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RFP-1409

November 21, 1969

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Clarence A. Pippin

THE DOW CHEMICAL COMPANY
ROCKY FLATS DIVISION
P. O. BOX 888
GOLDEN, COLORADO 80401

U.S. ATOMIC ENERGY COMMISSION
CONTRACT AT(29-1)-1106

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Printed in the United States of America
Available from
Clearinghouse for Federal Scientific and Technical Information
National Bureau of Standards, U. S. Department of Commerce
Springfield, Virginia 22151
Price: Printed Copy $3.00; Microfiche $0.65

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RFP-1409
UC-38 ENGINEERING AND EQUIPMENT
TID-4500–54th Ed.

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for the
Albuquerque Operations Office
U. S. Atomic Energy Commission

CONTENTS

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Clarence A. Pippin

Abstract. The effect of machining variables on tool temperatures was studied in order to obtain the temperature-distribution patterns at the tool tip. Four distances (depths) below the top surface of the tool bit were investigated, and results have been tabulated.

The depths of cut were varied between 0.005 and 0.040 inches and the feed rates ranged from 0.0021 to 0.0167 inches per revolution. The cutting speed was maintained at approximately 400 feet per minute.

Surface temperatures were determined by extrapolation from the four depths experimentally investigated. The maximum tool-surface temperature was 614 °F, at a 0.040-inch depth of cut and a feed of 0.0167 inches per revolution.

The experimental work was done on Type-6061T6 aluminum which was easy to use. It is expected that such work will be useful to Rocky Flats as soon as random determinations can be made on plutonium.

INTRODUCTION

A large amount of tool-temperature data has been accumulated by various investigators. Unfortunately, none of the investigators report an outstanding method of getting such information and the best method known is extremely laborious. Metal buildup on the cutting tool has been troublesome, and the surface temperature of the tool will probably determine the extent of the metal buildup. There may also be a correlation between tool temperature and the maximum instantaneous temperature attained by the workpiece. Such conditions are important when the material being machined has one or more phase transformation points occurring at moderately low temperatures.

SUMMARY

Four depths of thermocouple placement were used for the seven positions investigated in the nose of the throw-away type tool,[1] Kendex SPG-433K6 (see Figure 1).[2] The nose radius for these tools was 0.045 inches. The hole size used for thermocouple placement (Figure 2) was 0.020 inches in diameter. When drilling holes in carbide tool bits by means of EDM (electrical discharge machining), it is difficult to get the holes in the exact location desired. By means of X-ray and of physical measurements, the locations of these positions were determined and are listed in Table I. All four holes of any particular position will not be identical, although an attempt was made to achieve such results. The average was used as noted in Table I.

Table II lists the surface temperatures as determined by extrapolation. The process of extrapolation always allows a chance for error, but the writer considers the reported data are reasonably reliable. The distance through which the extrapolation extends is not large. Any attempt to obtain the tool-surface temperature by direct measurement will probably involve friction as the chip moves over the tool. This factor might cause an appreciable error in any thermocouple reading.

As near as possible, the surface cutting speed was held at 400 feet per minute. In some cases, determinations were made above 400 feet per minute and then below 400. The temperature for 400 feet per minute was determined by interpolation. Fortunately, the correction for cutting speed was usually small.

Figure 3 through Figure 17 show enlarged sketches of the tool insert. *The shaded portion of each sketch shows the amount of metal being removed.* In order to define the scale on these figures, a distance of 0.010 inches is shown. The line, which bisects the angle between the left edge and the right edge, is perpendicular to the axis of the lathe when the tool is used. This is apparent, of course, from the depth of cut and feed as they are labeled on the figures. The surface-temperature distribution is as shown for each respective depth of cut and feed. In general, the surface temperature of the tool remains approximately the same if one doubles the depth of cut and reduces the feed to one half of its former value.

Figure 18 through Figure 45 are plots of the temperature *versus* distance from the surface for seven positions and for cut depths of 0.005, 0.010, 0.020, and 0.040 inches. Several factors contribute to the unpredictable temperature distributions shown here. Heat input to the tool comes from friction between the chip and tool, and from friction between the workpiece and the tool. Also the contact point between the chip and the tool does not

[1] Kennametal, Incorporated, Latrobe, Pennsylvania.
[2] Figures are included at end of text.

TABLE I. Location of Data Points within Tool.

Position	Distance from Left Edge (inches)	Distance from Right Edge (inches)	Distance from Top Surface (inches)
1A	0.031	0.031	0.071
1B	0.031	0.031	0.044
1C	0.031	0.031	0.031
1D	0.031	0.031	0.019
3A	0.062	0.046	0.070
3B	0.062	0.046	0.037
3C	0.062	0.046	0.021
3D	0.062	0.046	0.012
4A	0.094	0.092	0.067
4B	0.094	0.092	0.043
4C	0.094	0.092	0.034
4D	0.094	0.092	0.012
5A	0.072	0.028	0.060
5B	0.072	0.028	0.038
5C	0.072	0.028	0.010
5D	0.072	0.028	0.006
6A	0.020	0.075	0.078
6B	0.020	0.075	0.045
6C	0.020	0.075	0.020
6D	0.020	0.075	0.009
7A	0.105	0.028	0.067
7B	0.105	0.028	0.036
7C	0.105	0.028	0.017
7D	0.105	0.028	0.006
8A	0.019	0.103	0.066
8B	0.019	0.103	0.034
8C	0.019	0.103	0.021
8D	0.019	0.103	0.001

remain fixed even when the depth of cut and the feed are held constant. Frequently the tool, a short distance in from the surface, tends to be slightly warmer than on the surface. Some heat is lost from the surface by convection and radiation. However, when the chip is rubbing directly over a position, the temperature rises rapidly as the point being determined approaches the surface.

EXPERIMENTAL WORK

Several methods have been used in determining the tool temperature.[3] Since a large amount of energy is utilized in extremely small areas during experiments, there will be large temperature gradients. To utilize the cutting tool as one part of a thermocouple would give what might be labeled as an average temperature. Such information was considered of little value. However, if a thermocouple were inserted into the tool, an accurate temperature reading could be obtained. Unfortunately, in order to avoid the changing of the tool-temperature profile, only one thermocouple hole can be tolerated. This means that it takes a long time to complete a tool-temperature study.

In order to facilitate obtaining of the data, the Kendex Type-SPG433K6 *throw-away* inserts were used in an insert holder, Type SP42KSDN 65C. This holder was modified so that a Baldwin Lima Hamilton[4] high temperature micro-miniature thermocouple, Type TCRC-ES-50, was held in place by means of a spring (Figure 1). Thus, the exposed junction of the one-mil (0.001 inches) thermocouple must be held tightly against the surface in order to obtain surface temperature. The thermocouple is first of all installed inside a holder as shown in Figure 2. This holder is inserted in the outer protective shield and held in place by the previously mentioned spring. The hole in the tool into which the thermocouple is inserted has been identified (arrow) in Figure 2.

It was necessary to first decide on the placement of the thermocouple, including its depth below the surface of the tool. Eight positions (1 through 8) were decided upon and four depths (A, B, C, and D) at each position. The positions actually obtained in the tools were not precisely those requested by the author. However, the final positions were close enough for use in experimental work and are listed in Table I. These positions were determined by X-ray and by physical measurements. The holes were drilled in the tool inserts by means of electric discharge machining (EDM). The hole diameter was 0.020 inches.

Position 2 was abandoned because its position, as actually determined, essentially overlapped Position 1. The nose radius on these tools was 0.045 inches. Due to the configuration of the tool holder, the tool had a positive back rack of 6 degrees. The clearance angle between the front of the tool and the workpiece was 5 degrees.

The readout for the tool thermocouple consisted of a Beckman Fitgo Amplifier Model C-24, a Beckman Eput and Timer Model-6144 with a plug-in Voltage-to-Frequency Converter Unit, and a Beckman Model-1453 Printer.[5] An ice bath was used as the reference cold junction. The

[3]Erich Bickel. *The Temperature on a Turning Tool.* Swiss Federal Technical University, Zurich, Switzerland. Proceedings of the International Production Engineering Research Conference, Carnegie Institute of Technology, Pittsburg, Pennsylvania. September 9-12, 1963. Pages 89-94.

[4]Baldwin Lima Hamilton, B. L. H. Electronics, Waltham, Massachusetts.

[5]Beckman Instruments, Richmond, California.

TABLE II. Tabulated Tool Surface Temperatures.

Position	Depth of Cut (inches)	Feed (inches per revolution) 0.0021	0.0042	0.0083	0.0167
		Fahrenheit Degrees			
1	0.005	163	174	200	–
1	0.010	169	222	312	420
1	0.020	166	212	326	510
1	0.040	260	311	401	610
3	0.005	142	181	232	–
3	0.010	170	212	273	355
3	0.020	182	260	392	452
3	0.040	253	425	510	523
4	0.005	129	143	167	–
4	0.010	151	168	202	249
4	0.020	170	192	243	344
4	0.040	203	237	305	445
5	0.005	136	156	211	–
5	0.010	159	188	244	344
5	0.020	207	237	300	414
5	0.040	266	311	412	551
6	0.005	146	161	188	–
6	0.010	162	188	240	334
6	0.020	204	251	338	464
6	0.040	247	325	459	614
7	0.005	139	158	191	–
7	0.010	158	176	210	249
7	0.020	184	216	274	355
7	0.040	219	267	350	460
8	0.005	130	152	187	–
8	0.010	152	184	241	280
8	0.020	191	231	301	357
8	0.040	232	290	392	486

accuracy of this readout system is far better than that required and more convenient.

The workpiece in every case was a cylindrical piece of Type-6061T-6 aluminum which was 4½ inches in diameter and 12 inches long, when machining began. Certain of the workpieces had a Baldwin Lima Hamilton high temperature microminiature thermocouple, Type TCRC-ES-50, embedded in them. The centerline of this thermocouple was parallel to the outer surface of the workpiece and 0.020 inches in from the surface. As the tool is cutting, the thermocouple is repeatedly cut off. It was expected that an intrinsic thermocouple would be formed between the two thermocouple wires and either the aluminum or the tool. All work involving the cutting of this thermocouple was done using a depth of cut of 0.040 inches which places the thermocouple at the center of the cut.

The workpieces in which the thermocouple was embedded had to be modified. The tailstock end of the workpiece was turned to accept the slip-ring assembly. In addition, a 1-inch axial hole and a $^5/_{16}$-inch radial hole were required in order to allow the thermocouple to be connected to the slip-ring assembly.

It is not obvious whether a thermocouple being cut off will give the peak temperature, the temperature on the surface of the tool, or some temperature in between. At least, the peak temperature would be given. There is a question as to whether friction changes the reading of a thermocouple. Although such information would be of value, more reliance was placed on the readings obtained from the tool thermocouple.

The major problem in making the measurement of the embedded thermocouple is in the recording of the signal. The cutoffs occurred about 0.167 seconds apart and the action took place in about 0.2 milliseconds. If the thermocouple remains *open* after it is cut, then there will be a large pickup of 60-hertz noise which will blot out all the previous valid temperature measurements. Readout attempts were made on an oscilloscope and also on a Visicorder (oscillograph)[6] with a Model M-8000 galvanometer[7] which has a flat response to 4800 hertz. The best appearing data seemed to be on the Visicorder, but still some doubt remained as to its accuracy. A galvanometer can indicate either too large or too small a value. More details on other attempts to get good data from a thermocouple being cut by the tool are given later in the report.

Now returning to the vast majority of the work involving only the tool temperature, the depths of cut were chosen as 0.005, 0.010, 0.020, and 0.040 inches. The feed rates were 0.0021, 0.0042, 0.0083, and 0.0167 inches per revolution. A feed rate of 0.0167 inches per revolution was not used with a depth of cut of 0.005 inches. In order to keep the number of variables down, the temperature of the workpiece was maintained between 86° and 87 °F at the start of each run. The surface feet per minute (sfm) were held near to 400. This was difficult because the rotational speed of the lathe could not be changed by small amounts. Fortunately, this factor did not appear to be critical. Complete details are given on tabulated temperature data in Table III for all positions. Position 2 data are not given as noted earlier.

An example of the tool nomenclature used is as follows:

1. The four depths of thermocouple placement for Position 1 was labeled as 1A, 1B, 1C, and 1D.

2. The intended depths below the top of the tool surface (although not the same as the actual depths) were 0.072 inches for A, 0.036 inches for B, 0.018 inches for C, and 0.009 inches for D.

3. For any given position, the D depth was always used first and then C, B, and A used in that order. This study was started with 1D and progressed to 8A. However, certain runs had to be repeated to obtain better data.

[6] Minneapolis-Honeywell, Incorporated, Denver, Colorado.
[7] *Ibid.*

In the Environmental Testing and Development Laboratory, a portable Ampex[8] magnetic tape system with FM capability was available. Thus, three more runs were made in attempts to get better temperature information from a thermocouple embedded in the workpiece. All three runs were made with a depth of cut of 0.040 inches, but with feeds of 0.0042, 0.0083, and 0.0167 inches per revolution. Data were recorded at 60 inches per second tape speed and reproduced at 15 inches per second. This allowed an extension of the time base by a factor of 4. Once the data are on magnetic tape, one can use various types of equipment to read the data in an accurate manner. The data on the third run (feed rate was 0.0167 inches per revolution) were inaccurate because of an error in the operation of the tape recorder.

CONCLUSIONS

1. The maximum tool surface temperature noted for the maximum depth of cut and feed rate was 614 °F.

2. The maximum workpiece temperature noted at the point where the metal was heavily worked reached 1100 °F. This was at a feed rate of 0.0083 inches per revolution, but the temperature reached at a feed rate of 0.0167 inches would probably be higher.

3. The previous conclusion assumes that temperature readings are valid in spite of rubbing friction contact on the thermocouple junction. Such a condition may cause erroneous readings.

4. The effect of a change in cutting speed upon the tool temperature was much less than that obtained by a change in depth of cut or in the feed rate.

5. In general, the surface temperature of the tool remains the same if the depth of cut is doubled, and simultaneously the feed is reduced to one half its former value.

RECOMMENDATIONS

It is suggested that applications of this study be extended to plutonium. The general shapes of the temperature curves for plutonium are expected to be similar to those for aluminum. However, the curves would be shifted and random determination of the tool temperature during plutonium machining should allow such shifts to be made.

[8] Ampex Data Products, Redwood City, California.

TABLE III: Tabulated Temperature Data.

Tool	Depth	Surface Feet per Minute	Final Tool Temperature (°F)	Final Part Temperature (°F)	Initial Part Temperature (°F)	Feed (inches per revolution)	Distance from Top of Tool (inches)
*1A	0.005	381	132	87.8	87.1	0.0021	0.071
1A	0.005	381	157	89.4	87.1	0.0042	
1A	0.005	380	191	89.6	87.1	0.0083	
1A	0.010	379	158	91.1	86.9	0.0021	
1A	0.010	379	185	91.3	86.9	0.0042	
1A	0.010	377	238	92.4	87.2	0.0083	
1A	0.010	375	310	91.5	87.3	0.0167	
1A	0.020	373	184	94.7	87.1	0.0021	
1A	0.020	373	218	95.9	87.3	0.0042	
1A	0.020	370	300	97.4	87.4	0.0083	
1A	0.020	366	378	93.8	87.1	0.0167	
1A	0.040	362	220	101.8	87.4	0.0021	
1A	0,040	362	286	105.0	87.4	0.0042	
1A	0.040	354	360	104.2	87.0	0.0083	
1A	0.040	347	424	97.1	87.3	0.0167	
1B	0.005	422	141	88.6	87.0	0.0021	0.044
1B	0.005	422	162	88.3	86.8	0.0042	
1B	0.005	421	205	89.5	87.1	0.0083	
1B	0.010	421	164	89.9	86.6	0.0021	
1B	0.010	421	195	90.5	86.8	0.0042	
1B	0.010	419	261	91.1	86.8	0.0083	
1B	0.010	417	337	89.9	87.3	0.0167	
1B	0.020	415	200	93.4	86.2	0.0021	
1B	0.020	415	232	93.7	87.0	0.0042	
1B	0.020	411	322	94.6	86.8	0,0083	
1B	0.020	407	410	91.2	86.9	0.0167	
1B	0.040	403	233	99.0	87.3	0.0021	
1B	0.040	403	294	100.7	87.2	0.0042	
1B	0.040	397	412	103.6	87.3	0.0083	
1B	0.040	389	516	96.7	87.1	0.0167	
1C	0.005	422	151	89.2	86.8	0.0021	0.031
1C	0.005	421	190	89.2	86.8	0.0042	
1C	0.005	420	234	89.2	87.1	0.0083	
1C	0.010	418	194	93.0	86.9	0.0021	
1C	0.010	417	222	91.9	86.6	0.0042	
1C	0.010	415	308	90.9	86.7	0.0083	
1C	0.010	413	388	89.6	87.0	0.0167	
1C	0.020	411	234	99.4	86.9	0.0021	
1C	0.020	407	276	96.8	87.0	0.0042	
1C	0.020	403	378	94.6	87.0	0.0083	
1C	0.020	690	418	93.6	86.8	0.0083	
1C	0.020	400	484	92.5	87.0	0.0167	
1C	0.040	392	274	112.6	87.0	0.0021	
1C	0.040	385	350	108.3	87.2	0.0042	
1C	0.040	377	436	103.0	87.0	0.0083	
1C	0.040	369	532	96.7	86.8	0.0167	

*Position 2 data are not included.

TABLE III. (Continued)

Tool	Depth	Surface Feet per Minute	Final Tool Temperature (°F)	Final Part Temperature (°F)	Initial Part Temperature (°F)	Feed (inches per revolution)	Distance from Top of Tool (inches)
1D	0.005	426	156	89.6	86.7	0.0021	0.019
1D	0.005	212	136	89.3	86.7	0.0021	
1D	0.005	424	187	89.6	86.7	0.0042	
1D	0.005	211	155	89.4	86.7	0.0042	
1D	0.005	422	230	89.1	86.7	0.0083	
1D	0.005	210	187	89.1	86.7	0.0083	
1D	0.010	420	188	90.7	86.7	0.0021	
1D	0.010	210	155	89.5	89.7	0.0021	
1D	0.010	418	220	91.6	86.7	0.0042	
1D	0.010	208	191	91.9	86.7	0.0042	
1D	0.010	415	312	90.7	86.7	0.0083	
1D	0.010	206	218	90.7	86.7	0.0083	
1D	0.010	410	401	89.8	86.5	0.0167	
1D	0.020	380	224	97.8	86.7	0.0021	
1D	0.020	190	176	94.2	86.8	0.0021	
1D	0.020	376	255	95.3	86.8	0.0042	
1D	0.020	188	198	92.8	86.8	0.0042	
1D	0.020	372	367	93.8	86.8	0.0083	
1D	0.020	186	235	90.8	86.5	0.0083	
1D	0.020	369	487	90.6	86.2	0.0167	
1D	0.020	184	390	91.4	86.6	0.0167	
1D	0.040	365	261	109.0	86.8	0.0021	
1D	0.040	182	202	99.0	86.8	0.0021	
1D	0.040	357	308	102.8	86.8	0.0042	
1D	0.040	179	228	97.6	86.8	0.0042	
1D	0.040	350	413	98.4	86.8	0.0083	
1D	0.040	175	269	95.4	86.8	0.0083	
1D	0.040	342	548	94.8	86.7	0.0167	
1D	0.040	171	472	97.0	86.8	0.0167	

NOTE: Average distances of holes from left and right tool edges were 0.031 and 0.031, respectively.

Tool	Depth	Surface Feet per Minute	Final Tool Temperature (°F)	Final Part Temperature (°F)	Initial Part Temperature (°F)	Feed (inches per revolution)	Distance from Top of Tool (inches)
3A	0.005	422	143.5	90.1	86.9	0.0021	0.071
3A	0.005	421	147.5	89.2	86.6	0.0042	
3A	0.005	420	172.5	88.8	86.7	0.0083	
3A	0.010	420	155	93.4	86.6	0.0021	
3A	0.010	418	172	91.3	86.6	0.0042	
3A	0.010	416	237	91.8	86.9	0.0083	
3A	0.010	414	288	90.1	86.8	0.0167	
3A	0.020	412	188	100.5	86.8	0.0021	
3A	0.020	408	212	97.2	86.7	0.0042	
3A	0.020	405	298	94.9	86.8	0.0083	
3A	0.020	401	404	93.1	86.8	0.0167	
3A	0.040	397	236	114.4	86.5	0.0021	
3A	0.040	389	304	108.8	86.7	0.0042	
3A	0.040	379	372	101.7	85.9	0.0083	
3A	0.040	371	468	97.8	86.7	0.0167	
3B	0.005	430	138	89.1	86.6	0.0021	0.038
3B	0.005	429	153	90.0	86.8	0.0042	0.038
3B	0.005	428	187	90.2	86.7	0.0083	
3B	0.010	426	160	93.5	86.7	0.0021	
3B	0.010	423	182	92.9	86.7	0.0042	
3B	0.010	421	230	91.9	86.5	0.0083	
3B	0.010	418	312	90.2	86.4	0.0167	

TABLE III. (Continued).

3B	0.020	415	195	101.9	86.6	0.0021	
3B	0.020	410	225	97.7	85.5	0.0042	
3B	0.020	405	307	96.1	86.5	0.0083	
3B	0.020	400	402	93.6	85.7	0.0167	
3B	0.040	394	243	116.8	86.8	0.0021	
3B	0.040	384	305	113.3	86.9	0.0042	
3B	0.040	374	384	107.1	86.7	0.0083	
3B	0.040	364	509	99.4	86.6	0.0167	
3C	0.005	372	140	89.3	86.6	0.0021	0.021
3C	0.005	370	151	89.4	86.7	0.0042	
3C	0.005	369	180	89.2	86.7	0.0083	
3C	0.010	368	165	94.6	86.7	0.0021	
3C	0.010	366	178	92.8	86.7	0.0042	
3C	0.010	365	218	91.6	86.7	0.0083	
3C	0.010	363	312	90.5	86.6	0.0167	
3C	0.020	361	201	102.0	86.7	0.0021	
3C	0.020	358	218	98.0	86.8	0.0042	
3C	0.020	353	303	96.3	86.7	0.0083	
3C	0.020	349	415	93.5	86.8	0.0167	
3C	0.040	346	236	114.4	86.0	0.0021	
3C	0.040	338	277	109.0	86.7	0.0042	
3C	0.040	331	389	104.4	86.8	0.0083	
3C	0.040	320	538	98.1	86.3	0.0167	
3D	0.005	346	137	89.1	87.0	0.0021	0.012
3D	0.005	420	141	89.2	87.0	0.0021	
3D	0.005	346	155	89.8	86.9	0.0042	
3D	0.005	420	166	89.4	87.0	0.0042	
3D	0.005	346	178	89.8	86.9	0.0083	
3D	0.005	420	200	90.2	87.0	0.0083	
3D	0.010	343	158	91.3	86.8	0.0021	
3D	0.010	416	168	90.5	87.0	0.0021	
3D	0.010	343	181	92.6	87.0	0.0042	
3D	0.010	416	196	93.2	87.0	0.0042	
3D	0.010	340	223	93.1	87.0	0.0083	
3D	0.010	412	245	93.5	87.0	0.0083	
3D	0.010	337	330	91.7	87.0	0.0167	
3D	0.010	408	325	91.2	86.9	0.0167	
3D	0.020	332	182	95.2	87.1	0.0021	
3D	0.020	405	193	95.2	87.1	0.0021	
3D	0.020	332	212	96.4	87.0	0.0042	
3D	0.020	405	228	96.8	87.1	0.0042	
3D	0.020	326	318	98.7	87.1	0.0083	
3D	0.020	397	335	98.6	87.0	0.0083	
3D	0.020	320	411	95.5	86.9	0.0167	
3D	0.020	390	430	92.8	86.9	0.0167	
3D	0.040	310	222	101.2	87.0	0.0021	0.012
3D	0.040	382	237	103.0	87.1	0.0021	
3D	0.040	310	280	104.0	86.8	0.0042	
3D	0.040	382	330	108.2	87.0	0.0042	
3D	0.040	298	420	111.1	87.0	0.0083	
3D	0.040	367	440	108.6	87.0	0.0083	
3D	0.040	285	538	100.6	87.2	0.0167	
3D	0.040	352	529	99.3	87.2	0.0167	

NOTE: Average distances of holes from left and right tool edges were 0.062 and 0.046, respectively.

TABLE III. (Continued).

Tool	Depth	Surface Feet per Minute	Final Tool Temperature (°F)	Final Part Temperature (°F)	Initial Part Temperature (°F)	Feed (inches per revolution)	Distance from Top of Tool (inches)
4A	0.005	363	123	89.5	86.7	0.0021	0.067
4A	0.005	362	135.5	89.6	85.6	0.0042	
4A	0.005	361	159	88.8	86.5	0.0083	
4A	0.010	360	136	84.4	74.9	0.0021	
4A	0.010	358	142	91.0	84.2	0.0021	
4A	0.010	356	160	92.5	86.8	0.0042	
4A	0.010	354	189	90.8	85.5	0.0083	
4A	0.010	352	256	90.3	86.4	0.0167	
4A	0.020	351	169	101.0	86.8	0.0021	
4A	0.020	347	185.5	97.5	86.5	0.0042	
4A	0.020	343	257	96.5	86.9	0.0083	
4A	0.020	339	318	93.4	87.0	0.0167	
4A	0.040	335	213	117.4	86.6	0.0021	
4A	0.040	328	245	110.3	86.8	0.0042	
4A	0.040	320	312	105.3	86.9	0.0083	
4A	0.040	313	410	100.0	87.0	0.0167	
4B	0.005	423	132	89.7	86.7	0.0021	0.043
4B	0.005	422	144.5	89.2	86.8	0.0042	0.043
4B	0.005	421	169.5	88.7	86.7	0.0083	0.043
4B	0.010	418	151	93.1	86.7	0.0021	0.043
4B	0.010	417	166.5	91.5	86.7	0.0042	0.043
4B	0.010	416	206.5	91.0	86.7	0.0083	0.043
4B	0.010	414	270	89.5	86.9	0.0167	0.043
4B	0.020	408	183	97.9	86.9	0.0021	0.043
4B	0.020	405	202	95.0	86.3	0.0042	0.043
4B	0.020	401	270	92.8	86.9	0.0083	0.043
4B	0.020	398	379	93.3	86.7	0.0167	0.043
4B	0.040	393	223	110.1	86.7	0.0021	0.043
4B	0.040	386	284	105.2	86.6	0.0042	0.043
4B	0.040	378	375	102.2	86.7	0.0083	0.043
4B	0.040	371	453	95.3	85.2	0.0167	0.043
4C	0.005	421	128.5	90.2	86.6	0.0021	0.024
4C	0.005	419	147	90.8	86.8	0.0042	0.024
4C	0.005	418	175	90.2	86.9	0.0083	0.024
4C	0.010	417	155	96.0	86.8	0.0021	0.024
4C	0.010	415	175	94.2	86.6	0.0042	0.024
4C	0.010	412	212.5	92.6	86.7	0.0083	0.024
4C	0.010	409	281	91.3	86.7	0.0167	0.024
4C	0.020	406	189	106.2	86.8	0.0021	0.024
4C	0.020	401	208	99.3	87.0	0.0042	0.024
4C	0.020	396	278	97.1	86.6	0.0083	0.024
4C	0.020	392	348	93.5	86.8	0.0167	0.024
4C	0.040	386	229	118.3	86.6	0.0021	0.024
4C	0.040	375	278	113.7	87.0	0.0042	0.024
4C	0.040	365	343	105.9	86.7	0.0083	0.024
4C	0.040	354	356	101.3	86.3	0.0167	0.024

TABLE III. (Continued).

4D	0.005	363	129.5	89.1	85.9	0.0021	0.012
4D	0.005	362	145	89.6	86.8	0.0042	0.012
4D	0.005	361	172	89.6	86.8	0.0083	0.012
4D	0.010	360	155	95.0	86.9	0.0021	0.012
4D	0.010	358	170	92.9	86.7	0.0042	0.012
4D	0.010	356	207	92.4	87.1	0.0083	0.012
4D	0.010	354	248.5	90.1	86.8	0.0167	0.012
4D	0.020	353	180	100.9	85.7	0.0021	0.012
4D	0.020	349	202	98.0	86.8	0.0042	0.012
4D	0.020	345	269	96.4	87.0	0.0083	0.012
4D	0.020	342	338	94.2	86.8	0.0167	0.012
4D	0.040	338	215	117.7	86.9	0.0021	0.012
4D	0.040	330	250	111.4	86.6	0.0042	0.012
4D	0.040	321	322		86.9	0.0083	0.012
4D	0.040	313	430	100.4	86.8	0.0167	0.012

NOTE: Average distances of holes from left and right tool edges were 0.094 and 0.092, respectively.

5A	0.005	383	121	89.5	86.6	0.0021	0.078
5A	0.005	460	127	90.5	86.9	0.0021	
5A	0.005	382	138	89.2	86.8	0.0042	
5A	0.005	458	140	90.3	87.0	0.0042	
5A	0.005	380	165	89.1	86.9	0.0083	
5A	0.005	457	165	89.6	86.8	0.0083	
5A	0.010	379	140.5	92.3	86.4	0.0021	
5A	0.010	455	144.5	93.5	86.8	0.0021	
5A	0.010	377	152	91.0	86.4	0.0042	
5A	0.010	452	158.5	92.2	86.8	0.0042	
5A	0.010	375	179.5	91.2	86.8	0.0083	
5A	0.010	449	190	91.6	86.8	0.0083	
5A	0.010	371	263	91.0	86.4	0.0167	
5A	0.010	442	263	90.8	86.6	0.0167	
5A	0.020	367	164	98.4	85.9	0.0021	
5A	0.020	439	168	98.4	85.9	0.0021	
5A	0.020	361	185	102.2	86.9	0.0042	
5A	0.020	355	248	98.6	86.8	0.0083	
5A	0.020	350	321	95.1	86.6	0.0167	
5A	0.040	345	208	122.0	86.8	0.0021	
5A	0.040	335	240	116.3	86.9	0.0042	
5A	0.040	324	332	111.7	86.6	0.0083	
5A	0.040	314	410	102.3	86.9	0.0167	

5B	0.005	335	135	90.0	86.7	0.0021	0.038
5B	0.005	461	140	89.9	86.8	0.0021	
5B	0.005	335	157	90.4	87.0	0.0042	
5B	0.005	461	163	90.5	86.8	0.0042	
5B	0.005	333	178	91.3	87.1	0.0083	
5B	0.005	458	189	91.1	87.2	0.0083	
5B	0.010	332	150	92.3	87.0	0.0021	
5B	0.010	454	160	93.0	87.2	0.0021	
5B	0.010	332	175	93.2	87.1	0.0042	
5B	0.010	454	188	93.4	87.2	0.0042	
5B	0.010	328	217	93.6	86.2	0.0083	
5B	0.010	449	245	93.9	87.1	0.0083	
5B	0.010	324	278	93.2	86.2	0.0167	
5B	0.010	444	284	91.6	87.2	0.0167	

TABLE III. (Continued).

Tool	Depth	Surface Feet per Minute	Final Tool Temperature (°F)	Final Part Temperature (°F)	Initial Part Temperature (°F)	Feed (inches per revolution)	Distance from Top of Tool (inches)
5B	0.020	442	188	99.0	87.1	0.0021	
5B	0.020	523	192	99.7	87.1	0.0021	
5B	0.020	442	218	98.2	87.2	0.0042	
5B	0.020	523	236	98.7	87.1	0.0042	
5B	0.020	431	300	98.3	86.9	0.0083	
5B	0.020	511	300	95.7	87.1	0.0083	
5B	0.020	421	343	92.7	86.9	0.0167	
5B	0.020	498	347	92.2	87.2	0.0167	
5B	0.040	410	224	105.1	87.0	0.0021	0.038
5B	0.040	480	229	105.7	87.4	0.0021	
5B	0.040	410	295	108.4	87.2	0.0042	
5B	0.040	480	302	107.3	86.7	0.0042	
5B	0.040	389	360	107.6	86.9	0.0083	
5B	0.040	455	364	105.6	87.2	0.0083	
5B	0.040	368	420	99.6	87.2	0.0167	
5B	0.040	430	412	96.9	86.4	0.0167	
5C	0.005	424	141	88.7	85.4	0.0021	0.010
5C	0.005	423	160	89.8	86.9	0.0042	
5C	0.005	422	187	88.9	86.9	0.0083	
5C	0.010	421	168	93.6	86.8	0.0021	
5C	0.010	419	186	92.0	86.9	0.0042	
5C	0.010	417	243	91.0	86.8	0.0083	
5C	0.010	415	314	90.2	86.9	0.0167	
5C	0.020	410	201	100.0	86.9	0.0021	
5C	0.020	406	229	96.5	86.9	0.0042	
5C	0.020	402	319	94.8	87.0	0.0083	
5C	0.020	598	316	93.5	86.7	0.0083	
5C	0.020	396	440	92.8	87.0	0.0167	
5C	0.040	392	248	113.2	86.4	0.0021	
5C	0.040	384	308	107.8	87.0	0.0042	
5C	0.040	376	396	102.3	86.5	0.0083	
5C	0.040	369	525	97.2	86.9	0.0167	
5D	0.005	411	139	89.9	86.8	0.0021	0.006
5D	0.005	413	158	87.2	83.5	0.0042	
5D	0.005	415	160	84.3	79.8	0.0042	
5D	0.005	410	161	91.0	86.7	0.0042	
5D	0.005	659	171	89.6	86.4	0.0042	
5D	0.005	408	192	90.2	86.8	0.0083	
5D	0.010	407	165	94.9	86.8	0.0021	
5D	0.010	405	184	95.4	86.8	0.0042	
5D	0.010	402	245	93.2	87.0	0.0083	
5D	0.010	400	325	91.7	87.0	0.0167	
5D	0.020	397	201	106.2	87.0	0.0021	
5D	0.020	392	222	100.4	85.7	0.0042	
5D	0.020	386	316	97.7	86.9	0.0083	
5D	0.020	381	422	93.6	86.7	0.0167	
5D	0.040	376	247	120.4	86.6	0.0021	
5D	0.040	365	307	114.2	86.9	0.0042	
5D	0.040	354	396	110.1	86.8	0.0083	
5D	0.040	345	530	103.3	87.0	0.0167	

NOTE: Average distances of holes from left and right tool edges were 0.072 and 0.028, respectively.

TABLE III. (Continued).

6A	0.005	409	131	87.5	84.5	0.0021	0.055
6A	0.005	410	146	84.8	80.3	0.0042	0.055
6A	0.005	408	151	91.1	86.8	0.0042	0.055
6A	0.005	407	171	90.1	86.8	0.0083	0.055
6A	0.010	405	156	95.9	86.9	0.0021	0.055
6A	0.010	403	169	94.2	86.6	0.0042	0.055
6A	0.010	400	210	93.2	86.9	0.0083	0.055
6A	0.010	398	290	91.2	86.4	0.0167	0.055
6A	0.020	395	190	104.2	86.4	0.0021	0.055
6A	0.020	390	206	99.3	86.8	0.0042	0.055
6A	0.020	385	288	97.9	86.9	0.0083	0.055
6A	0.020	380	364	94.0	86.6	0.0167	0.055
6A	0.040	374	234	120.4	86.7	0.0021	0.055
6A	0.040	364	278	112.9	86.9	0.0042	0.055
6A	0.040	353	366	107.2	86.8	0.0083	0.055
6A	0.040	343	453	100.9	86.7	0.0167	0.055
6B	0.005	461	129	90.7	86.7	0.0021	0.045
6B	0.005	277	115.5	89.3	86.8	0.0021	0.045
6B	0.005	459	142	89.7	86.8	0.0042	0.045
6B	0.005	276	129	89.7	86.7	0.0042	0.045
6B	0.005	458	169	88.2	86.5	0.0083	0.045
6B	0.005	275	148	88.2	86.7	0.0083	0.045
6B	0.010	457	149	92.2	86.5	0.0021	0.045
6B	0.010	274	135	91.1	86.7	0.0021	0.045
6B	0.010	454	166	90.5	86.1	0.0042	0.045
6B	0.010	273	147.5	90.7	86.8	0.0042	0.045
6B	0.010	452	205	90.5	86.8	0.0083	0.045
6B	0.010	271	173	90.0	86.8	0.0083	0.045
6B	0.010	448	290	89.5	86.8	0.0167	0.045
6B	0.010	270	255	90.6	86.8	0.0167	0.045
6B	0.020	447	181	97.6	86.5	0.0021	0.045
6B	0.020	268	161	95.1	86.8	0.0021	0.045
6B	0.020	441	201	94.6	86.8	0.0042	0.045
6B	0.020	265	175	93.7	86.8	0.0042	0.045
6B	0.020	435	280	93.3	86.7	0.0083	0.045
6B	0.020	262	210	92.8	86.8	0.0083	0.045
6B	0.020	430	374	91.0	86.8	0.0167	0.045
6B	0.020	259	325	92.0	86.8	0.0167	0.045
6B	0.040	425	228	107.6	86.8	0.0021	0.045
6B	0.040	256	204	104.8	86.8	0.0021	0.045
6B	0.040	415	280	102.1	86.6	0.0042	0.045
6B	0.040	249	226	99.4	86.7	0.0042	0.045
6B	0.040	404	380	98.8	86.8	0.0083	0.045
6B	0.040	243	330	99.5	86.8	0.0083	0.045
6B	0.040	394	498	94.2	86.9	0.0167	0.045
6B	0.040	237	436	97.3	86.9	0.0167	0.045
6C	0.005	408	130	89.2	86.8	0.0021	0.020
6C	0.005	407	157	89.8	86.3	0.0042	0.020
6C	0.005	406	187	89.9	87.0	0.0083	0.020
6C	0.010	404	163	93.8	86.5	0.0021	0.020
6C	0.010	402	183	93.3	86.6	0.0042	0.020
6C	0.010	399	231	92.5	87.0	0.0083	0.020
6C	0.010	397	326	90.5	86.8	0.0167	0.020
6C	0.020	394	202	103.0	87.1	0.0021	0.020
6C	0.020	389	232	99.4	87.0	0.0042	0.020
6C	0.020	383	316	97.2	86.5	0.0083	0.020
6C	0.020	476	328	96.7	86.8	0.0083	0.020
6C	0.020	373	422	94.5	86.6	0.0167	0.020

TABLE III. (Continued).

Tool	Depth	Surface Feet per Minute	Final Tool Temperature (°F)	Final Part Temperature (°F)	Initial Part Temperature (°F)	Feed (inches per revolution)	Distance from Top of Tool (inches)
6C	0.040	368	268	121.7	86.7	0.0021	0.020
6C	0.040	357	318	116.4	87.2	0.0042	0.020
6C	0.040	347	434	109.7	87.0	0.0083	0.020
6C	0.040	337	554	102.5	87.0	0.0167	0.020
6D	0.005	360	135	87.6	84.1	0.0021	0.009
6D	0.005	359	156	90.0	87.1	0.0042	0.009
6D	0.005	358	181	89.0	86.8	0.0083	0.009
6D	0.010	304	146	85.4	74.3	0.0021	0.009
6D	0.010	362	137	85.2	75.0	0.0021	0.009
6D	0.010	357	161	94.3	86.6	0.0021	0.009
6D	0.010	355	180	92.6	86.6	0.0042	0.009
6D	0.010	353	220	91.7	86.8	0.0083	0.009
6D	0.010	351	324	91.0	87.1	0.0167	0.009
6D	0.020	349	200	101.4	86.8	0.0021	0.009
6D	0.020	346	229	99.1	87.2	0.0042	0.009
6D	0.020	342	315	96.1	86.7	0.0083	0.009
6D	0.020	338	434	94.0	86.8	0.0167	0.009
6D	0.040	302	252	114.8	84.6	0.0021	0.009
6D	0.040	327	308	108.1	86.9	0.0042	0.009
6D	0.040	319	460	105.8	87.2	0.0083	0.009
6D	0.040	312	560	100.1	87.1	0.0167	0.009

NOTE: Average distances of holes from left and right tool edges were 0.020 and 0.075, respectively.

Tool	Depth	Surface Feet per Minute	Final Tool Temperature (°F)	Final Part Temperature (°F)	Initial Part Temperature (°F)	Feed (inches per revolution)	Distance from Top of Tool (inches)
7A	0.005	361	125	88.6	87.0	0.0021	0.067
7A	0.005	361	144	89.4	87.0	0.0042	0.067
7A	0.005	360	179	90.2	87.0	0.0083	0.067
7A	0.010	359	144	90.4	86.6	0.0031	0.067
7A	0.010	359	171	90.6	86.4	0.0042	0.067
7A	0.010	357	226	92.5	86.7	0.0083	0.067
7A	0.010	355	320	90.9	86.3	0.0167	0.067
7A	0.020	353	181	94.2	87.0	0.0021	0.067
7A	0.020	353	222	96.1	86.8	0.0042	0.067
7A	0.020	350	312	97.3	87.0	0.0083	0.067
7A	0.020	346	354	94.3	87.0	0.0167	0.067
7A	0.040	342	216	101.1	86.9	0.0021	0.067
7A	0.040	342	292	104.9	86.4	0.0042	0.067
7A	0.040	335	362	107.5	86.9	0.0083	0.067
7A	0.040	327	406	98.5	87.0	0.0167	0.067
7B	0.005	339	125	88.9	87.0	0.0021	0.036
7B	0.005	339	141	88.4	87.0	0.0042	0.036
7B	0.005	338	170	89.3	86.8	0.0083	0.036
7B	0.010	337	146	89.9	86.7	0.0021	0.036
7B	0.010	337	170	89.6	86.6	0.0042	0.036
7B	0.010	335	210	90.9	86.9	0.0083	0.036
7B	0.010	333	285	90.6	87.0	0.0167	0.036
7B	0.020	331	173	93.5	87.0	0.0021	0.036
7B	0.020	331	194	94.0	87.0	0.0042	0.036
7B	0.020	327	264	96.1	86.8	0.0083	0.036
7B	0.020	323	338	92.2	86.0	0.0167	0.036

TABLE III. (Continued).

7B	0.040	320	208	101.7	87.2	0.0021	0.036
7B	0.040	320	245	102.0	87.1	0.0042	0.036
7B	0.040	312	335	105.8	87.0	0.0083	0.036
7B	0.040	304	446	117.4	87.2	0.0167	0.036
7C	0.005	381	130	88.3	87.0	0.0021	0.017
7C	0.005	381	147	89.2	87.0	0.0042	0.017
7C	0.005	380	176	89.1	86.7	0.0083	0.017
7C	0.010	379	153	90.2	86.7	0.0021	0.017
7C	0.010	379	175	91.0	86.9	0.0042	0.017
7C	0.010	377	209	91.0	87.0	0.0083	0.017
7C	0.010	375	287	90.3	87.0	0.0167	0.017
7C	0.020	373	174	92.3	86.5	0.0021	0.017
7C	0.020	373	204	94.1	86.7	0.0042	0.017
7C	0.020	370	282	95.2	85.8	0.0083	0.017
7C	0.020	365	344	92.6	86.9	0.0167	0.017
7C	0.040	362	204	98.6	86.3	0.0021	0.017
7C	0.040	362	244	100.8	86.7	0.0042	0.017
7C	0.040	354	344	102.3	86.8	0.0083	0.017
7C	0.040	347	452	97.1	87.0	0.0167	0.017
7D	0.005	426	135	88.8	86.1	0.0021	0.006
7D	0.005	426	151	88.7	86.8	0.0042	0.006
7D	0.005	425	182	89.4	87.0	0.0083	0.006
7D	0.010	423	154	90.3	87.0	0.0021	0.006
7D	0.010	423	176	90.8	86.9	0.0042	0.006
7D	0.010	422	227	90.6	86.7	0.0083	0.006
7D	0.010	421	245	89.2	86.8	0.0167	0.006
7D	0.020	413	180	93.0	86.2	0.0021	0.006
7D	0.020	413	212	95.4	86.6	0.0042	0.006
7D	0.020	410	282	93.4	86.3	0.0083	0.006
7D	0.020	407	350	91.4	86.8	0.0167	0.006
7D	0.040	403	212	100.1	86.7	0.0021	0.006
7D	0.040	403	260	101.0	87.0	0.0042	0.006
7D	0.040	396	346	100.4	87.0	0.0083	0.006
7D	0.040	389	456	95.2	86.8	0.0167	0.006

NOTE: Average distances of holes from left and right tool edges were 0.105 and 0.028, respectively.

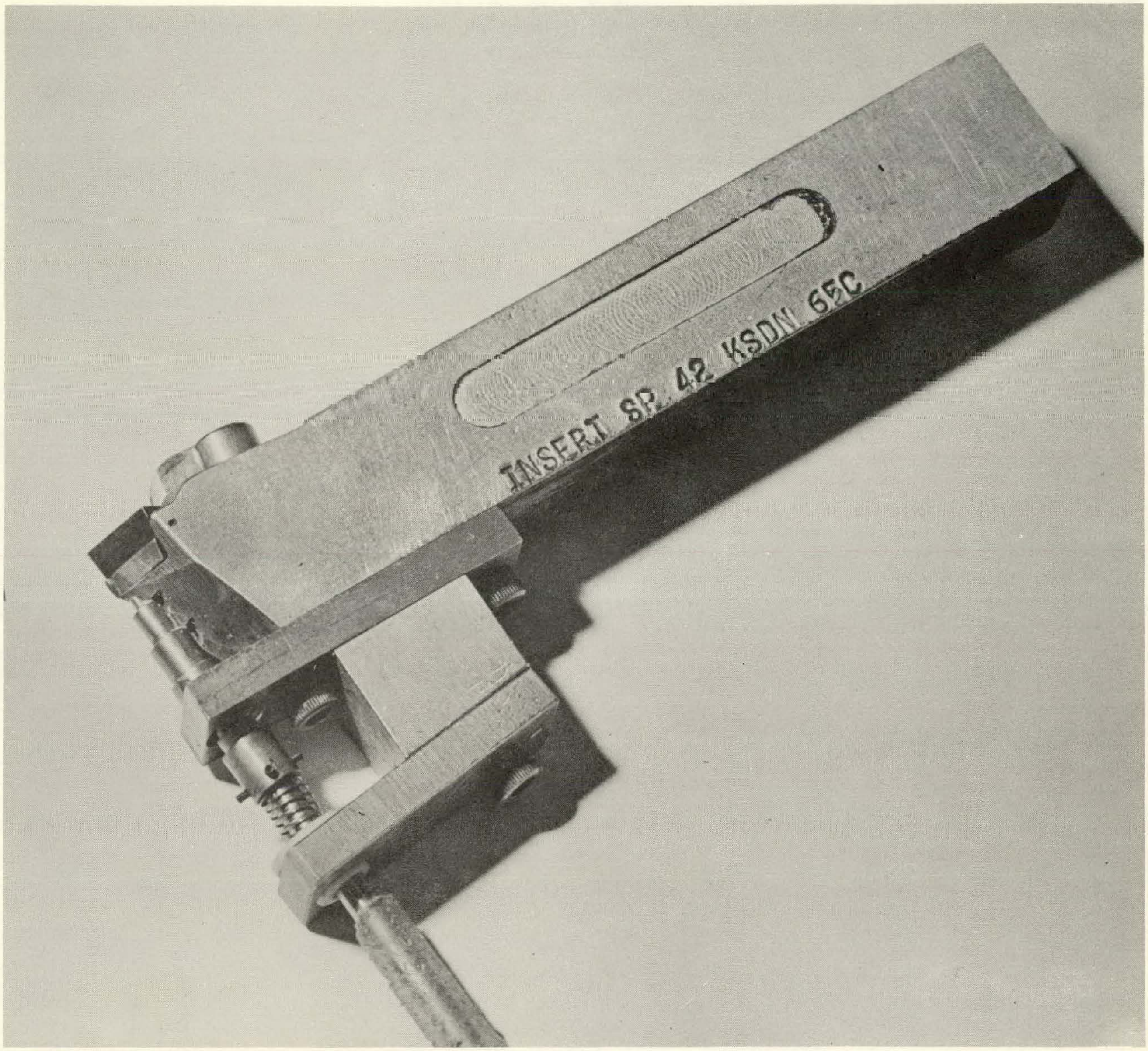
8A	0.005	343	124	89.0	86.8	0.0021	0.066
8A	0.005	343	139	90.1	87.0	0.0042	0.066
8A	0.005	342	166	90.9	87.1	0.0083	0.066
8A	0.010	341	141	91.5	86.9	0.0021	0.066
8A	0.010	341	161	93.1	87.2	0.0042	0.066
8A	0.010	339	212	93.9	87.0	0.0083	0.066
8A	0.010	337	292	93.5	86.9	0.0167	0.066
8A	0.020	336	174	97.6	87.0	0.0021	0.066
8A	0.020	336	208	99.4	87.0	0.0042	0.066
8A	0.020	332	278	100.0	86.9	0.0083	0.066
8A	0.020	324	364	98.6	86.5	0.0167	0.066
8A	0.040	321	218	107.6	86.9	0.0021	0.066
8A	0.040	321	270	110.2	86.9	0.0042	0.066
8A	0.040	313	370	112.6	86.1	0.0083	0.066
8A	0.040	306	416	100.7	86.5	0.0167	0.066
8A	0.040	351	275	109.7	87.3	0.0042	0.066

TABLE III. (Continued).

Tool	Depth	Surface Feet per Minute	Final Tool Temperature (°F)	Final Part Temperature (°F)	Initial Part Temperature (°F)	Feed inches per revolution	Distance from Top of Tool (inches)
8B	0.005	433	128	90.0	87.0	0.0021	0.034
8B	0.005	433	146	90.9	87.0	0.0042	0.034
8B	0.005	431	186	91.5	87.0	0.0083	0.034
8B	0.010	429	155	94.8	86.8	0.0021	0.034
8B	0.010	429	175	94.2	86.8	0.0042	0.034
8B	0.010	426	238	94.9	87.0	0.0083	0.034
8B	0.010	423	320	92.8	87.0	0.0167	0.034
8B	0.020	420	184	101.1	87.0	0.0021	0.034
8B	0.020	420	235	102.4	87.0	0.0042	0.034
8B	0.020	414	324	104.2	87.0	0.0083	0.034
8B	0.020	408	365	95.2	87.1	0.0167	0.034
8B	0.040	401	234	113.1	87.0	0.0021	0.034
8B	0.040	401	340	119.5	87.0	0.0042	0.034
8B	0.040	387	390	114.8	87.1	0.0083	0.034
8B	0.040	376	440	102.7	86.9	0.0167	0.034
8C	0.005	438	132	89.9	86.8	0.0021	0.021
8C	0.005	438	148	90.1	86.6	0.0042	0.021
8C	0.005	437	193	90.1	86.2	0.0083	0.021
8C	0.010	437	158	92.4	86.7	0.0021	0.021
8C	0.010	437	182	92.4	87.0	0.0042	0.021
8C	0.010	433	234	93.8	87.0	0.0083	0.021
8C	0.010	431	320	91.7	87.0	0.0167	0.021
8C	0.020	428	191	98.6	86.9	0.0021	0.021
8C	0.020	428	240	98.4	86.6	0.0042	0.021
8C	0.020	423	318	99.4	87.0	0.0083	0.021
8C	0.020	418	378	94.2	86.8	0.0167	0.021
8C	0.040	392	244	108.7	86.6	0.0021	0.021
8C	0.040	392	284	109.4	87.0	0.0042	0.021
8C	0.040	382	396	112.4	87.0	0.0083	0.021
8C	0.040	372	470	101.3	86.8	0.0167	0.021
8C	0.040	413	248	111.4	87.0	0.0021	0.021
8D	0.005	407	131	87.6	85.8	0.0021	0.001
8D	0.005	407	152	88.4	85.7	0.0042	0.001
8D	0.005	405	187	89.1	86.6	0.0083	0.001
8D	0.010	404	153	90.4	86.6	0.0021	0.001
8D	0.010	404	175	89.5	86.5	0.0042	0.001
8D	0.010	401	243	92.8	86.8	0.0083	0.001
8D	0.010	400	280	89.7	86.2	0.0167	0.001
8D	0.020	397	195	95.8	86.0	0.0021	0.001
8D	0.020	397	220	96.4	86.8	0.0042	0.001
8D	0.020	392	305	96.8	86.8	0.0083	0.001
8D	0.020	388	357	93.0	86.6	0.0167	0.001
8D	0.040	382	234	105.4	87.0	0.0021	0.001
8D	0.040	382	286	106.4	86.8	0.0042	0.001
8D	0.040	372	395	106.0	86.8	0.0083	0.001
8D	0.040	363	482	99.4	86.9	0.0167	0.001

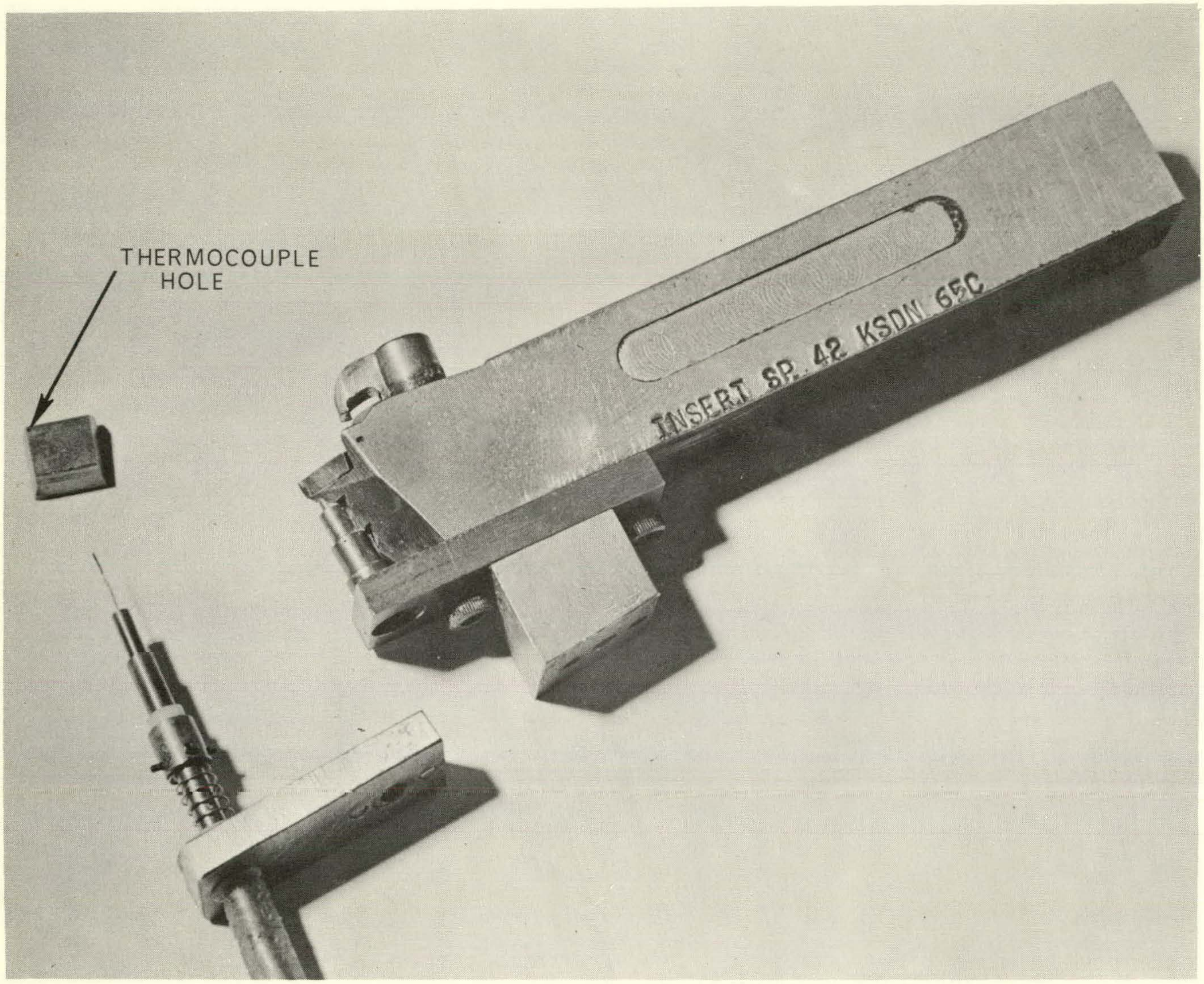
NOTE: Average distances of holes from left and right tool edges were 0.019 and 0.103, respectively.

ILLUSTRATIONS



13490-7

FIGURE 1. Assembled Tool and Thermocouple in Place.



13490-10

FIGURE 2. Thermocouple, Tool, and Holder Prior to Assembly.

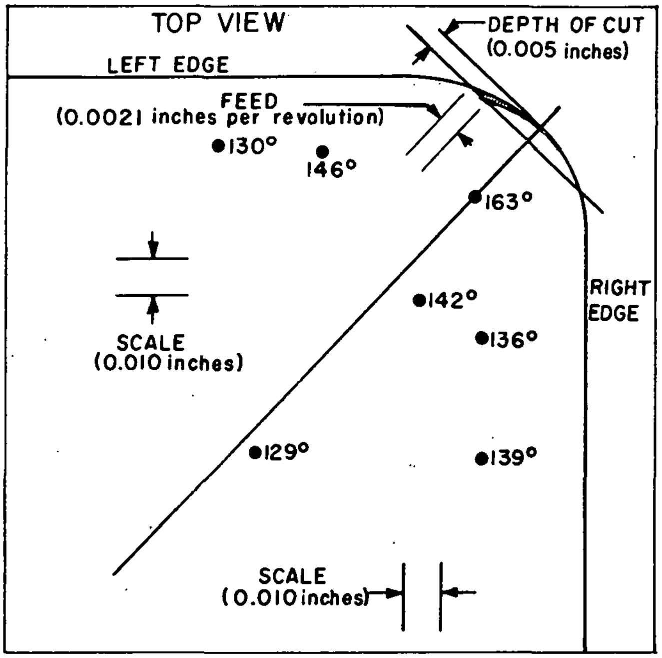


FIGURE 3. Surface Temperature Distribution. (Shaded portions of figure show amount of metal being removed.)

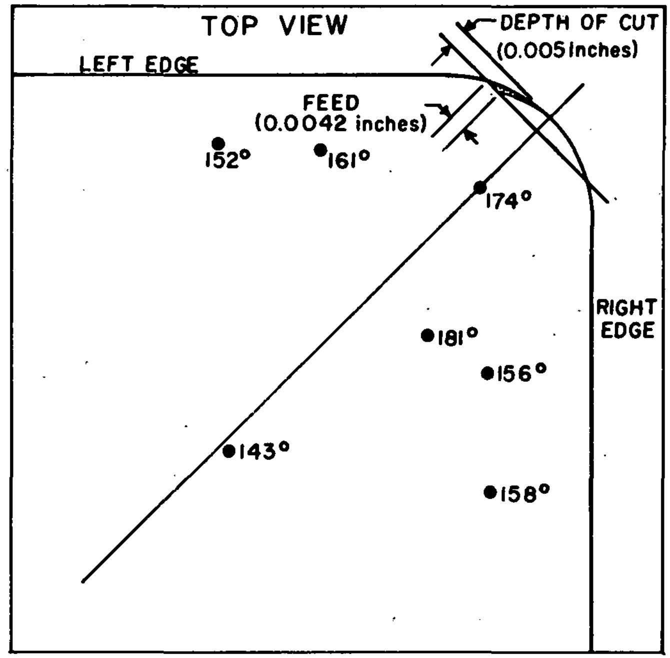
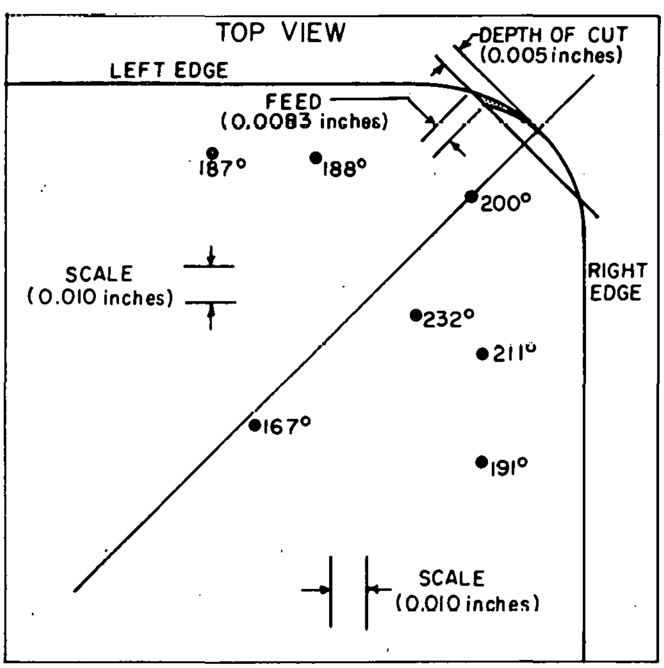
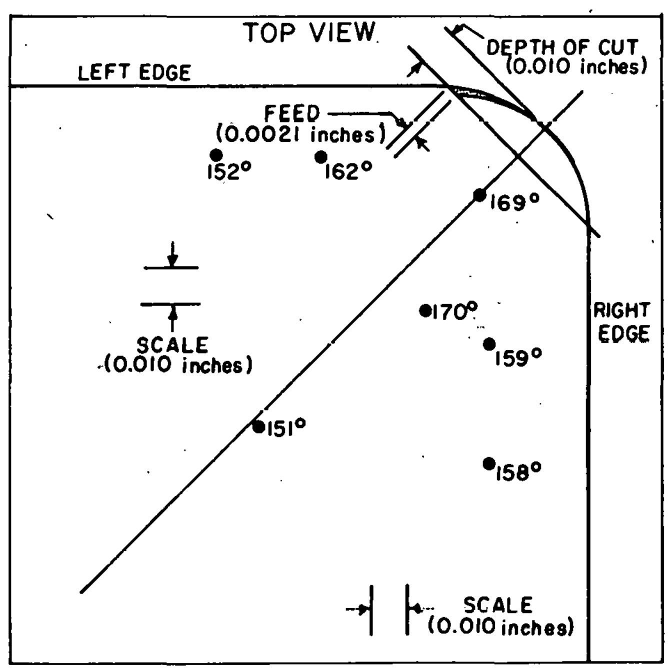


FIGURE 4. Surface Temperature Distribution.

FIGURE 5. Surface Temperature Distribution.

FIGURE 6. Surface Temperature Distribution.





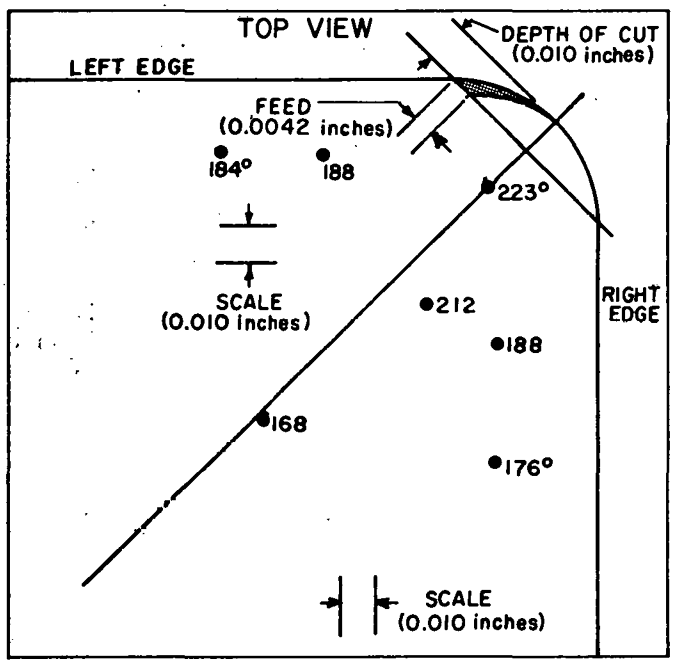


FIGURE 7. Surface Temperature Distribution.

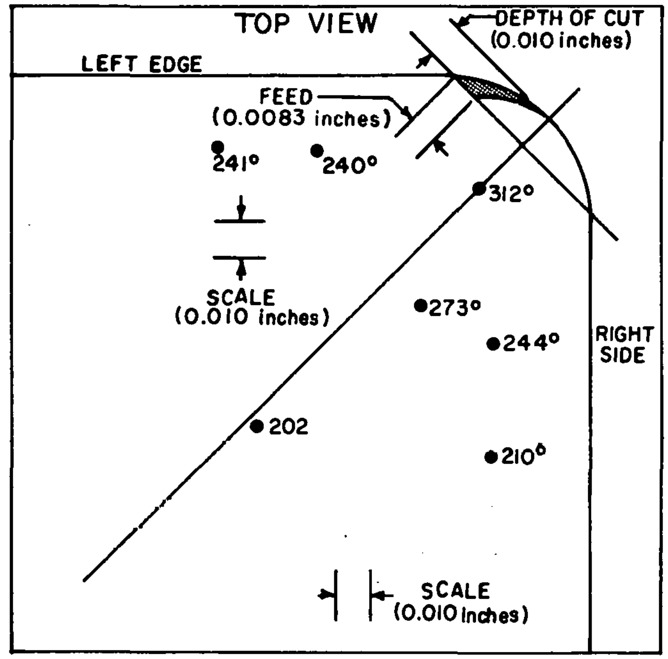


FIGURE 8. Surface Temperature Distribution.

FIGURE 9. Surface Temperature Distribution.

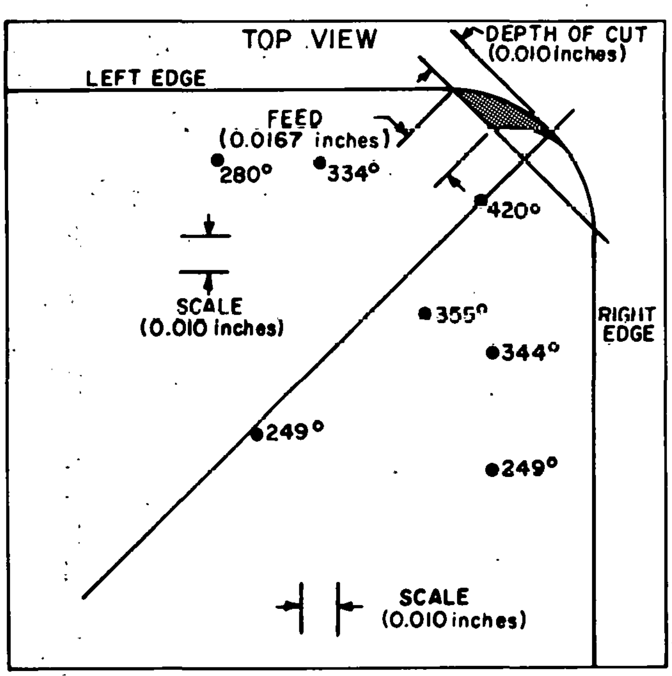
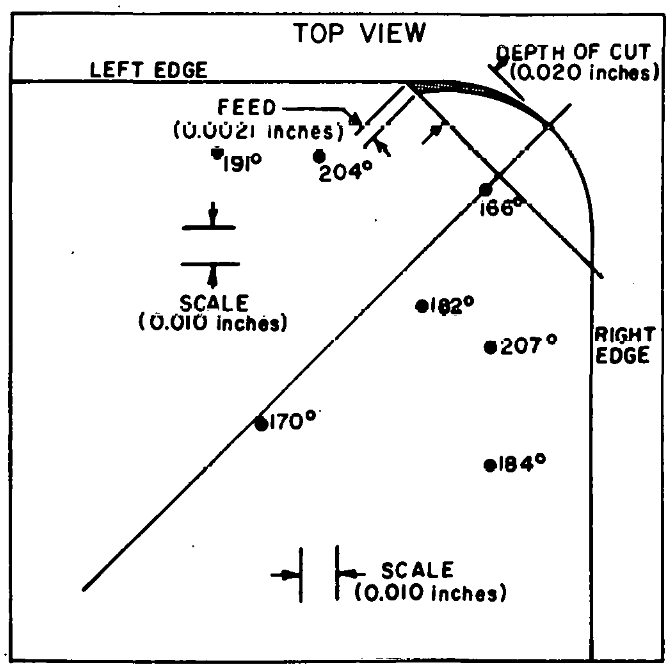


FIGURE 10. Surface Temperature Distribution.



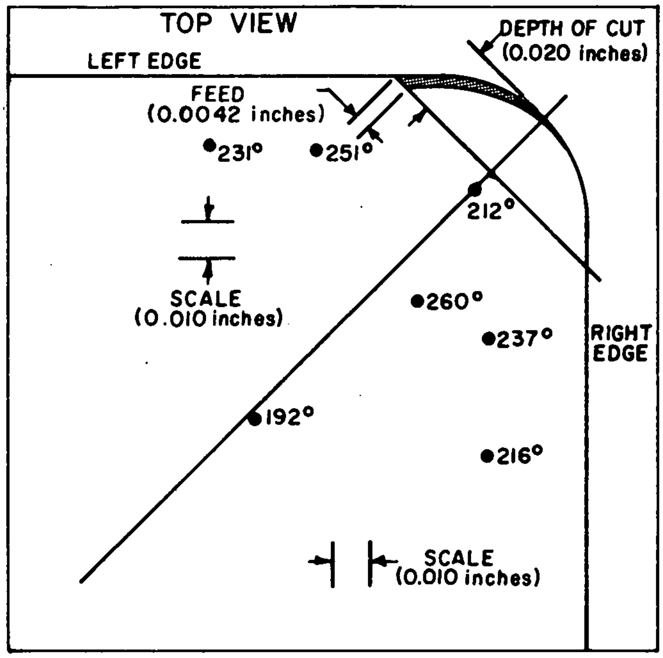


FIGURE 11. Surface Temperature Distribution.

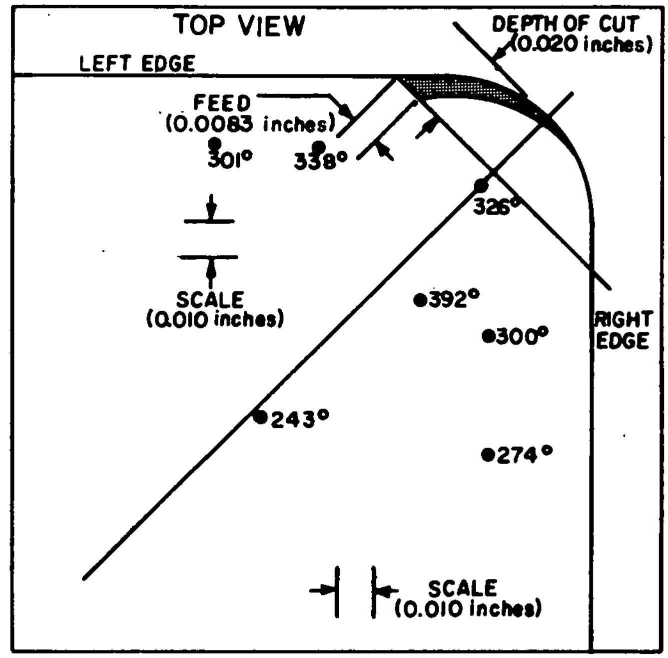


FIGURE 12. Surface Temperature Distribution.

FIGURE 13. Surface Temperature Distribution.

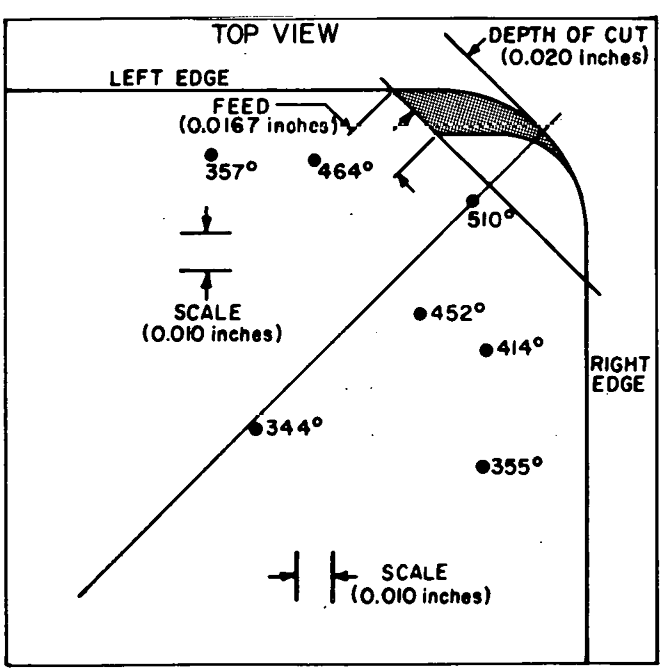
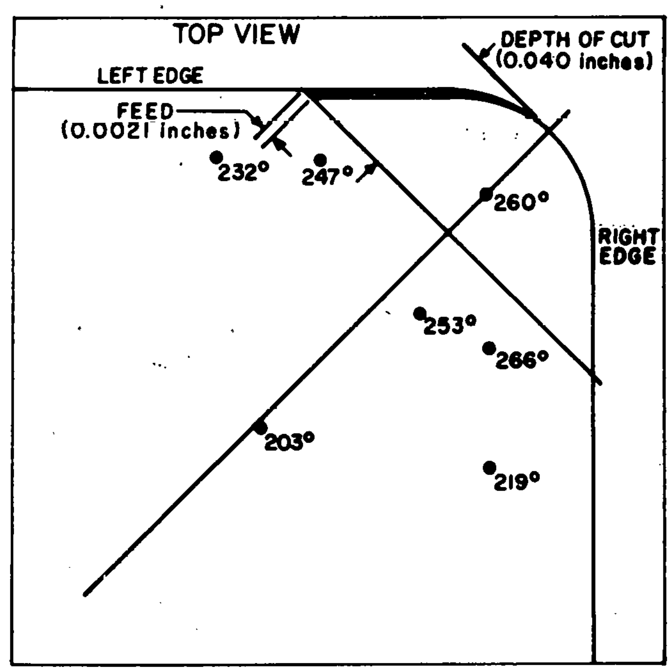


FIGURE 14. Surface Temperature Distribution.



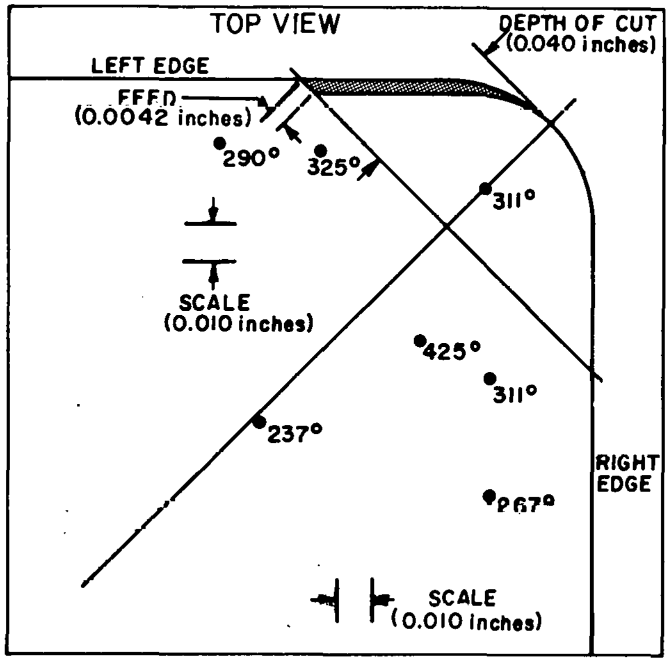


FIGURE 15. Surface Temperature Distribution.

FIGURE 16. Surface Temperature Distribution.

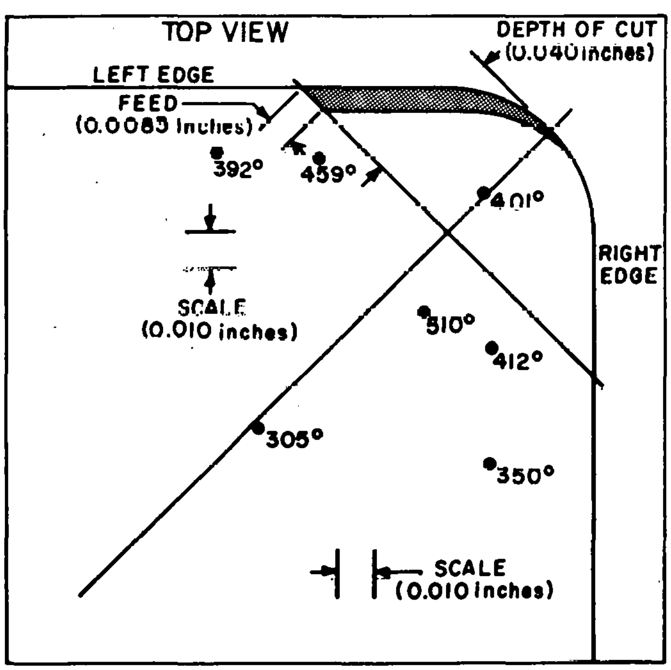
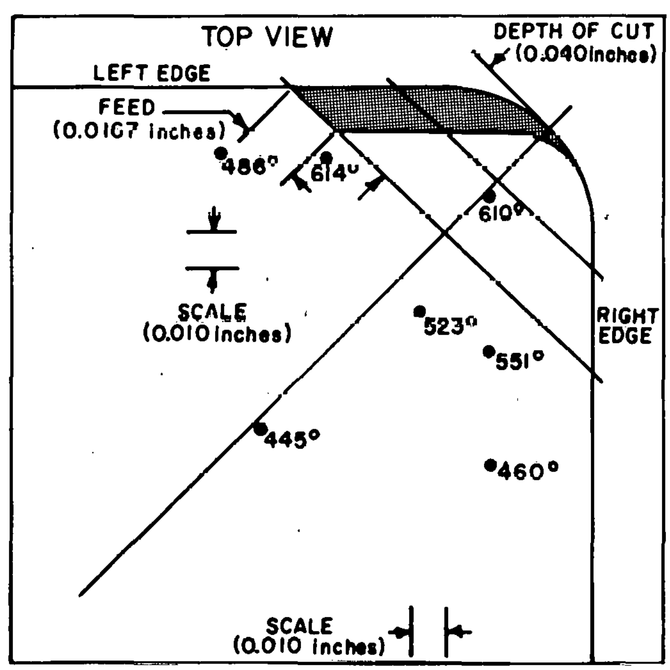
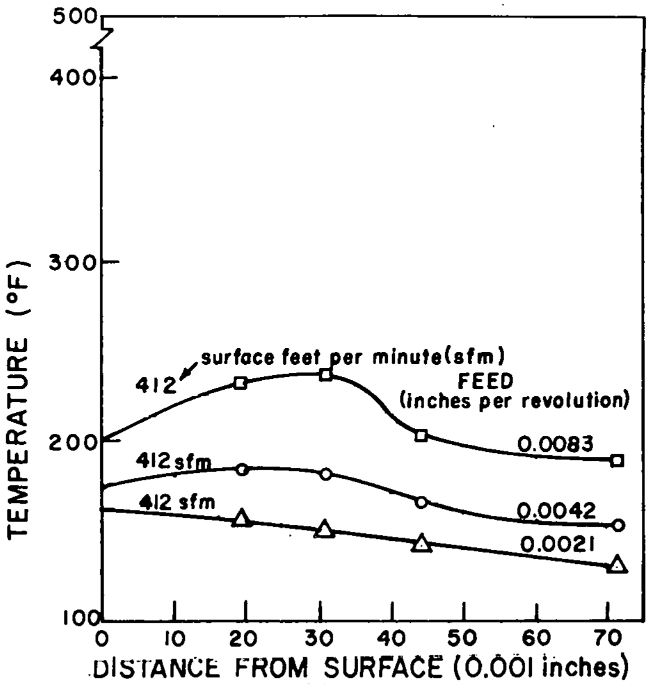


FIGURE 17. Surface Temperature Distribution.

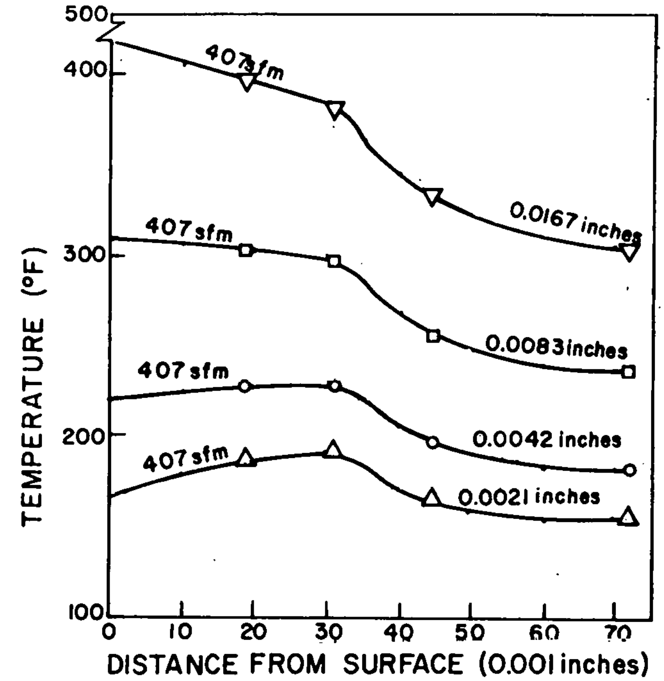




Legend

Position 1: Depth of Cut = 0.005 inches.

FIGURE 18. Temperature versus Distance from Surface.



Legend

Position 1: Depth of Cut = 0.010 inches

FIGURE 19. Temperature versus Distance from Surface.

FIGURE 20. Temperature versus Distance from Surface.

Legend

Position 1: Depth of Cut = 0.020 inches.

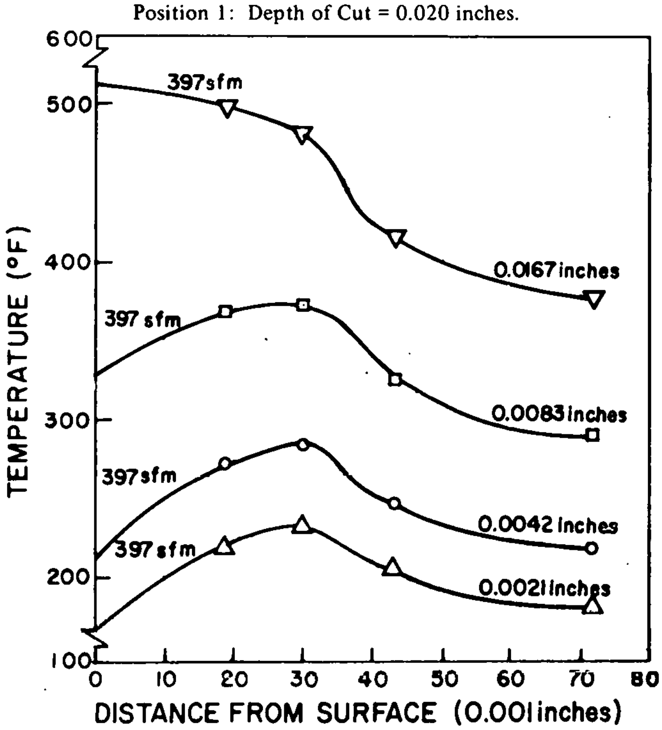
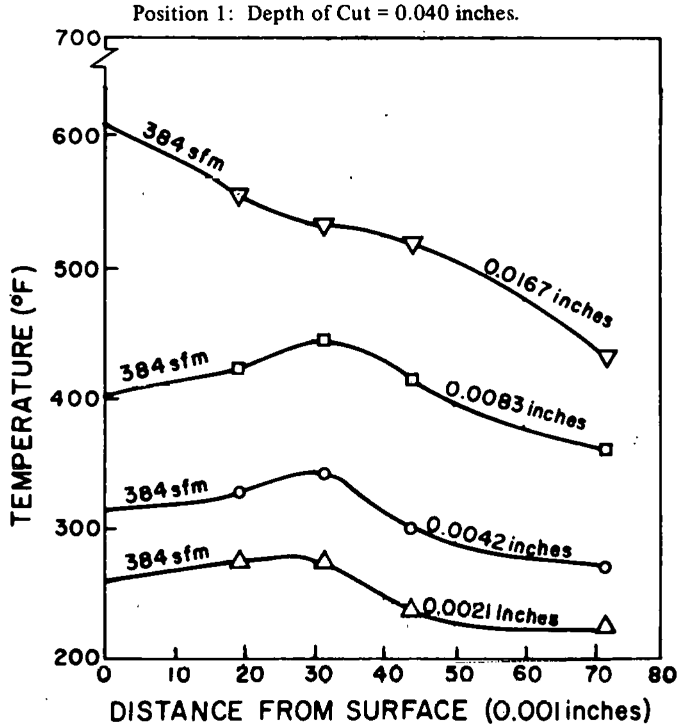
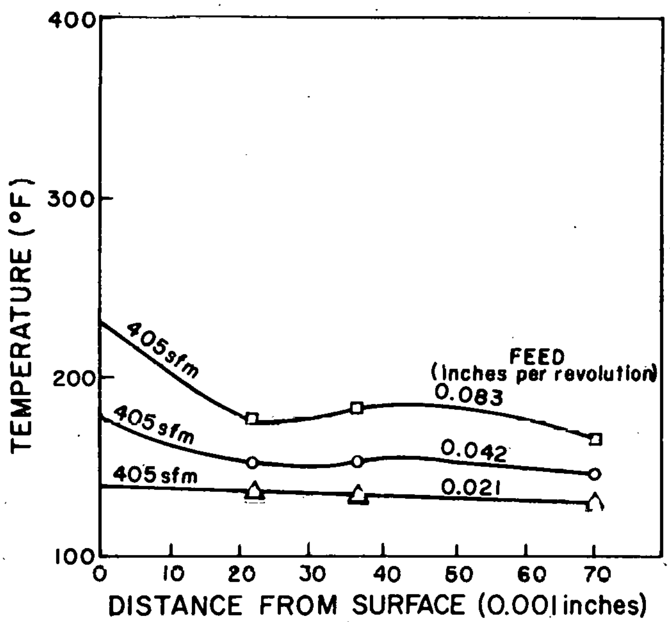


FIGURE 21. Temperature versus Distance from Surface.

Legend

Position 1: Depth of Cut = 0.040 inches.

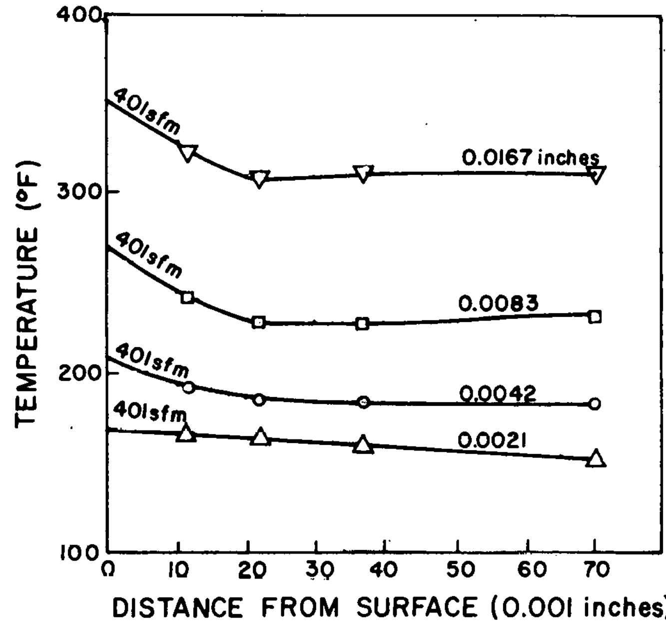




Legend

Position 3: Depth of Cut = 0.005 inches.

FIGURE 22. Temperature versus Distance from Surface.



Legend

Position 3: Depth of Cut = 0.010 inches.

FIGURE 23. Temperature versus Distance from Surface.

FIGURE 24. Temperature versus Distance from Surface.

Legend

Position 3: Depth of Cut = 0.020 inches.

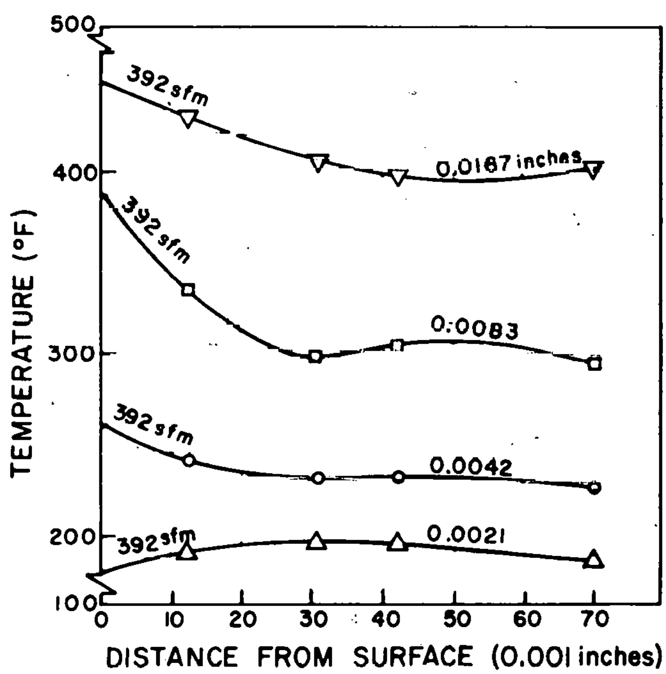
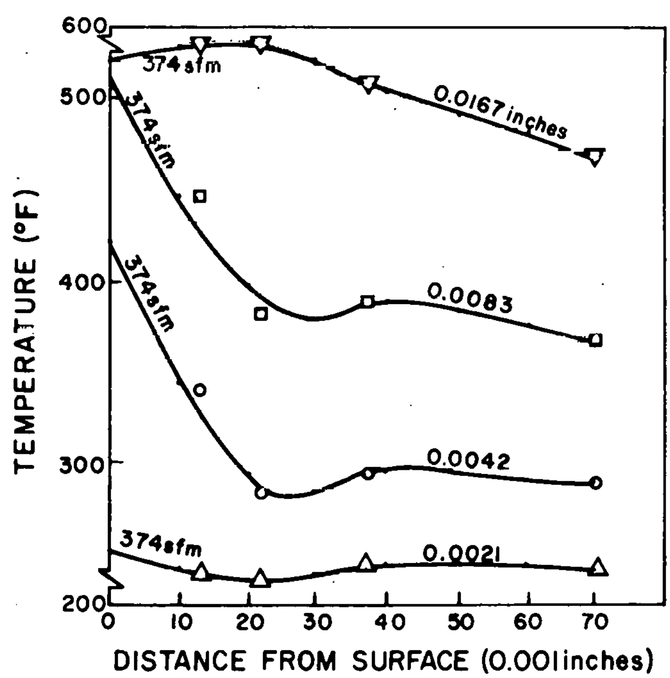
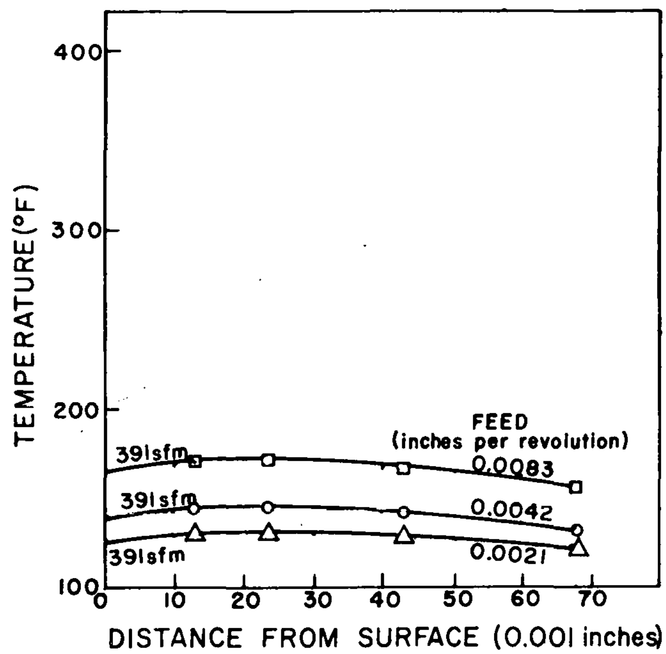


FIGURE 25. Temperature versus Distance from Surface.

Legend

Position 3: Depth of Cut = 0.040 inches.

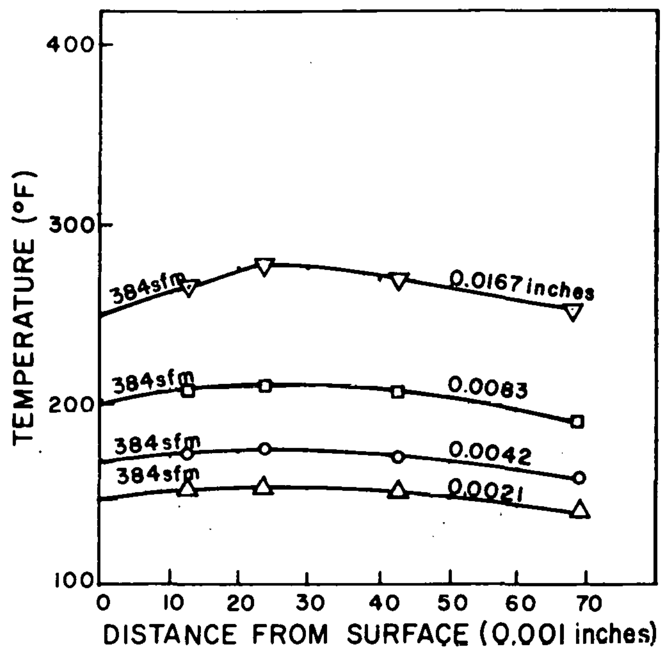




Legend

Position 4: Depth of Cut = 0.005 inches.

FIGURE 26. Temperature versus Distance from Surface.



Legend

Position 4: Depth of Cut = 0.010 inches.

FIGURE 27. Temperature versus Distance from Surface.

FIGURE 28. Temperature versus Distance from Surface.

Legend

Position 4: Depth of Cut = 0.020 inches.

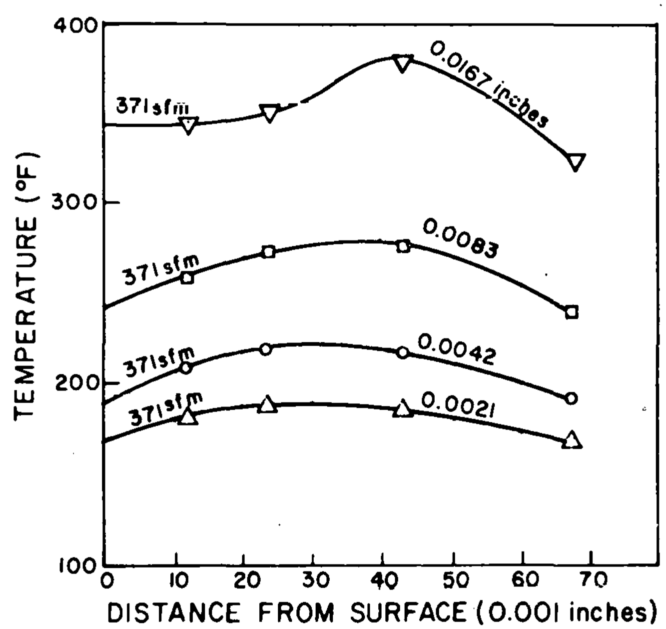
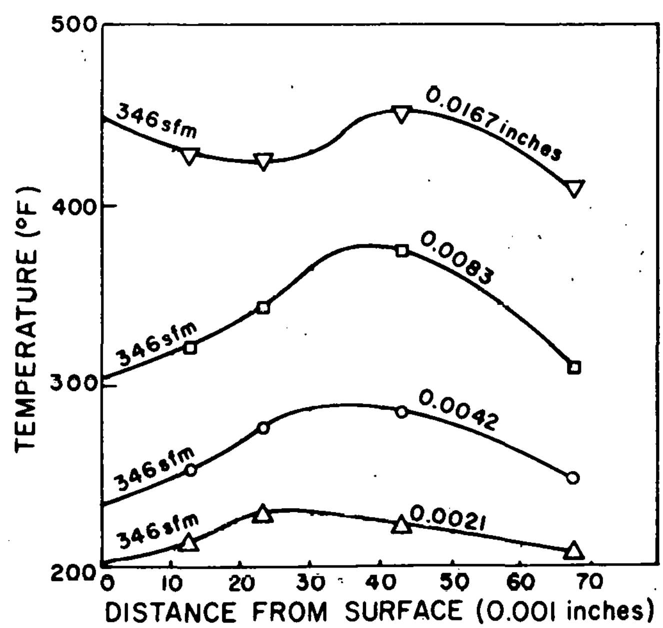
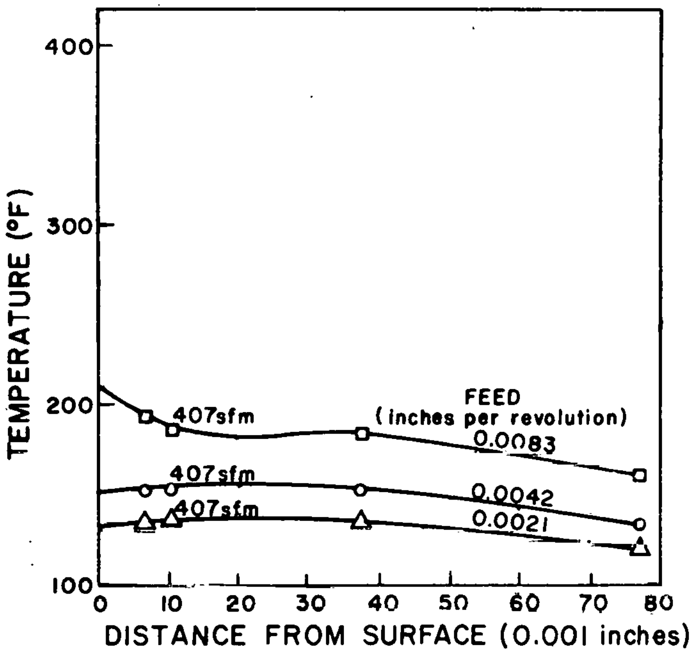


FIGURE 29. Temperature versus Distance from Surface.

Legend

Position 4: Depth of Cut = 0.040 inches.

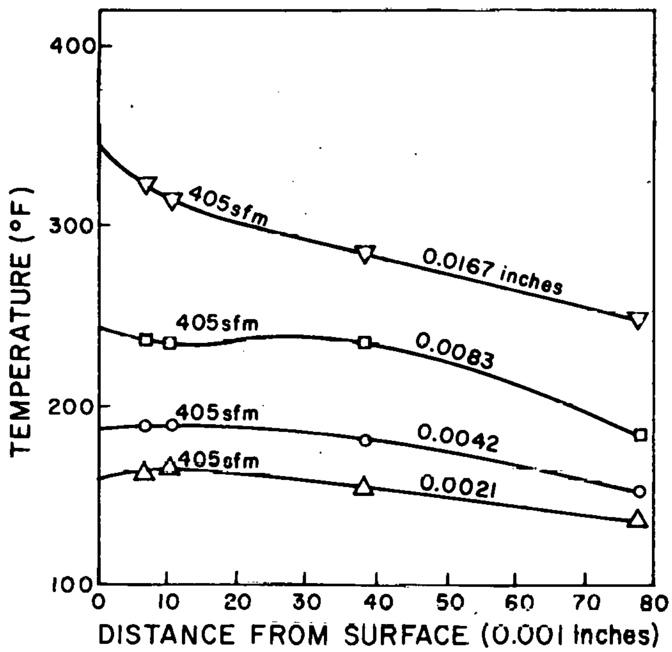




Legend

Position 5: Depth of Cut = 0.005 inches.

FIGURE 30. Temperature versus Distance from Surface.



Legend

Position 5: Depth of Cut = 0.010 inches.

FIGURE 31. Temperature versus Distance from Surface.

FIGURE 32. Temperature versus Distance from Surface.

Legend

Position 5: Depth of Cut = 0.020 inches.

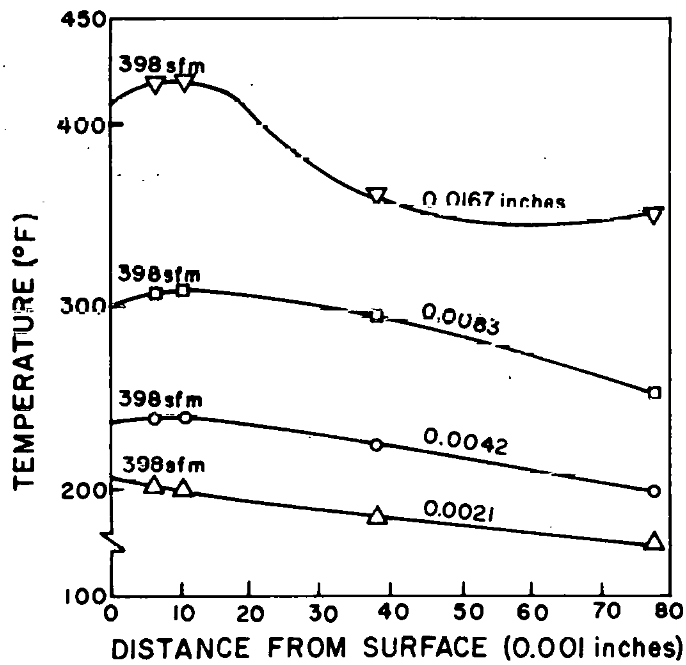
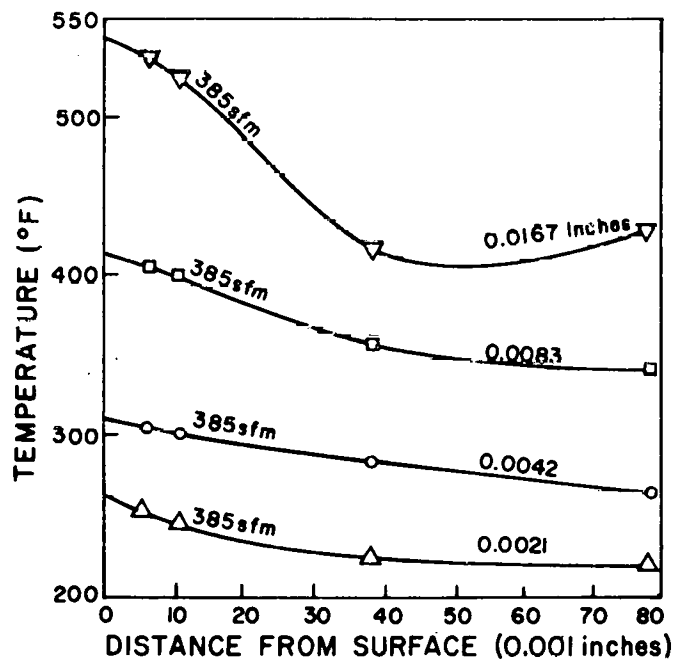
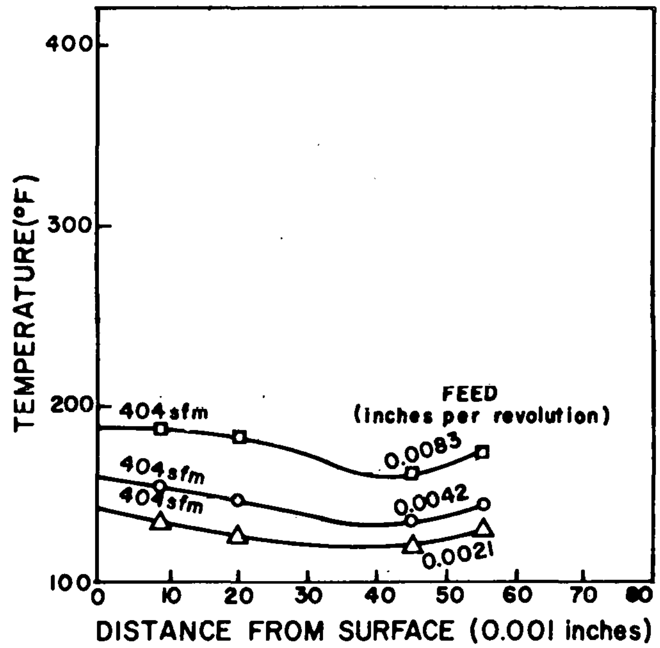


FIGURE 33. Temperature versus Distance from Surface.

Legend

Position 5: Depth of Cut = 0.040 inches.

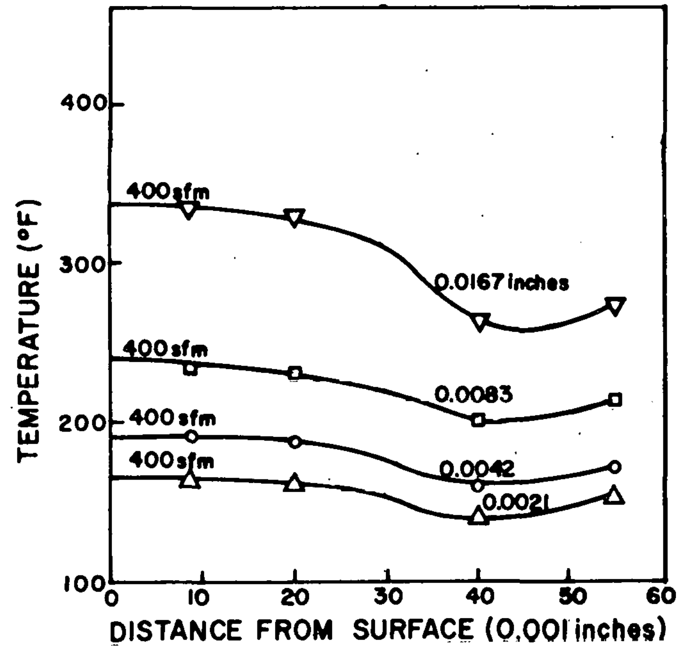




Legend

Position 6: Depth of Cut = 0.005 inches.

FIGURE 34. Temperature versus Distance from Surface.



Legend

Position 6: Depth of Cut = 0.010 inches.

FIGURE 35. Temperature versus Distance from Surface.

FIGURE 36. Temperature versus Distance from Surface.

Legend

Position 6: Depth of Cut = 0.020 inches.

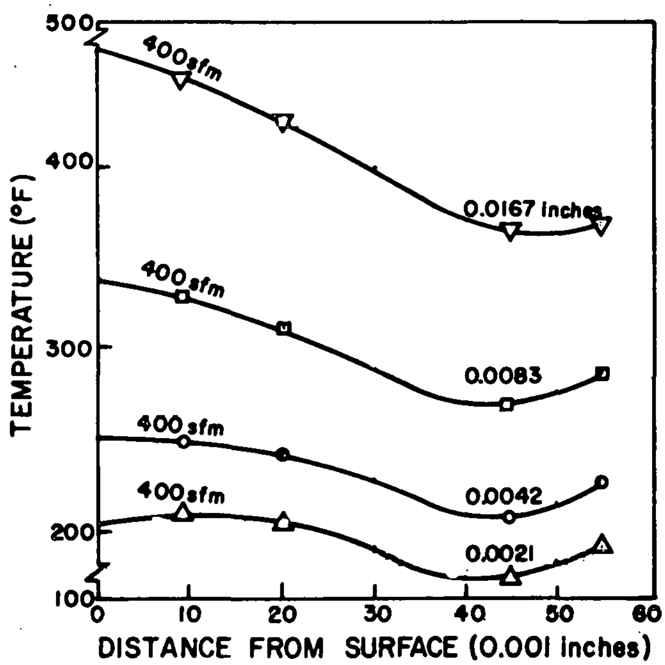
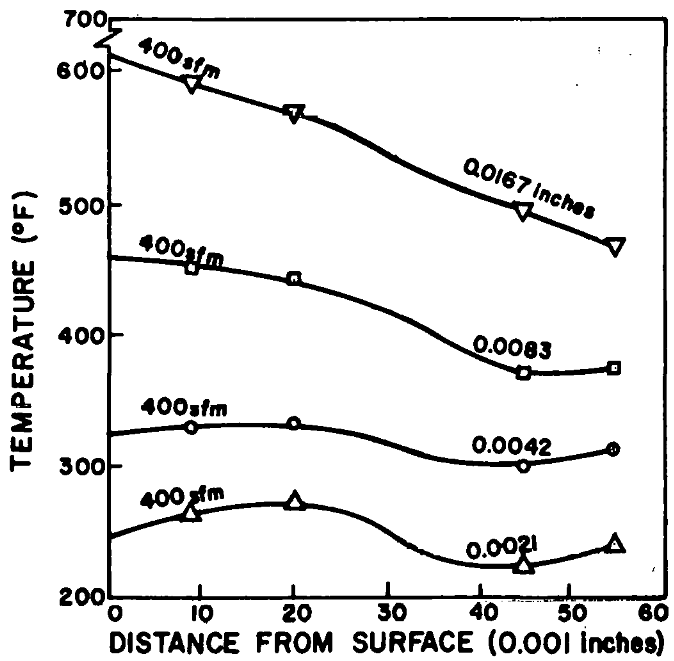
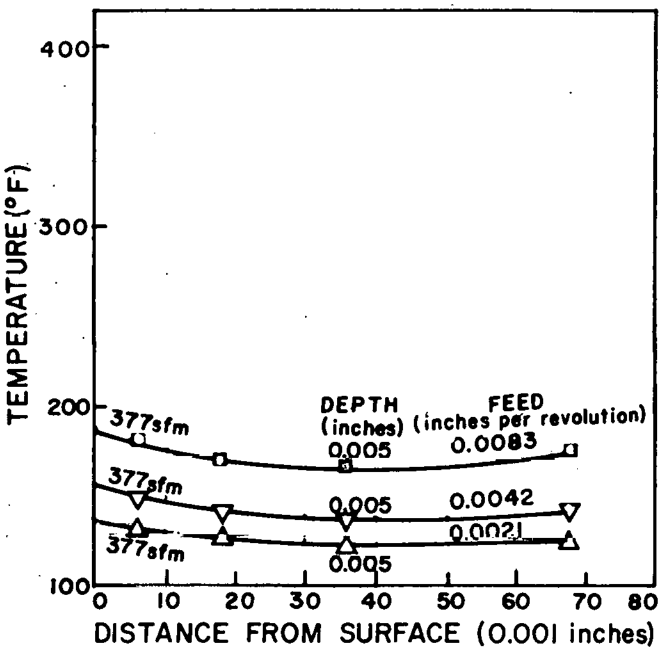


FIGURE 37. Temperature versus Distance from Surface.

Legend

Position 6: Depth of Cut = 0.040 inches.

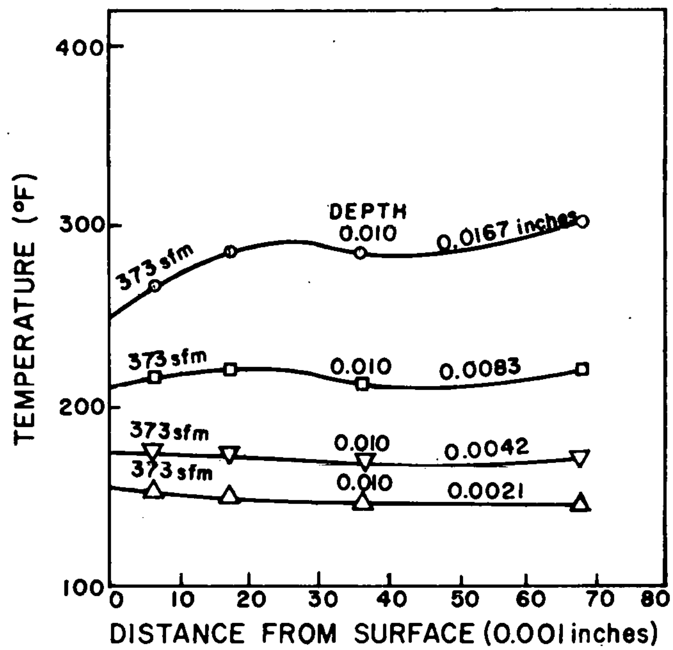




Legend

Position 7: Depth of Cut = 0.005 inches.

FIGURE 38. Temperature versus Distance from Surface.



Legend

Position 7: Depth of Cut = 0.010 inches.

FIGURE 39. Temperature versus Distance from Surface.

FIGURE 40. Temperature versus Distance from Surface.

Legend

Position 7: Depth of Cut = 0.020 inches

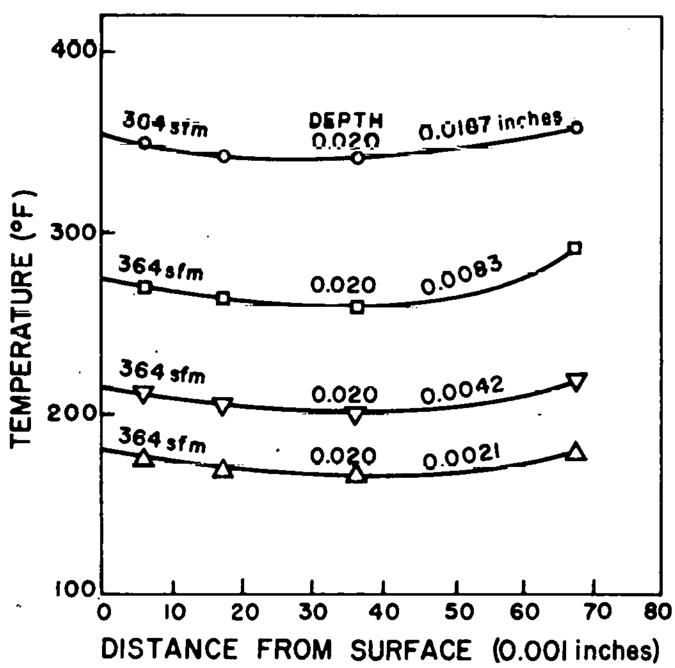
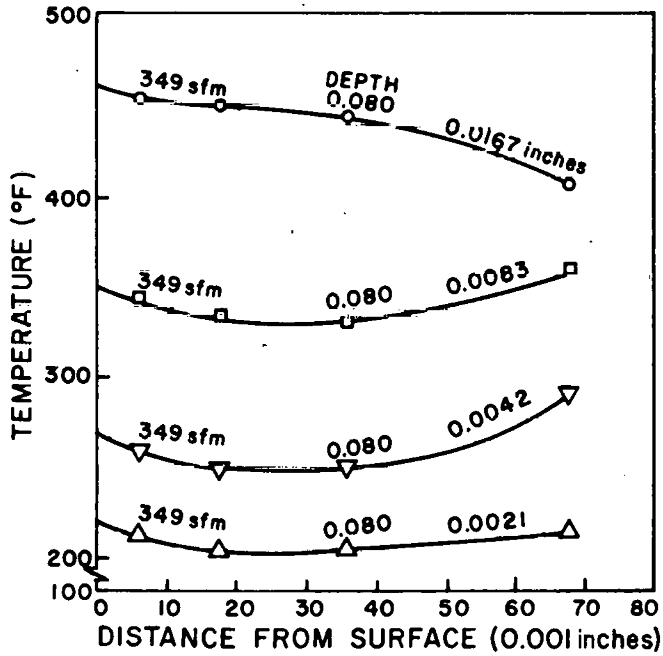
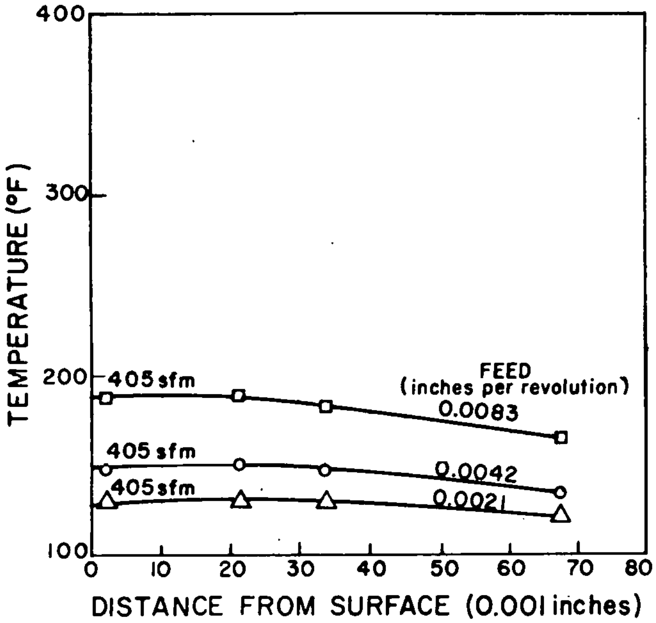


FIGURE 41. Temperature versus Distance from Surface.

Legend

Position 7: Depth of Cut = 0.040 inches.

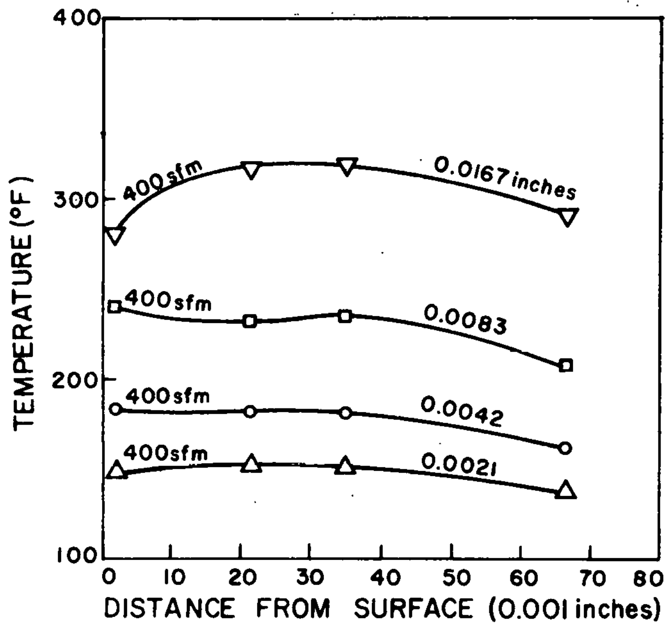




Legend

Position 8: Depth of Cut = 0.005 inches.

FIGURE 42. Temperature versus Distance from Surface.



Legend

Position 8: Depth of Cut = 0.010 inches.

FIGURE 43. Temperature versus Distance from Surface.

FIGURE 44. Temperature versus Distance from Surface.

Legend

Position 8: Depth of Cut = 0.020 inches.

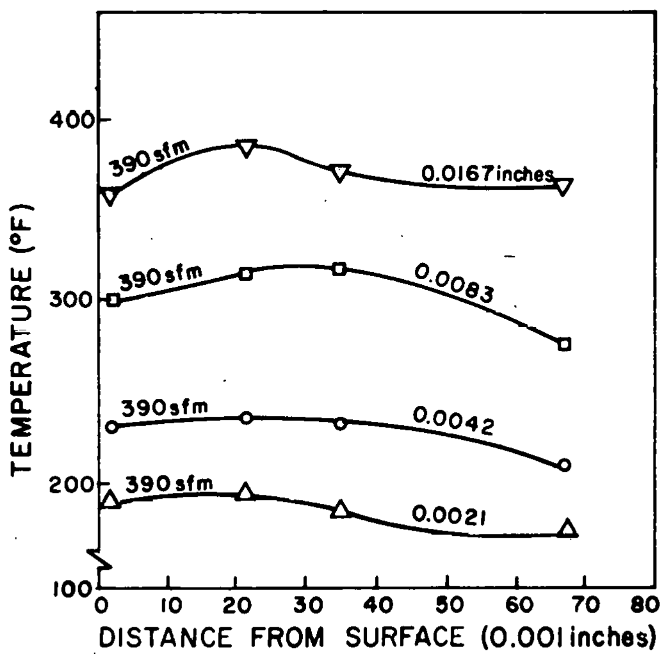


FIGURE 45. Temperature versus Distance from Surface.

Legend

Position 8: Depth of Cut = 0.040 inches.