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FABRICATION OF HEMISPHERICAL OPPOSED SELF-ACTING GAS BEARINGS FOR THE THIRD-GENERATION GYROSCOPE

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ABSTRACT

Techniques are outlined for the fabrication of spherical gas bearings by machine lapping and sputter etching.

The problems associated with producing three-dimensional patterns on the spherical surfaces by photo-resist acid-etching techniques and sputter etching are new areas of development.

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FABRICATION OF HEMISPHERICAL OPPOSED SELF-ACTING GAS BEARINGS FOR THE THIRD-GENERATION GYROSCOPE

1. INTRODUCTION

The design and application of a self-acting gas bearing for the gyroscope spin axis was part of the recent Third-Generation-Gyro Development Program conducted for the NASA Electronics Research Center by the Inertial Gyro Group of the Charles Stark Draper Laboratory. Figure 1 shows the bearing developed under that program, which comprises a rotating outer member integral with the gyro wheel supported by a gas fluid film generated by two opposed spiral-grooved hemispherical inner-bearing parts.

For the past seven years, the Inertial Gyro Group has been working on the development of opposed hemispherical self-acting gas bearings for the spin axis of several floated gyroscope designs. Although much work has been done on various forms of self-acting gas bearings by many organizations, the work with opposed hemispheres is somewhat unique. This type of self-acting gas bearing has the following advantages:[(1)*]

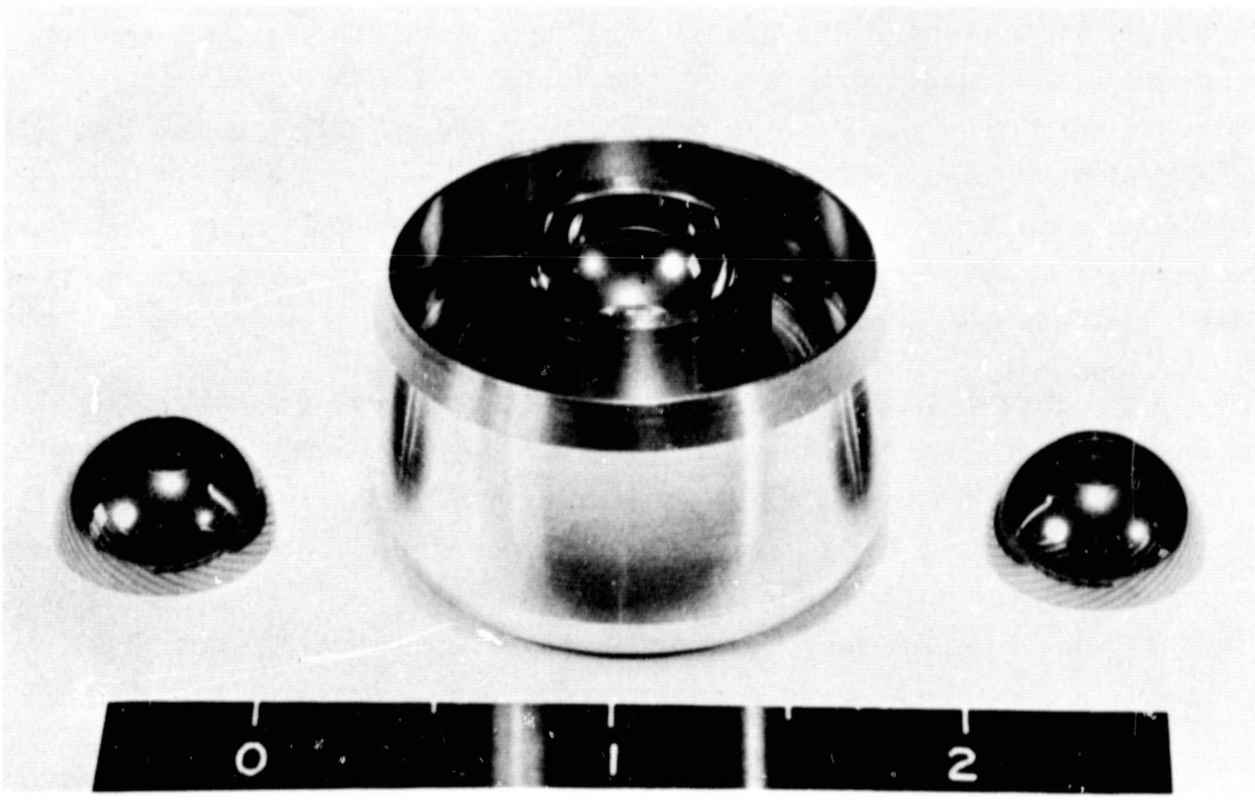


Fig. 1 Third-generation-gyro hemispherical gas bearings.

*Superscript numerals refer to similarly numbered references in the List of References.

(1) Self-aligning bearing assembly

(2) No half-frequency whirl

(3) Low aniso compliance torque sensitivity to axial gap setting

(4) Low cross-compliance torque sensitivity to axial gap setting

(5) More linear deflections to loading

There are of course some disadvantages with respect to other gas-bearing designs. The spool-type bearing has the advantage of being able to develop an equivalent stiffness at a lower level of bearing torque. The tapered bearing has the advantage that the bearing gap is easily controlled. In addition, fabrication techniques for the hemispherical bearing are somewhat a problem, or rather, were at the outset. These are the subject of this report.

2. BACKGROUND

As previously stated, the development of the hemispherical opposed bearings extended over a period of several years. It became obvious in the beginning that the proper pumping groove parameters could be empirically derived (very expensive) or theoretically derived using a normalized Reynold's equation. The design parameters of this gas bearing for various requirements can be optimized by a computer program.[2] The original work was done by Malanoski[3] of Mechanical Technology Incorporated for the Draper Laboratory under a subcontract of Navy Contract NObs 78136 (FBM). Since that time (1964), variations and extensions of computer programs have been carried out by Draper Laboratory personnel. Recently Keating has written a program variation to include the effects of the mean free path of the gas molecules in the bearing computations.

Until recently, fabrication of the bearing components to these parameters was essentially a hand-finishing operation.[4] Figures 2 and 3 show the hand lapping operations for the inner and outer bearings, respectively. The final operation of machining in the loxodromic (rhumb) groove pattern in the inner bearings was accomplished in a grooving machine (Fig. 4). The grooves were individually tooled in the bearing by the controlled motion of the bearing under a fixed tool: a diamond-charged lapping wheel or a chisel-shaped diamond (Fig. 5).

The diamond-charged lapping wheel had the disadvantage of poor geometry control at times and required attention to the dressing of the lapping wheel. The diamond chisel-point tool had the disadvantage of producing a highly stressed surface condition and possible fractures in most of the hard bearing materials.

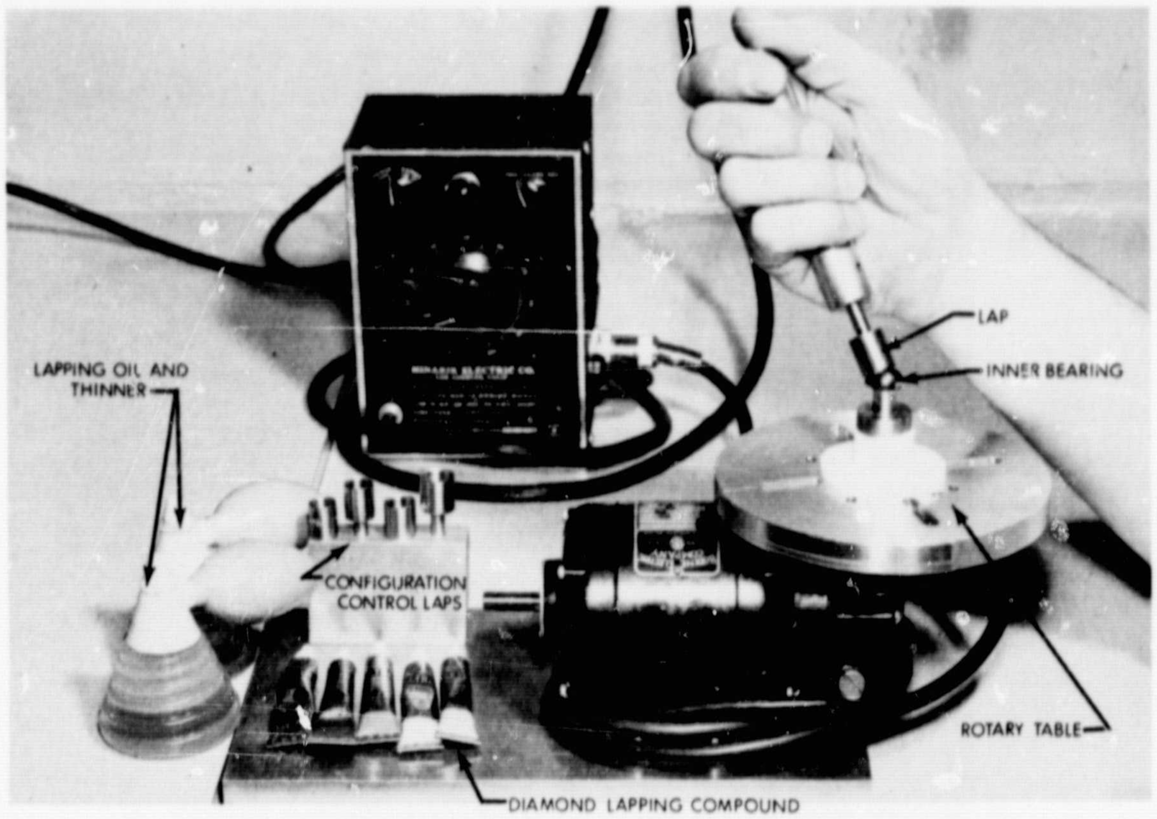


Fig. 2 Hand lapping of a hemispherical inner bearing.

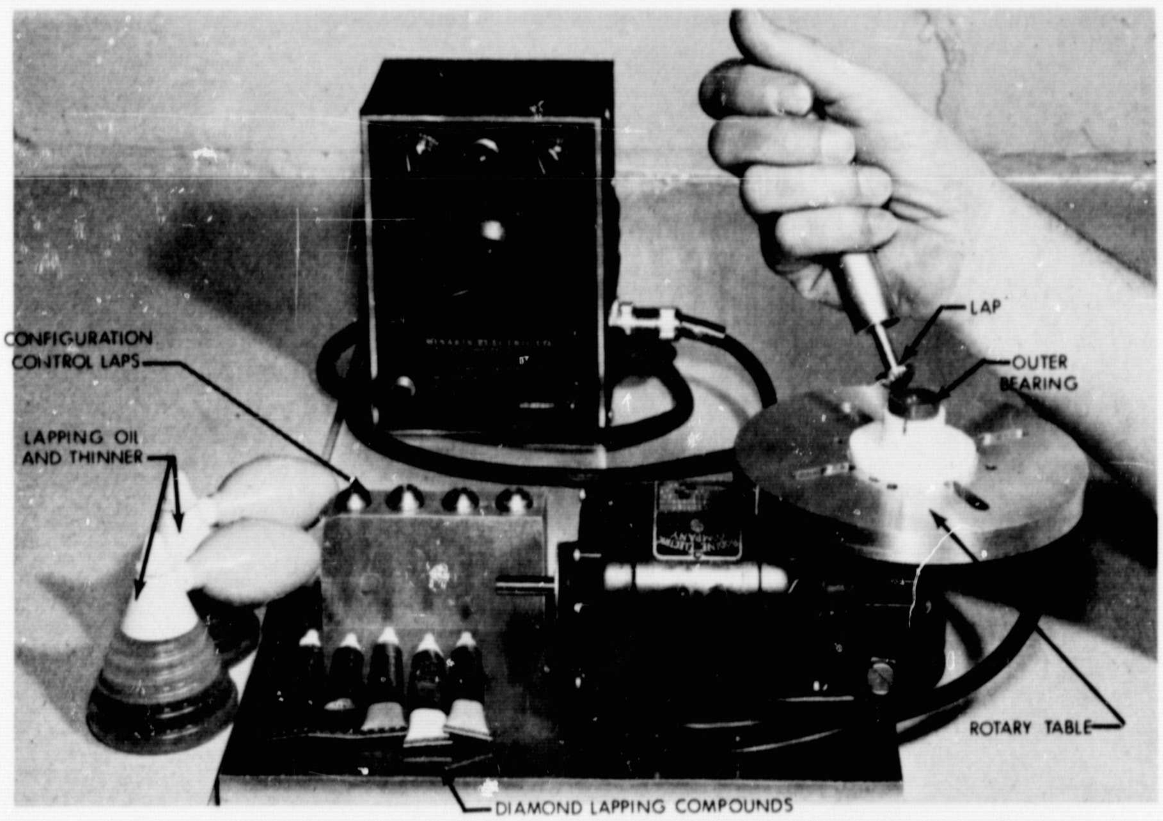


Fig. 3 Hand lapping of a hemispherical outer bearing.

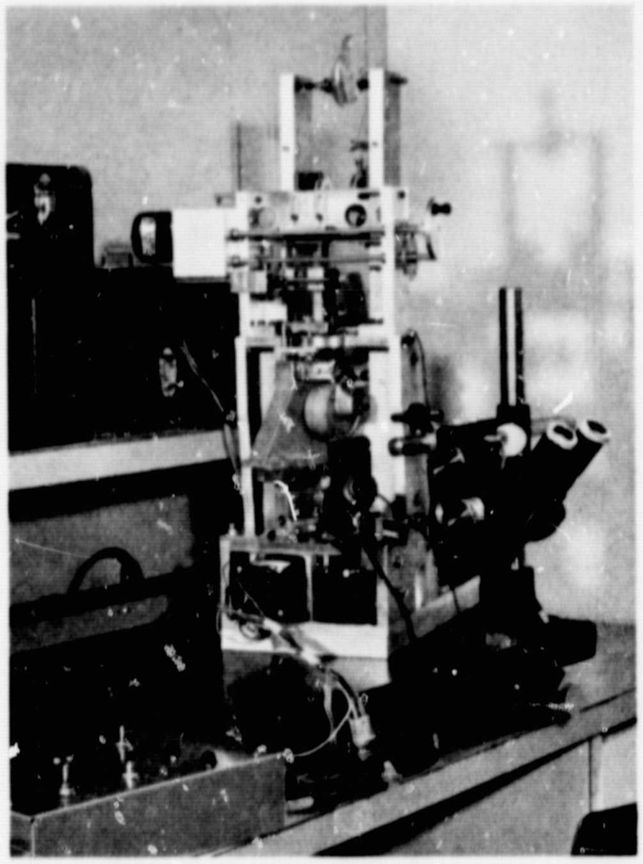


Fig. 4 Single-point grooving machine for gas-bearing inner hemispheres.

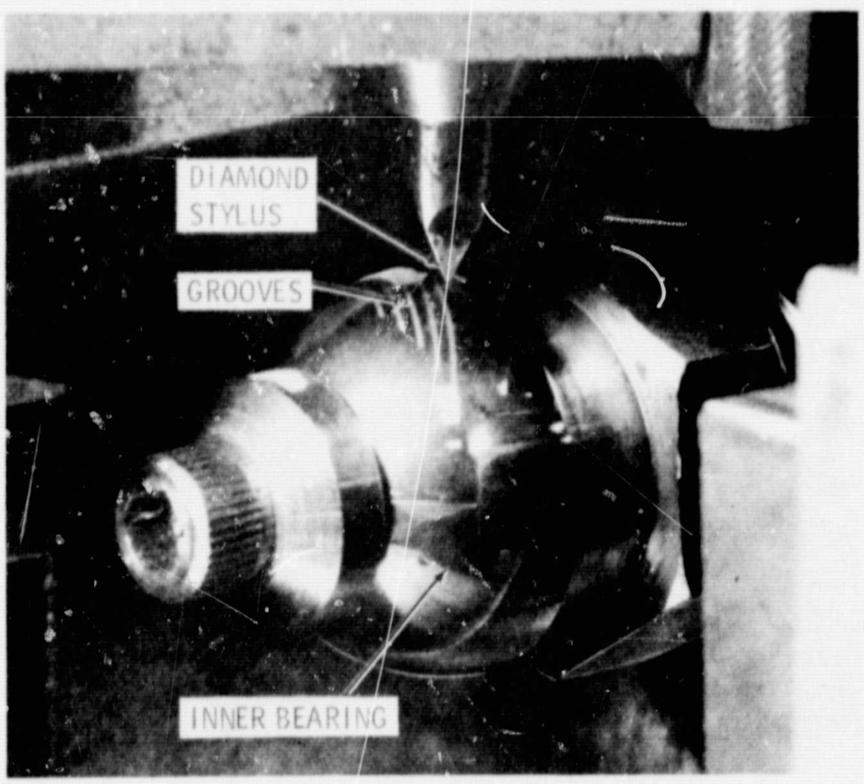


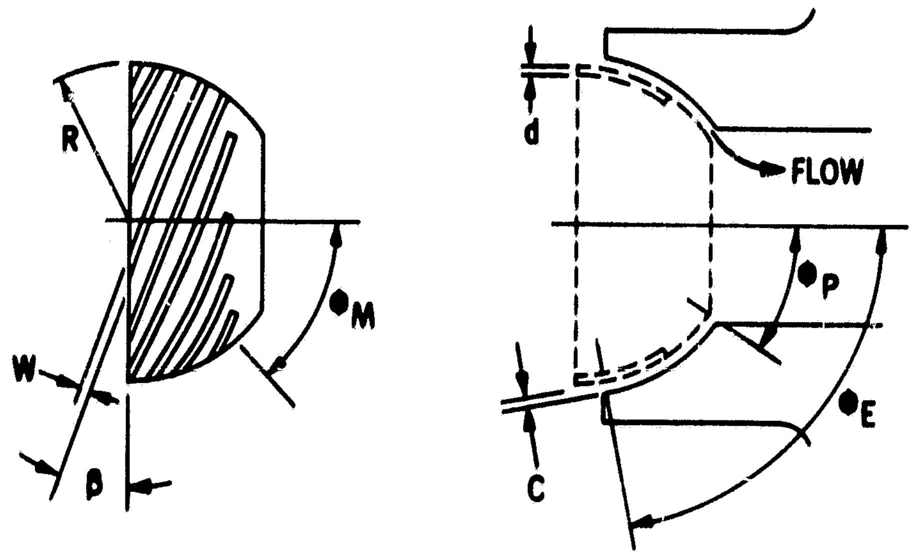
Fig. 5 Single-point grooving machine and diamond stylus.

Both the hand lapping and the individual tooling of the grooves required many skilled man-hours. In addition, the individual tooling of each groove resulted in significant groove-geometry variations that created really individual bearings. While this process was satisfactory in the early development stages, it has been the goal of the Group to develop a means to fabricate these bearings by more reproducible techniques, requiring less time and less skilled man-hours, with improved grooving conditions.

This report outlines the present fabrication techniques used to manufacture the gas bearing of the third-generation gyroscope.

3. THIRD-GENERATION-GYRO GAS-BEARING FABRICATION

The gas bearing developed for the third-generation gyro has a diameter of 0.656 inch and other dimensions as indicated in Fig. 6. Sphericity is held within 5 microinches. The bearing material is a coating of plasma-gun-deposited chromium oxide on a substrate of instrument-grade beryllium. The final coating thickness after lapping is 0.003 to 0.004 inch.



SPHERICAL RADIUS	R	=	0.328 INCH
ENTRANCE ANGLE	ϕ_E	=	90°
EXIT ANGLE	ϕ_P	=	60.6°
FILM THICKNESS	C	=	40 MICROINCHES

GROOVE DIMENSIONS:

WIDTH	W	=	0.012 INCH
DEPTH	d	=	97 MICROINCHES
ANGLE	β	=	27.5°
NUMBER	n	=	30

Fig. 6 Bearing configuration

The as-coated condition has a nonuniform coating thickness varying from approximately 0.008 to 0.012 inch. Prior to lapping, the coated parts are dressed to remove the coating flashing from adjacent surfaces and are then ground to improve sphericity. After the grinding operation, the coating has a fairly uniform thickness of about 0.008 inch. The bearing components are then ready for finishing operations: lapping and grooving.

3.1 Inner-Bearing Lapping

The inner bearing is designed to have a full equator; and therefore, two bearings can be cemented together, back-to-back, to produce a ball (with a hole through it). The advantages are somewhat obvious: sphericity is easily generated on a full sphere; dimensional control is a simple measurement of a diameter and a roundness evaluation is all that is required (Fig. 7); and in the end, a matched pair is created.

The ball lapping machine (Fig. 8) has three free-floating laps of Meehanite charged with various decreasing grades of diamond lapping compound as final size is approached. Two laps rotate and one lap oscillates to produce a random motion in the ball. When final size is reached, the ball is easily separated by weakening the adhesive (Eastman 910) with heat.

Size determination of hemispheres is accomplished by use of air-gage comparators (Figs. 9 and 10).[5] A single inner lapping machine (Fig. 11) can be used if minor adjustment in a lapped hemisphere size is required.

Sphericity can be verified by inspection on a rotary table (Fig. 12). The bearing can be placed directly on the rotary table or on an angled fixture to check roundness in different planes to evaluate sphericity.

3.2 Outer-Bearing Lapping

The outer hemispherical bearing of the third-generation gyroscope wheel is integral with the wheel hub (Fig. 13). Each side of the hub is lapped, in turn, in the fixture shown in Fig. 14 similar in principle to the single-inner-bearing lapping machine. Lapping parameters, lap size, and lapping angle must be controlled to properly locate the center of the finished bearing to a reference surface on the hub.

Measurement techniques are as previously described and are similar to those of the inner bearing.

A more extensive description of the lapping procedures for the hemispherical bearings can be found in Ref. 6.

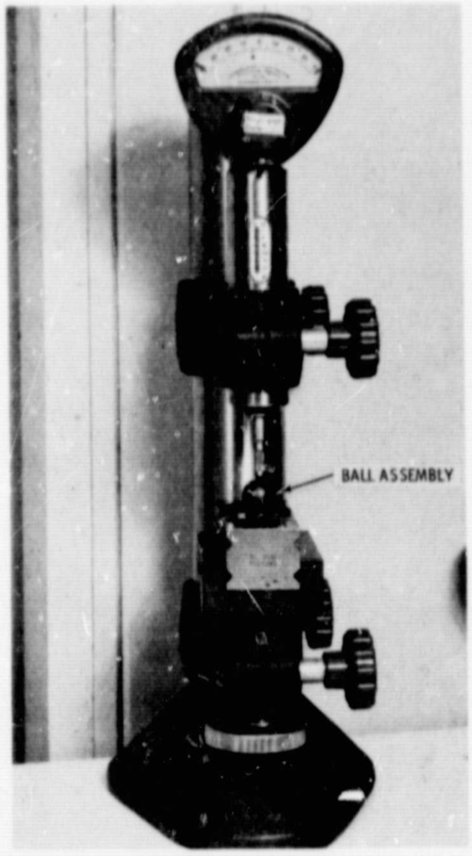


Fig. 7 Diametral inspection of the inner-bearing ball assembly.

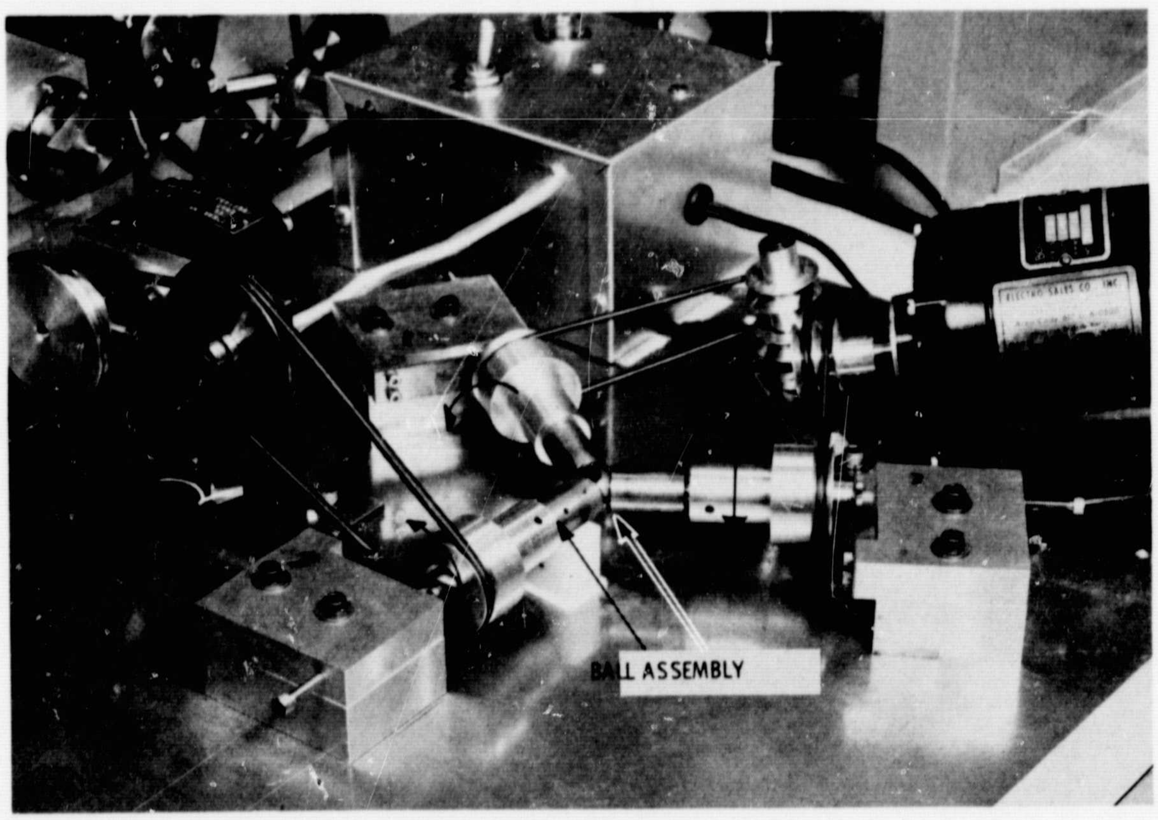


Fig. 8 Ball lapping machine.

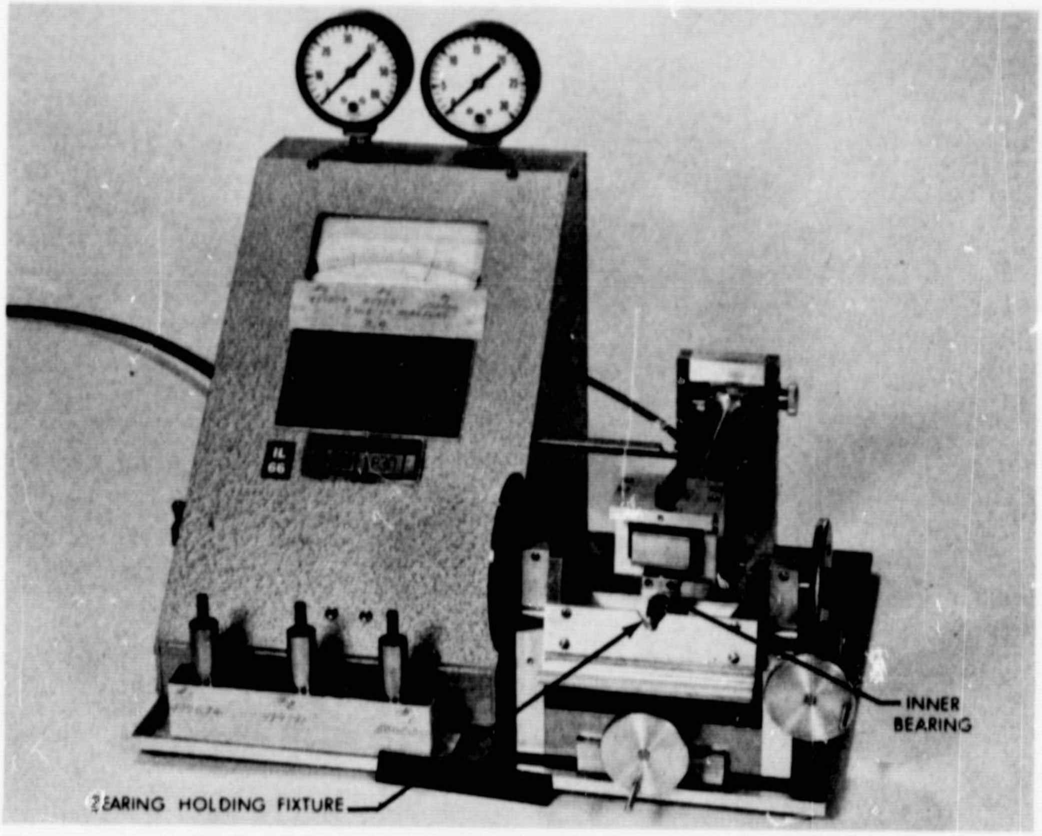


Fig. 9 Gaging setup for gas-bearing inner hemispheres.

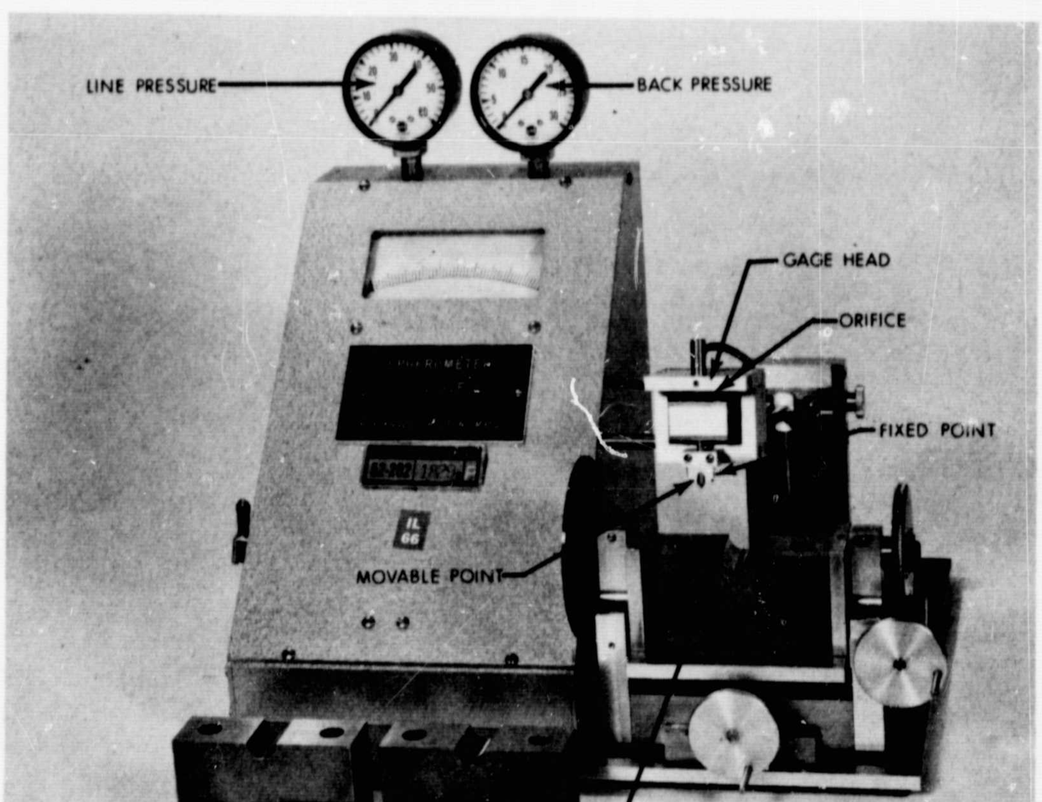


Fig. 10 Gaging setup for gas-bearing outer hemispheres.

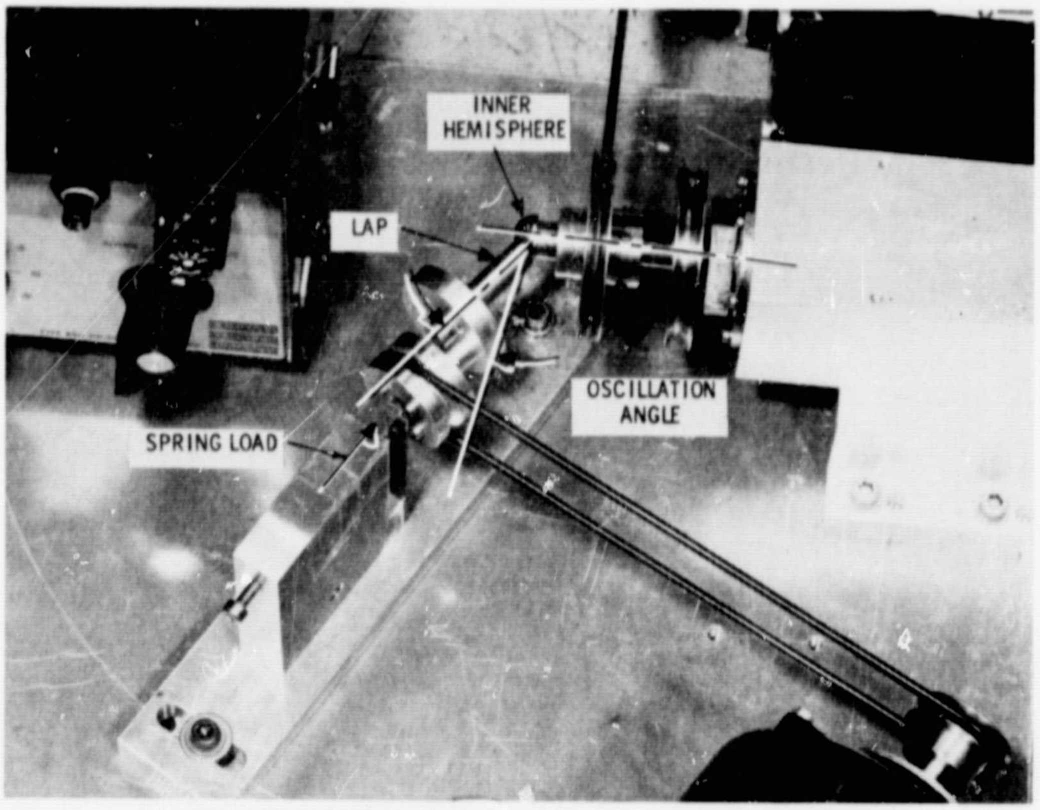


Fig. 11 Single-inner-bearing lapping machine.

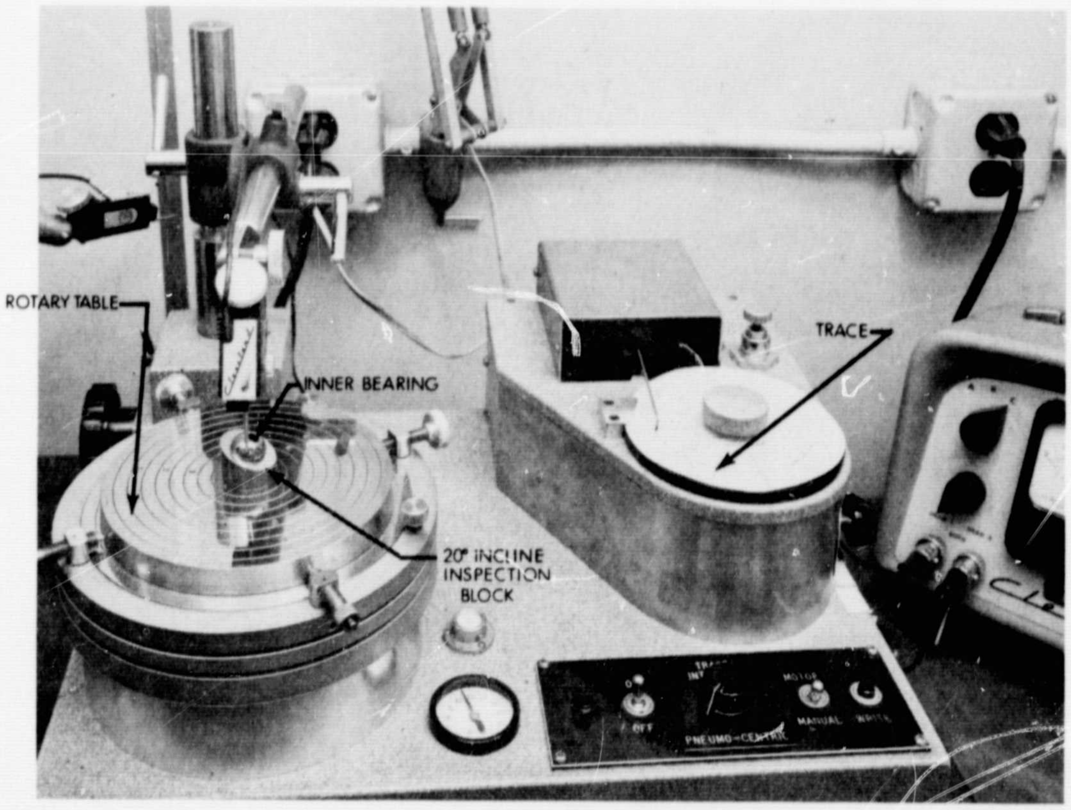


Fig. 12 Sphericity inspection of the inner hemisphere.

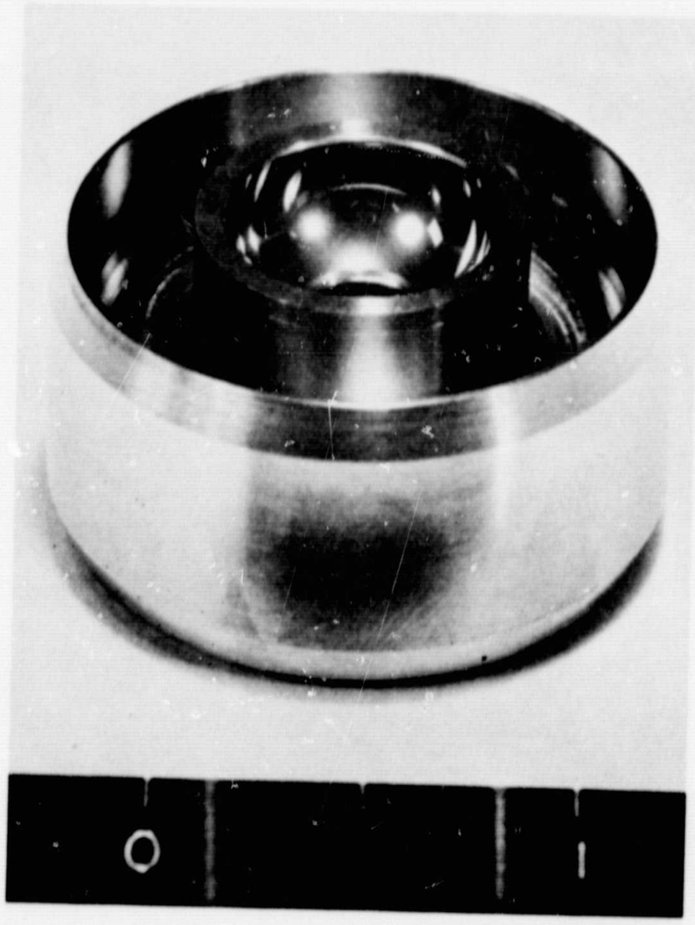


Fig. 13 Outer bearing in the beryllium wheel hub.

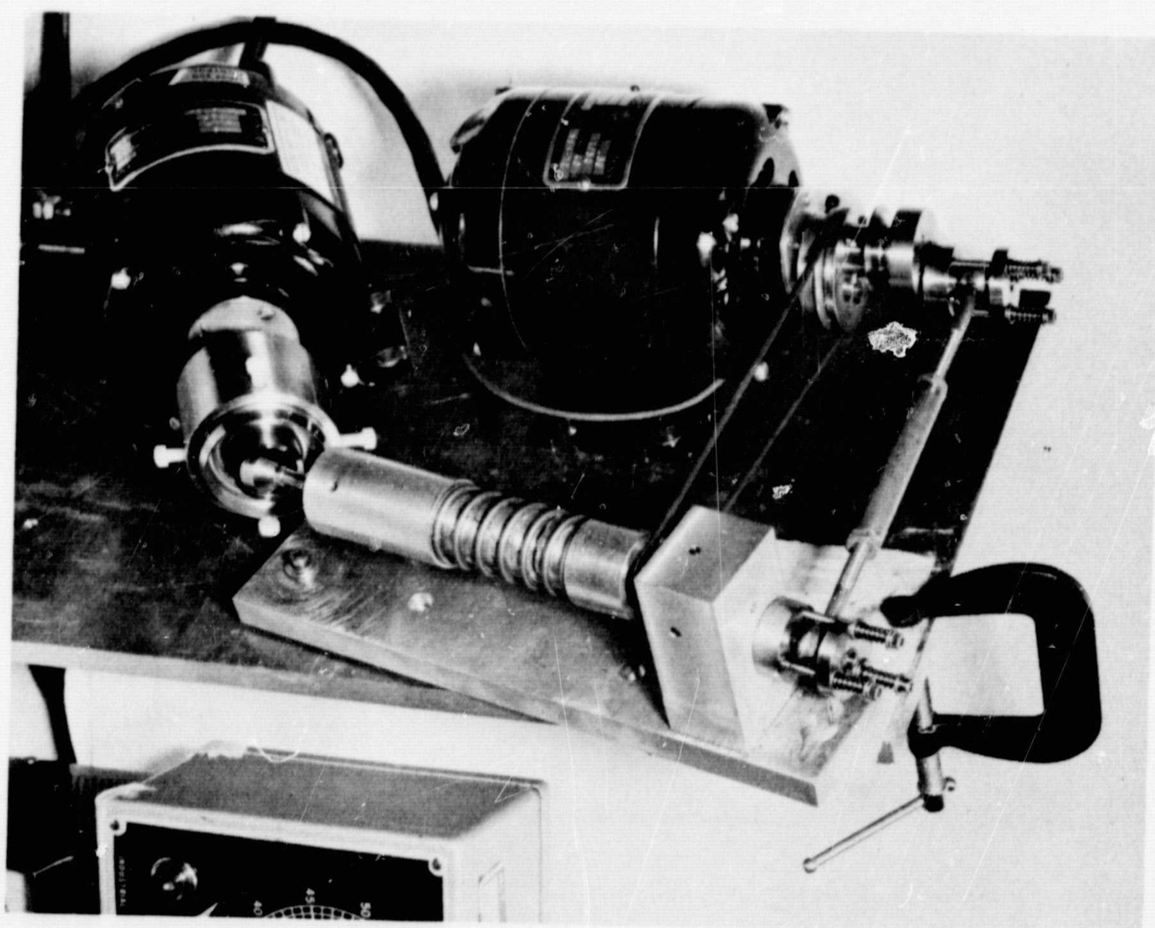


Fig. 14 Outer-bearing lapping machine.

3.3 Grooving by Sputter Etching

Most gas-bearing grooving techniques: lapping, tooling, acid-etching, air abrasive, etc., have problems relating to the uniformity of the grooves, profile, and finish. In addition, some techniques result in highly stressed, fractured, groove edges. Grooving by sputter etching through a mask can avoid all of these problems.[7]

Sputter etching is the reverse of sputtering generally used to deposit coatings on various surfaces (usually flat) and materials. The "target" is the material that is to be deposited on a substrate. Accelerated gas ions (usually argon) bombard the target and ejected particles from the target will deposit on surfaces placed in their path. If a part is placed on the target and covered with a mask, the pattern in the mask will be etched into the part by the gas ions.

Etching through a mask by sputtering has a distinct advantage over acid etching. The etching action of acid is sideways as well as down, so that the mask is undercut; this results in sloping sidewalls. Sputter etching, on the other hand, etches by line of sight and therefore produces straight sidewalls.

The sputtered surface finish will generally reproduce the original finish in uniform materials. Composite materials such as tungsten carbide in a matrix of cobalt, coarse-grained ceramics, or plasma-deposited materials such as chromium oxide, will result in rougher finishes. At low power (about 100 watts) to avoid severe heating, etching rates are reasonable (about a microinch per minute for deposited chromium oxide), and are easily controlled.

Sputter etching through a mask will provide (with proper controls) uniform well-defined and reproducible groove patterns. Groove depths can be maintained within five microinches along the groove and groove to groove. While this is easily done in a conventional flat thrust bearing, a hemisphere presents a somewhat more difficult task. Two problems are in creating the three-dimensional mask and in obtaining some knowledge of the plasma field in the sputtering setup. Flat masking is conventional and easily accomplished. A well-fitting spherical mask is more difficult to manufacture.

A spherical mask form (Fig. 15) is machined and plated with 0.0025 to 0.0035 inch of nickel. The nickel is coated with photo-resist and exposed through a cylindrical mask (in principle, Fig. 16) in a rotating fixture. The pattern is developed and then the nickel is etched through. The resulting mask is then leached from the aluminum form (Fig. 17).

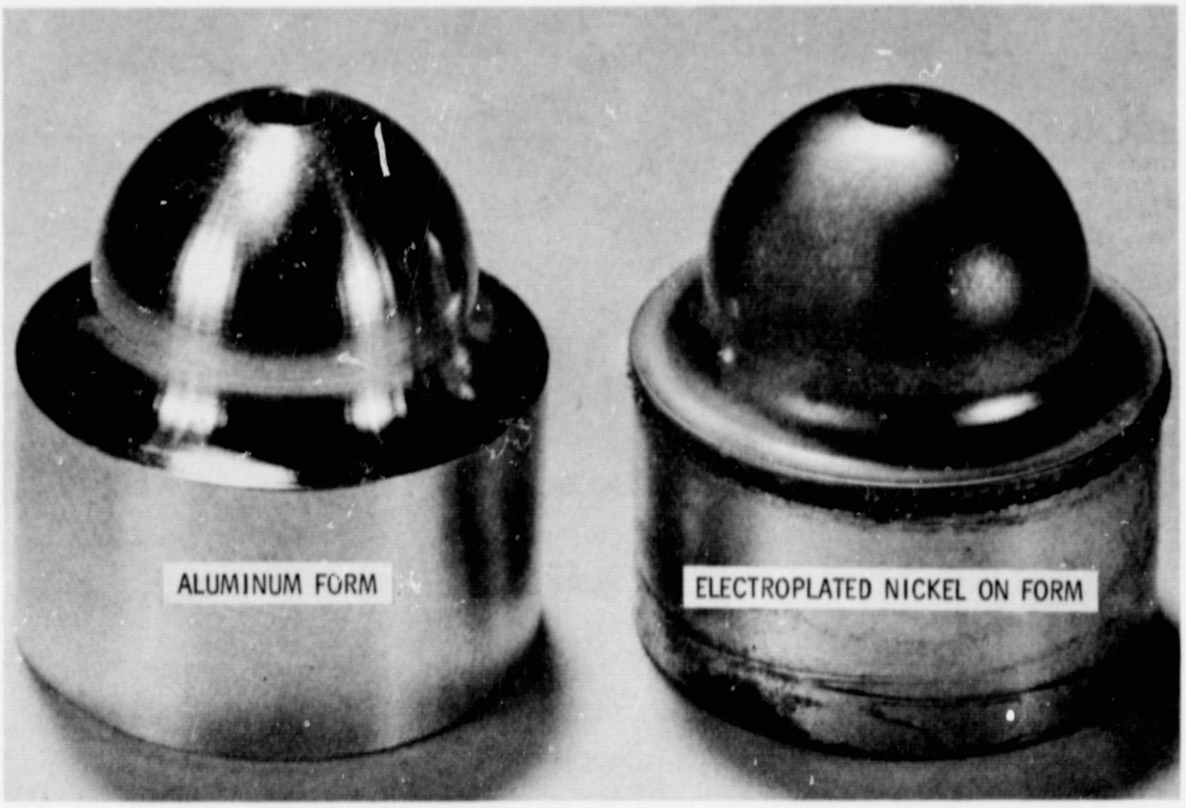


Fig. 15 Plating of spherical mask on aluminum form.

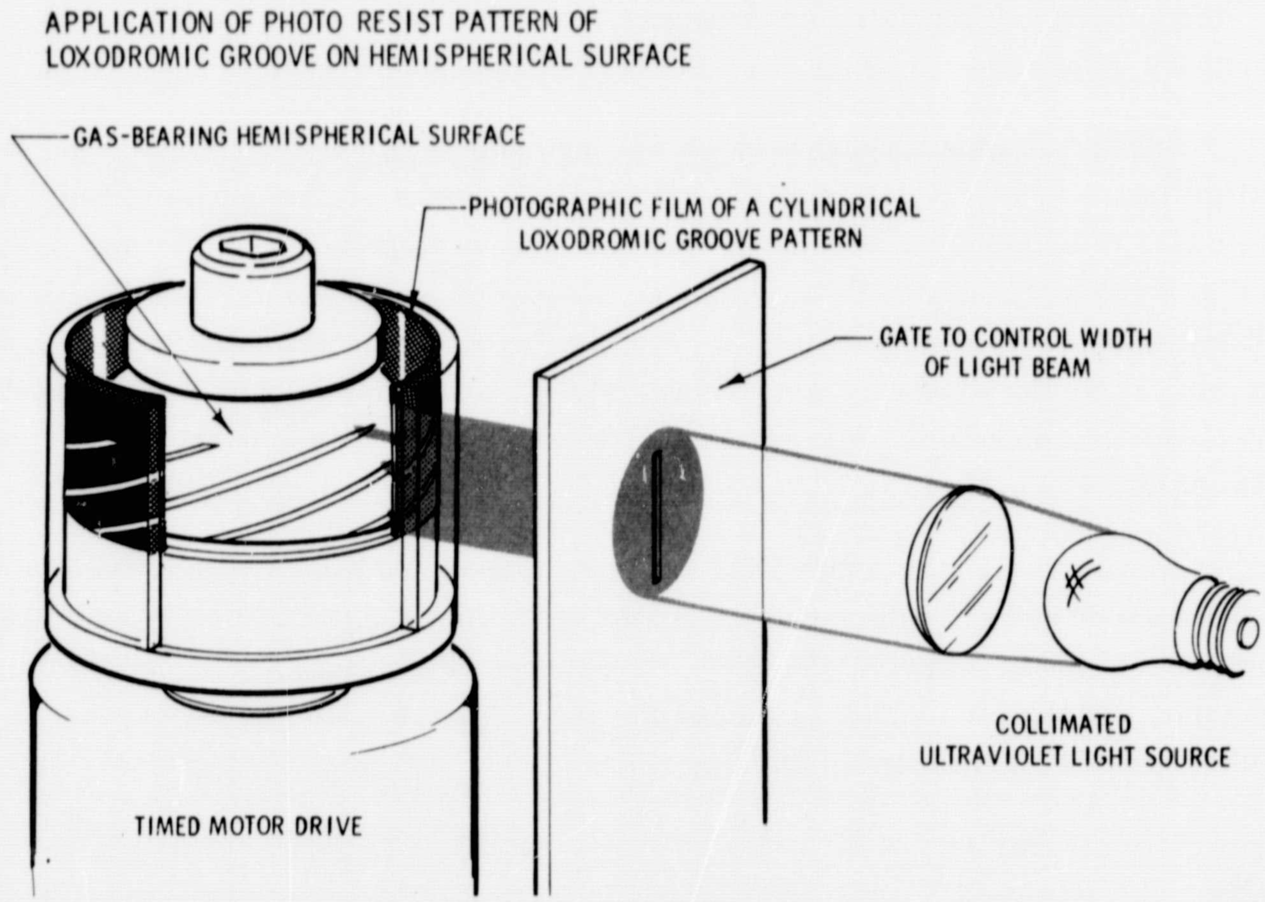


Fig. 16 Application of photo-resist pattern of loxodromic groove on hemispherical surface.

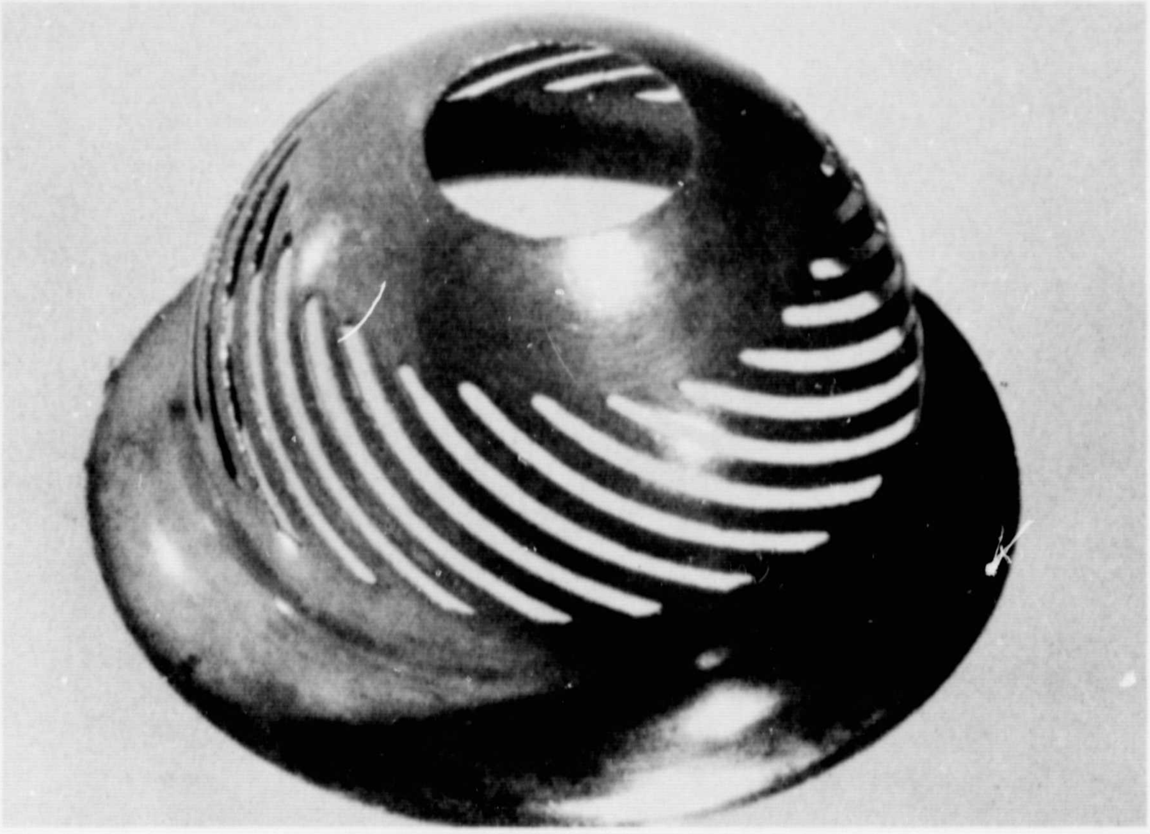


Fig. 17   Acid-etched mask after leaching from aluminum form.

The mask pattern can also be machined into the nickel plating with an end mill and the indexing device used in the old grooving machine. A pair of machined masks is shown in Fig. 18.

The machined masks have the advantage of good straight sidewalls, and the acid-etched mask groove edges have sloped sidewalls. Again, the sidewalls are sloped due to the omnidirectional properties of the etching action. Spraying techniques, different etchants, etc. can be varied to reduce the slope effects. Efforts are presently underway to redesign the fixturing to expose a photo-resist pattern, registered, on both sides of the mask in order to etch simultaneously through from both sides.

The mask is then located over the final-lapped inner bearing (Fig. 19) with a cap mask to fix the latitude angle of the groove terminus. The bearing then is etched in a conventional RF sputtering machine. Uniformity and quality of the grooving is dependent upon power levels and positioning within the ionized field. Particular equipment requires some experimentation to establish the proper parameters. Special fixturing, such as shaped electrodes and rotating fixturing, is being investigated for multiple sputtering.

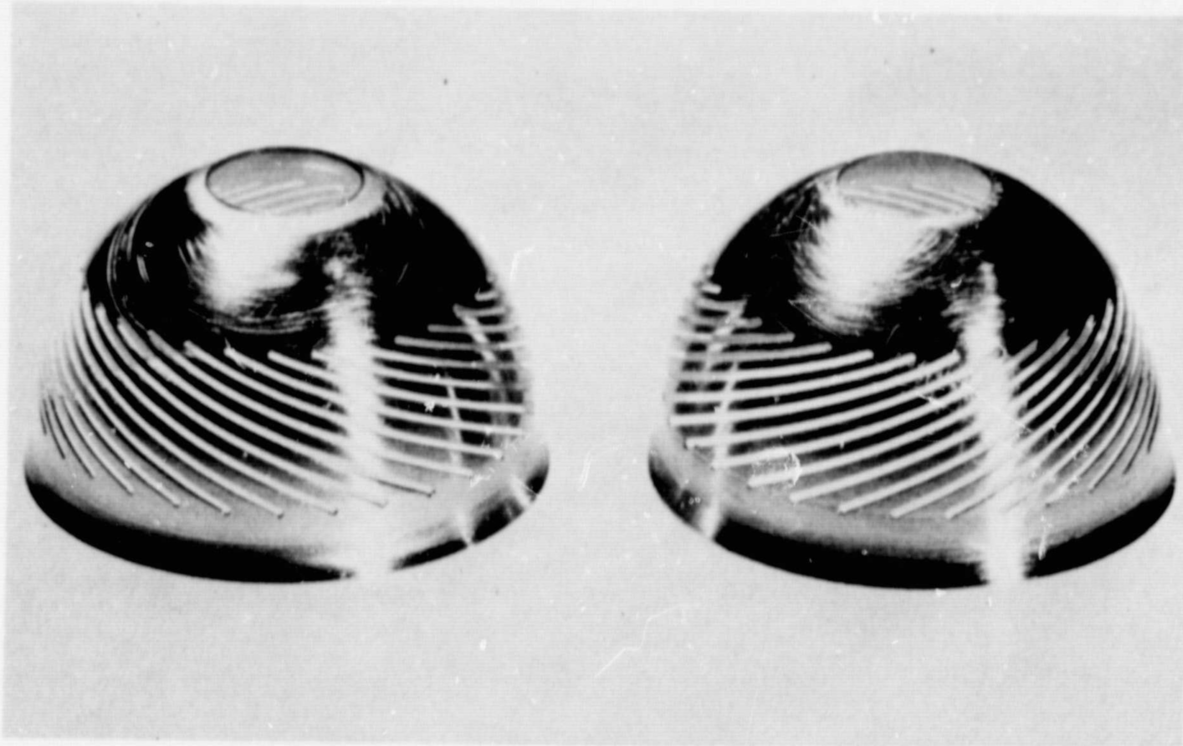


Fig. 18 A pair of machine-grooved nickel masks.

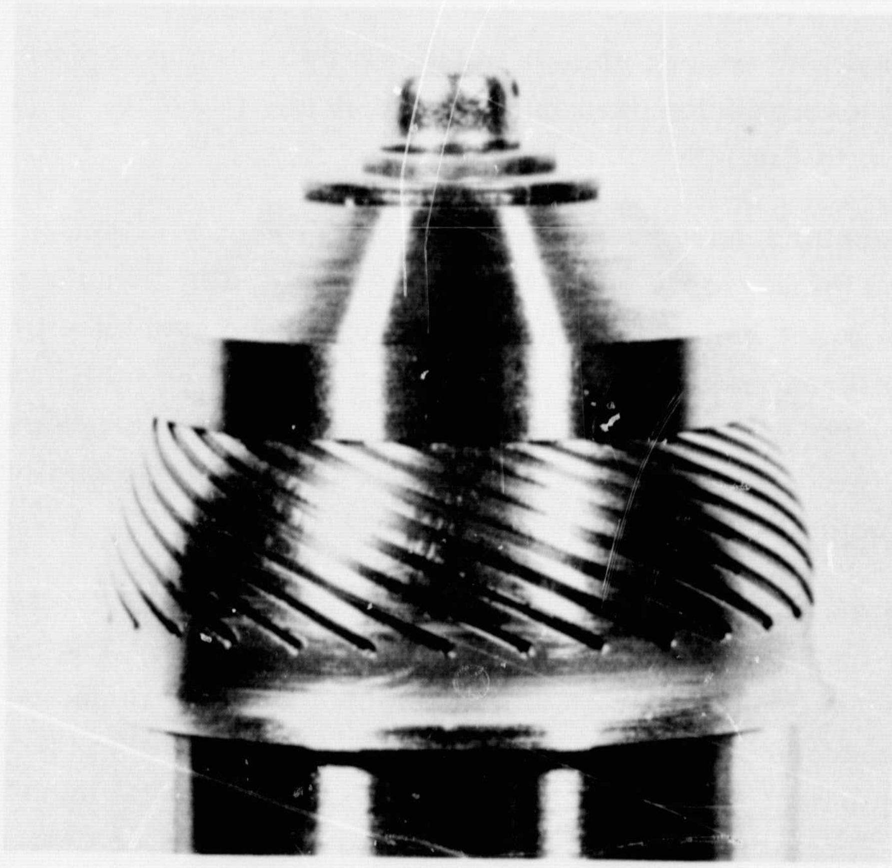


Fig. 19 Mask mounted on inner bearing ready for sputter etching.

The mask pattern is perfectly reproduced on the bearing surface and the depth is controlled by the sputtering machine parameters (Fig. 20). Low power levels reduce heat distortion problems and result in sputtering times of about two to three hours on Laboratory equipment. Masks can be reused a few times as they sputter away as well.

4. CONCLUSIONS

The fabrication of hemispherical gas bearings has progressed in the past year from a highly skilled hand-crafted art to a more reproducible, production-oriented procedure. The output is not only a less expensive procedure but also one that produces a more accurate and repeatable bearing. The greatest improvement is the development of the sputter-etching techniques. This is an excellent process for fine patterns (as the microelectronics industry knows) on all materials. The work, masking and etching, on a three-dimensional surface, however, is unique, and probably is an advance in the state-of-the-art in this field.

We expect to follow this development with the sputter depositing of coatings for bearing surfaces. The advantages are high-quality nonporous coatings of any desired material and an in-house, controlled operation. This work should lead to better coatings than those presently available.

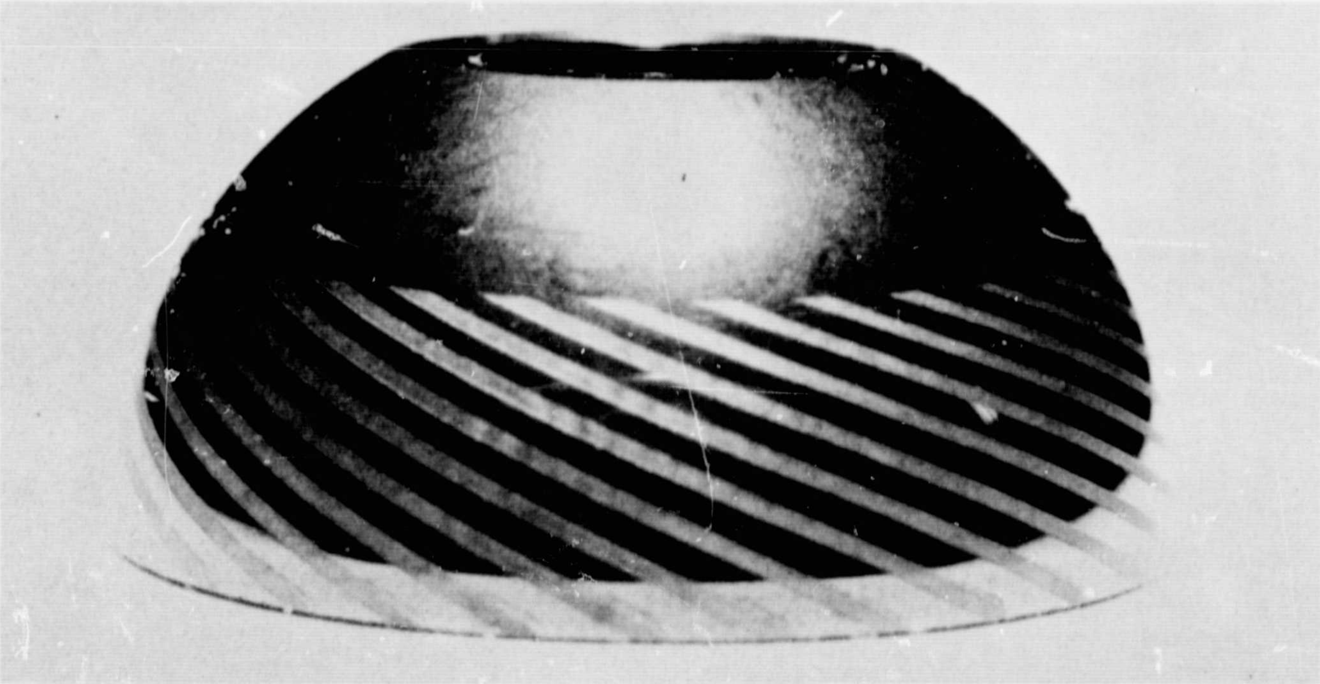


Fig. 20 Sputter-etched grooving on a spherical bearing.

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