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1977 PROGRESS REPORT ON MANUFACTURING TECHNIQUES FOR GRAVITY PROBE B GYROSCOPES

By John R. Rasquin
Materials and Processes Laboratory

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16. ABSTRACT

The purpose of this report is to present additional and improved techniques for the manufacture of Gravity Probe B gyroscopes. Improvements discussed include the redesign of the housings, new techniques for indentation of the electrode surfaces, and a new rotor ball lapping machine. These three items represent a significant improvement in operation of the gyroscope and also make possible the fabrication of a gyroscope which will meet flight requirements.

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INTRODUCTION

This report presents the significant improvements in the manufacture of gyroscope rotors and housings which have been developed since the publication of the first report on this project [1]. Background information and a detailed description of manufacturing techniques are given in Reference 1. During the past year, a major redesign of the gyroscope housing became necessary due to operational difficulties. In addition, a new rotor ball lapping machine has been designed, tested, and proven to be outstanding. Finally, there has been a radical advancement in the technique for forming the six electrode cavities in the fused silica gyro housings.

HOUSING REDESIGN

The initial MSFC gyro design incorporated a spinup groove ground around the inside periphery of the housing flange. There were two main difficulties with this design:

a. It was impossible to accelerate the rotor to the 1977 milestone speed of 100 Hz or the required flight speed of 200 Hz because of aerodynamic drag. This drag resulted from inadequate clearance or pumping space between the rotor ball and the gyro housings so that the vacuum pumping system could not properly exhaust all gas from the inside of the gyro. The drag limited the maximum rotor speed to 20 Hz at ambient temperature.

b. There was no place to deposit the superconducting pickup loop for the Josephson Junction Magnetometer used for rotor position sensing.

The new MSFC housing design overcomes these difficulties. The rotor achieved a speed of 109 Hz before control of the electrostatic suspension system failed in a July 1977 spinup test.

The new housing design concept is shown in Figure 1. The rotor now spins on an axis 90 degrees displaced from the previous spin axis and there are two spinup grooves instead of one. Since the two spinup grooves are displaced 180 degrees from one another, there is less tendency for the rotor to be forced off center by the spinup gas. Because the spinup groove is no longer ground into the housing flange, the pickup loop for the Josephson Junction can be sputtered onto the flange. Spinup grooves are now cut into the quartz housings by an ultrasonic milling machine. During the year 1976-77, manufacture of the housing shells became more routine and are now made and finished lapped by a subcontractor. The electrodes are still indented and finished by MSFC's Materials and Processes Laboratory as are the custom made dowel pins. These pins are ground and fitted to meet accuracy requirements.

The new spinup grooves cause a problem in alignment and fit-up procedures because the grooves allow the close fitting alignment ball to move slightly. A more detailed explanation of the alignment and fitting procedures is described in Reference 1. An alternate method of aligning the housings during assembly is presently being considered because a ball with a hole drilled through its center allows misalignment of the housing up to approximately 50 μin. However, the housings are now made concentric enough so that they can be better aligned in the Indiron or Talyrond machines and then clamped and fitted with dowel pins.

HOUSING ELECTRODES

Formerly, the electrodes were made by indenting the edges in a jig boring machine and then lapping them to depth with a lapping machine. This method is extremely slow and it is very difficult to maintain sphericity because of the limited stroke of the lap due to the indented edges. The process, which is described in Reference 1, took approximately 3 weeks to accomplish.

A new method of chemical milling the electrode cavities has been demonstrated. The edge of the cavities are indented as before on a jig borer, but now the areas are etched away with undiluted hydroflouric acid. Moreover, the acid will etch the electrodes to the desired depth and sphericity in only 19 min.

Figure 2 shows the teflon tub used to hold the housings in place in the acid etchant. Obviously, both housings must be etched in the same bath for the same amount of time for uniformity. Beeswax is used as a resist. The two pegs (the tops of which can be seen in Fig. 2) hold the housings to the bottom of the tub when the acid is being poured out. It was found, through experiment, that if the surface to be etched is initially smooth, the electrode surface will meet smoothness specifications subsequent to etching. It is apodictical that any surface will become rougher when etched if it is perfectly smooth to start with. However, since less than a mil is etched away, the generated roughness is inconsequential.

BALL LAPPING MACHINE

The first ball lapping machine used by this laboratory consisted of four small dc motors mounted so that their shafts rotated in a horizontal plane with the shaft ends pointed towards a common center. The machine is described in detail in Reference 1. The problem with this arrangement is gravity. Since the ball and the laps are pulled down by gravity, the laps have a tendency to lap more at the top of the circle of rotation rather than uniformly over the circle of rotation.

A new ball lapping machine [2,3,4] has been designed to overcome the difficulty. With previous practice it has been somewhat of a black art to make a good rotor ball round to less than $\pm 12 \times 10^{-6}$ mm ($\pm 0.50\,\mu$in.). Recently, it was possible for an unskilled student trainee to make a rotor ball to $\pm 6 \times 10^{-6}$ mm ($\pm 0.25\,\mu$in.) roundness with the new machine in approximately 16 hr. Although it takes as much time to process a ball as before, the new machine is so consistent that instead of one ball in four being satisfactory, all rotor balls meet roundness requirements, with the obvious savings in time.

The new machine is shown in Figure 3. This machine uses the same four motors that the previous machine used to rotate the laps. However, the motors are mounted at 120 degree intervals around a circle on the base plate of the machine with their shafts pointing upward at an angle of 20 degrees. A spring-loaded rotary lap is fitted on each shaft. Upward vector thrust of the spring loaded laps is equal to the weight of the ball plus the downward vector thrust of the spring loaded lap of the fourth motor which is mounted directly over the top of the ball. Each lap has 4 degrees of freedom to follow the contours of the ball. Figure 4 shows one of the lap holders with a pitch lap in it which is spring-loaded on the motor shaft. Saw cuts in the lap holder allow the lap 2 degrees of freedom while spring loading provides the third. All motor shafts must be adjusted so that they point through a common center. This adjustment is made by mounting pointers on the ends of the motor shafts and adjusting the position of the motors so that all four pointers come together as shown in Figure 5.

Each lap motor has a reversing switch operated by a motor driven camshaft as shown in Figure 6. There are 16 possible combinations (2^n) of these switches, but only 6 are beneficial for lapping purposes. The camshaft with the 6 switch sequences is rotated at 1 rpm so that each switch position is held for 10 sec. The Table gives the switch sequences and assumes that each lap motor rotates in the direction as indicated by CW (clockwise) and CCW (counterclockwise) with respect to the ball. The motor drive cams could be replaced with solid state digital logic controls if desired.

TABLE. SWITCH SEQUENCES

Position	Switch 1	Switch 2	Switch 3	Switch 4
1	CW	CCW	CCW	CW
2	CCW	CW	CW	CCW
3	CW	CW	CCW	CCW
4	CCW	CCW	CW	CW
5	CW	CCW	CW	CCW
6	CCW	CW	CCW	CW

Two types of laps are used with the ball lapping machine. A metal lap made of brass or mehanite machined in the form of a cylinder with approximately a 6 mm wall thickness is used to fine grind the ball from 0.75 mm oversize to 0.025 mm oversize. The laps need to be approximately 40 mm long to allow for wear. 500 grit aluminum oxide is used for this operation. Fine grinding takes approximately 8 man h. The rotor ball at this time should be within 380×10^{-6} mm of round. The quartz ball is now ready for polishing.

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CONCLUSIONS

The new MSFC Model 77 gyroscope redesign (Fig. 7), the new chemical milling indenting process for making the housing electrodes, and the new ball lapping machine are considered significant developments. They represent considerable future tangible savings in time and money to the Government. For instance, the first gyroscope made by the Materials and Processes Laboratory took more than 4 months to fabricate and assemble, but the Model 77 was built in less than 1 month by employing the chemical milling process and new ball lapping machine.

In fact, the new ball lapping machine is so much faster and accurate that the capability limit for measuring roundness of rotor balls at MSFC has been reached and exceeded. Rotors are now being made to closer roundness tolerances by the Materials and Processes Laboratory than our present standard Model 51 Talyrond can measure. Since the performance of the relativity gyroscope depends on the degree of roundness of the rotor, it will soon be necessary to fabricate rotors to one more order of magnitude in roundness. This reduction in tolerance limits will require a like improvement in measuring capability.

It is concluded, therefore, that this development effort has been very successful and will result in improved gyroscope performance for the Gravity Probe "B" project.

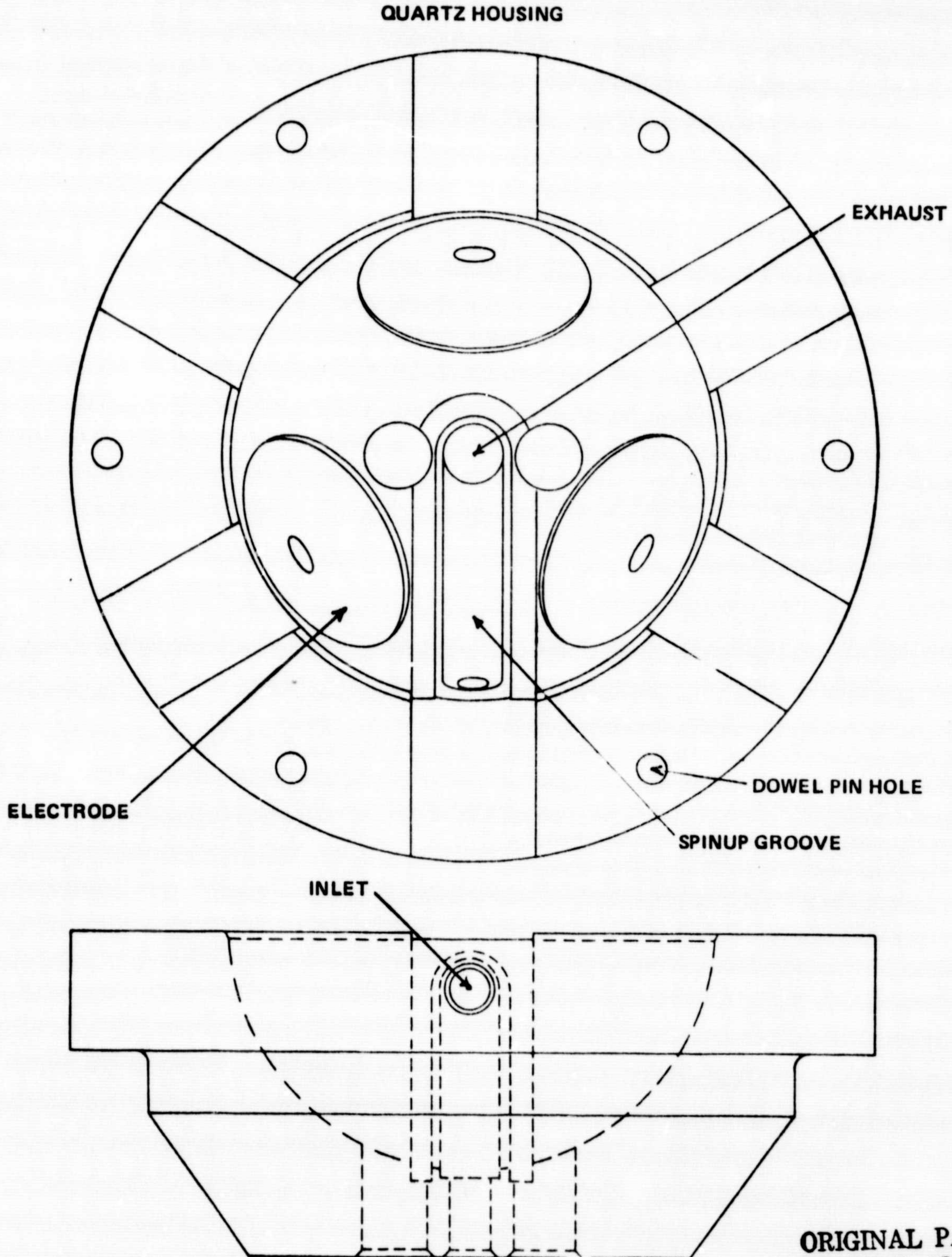

Figure 1. Simplified new housing design.

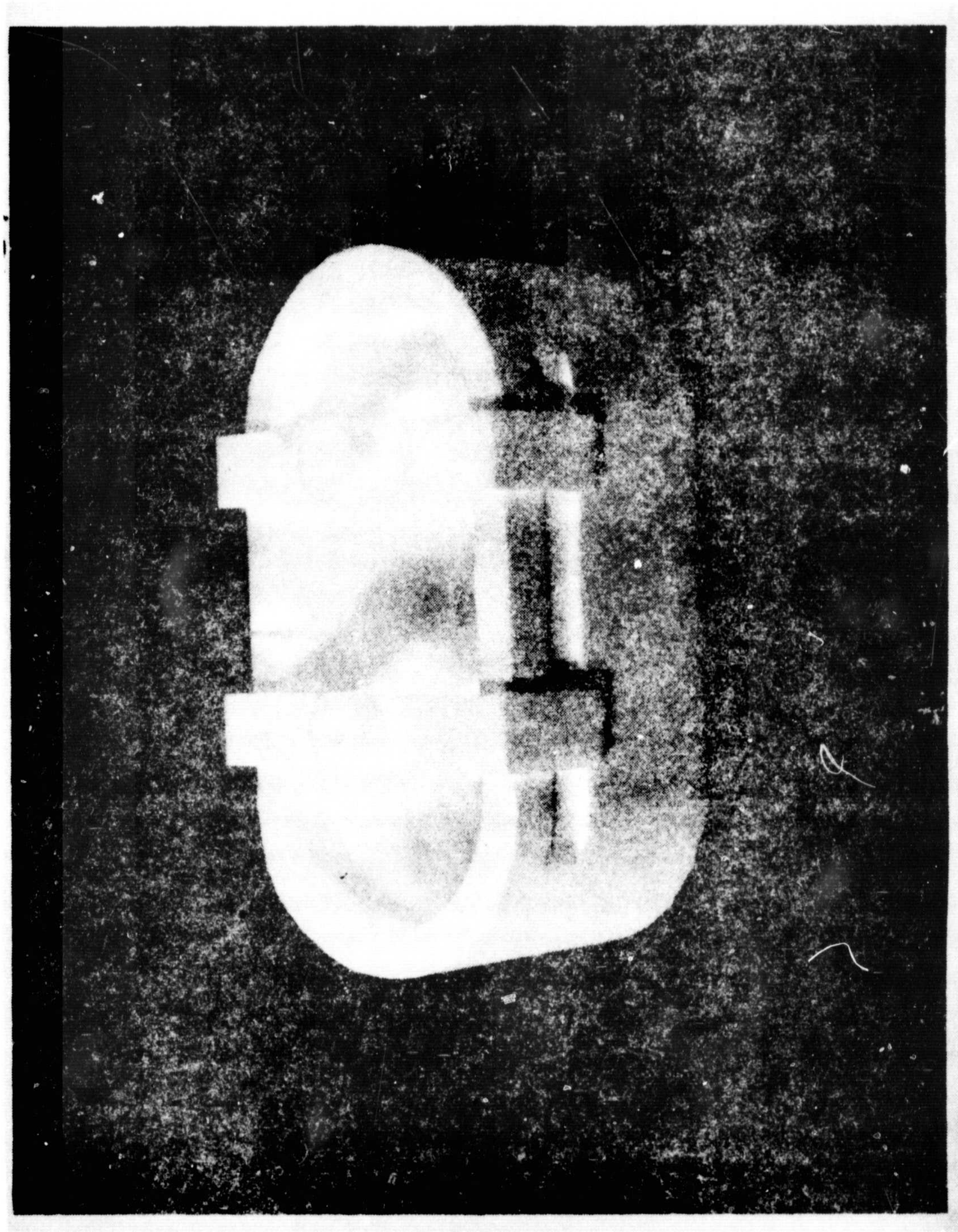

Figure 2. Teflon etching tub.

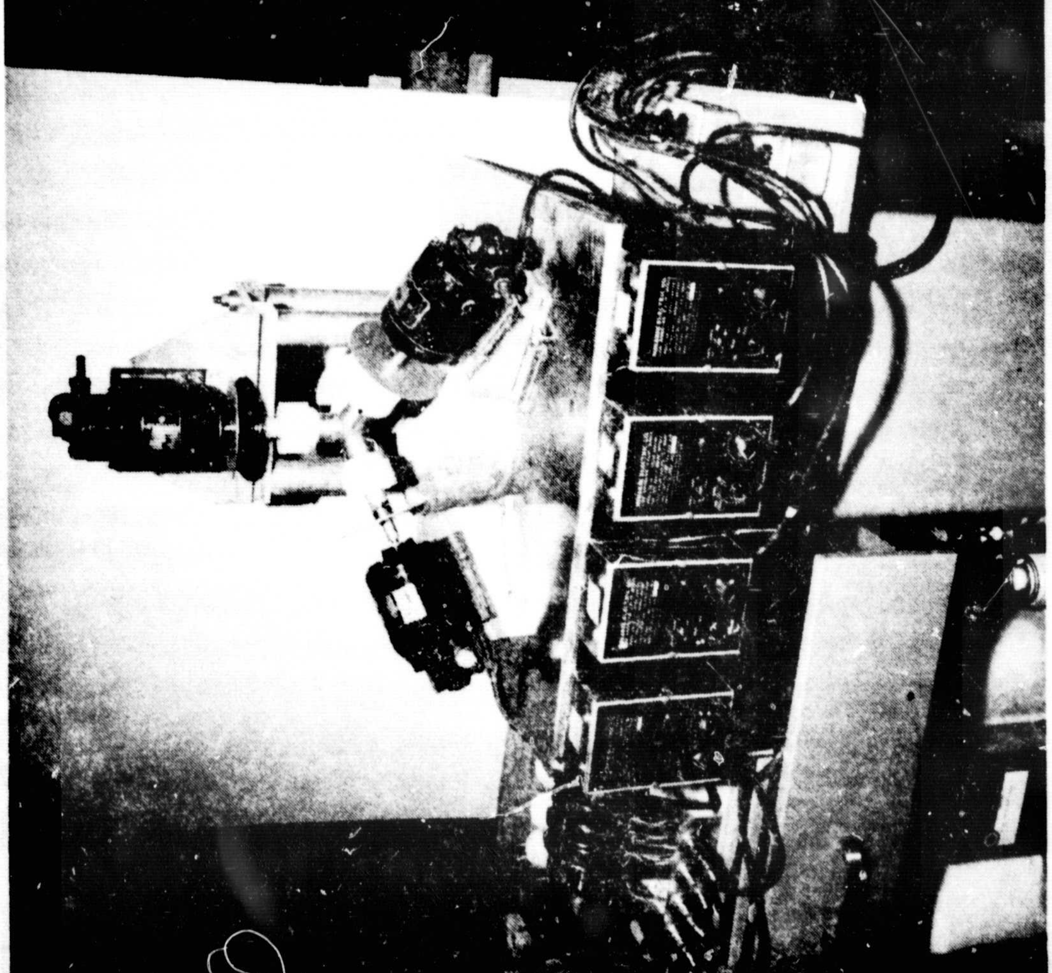

Figure 3. New ball lapping machine.

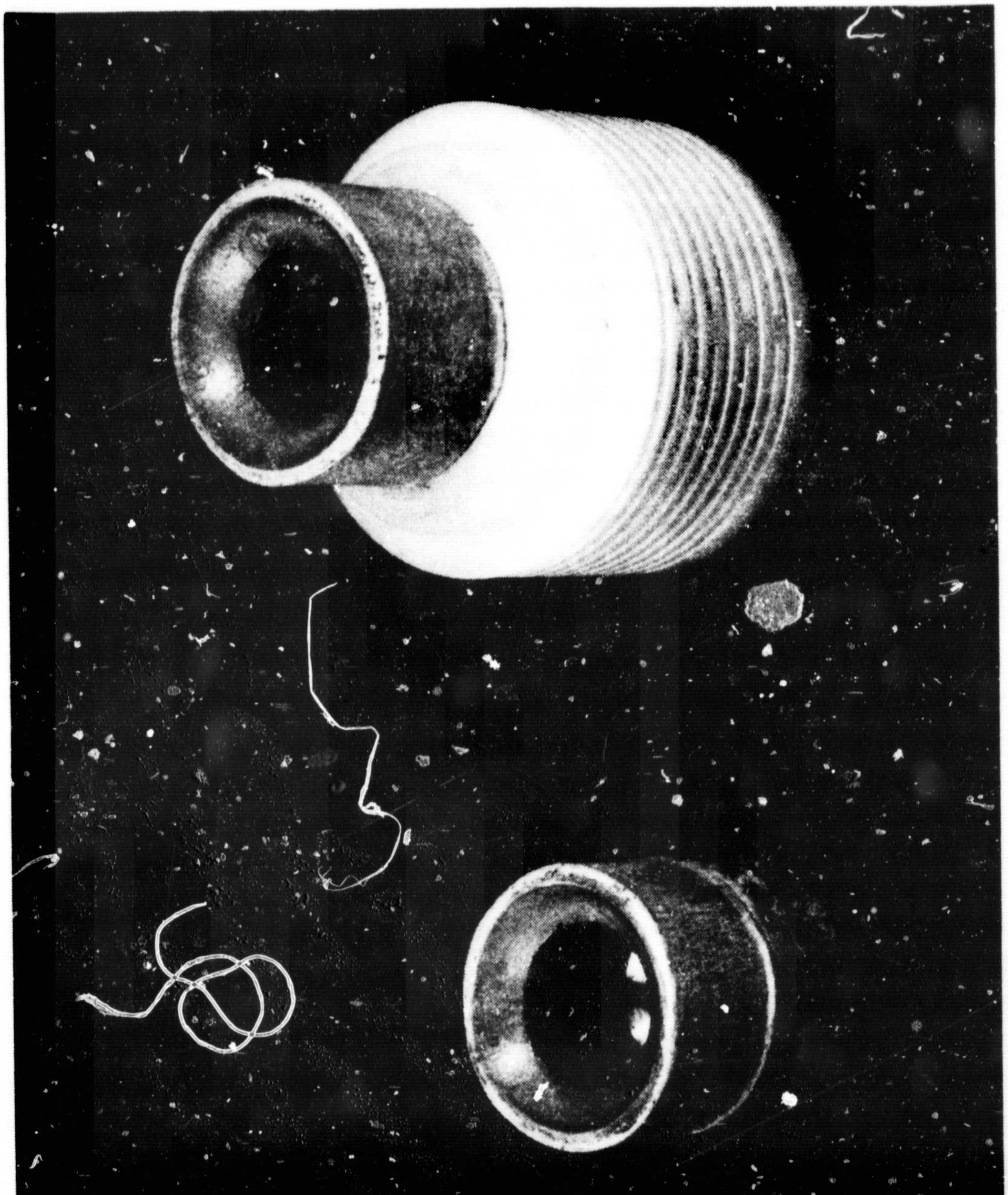

Figure 4. Ball laps and holder.

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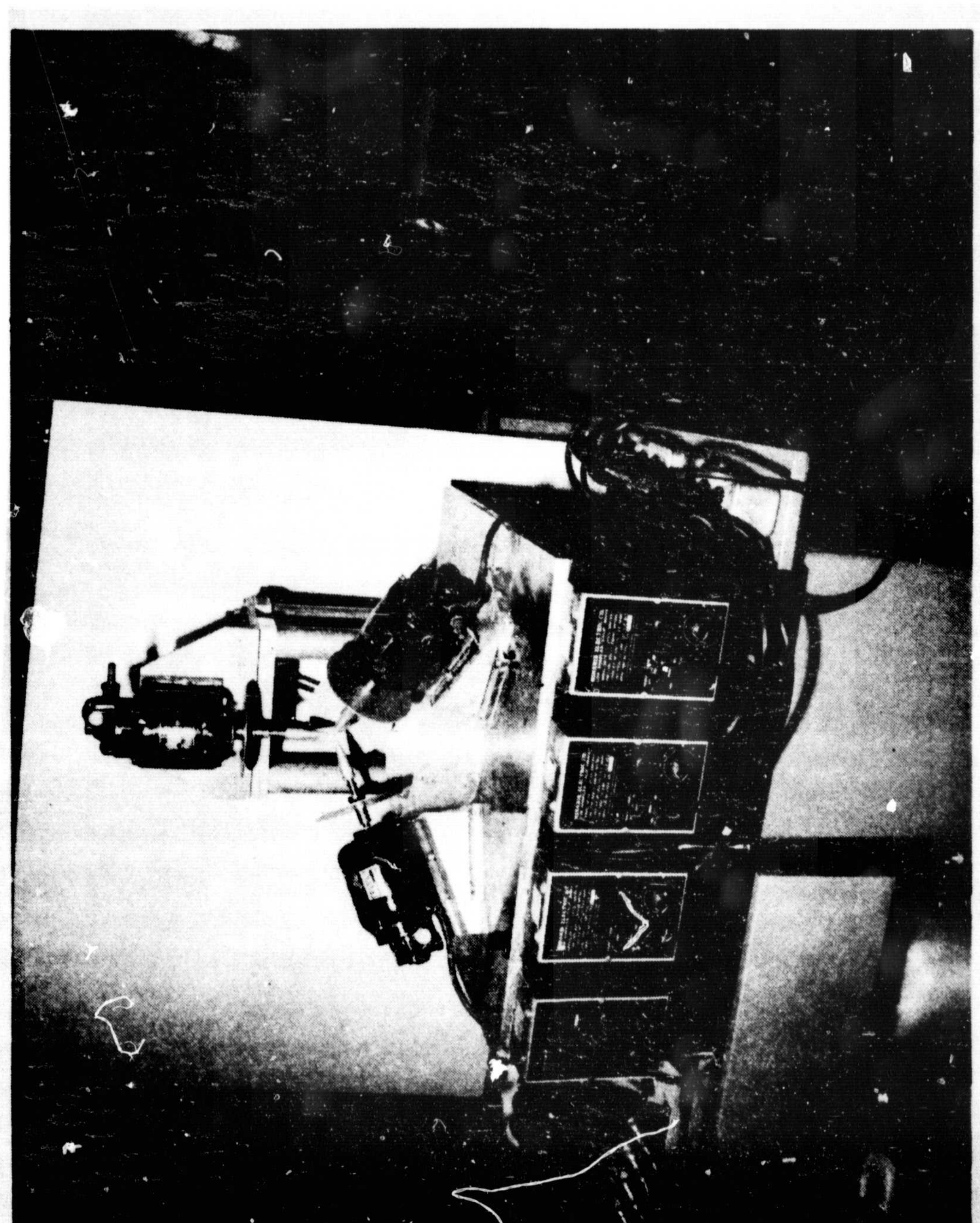

Figure 5. Alignment of lapping motors.

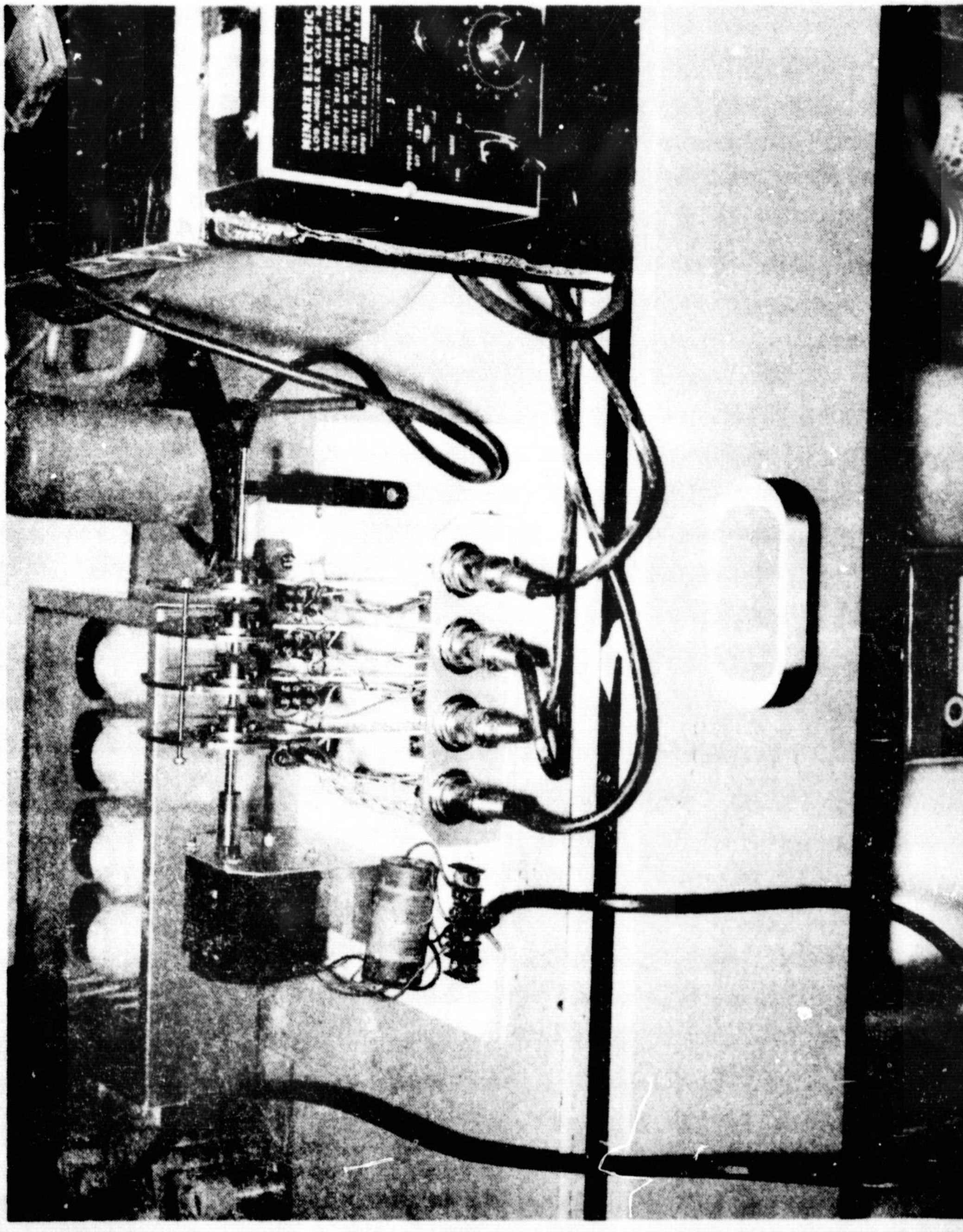

Figure 6. Cam operated reversing switch.

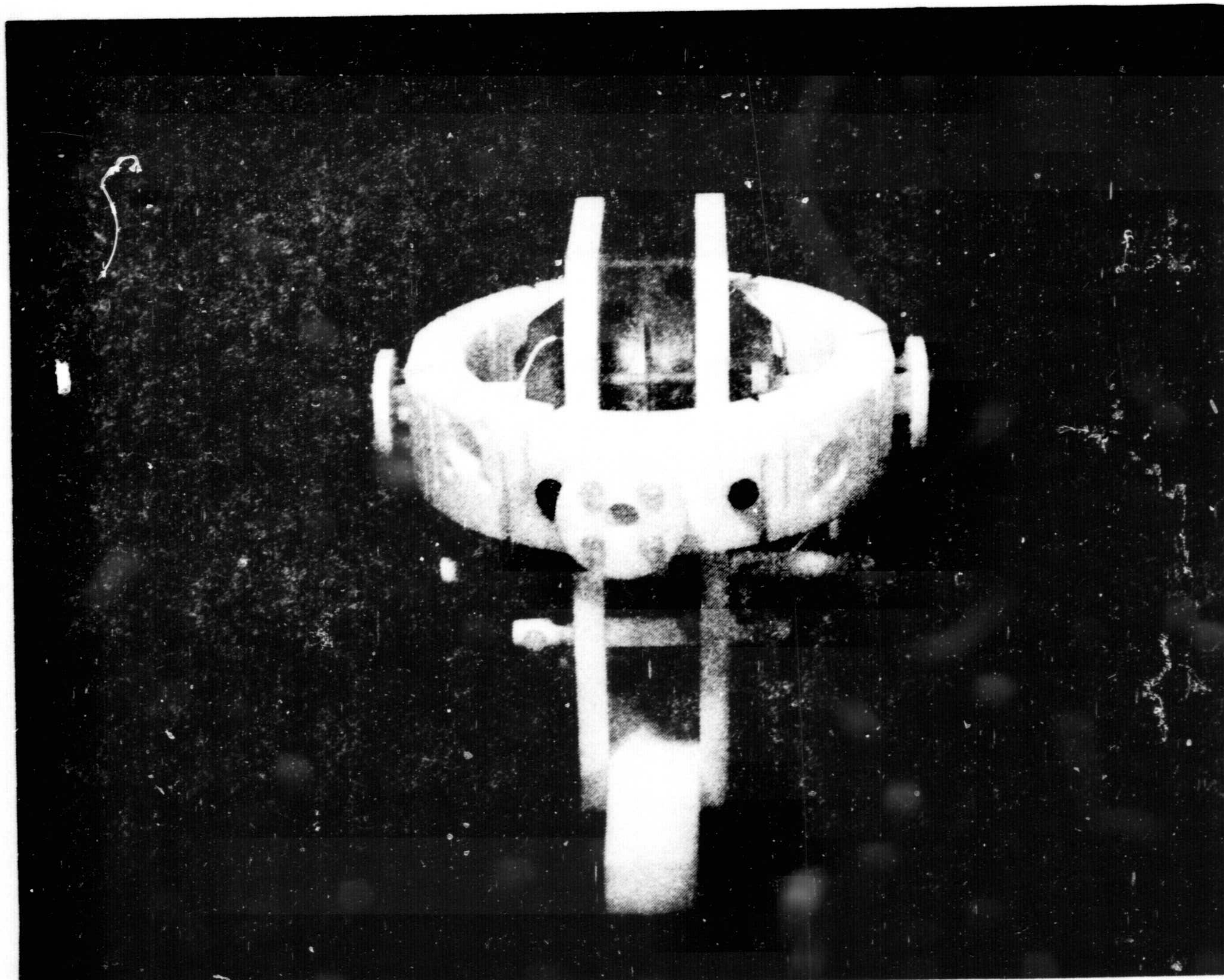

Figure 7. Completed gyroscope in new Teflon mount.

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APPROVAL

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By John R. Rasquin

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or nuclear energy activities or programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

R. J. SCHWINGHAMER
Director, Materials and Processes Laboratory

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