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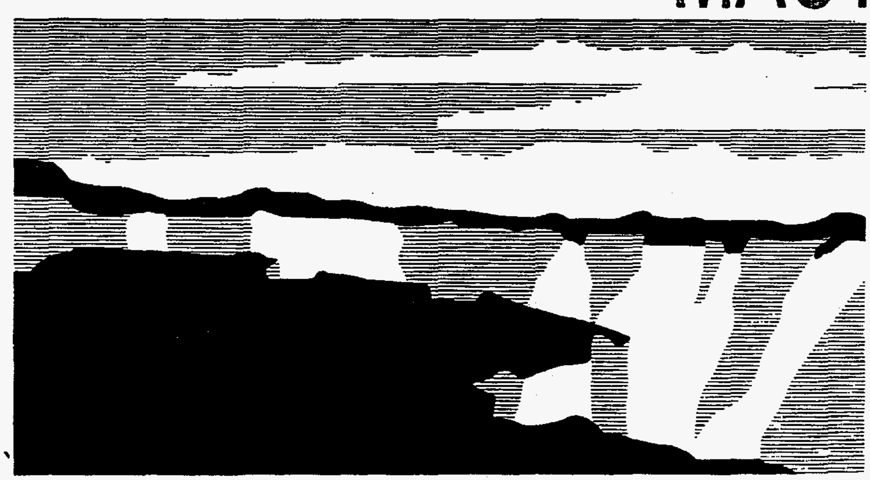

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FABRICATION AND CHARACTERIZATION OF ALUMINUM HEAVY LINERS FOR THE PULSE POWER SYSTEMS OF THE HIGH ENERGY DENSITY PHYSICS PROGRAM AT LOS ALAMOS.

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Introduction

Aluminum heavy liners of three basic types have been fabricated for Los Alamos pulse power experiments. The first fabrications used a conventional hand operated lathe with high speed steel cutting tools. More recent fabrications have used numerically controlled lathes with carbide insert cutting tools. A numerically controlled Pneumo lathe with an air bearing spindle and with air bearing cross slides has been used to fabricate the most recent examples of the 3.2 gm Pegasus Precision Liner that is normally accelerated to 3 mm/μs for experiments at the Pegasus II pulse power facility. The basic dimensions, including wall thickness, of fourteen of these parts have been characterized by an automated inspection machine. Liner surface finishes are measured directly by stylus profilometer and by optical interferometric analysis of cast polymeric replicas. Statistics of these measurements will be presented. Plans for future fabrication of similar and larger liners with increasingly stringent specification of wall thickness and of surface finish are described along with corresponding plans for liner characterization improvements.

Heavy Liners of the High Energy Density Physics (HEDP) Program

Pegasus Precision Liner

The Pegasus Precision Liner was first fabricated in early 1993 and used for the Pegasus Heavy Liner experiments beginning in April that year. Liner application experiment designs soon followed and the liner has subsequently been used repeatedly at a rate averaging near one per month [1,2]. The original liners were fabricated using high speed steel tooling and several custom supports and transfer fixtures on a Hardinge lathe. Machining was approached conservatively because of the known difficulties of cutting pure (1100 Series) aluminum and because of concern for maintaining close tolerances while supporting heavy current joint flanges with the thin .040 cm wall of the active portion of the liner. Fig. 1. shows the liner to scale in cross section. The figure also shows the standard glide plane configuration that has been used for most experiments. Glide planes are made from OFHC copper with an 8° taper and a small cutter notch at the liner wall. The liner is converged from 2.4 cm radius to 1.5 cm radius in the normal configuration by a nominal maximum current of 5 MA and is accelerated to 3 mm/us inner wall velocity.

The material specified for the liner, 1100 Series Aluminum, is a wrought product no less than 99.00 wt % Al. The material may contain nominally 0.12 % Cu. Fe bearing phases are frequently observed metallographically. Resistivity is 2.9-3.0 μΩ cm, density is 2.70 - 2.71 gm/cm^3 [3]. The material is normally available from U.S. vendors as plate up to 2.5 cm thick and as bar stock up to 10 cm diameter. The outer conductor load current joint design of the Pegasus II power flow channel requires a load flange diameter in excess of 10 cm. Therefore it is not possible to cut the Pegasus Precision Liner from a length of the available bar stock. That is resolved by cutting a disk from 1100 Series Al plate of sufficient size to form the outer conductor current joint flange which is vacuum e-beam welded to a length of 10 cm d. rod to generate a blank from which the liner may be machined. The weld joint design is shown in Fig. 2. The preferred way to rough form the blanks is by numerically controlled lathe with a conventional bearing spindle using carbide cutting edges. An acceptable alternative is to use a conventional hand operated lathe. In either case, for reasons of economy, most dimensions are brought to within .05 cm of final size before beginning finishing operations.

Recent liners have been finished with carbide inserts on a numerically controlled Pneumo lathe equipped with an air bearing spindle and air bearing cross slides, shown in Fig. 3. Except when noted otherwise, this paper addresses topics of Pegasus Precision Liners fabricated on this equipment using 0.02 cm radius carbide inserts. The spindle is operated at 800 rpm, tool feed rates are 1.8 cm/min for roughing cuts and 1.3 cm/min for finishing cuts. Corresponding depths of cut are .008 cm and .0003 cm. Mineral oil mist is used for lubrication..

Pegasus and Procyon High Current Liners

A small number of HEDP liner development experiments have used liners of greater wall thickness than the Pegasus Precision Liner and have been driven by higher currents, to larger convergence ratios, to generate higher shock pressures. These liners have used bolted current joints in an adaptation of a current joint design developed initially for the Procyon explosively driven system. To date, liners of this type have been finished on conventional lathes although any future fabrications will include finishing on a numerically controlled air bearing spindle lathe to incorporate the better surface finish and the dimensional control provided by those machines. Bolted current joints are currently being evaluated for sufficient merit to be included in all future HEDP liner based experiments

Liner Characterization

Specifications

Dimensional tolerances of the HEDP liners have typically been specified +/- .0025 cm (.001 inch). In all cases inside diameter and liner wall thickness tolerance have been an exception; both specified +\- .0012 cm. Concentricity of cylindrical surfaces and parallelism of flat surfaces are specified .0025 cm. A value for liner surface finish has not been specified. However, a requirement has been established to measure and document surface finish of the inside diameter of each liner. Liner metrology procedures are not specified nor are machine tool operating parameters nor cutting tool parameters although all of these are becoming increasingly standardized by the fabricating group. Standardized procedure has been accelerated by increased use of numerically controlled equipment in the liner fabrication process.

Lineal Dimension Measurements

Measurement of lineal liner dimensions has evolved from use of hand held instruments to surface tables and gauge blocks to use of the Brown and Sharp programmable coordinate measuring machine (CMM) shown in Fig. 4. This apparatus uses a driven x,y,z stage to position the inspection probe relative to the part being inspected. The part surface is contacted by a 5 mm diameter polished ruby sphere that is mounted on a stalk supported by a sophisticated electrical switching device sensor. When the ruby sphere is brought into contact with a surface to be measured, current continuity in the sensor is broken. That event causes the coordinates of the measurement machine to be recorded as a data point. A calibrating sphere, seen in the figure, is used to factor out geometrically induced errors derived from displacement of the measurement sphere surface with respect to the sensor switch locations.

Metrology of liners that were used in the fourteen most recent Pegasus Precision Liner driven experiments included measurements by the Brown and Sharp CMM. It should be noted that fabrication procedures were instituted to routinely generate liners that would easily meet the original design specifications and are not necessarily the same as would be used in the case of more demanding tolerances. Wall thickness was measured in effect by subtracting inner and outer radius at 90° increments in each of four symmetrically spaced azimuthal planes and then averaging the 16 values thereby obtained from each part. The mean of the wall thickness values of the 14 liners is 0.04045 cm. The mean value of the population standard deviations is 3.5 μm. Treating 224 individual measurements of wall thickness, that is, 16 measurements of each of 14 parts, as a sample of a larger population results in a mean wall thickness of .04045 cm with a sample standard deviation of 3.8 μm. Extremal values of the data set include six instances of 0.0396 cm and one instance of 0.0414 cm, a difference of 18 μm, slightly greater than four times the sample standard deviation. We interpret these statistics as indicating this group of 14 liners easily met the important wall thickness tolerance specification of +\- 0.0012 cm which allows 24 μm total variation.

The values cited above include errors of the measurement tool. To test the Brown & Sharp coordinate measuring machine's accuracy and repeatability, the thickness of a gauge block was measured 20 times in a manner similar to that used to measure liner wall thickness. The calibrated gauge block was 0.05000 cm +\- 0.00001 cm in thickness. The average of 20 thickness measurements by the CMM was 0.05014 cm with a standard deviation of 0.5 μm.

The gauge block test represents a best case since no curvature needs to be accounted for and a CMM z-axis translation was not involved. Complete measurement of cylindrical liners involves both surface curvature and z axis translation. The results of the gauge block measurements indicate that most of the variation in the liner wall thickness measurements were caused by manufacturing. However, since the standard deviations of both the liner and the gauge block measurements are within one order of magnitude, additional tests using a calibrated cylinder need to be performed before this conclusion can be stated with a high degree of confidence.

Surface Finish Measurements

Surface finish of the inside surface of HEDP liners has been measured primarily with a stylus type profilometer. At least until recently, perturbations on the inside surface have been of greatest concern to the growth of instabilities during implosion. A stylus profilometer manufactured by Federal Corporation is available and suitable for the measurements. An instrument of the type and similar to that used is shown in Fig. 5. A Wyko Rough Surface Tester (RST), shown in Fig. 6, has been useful for analyzing the topography of cast polymeric replicas of small areas from the inside surface of machined cylinders. IMPREGUM, a dentistry product, has been suitable for obtaining surface replicas. Both of these instruments present several recognized surface finish metrics as defined by US and international standards organizations. Liner surface finish has been documented as R_q, an rms value. R_q measured on the inside surface of the Pegasus Precision Liner is typically 0.2 μm rms average, measured by Federal profilometer. The RST has not been used for routine measurements of liner surfaces although it is used frequently to characterize surfaces of passive components of liner driven experiments. It has been used to measure the outside surface finish of at least two liners. Values obtained were $R_q = 0.3036$ μm on Pegasus Precision Liner #3-18 which was used in Pegasus experiment LS-1. A backup liner machined identically to that used for the Megabar 1 experiment yielded a value of $R_q = 1.873$ μm on the outside surface.

Cutting Tool Surface Finish Measurements

Surface finish of a silicon nitride coated tungsten carbide tool insert of the type used for liner fabrication has been measured. Surface finish of a polycrystalline diamond tool was similarly measured. Polycrystalline diamond is of interest as a tool material to be evaluated in the event improved surface finish becomes a requirement. Measurements were made on the clearance face of the tools, that is, the face that contacts the part being machined as opposed to the rake face which contacts the chip. The surface finish of the carbide was 0.51 μm rms and that of the diamond was 0.32 μm rms. These finishes are comparable so the expectation of significant improvement in surface finish from the polycrystalline diamond is not assured. However the diamond tool surface is noted to be the better of the two and diamond tool pressure is expected to be lower which should contribute to surface finish improvement. Surface finish would be markedly improved by the use of single crystal diamond tools. The air bearing equipment that is described here is compatible with single crystal diamond tooling which, in fact, is often used in applications specifying optical quality machined surfaces.

Proposed Liner Fabrication

A fourth small batch of Pegasus Precision Liners is in fabrication at this writing. These parts will be fabricated identically to the third series of liners which have been described here and will contribute to our knowledge of process and measurement reproducibility. We then expect to employ similar fabrication procedures to fabricate a liner with dimensions in the dynamic region to the same specifications of the Pegasus Precision liner but with bolted current joints. This liner is planned to become the driver of 300 kB Pegasus II liner driven experiments in the near future. Liners for the Megabar series of Pegasus experiments and other small quantities of specialty liners will normally be fabricated as described here, including finishing operations on the air bearing equipment, perhaps with some improvements if warranted by programmatic requirements.

Advent of the ATLAS driver in less than five years is drawing attention toward fabricating larger, heavier liners, more efficiently, and perhaps with more stringent specifications. We are also considering precision fabrication of liners as large as that designed by VNIIEF for the joint Los Alamos HEL experiment scheduled in the late summer of 1996. Fig 7 shows a unique apparatus, the Precision Automated Turning System (PATS), built as a prototype under contract to Los Alamos by Moore Special Tool Co. Authors Day, Hatch and Hannah are participating in the ongoing evaluation and the initial programming of this apparatus. We have proposed using the PATS to demonstrate fabrication of examples of liners we would expect to fulfill future HEDP requirements. We have also proposed fabrication of several Pegasus Precision Liners when operation of the machine has been sufficiently demonstrated.

Fig. 8 is a drawing of the PATS that defines axes of motion. Corresponding values of straightness and resolution, provided by Moore, are presented in Table 1. The PATS machine is easily capable of producing any sized geometry that is currently being considered in the HEDP program. Cylinder capacity is 600 cm diameter and 30 cm height. Accuracy of the PATS has not been determined but is expected to be better than 1 μm. An attractive attribute of the PATS machine is inclusion of stages for measuring instrumentation, axes U and W. Sensors that would be appropriate to HEDP liner requirements are being identified. We believe this capability of the PATS can be significantly superior to the characterization of liners by the Brown & Sharp CMM that has been described here. Obviously, measurement stages incorporated into the machine tool can contribute significantly to fabrication process efficiency.

Conclusion

Fabrication of the Pegasus Precision Liner has been described in greater detail than has occurred previously. This liner has performed very reliably in driving experiments designed for 300 kB shock pressure. Recent interests in high shock pressures from similarly sized liners and interest in the stability of these liners has caused us to begin closer examination of liner metrology topics. We have recently become interested in the possibility of liner fabrication using the Los Alamos Precision Automated Turning System, PATS, for future ATLAS requirements and as a consequence of Los Alamos collaboration with VNIIEF in the High Energy Liner experiments at Arzamas-16.

Acknowledgments

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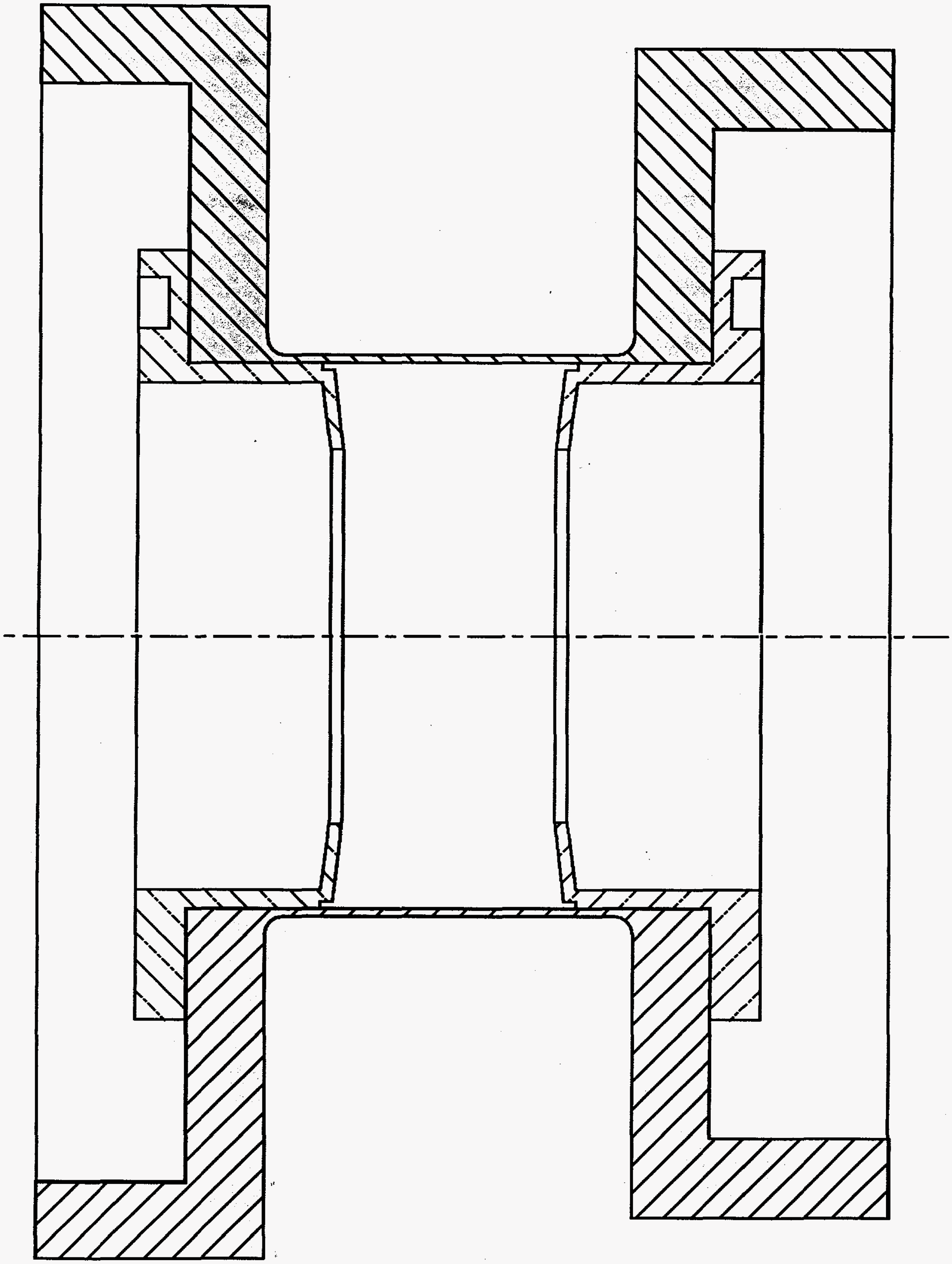
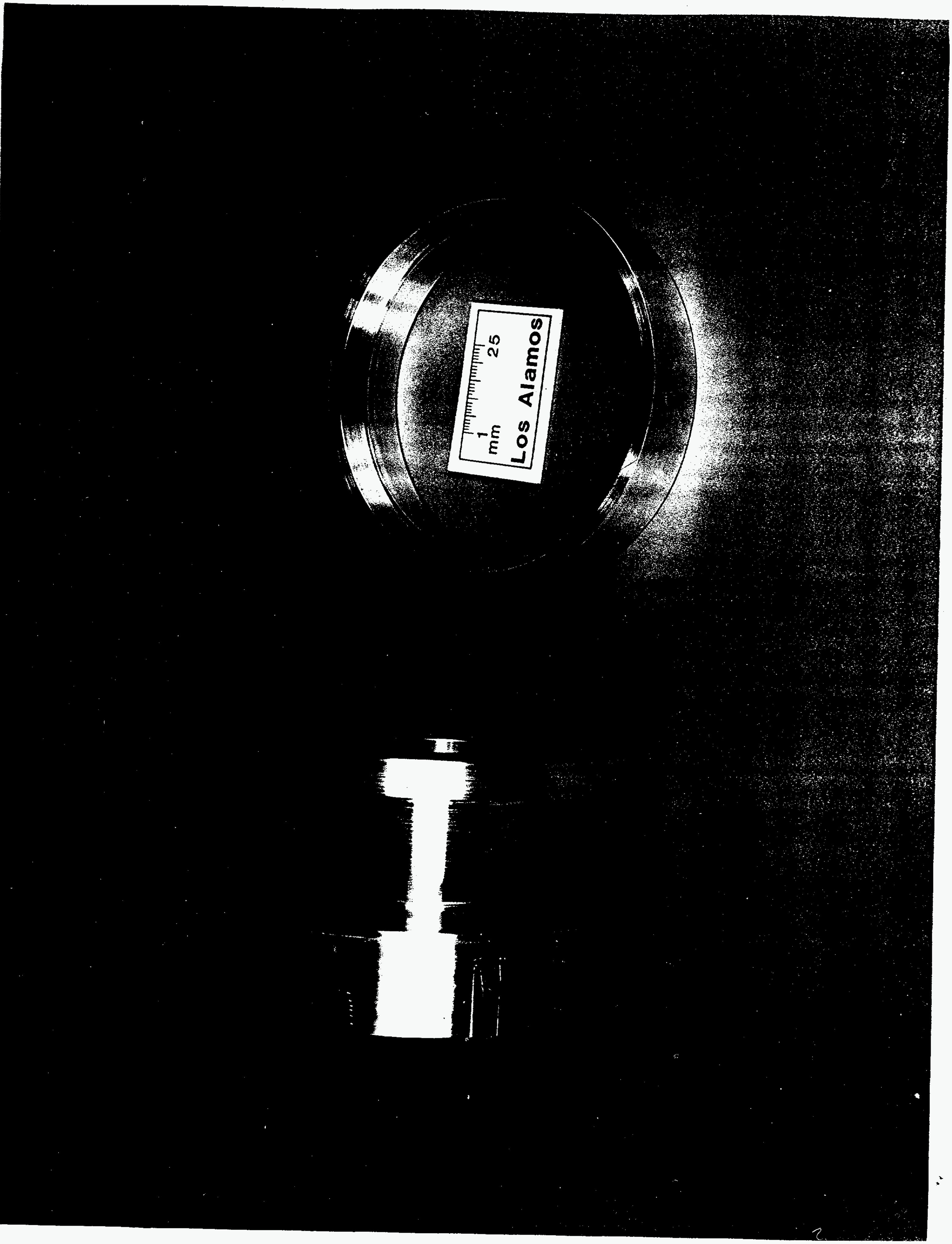
2. W. E. Anderson, “HEDP Heavy Liner Fabrication History”, Unpublished Memo to Carl Ekdahl, MST-7:U-96-025, 1996.
3. “Aluminum and Aluminum Alloys”, in ASM Metals Reference Book Third Edition, (Ed. Michael Bauccio), ASM International, 1993, p.399-407.

Figure Captions

Table Captions

AXIS	STRAIGHTNESS	RESOLUTION
Machining X	0.50 μm horizontal 0.43 μm vertical	0.1 μm
Machining Z	0.20 μm horizontal 0.35 μm vertical	0.1 μm
Measuring U		0.1 μm
Measuring W		0.1 μm

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• ONE MICROINCH RESOLUTION
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• 8 INCH TRAVEL, Z-AXIS
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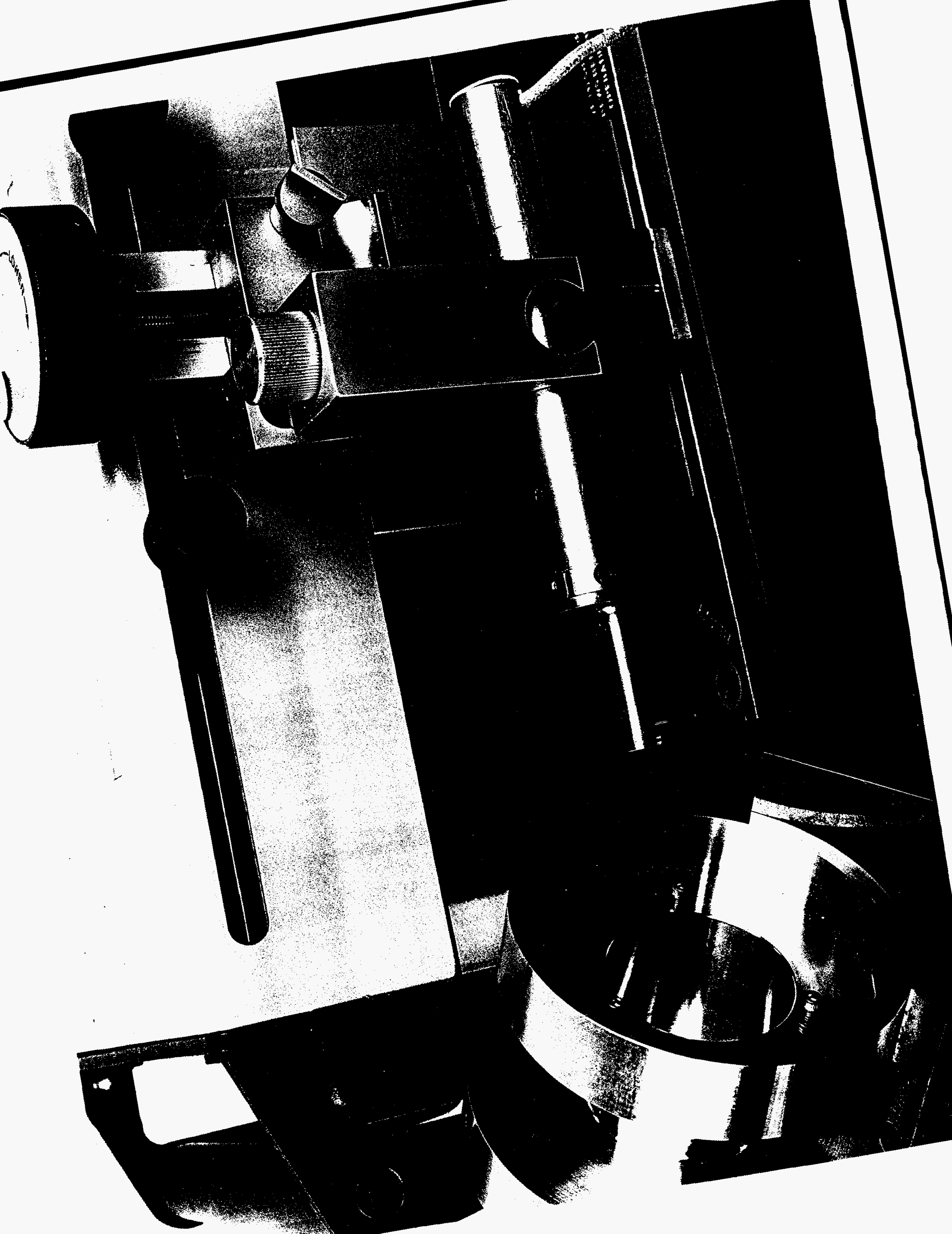


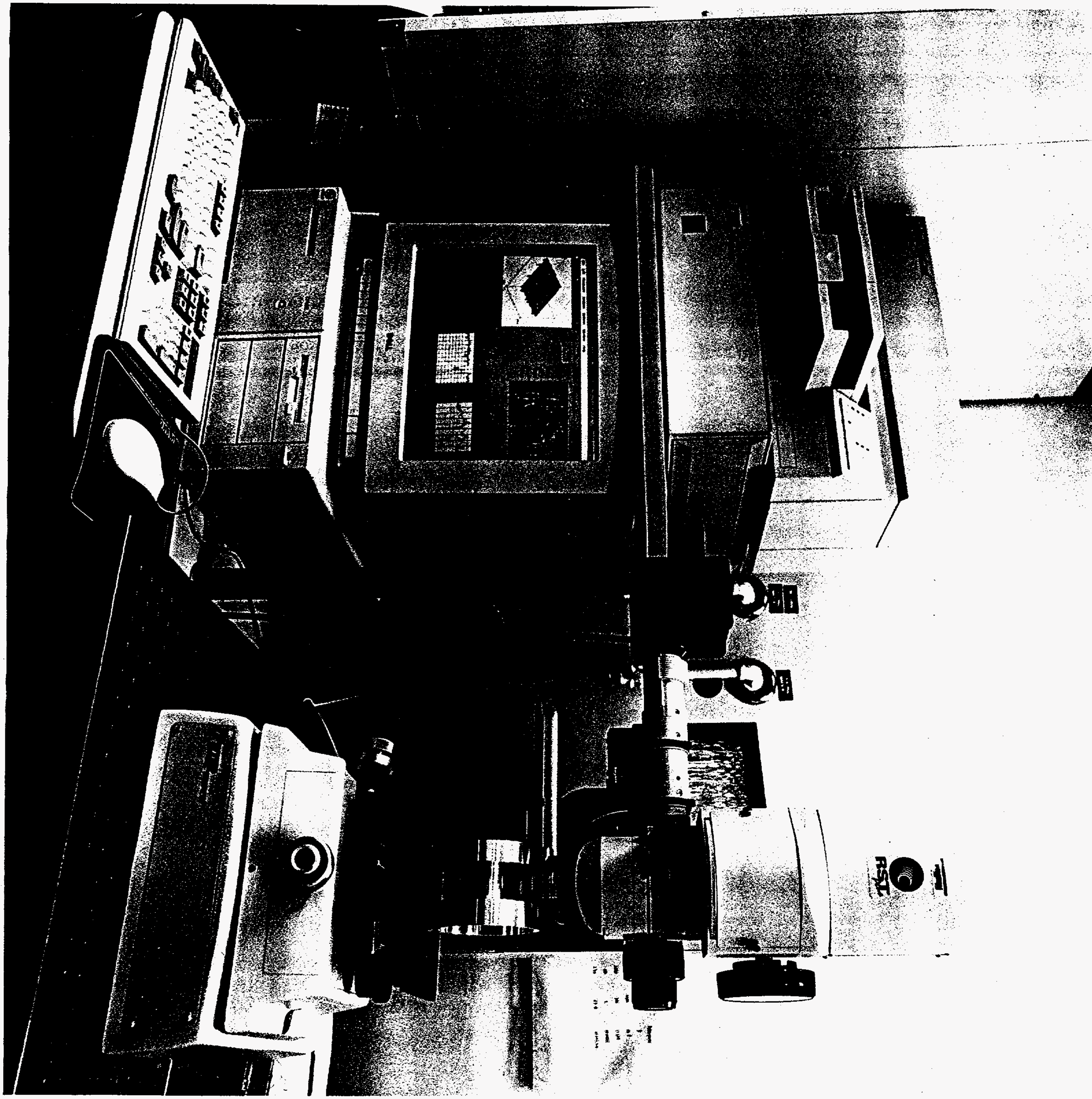
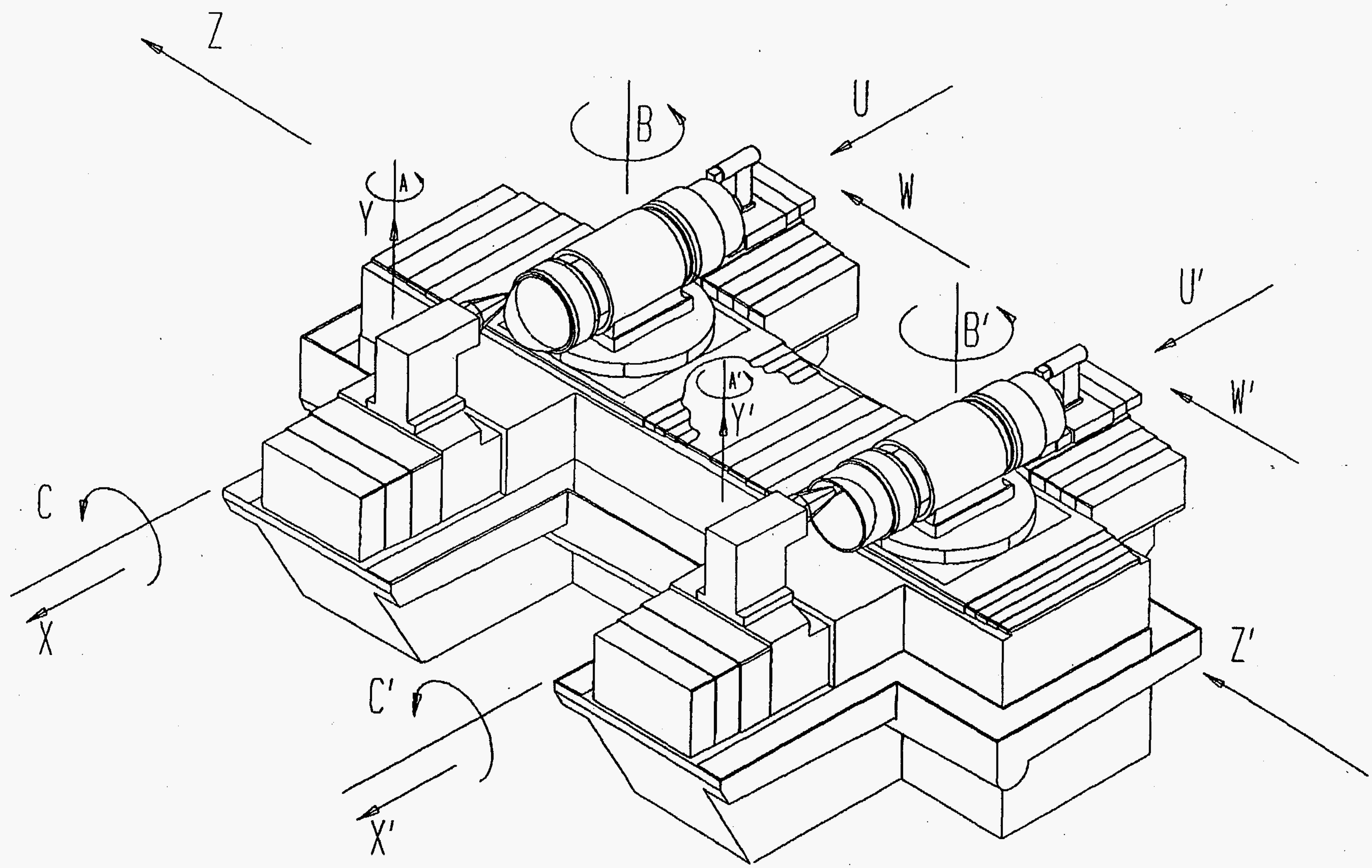



FIG 7



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