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Study of Die Polishing for United States Mint Phase III

Karl Ousterhout

U.S. DEPARTMENT OF COMMERCE
National Bureau of Standards
Center for Manufacturing Engineering
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U.S. DEPARTMENT OF COMMERCE, C. William Verity, *Secretary*
NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Director*

Study of Die Polishing for
United States Mint

Phase III

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I. Statement of Problem

This research was undertaken to determine the feasibility of automating the polishing process of proof dies at the United States Mint. The dies polished during this research endeavor were the obverse Kennedy half-dollar dies. While most of the techniques used in this study are new, some of the techniques developed by Sidney Weiser (Phase 1 December 16, 1985 and Phase 2 December 3, 1986) were incorporated into the polishing procedure.

The main goals of this research are:

1. Develop a method of mechanically polishing proof dies which results in a quality level equal to or better than that now achieved by current manual methods.

2. Develop the optimum production rate that can be achieved in mechanically polishing proof dies.

3. Utilize a machine tool with at least 4 axes of motion.

4. Exercise initiative and ingenuity in the use of conventional and computer technologies, and develop through experimentation the best polishing compounds and materials, tooling, tool paths, speeds, masking techniques or other methods of protecting areas not to be polished.

II. Introduction

The techniques developed during Phase I and Phase II proved that it is possible to automate the proof die polishing process. A three-axis vertical milling machine was used to develop and test these techniques. The die was mounted on the table of the machine, which provided two orthogonal translations in the horizontal plane. The column of the machine provided the vertical axis of motion. With this machine, the concentric tool paths were programmed using two linear axes of the table, while the table was stepped vertically from one concentric path to another in order to follow the die surface profile in the vertical plane. As a result of this type of tool motion, the pattern of concentric tool paths was visible on the surface of the die. To eliminate this visible tool pattern, three finish passes with a randomized star pattern were introduced into the polishing procedure in Phase II. Although this method was successful in removing the tool marks, it unnecessarily increased the turn-around time for each die. A better approach would be to avoid creating these marks in the first place. Providing a rotary axis for the die to be rotated while the polishing tool was moving radially in and out and following the surface profile vertically proved to be a solution to this problem. In addition, this configuration results in simpler NC programming and faster execution.

Another problem observed during the earlier phases of the research involved overpolishing of some parts of the die due to the compliance of the polishing tool. To decrease the compliance of the tool requires better control of the tool orientation with respect to the die surface. The ideal situation is to position the polishing tool surface tangent to the die surface continuously during the operation. This permits the polishing tool to cover the surface area with less deflection and pressure. But this technique requires an additional programmable rotary axis of the polishing machine. Since such a machine is unavailable, a four-axis vertical milling machine (FP4NC) was used in the current phase of the research. In addition to two linear motions in the horizontal plane and a vertical motion, this machine has a programmable rotary table with a vertical axis of rotation. Furthermore, the spindle of this machine can be indexed manually to give the tool an inclination over the part surface. This feature of the vertical milling machine proved useful in testing the idea of keeping the tool tangent to the die surface. Various tool angles were tested to check the influence of tool orientation on the polishing quality.

The techniques developed during Phase I and Phase II which were incorporated into the polishing procedure are:

1. The same type of rotating compliant tool holder was used for roughing.

2. Oak veneer was used for the roughing tool.

3. Hard felt plugs were used for final polishing.

Also, the same data points were initially used; however, upon inspection it was determined that the original tool paths did not follow paths of constant height on the die surface. Consequently, the polishing tool would not be in intimate contact with the die at all times. To insure that the polishing tool would be in contact with the die at all times, the die surface was traced with a dial indicator and appropriate tool offsets were added to the original data resulting in the tool path program shown in Appendix A. The addition of this data allowed the polishing tool to follow the exact contour of the die surface.

The 23 obverse side Kennedy 50 half-dollar dies which were delivered to The National Bureau of Standards are listed below.

Serial Number

#S609327
#S609328
#S609329
#S609330
#S609331
#S609332
#S609334
#S692249
#S692250
#S692251
#S692253
#S692254
#S692255
#S692256
#S692257
#S692258
#S692259
#S692127
#S692128
#S692130
#S692131
#S692133

All of the dies listed above were polished except for die #S692133. The 12-micron, 3-micron, and 1-micron diamond polishing compounds and the hard felt polishing tools were supplied by the U.S. Mint and are identical to the materials used in the manual polishing process performed by the U.S. Mint.

III. Technical Approach

As mentioned previously, a four axis-Deckel milling machine[1] was used to polish the dies. Since four axes of motion were used (instead of three), a new technique was developed to polish the dies. The spindle was fixed to the desired angle and the die was rotated (A axis) while simultaneously moving the tool in both the radial (X axis) and the vertical direction (Z axis). Since the milling machine is not capable of attaining high spindle speeds, a Precise Products Corporation #7332 high-speed grinding tool was mounted directly to the quill of the vertical mill. This grinder has a variable power source which allows spindle speed to be adjusted between the range of 3,000 and 45,000 rpm.

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[1]Certain commercial equipment, instruments, or materials are identified in this paper in order to adequately specify the experimental procedure. Such identification does not imply recommendation or endorsement by the National Bureau of Standards, nor does it imply that the materials or equipment identified are necessarily the best available for the purpose.

The compliant roughing tool holder was fashioned by cementing a 3/4-inch diameter neoprene rubber pad, Durometer 40, to the bottom of a steel mandrel (see Figure 1, page 5). The actual roughing tool was made from a 3/4-inch diameter, 0.020 inch thick piece of pressure sensitive oak veneer. To insure that all the roughing tools used were similar, both the neoprene rubber pad and the oak veneer were cut by a die. The polishing tool supplied by the U.S. Mint was made by cementing a 3/4-inch diameter plug of hard felt to a steel mandrel (see Figure 2, page 5). Because a new polishing tool readily absorbs both the diamond compound and the lubricating oil, four consecutive dies were polished with the same polishing tool before changing the polishing tool.

As mentioned previously, the original data points (with the addition of vertical displacements) were used for the polishing process. Ten consecutive passes were used to polish the face of the die. Also, after the initial setup phase, it was determined that the random star pattern developed in Phase II was not needed. Therefore, on the average, a single roughing or finishing pass was completed in four minutes (see individual data sheets for specific times). This results in a total polishing time of 12 minutes - a 50% improvement over the polishing time achieved in Phase II.

The tool height was initially set by bringing the tool into contact with a piece of 0.004-inch thick clean paper which was inserted between the tool and the die. The force needed to pull the paper out was set with a small spring scale. The tool was then lowered the thickness of the paper plus an additional preload (see individual data sheets for specific information).

The following pages contain the initial conditions, polishing technique, and the results of the polishing procedure.

Figure 1

ROUGHING TOOL

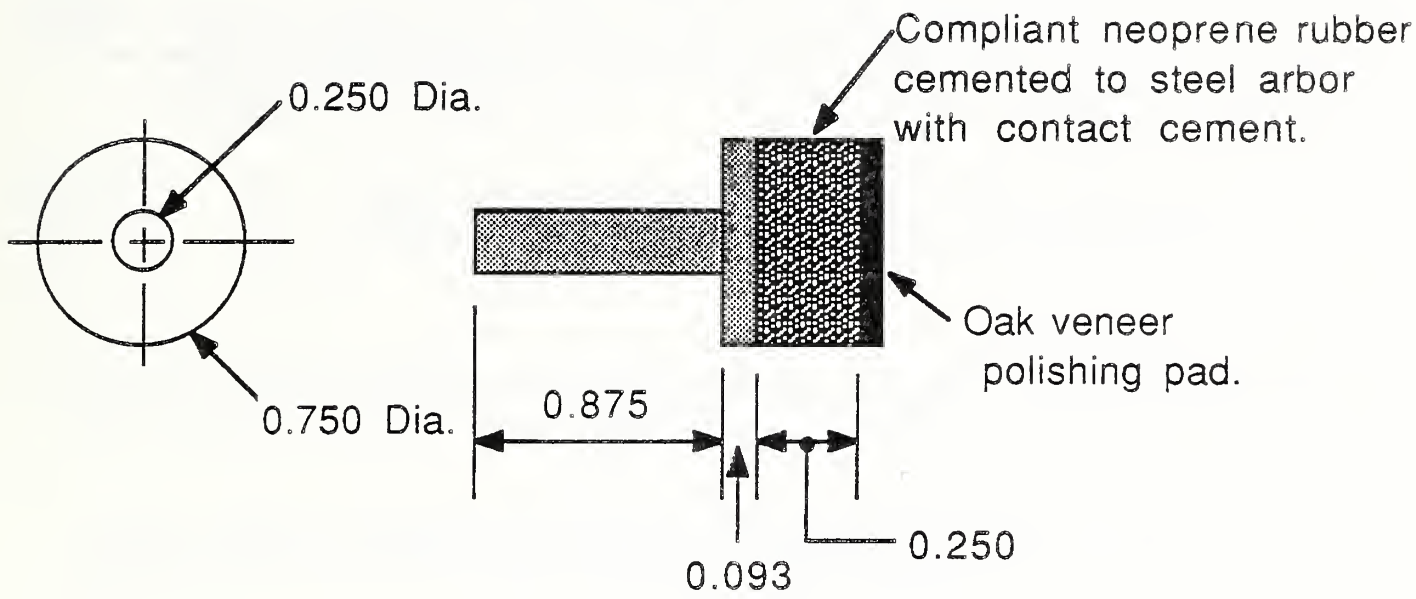
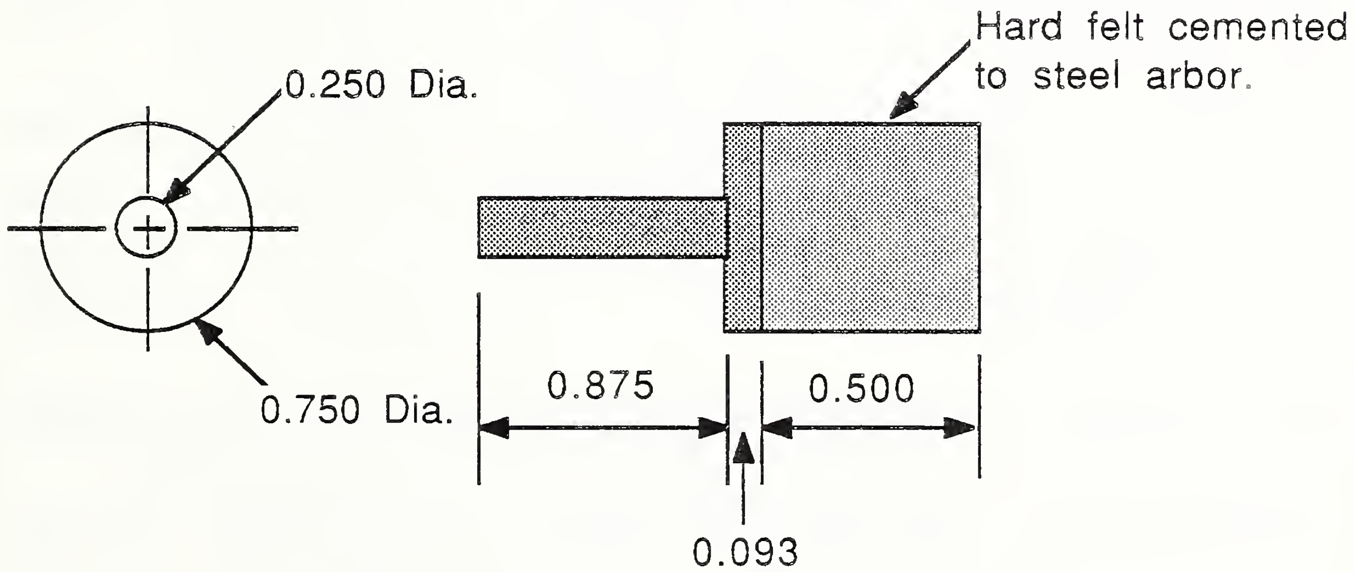


Figure 2

POLISHING TOOL



TEST # 1 Part: Obverse side Kennedy 50 cent die
SERIAL # S609327 Performed by: Karl Ousterhout

Method:	Part mounted to rotary table of C.N.C. milling machine. Part rotates about the Z axis (A axis rotation) while the polishing tool moves in both the radial direction (X axis) and in the vertical direction (Z axis) to generate the tool path.
Polishing: Pattern:	Ten concentric passes around the surface of the die. Tool travel in the vertical direction = 0.011 inches.
Lubricant:	Hyprez - Hyperlube oil

Tools:	First roughing	- 3/4-inch diameter pressure sensitive oak veneer adhered to 0.250-inch thick neoprene rubber pad, Durometer 40.
	Second roughing	- 3/4-inch diameter pressure sensitive oak veneer adhered to 0.250-inch thick neoprene rubber pad, Durometer 40.
	Polishing	- 3/4-inch diameter X 1/2-inch long hard felt plug.
Preload:	First roughing	- Contact with 0.004-inch thick paper, 4.5 Oz. pullout force. Additional preload of 0.006 inches.
	Second roughing	- Contact with 0.004-inch thick paper, 1.5 Oz. pullout force. Additional preload of 0.006 inches.
	Polishing	- Contact with 0.004-inch thick paper, 1.5 Oz. pullout force. Additional preload of 0.002 inches.

Spindle speed = 15,000 rpm
Head angle = 2 degrees
Time = 4.2 minutes per cycle.
Total time = 12.6 minutes

Results:	First roughing	- General appearance very good. One low spot visible on the back of head. Concentric plane pattern visible. Scratches visible with 2X magnification.
	Second roughing	- Concentric plane pattern has disappeared. Scratches still evident with 2X magnification. Over polished "R" of "LIBERTY".
	Polishing	- Faint scratches still visible with 2X magnification. Three low spots evident-(1) behind head, (2) between "I" and "B" of "LIBERTY", and (3) by "IN GOD".

TEST # 2 Part: Obverse side Kennedy 50 cent die
SERIAL # S609328 Performed by: Karl Ousterhout

Method: Part mounted to rotary table of C.N.C. milling machine. Part rotates about the Z axis (A axis rotation) while the polishing tool moves in both the radial direction (X axis) and in the vertical direction (Z axis) to generate the tool path.

Polishing Pattern: Ten concentric passes around the surface of the die. Tool travel in the vertical direction = 0.011 inches.

Lubricant: Hyprez - Hyperlube oil

Tools:
- First roughing - 3/4-inch diameter pressure sensitive oak veneer adhered to 0.250-inch thick neoprene rubber pad, Durometer 40.
- Second roughing - 3/4-inch diameter pressure sensitive oak veneer adhered to 0.250-inch thick neoprene rubber pad, Durometer 40.
- Polishing - 3/4-inch diameter X 1/2-inch long hard felt plug.

Preload:
- First roughing - Contact with 0.004-inch thick paper, 4.5 Oz. pullout force. Additional preload of 0.004 inches.
- Second roughing - Contact with 0.004-inch thick paper, 1.5 Oz. pullout force. Additional preload of 0.006 inches.
- Polishing - Contact with 0.004-inch thick paper, 1.5 Oz. pullout force. Additional preload of 0.004 inches.

Spindle speed = 17,500 rpm
Head angle = 2 degrees
Time = 4.2 minutes per cycle.
Total time = 12.6 minutes

Results:
- First roughing - Concentric plane pattern visible. Scratches visible with 2X magnification. Missed areas on top of head - should have used 0.006 inch preload.
- Second roughing - Concentric plane pattern barely visible. Scratches still evident with 2X magnification.
- Polishing - Faint scratches still visible with 2X magnification. Missed many spots due to lack of preload on first roughing pass. Increase in spindle speed did not adversely affect the die surface finish.

TEST # 3 Part: Obverse side Kennedy 50 cent die
SERIAL # S609329 Performed by: Karl Ousterhout

Method: Part mounted to rotary table of C.N.C. milling machine. Part rotates about the Z axis (A axis rotation) while the polishing tool moves in both the radial direction (X axis) and in the vertical direction (Z axis) to generate the tool path.

Polishing: Ten concentric passes around the surface of the die.
Pattern: Tool travel in the vertical direction = 0.011 inches.

Lubricant: Hyprez - Hyperlube oil

Tools:	First roughing	- 3/4-inch diameter pressure sensitive oak veneer adhered to 0.250-inch thick neoprene rubber pad, Durometer 40.
	Second roughing	- 3/4-inch diameter pressure sensitive oak veneer adhered to 0.250-inch thick neoprene rubber pad, Durometer 40.
	Polishing	- 3/4-inch diameter X 1/2-inch long hard felt plug.
Preload:	First roughing	- Contact with 0.004-inch thick paper, 4.5 Oz. pullout force. Additional preload of 0.006 inches.
	Second roughing	- Contact with 0.004-inch thick paper, 1.5 Oz. pullout force. Additional preload of 0.006 inches.
	Polishing	- Contact with 0.004-inch thick paper, 1.5 Oz. pullout force. Additional preload of 0.004 inches.

Spindle speed = 17,500 rpm
Head angle = 2 degrees
Time = 4.2 minutes per cycle.
Total time = 12.6 minutes.

Note: Program corrected for over polishing of hair line.

Results:	First roughing	- Very good finish. Lost one hair by "R" of "LIBERTY". Concentric plane pattern visible. Scratches visible with 2X magnification.
	Second roughing	- Concentric plane pattern has disappeared. Scratches still evident with 2X magnification. Over polished "R" of "LIBERTY".
	Polishing	- Faint scratches still visible with 2X magnification. Low spots evident between "I" and "B" of "LIBERTY" and "IN GOD".

TEST # 4 Part: Obverse side Kennedy 50 cent die

SERIAL # S609330 Performed by: Karl Ousterhout

Method: Part mounted to rotary table of C.N.C. milling machine. Part rotates about the Z axis (A axis rotation) while the polishing tool moves in both the radial direction (X axis) and in the vertical direction (Z axis) to generate the tool path.

Polishing Pattern: Ten concentric passes around the surface of the die. Tool travel in the vertical direction = 0.011 inches.

Lubricant: Hyprez - Hyperlube oil

Tools:

Tools:	First roughing	- 3/4-inch diameter pressure sensitive oak veneer adhered to 0.250-inch thick neoprene rubber pad, Durometer 40.
	Second roughing	- 3/4-inch diameter pressure sensitive oak veneer adhered to 0.250-inch thick neoprene rubber pad, Durometer 40.
	Polishing	- 3/4-inch diameter X 1/2-inch long hard felt plug.
Preload:	First roughing	- Contact with 0.004-inch thick paper, 4.5 Oz. pullout force. Additional preload of 0.006 inches.
	Second roughing	- Contact with 0.004-inch thick paper, 1.5 Oz. pullout force. Additional preload of 0.006 inches.
	Polishing	- Contact with 0.004-inch thick paper, 1.5 Oz. pullout force. Additional preload of 0.004 inches.

Spindle speed = 17,500 rpm
Head angle = 3 degrees
Time = 4.2 minutes per cycle.
Total time = 12.6 minutes.

Results: First roughing - General appearance very good. Over polished at "R" of "LIBERTY". Concentric plane pattern visible. Scratches visible with 2X magnification.

Second roughing - Concentric plane pattern has disappeared. Scratches still evident with 2X magnification. Over polished "R" of "LIBERTY".

Polishing - Faint scratches still visible with 2X magnification. The only bad areas that remain are by "IN GOD" and "R" of "LIBERTY".

TEST # 5 Part: Obverse side Kennedy 50 cent die
SERIAL # S609331 Performed by: Karl Ousterhout

Method: Part mounted to rotary table of C.N.C. milling machine. Part rotates about the Z axis (A axis rotation) while the polishing tool moves in both the radial direction (X axis) and in the vertical direction (Z axis) to generate the tool path.

Polishing Pattern: Ten concentric passes around the surface of the die. Tool travel in the vertical direction = 0.011 inches.

Lubricant: Hyprez - Hyperlube oil

Tools:

Tools:	First roughing	- 3/4-inch diameter pressure sensitive oak veneer adhered to 0.250-inch thick neoprene rubber pad, Durometer 40.
	Second roughing	- 3/4-inch diameter pressure sensitive oak veneer adhered to 0.250-inch thick neoprene rubber pad, Durometer 40.
	Polishing	- 3/4-inch diameter X 1/2-inch long hard felt plug.
Preload:	First roughing	- Contact with 0.004-inch thick paper, 4.5 Oz. pullout force. Additional preload of 0.006 inches.
	Second roughing	- Contact with 0.004-inch thick paper, 1.5 Oz. pullout force. Additional preload of 0.006 inches.
	Polishing	- Contact with 0.004-inch thick paper, 1.5 Oz. pullout force. Additional preload of 0.004 inches.

Spindle speed = 17,500 rpm
Head angle = 3 degrees
Time = 4.46 minutes per cycle.
Total time = 13.38 minutes.

Results:	First roughing	- Best roughing to date. Concentric plane pattern visible. Scratches visible with 2X magnification. Did not over polish hair line.
	Second roughing	- Concentric plane pattern has disappeared. Scratches still evident with 2X magnification. Over polished "R" of "LIBERTY".
	Polishing	- Hair line much better than before - only lost one hair by "R" of "LIBERTY". Over polished "s" mint mark. Orange peel by "IN GOD".

TEST # 6
SERIAL # S609332

Part: Obverse side Kennedy 50 cent die
Performed by: Karl Ousterhout

Method: Part mounted to rotary table of C.N.C. milling machine. Part rotates about the Z axis (A axis rotation) while the polishing tool moves in both the radial direction (X axis) and in the vertical direction (Z axis) to generate the tool path.

Polishing Pattern: Ten concentric passes around the surface of the die. Tool travel in the vertical direction = 0.011 inches.

Lubricant: Hyprez - Hyperlube oil

Tools:
- First roughing - 3/4-inch diameter pressure sensitive oak veneer adhered to 0.250-inch thick neoprene rubber pad, Durometer 40.
- Second roughing - 3/4-inch diameter pressure sensitive oak veneer adhered to 0.250-inch thick neoprene rubber pad, Durometer 40.
- Polishing - 3/4-inch diameter X 1/2-inch long hard felt plug.

Preload:
- First roughing - Contact with 0.004-inch thick paper, 4.5 Oz. pullout force. Additional preload of 0.006 inches.
- Second roughing - Contact with 0.004-inch thick paper, 1.5 Oz. pullout force. Additional preload of 0.006 inches.
- Polishing - Contact with 0.004-inch thick paper, 1.5 Oz. pullout force. Additional preload of 0.004 inches.

Spindle speed = 17,500 rpm
Head angle = 4 degrees
Time = 4.2 minutes per cycle.
Total time = 12.6 minutes.

Note: Program changed to skip head for first seven passes.

Results:
- First roughing - General appearance very good. Tool not polishing up close enough to head before lifting up. Tool also coming down late - leaving unpolished portions. Concentric plane pattern visible. Scratches visible with 2X magnification.
- Second roughing - Concentric plane pattern has disappeared. Scratches still evident with 2X magnification. Slight over polishing of "R" of "LIBERTY" although not as bad as before.
- Polishing - Problem areas are before head and behind head where tool lifts up early and comes down late. Over polished "s" mint mark.

TEST # 7 — Part: Obverse side Kennedy 50 cent die

SERIAL # S609333 — Performed by: Karl Ousterhout

Method: Part mounted to rotary table of C.N.C. milling machine. Part rotates about the Z axis (A axis rotation) while the polishing tool moves in both the radial direction (X axis) and in the vertical direction (Z axis) to generate the tool path.

Polishing Pattern: Ten concentric passes around the surface of the die. Tool travel in the vertical direction = 0.011 inches.

Lubricant: Hyprez - Hyperlube oil

Tools:	First roughing	- 3/4-inch diameter pressure sensitive oak veneer adhered to 0.250-inch thick neoprene rubber pad, Durometer 40.
	Second roughing	- 3/4-inch diameter pressure sensitive oak veneer adhered to 0.250-inch thick neoprene rubber pad, Durometer 40.
	Polishing	- 3/4-inch diameter X 1/2-inch long hard felt plug.
Preload:	First roughing	- Contact with 0.004-inch thick paper, 4.5 Oz. pullout force. Additional preload of 0.006 inches.
	Second roughing	- Contact with 0.004-inch thick paper, 1.5 Oz. pullout force. Additional preload of 0.006 inches.
	Polishing	- Contact with 0.004-inch thick paper, 1.5 Oz. pullout force. Additional preload of 0.004 inches.

Spindle speed = 17,500 rpm
Head angle = 4 degrees
Time = 4.2 minutes per cycle.
Total time = 12.6 minutes.

Note: Program changed to allow tool to come closer to head before lifting up and to come down earlier.

Results:	First roughing	- General appearance worse than before. Orange peel evident in many spots. Concentric plane pattern visible. Scratches visible with 2X magnification.
	Second roughing	- Concentric plane pattern has disappeared. Scratches still evident with 2X magnification. Orange peel still visible.
	Polishing	- Faint scratches still visible with 2X magnification. Three low spots evident - (1) between "R" and "T" of "LIBERTY", (2) between "I" and "B" of "LIBERTY", and (3) by "IN GOD".

TEST # 8 Part: Obverse side Kennedy 50 cent die
SERIAL # S609334 Performed by: Karl Ousterhout

Method: Part mounted to rotary table of C.N.C. milling machine. Part rotates about the Z axis (A axis rotation) while the polishing tool moves in both the radial direction (X axis) and in the vertical direction (Z axis) to generate the tool path.

Polishing Pattern: Ten concentric passes around the surface of the die. Tool travel in the vertical direction = 0.011 inches.

Lubricant: Hyprez - Hyperlube oil

Tools: First roughing - 3/4-inch diameter pressure sensitive oak veneer adhered to 0.250-inch thick neoprene rubber pad, Durometer 40.

Second roughing - 3/4-inch diameter pressure sensitive oak veneer adhered to 0.250-inch thick neoprene rubber pad, Durometer 40.

Polishing - 3/4-inch diameter X 1/2-inch long hard felt plug.

Preload: First roughing - Contact with 0.004-inch thick paper, 4.5 Oz. pullout force. Additional preload of 0.006 inches.

Second roughing - Contact with 0.004-inch thick paper, 4.5 Oz. pullout force. Additional preload of 0.006 inches.

Polishing - Contact with 0.004-inch thick paper, 1.5 Oz. pullout force. Additional preload of 0.004 inches.

Spindle speed = 17,500 rpm
Head angle = 4 degrees
Time = 4.2 minutes per cycle.
Total time = 12.6 minutes.

Note: Program changed again to dip tool into low spots.

Results: First roughing - General appearance very good. No low spots visible anywhere. Concentric plane pattern visible. Scratches visible with 2X magnification.

Second roughing - Concentric plane pattern has disappeared. Scratches still evident with 2X magnification. Hair line looks very good.

Polishing - Over polished "s" mint mark. Along back of head polishing is not complete and does not extend up to head.

TEST # 9 | Part: Obverse side Kennedy 50 cent die
SERIAL # S692249 | Performed by: Karl Ousterhout

Method: Part mounted to rotary table of C.N.C. milling machine. Part rotates about the Z axis (A axis rotation) while the polishing tool moves in both the radial direction (X axis) and in the vertical direction (Z axis) to generate the tool path.

Polishing Pattern: Ten concentric passes around the surface of the die. Tool travel in the vertical direction = 0.011 inches.

Lubricant: Hyprez - Hyperlube oil

Tools: First roughing - 3/4-inch diameter pressure sensitive oak veneer adhered to 0.250-inch thick neoprene rubber pad, Durometer 40.

Second roughing - 3/4-inch diameter pressure sensitive oak veneer adhered to 0.250-inch thick neoprene rubber pad, Durometer 40.

Polishing - 3/4-inch diameter X 1/2-inch long hard felt plug.

Preload: First roughing - Contact with 0.004-inch thick paper, 4.5 Oz. pullout force. Additional preload of 0.006 inches.

Second roughing - Contact with 0.004-inch thick paper, 1.5 Oz. pullout force. Additional preload of 0.006 inches.

Polishing - Contact with 0.004-inch thick paper, 1.5 Oz. pullout force. Additional preload of 0.004 inches.

Spindle speed = 17,500 rpm
Head angle = 2 degrees
Time = 4.2 minutes per cycle.
Total time = 12.6 minutes.

Results: First roughing - Still missing one spot in back of head. Concentric circles are less noticeable than before. Low spot are visible by "L" of "LIBERTY", "1" of "1987", and behind neck.

Second roughing - Concentric plane pattern has disappeared. Small spots on top of head are being missed by polishing tool.

Polishing - Three low spots evident - (1) between "T" and "Y" of "LIBERTY", (2) between "I" and "B" of "LIBERTY", and (3) by "IN GOD". Over polished "s" mint mark.

TEST # 10 — Part: Obverse side Kennedy 50 cent die

SERIAL # S692250 — Performed by: Karl Ousterhout

Method: Part mounted to rotary table of C.N.C. milling machine. Part rotates about the Z axis (A axis rotation) while the polishing tool moves in both the radial direction (X axis) and in the vertical direction (Z axis) to generate the tool path.

Polishing Pattern: Ten concentric passes around the surface of the die. Tool travel in the vertical direction = 0.011 inches.

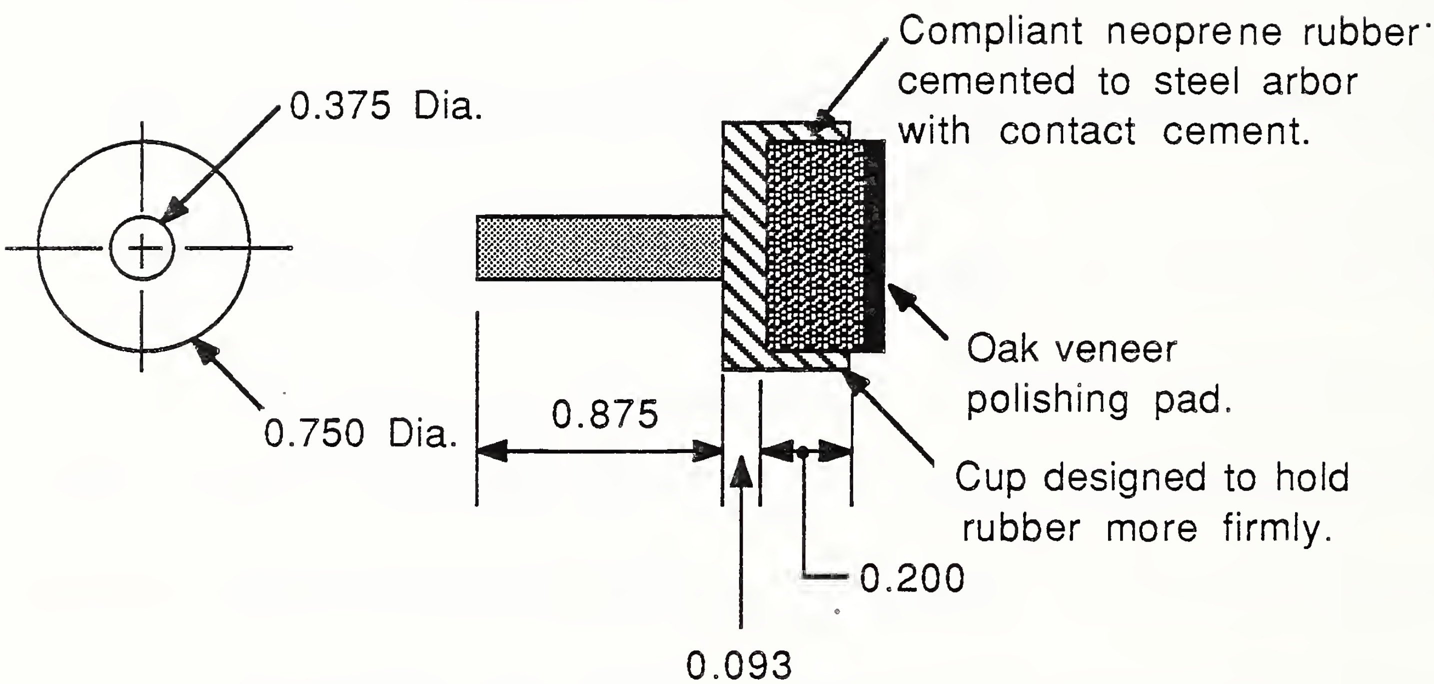
Lubricant: Hyprez - Hyperlube oil

Tools:	First roughing	- 3/4-inch diameter pressure sensitive oak veneer adhered to 0.250-inch thick neoprene rubber pad, Durometer 40.
	Second roughing	- 3/4-inch diameter pressure sensitive oak veneer adhered to 0.250-inch thick neoprene rubber pad, Durometer 40.
	Polishing	- 3/4-inch diameter X 1/2-inch long hard felt plug.
Preload:	First roughing	- Contact with 0.004-inch thick paper, 4.5 Oz. pullout force. Additional preload of 0.006 inches.
	Second roughing	- Contact with 0.004-inch thick paper, 1.5 Oz. pullout force. Additional preload of 0.006 inches.
	Polishing	- Contact with 0.004-inch thick paper, 1.5 Oz. pullout force. Additional preload of 0.004 inches.

Spindle speed = 15,000 rpm
Head angle = 2 degrees
Time = 4.2 minutes per cycle.
Total time = 12.6 minutes.

Figure 3

CUP ROUGHING TOOL



TEST # 11 — Part: Obverse side Kennedy 50 cent die

SERIAL # S692251 — Performed by: Karl Ousterhout

Method: Part mounted to rotary table of C.N.C. milling machine. Part rotates about the Z axis (A axis rotation) while the polishing tool moves in both the radial direction (X axis) and in the vertical direction (Z axis) to generate the tool path.

Polishing Pattern: Ten concentric passes around the surface of the die. Tool travel in the vertical direction = 0.011 inches.

Lubricant: Hyprez - Hyperlube oil

Tools:

- First roughing - 3/4-inch diameter pressure sensitive oak veneer adhered to 0.250-inch thick neoprene rubber pad, Durometer 40.
- Second roughing - 3/4-inch diameter pressure sensitive oak veneer adhered to 0.250-inch thick neoprene rubber pad, Durometer 40.
- Polishing - 3/4-inch diameter X 1/2-inch long hard felt plug.

Preload:

- First roughing - Contact with 0.004-inch thick paper, 4.5 Oz. pullout force. Additional preload of 0.006 inches.
- Second roughing - Contact with 0.004-inch thick paper, 1.5 Oz. pullout force. Additional preload of 0.006 inches.
- Polishing - Contact with 0.004-inch thick paper, 1.5 Oz. pullout force. Additional preload of 0.004 inches.

Spindle speed = 15,000 rpm
Head angle = 2 degrees
Time = 4.2 minutes per cycle.
Total time = 12.6 minutes.

Note: Tool holder sides were shortened 0.050 inches to allow rubber to flex more.

Results:

- First roughing - General appearance getting better. One low spot visible on the back of head. Concentric plane pattern visible. Scratches visible with 2X magnification. Corrected program for back of head. Tool is still overheating.
- Second roughing - Concentric plane pattern still visible. Scratches still evident with 2X magnification. Still missing back of head.
- Polishing - Faint scratches still visible with 2X magnification. Low spots which are visible are (1) behind head, (2) "IN GOD". Over polished outside edge of date - 1987 and "T" of "TRUST".

TEST # 12 SERIAL # S692253

Part: Obverse side Kennedy 50 cent die
Performed by: Karl Ousterhout

Method: Part mounted to rotary table of C.N.C. milling machine. Part rotates about the Z axis (A axis rotation) while the polishing tool moves in both the radial direction (X axis) and in the vertical direction (Z axis) to generate the tool path.

Polishing Pattern: Ten concentric passes around the surface of the die. Tool travel in the vertical direction = 0.011 inches.

Lubricant: Hyprez - Hyperlube oil

Tools:

First roughing - 3/4-inch diameter pressure sensitive oak veneer adhered to 0.250-inch thick neoprene rubber pad, Durometer 40.

Second roughing - 3/4-inch diameter pressure sensitive oak veneer adhered to 0.250-inch thick neoprene rubber pad, Durometer 40.

Polishing - 3/4-inch diameter X 1/2-inch long hard felt plug.

Preload:

First roughing - Contact with 0.004-inch thick paper, 4.5 Oz. pullout force. Additional preload of 0.004 inches.

Second roughing - Contact with 0.004-inch thick paper, 1.5 Oz. pullout force. Additional preload of 0.004 inches.

Polishing - Contact with 0.004-inch thick paper, 1.5 Oz. pullout force. Additional preload of 0.002 inches.

Spindle speed = 15,000 rpm
Head angle = 2 degrees
Time = 4.2 minutes per cycle.
Total time = 12.6 minutes.

Results:

First roughing - General appearance very good. One low spot visible on the back of head. Concentric plane pattern visible. Scratches visible with 2X magnification. Tool is still overheating.

Second roughing - Concentric plane pattern has disappeared. Scratches still evident with 2X magnification. Over polished "s" mint mark, "8" of "1987", and "T" of "TRUST".

Polishing - Faint scratches still visible with 2X magnification. Polished through "s" mint mark, "8" of "1987", and "T" of "TRUST". Hair line starting to lose sharpness.

TEST # 13 — Part: Obverse side Kennedy 50 cent die

SERIAL # S692254 — Performed by: Karl Ousterhout

Method: Part mounted to rotary table of C.N.C. milling machine. Part rotates about the Z axis (A axis rotation) while the polishing tool moves in both the radial direction (X axis) and in the vertical direction (Z axis) to generate the tool path.

Polishing Pattern: Ten concentric passes around the surface of the die. Tool travel in the vertical direction = 0.011 inches.

Lubricant: Hyprez - Hyperlube oil

Tools:	First roughing	- 3/4-inch diameter pressure sensitive oak veneer adhered to 0.250-inch thick neoprene rubber pad, Durometer 40.
	Second roughing	- 3/4-inch diameter pressure sensitive oak veneer adhered to 0.250-inch thick neoprene rubber pad, Durometer 40.
	Polishing	- 3/4-inch diameter X 1/2-inch long hard felt plug.
Preload:	First roughing	- Contact with 0.004-inch thick paper, 4.5 Oz. pullout force. Additional preload of 0.004 inches.
	Second roughing	- Contact with 0.004-inch thick paper, 1.5 Oz. pullout force. Additional preload of 0.006 inches.
	Polishing	- Contact with 0.004-inch thick paper, 1.5 Oz. pullout force. Additional preload of 0.004 inches.

Spindle speed = 15,000 rpm
Head angle = 2 degrees
Time = 3.6 minutes per cycle.
Total time = 10.8 minutes.

Results:	First roughing	- General appearance is better. Over polishing "8" of "1987". Concentric plane pattern visible. Scratches visible with 2X magnification. Tool is still overheating.
	Second roughing	- Concentric plane pattern has disappeared. Scratches still evident with 2X magnification. Over polished "s" mint mark, "T" of "TRUST", "8" and "9" of "1987".
	Polishing	- Faint scratches still visible with 2X magnification. Three low spots evident - (1) behind head, (2) between "I" and "B" of "LIBERTY", and (3) between "R" and "T" of "LIBERTY". Polished through outer edge of "1987".

TEST # 14 | Part: Obverse side Kennedy 50 cent die
SERIAL # S692255 | Performed by: Karl Ousterhout

Method: Part mounted to rotary table of C.N.C. milling machine. Part rotates about the Z axis (A axis rotation) while the polishing tool moves in both the radial direction (X axis) and in the vertical direction (Z axis) to generate the tool path.

Polishing Pattern: Ten concentric passes around the surface of the die. Tool travel in the vertical direction = 0.011 inches.

Lubricant: Hyprez - Hyperlube oil

Tools:	First roughing	- 3/4-inch diameter pressure sensitive oak veneer adhered to 0.250-inch thick neoprene rubber pad, Durometer 40.
	Second roughing	- 3/4-inch diameter pressure sensitive oak veneer adhered to 0.250-inch thick neoprene rubber pad, Durometer 40.
	Polishing	- 3/4 diameter X 1/2-inch long hard felt plug.
Preload:	First polishing	- Contact with 0.004-inch thick paper, 4.5 Oz. pullout force. Additional preload of 0.004 inches.
	Second polishing	- Contact with 0.004-inch thick paper, 1.5 Oz. pullout force. Additional preload of 0.006 inches.
	Polishing	- Contact with 0.004-inch thick paper, 1.5 Oz. pullout force. Additional preload of 0.006 inches.

Spindle speed = 15,000 rpm
Head angle = 2 degrees
Time = 3.6 minutes per cycle.
Total time = 10.8 minutes.

Results:	First roughing	- General appearance very good. over polished "8" of "1987". Concentric plane pattern visible. Scratches visible with 2X magnification. Tool is still overheating.
	Second roughing	- Concentric plane pattern has disappeared. Scratches still evident with 2X magnification. Over polished "T" of "TRUST", "8" and "9" of "1987".
	Polishing	- Faint orange peel visible with 2X magnification. Over polished front of neck.

TEST # 15 | Part: Obverse side Kennedy 50 cent die
SERIAL # S692256 | Performed by: Karl Ousterhout

Method: Part mounted to rotary table of C.N.C. milling machine. Part rotates about the Z axis (A axis rotation) while the polishing tool moves in both the radial direction (X axis) and in the vertical direction (Z axis) to generate the tool path.

Polishing Pattern: Ten concentric passes around the surface of the die. Tool travel in the vertical direction = 0.011 inches.

Lubricant: Hyprez - Hyperlube oil

Tools:	First roughing	- 3/4-inch diameter pressure sensitive oak veneer adhered to 0.250-inch thick neoprene rubber pad, Durometer 40.
	Second roughing	- 3/4-inch diameter pressure sensitive oak veneer adhered to 0.250-inch thick neoprene rubber pad, Durometer 40.
	Polishing	- 3/4 diameter X 1/2-inch long hard felt plug.
Preload:	First roughing	- Contact with 0.004-inch thick paper, 4.5 Oz. pullout force. Additional preload of 0.004 inches.
	Second roughing	- Contact with 0.004-inch thick paper, 1.5 Oz. pullout force. Additional preload of 0.006 inches.
	Polishing	- Contact with 0.004-inch thick paper, 1.5 Oz. pullout force. Additional preload of 0.006 inches.

Spindle speed = 15,000 rpm
Head angle = 2 degrees
Time = 3.6 minutes per cycle.
Total time = 10.8 minutes.

Note: Reduced tool holder cup length to .100 inches.

Results:	First roughing	- General appearance better. Numbers and letters look much better although "8" of "1987" seems to be on the thin side. Scratches visible with 2X magnification.
	Second roughing	- Concentric plane pattern has disappeared. Scratches still evident with 2X magnification. Numerals and letters look much better, however low spot behind head has reappeared.
	Polishing	- Faint scratches still visible with 2X magnification. Two low spots evident - (1) behind head and (2) between "I" and "B" of "LIBERTY".

TEST # 16 Part: Obverse side Kennedy 50 cent die
SERIAL # S692257 Performed by: Karl Ousterhout

Method: Part mounted to rotary table of C.N.C. milling machine. Part rotates about the Z axis (A axis rotation) while the polishing tool moves in both the radial direction (X axis) and in the vertical direction (Z axis) to generate the tool path.

Polishing: Ten concentric passes around the surface of the die.
Pattern: Tool travel in the vertical direction = 0.011 inches.

Lubricant: Hyprez - Hyperlube oil

Tools: First roughing - 3/4-inch diameter pressure sensitive oak veneer adhered to 0.250-inch thick neoprene rubber pad, Durometer 40.

Second roughing - 3/4-inch diameter pressure sensitive oak veneer adhered to 0.250-inch thick neoprene rubber pad, Durometer 40.

Polishing - 3/4-inch diameter X 1/2-inch long hard felt plug.

Preload: First roughing - Contact with 0.004-inch thick paper, 4.5 Oz. pullout force. Additional preload of 0.004 inches.

Second roughing - Contact with 0.004-inch thick paper, 1.5 Oz. pullout force. Additional preload 0.006 inches.

Polishing - Contact with 0.004-inch thick paper, 1.5 Oz. pullout force. Additional preload 0.004 inches.

Spindle speed = 15,000 rpm
Head angle = 2 degrees
Time = 3.6 minutes per cycle.
Total time = 10.8 minutes.

Note: Reduce tool cup holder length to .050 inches.

Results: First roughing - General appearance very good. Appears that tool is lifting too early. Scratches visible with 2X magnification.

Second roughing - Concentric plane pattern has disappeared. Scratches still evident with 2X magnification. Over polished "R" of "LIBERTY".

Polishing - Pit marks visible over most of the die. This is probably due to lack of preload on initial roughing pass.

TEST # 17 — Part: Obverse side Kennedy 50 cent die

SERIAL # S692258 — Performed by: Karl Ousterhout

Method: Part mounted to rotary table of C.N.C. milling machine. Part rotates about the Z axis (A axis rotation) while the polishing tool moves in both the radial direction (X axis) and in the vertical direction (Z axis) to generate the tool path.

Polishing Pattern: Ten concentric passes around the surface of the die. Tool travel in the vertical direction = 0.011 inches.

Lubricant: Hyprez - Hyperlube oil

Tools:

- First roughing - 3/4-inch diameter pressure sensitive oak veneer adhered to 0.250-inch thick neoprene rubber pad, Durometer 40.
- Second roughing - 3/4-inch diameter pressure sensitive oak veneer adhered to 0.250-inch thick neoprene rubber pad, Durometer 40.
- Polishing - 3/4 diameter X 1/2-inch long hard felt plug.

Preload:

- First roughing - Contact with 0.004-inch thick paper, 4.5 Oz. pullout force. Additional preload of 0.006 inches.
- Second roughing - Contact with 0.004-inch thick paper, 1.5 Oz. pullout force. Additional preload of 0.006 inches.
- Polishing - Contact with 0.004-inch thick paper, 1.5 Oz. pullout force. Additional preload of 0.004 inches.

Spindle speed = 15,000 rpm
Head angle = 2 degrees
Time = 3.6 minutes per cycle.
Total time = 10.8 minutes.

Results:

- First roughing - General appearance very good. Faint orange peel visible from tip of nose to top of head. Concentric plane pattern visible. Scratches visible with 2X magnification.
- Second roughing - Concentric plane pattern has disappeared. Scratches still evident with 2X magnification. slight orange peel at top of head.
- Polishing - Faint scratches and orange peel still visible with 2X magnification.

TEST # 18
SERIAL # S692259

Part: Obverse side Kennedy 50 cent die
Performed by: Karl Ousterhout

Method: Part mounted to rotary table of C.N.C. milling machine. Part rotates about the Z axis (A axis rotation) while the polishing tool moves in both the radial direction (X axis) and in the vertical direction (Z axis) to generate the tool path.

Polishing Pattern: Ten concentric passes around the surface of the die. Tool travel in the vertical direction = 0.011 inches.

Lubricant: Hyprez - Hyperlube oil

Tools:

First roughing	-	3/4-inch diameter pressure sensitive oak veneer adhered to 0.250-inch thick neoprene rubber pad, Durometer 40.
Second roughing	-	3/4-inch diameter pressure sensitive oak veneer adhered to 0.250-inch thick neoprene rubber pad, Durometer 40.
Polishing	-	3/4 diameter X 1/2-inch long hard felt plug.

Preload:

First roughing	-	Contact with 0.004-inch thick paper, 4.5 Oz. pullout force. Additional preload of 0.006 inches.
Second roughing	-	Contact with 0.004-inch thick paper, 1.5 Oz. pullout force. Additional preload of 0.006 inches.
Polishing	-	Contact with 0.004-inch thick paper, 1.5 Oz. pullout force. Additional preload of 0.004 inches.

Spindle speed = 15,000 rpm
Head angle = 2 degrees
Time = 3.6 minutes per cycle.
Total time = 10.8 minutes.

Note: Program compensated for errors at top of head.

Results:

First roughing	-	General appearance much better than before. Last pass may be leaving a ring around the die. Concentric plane pattern visible. Scratches visible with 2X magnification.
Second roughing	-	Concentric plane pattern has disappeared. Tiny pit marks up by the top of head - otherwise fine.
Polishing	-	Faint pit marks up by the top of the head still visible with 2X magnification. Ring around die due to last pass.

TEST # 19
SERIAL # S692127

Part: Obverse side Kennedy 50 cent die
Performed by: Karl Ousterhout

Method: Part mounted to rotary table of C.N.C. milling machine. Part rotates about the Z axis (A axis rotation) while the polishing tool moves in both the radial direction (X axis) and in the vertical direction (Z axis) to generate the tool path.

Polishing: Ten concentric passes around the surface of the die.
Pattern: Tool travel in the vertical direction = 0.011 inches.

Tools:
First roughing - 3/4-inch diameter pressure sensitive oak veneer adhered to 0.250-inch thick neoprene rubber pad, Durometer 40.

Second roughing - 3/4-inch diameter pressure sensitive oak veneer adhered to 0.250-inch thick neoprene rubber pad, Durometer 40.

Polishing - 3/4-inch diameter X 1/2-inch long hard felt plug.

Preload:
First roughing - Contact with 0.004-inch thick paper, 4.5 Oz. pullout force. Additional preload of 0.006 inches.

Second roughing - Contact with 0.004-inch thick paper, 1.5 Oz. pullout force. Additional preload of 0.006 inches.

Polishing - Contact with 0.004-inch thick paper, 1.5 Oz. pullout force. Additional preload of 0.004 inches.

Spindle speed = 17,500 rpm
Head angle = 2 degrees
Time = 3.6 minutes per cycle.
Total time = 10.8 minutes.

Results:
First roughing - General appearance better than before. Polishing tool coming down too early at back of head and over polishing "R" of "LIBERTY". Concentric plane pattern visible. Scratches visible with 2X magnification.
Second roughing - Concentric plane pattern has disappeared. Scratches still evident with 2X magnification. Over polished "R" of "LIBERTY".
Polishing - Faint orange peel between "I" and "B" of "LIBERTY". Polished through "s" mint mark.

TEST # 20	Part: Obverse side Kennedy 50 cent die
SERIAL # S692128	Performed by: Karl Ousterhout

Method: Part mounted to rotary table of C.N.C. milling machine. Part rotates about the Z axis (A axis rotation) while the polishing tool moves in both the radial direction (X axis) and in the vertical direction (Z axis) to generate the tool path.

Polishing: Ten concentric passes around the surface of the die.
Pattern: Tool travel in the vertical direction = 0.011 inches.

Tools:
- First roughing - 3/4-inch diameter pressure sensitive oak veneer adhered to 0.250-inch thick neoprene rubber pad, Durometer 40.
- Second roughing - 3/4-inch diameter pressure sensitive oak veneer adhered to 0.250-inch thick neoprene rubber pad, Durometer 40.
- Polishing - 3/4-inch diameter X 1/2-inch long hard felt plug.

Preload:
- First roughing - Contact with 0.004-inch thick paper, 4.5 Oz. pullout force. Additional preload of 0.006 inches.
- Second roughing - Contact with 0.004-inch thick paper, 1.5 Oz. pullout force. Additional preload of 0.006 inches.
- Polishing - Contact with 0.004-inch thick paper, 1.5 Oz. pullout force. Additional preload of 0.004 inches.

Spindle speed = 17,500 rpm
Head angle = 2 degrees
Time = 3.6 minutes per cycle.
Total time = 10.8 minutes.

Note: Program changed to compensate for top of head and mint mark.

Results:
- First roughing - General appearance very good. Concentric plane pattern visible. Scratches visible with 2X magnification.
- Second roughing - Concentric plane pattern has disappeared. Scratches still evident with 2X magnification.
- Polishing - Finish looks very good. Polished through "s" mint mark.

TEST # 21
SERIAL # S692130

Part: Obverse side Kennedy 50 cent die
Performed by: Karl Ousterhout

Method: Part mounted to rotary table of C.N.C. milling machine. Part rotates about the Z axis (A axis rotation) while the polishing tool moves in both the radial direction (X axis) and in the vertical direction (Z axis) to generate the tool path.

Polishing Pattern: Ten concentric passes around the surface of the die. Tool travel in the vertical direction = 0.011 inches.

Lubricant: Hyprez - Hyperlube oil

Tools:

- First roughing - 3/4-inch diameter pressure sensitive oak veneer adhered to 0.250-inch thick neoprene rubber pad, Durometer 40.
- Second roughing - 3/4-inch diameter pressure sensitive oak veneer adhered to 0.250-inch thick neoprene rubber pad, Durometer 40.
- Polishing - 3/4-inch diameter X 1/2-inch long hard felt plug.

Preload:

- First roughing - Contact with 0.004-inch thick paper, 4.5 Oz. pullout force. Additional preload of 0.006 inches.
- Second roughing - Contact with 0.004-inch thick paper, 1.5 Oz. pullout force. Additional preload of 0.006 inches.
- Polishing - Contact with 0.004-inch thick paper, 1.5 Oz. pullout force. Additional preload of 0.004 inches.

Spindle speed = 17,500 rpm
Head angle = 2 degrees
Time = 3.6 minutes per cycle.
Total time = 10.8 minutes.

Note: Program changed to compensate for "s" mint mark.

Results:

- First roughing - Excellent final finish. Best finish to date. Concentric plane pattern visible. Scratches visible with 2X magnification.
- Second roughing - Concentric plane pattern has disappeared. Scratches still evident with 2X magnification.
- Polishing - Slight over polishing of "s" mint mark. Otherwise the die is probably acceptable.

TEST # 22
SERIAL # S692131

Part: Obverse side Kennedy 50 cent die
Performed by: Karl Ousterhout

Method: Part mounted to rotary table of C.N.C. milling machine. Part rotates about the Z axis (A axis rotation) while the polishing tool moves in both the radial direction (X axis) and in the vertical direction (Z axis) to generate the tool path.

Polishing: Ten concentric passes around the surface of the die.
Pattern: Tool travel in the vertical direction = 0.011 inches.

Lubricant: Hyprez - Hyperlube oil

Tools:

First roughing - 3/4-inch diameter pressure sensitive oak veneer adhered to 0.250-inch thick neoprene rubber pad, Durometer 40.

Second roughing - 3/4-inch diameter pressure sensitive oak veneer adhered to 0.250-inch thick neoprene rubber pad, Durometer 40.

Polishing - 3/4-inch diameter X 1/2-inch long hard felt plug.

Preload:

First roughing - Contact with 0.004-inch thick paper, 4.5 Oz. pullout force. Additional preload of 0.006 inches.

Second roughing - Contact with 0.004-inch thick paper, 1.5 Oz. pullout force. Additional preload of 0.006 inches.

Polishing - Contact with 0.004-inch thick paper, 1.5 Oz. pullout force. Additional preload of 0.004 inches.

Spindle speed = 17,500 rpm
Head angle = 2 degrees
Time = 3.6 minutes per cycle.
Total time = 10.8 minutes.

Note: Program changed to compensate for "s" mint mark.

Results:

First roughing - Appearance very good. Scratches visible with 2X magnification.

Second roughing - Concentric plane pattern has disappeared. Scratches still evident with 2X magnification.

Polishing - Slight over polishing of "s" mint mark. Otherwise die looks very good.

IV. Conclusion and Recommendations

The die polishing techniques developed by this research prove that automated die polishing is feasible. However, there are currently too many variables which change from die to die for the die polishing process to be fully automated. During the course of the research the following variables were noted to change on a frequent basis:

(1) Die height
(2) Die base diameter
(3) Die surface profile

The die height and base diameter changed from die to die while the surface profile did not change much (if any) for dies with consecutive serial numbers (i.e., in the same batch). Noticeable changes were noted when dies with different serial numbers were polished one after the other. Even though the surface profile changes were on the order of 0.0002 - 0.0005 inches, these minute changes seriously affect the polishing process. The main reason for this is the lack of any kind of feedback to monitor the die-tool interface during the polishing operation.

The parameters which produced the best results during the polishing process were:

(1) Polishing tool angle of 2 degrees.

(2) Spindle speed of 17,500 rpm.

(3) Cycle time of 3.6 minutes. This corresponds to a feed rate of 5 inches per minute.

Using the information above, the U.S. Mint could partially automate the die polishing process by following the procedure described in the following paragraph.

Set up the polishing machine and polish a large batch of dies with 12 micron diamond compound. After the individual dies have been polished they should be inspected for minor defects. And, if any are found, they should be polished out by hand. Continuing in this manner, the dies would return to the machine to be polished with a 3-micron diamond compound. And, after inspection and touch-up, return to the machine for polishing with a 1-micron diamond compound. Any remaining defects could be polished out by hand.

This simple but effective die polishing procedure would greatly increase the productivity of the U.S. Mint. For full automation of the die polishing process an additional phase of the die polishing research should seriously be considered to alleviate some of the problems encountered during the present research.

The next phase of this research should use a machine with at least two rotary and two linear axes. The present study demonstrates that tilting the polishing tool improved the overall performance. With an additional rotary axis, the amount of tilting can be programmed for the tool to be tangent continuously over the surface profile of the die.

To compensate for the three variables mentioned earlier, the following two methods should be explored:

(1) Force Feedback: This method would use real-time control techniques to enable the polishing tool to exert constant pressure on the die surface. By using this method, subtle changes in die height and surface profile would be compensated for automatically. No measurements of the die surface would be necessary.

(2) Surface mapping: This technique would involve three dimensional scanning of the die surface. First, scan the die surface with a suitable scanning device such as ultra-sound. Second, change the data obtained from the scanning process into appropriate numerical values. Third, transform the numerical values into a code compatible with the die polishing machine tool controller. Fourth, load the transformed code into the die polishing machine controller.

Regardless of the method employed, the polishing operation should be completed with a final inspection to ensure the surface quality is acceptable. This can be accomplished using an ultrasound sensor. By replacing the polishing tool with this sensor and running the same NC program on the machine tool, it is possible to scan the entire die surface following the same tool path. During the scanning, a control computer stores the locations of the rough spots. After the scanning, the sensor is replaced by the polishing tool again, and based on the sensory information gathered, the control computer directs the tool to repolish the bad spots. This type of deterministic control system with in-process gaging would significantly decrease the incidence of producing unacceptable dies.

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☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)

This research was undertaken to determine the feasibility of automating the polishing process of proof dies at the United States Mint. The dies polished during this research endeavor were the obverse Kennedy half-dollar dies. While most of the techniques used in this study are new, some of the techniques developed by Sidney Weiser (Phase I December 16, 1985 and Phase II December 3, 1986) were incorporated into the polishing procedure. The main goals of this research are:

1. Develop a method of mecahnically polishing proof dies which results in a quality level equal to or better than that now achieved by current manual methods.

2. Develop the optimum production rate that can be achieved in mechanically polishing proof dies.

3. Utilize a machine tool with at least 4 axes of motion.

4. Exercise initiative and ingenuity in the use of conventional and computer technologies, and develop through experimentation the best polishing compounds and and materials, tooling, tool paths, speeds, masking techniques or other methods of protecting areas not to be polished.

12. KEY WORDS (Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)

dies, polishing, polishing compounds, polishing proof

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