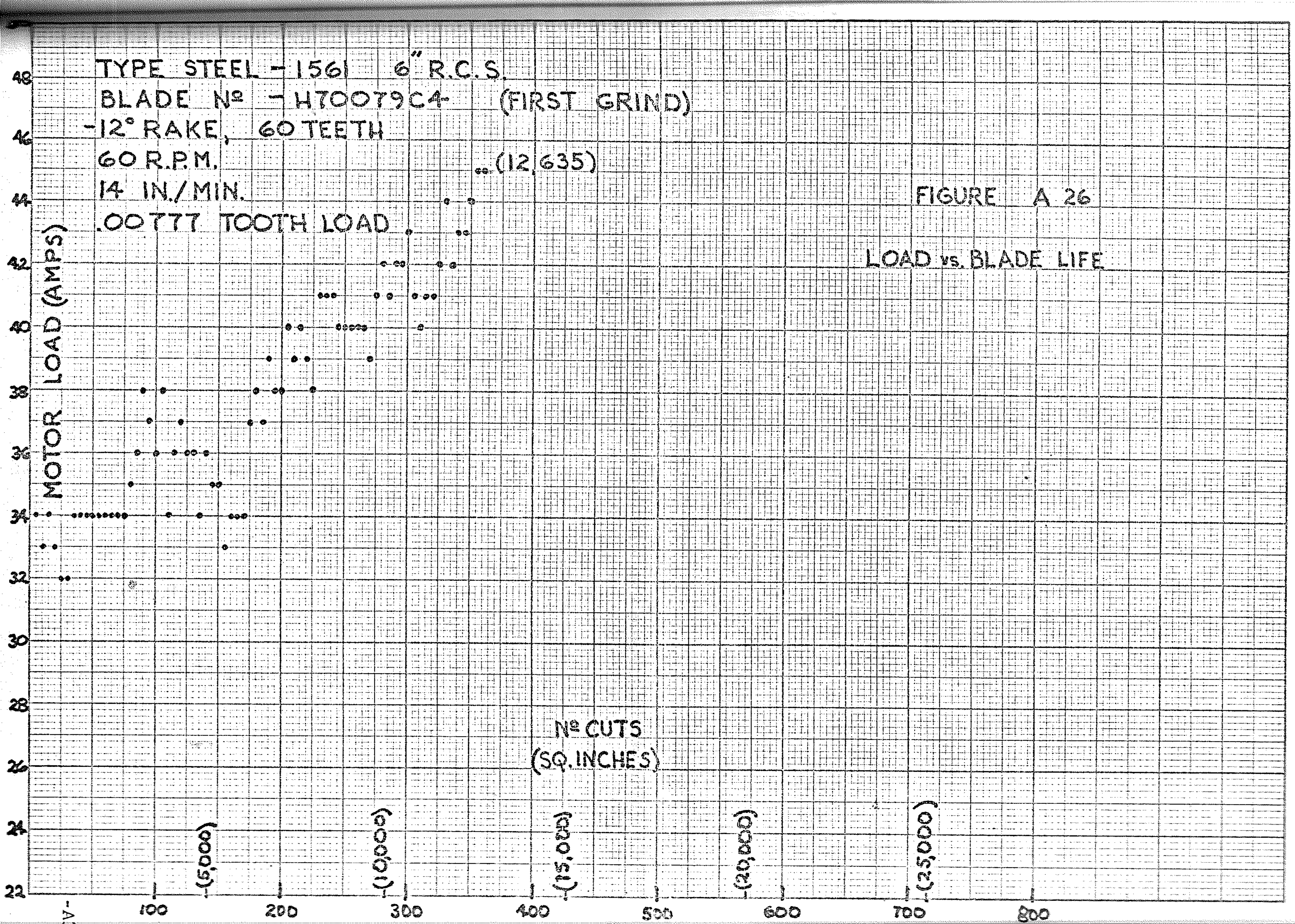
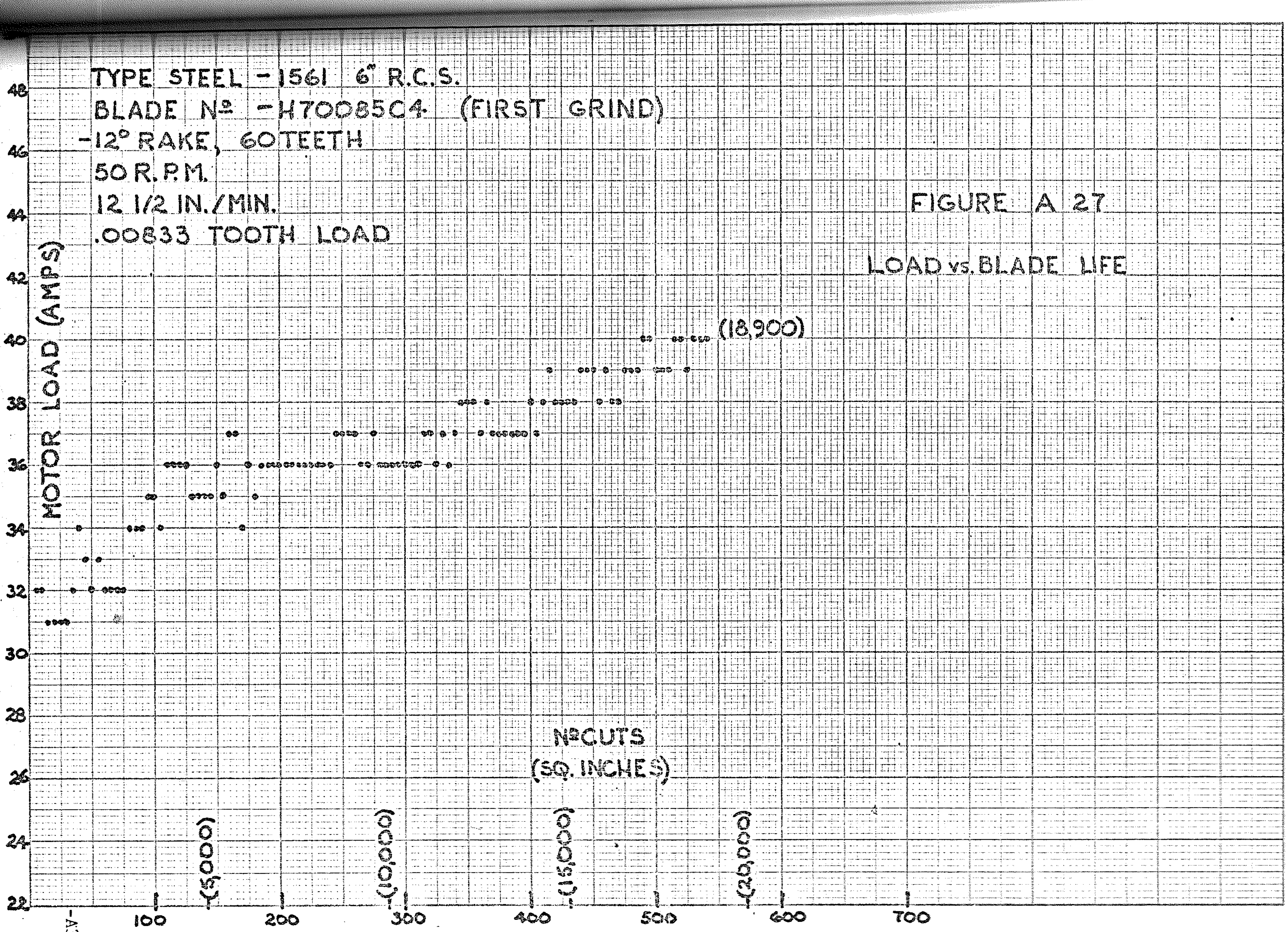
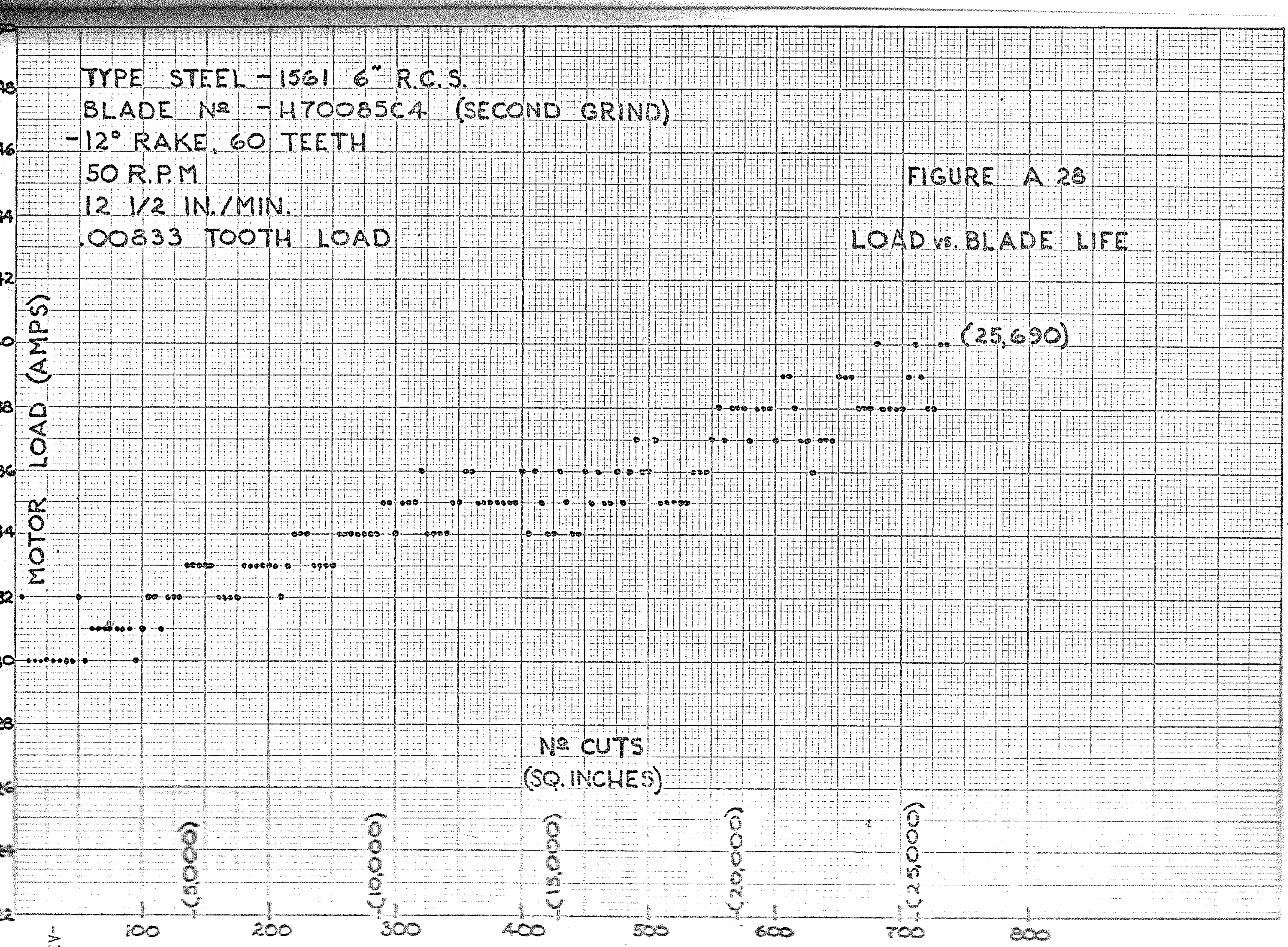


FIGURE A 25

LOAD vs. BLADE LIFE


TYPE STEEL - 1561 6" R.C.S.
BLADE Nº - H70079C4 (FIRST GRIND)
-12° RAKE, 60 TEETH
60 R.P.M.
14 IN./MIN.
.00777 TOOTH LOAD
(12,635)
FIGURE A 26
LOAD vs. BLADE LIFE
MOTOR LOAD (AMPS)
Nº CUTS
(SQ. INCHES)
(5,000)
(10,000)
(15,000)
(20,000)
(25,000)
100
200
300
400
500
600
700
800
22
24
26
28
30
32
34
36
38
40
42
44
46
48


TYPE STEEL - 1561 6" R.C.S.
BLADE Nº -H70085C4 (FIRST GRIND)
-12° RAKE, 60 TEETH
50 R.P.M.
12 1/2 IN./MIN.
.00833 TOOTH LOAD
FIGURE A 27
LOAD vs. BLADE LIFE
(18,900)
MOTOR LOAD (AMPS)
48
46
44
42
40
38
36
34
32
30
28
26
24
22
Nº CUTS
(SQ. INCHES)
(5,000)
(10,000)
(15,000)
(20,000)
100
200
300
400
500
600
700


TYPE STEEL - 1561 6" R.C.S.
BLADE № - H70085C4 (SECOND GRIND)
- 12° RAKE, 60 TEETH
50 R.P.M.
12 1/2 IN./MIN.
.00833 TOOTH LOAD
FIGURE A 28
LOAD vs. BLADE LIFE
(25,690)
MOTOR LOAD (AMPS)
№ CUTS
(SQ. INCHES)
(5,000)
(10,000)
(15,000)
(20,000)
(25,000)
22
26
28
30
32
34
36
38
40
42
44
46
48
50
100
200
300
400
500
600
700
800

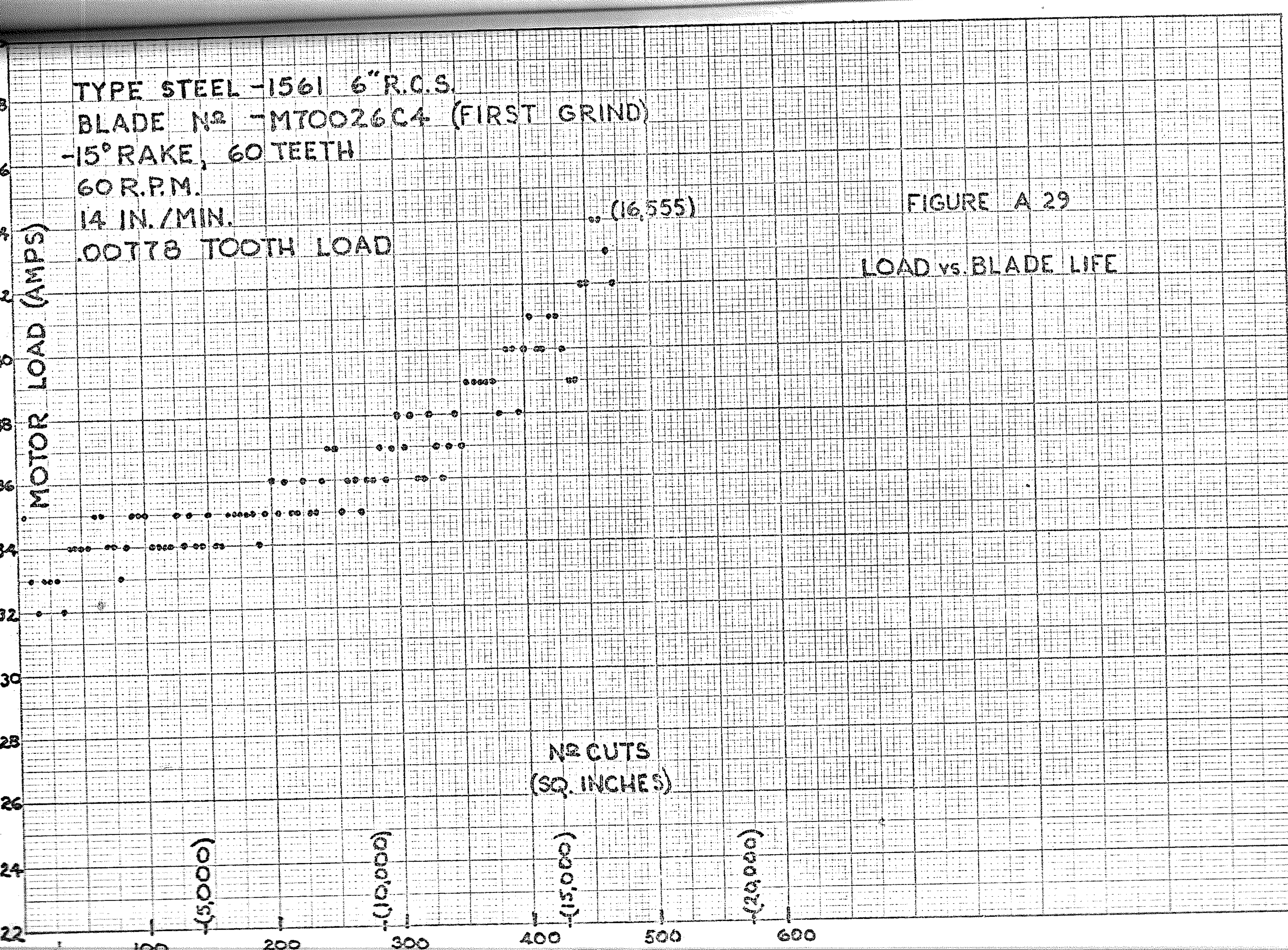
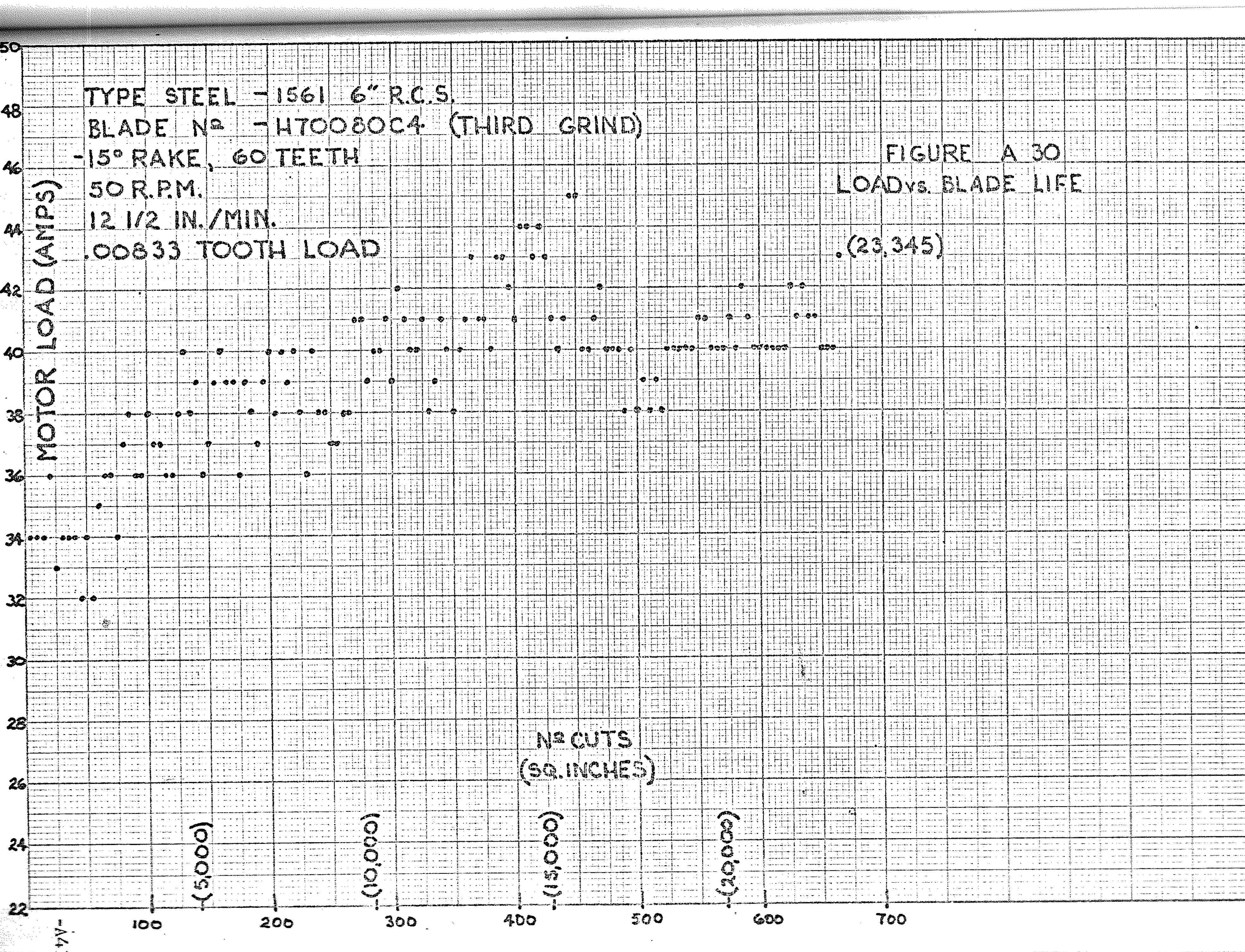


FIGURE A 29

LOAD vs. BLADE LIFE


TYPE STEEL - 1561 6" R.C.S.
BLADE № - H70080C4 (THIRD GRIND)
-15° RAKE, 60 TEETH
50 R.P.M.
12 1/2 IN./MIN.
.00833 TOOTH LOAD
FIGURE A 30
LOAD vs. BLADE LIFE
(23,345)
MOTOR LOAD (AMPS)
№ CUTS
(SQ. INCHES)
(5,000)
(10,000)
(15,000)
(20,000)
50
48
46
44
42
40
38
36
34
32
30
28
26
24
22
100
200
300
400
500
600
700

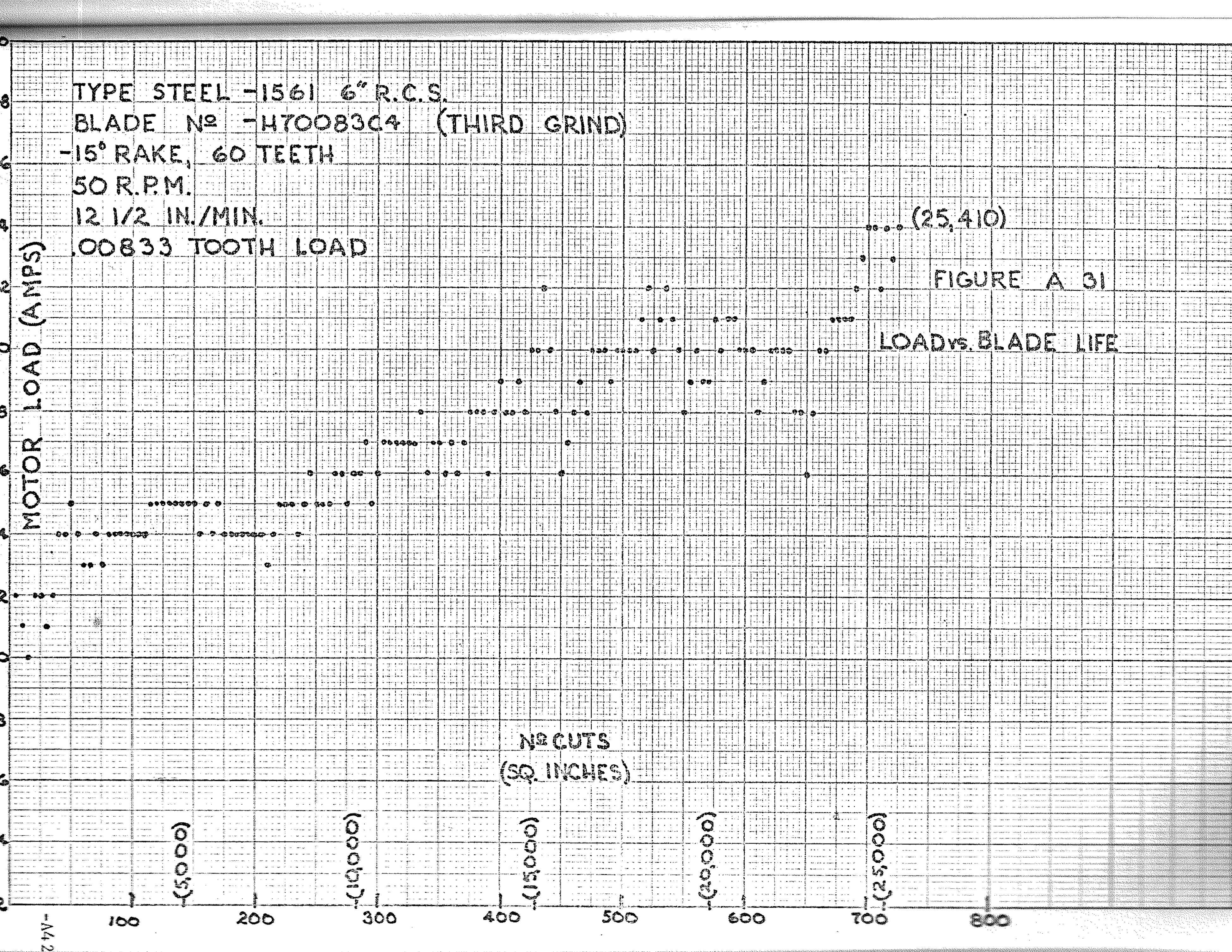


FIGURE A 31

LOAD vs. BLADE LIFE

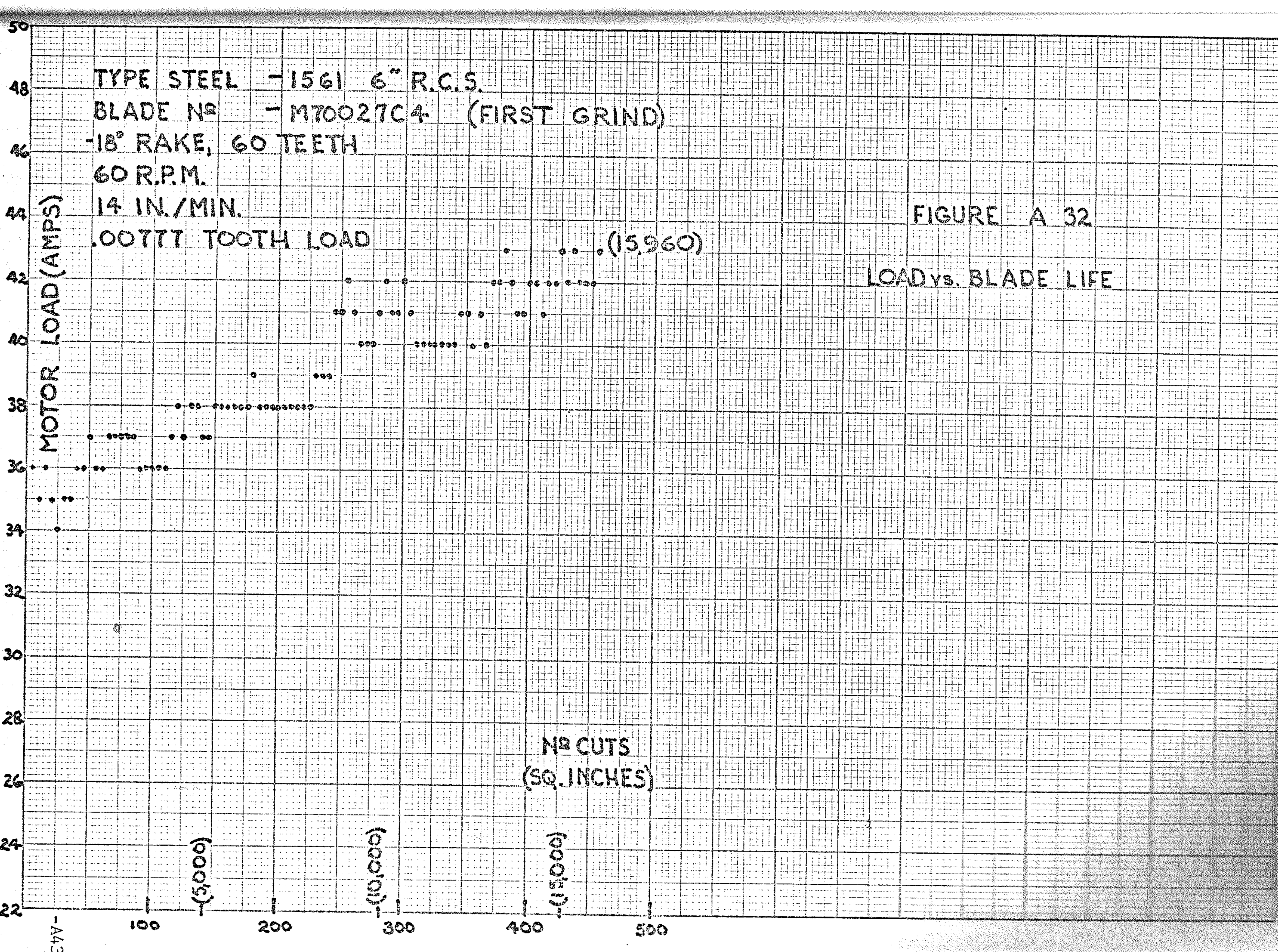
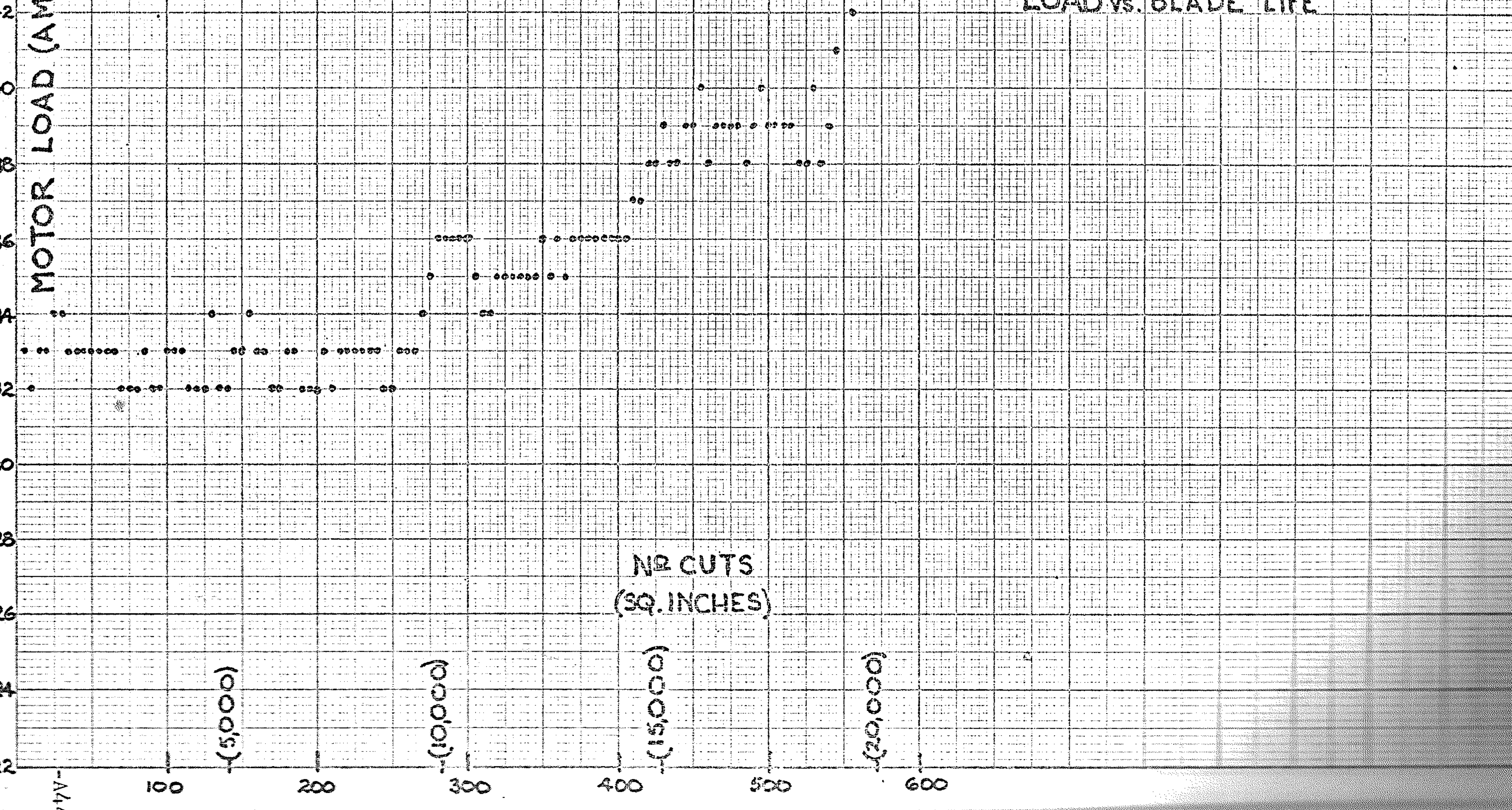
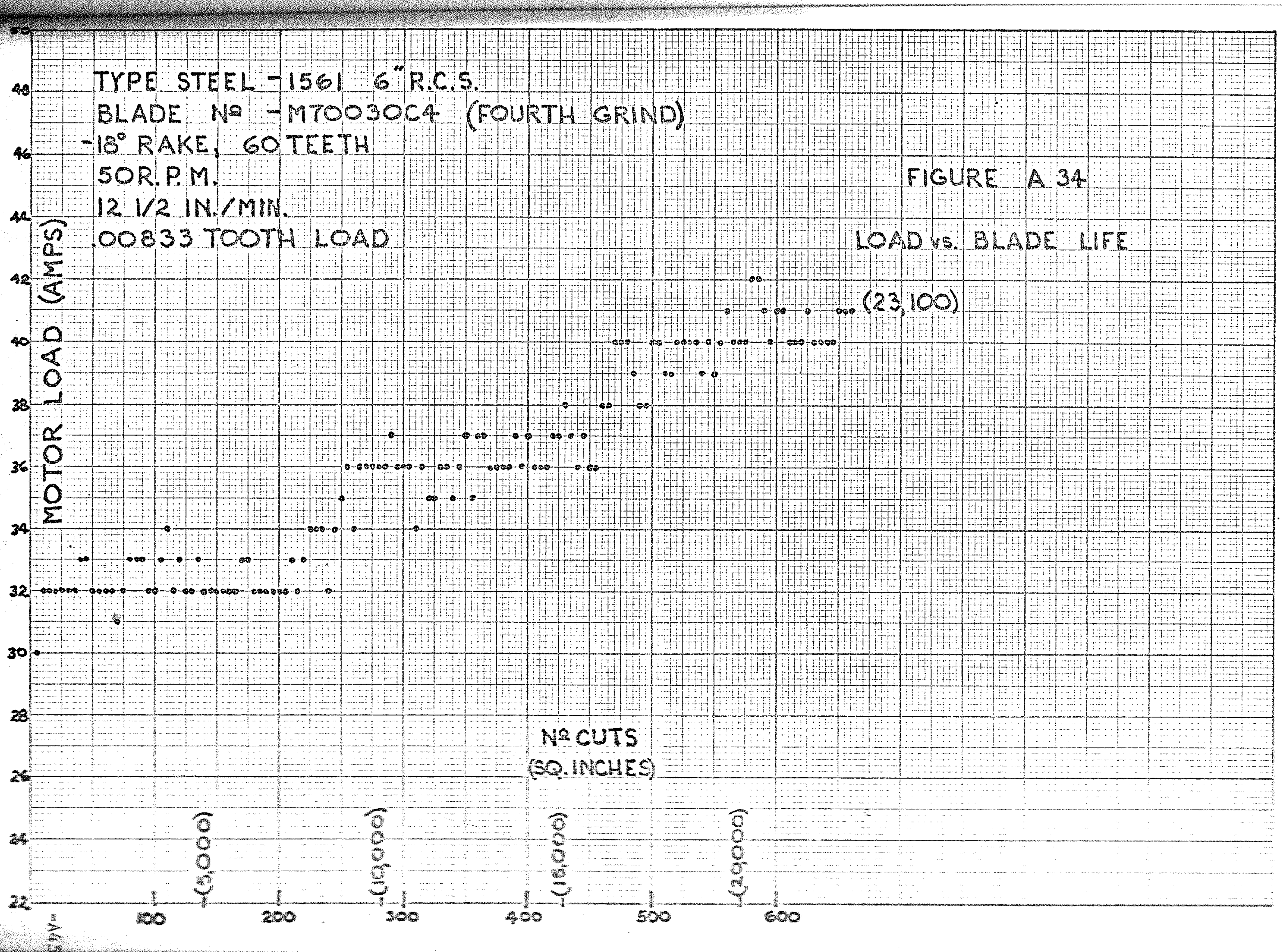


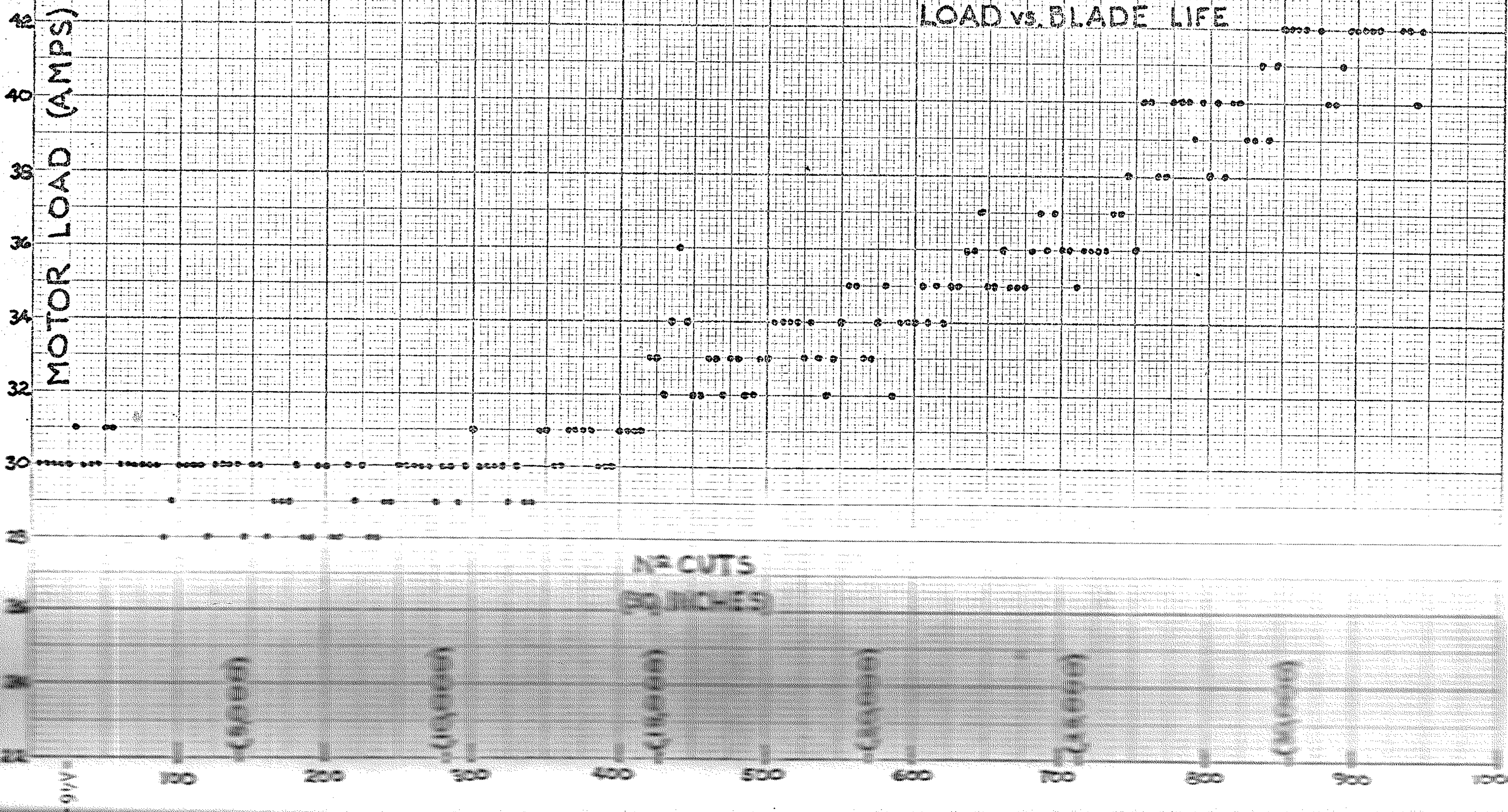
FIGURE A 32

LOAD vs. BLADE LIFE



TYPE STEEL-1561 6" R.C.S.
BLADE Nº-M70030C4 (FIRST GRIND)
-18° RAKE, 60 TEETH
55 R.P.M.
13 IN./MIN.
.00787 TOOTH LOAD
FIGURE A 33
LOAD vs. BLADE LIFE
(19,320)
MOTOR LOAD (AMPS)
Nº CUTS
(SQ. INCHES)
(5,000)
(10,000)
(15,000)
(20,000)
22
24
26
28
30
32
34
36
38
40
42
44
46
48
50
100
200
300
400
500
600


TYPE STEEL - 1561 6" R.C.S.
BLADE Nº - M70030C4 (FOURTH GRIND)
-18° RAKE, 60 TEETH
50 R.P.M.
12 1/2 IN./MIN.
.00833 TOOTH LOAD
FIGURE A 34
LOAD vs. BLADE LIFE
(23,100)
MOTOR LOAD (AMPS)
Nº CUTS
(SQ. INCHES)
(5,000)
(10,000)
(15,000)
(20,000)
22
24
26
28
30
32
34
36
38
40
42
44
46
48
50
100
200
300
400
500
600



TYPE STEEL - 1561 6" R.C.S.
BLADE № - M7002TC4 (FIFTH GRIND)
-18° RAKE, 60 TEETH
50 R.P.M.
12 1/2 IN./MIN.
.00833 TOOTH LOAD
FIGURE A 35
LOAD vs. BLADE LIFE
(34,650)
MOTOR LOAD (AMPS)
№ CUTS
(SQ. INCHES)
50
48
46
44
42
40
38
36
34
32
30
100
200
300
400
500
600
700
800
900
1000

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