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AN AUTOMATIC POLISHING MACHINE
FOR REMOTE METALLOGRAPHY

by

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Metallurgy Program 6.10.6

August 1959

This report supersedes the following Metallurgy Division Quarterly
Report References:

- ANL-4399 - F. L. Brown and S. H. Paine, "Development of Hot
Metallographic Techniques: Electrolytic Cut-Off and
Preparation," pp. 91-92, 94, 95; 31 December 1949.
- ANL-5097 - F. L. Brown, R. J. Fousek and S. H. Paine, "Development
of Remote Polishing Techniques," pp. 58-62; 30 June 1953.

Operated by The University of Chicago
under
Contract W-31-109-eng-38

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TABLE OF CONTENTS

	<u>Page</u>
ABSTRACT	4
A. INTRODUCTION	4
B. DESIGN REQUIREMENTS	5
Criteria for Determining Quality of Specimen Preparation. . .	5
Analysis of the Mechanics of Manual Polishing	7
Use and Maintenance of the Machine in a Cave.	8
Design Decisions	8
C. DETAILS OF CONSTRUCTION.	9
D. DISCUSSION OF TECHNIQUE AND PERFORMANCE	13
E. SUMMARY	17
F. ACKNOWLEDGMENTS	17
REFERENCES	18

LIST OF FIGURES

<u>No.</u>	<u>Title</u>	<u>Page</u>
1.	Cutaway Diagram of ANL Automatic Polishing Machine.	10
2.	ANL Polishing Machine as it Appears during Grinding and Polishing Operations.	11
3.	View of Polishing Machine Showing Head at the Specimen Loading Stage, Lap in Elevated Position.	11
4.	View of Polishing Machine Showing Clamp Wrench Motor Engaged, Lap Retainer Ring Removed	12
5.	Photomicrographs of Uranium Polished Remotely	15
6.	Photomicrographs of Irradiated Uranium Polished Remotely .	16

LIST OF TABLES

<u>No.</u>	<u>Title</u>	<u>Page</u>
I.	Mechanical Analysis of Quality Metallographic Polishing. . . .	6

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ABSTRACT

Requirements for successful polishing of metallographic specimens are discussed and the design of a machine to accomplish such work on radioactive specimens in a metallographic cave is presented. Quality results, readily obtained by use of the ANL machine, are illustrated by photomicrographs.

A. INTRODUCTION

Of outstanding importance in the development of metallographic techniques for neutron-irradiated metals is the question how to produce a satisfactory surface for microscopic examination. The problem of the mechanical preparation of specimens, as it was faced in the early days of hot metallography at Argonne National Laboratory, had two aspects. First, because the operation would need to be conducted remotely, it would have to be performed by automatic or semi-automatic machinery. In general, the versatility of operations possible when specimens are held manually may be seriously curtailed when the task is given to a machine, and the quality of the work is accordingly affected. Second, it was foreseen that the handling of the radioactive abraded residues from the polishing operations would present a hazard to personnel. Precautions required to control radioactive contamination would surely make the polishing procedures much slower than they otherwise might be.

Some thought was given to methods which would avoid the need of mechanical cutting and polishing and would contain all radioactivity in electrolytes.^(1,2) Such methods have proved to be of limited utility, with the exception of the electrical discharge method for rough cutting of specimens.^(3,4) It became evident during the course of the studies that almost all metallographic specimens could best be prepared up to the final etch by mechanical methods in spite of the unusual difficulties which must be surmounted.

In recent years automatic polishing machines which overcome the need for special manual skill on the part of the technician, and demand only that he be familiar enough with the mechanics of the polishing operation to make the proper selection of polishing procedures, have been

developed. But it was not very accurate for work with large quantities on a routine basis. There were various disadvantages, however, which made them unsuitable for use when the highest quality of research work is desired, that is a basis in which they attain speed of production at the expense of the quality of quality. It was thought at ANL that the nature of the metallographic work to be done would merit primarily emphasis on high quality. Therefore it was decided to develop a special polishing machine which would give the remote metallographer as great latitude as possible in applying his techniques.

As the machine which was finally developed and constructed for group use in the ANL hot metallography cave (5.6.7) incorporates a number of features not found in other metallographic equipment, it may be of interest first to discuss the development of design requirements before proceeding to the details of construction. A final section will be devoted to metallographic techniques developed for use with the machine, together with illustrative examples of its performance.

DESIGN REQUIREMENTS

A number of important considerations were involved in the selection of suitable design features. It all had to be weighed carefully before the design could be made.

1. Design for the high quality of specimen presentation

If the machine is to be used for the high quality of specimen presentation, six main items may be used to describe the high quality of presentation in a specimen:

1. The surface is essentially free from cold-work or deformation marks.
2. It is essentially free from scratches.
3. It is essentially free from sharp features on the metallograph.
4. The edges, which are often features are to be observed are free from edge rounding.
5. The surface is free from embedded, loose particles, dust, and "oil" spots.
6. The surface is free from retained oil in the surface and in essential features.

The first three of these requirements are necessary even in routine work. The last three are a much more exacting test of metallographic skill, yet are very desirable for research grade work. A brief analysis of the mechanical conditions related to each item is given in Table I.

Table I

Mechanical Analysis of Quality Metallographic Polishing

Elements of Quality Preparation	Mechanics Required to Obtain Quality
1. Minimal surface working and smearing of metal	Proper adjustment of pressure to frictional drag. Proper lubrication; absence of vibration or chattering.
2. Uniform scratches of minimal depth	Uniform grit size and uniform working of entire lap. Polishing across scratches of preceding grit size. Proper selection of lap.
3. Flatness over polished surface	Proper alignment of surface with lap, opposing frictional torque. Proper pressure.
4. Flatness at extreme edge of surface	Intensive degree of alignment and pressure control. Limited oscillation of specimen so that the trailing edge of the polished surface is preserved. Minimal polishing time for each step.
5. Minimal pits, "comet tails" and embedded abrasive	Proper selection of lap. Proper control of pressure and lubrication. Rotation of specimen. Minimal polishing time for each step.
6. Retention of nonmetallic inclusions	Proper preparation of lap to keep grit from rolling. Proper control of pressure and lubrication. Minimal polishing time for each step.

Analysis of the Mechanics of Manual Polishing

It will now be informative to consider how the hand of a skilled metallographer works a specimen. Trained muscular and sensory coordination, of course, are the secret of success, but these can, to some degree at least, be analyzed profitably. The following is suggested:

1. The metallographer's hand holds the specimen and levels it on the polishing wheel, nicely balancing this adjustment against the torque in the specimen which results from the frictional drag of the spinning lap.
2. The hand applies a program of motion to the specimen, either by sweeping it across the lap, or by oscillating it about a vertical axis, or by a combination of such motions.
3. The hand is so constituted that it damps shock and vibration while the specimen is in contact with the lap.
4. Pressure of specimen to lap is applied by the hand in such a way that it is instantly variable.
5. Feedback of information concerning changes in lubrication, response to the abrasive vehicle, and other more subtle conditions is provided by the hand. This must bring a reaction based on the metallographer's experience, very often without conscious analysis.

When one examines the above list with the thought of duplicating the hand's work mechanically, it is at once evident that a machine can be equal or superior to the hand in the first two functions. Torque deflections, which tend to produce facets or a cylindrical surface, can be eliminated entirely. Sweeping and oscillating motions are fairly simple design problems. Precise alignments are obtained and duplicated routinely in machine shop operations, and jig boring techniques are far more accurate than the human hand.

It follows, then, that if the hand is good enough in these duties its real excellence must appear in connection with the other factors, especially the last one listed. However, much of the feedback in the hand relates to alignment and the motion program (Items 1 and 2). If these were produced mechanically the hand would only need to be concerned with stabilizing the specimen against vibration (Item 3) and with regulating the pressure on the lap (Item 4). The significance of these elements of the polishing operation, therefore, needs to be thoroughly understood as a prelude to the design of an automatic machine. A program of motion and the degree of versatility which should be built into it needs also to be considered.

Use and Maintenance of the Machine in a Cave

Requirements for a satisfactory design must also consider the mechanics of using and maintaining the polishing machine in a cave through the medium of master-slave manipulators. Radioactive contamination is a further complication. In this connection, a number of important problems arise, all of which have a bearing on the general efficiency of the polishing procedure:

1. The machine must be so designed that it is easy to load and unload the specimens without fouling either the manipulator with abrasive from the lap, or the lap with any trace of dust or unclassified grit from the cave.
2. The abrasive charge on the lap and degree of lubrication applied during the working of a specimen must be capable of easy control.
3. It must be possible to change abrasive wheels readily and to resurface them easily without contaminating the manipulators or cave with the radioactive abraded residues from the polishing operations.
4. Design should minimize the spread of radioactive contamination from the rotation of the polishing head.
5. Decontamination of the polishing machine to moderate levels of activity should be readily accomplished by remote manipulation.

Design Decisions

The problems mentioned above may be attacked in a number of different ways. However, efficiency of operation will usually be enhanced by uncomplicated solutions, and the incidence of equipment failures will be reduced. Therefore, an effort was made to find answers as simple as possible without sacrificing versatility unduly or impairing the quality of results.

Ideas resulting from the analysis were tested in various ways on conventional equipment. They were explored more carefully on a special apparatus in which the specimen was held and manipulated by a jig-borer head mounted above a conventional polishing lap. Ways astride the lap supported the head, which moved back and forth along the radius of the lap by the action of a fish reel cam. Results of these studies were encouraging. However, the study apparatus lacked simplicity and was judged to be quite susceptible to radioactive contamination.

Out of the analysis and progressive experimentation described above grew the concept of a polishing head floated in rigid alignment with a standard rotating lap by means of a pivoted and counterweighted pantograph support. Mass would give the system a low vibration period because of high rotational inertia. Small variable overweights on the head would control contact pressure of the specimen. Mounting the pantograph arm at an angle would make the frictional drag entirely independent of changes in lubrication between the lap and specimen. A pilot model of this concept was designed, constructed and tested. It proved to be much simpler than the study apparatus.⁽⁸⁾ The final design of the battery of machines installed in the hot metallography cave is based on the pilot model, although a number of modifications have been incorporated to increase utility. Specific features of the design and construction are discussed in the following section.

C. DETAILS OF CONSTRUCTION

Six machines were constructed. Locking casters make each one mobile so that it can easily be removed from the cave and replaced by another if mechanical trouble should develop. The basic polishing equipment is a commercially available, standard, 160-rpm metallographic polishing unit, having a conventional eight-inch lap. It is mounted in a standard console cabinet having a special single piece stainless steel top. Figures 2, 3 and 4 show different views of the modified apparatus, and Fig. 1 is a drawing which presents the modifications in better detail.

The pantograph support post and base (a) in which it swivels (see Fig. 1) is mounted on a corner of the console top, to which it is secured firmly by three bolts (b), each spring loaded to 50 pounds pressure. Its level may be adjusted critically with an Allen wrench by means of three leveling screws (c) on which the post rests. The pantograph and polishing head system (d) is supported by ball bearings which make its motion frictionless. All bearings in pantograph, head and support column are prestressed so that mechanical slop and misalignment are eliminated from the system. A clamped counterweight (e) brings initial balance to the assembly, and a solenoid catch (f) is provided to lock it with the head in the up position.

The polishing head has within it a motor drive (g) for oscillating the specimen collet (h) through an angle of 30 degrees at a rate of 56 cpm. Oscillation is provided, rather than rotation, so that a trailing edge on the specimen may be left with maximum flatness. Specimen size is standardized at one-inch diameter to conform to the requirements of the hot metallograph attached to the metallographic cave.^(9,10) As the specimen is initially inserted into the collet it is held by a small permanent magnet in the collet. A mild iron washer embedded in the specimen mount provides the attraction. A clamp (i) is provided to lock it tightly in place, and a knockout pin (j) permits easy removal.

- l Sweep disconnect solenoid
- m Specimen loading stage
- n Loading guide
- o Collet clamp motor
- p Lap elevator push rods
- q Hydraulic ram
- p Polishing lap wheel
- s Splash bowl
- t Lap retainer ring pickup arm
- u Lap retainer ring

Fig. 2 ANL Polishing Machine as it Appears during Grinding and Polishing Operations

Fig. 3 View of Polishing Machine Showing Head at the Specimen Loading Stage, Lap in Elevated Position

Fig. 4 View of Polishing Machine Showing Clamp Wrench Motor Engaged, Lap Retainer Ring Removed

A sweeping motion to work the specimen on the lap is imparted to the pantograph arm by means of a motor drive linkage (k) mounted below the console top. The speed is approximately 15 cpm. A sweep disconnect solenoid (l) permits the head and arm to be moved laterally away from the lap toward the specimen loading stage (m).

Arrangements for loading and unloading specimens from the collet consist of a loading guide (n) and clamp motor (o) mounted on a bracket from the side of the loading stage. The former centers the polishing head over the stage (m), and the latter engages the collet clamp (i) in this position so that it may be either tightened or loosened.

Some modifications to the polishing lap assembly have been made necessary by the cave operation. The lap drive shaft has been bored along its axis to receive a lap elevator push rod (p) activated by a hydraulic ram (q) mounted at the bottom of the lap drive gear housing. Polishing wheels have a propensity for freezing onto their tapered hubs; this arrangement completely eliminates the trouble. Stroke of the ram is long enough to elevate the lap wheel (r) entirely out of the splash guard covering the splash bowl (s). The inner diameter of the splash guard (not shown in the drawing) has been increased appreciably so that it need not be removed to permit elevation of the lap.

When the lap is up a pickup arm (t) mounted on the specimen stage post may be swung to a position beneath the lap retainer ring (u). If it is left there while hydraulic pressure is released, the lap wheel will sink back into the bowl, leaving the retainer ring on the arm. Swinging it to one side then permits the lap wheel to be raised again so that the lap may be renewed or the wheel removed and replaced.

When assembled for operation, the pantograph arms are enclosed in a flexible neoprene boot and its head is protected by side plates from contamination. Figure 2 is a general view of the apparatus as it appears during a polishing operation. Pins project from one side and the front of the head. These provide projections which may easily be grasped by the manipulators and on which may be hung weights to adjust the pressure of specimen against lap.

Figure 3 shows the polishing head at the specimen loading station as it appears either when about to receive a specimen or after ejecting it from its collet. On the side closest to the lap may be seen the atomizer arrangement for applying lubricant evenly to the lap during grinding and polishing. In this view the lap has been elevated above the splash guard in position for the pickup arm to engage the lap retainer ring.

In Fig. 4 the specimen collet clamp is shown engaged by its motorized wrench. The lap retainer ring has been transferred to its pickup arm and swung out of the way for servicing the lap or removing the polishing wheel.

D. DISCUSSION OF TECHNIQUE AND PERFORMANCE

The machine is brought into critical adjustment by turning the leveling screws until a specimen held in the collet is ground evenly over its entire face both before and after a 180° rotation. These adjustments cannot be made remotely. Alignment must be very accurate so that a specimen may be transferred from one machine to another without producing facets during each successive grinding and polishing operation. However, once set, the machines require no further truing for many months.

The lap retainer ring and pickup arm make it easy to service the polishing machine remotely when abrasive discs are used, because the polishing wheel itself does not need to be removed when the disc is renewed. Cloth laps are also used on the machine. At first it was thought that proper stretching of them over the surface of the wheel would require replacement of the simple retainer ring by a conventional clamping ring and manual handling outside of the cave. Because of the added work this would involve, it was decided to carry the polishing of specimens as far as possible on paper.

Experimentation showed that with uranium it is quite possible to go all the way from Durite 80D emery paper to quarter-micron diamond compound on Vellux paper. Thus, a surface suitable for fast electropolishing may be obtained without using a cloth lap. However, the scratches remaining after the quarter-micron grit are coarser than those left by a cloth lap.

A later trial showed that the lap retainer ring quite adequately held cloth laps in place, as well as paper discs, when cut to overhang the edge of the wheel. The rounded pin projecting from the axis of the wheel (see Figs. 1 to 4) was found useful in remotely aligning both paper discs and cloth laps by means of a central hole. Silk, Gamal and Microcloth have all been used effectively in this manner, and the choice of lap material now appears to depend only on the metallographer's imagination.

With the cloth limitation removed, quality and efficiency of polishing are the sole factors entering into selection of media. Excellent results are obtained when the operation is transferred from paper to silk for the 3-micron and one-micron steps, and then to Gamal for the quarter-micron step. This produces a surface which will quickly respond to final electropolishing. Further application of a compound such as C-Ro or Linde B leaves a fine polish for specimens which are to be photographed unetched. It is obvious that other sequences and materials may be used successfully.

In conventional metallographic technique water is often used liberally as a lubricant during the grinding stages and water or dilute soap solution during polishing. This practice is not acceptable in remote metallography, as it creates a radioactive waste disposal problem and also greatly increases the danger of airborne contamination through spattering and evaporation. The ANL policy has been to use the minimum amount of lubricant or abrasive carrier compatible with good results. A slow-evaporating vehicle with some oiliness in its residue is favored, such as Hyprez, and it has been found that with moderate grinding pressure only sufficient lubricant is needed to keep the paper moist. The volume of waste liquid can be kept small enough to permit permanently plugging the splash bowl drain and using disposable tissue to keep the bowl itself clean. In this way the bulk of contaminated material from the polishing operation and cleanup is held to a minimum, an important factor in the economics of cave operation.

Figures 5 and 6 are photomicrographs which illustrate the performance of the machine on various uranium specimens, using slightly different procedures. In Fig. 5 two specimens of sheared uranium plate, polished perpendicular to the sheared face and the rolling plane, are shown. Both have received a final polish of C-Ro on Gamal cloth, but one (a) received its last diamond grit abrasion on cloth, whereas the other (b) received it on paper. Figure 6(a) shows a piece of coarse-grained, gamma-extruded uranium polished through a surface pit

Figure 5. Photomicrographs of Uranium Polished Remotely in a Plane Perpendicular to a Sheared Face. (As-polished, 100-X)

(a)

(b)

Figure 6. Photomicrographs of Irradiated Uranium Polished Remotely in a Plane Perpendicular to Corroded Surfaces (As-polished, 100-X)

(a)

(b)

14247, 14251

(a) Corroded by mercury.

(b) Corroded by hydrochloric acid.

caused by mercury. Figure 6(b) shows a fine-grained specimen which has been acid etched to obtain a surface burnup analysis. In all these specimens edge roundoff is minimal, comet-tail pitting is very slight and the nonmetallic inclusions have been retained fairly intact. It would be difficult for a skilled metallographer to reproduce these results manually.

Each of the specimens shown in the figures was taken through six stages of emery grinding and five stages of diamond grit on paper before the cloth polish. Total machine operating time was approximately 80 minutes. It is expected that further experience will permit the selection of four or five standard steps so that for the more routine work no lap change-over will be necessary and a flow of specimens from one machine to another can be maintained. The uninterrupted output of a bank of machines would probably not be greater than ten specimens per day if high standards of quality are to be maintained. However, an output of this size would be more than adequate for the ANL needs for some time to come.

E. SUMMARY

In conclusion, the ANL polishing machine seems in every respect to fulfill the purpose originally envisioned when design studies were begun. In the comparatively new field of radiometallography it is essential that the research metallurgist be sure that what he sees through the microscope is indeed representative of the structural changes that have occurred in the specimen during irradiation. Those experienced in "cold" metallography know well how easy it is for poor specimen preparation to mask and distort the visual evidence. Therefore, it is essential that the hot metallographer have a wide latitude in the selection and variation of "hot" metallographic polishing procedures; this the ANL machine provides. It has also proved remarkably easy to operate and service remotely.

F. ACKNOWLEDGMENTS

W. A. Ahrens gave valuable suggestions and technical assistance, and his work helped a great deal in simplifying the remote polishing procedures.

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