Progress Report No. 2

DEVELOPMENT OF TEST METHODS
TO EVALUATE "MM" GRINDING WHEELS

R. E. McKEE
Associate Professor of Production Engineering

Project 2190-1

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DEVELOPMENT OF TEST METHODS TO EVALUATE "MM" GRINDING WHEELS

This report covers the results of tests developed in evaluating the performance of "MM" as compared with diamond wheels in accordance with the original discussions between Messrs. Franklin and Lane, Prof. Boston, and the writer. It is divided into five main parts: (1) conditions of test machine, wheel speed, table traverse feed, depth of cut, work material, and surface finish measurement, (2) testing procedures, (3) definitions of terms, (4) discussion of results, and (5) conclusions.

I. CONDITIONS OF TEST

Machine: The machine used was a Cincinnati No. 2 tool and cutter grinder, representing a type commonly used in tool rooms, grinding departments, etc.

Wheel Speed: The measured spindle speed of the machine was 4000 revolutions per minute, representing 6280 feet per minute on the 6-inch-diameter "MM" wheels, and 3660 feet per minute on the 3.5-inch- diameter diamond wheel.

Table Traverse Feed: The table on the tool and cutter grinder was hand-fed, and the number of traverses per test was held constant at 20 with no allowance for spark-out.

Depth of Cut: The depth of cut was held constant at 1/4 of .001 inch (0.00025 in.) per traverse. This is normal practice in the grinding of carbides.

Work Material: The 1/2-inch square tool bit were obtained from Carboloy department of General Electric in three grade specifications: 78B, 883, and 831. The 78B is a steel-cutting grade generally known for its toughness. The 883 grade is used in the machining of cast iron and non-ferrous materials because of its high resistance to wear combined with toughness. The 831 grade is a wear-resisting grde for high-speed, finishing cuts where close tolerance is a requirement.

Surface-Finish Measurement: The surface-finish measurements were obtained with a Profilometer, manufactured by Micrometrical of Ann Arbor, Michigan. The values obtained represent the average of three readings taken on the ground end surface of the tool bit.

II. TESTING PROCEDURES

The wheels were mounted on standard adaptors and diamond-trued with a 0.25-wgt octahedron diamond tool. The 1/2-inch-square tool bits were held in a V-block, assembled in a standard swivel tool-grinder vise and subjected to grinding on the end by traversing across the face of the wheel. This type of operation is similar to the cup-wheel setup on a vertical-spindle surface grinder.

After truing the wheel with a diamond tool, 20 successive cuts were made with an infeed of 0.00025 inch per traverse for a total infeed of 0.005 inch per test. Measurements of the tool length were observed to an accuracy of 0.0001 inch before and after the test to determine the volume of metal removal. The amount of wheel wear was obtained by measuring the width of land wear under a binocular microscope with filar lens. Tool chipping and heat effects were observed in a binocular microscope. Surface-finish readings were made with a Profilometer in microinches, rms.

III. DEFINITION OF TERMS

Volume of Metal Removal (V_m) - Cubic inches of metal removed during the grinding operation.

Volume of Wheel Wear (V_w) - Cubic inches of wheel wear obtained by measuring the area of wheel wear and multiplying by the wheel circumference.

Volume Ratio (V_m/V_w) - The ratio of metal removal to wheel wear is an index to efficiency of the operation. Objectively it is desirable to obtain high metal removal with low wheel wear.

Surface Finish - The value in microinches, rms, as obtained by a diamond stylus that originates a minute electric current which is indicated on a milliammeter, calibrated in microinches.

IV. DISCUSSION OF RESULTS

Figures 1, 2, and 3 show the volume of metal removal for each of the wheels on Carboloy 78B, 831, and 883, respectively. The 180B (diamond) wheel shows the highest metal removal in all cases with the C60I8V5 and C180H5VMM wheels giving nearly the same performance on 78B only (Fig. 1). The 180B (diamond) wheel was selected at random from a supply in the tool crib and does not represent a specific recommendation. The 831 and 883 carbide materials produced lesser amounts of metal removal on all of the silicon carbide wheels as shown in Figures 2 and 3.

Figure 4 is a summary of the tests on the three carbide tool materials. It is a composite of figures 1, 2, and 3, showing that the C100H5VMM and C120H5VMM wheels gave relatively low metal removal on all materials and that the C60I8V5 and C180H5VMM wheels compare with the diamond wheel when used on Carboloy 78B only.

Figures 5, 6, and 7 show the volume of wheel wear when grinding each of the carbide materials. The volume of wheel wear on the diamond wheel was almost too small to be measured as compared to the silicon carbide wheels. The results are not consistent for the silicon carbide wheels on the various materials, but one obvious deduction is that the volume of wheel removal is relatively high in two of three cases as compared to the performance of the diamond wheel in all three cases.

Figure 8 is a composite of the results shown in Figures 5, 6, and 7. It combines the three curves in one figure to show the relative values of silicon carbide-wheel wear to that of a diamond wheel. In general, the diamond-wheel wear averages approximately 0.002 cubic inch per test, whereas the silicon carbide wheels average from approximately 0.048 cu. in. for the C180H5VMM to 0.122 cu. in. for the C60I8V5.

Figures 9, 10, and 11 show the surface-finish measurements in microinches, rms, across and parallel to the grinding marks on the Carboloy 78B, 831, and 883 respectively. Figure 9 shows the 180B (diamond), C60I8V5 and C100H5VMM to be approximately equal in the roughness of surface finish at 4 to 8 microinches, rms. The C120H5VMM and C180H5VMM wheels show 10 to 12 and 11.5 to 18.5, respectively. There is an indication of poorer quality surface finish with a decrease in grain size of the VMM wheels. Figure 10 shows nearly identical performances for the 180B (diamond) and C60I8V5 wheels on the 831 carbide, and higher numbers of surface finish for all of the VMM wheels. Figure 11 gives about the same trend shown in Figures 9 and 10, except that the measurements across the feed marks are more widely separated from those parallel to the marks, indicating a tendency toward grooving of the tool face.

Figure 12 is a composite of all the surface-finish curves shown in Figures 9, 10, and 11. The 180B diamond and C60I8V5 are quite similar in their ability to produce good surface quality (by measurement). The C100H5 VMM, C120H5VMM, and C180H5VMM wheels give variable results depending on the material, but are definitely higher in the surface-finish readings than the preceding wheels.

V. CONCLUSIONS

The 180B diamond wheel showed the best results in all phases of the testing, i.e., volume of metal removed, volume of wheel wear, volume ratio, and surface finish.

The use of different tools result in different ratings for the silicon carbide wheels in comparison with the diamond. It was noted that the silicon carbide wheel that gave the best comparison in one part of a tool test (e.g., column of metal removed) did not give an equally good result in another part of the tool test (wheel wear). Nor did the wheel giving a good result with one tool material give an equally good result for the same phase of another tool-material test.

The C180H5VMM wheel gave the best average results when using the Carboloy 78B tool material. Although it had second highest rate of wheel wear among the carbides wheels, it did give the best metal-removal rate and had the sharpest edges on the tool used with it. Thermal cracking on the tool was very slight and it actually showed a truer picture of the wheel's ability to finish a surface in that the glazing effect upon the tool face was reduced. This meant higher readings from the Profilometer, but the readings are perhaps more valid than those of the other carbide wheels.

There was no single wheel that could be considered the best in the tests using the Carboloy 831 tool. The C180H5VMM wheel had the best metal removal rate, but its ability to produce surface quality at the end of the test was so poor that it greatly offset the wheel's cutting rate on this tool material. The C120H5VMM wheel gave the best volume ratio, which would tend to show a better balance between metal removal and wheel wear. Its metal removal rate was second lowest, which was offset by its low rate of wheel wear to give it a rather good volume ratio.

The C120H5VMM and C180H5VMM wheels showed evidence of giving the best results when using the Carboloy 883 tool. The former wheel showed the best metal-removal rate, while the latter gave a much lower wheel wear. Both had better then average surface characteristics with only slightly chipped edges and few thermal cracks.

The results of the tests show that further experimentation with the 78B carbide tool is desired. Further variation in wheel characteristics would allow more information to be considered in comparing the Macklin wheels with the standard diamond grinding wheels.

Table I shows the comparison of the diamond wheel to the silicon carbide wheels when using Carboloy 78B tool material. The C180H5VMM wheel compared most favorably to the diamond wheel in volume of metal removed. The C120H5VMM wheel compared favorably to the diamond in wheel wear. The C120H5VMM wheel had the best volume ratio in comparison to the diamond 180B. The surface finish of the C100H5VMM wheel gave better results "with the finish marks" than did the diamond wheel. "Across finish" on the C60I8V5 was also better than that of the diamond. Glazed surface conditions were the actual reasons for better readings on the C100H5VMM and C60I8V5 wheels. The diamond wheel gave better surface qualities, sharper edges, and cleaner appearances (without evidence of thermal cracking under the microscope) in all comparisons.

Using the diamond wheel as a base (100%) a range comparsion indicates the following results:

> In volume of metal removed the range for the carbide wheels is 21 to 94% of the diamond's volume of metal removed. Wheel wear for the carbide material ranges for 1400 to 10,700% of the diamond wheel. Volume ratio was .27 to 1.36% of the diamond. In surface quality, the range was 64.3 to 164% for with and, 71.4 to 264% for across the feed marks.
>
> All silicon carbide wheels showed evidence of thermal cracks and some chipping at the edges of the tool as compared to the surfaces produced by the diamond wheel.

Table II shows the comparison of the diamond wheel to the silicon carbide wheels when using the Carboloy 831 tool material. In volume of metal removed, the C60I8V5 and C120H5VMM were the best in comparison to the 180B diamond wheel. The C120H5VMM wheel showed the least wheel wear of the silicon carbide wheels, but this was still considerably greater than that of the diamond wheel. Volume ratios were considerably lower than that of the diamond and were grouped close together. The C180H5VMM showed the best volume ratio, but this was only 0.017% of the diamond's volume ratio. The surface-finish tests of the C60I8V5 wheel compared very closely across and were exactly the same with the feed marks as those of the diamond. This again was not due to actual quality similarities of the surfaces, but rather to the glazed condition of the surface of the C60I8V5 wheel. With the diamond again as a base (100%), the range of the silicon carbides in volume of metal removed was 30.9 to 67% of the diamond's rate of metal removal. Wheel wear was 2,867 to 19,367% of the diamond and the volume ratio 0.004 to 0.017%. The range for surface finish was 100 to 575% for "with" and 88.9 to 66.7% for "across" the feed marks.

Again all silicon carbides showed thermal cracks and chipping at the surface edges under the miscroscope. The use of the 831 tool with the C180H5VMM resulted in rather extensive chipping which started after the third pass of the tool was made.

Table III compares the diamond wheel to the silicon carbide wheels when a Carboloy 883 tool material was used. The C120H5VMM wheel gave the best results of the silicon carbides in metal removal. The C180H5VMM had the least wheel wear but was 332% more than that of the diamond. Volume ratios were again much lower than that of the diamond with the C180H5VMM volume ratio being the best, but only 3.9% of the diamond's volume ratio. The C60I8V5 and the C120H5VMM wheels had better surface readings than that of the diamond in "with" readings. The C60I8V5, C100H5VMM and the C120H5 VMM wheels had equal or better surface finish readings than that of the diamond across the feed marks. However, in both "with" and "across" readings, the diamond wheel again produced a cleaner and smoother surface, the lower values shown for silicon carbides wheels had glazed surfaces. All tools used with the silicon carbide wheels had chipped edges and scratched surfaces while the tool ground by the diamond wheel had sharp edges and cleanly cut surfaces.

Using the same base of 100% for the diamond wheel, ranges were: 11.8 to 20.6% in volume of metal removal, 332 to 4316% in wheel wear, 0.413 to 3.9% in volume ratio, 60 to 167% in surface finish with and 55 to 155% in surface finish across the feed marks.

Table I

Wheel Speed	180B Diamond	3660 FPM
	SiC ○	6280 FPM
Work Infeed	0.00025 inch	per traverse
Number of Traverses	20	
Tool Material	Carboloy 78B	

Wheels	Metal Removal (Cubic inches) V_m	Wheel Wear (Cubic inches) V_w	Volume Ratio $V_r = \frac{V_m}{V_w}$	Surface Finish (Microinches) With	Across	Surface Condition
Diamond 180B	.0017	.00076	2.237	7	7	Smooth, clean surface, Sharp edges
C 60 I8 V5	.00135	.0824	.0164	45	5	Burned end, Thermal cracks, Slightly chipped edges
C100 H5 VMM	.0004	.0657	.0061	5	8	Slightly burned surface, scratches, 1 medium-sized crack, Slightly chipped edges
C120 H5 VMM	.00035	.0115	.0304	10	12	Burned end, Surface scratches, Thermal cracks, Very slightly chipped edges
C180 H5 VMM	.0016	.0673	.0237	11.5	18.5	Burned end, Surface scratches, Hairline thermal cracks, Fairly sharp edges
% difference between Diamond and Silicon Carbide abrasive using Diamond as 100%	21-94	1400-10,700	.27-1.36	64.3-164	71.4-2.64	

Table II

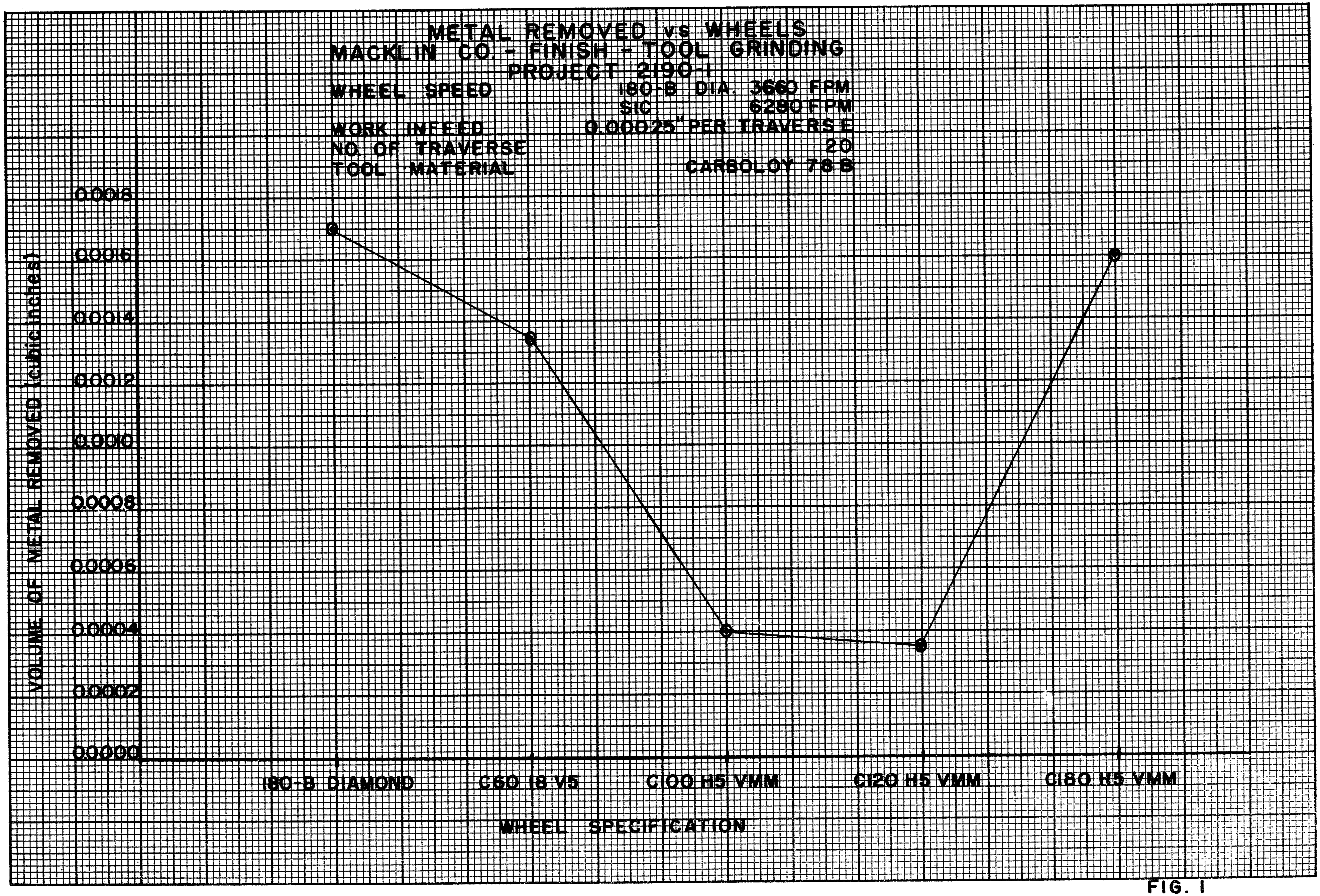
Wheel Speed	180B Diamond	3660 FPM
	SiC	6280 FPM
Work Infeed	0.00025 inch	per traverse
Number of Traverses	20	
Tool Material	Carboloy 831	

Wheels	Metal Removal (Cubic inches) V_m	Wheel Wear (Cubic inches) V_w	Volume Ratio $V_r = \frac{V_m}{V_w}$	Surface Finish (Microinches) With	Surface Finish (Microinches) Across	Surface Condition
Diamond 180B	.00097	.000003	254.0	4	4.5	Smooth clean surface, Sharp edges
C 60 I8 V5	.0003	.0264	.0113	4	4	Burned end, Thermal cracks, chipped edges
C100 H5 VMM	.00052	.0403	.0128	10	15	Burned end, Thermal cracks, slightly chipped edges
C120 H5 VMM	.00035	.0086	.0406	12	12	Burned end, Scratched surface, Hairline thermal cracks, Chipped edges
C180 H5 VMM	.00065	.0581	.0112	23	30	Burned end, Scratched surface, Thermal cracks, Badly chipped edges
% difference between Diamond and Silicon carbide abrasive using Diamond as 100%	30.9-67.0	2867-19,367	.004-.017	100-575	88.9-667	

Table III

Wheel Speed	180B Diamond	3660 FPM
	SiC	6280 FPM
Work Infeed	0.00025 inch	per traverse
Number of Traverses	20	
Tool Material	Carboloy 883	

Wheels	Metal Removal (Cubic inches) V_m	Wheel Wear (Cubic inches) V_w	Volume Ratio $V_r = \frac{V_m}{V_w}$	Surface Finish (Microinches) With	Surface Finish (Microinches) Across	Surface Condition
Diamond 180B	.0017	.00606	.286	7.5	20	Smooth, clean surface, Sharp edges
C 60 I8 V5	.0003	.259	.0012	4.5	13	Scratched surface, Slightly chipped edges
C100 H5 VMM	.0002	.0642	.0031	10	11	Light surface scratches, Slight thermal cracks, Slightly chipped edges
C120 H5 VMM	.00035	.0682	.0051	7	20	Burned end, scratched surface, Slight thermal cracks, Chipped edges
C180 H5 VMM	.00022	.0199	.0111	12.5	21	Burned end, Scratched surface, Hairline thermal cracks, Slightly chipped edges
% difference between Diamond and Silicon carbide abrasive using Diamond as 100%	11.8-20.6	332-4316	0.413-3.90	60-167	55-105	



METAL REMOVED vs WHEELS
MACKLIN CO. - FINISH - TOOL GRINDING
PROJECT 2190-1
WHEEL SPEED 180-B DIA. 3660 FPM
SIC 6280 FPM
WORK INFEED 0.00025" PER TRAVERSE
NO. OF TRAVERSE 20
TOOL MATERIAL CARBOLOY 78 B
VOLUME OF METAL REMOVED (cubic inches)
0.0018
0.0016
0.0014
0.0012
0.0010
0.0008
0.0006
0.0004
0.0002
0.0000
180-B DIAMOND
C60 I8 V5
C100 H5 VMM
C120 H5 VMM
C180 H5 VMM
WHEEL SPECIFICATION

FIG. 1

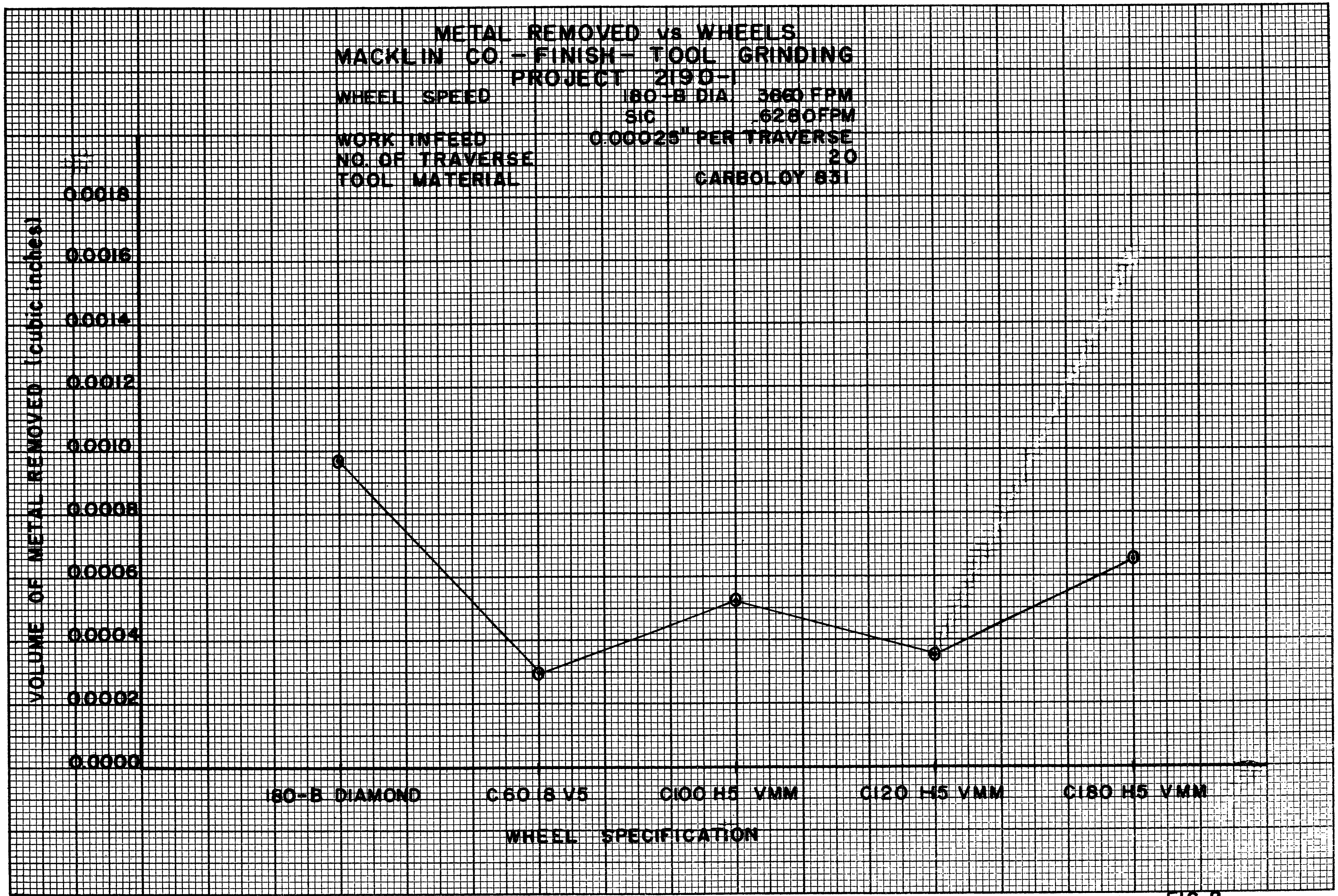

METAL REMOVED vs WHEELS
MACKLIN CO. - FINISH - TOOL GRINDING
PROJECT 2190-1
WHEEL SPEED 180-B DIA. 3660 FPM
SIC 6280 FPM
WORK INFEED 0.00025" PER TRAVERSE
NO. OF TRAVERSE 20
TOOL MATERIAL CARBOLOY 831
VOLUME OF METAL REMOVED (cubic inches)
0.0018
0.0016
0.0014
0.0012
0.0010
0.0008
0.0006
0.0004
0.0002
0.0000
180-B DIAMOND
C60 I8 V5
C100 H5 VMM
C120 H5 VMM
C180 H5 VMM
WHEEL SPECIFICATION

FIG. 2

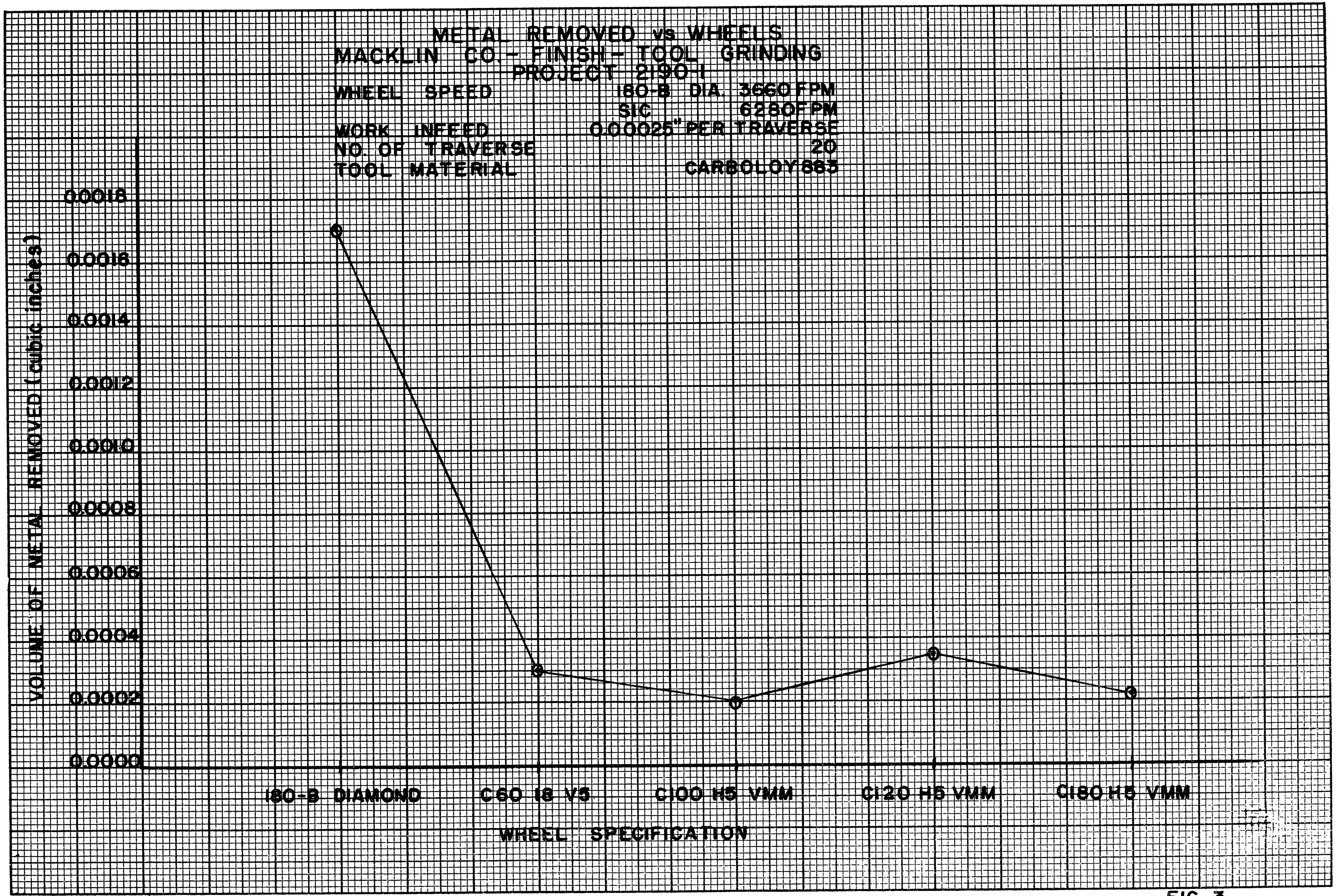

METAL REMOVED vs WHEELS
MACKLIN CO. - FINISH - TOOL GRINDING
PROJECT 2190-1
WHEEL SPEED 180-B DIA. 3660 FPM
SIC 6280 FPM
WORK INFEED 0.00025" PER TRAVERSE
NO. OF TRAVERSE 20
TOOL MATERIAL CARBOLOY 883
VOLUME OF METAL REMOVED (cubic inches)
0.0018
0.0016
0.0014
0.0012
0.0010
0.0008
0.0006
0.0004
0.0002
0.0000
180-B DIAMOND
C60 18 V5
C100 H5 VMM
C120 H5 VMM
C180 H5 VMM
WHEEL SPECIFICATION

FIG. 3

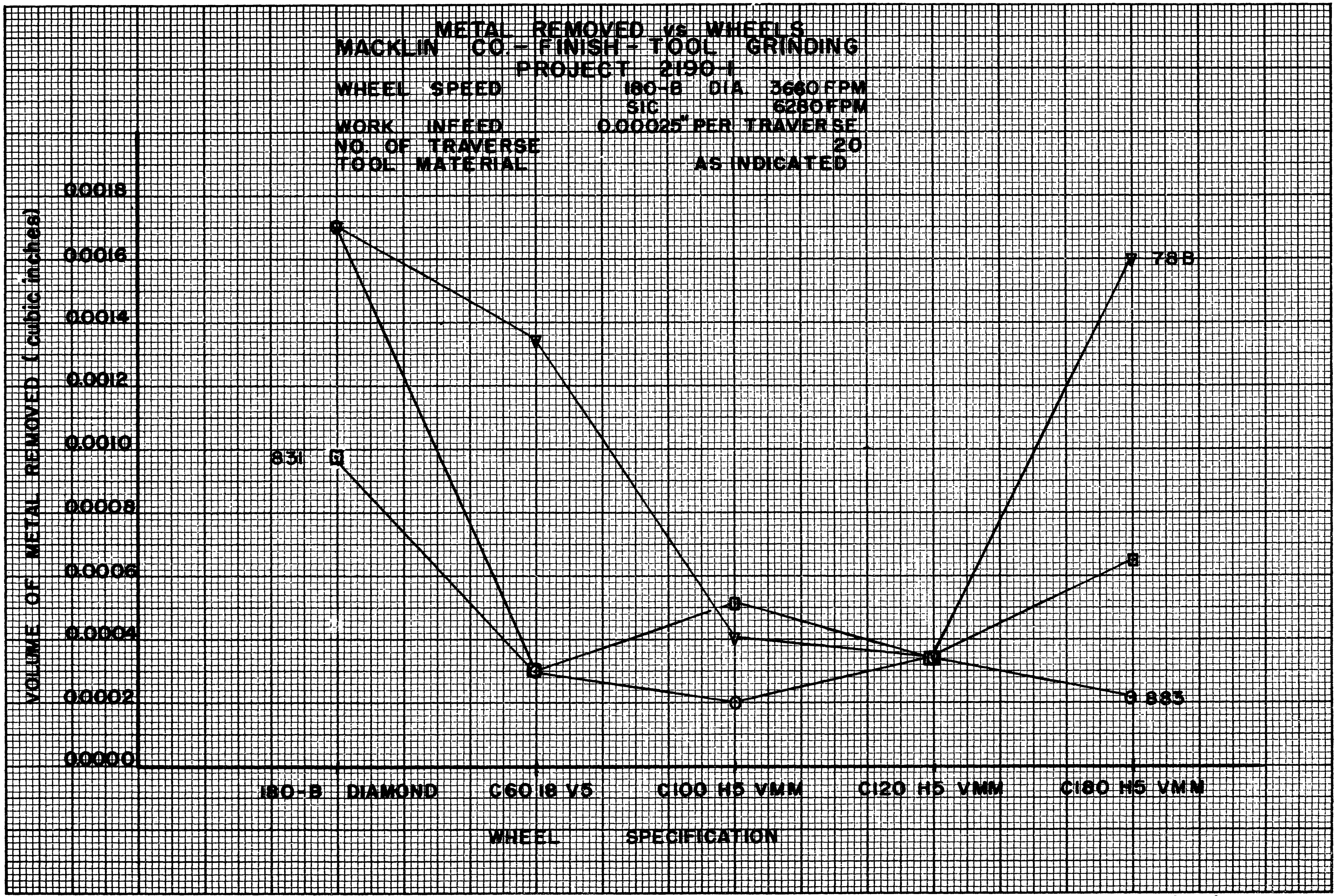

METAL REMOVED vs WHEELS
MACKLIN CO. - FINISH - TOOL GRINDING
PROJECT 2190-I
WHEEL SPEED 180-B DIA 3660 FPM
SIC 6280 FPM
WORK INFEED 0.00025" PER TRAVERSE
NO. OF TRAVERSE 20
TOOL MATERIAL AS INDICATED
VOLUME OF METAL REMOVED (cubic inches)
0.0018
0.0016
0.0014
0.0012
0.0010
0.0008
0.0006
0.0004
0.0002
0.0000
831
78B
883
180-B DIAMOND
C60 I8 V5
C100 H5 VMM
C120 H5 VMM
C180 H5 VMM
WHEEL SPECIFICATION

FIG. 4

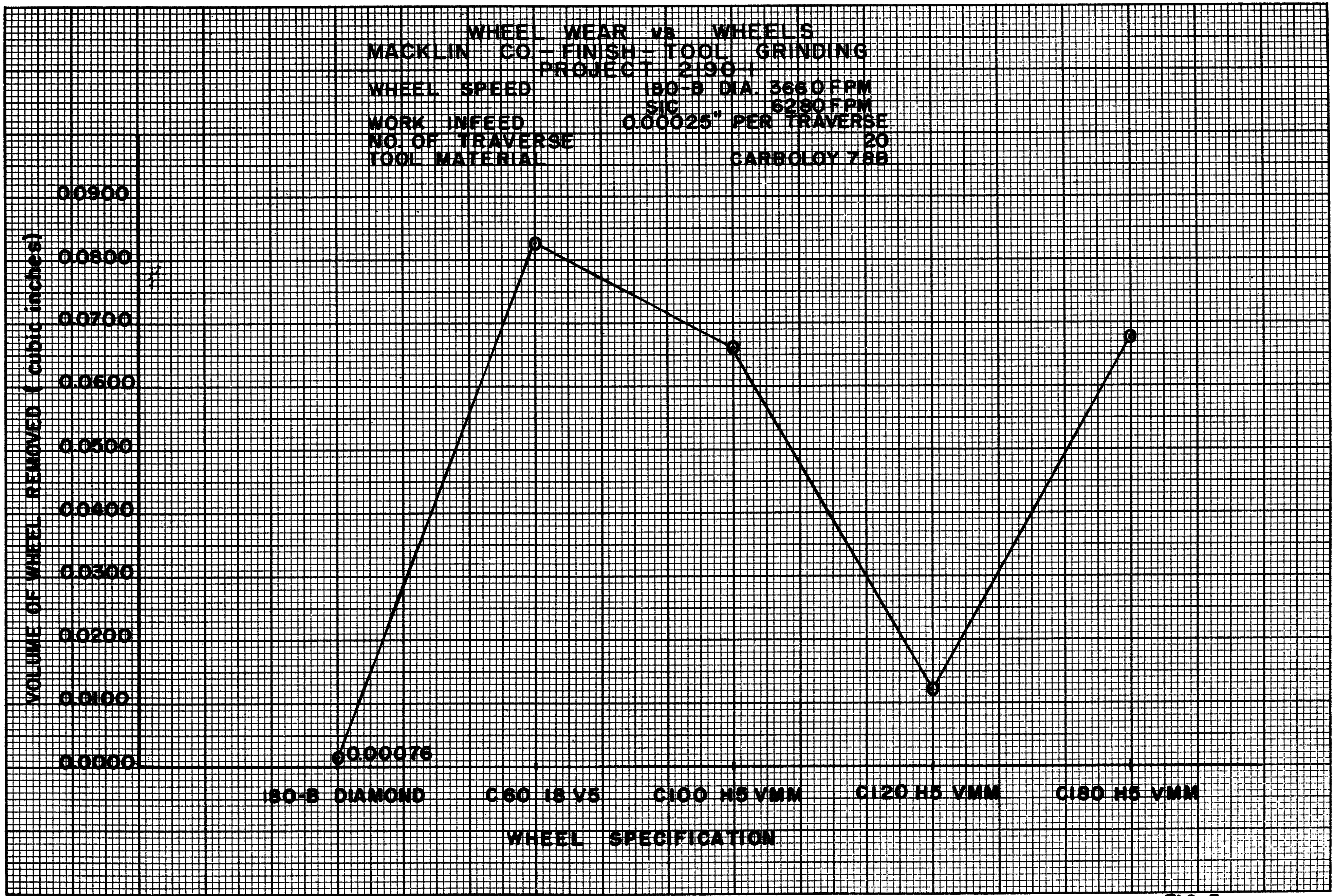

WHEEL WEAR vs WHEELS
MACKLIN CO - FINISH - TOOL GRINDING
PROJECT 2190-1
WHEEL SPEED 180-B DIA. 3660 FPM
SIC 6280 FPM
WORK INFEED 0.00025" PER TRAVERSE
NO. OF TRAVERSE 20
TOOL MATERIAL CARBOLOY 78B
VOLUME OF WHEEL REMOVED (cubic inches)
0.0900
0.0800
0.0700
0.0600
0.0500
0.0400
0.0300
0.0200
0.0100
0.0000
0.00076
180-B DIAMOND
C60 I8 V5
C100 H5 VMM
C120 H5 VMM
C180 H5 VMM
WHEEL SPECIFICATION

FIG. 5

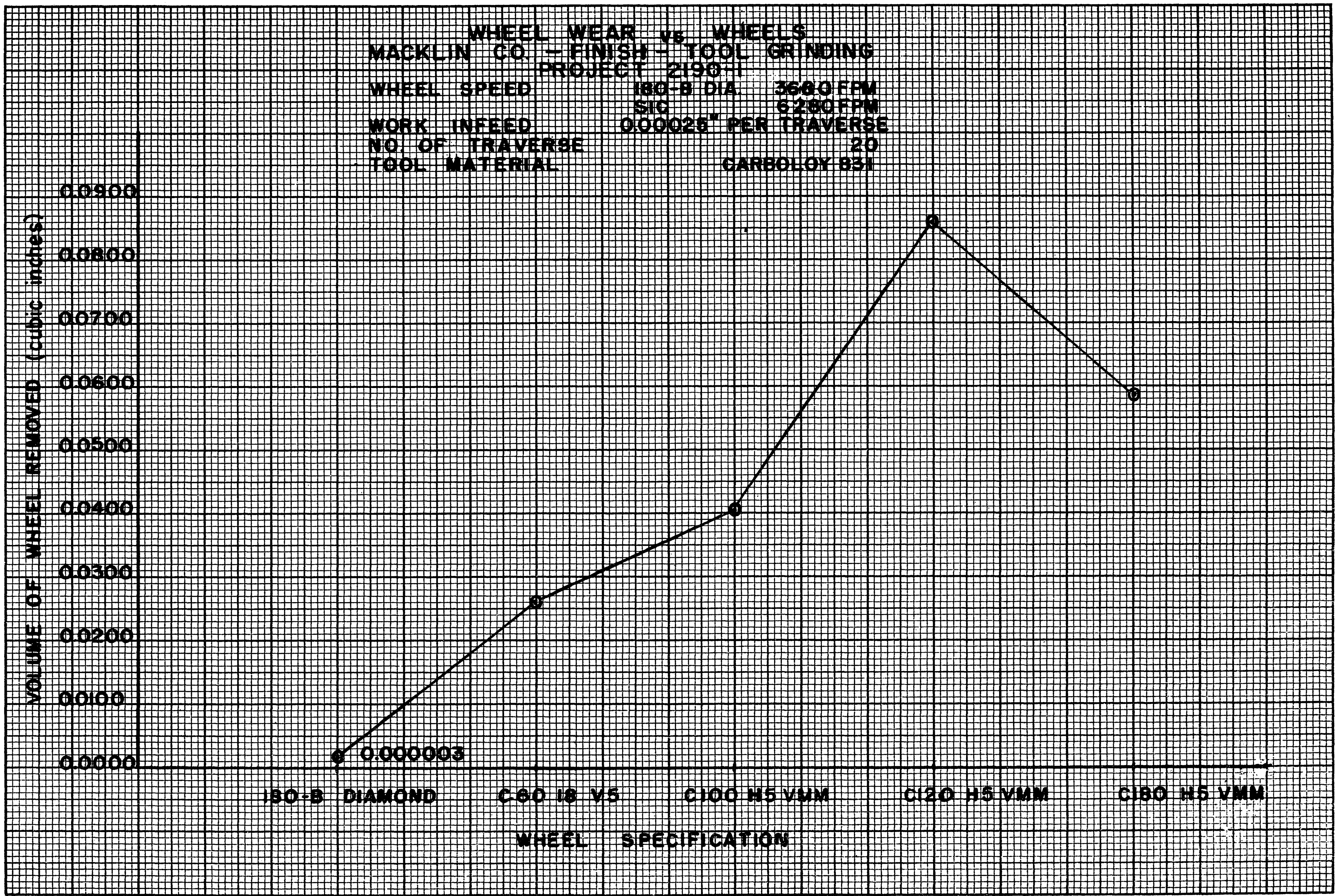

WHEEL WEAR vs WHEELS
MACKLIN CO. – FINISH – TOOL GRINDING
PROJECT 2190-1
WHEEL SPEED 180-B DIA. 3680 FPM
SIC 6280 FPM
WORK INFEED 0.00025" PER TRAVERSE
NO. OF TRAVERSE 20
TOOL MATERIAL CARBOLOY 831
VOLUME OF WHEEL REMOVED (cubic inches)
0.0900
0.0800
0.0700
0.0600
0.0500
0.0400
0.0300
0.0200
0.0100
0.0000
0.000003
180-B DIAMOND
C-60 I8 V5
C100 H5 VMM
C120 H5 VMM
C180 H5 VMM
WHEEL SPECIFICATION

FIG. 6

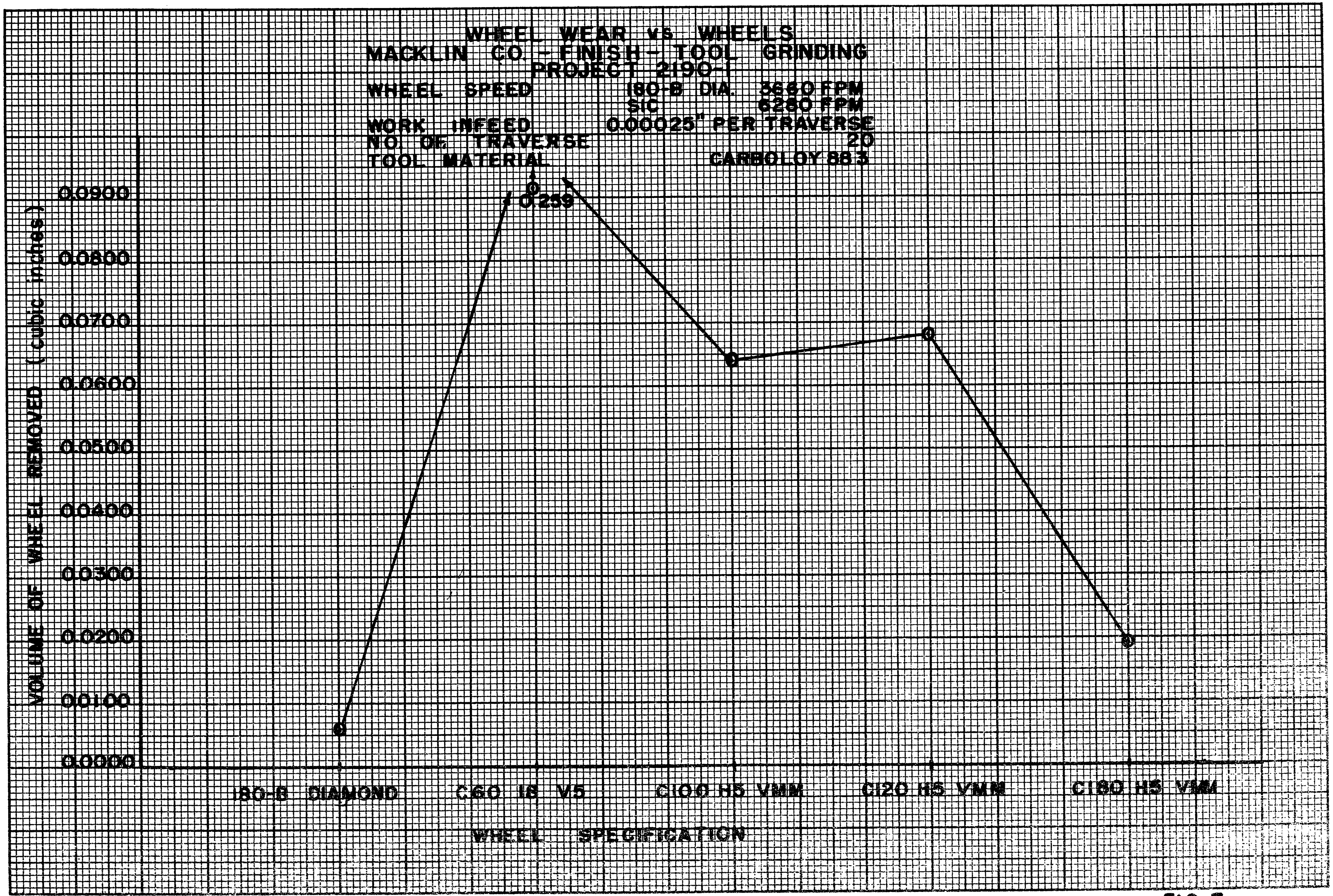

WHEEL WEAR vs WHEELS
MACKLIN CO - FINISH - TOOL GRINDING
PROJECT 2190-1
WHEEL SPEED 180-B DIA. 3660 FPM
SIC 6280 FPM
WORK INFEED 0.00025" PER TRAVERSE
NO. OF TRAVERSE 20
TOOL MATERIAL CARBOLOY 883
0.259
VOLUME OF WHEEL REMOVED (cubic inches)
0.0900
0.0800
0.0700
0.0600
0.0500
0.0400
0.0300
0.0200
0.0100
0.0000
180-B DIAMOND
C60 I8 V5
C100 H5 VMM
C120 H5 VMM
C180 H5 VMM
WHEEL SPECIFICATION

FIG. 7

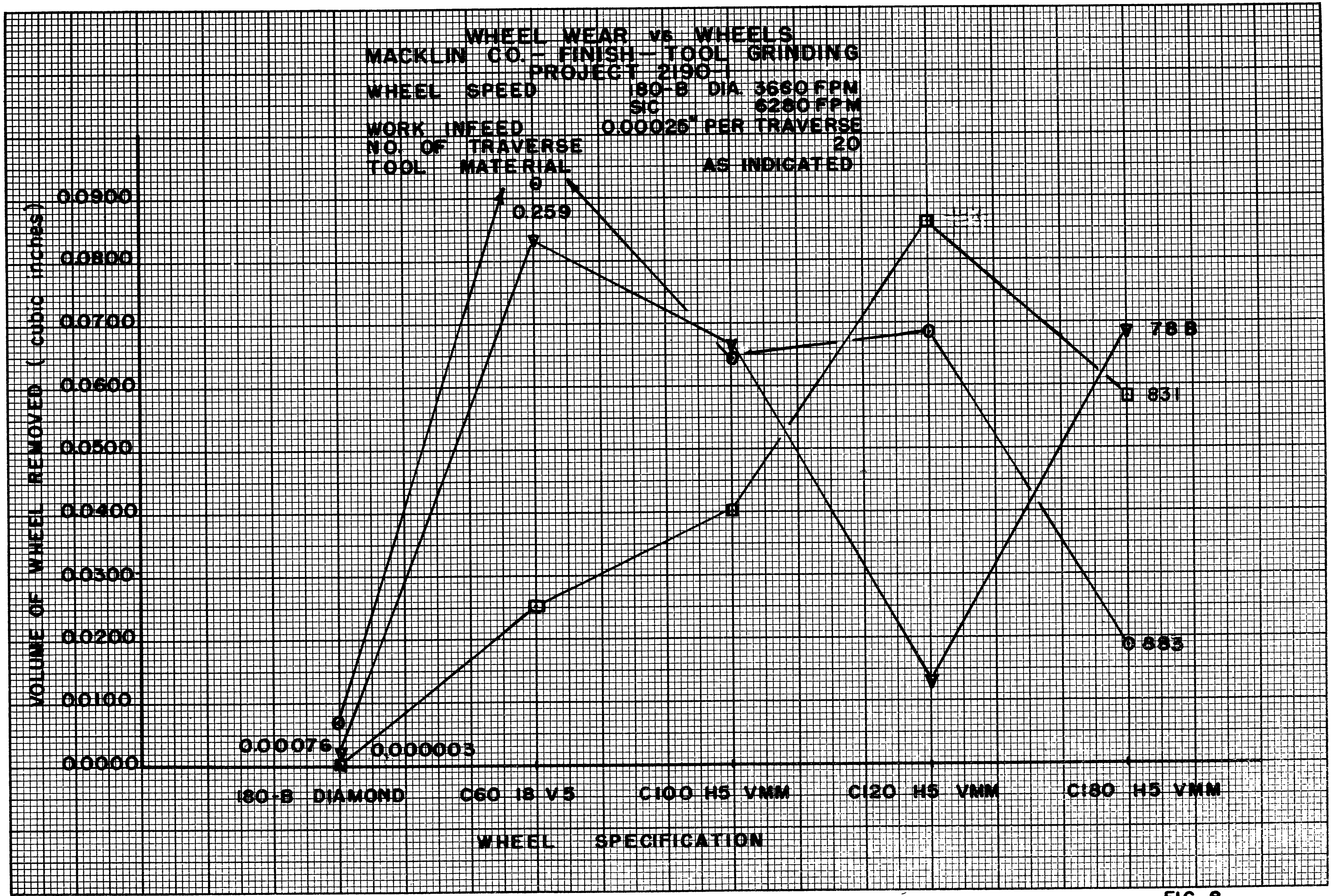

WHEEL WEAR vs WHEELS
MACKLIN CO. – FINISH – TOOL GRINDING
PROJECT 2190-1
WHEEL SPEED 180-B DIA. 3660 FPM
SIC 6280 FPM
WORK INFEED 0.00025" PER TRAVERSE
NO. OF TRAVERSE 20
TOOL MATERIAL AS INDICATED
0.259
0.00076
0.000003
78 B
831
883
0.0900
0.0800
0.0700
0.0600
0.0500
0.0400
0.0300
0.0200
0.0100
0.0000
VOLUME OF WHEEL REMOVED (cubic inches)
180-B DIAMOND
C60 I8 V5
C100 H5 VMM
C120 H5 VMM
C180 H5 VMM
WHEEL SPECIFICATION

FIG. 8

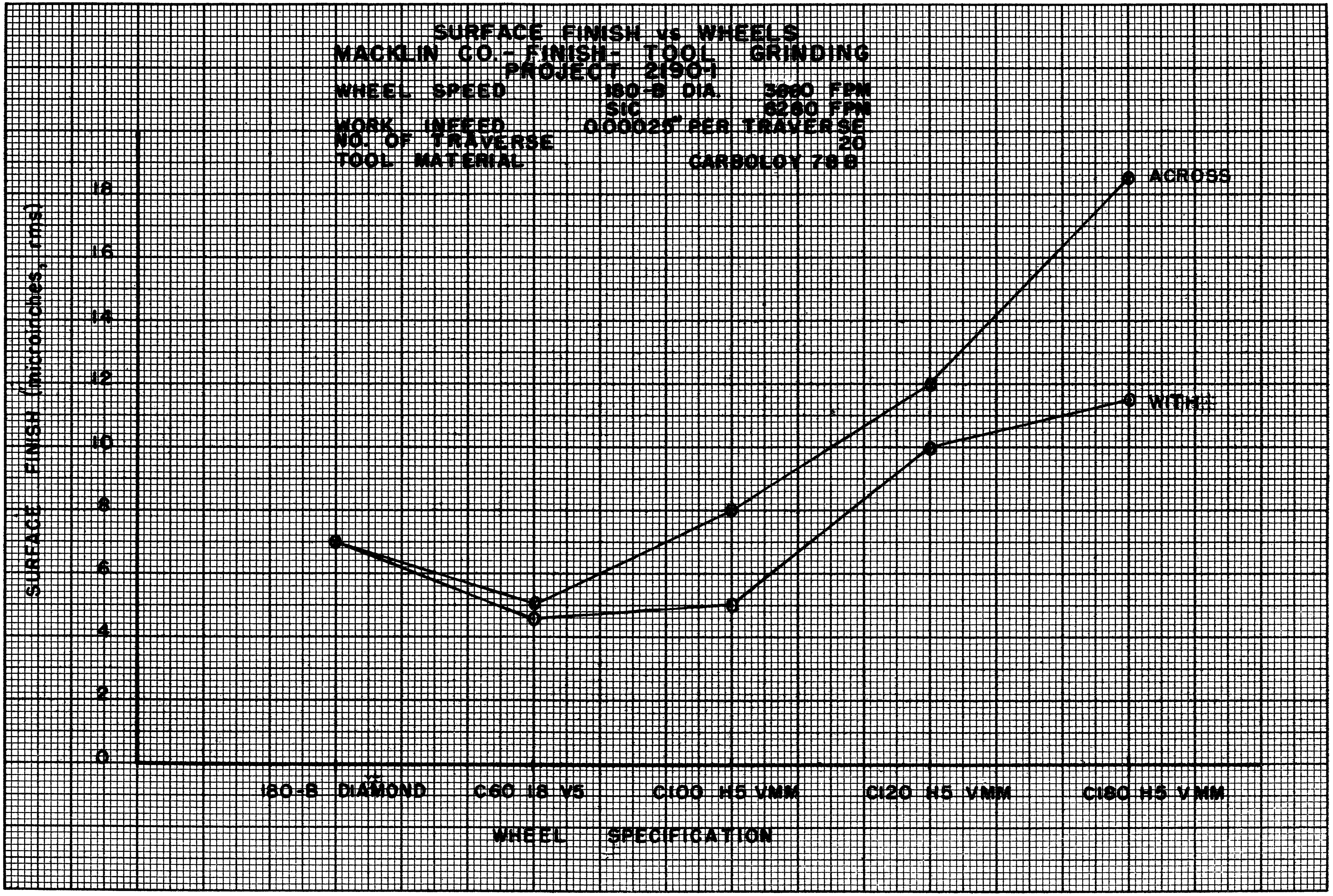

SURFACE FINISH vs WHEELS
MACKLIN CO.- FINISH- TOOL GRINDING
PROJECT 2190-1
WHEEL SPEED 180-B DIA. 3600 FPM
SIC 6260 FPM
WORK INFEED 0.00025" PER TRAVERSE
NO. OF TRAVERSE 20
TOOL MATERIAL CARBOLOY 78 B
ACROSS
WITH
SURFACE FINISH (microinches, rms)
0
2
4
6
8
10
12
14
16
18
180-B DIAMOND
C60 I8 V5
C100 H5 VMM
C120 H5 VMM
C180 H5 VMM
WHEEL SPECIFICATION

FIG. 9

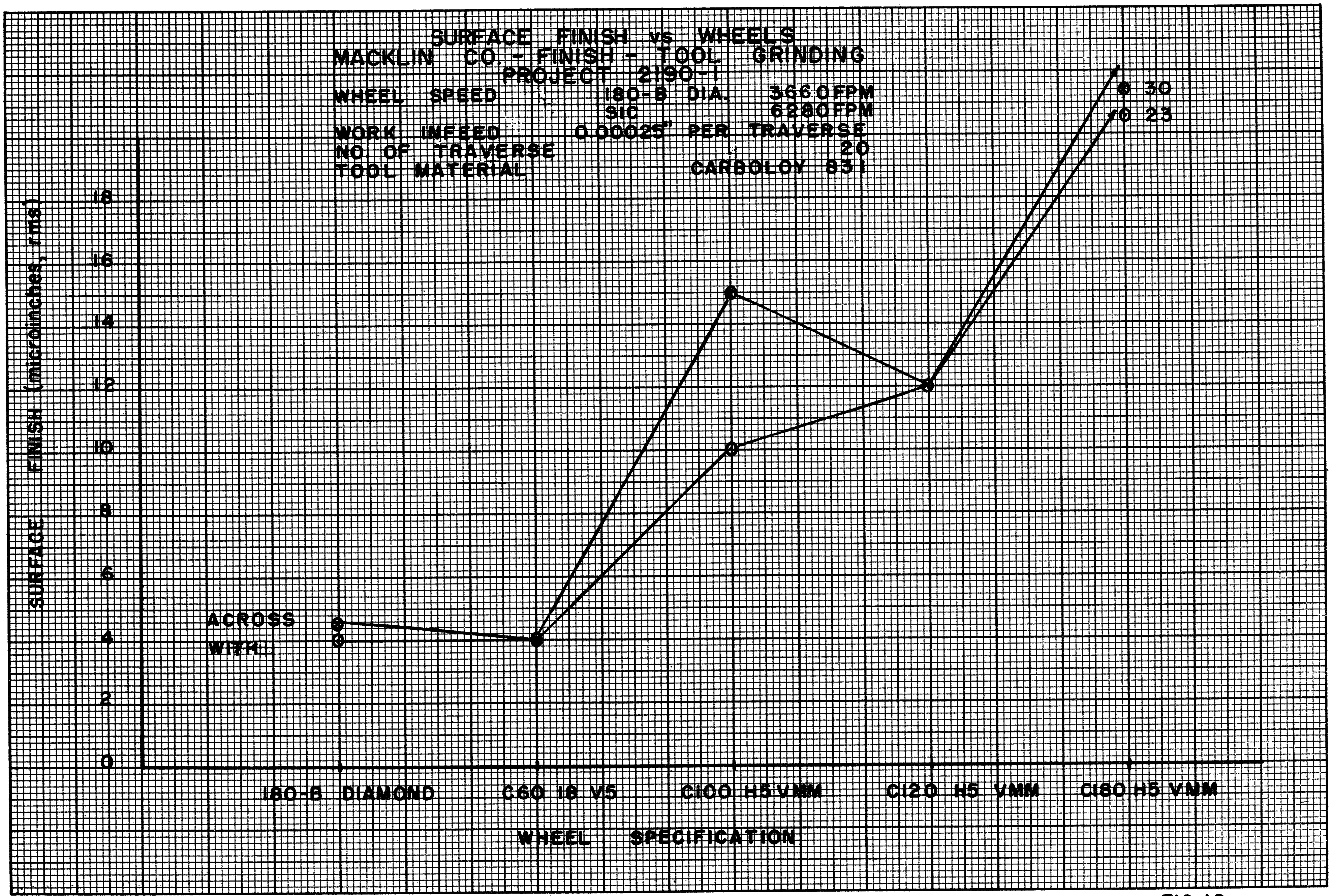

SURFACE FINISH vs WHEELS
MACKLIN CO. - FINISH - TOOL GRINDING
PROJECT 2190-1
WHEEL SPEED 180-B DIA. 3660 FPM
SIC 6280 FPM
WORK INFEED 0.00025" PER TRAVERSE
NO. OF TRAVERSE 20
TOOL MATERIAL CARBOLOY 831
SURFACE FINISH (microinches, rms)
18
16
14
12
10
8
6
4
2
0
ACROSS
WITH
30
23
180-B DIAMOND
C60 I8 V5
C100 H5 VMM
C120 H5 VMM
C180 H5 VMM
WHEEL SPECIFICATION

FIG. 10

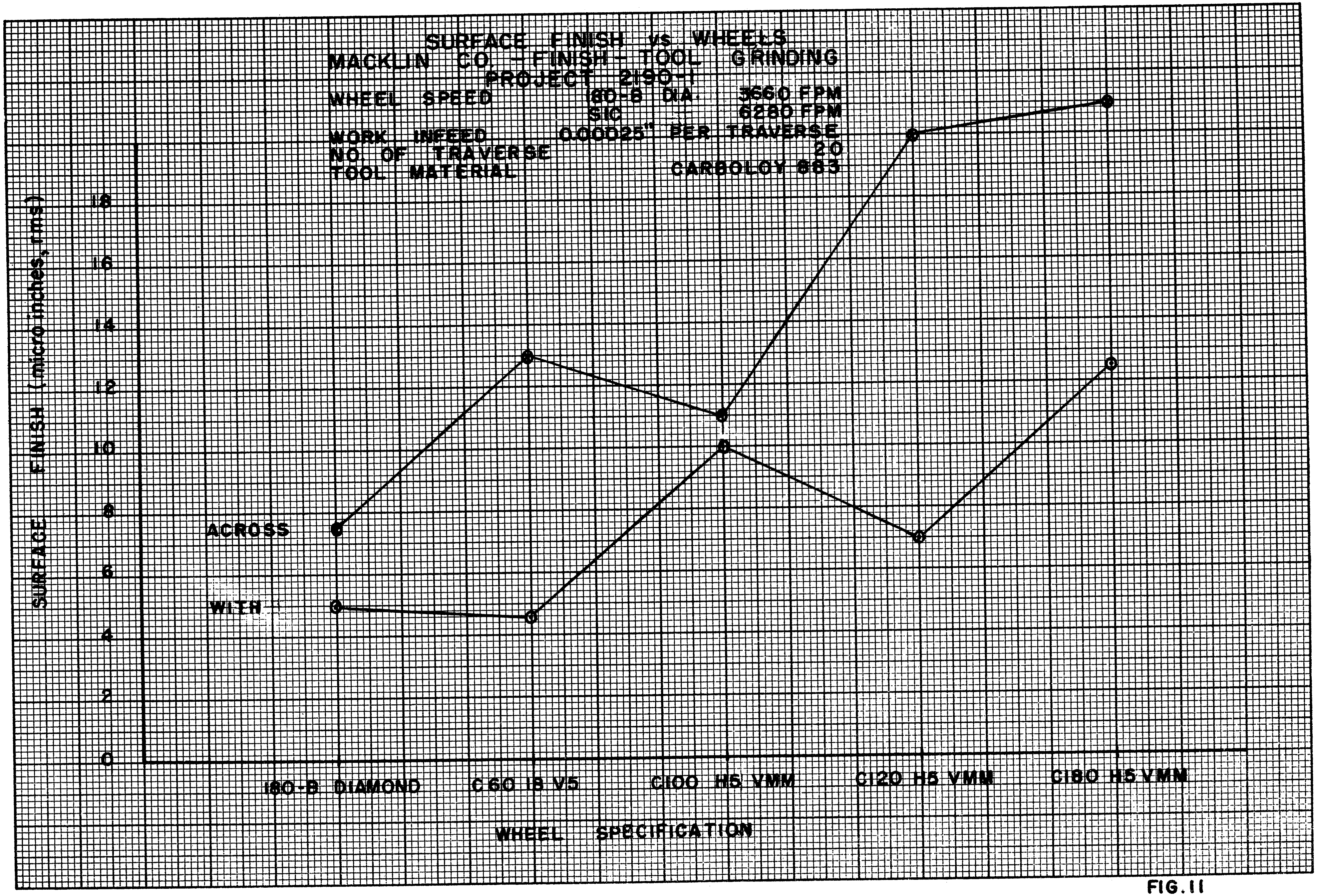

SURFACE FINISH vs WHEELS
MACKLIN CO. - FINISH - TOOL GRINDING
PROJECT 2190-1
WHEEL SPEED 180-B DIA. 3660 FPM
SIC 6280 FPM
WORK INFEED 0.00025" PER TRAVERSE
NO. OF TRAVERSE 20
TOOL MATERIAL CARBOLOY 883
SURFACE FINISH (micro inches, rms)
18
16
14
12
10
8
6
4
2
0
ACROSS
WITH
180-B DIAMOND
C60 I8 V5
C100 H5 VMM
C120 H5 VMM
C180 H5 VMM
WHEEL SPECIFICATION

FIG. 11

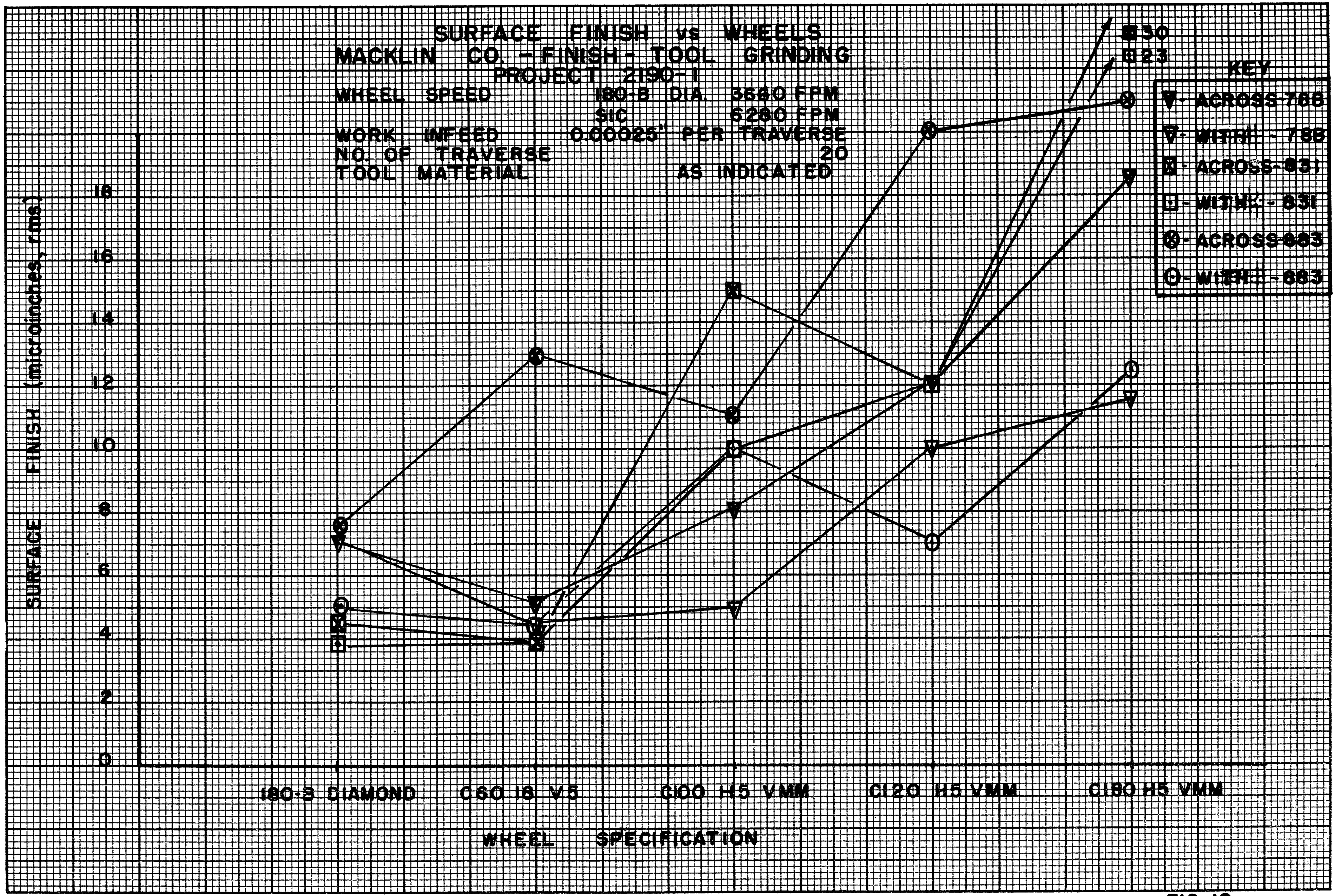

SURFACE FINISH vs WHEELS
MACKLIN CO. - FINISH - TOOL GRINDING
PROJECT 2190-1
WHEEL SPEED 180-B DIA. 3560 FPM
SIC 6280 FPM
WORK INFEED 0.00025" PER TRAVERSE
NO. OF TRAVERSE 20
TOOL MATERIAL AS INDICATED
30
23
KEY
ACROSS-788
WITH - 788
ACROSS-831
WITH - 831
ACROSS-883
WITH - 883
SURFACE FINISH (microinches, rms)
18
16
14
12
10
8
6
4
2
0
180-B DIAMOND
C60 I8 V5
C100 H5 VMM
C120 H5 VMM
C180 H5 VMM
WHEEL SPECIFICATION

FIG. 12