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THE DEVELOPMENT OF A MULTI-CATHODE ELECTRON GUN

by

Lester A. Roberts

7 September 1973

Contract No. 952784

This work was performed for the Jet Propulsion Laboratory, California Institute of Technology, sponsored by the National Aeronautics and Space Administration under Contract NAS7-100.

FINAL REPORT

Watkins-Johnson Company
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I. PURPOSE AND GOALS OF THE PROJECT

The purpose of this project was to develop the technology for a multi-cathode electron gun (MEG) which is capable of automatically interchanging cathode structures of a microwave electron tube upon command. The need for this type of device was predicated upon the requirements for ultra-long life traveling-wave tubes to be used in spacecraft transmitters for the outer planet missions of the 1970 decade and beyond. The technique of interchanging cathode structures would allow the extension of single cathode tube life by a multiplying factor equal to the number of cathodes enclosed in the vacuum envelope. Reliable, unattended operation from nine to fifteen years may be needed for some of these missions and this poses a life requirement which exceeds the present capability of cathode technology. This MEG technique actually would extend the life of a microwave electron tube into the range of fifty to one hundred years.

The conception of this idea and the demonstration of the potential feasibility with an electro-mechanical model must be credited to members of the technical staff of the Jet Propulsion Laboratory. The task, which was performed on this project at the Watkins-Johnson Company, was to reduce the MEG concept to actual vacuum tube practice using materials and techniques which are compatible with long-life, space-type traveling-wave tube design.

The development consisted of three major periods. In the first period, the major components of the device were tested under various thermal, vacuum, and mechanical operating conditions. In this phase, problems with the initial concept were determined, corrections were devised and refinements were further tested. The second phase was to construct an exact mechanical model of the gun using all the materials and mechanisms which were to be used in the final operating device. This device was further tested under the thermal and vacuum conditions to which it would be subjected during bakeout and processing and then final operation. The third phase was to build an operating gun with functioning cathodes which could deliver an electron beam to a collector electrode. This gun was capable of interchanging cathode positions and performing all the other required functions of the MEG device. A fourth phase of operating the gun in conjunction with a microwave tube was never carried out because of program funding limitations.

The JPL Concept

The JPL concept basically consists of mounting a number of cathode structures on a rotating platform. Each cathode assembly and its surrounding focus electrode must be capable of being sequentially moved into position behind the anode of the electron gun. By rotation of the platform, the different cathodes can be placed into the operating position.

This is shown more clearly in a photograph of the JPL conceptual model of the MEG shown in Figure 1. Here the cathode platform is shown with eight cathode assemblies. The bottom-most assembly represents the active cathode position and is indicated by a lighted cathode. The anode of the gun is not shown on this model. The thermostatic motor, which provides the rotational force necessary to advance the platform position can be seen behind the cathode platform in both Figs. 1 and 2. The torque producing element of the thermostatic motor is a spirally wound bi-metal element located in the motor housing. When activated by an electric current, the bi-metal element heats and imparts rotational motion to the motor shaft. The cathode platform is then advanced to the next cathode position. On removal of the current, the motor cools and returns to its original rotational position and is then ready for the next cycle of advance. The engagement between the motor and the cathode platform is accomplished by spring dogs which push on driving pins in the driving platform.

For correct electron gun performance, the active cathode must be precisely positioned with respect to the anode-electrode of the electron tube. The extreme accuracy of positioning is accomplished by two-aspects of the mechanism design. The first is the platform bearing system. This uses a precision bearing technology capable of providing repeatable radial position of the cathode with respect to an absolute point in space of 0.0002 inch from cathode to cathode. The second aspect of the accurate location system is the locking arm. It positions the azimuthal position of the cathode with respect to an absolute point in space of 0.0003 inch from cathode to cathode. When the cathode advancing cycle is complete and the motor has cooled and returned to its original rotational position, the finger of the locking arm is driven into a precisely located slot in the cathode driving platform. This brings the cathode position into the correct azimuthal position within the accuracy stated above.

The power to operate the thermostatic motor is provided by an external, programmed power supply. The programming circuit obtains information as to the location of the cathode platform rotational position and the locking arm engagement by means of telemetry contacts which are part of the gun mechanism.

The JPL conceptual model proved the feasibility of the MEG concept. Watkins-Johnson's assignment was to reduce this electro-mechanical concept to actual vacuum tube practice. Material choices had to be made which were compatible with the requirements of the individual components. Extensive testing was necessary to determine reliability of the various mechanisms under the extreme conditions of high vacuum operation and 500 degrees C vacuum processing temperatures.

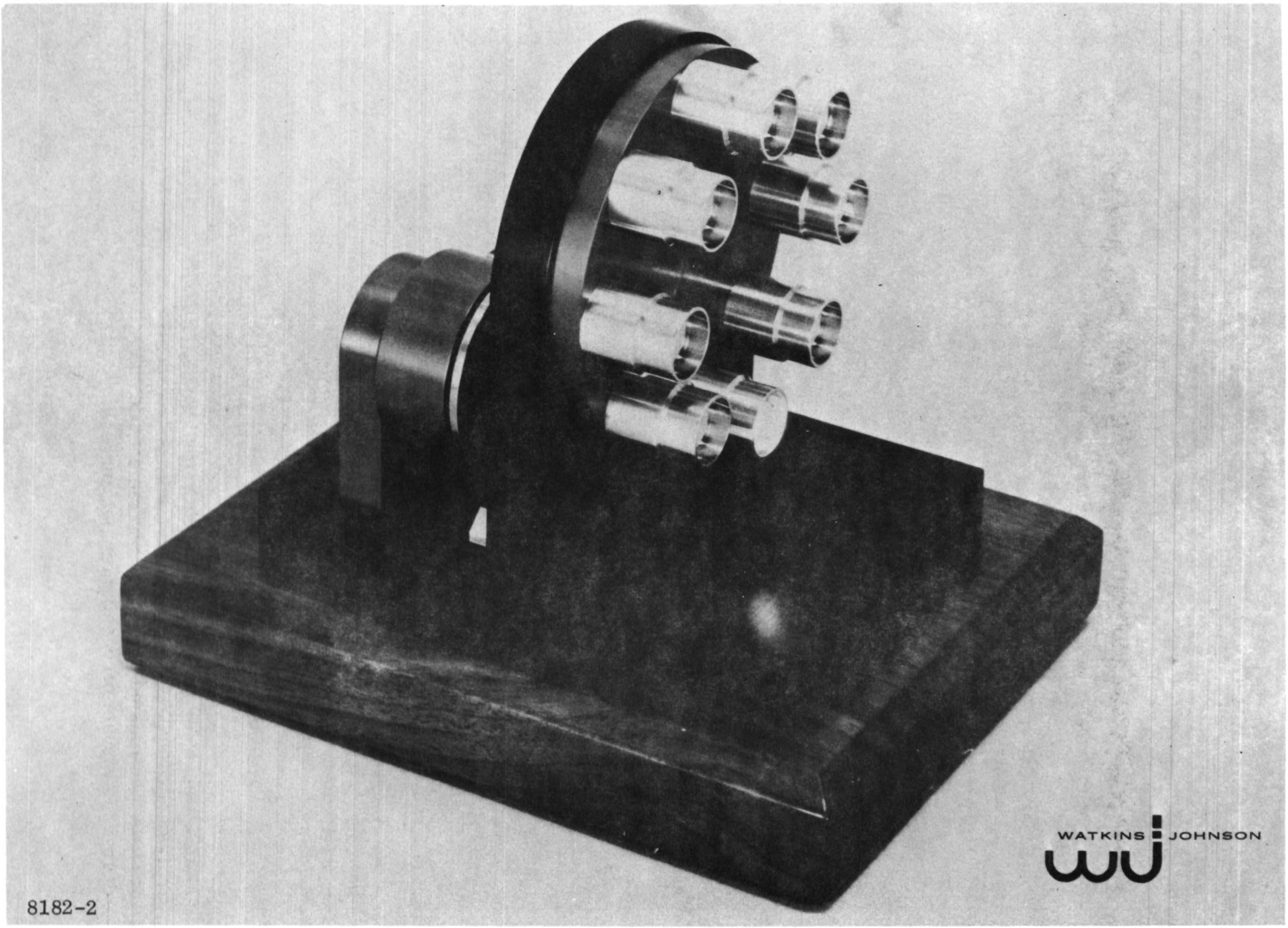

Fig. 1 - Photograph of the Jet Propulsion Laboratory conceptual model of the MEG.

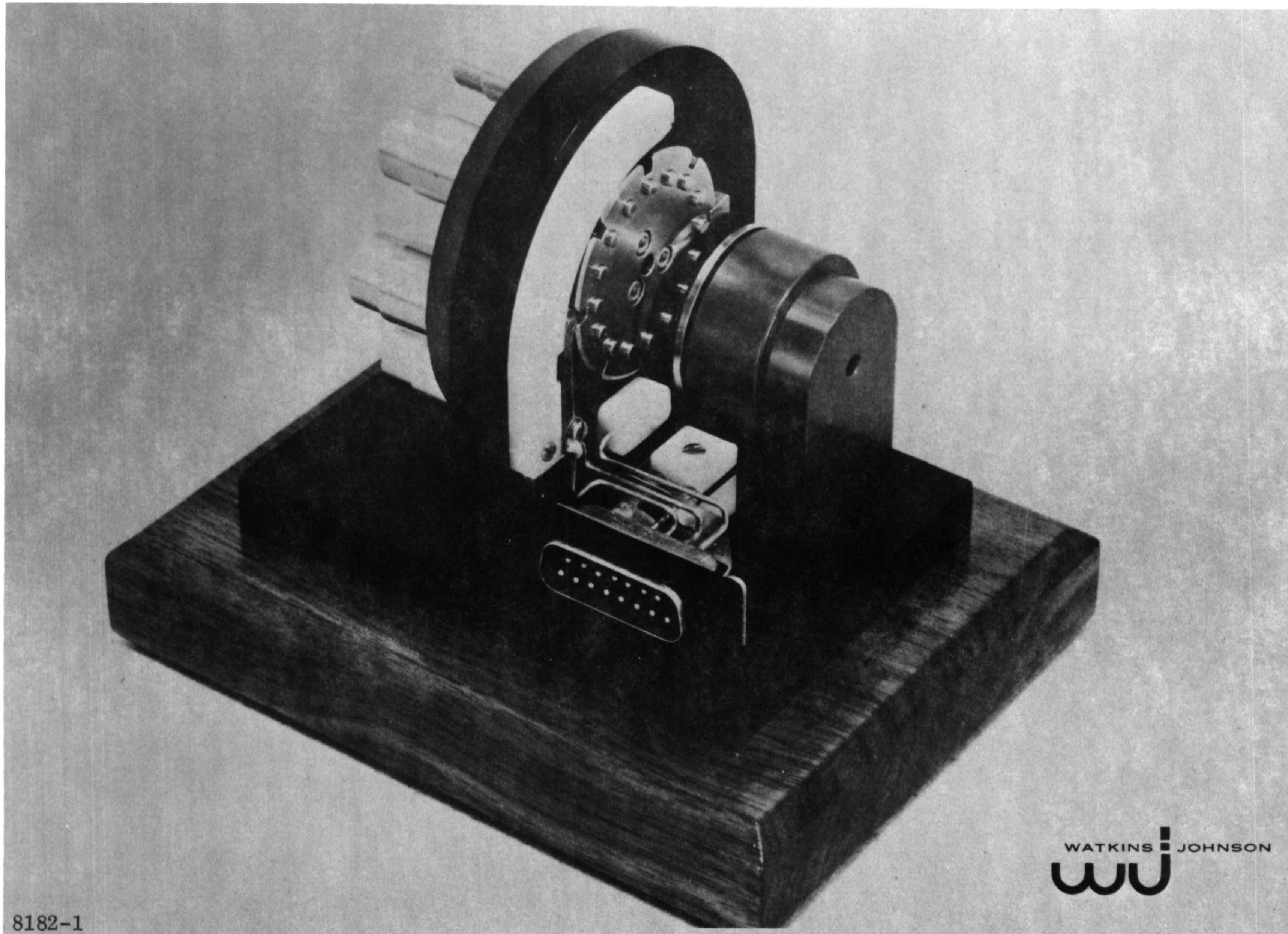

Fig. 2 - Photograph of the reverse side of the Jet Propulsion Laboratory conceptual model of the MEG.

The final evolution of the design is shown in the cross-sectional drawings of Fig. 3 and Fig. 4. Figure 3 is a longitudinal cross-section through the gun. It shows the relative location of the cathode platform with its cathode assemblies to the anode of the gun above and the motor mechanism below. A lateral cross-section through the gun is shown in Fig. 4 at a plane between the motor driving plate and the driving platform looking in the direction of the driving platform.

This shows the detent arm in its normal rest position with its telemetry contact open. In this view the locking arm has not quite returned to its rest position in the driving platform slot. When it is completely seated, the locking arm telemetry contact will be opened to indicate the completion of the platform advance cycle.

II. BRIEF SKETCH OF THE DEVELOPMENT

Most of the historical details of the project are unimportant, so only a brief outline of the development program will be given.

Initial Bearing Concept

The initial concept of the main bearing design is shown in Fig. 5. It consisted of a ball bearing raceway which can be seen as part of the main cathode platform at the right and on the inner body structure shown on the left. The ball-separator ring is shown in the center. The force necessary to hold the bearing together was provided by a small thrust bearing at the end of the shaft. It is not shown in this photograph. This bearing was constructed and tested through bakeout temperatures of 500 degrees C. Starting torque and platform advancing torque were measured before and after the bakeout process. It was found that this type of bearing did not have a sufficiently low torque characteristic for this application. This type of bearing does not work with strict rolling motion of the balls. Some skidding motion of the balls is also involved and this leads to increased torque as loading forces between the two bearing races are increased. A major redesign of the bearing was made at this point in the program.

Construction Materials

Choice of materials for the MEG were based upon the following list of requirements:

1. The ability to meet mechanical or electrical requirements.
2. The ability to meet vacuum cleanliness requirements.
3. The ability to meet mechanical stability at high temperatures.
4. No inclusion of certain chemical components which could damage cathode operation.

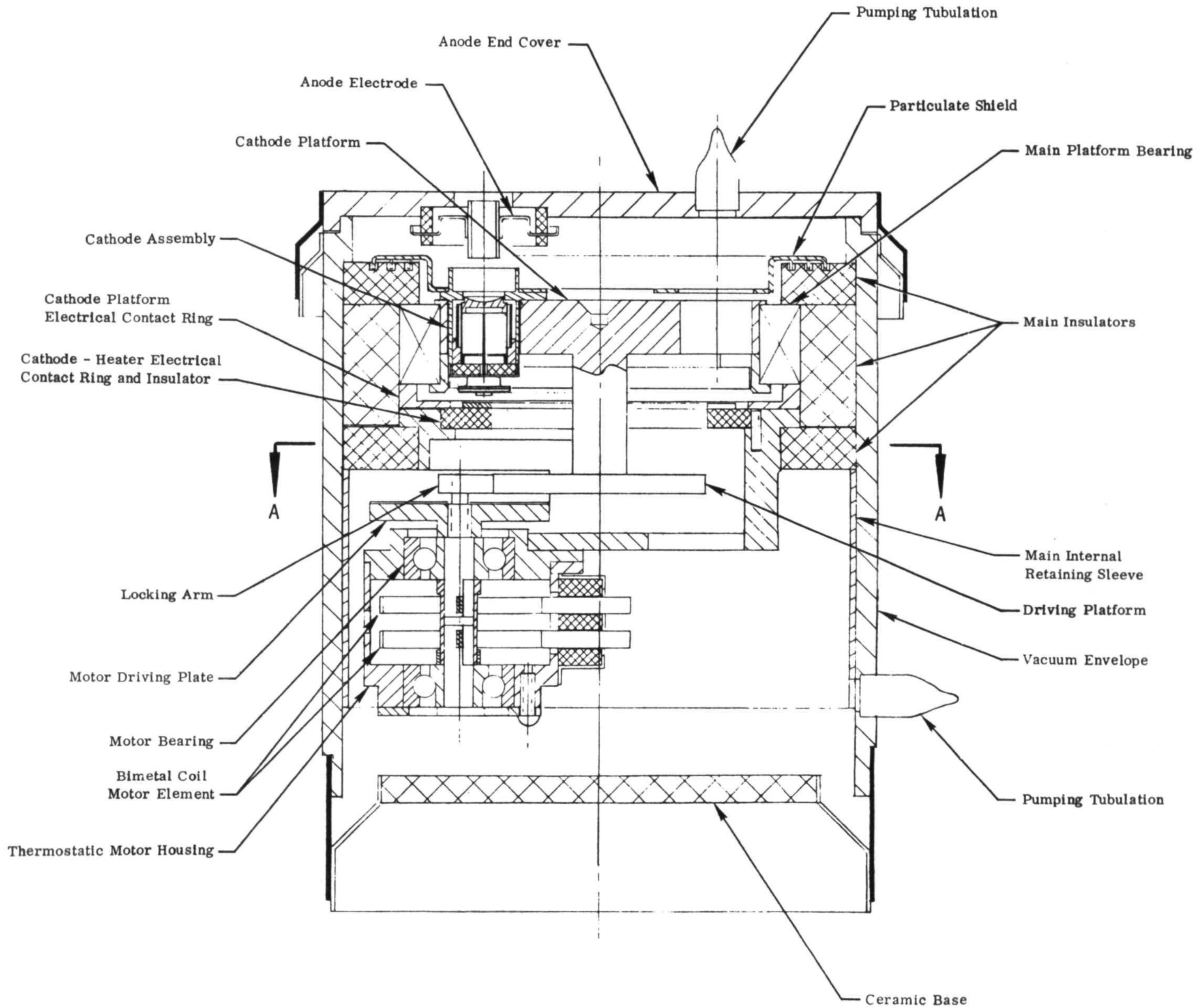

Fig. 3 - Cross-sectional view of the MEG.

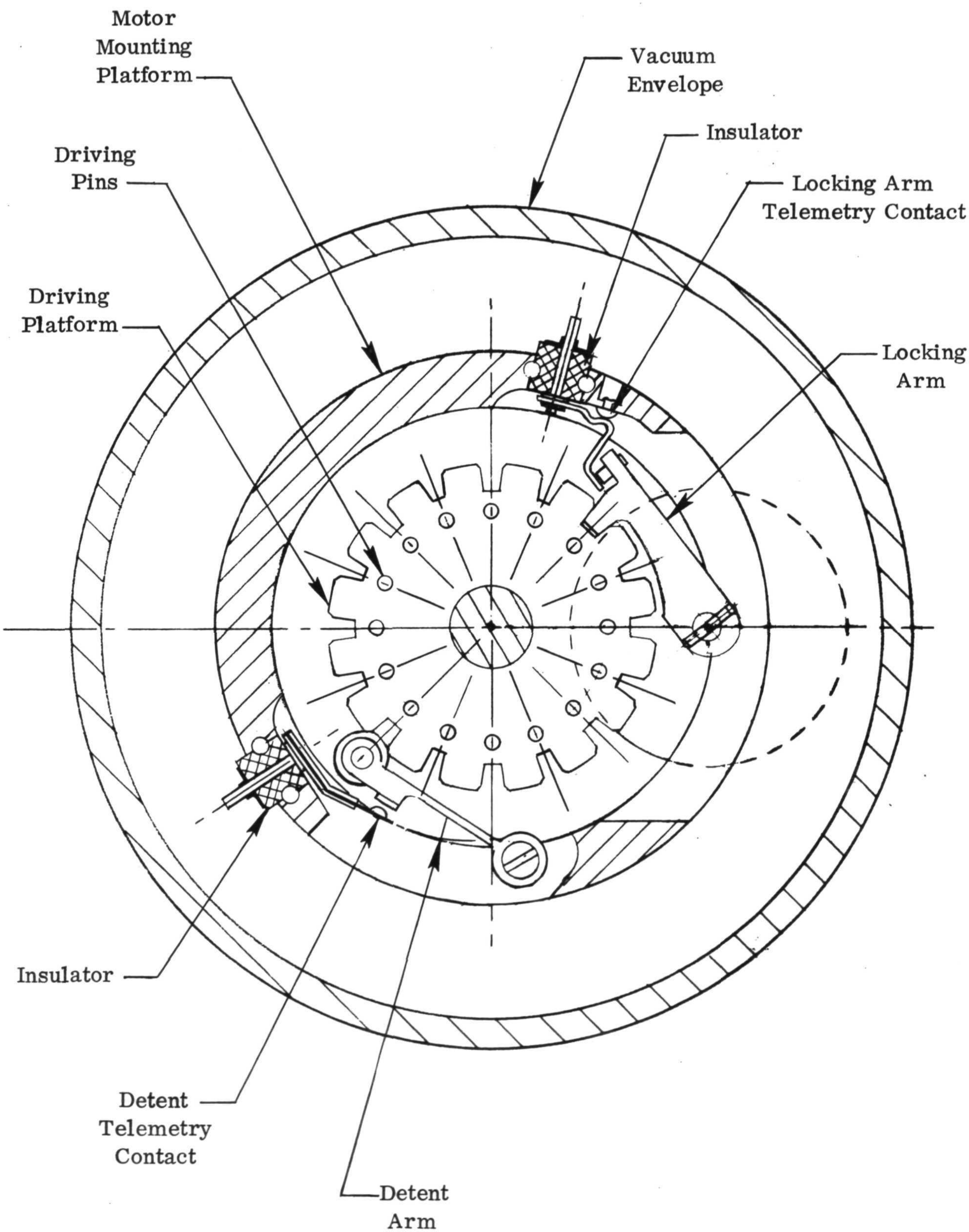

Fig. 4 - Cross-sectional view parallel to, but not through, Plane A-A of Fig. 3 (see text).

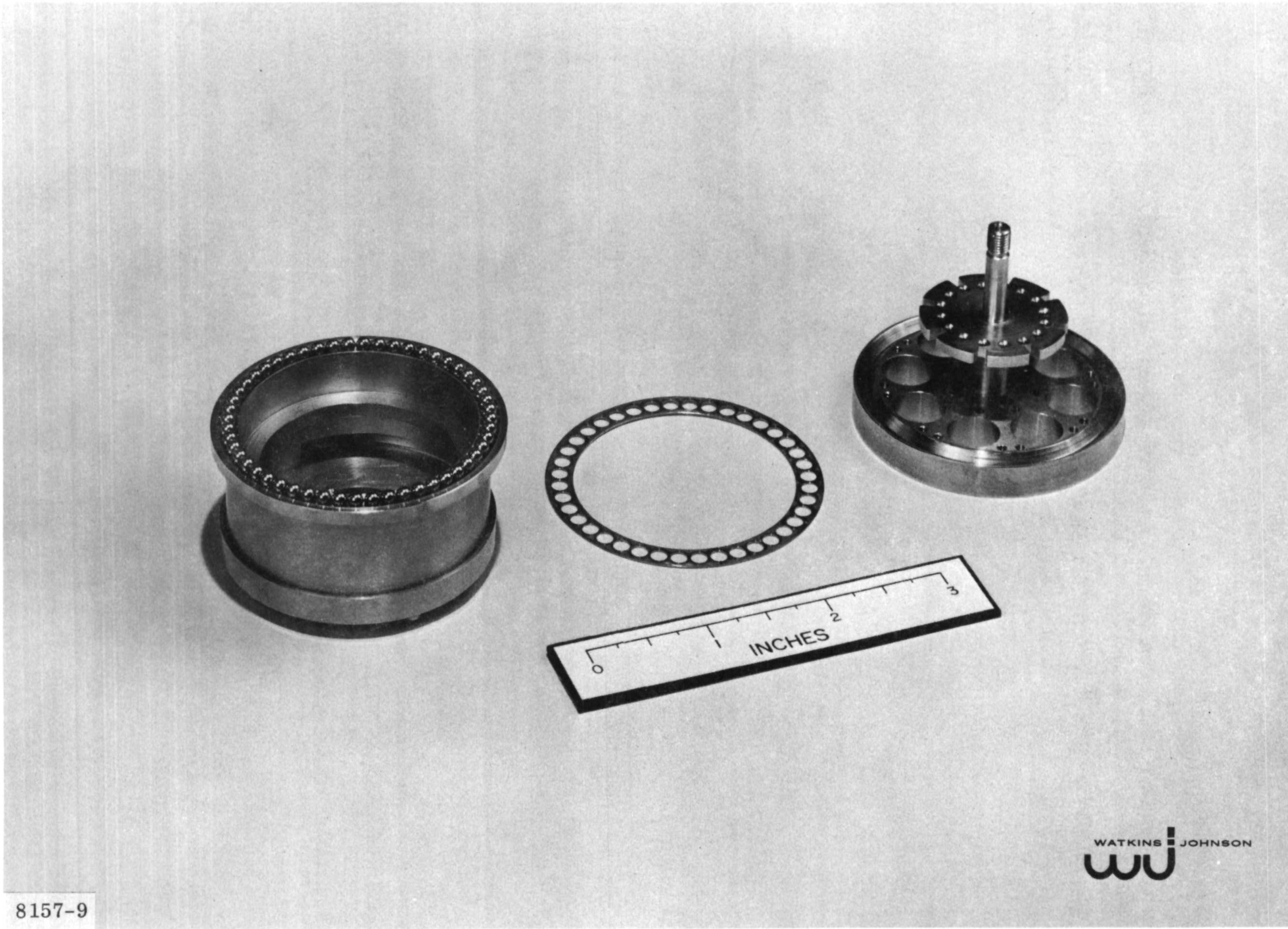

Fig. 5 - Initial main platform bearing concept.

Any new materials, whose use in vacuum tubes had not been previously establshed, was subjected to a material analysis. Either spectroscopic or chemical analysis was made to determine if they contained any of these forbidden elements. A list of materials used for the various tube components is given in Table I.

Component Testing

Extensive testing took place of the various mechanical components of the MEG. Extensive tests of motor torque were made to determine the characteristics of this important element of the tube. This testing was conducted in a vacuum because all convective cooling of the motor element had to be eliminated. Extensive testing for molecular sticking of the surfaces which were in mechanical contact was carried out. It was anticipated that molecular sticking would be one of the more difficult problems that would be encountered. This is because certain material surfaces would be subjected to high compressive forces at high vacuum and high temperature conditions. The solution of this problem was not difficult. Materials in contact either were designed to have large differential expansions or to be extremely hard. Molecular sticking turned out not to be a problem at all.

Several different types of electrical contacts are required on the MEG. Extensive testing was done on the various contacts to determine if either their contact resistance or molecular sticking characteristics would change as a result of high temperature processing in a vacuum. It was particularly necessary to determine if contact sticking would occur with high currents flowing through the contacts at the high-temperature, high-vacuum conditions. This is a condition that would exist during activation and processing of the cathodes. It was desired that no fusing of contact surfaces should occur as a result of these processing conditions. It was determined that the contact materials chosen did not give rise to these problems.

Extensive mechanical vibration and shock tests were made of the main platform bearing to determine if adverse effects would occur due to these environments. If small metal particles were generated during vibration, these could possibly have a large effect upon bearing torque performance. Vibration tests were made across the mechanical frequency range of 5 to 2000 cycles per second under sinusoidal and random vibration conditions in three planes. The vibration requirements for Mariner-Mars 1971 were used. Vibration characteristics of the thermostatic motor element were also determined. It was found that no serious effects resulted from the vibration forces on the bearing or motor elements.

TABLE I

TABLE OF MATERIALS

Element	Material
Vacuum Envelope	
Outer body cylinder	Kovar
Front body cover	Kovar
Vacuum header	Aluminum Oxide Ceramic Kovar
Collector	Copper, Ceramic (Al_2O_3), Kovar
Internal Mechanism	
Main platform	Molybdenum[1]
Motor mounting plate	Molybdenum[1]
Main bearing (races and balls)	Haynes 25 Alloy
Insulating ceramics	Aluminum Oxide
Spring material	Fansteel 60 Alloy
Bi-metal Material	Chace 2300 Alloy
Machine screws	304 Stainless Steel
Motor bearings	Haynes 25 Alloy
Motor body and shaft	Molybdenum[1]
Electrical contacts	Paliney "M"[2]
Cathode Assemblies	
Cathode	Nickel Alloy
Heater	Tungsten
High current electrical conductors	OFHC Copper
Low current electrical conductors	Grade A Nickel

[1] Arc melted, vacuum cast material

[2] J. M. Ney Co.

Extensive high temperature and high vacuum processing tests were carried out on all elements of the mechanism. The attempt was made to predetermine any operating difficulties that would result from these unusual operating conditions. Extensive cycling of the mechanism under vacuum operating conditions was used as a method for checking for problems and errors. Many difficulties were uncovered and corrected as a result of this testing program. The achievement of a final operating tube was a direct result of this preliminary testing phase of the program. It could not have been achieved without it.

III. MAJOR PROBLEMS AND SOLUTIONS

Bearing Torque

The problem which had the most impact upon the development program, was the problem of high bearing torque of the initial concept bearing. This required a complete redesign of the main bearing system and resulted in changing over to a dual-race bearing design which incorporated strictly rolling-ball motion. The material chosen for both the races and balls was Haynes 25 alloy. In addition to being an extremely hard metal alloy, it also has the additional property of being non-magnetic. Non-magnetic properties were necessary to prevent unwanted magnetic defocusing effects on the electron beam in the cathode-anode region of the gun. This material satisfied the overall requirements very well, and proved to be an excellent vacuum material.

Bearing Lock-up

A very puzzling problem occurred which was a lock-up of the main bearing during the high temperature processing of the tube. The examination of the main bearing after the high temperature cycle showed that the lock-up was not due to molecular sticking but instead to a mechanical dislocation of the balls in the bearing. This problem was finally diagnosed as resulting from too high a rate of change of temperature at the beginning and end of the vacuum bakeout cycle. If the temperature change was too rapid, temperature of the inner race of the bearing would lag behind the temperature of the outer race. The resulting differential expansion of the bearing races allowed the balls to move under the forces of gravity to positions that would prevent proper bearing motion once temperature equilibrium were reached. If the bearing was subjected to too rapid a temperature change, it became incapable of rotation at either the bakeout temperature of 500 degrees C or at room temperature at completion of the cycle. This problem was solved by building a temperature controller which accomplished the temperature increase or decrease over an eighteen hour period. This slow rate of temperature change then kept the differential expansion of the bearing races to a negligible value and completely solved the problem of bearing lockup.

Overstress of Motor Element

Another major problem which occurred was the loss of motor torque due to the combination of high bakeout temperatures and overheating during normal motor operating cycles. This problem was overcome by a change in the mechanism to allow the cathode platform advance from one cathode position to the next to be accomplished in two smaller steps rather than one large step. Each motor advance was then limited to a 22.5 degree linear and repeatable region of its operating characteristics.

Motor Bearing Mounting System

Another significant problem occurred in the mounting system for the motor bearings. At first, the bearings were mounted directly in the molybdenum end walls of the motor body. During high temperature vacuum bakeout, the outer motor bearing race had a greater expansion than the molybdenum wall. The high strength of the bearing race material distorted the recess in the molybdenum end wall so that on cooling, the bearing was no longer tightly held to coincide with the required motor axis. It was surprising to find that the molybdenum was distorted with no measurable distortion of the motor race occurring. This problem was solved by making the motor end caps out of the same material as the bearing and arranging it to expand away from the molybdenum motor body at high temperatures. It would then return to its proper location after the heating cycle was complete and would hold the motor bearing with its original accuracy.

Minor Problems

Other minor problems occurred during the course of the development and simple remedies were devised for each of these. No detailed discussion of these other problems will be given here.

IV. DETAILED EXPLANATION OF MEG SYSTEM

The detailed explanation of the MEG operating system will be carried out using photographs of the various components of the MEG mechanism to aid in the explanation.

Thermostatic Motor

The main element of the thermostatic motor is a spirally wound coil made of bi-metal material. An end view of the coil is shown in Fig. 6. Here the coil is mounted to the central motor shaft and the outer end passes out through the wall of the motor through ceramic insulators. Fig. 7 shows another view of the motor. It can be seen that the bi-metal element is actually composed of two parallel tapes which have a common junction at the motor shaft. The bi-metal element is machined out of a single piece of material and then is wound on a spiral forming fixture. By having the coil insulated from ground at all points except the motor shaft, the bi-metal element may be heated by passing an electrical current through it. Under vacuum conditions, the motor operating current is typically in the neighborhood of 15 amperes. With the bi-metal material rigidly held at the ceramic insulator, heating of the material causes rotation of the shaft to occur in the counter clockwise direction observed from the end of the shaft shown in either Fig. 6 or 7. In these views, the end plate, which contains one of the motor bearings, has been removed in order to give a view of the bi-metal element. Fig. 8 shows a view of the motor from the opposite end. A single-race ball bearing can be seen in this view. A similar bearing supports the opposite end of the shaft. The motor housing design is such that the mounting of the end caps provides the proper amount of thrust loading on the bearing to make them accurately locate the shaft.

Figure 9 shows a view of the motor again from the end shown in Figs. 6 and 7 with all the motor driving components assembled. The locking arm and the ratchet mechanism can be seen in this view. The locking arm is accurately pinned to a predetermined position on the motor shaft. When the motor is cold, it is engaged with considerable force into a slot on the driving platform which will be shown in a later figure. The spring dogs, which push on the pins of the driving platform to advance the mechanism, are seen attached to the driving plate. These spring dogs are formed from the alloy, Fansteel 60. This is a high temperature spring material which does not lose its strength nor its springiness at the 500 degrees C vacuum bakeout temperature.

The deflection characteristic of the motor is shown in Fig. 10. This shows equilibrium shaft rotation as a function of motor input power and was measured with the motor in a vacuum. It is seen that the characteristic remains essentially the same before and after the high temperature bakeout cycle. Fig. 11 shows the torque developed by the motor as a function of input power. This is a measure of the static or blocked rotor torque and shows the torque that can be developed at zero deflection. Fig. 12 shows the free deflection of the motor that occurs as a function of bakeout temperature.

Main Bearing and Cathode Platform

A front view of the main bearing and cathode platform is shown in Fig. 13. The main bearing is a dual-race bearing, which was especially developed for this particular application by Industrial Tectonics of Compton, California. It is a lubrication-free, high-temperature bearing with positional accuracy and repeatability better than 0.0001 inches. The bearing can be completely disassembled to facilitate cleaning before assembly for vacuum operation. The cathode platform is an integral part of the bearing

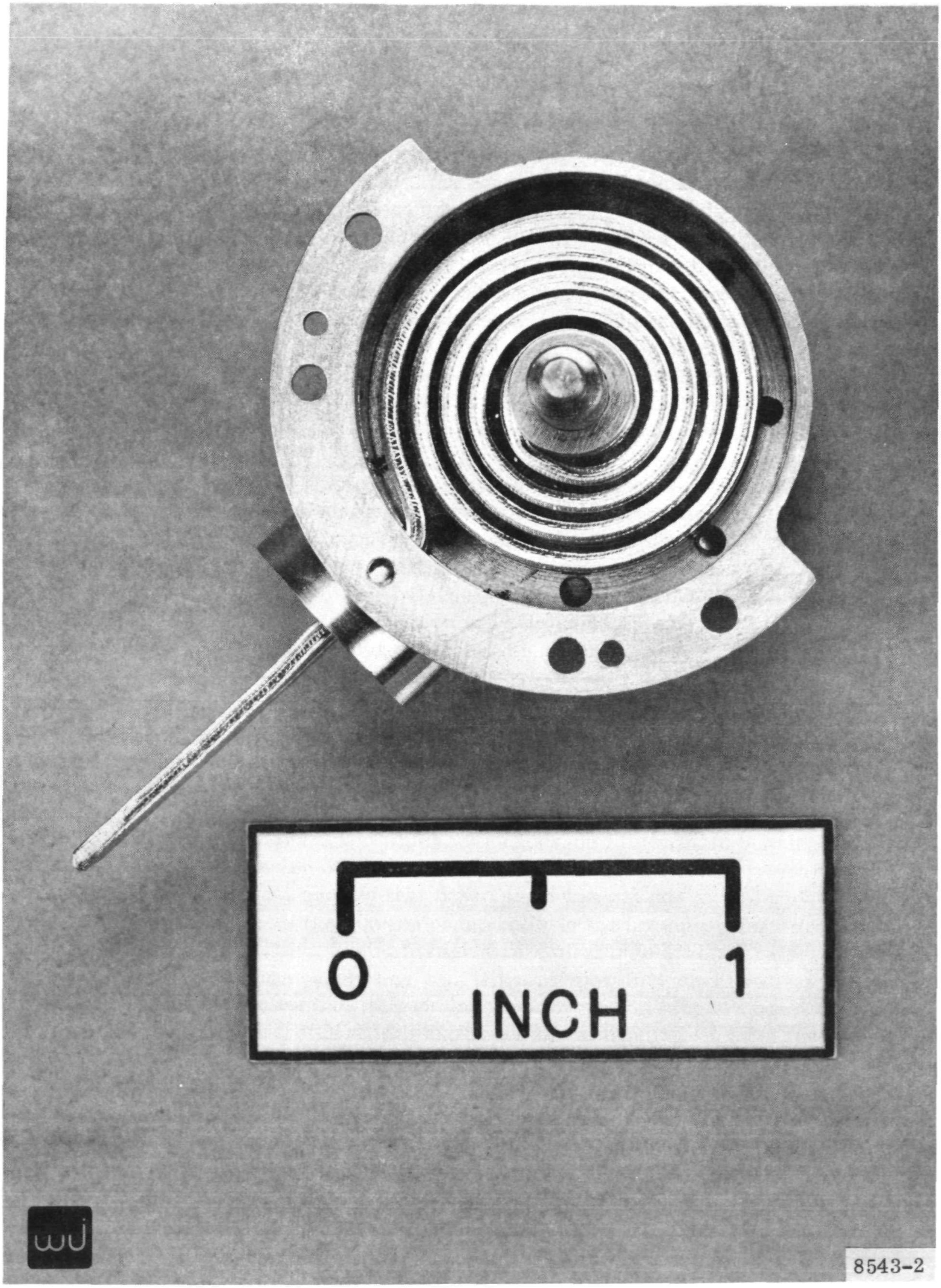

Fig. 6 - End view of the thermostatic motor assembly with the end bearing plate removed. The spiral bimetal thermostatic motor element is shown.

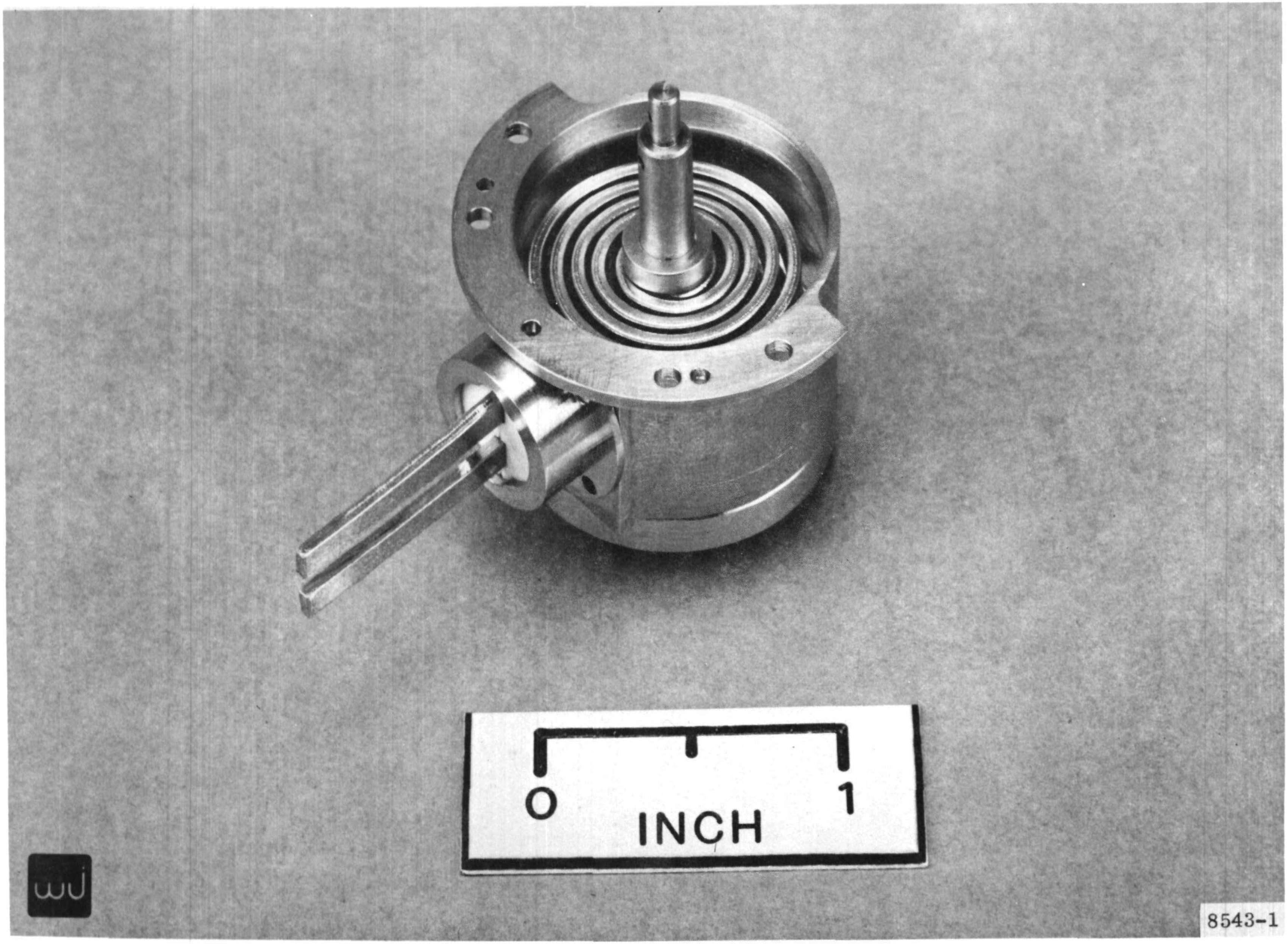

Fig. 7 - View of the thermostatic motor assembly showing the parallel motor elements and insulating ceramic.

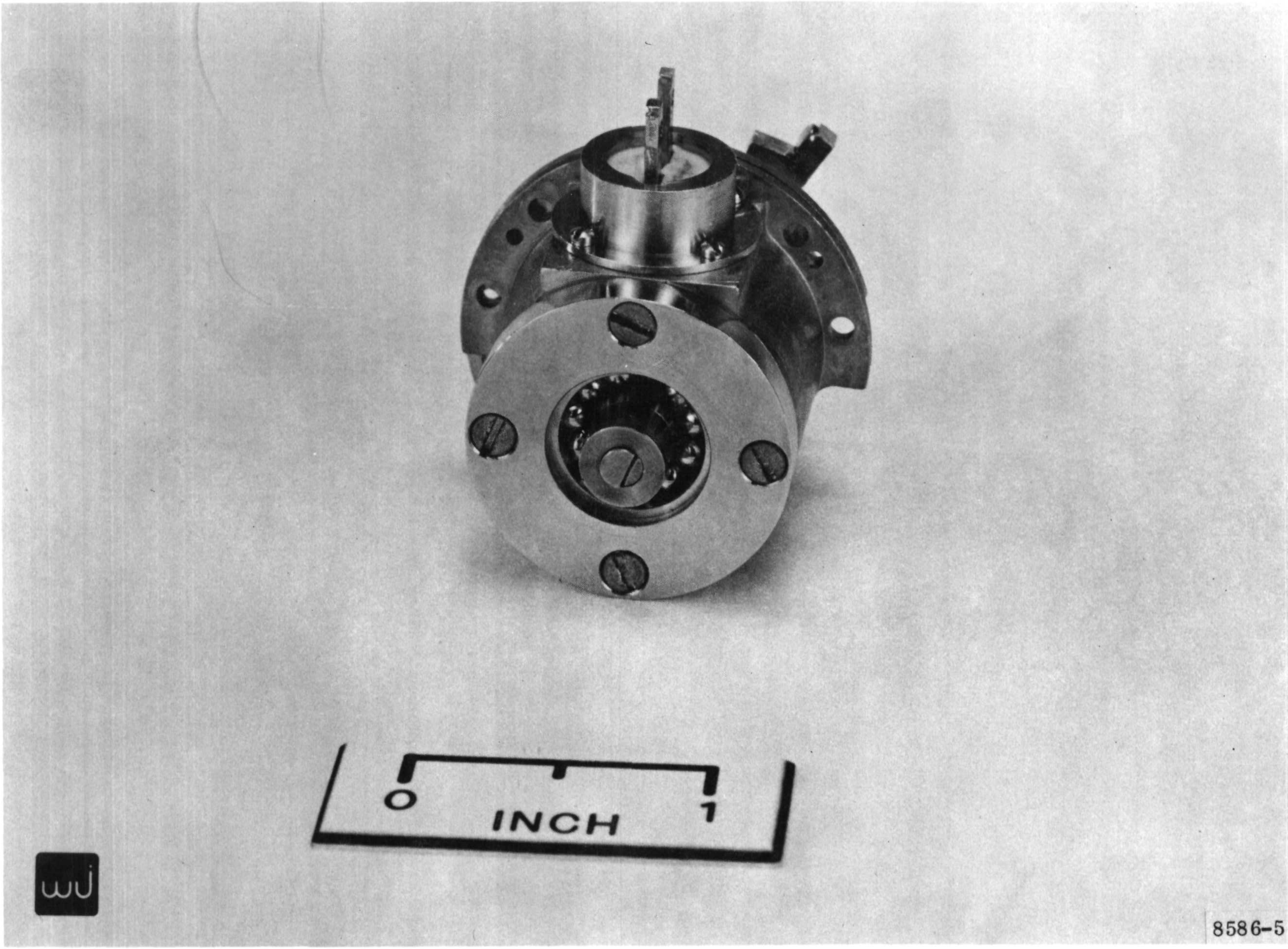

Fig. 8 - View of motor assembly from opposite end showing motor shaft bearing.

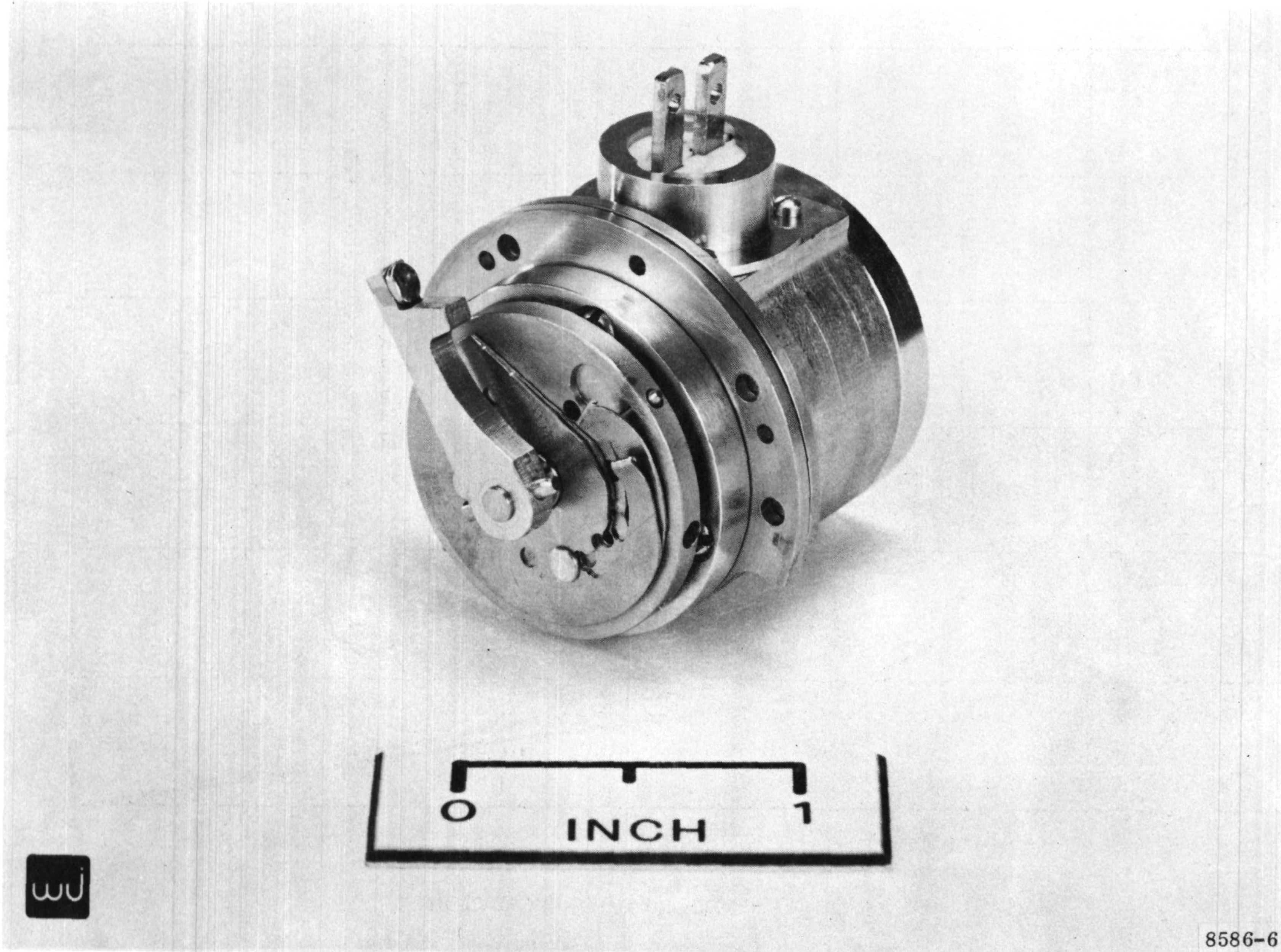

Fig. 9 - Complete motor assembly showing driving elements and locking arm.

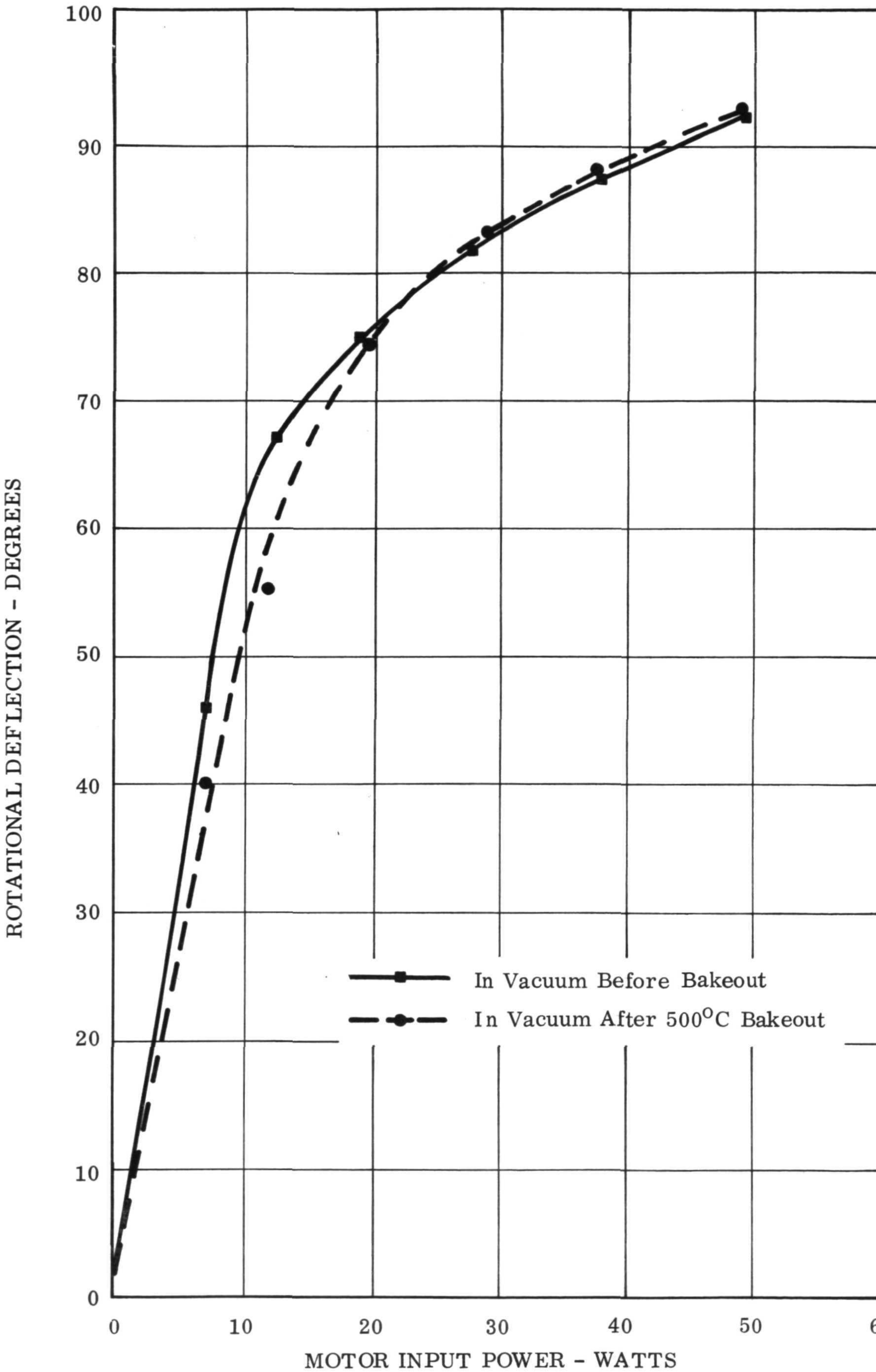

Fig. 10 - Deflection characteristic of thermostatic motor drive element

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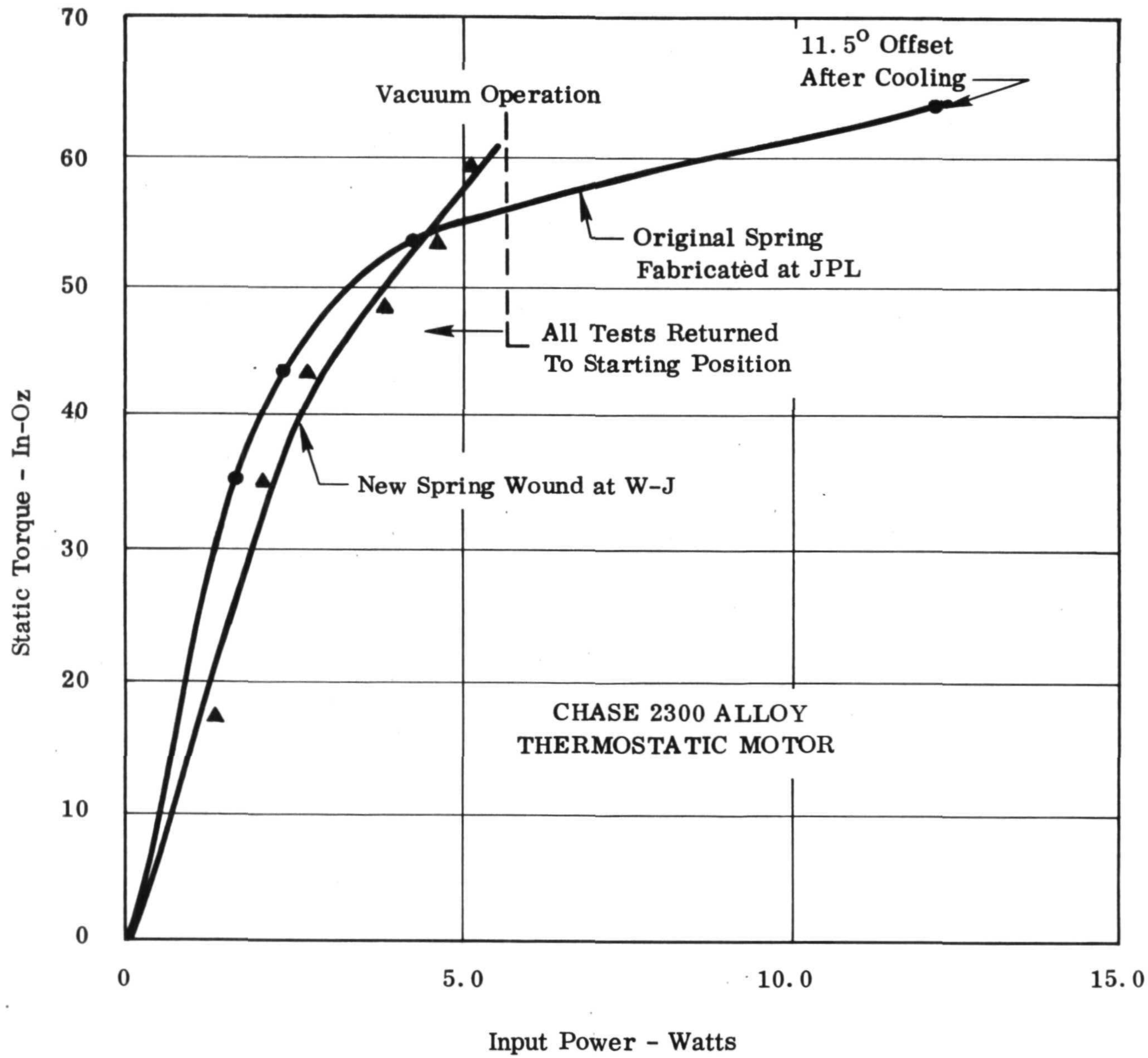

Fig. 11 --Blocked rotor torque of thermostatic motor spring.

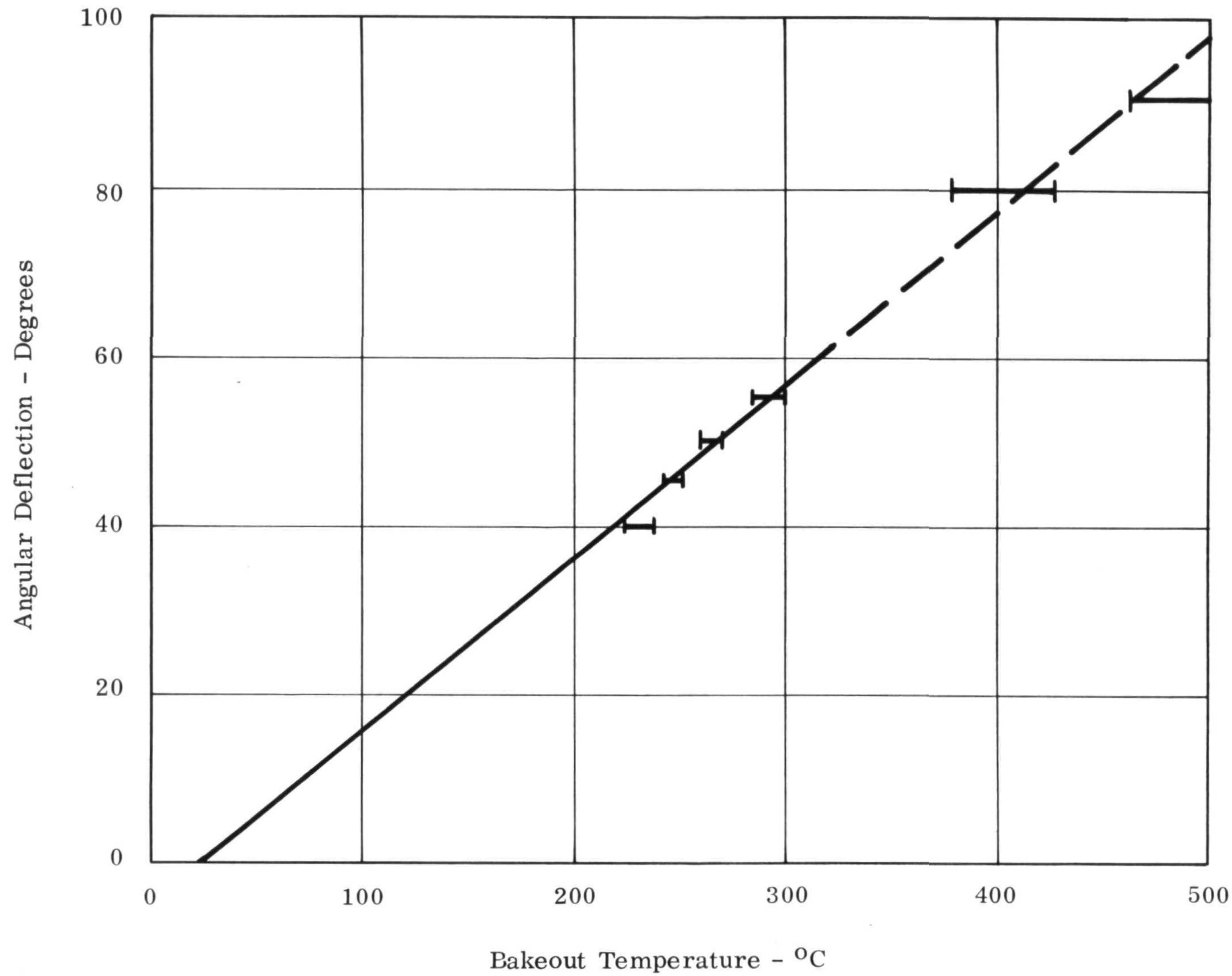

Fig. 12 - Deflection versus bakeout temperature of the thermostatic motor spring drive element. The horizontal bars indicate the measurement uncertainties which were present in the test.

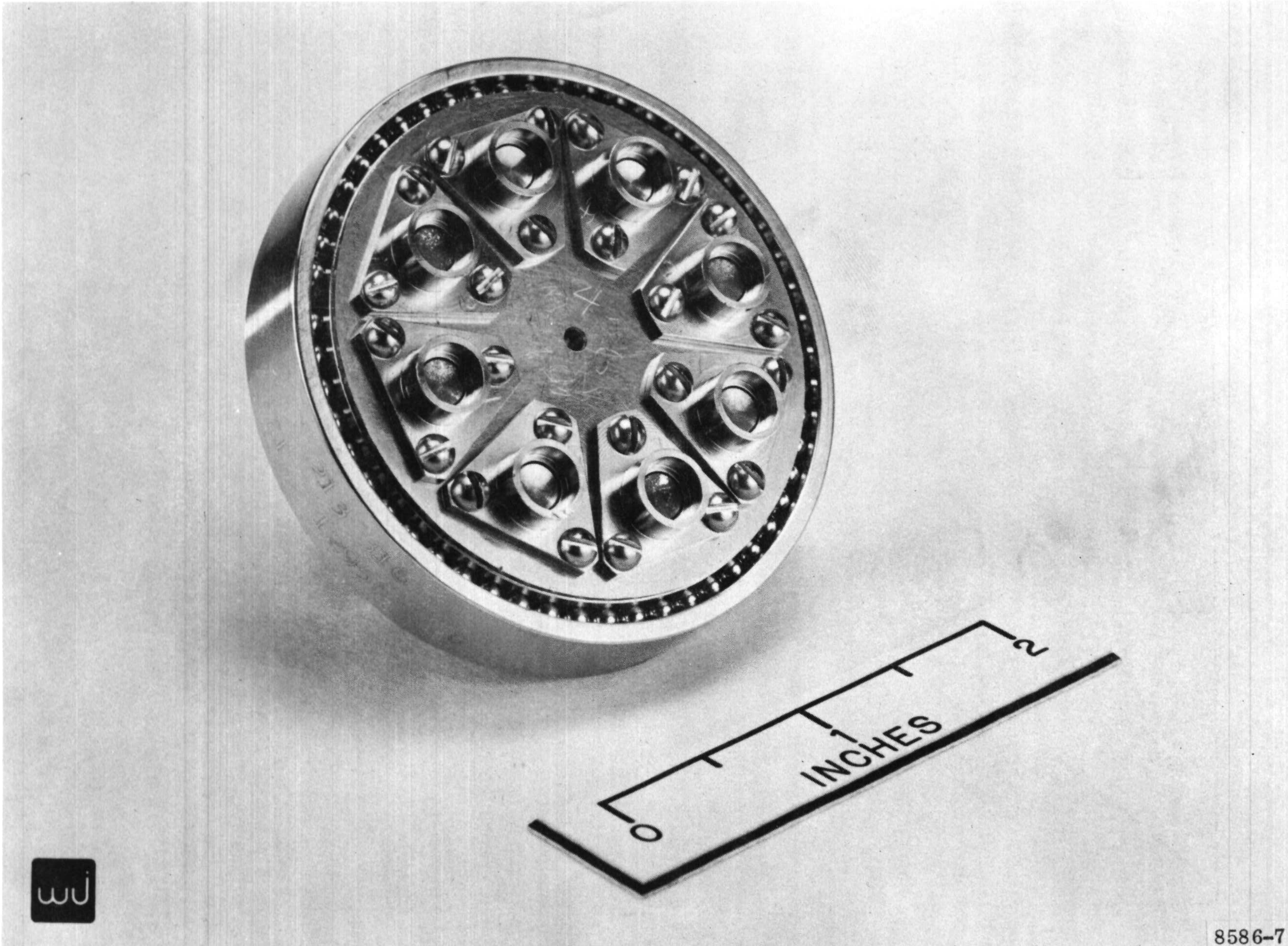

Fig. 13 - Main bearing and cathode platform with cathode assemblies mounted in place.

mechanism because it is designed to hold the two halves of the inner race together. The bearing is so designed that when the two halves of the inner race are brought up snug against each other, that the proper loading forces are applied to the ball bearings to give the required positional accuracy as well as the starting and rolling torque requirements.

The cathode mounting platform is fabricated with an elaborate machining process which sets the overall radial and azimuthal positional accuracy of the cathode mounting holes in the platform to be within ± .0003 inches. This includes the bearing accuracy plus the machining accuracy of the hole location. Tests on the completed bearing and platform showed that the absolute error of location of the hole centers was 0.0002 inch in the radial direction for all eight holes and 0.0003 inch in the azimuthal direction for seven of the holes. For the eighth hole, the azimuthal error was .00062 inch.

Each cathode assembly shown in Fig. 13 is completely self contained and has manufacturing tolerances which force them to accurately locate within the platform mounting holes. The mounting screws hold the cathodes up tight against the main platform, but otherwise do not contribute to the location of the cathode assemblies. These screws are later laser-welded in place to make sure that they do not loosen during processing or operation of the device.

The back of the platform is shown in Fig. 14. The rear end of each cathode assembly can be seen together with its electrical contact. The driving platform together with the cathode mounting platform is machined from one integral piece of molybdenum. The driving platform is supported above the back surface of the main platform on a pedestal. This allows it to engage with the driving mechanism and the locking arm of the motor assembly. Around the periphery of the driving platform, there are sixteen engagement slots for the locking arm. The advance from one cathode position to the next, is accomplished by a two-step operation wherein the 45 degree advance is accomplished by two 22-1/2 degree advances. The locking arm engages after each step.

The Cathode Assembly

A front and rear view of the cathode assembly is shown in Fig. 15. These structures are self-contained and are manufactured to extremely high tolerances. The heater within the cathode uses the cathode body assembly as one terminal and is connected to the heater voltage supply through the cathode mounting platform. The other terminal of the heater is brought out to the insulated terminal at the rear of the cathode assembly. This terminal engages with electrical contacts which provide the other connection to the heater voltage supply.

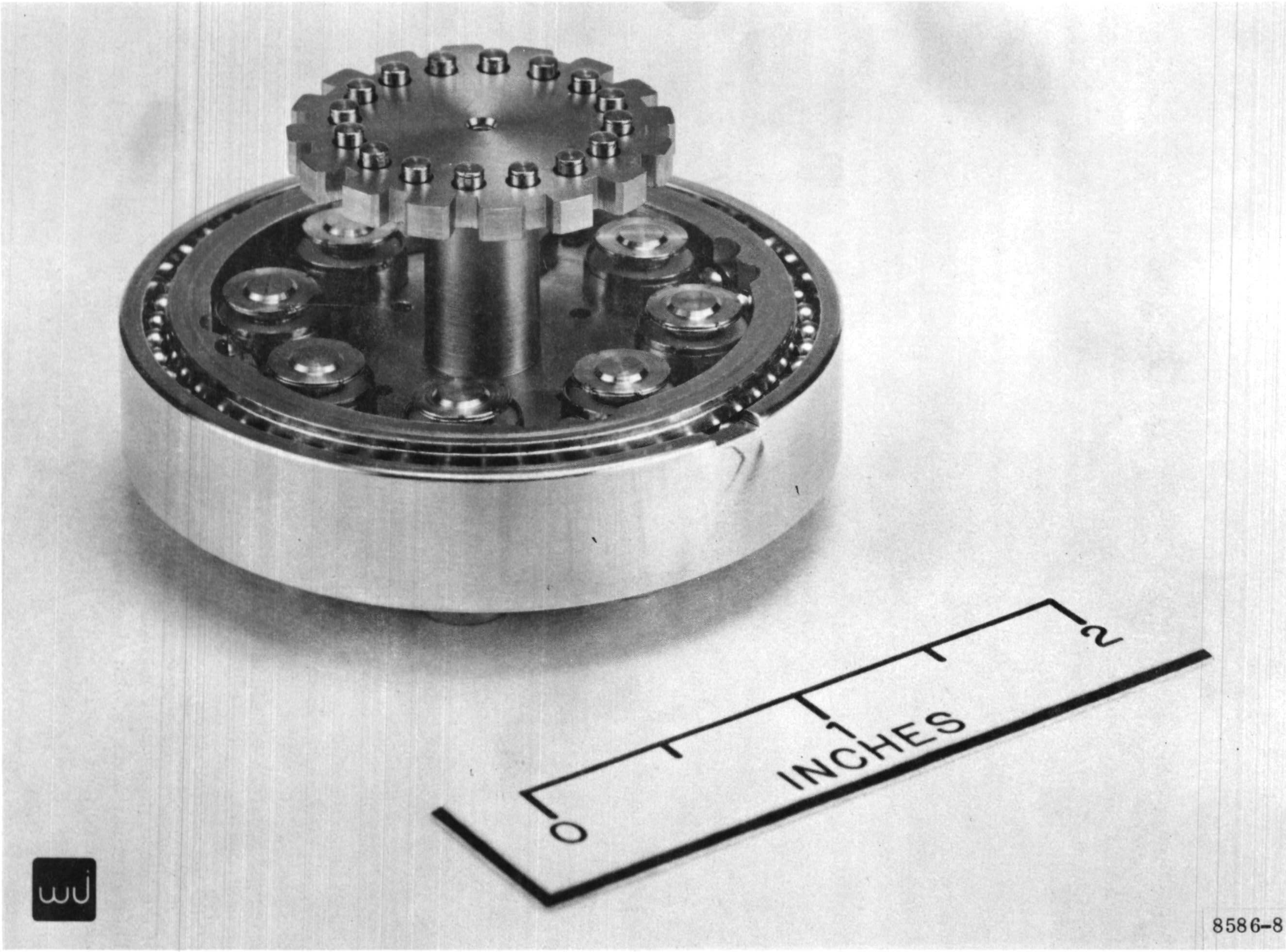

Fig. 14 - Back side of cathode platform showing rear of cathode assemblies. Driving platform with driving pins and locking arm engagement slots is located on pedestal.

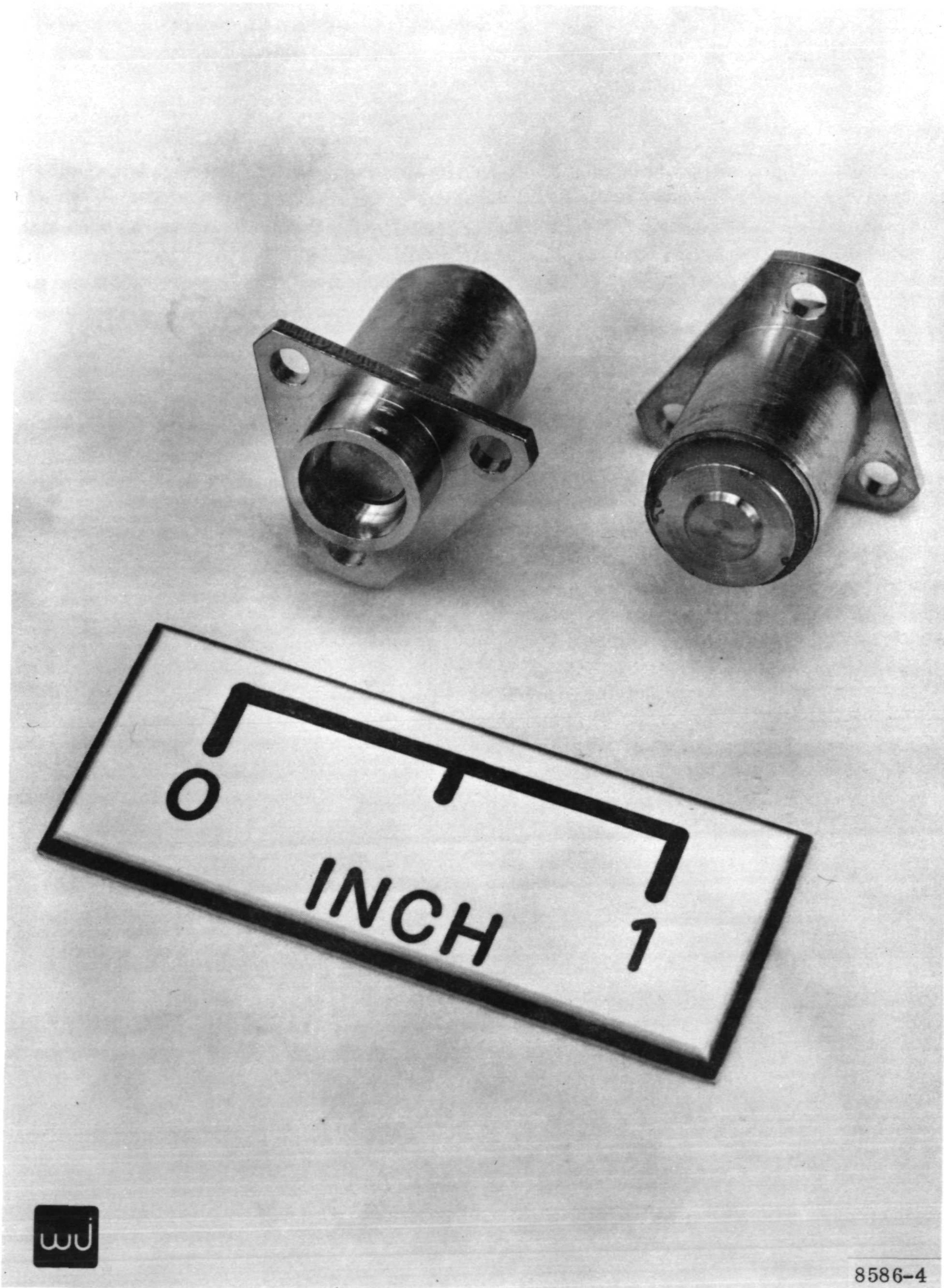

Fig. 15 - Front and rear view of cathode assemblies. Heater terminal is the disc at rear of right assembly.

The positional accuracy of the cathode is set by the engagement of the outside surface of the cylindrical wall into the holes in the cathode mounting platform. The depth of the cathode is set by bringing the flange tight against the cathode platform. The cathode assemblies are fabricated and then are individually vacuum fired and stored within a small glass vacuum envelope. These envelopes are sealed off and are not opened until just before the cathode is to be installed in the overall MEG assembly. The cathode is then coated at this time.

The Main Insulator Assembly

Figure 16 shows a partially exploded view of the main insulator assembly. This insulator provides the voltage isolation between the vacuum envelope of the gun and the interior MEG assembly which operates at cathode potential. The insulator assembly consists of an upper and a lower ceramic ring between which are sandwiched a ring which is cut into four segments. The inside and outside diameters of the segmented ring are ground to an extremely high accuracy. This accurately locates and holds the interior assembly with respect to the outer vacuum envelope. The ring is segmented to allow relative expansion of the interior metal assembly and the ceramic insulator during the bakeout process. Since the ceramic has a much lower expansion coefficient than the metal parts of the bearing, it would be broken by the outward expansion forces which would occur during the high temperature cycle. With the segmented arrangement, the parts are capable of relative expansion at high temperatures and will return to their original positional accuracy on return to the normal temperature range. The outer race of the main bearing as well as the motor mount platform are captured between the upper and lower rings of the insulator assembly.

Figure 17 shows the bearing and the cathode platform assembled into the insulator. A new element has been added in this photograph. This is the particulate shield and mounts on the cathode platform. This is shown in more detail in Fig. 18. The bottom side of the particulate shield contains three thin rings of metal. These engage with the three grooves on the top ring of the insulator. The parts are so designed that the rings are suspended within the three grooves without actually touching, but come within a clearance of a few thousandths of an inch. The purpose of this shield is to block the movement of free floating particles under zero gravity conditions, which might be developed by the mechanisms to the rear of the cathode platform, from reaching the cathode side of the platform. This is to prevent these foreign particles from reaching the cathode surfaces.

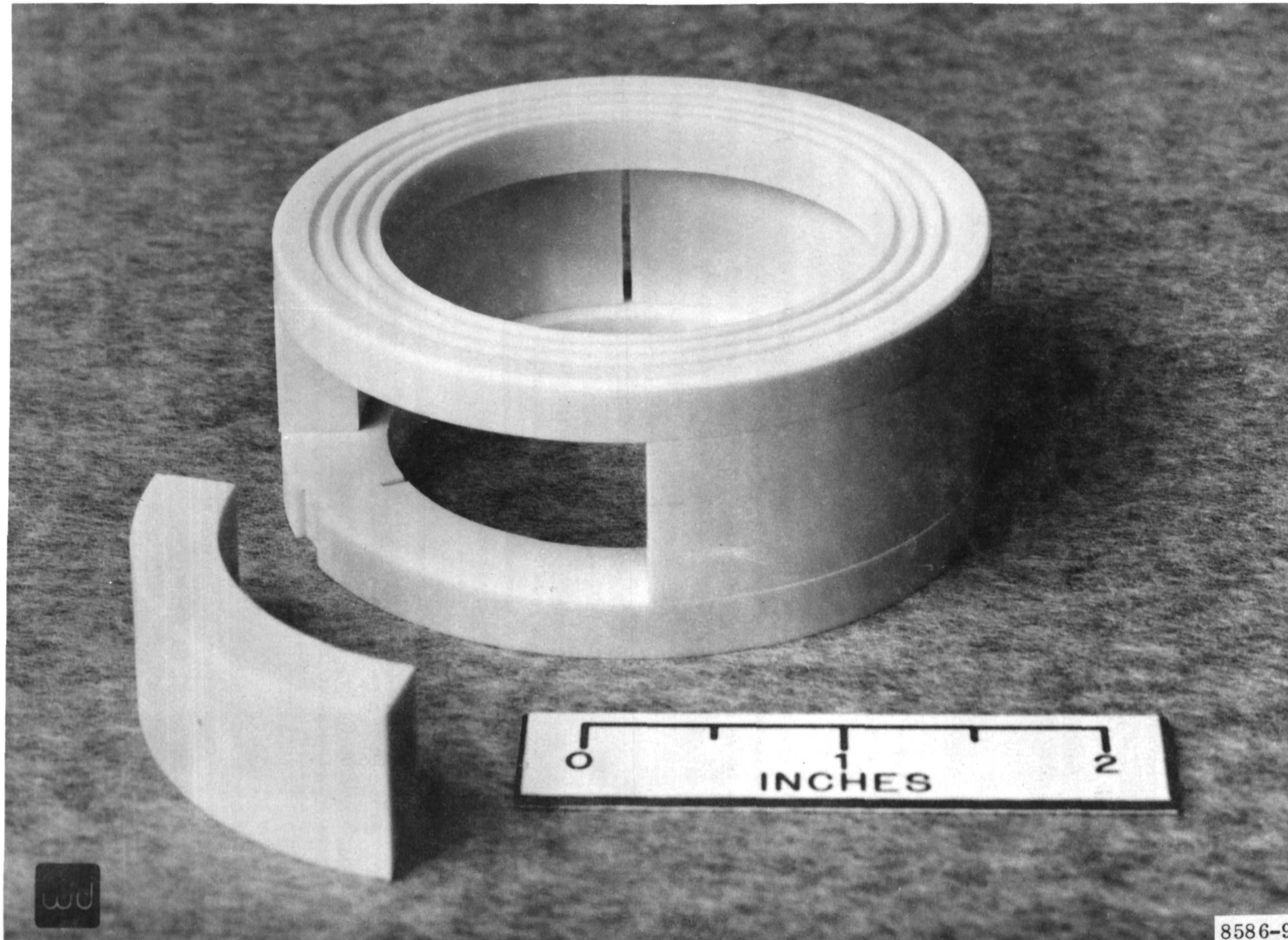

Fig. 16 - Exploded view of main insulator assembly. Central ring is segmented to allow for thermal expansion.

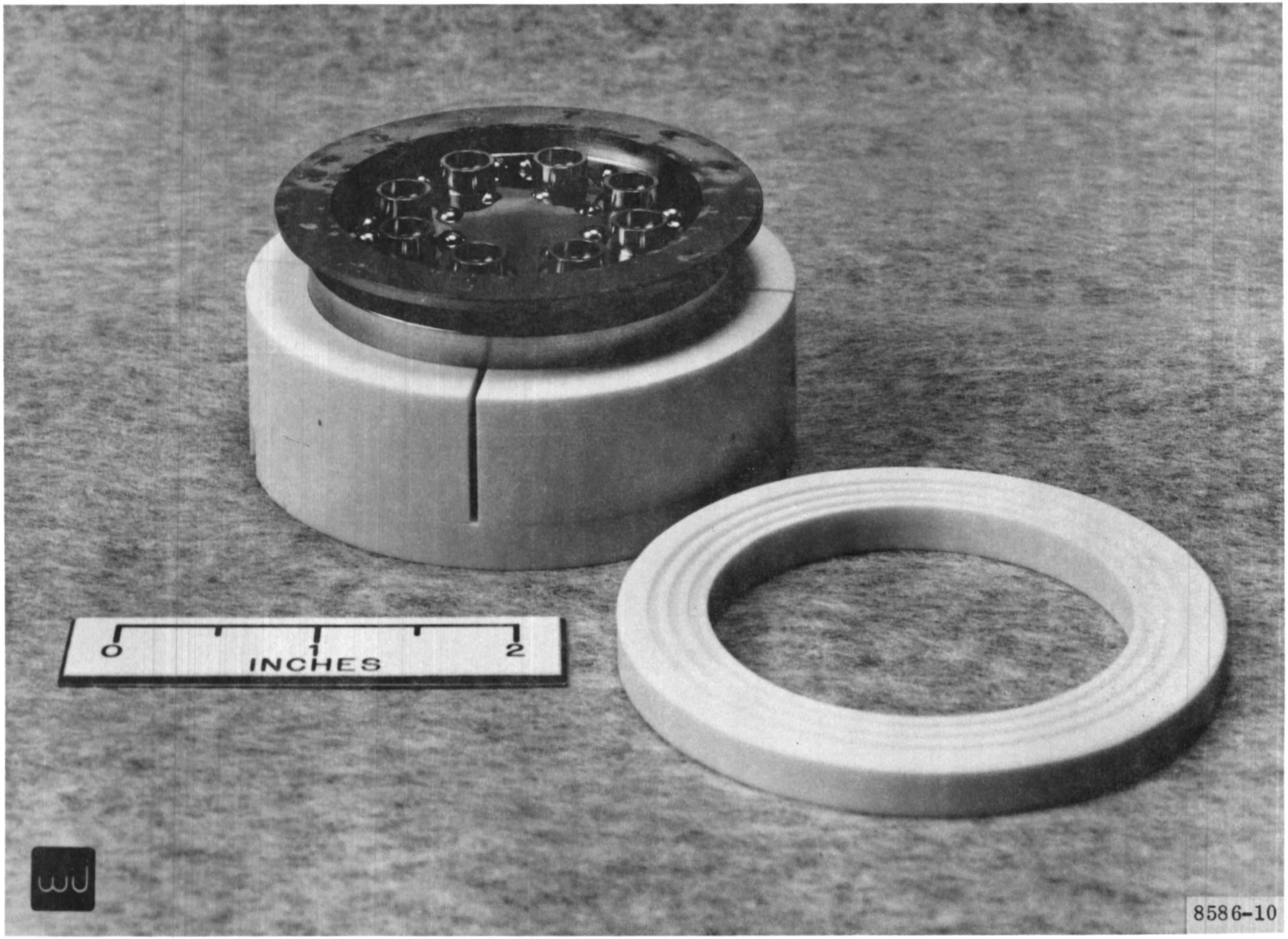

Fig. 17 - View of bearing and cathode platform assembled into main insulator. Top ring has been left off.

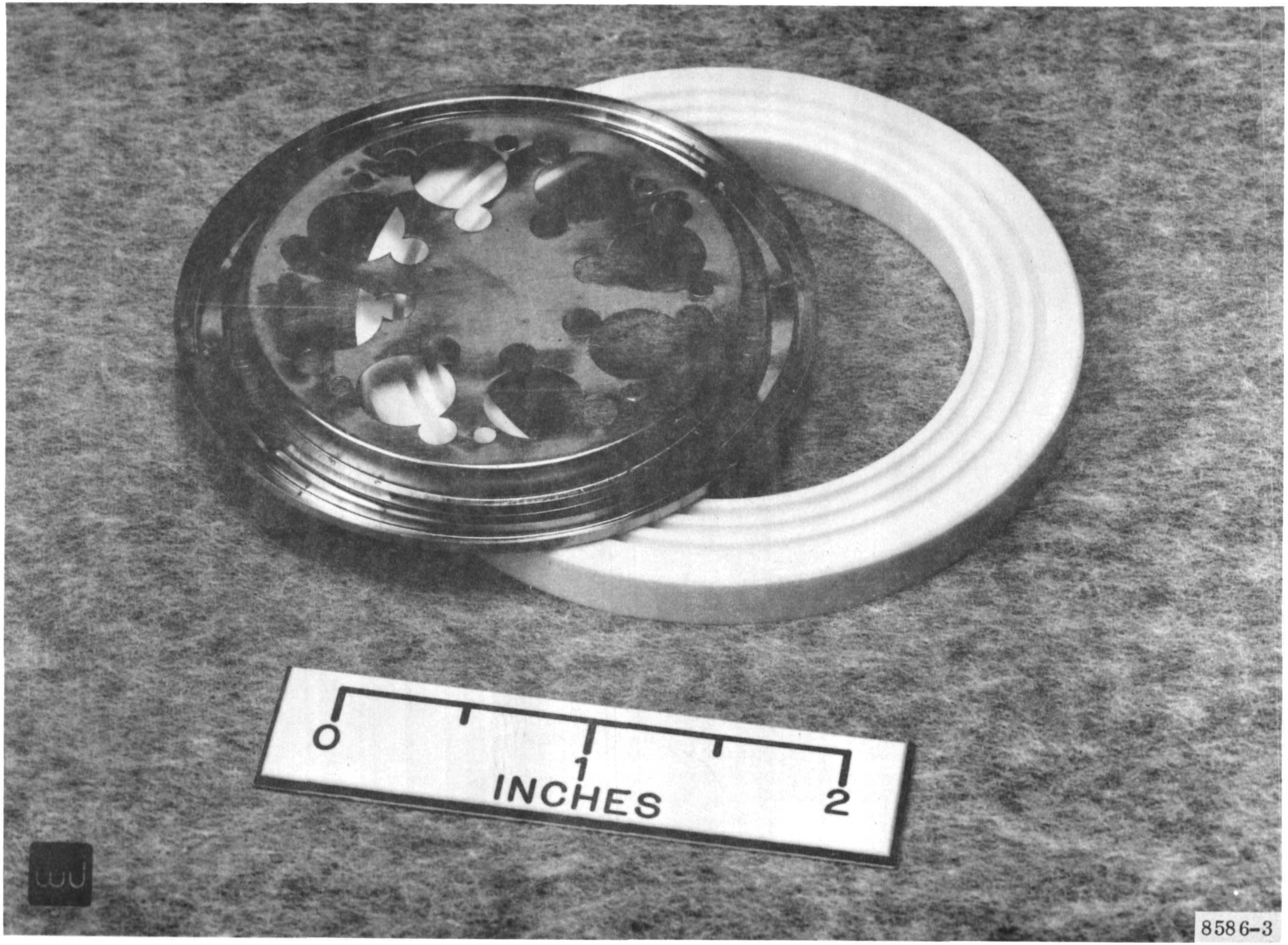

Fig. 18 - View of top insulator ring and particulate shield. Shield is turned over to show rings which extend into grooves.

Electrical Contacts

There are two sets of electrical contacts within the gun which are associated with supplying electrical power to heat the cathodes. There are two other contacts which are associated with telemetry indications of the position of the detent arm and the locking arm. The contacts for the heater circuit will be discussed first.

Figure 19 shows the electrical contact assembly which supplies power to the rear contact terminal of the cathode assembly which was shown in Figs. 14 and 15. This contact assembly handles a dual function. It supplies heater power at the active cathode location as well as heater power simultaneously to all the cathodes during the bakeout and cathode processing portion of the tube activation cycle. All of the contacts are mounted on a common metal ring which, in turn, is mounted on an aluminum oxide ceramic insulator ring. This then requires only one electrical lead to be brought out of the vacuum envelope for all of these contacts. The contact which corresponds to the active cathode location is seen at the far left side of the contact ring. This electrical contact is mounted on a spring made of Fansteel 60 material. The leaf spring is set so that its equilibrium position will always keep the contact terminal in physical contact with the associated terminal on the active cathode assembly. The other seven contacts which correspond to the other seven cathode locations, are mounted on bi-metal leaf-spring material. The motion of these contact springs is activated by the temperature of the bakeout cycle of the tube. During bakeout, these springs lift and bring their contacts into electrical connection with the back contact of the seven normally non-active cathodes. Through the use of these temperature actuated, bi-metal switches, simultaneous processing of all the cathodes is accomplished. It would be otherwise impractical to sequentially activate all of the cathodes. Even though some net relaxation of the bi-metal spring tension takes place during the bakeout cycle, the contacts remain closed for the duration of the cycle.

The return circuit for the heater currents is through the cathode platform. The electrical return circuit from the rotating platform is accomplished by the contact assembly shown in Fig. 20. These again are Fansteel 60 springs, formed by a die-cutting operation out of one sheet of material. Contacts are so designed that when the contact assembly is in its proper location pressing against the bottom of the main platform, that each spring bridge is supported from both ends which gives increased contact pressure.

The two remaining contacts are telemetry indicators. One of these contacts closes as soon as the locking arm begins to lift out of the alignment slot in the driving platform (See Fig. 4). This is the first indication that the operating cycle has begun after current is applied to the thermostatic motor. This lights the unlock light on the programmer unit. As soon as the platform starts to turn, the detent arm begins to lift out of the

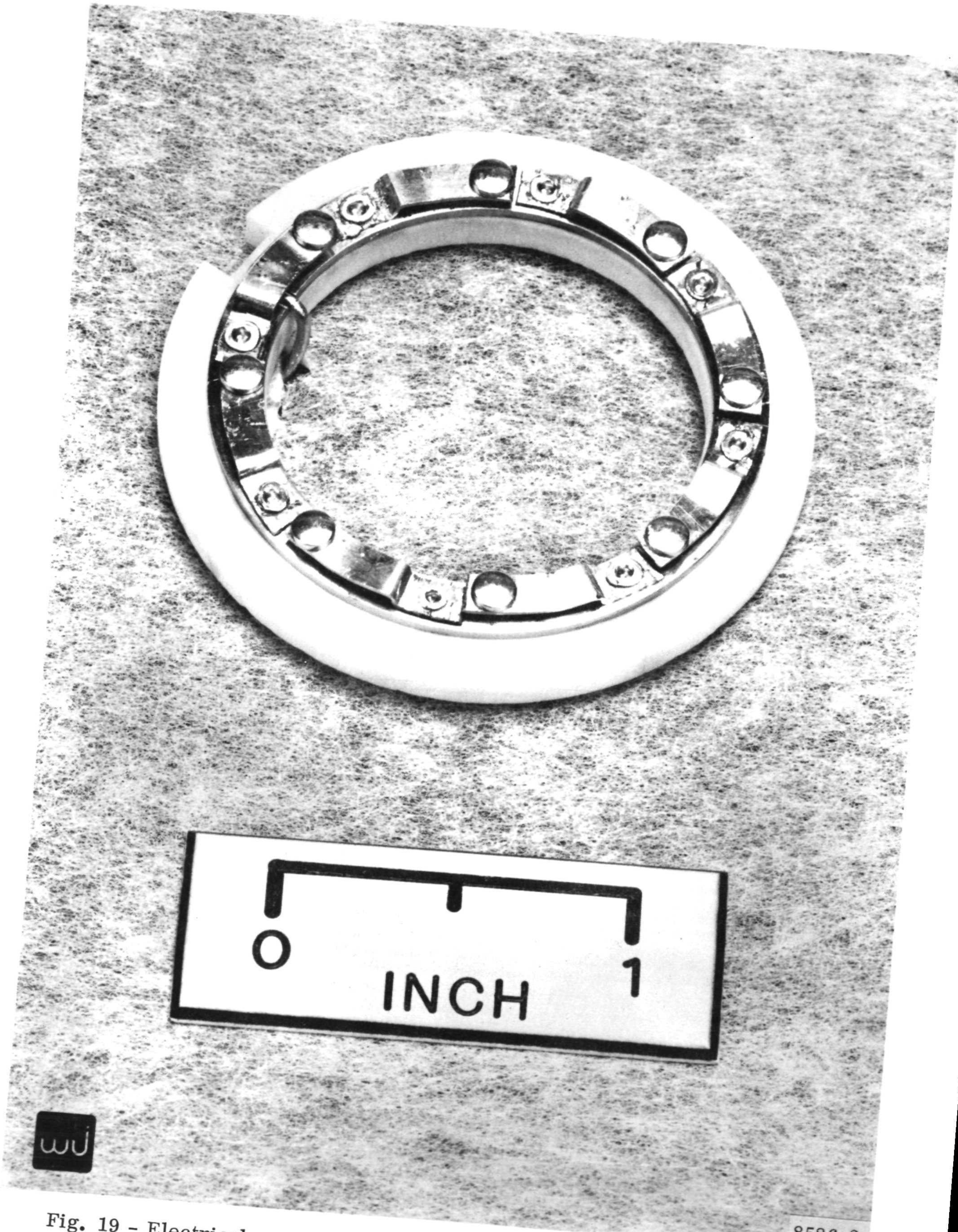

Fig. 19 - Electrical contact assembly which supplies heater power to cathode assemblies

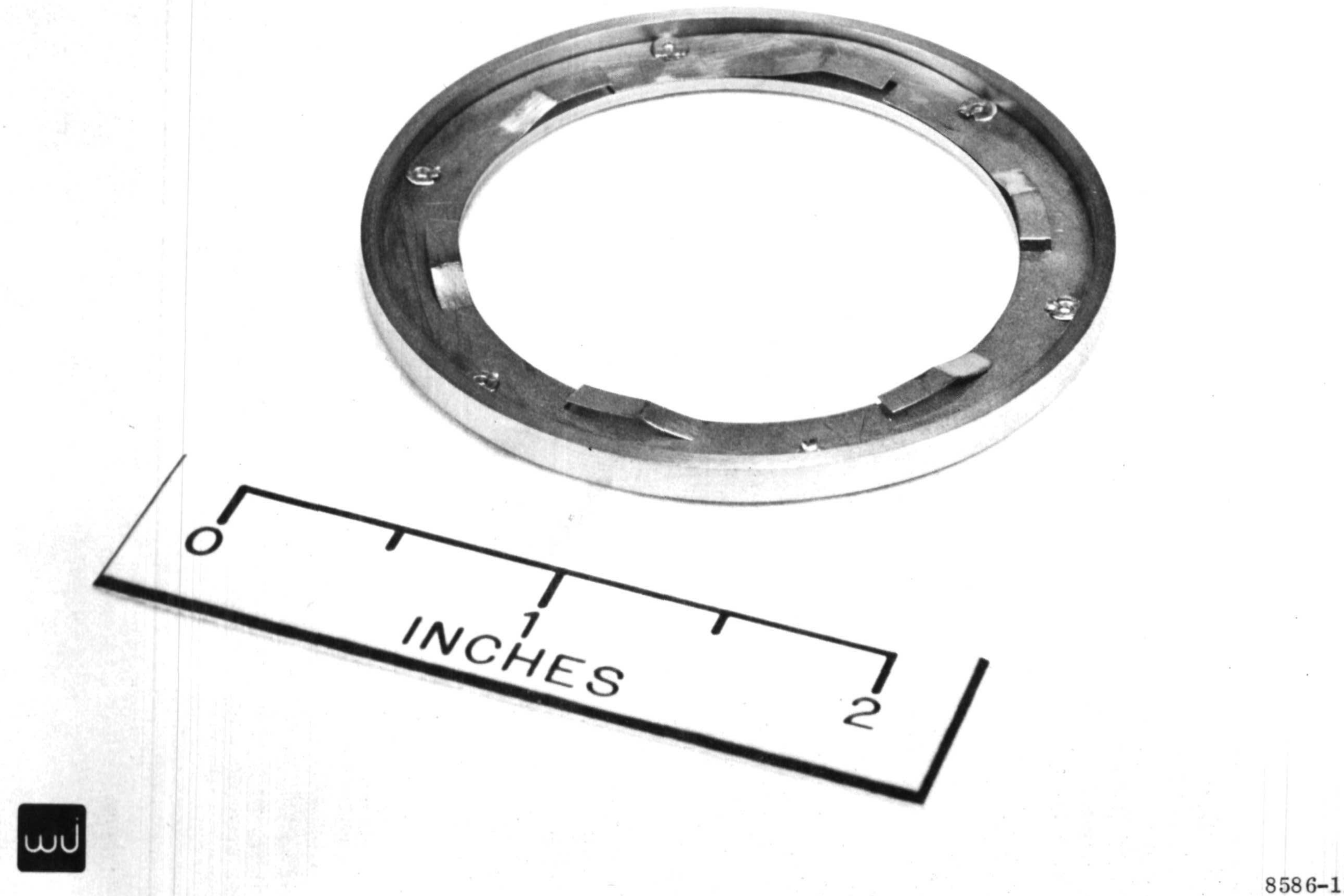

Fig. 20 - Electrical contacts which provide return circuit for heater current from cathode platform.

detent slot and closes a contact indicating that platform motion has begun (See Fig. 4). This lights the detent light on the programmer panel. As soon as the platform has advanced to its next position, the detent drops into the next detent slot, the detent contact is opened and electrical power is removed from the thermostatic motor by the programmer. Indication of the completion of the cycle is given when the motor has sufficiently cooled for the locking arm to drop back into its locating slot. This opens this contact and shuts off the unlock light.

Motor Mounting Platform

The platform which supports the motor with respect to the rest of the MEG assembly is shown in Fig. 21. In this view, the cathode mounting platform with the mounted cathode assemblies is face down. The main bearing outer race is seen as the lowest outer surface. On this is stacked the electrical contact ring (shown in Fig. 20), and then the motor mounting platform. In this view, without the motor mounted in place, the driving platform is clearly visible. The detent arm pivots on the motor mounting platform and the detent roller on the end of the arm engages with the detent and locking slots in the driving platform. These slots perform a dual function. The deep part of the slot accurately engages with the locking arm finger and sets the final rotational position of the platform system. The top part of each slot is beveled to engage the detent roller. This provides an approximate location for the platform while the motor is cooling before the locking arm is engaged with its slot. The long curved spring, which pushes on the detent arm and provides the force to hold it into the detent slot, can be seen mounted from the side of the motor mount platform. This is also made from Fansteel 60. Fig. 22 is a similar view with the motor mounted in place. The locking arm cannot be seen in this view, but it locates in a slot diametrically opposed to the detent slot across the driving platform.

The spring dogs which are located on the motor driving plate shown in Fig. 9, also do not show in this view. They engage the roller pins which extend upward out of the driving platform. When the platform has advanced one step and the motor is cooling off, the spring dogs are pulled back over the tops of the pins and come again to rest on the driving platform. After the completion of the cycle, they are then ready to push on the next set of pins and advance the platform another step. By this ratchet action, the platform rotational motion is accomplished.

The telemetry electrical contacts are supported by the two circular ceramic insulators which are visible in Fig. 22. These insulators are positionally locked into the motor mounting platform by pins which are driven into the two vertical holes visible just above each insulator. The pins engage in locating slots in the sides of the insulator body.

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Fig. 21 - Motor mounting platform showing relationship to driving platform and main bearing.

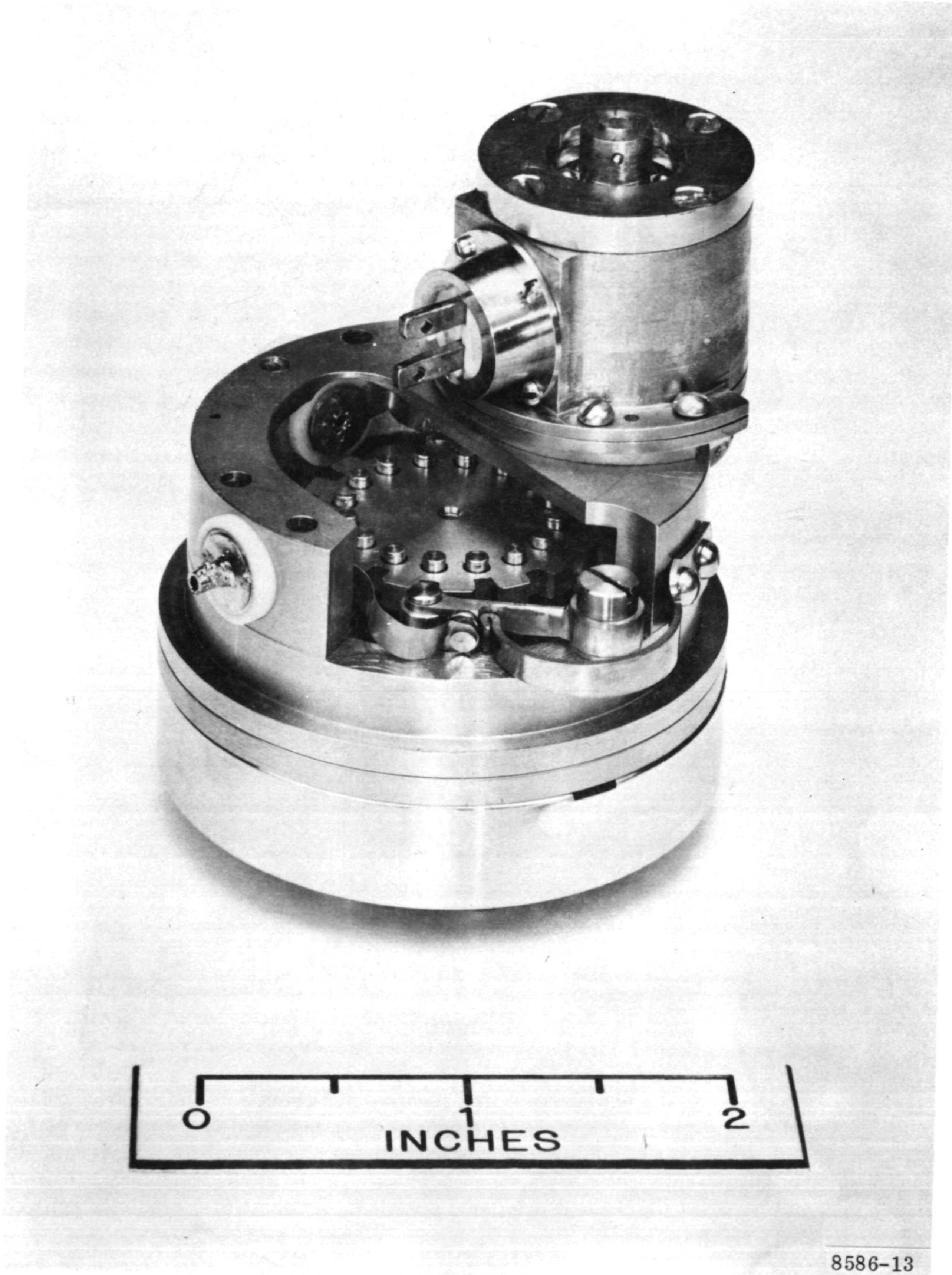

Fig. 22 - Motor mounting platform with motor in place.

This prevents any rotational or longitudinal motion of the insulators. The detent electrical contact is visible in this photograph in the foreground, but the locking arm electrical contact on the far side is not visible. The final version of the detent electrical contact spring arm is considerably modified from that shown in Fig. 18. It has been redesigned to be stiff and rigid over most of its length and flexible only over a short distance near its tip. This can be seen in Fig. 4. This leads to improved positional stability of the contact location and allows a small contact gap to be set and maintained. This contact gap needs to be maintained at .010 inch or less. The small gap prevents the thermostatic motor from being prematurely turned off before the cathode platform completely reaches the next position.

The Vacuum Envelope

Figure 23 shows the components of the vacuum envelope which surrounds and supports the MEG mechanism. The mechanism in its supporting main insulator is inserted in the cylindrical body from the bottom. The fit between these elements is so close that a special insertion fixture is required. Its final depth position into the body is determined by locating shoulders at the upper end of the cylindrical body. The ceramic insulating base, through which the electrical connections are brought into the vacuum envelope, is shown at the lower left. The copper and nickel current carrying conductors pass out of the base through the Kovar sleeves shown brazed to the ceramic. The large diameter sleeves are for the large copper conductors which carry current to the motor and to the heaters. The smaller sleeves allow passage of the smaller nickel leads from the telemetry contacts. One of the heater leads is a common return for both the heater current and the telemetry circuit. Two of the smaller feedthrough sleeves are spares.

After the base is assembled in place over the leads and is fit into the cylindrical body, the rim of the base is sealed into place with a heli-arc weld. Each of the feedthrough leads is then brazed into its copper sleeve using radiation heating from a surrounding resistance heater. This complet es the closure of the back.

The front, or anode plate of the tube, is also shown on the lower right of Fig. 23. The collector electrode (center foreground) is RF brazed into the cylindrical projection on the left half of this plate. The large cylindrical projection on the right half of the plate is the base of pump out tubulation. The small cylindrical projection at the extreme r ight side of the plate is the outer sleeve of a locating pin which sets the correct rotational position of the plate. Before the cathode assemblies are installed in the cathode platform, a dummy alignment fixture is inserted in the mounting hole of the active cathode location. This dummy pin has a projection which accurately aligns the anode hole and the anode plate, and set its correct rotational position. At this time, a hole is drilled

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Fig. 23 - Components of the vacuum envelope. In foreground (left to right) are ceramic base, collector and anode plate. In background is the cylindrical vacuum envelope.

into the body through the locating pin sleeve. Thus, the correct rotational position of the anode plate is set with the respect to the cathode position. Through the use of a locating pin in this hole, the precise rotational position is set and can be exactly repeated after the cathodes are installed.

Once the pin location has been set, the collector electrode is RF brazed into the projecting cylinder on the face of the anode plate. The tubulation on this collector is closed off since pumping of the tube is performed through other ports.

The Assembled Mechanism

Figure 24 is a view from the rear of the vacuum envelope looking toward the MEG mechanism after it has been inserted in the outer body and is ready to be locked into place. The main internal retaining sleeve, which bears down on the main ceramic insulators and which holds the whole mechanism tightly in place, can be seen fitting snugly against the outer vacuum wall. A series of notches around this periphery provides tabs with which the ring can be welded into the vacuum wall. A better view of this locking ring is seen in Fig. 25. An assembly fixture (which is not shown) presses downward on this ring placing the ceramics and the interior stacked assemblies under compression. The tabs of this ring are then laser welded to the vacuum wall. A key from this ring engages with a key-way in the topmost ceramic which in turn fixes the rotational position of the interior mechanism. The electrical leads which project out through the back ceramic base of the tube can also be seen in Fig. 25.

After the mechanism is assembled to the stage shown in Fig. 25, the ceramic base is lowered into place over the electrical leads and the mating flanges of the base and the body are heliarc welded. The electrical leads are brazed into the sleeves on the base by radiation heating.

Figure 26 shows the coated cathode assembly with the particulate shield in place. This is the final view prior to closing the anode plate. The final closure is made by a heliarc weld around the circumference of the mating flanges. The configuration of both the front and back sealing flanges is shown most clearly in the cross-sectional drawing of Fig. 3.

Figure 27 shows the completely assembled gun after completion of the bakeout process. The pumping tubulations have been pinched off. An appendage pump is outside of the top of the picture. The collector electrode is at the left side of the anode plate. The long tubing projecting upward from it is a pumping tubulation which is not used in this application and is sealed off.

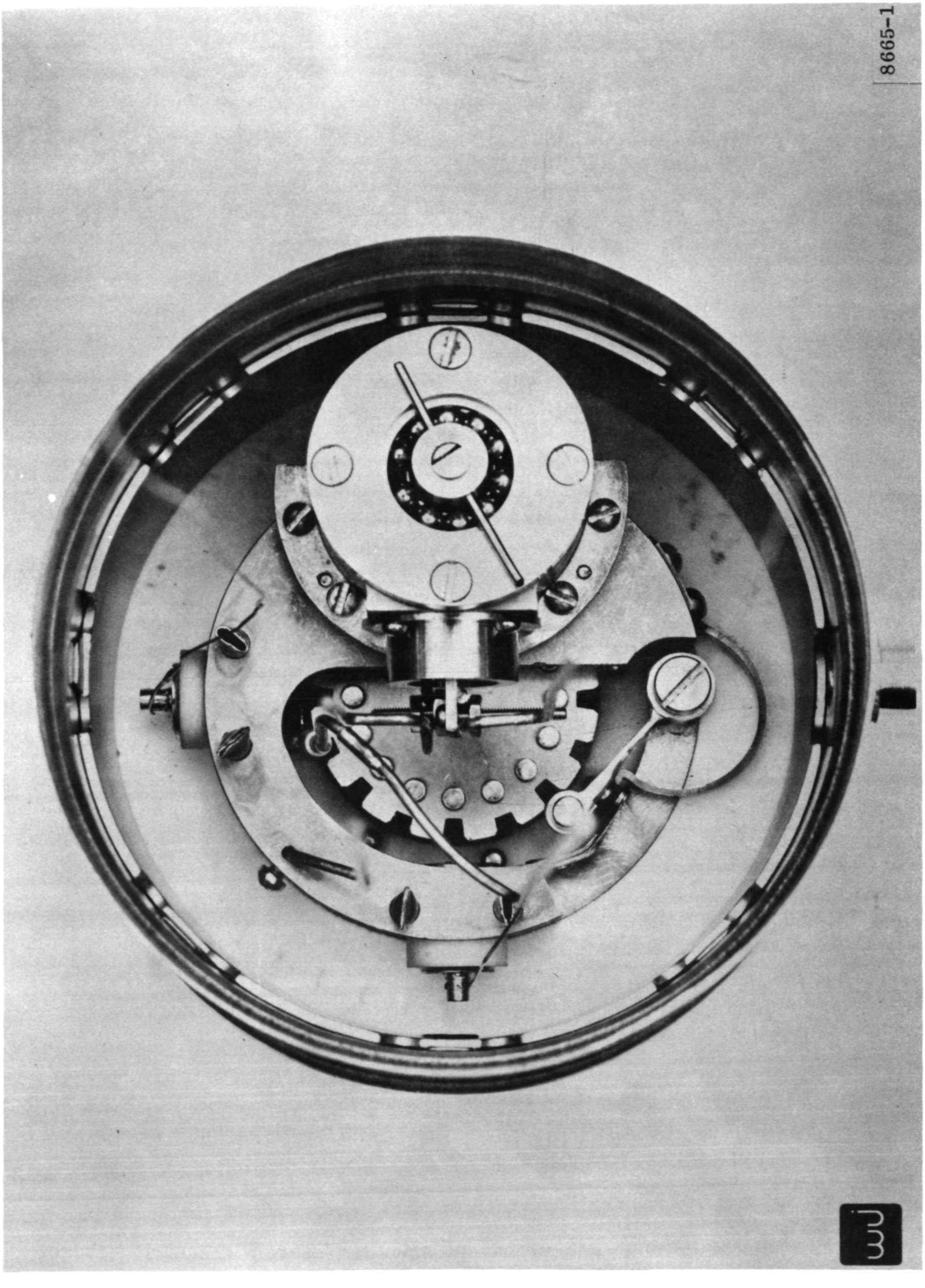

Fig. 24 - View from rear of vacuum envelope looking toward MEG mechanism.

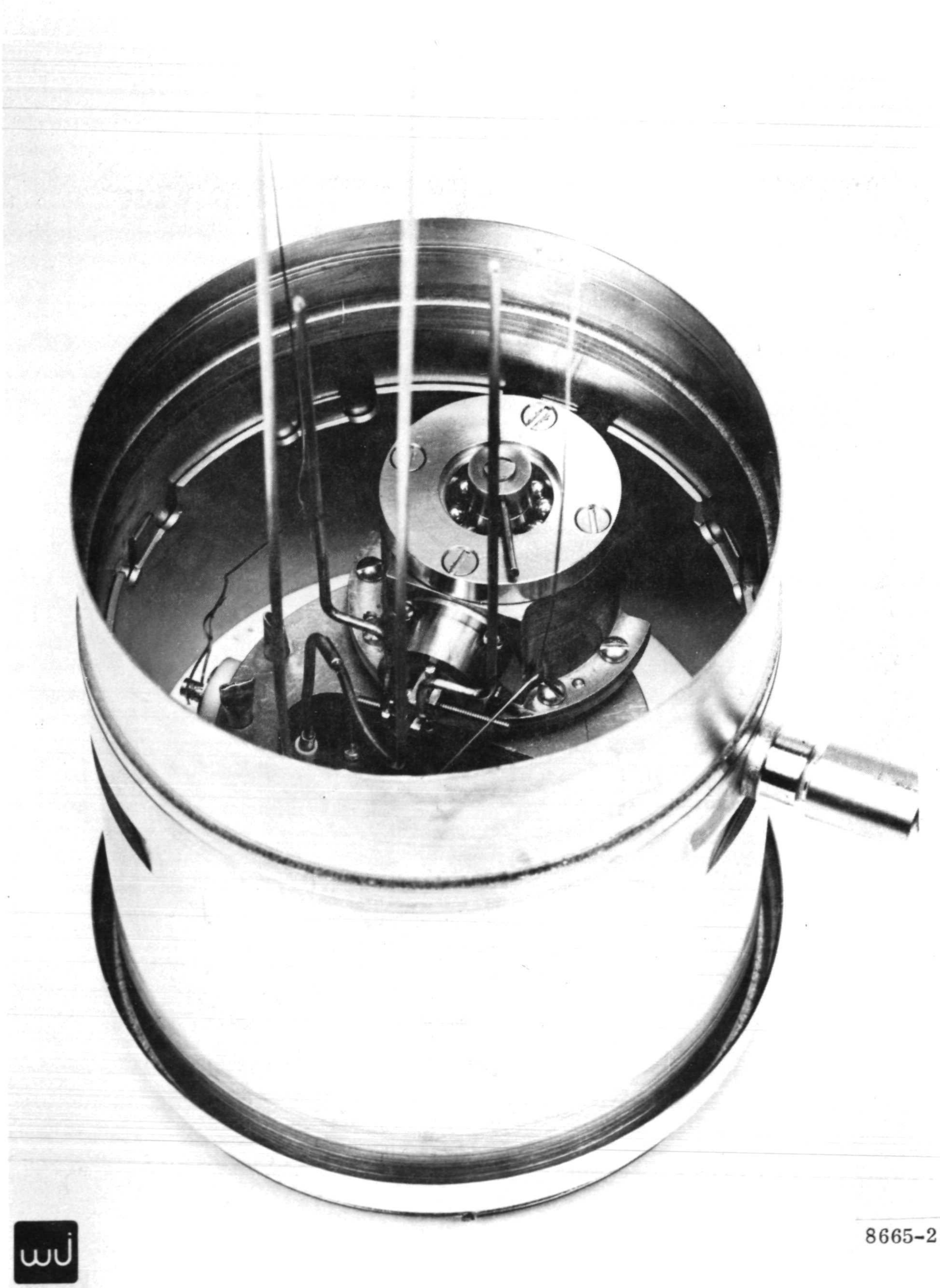

Fig. 25 - View of envelope and mechanism prior to closure with insulating base. Electrical leads can be seen.

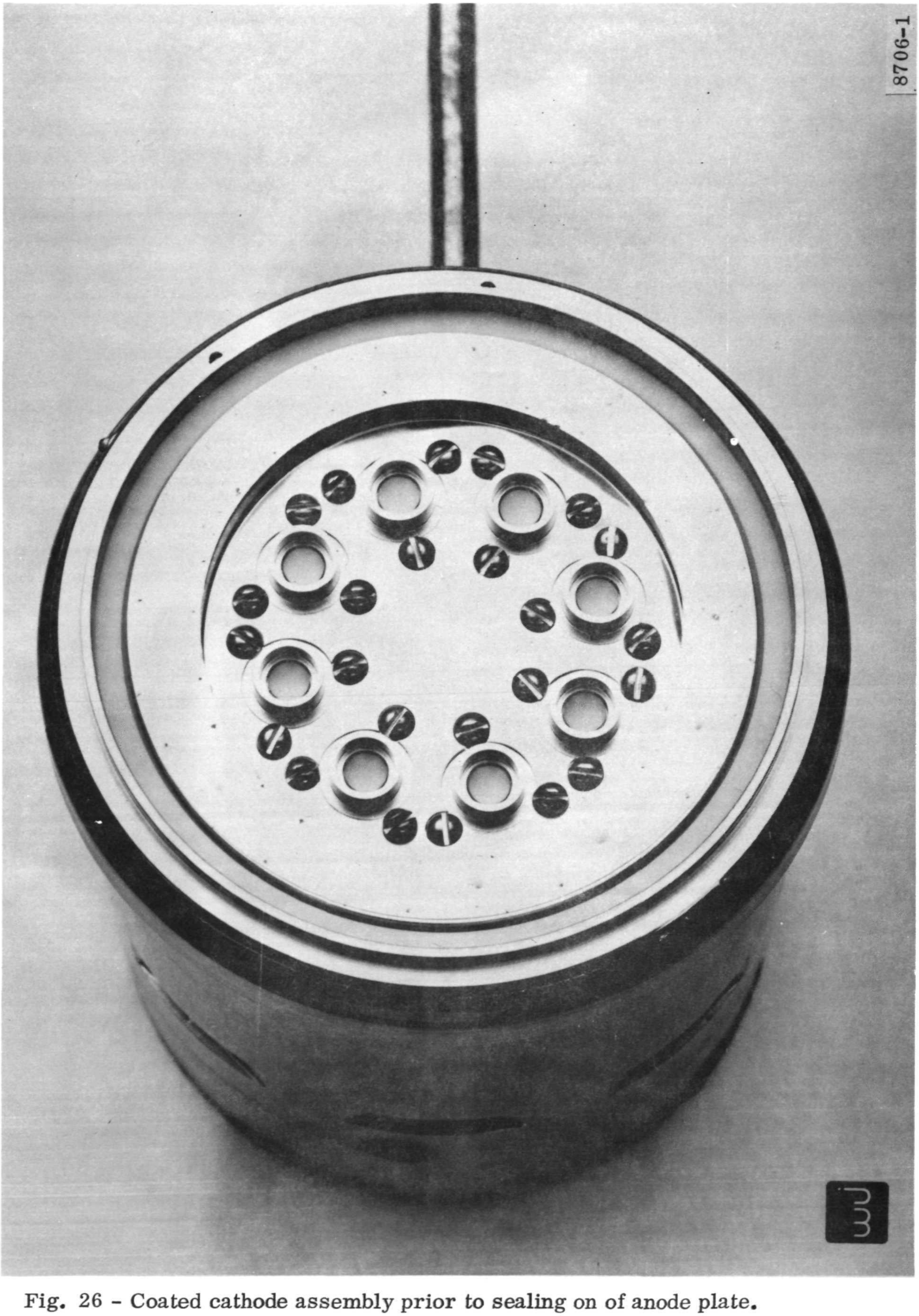

Fig. 26 - Coated cathode assembly prior to sealing on of anode plate.

Fig. 27 - Completely assembled MEG after completion of bakeout process.

When the gun is to be used with an actual TWT, the TWT will be mounted at the collector location with a modification of the anode plate.

Processing

Evacuation of the vacuum envelope is accomplished through two pumping tubulations. One evacuates the chamber containing the cathode surfaces and the other evacuates the chamber which contains the bearing and motor mechanism. This is done because the pumping path internally between the two chambers is made intentionally with an extreme restriction. The two tubulations are connected externally to a common system.

The increasing and decreasing temperature cycles of the high temperature bakeout take place over an eighteen hour period of time. This is done to prevent the bearing lockup due to temperature differential between inner and outer main bearing races as explained in an earlier section of this report.

All cathodes are heated simultaneously during the cathode breakdown cycle. The temperature of the bakeout activates the bi-metal arms which support the electrical contacts for seven of the cathodes and brings them into contact with the heater terminals. The eighth contact is made of high temperature spring material and is always in contact with the heater terminal at the active cathode location.

Before bakeout, the cathode platform is advanced to an intermediate position one-half way between active locations. The temperature of the bakeout then heats the thermostatic motor element which advances the cathode platform to the next detent position which corresponds to an active cathode location. Cathode activation takes place at this location.

Operating Results

The MEG device was completed to the point shown in Fig. 27. The mechanism was perfected to the point where it would operate reliably and smoothly in advancing the platform from one cathode position to the next. Numerous vacuum tests were made on the completed device including the advancing of the mechanism more than one complete rotation in 20 cycles.

During the development of the device numerous tests were made on the bearing and platform mechanism mounted in the support ceramics and vacuum envelope where the complete bakeout cycle was carried out in a vacuum. This included the extended temperature rise and fall times required by the bearing. It was determined that the bearing was capable of freely turning after the bakeout cycle with a typical starting torque of eight inches/ounces.

The completed device with coated cathodes was carried through the bakeout cycle on two different occasions. During the first occasion, the particulate shield warped enough to prevent the mechanism from turning to the next detent position during the bakeout. After disassembly, it was determined that the bearing was completely free and had not contributed to the difficulty. On the second occasion, the particulate shield was left off. The mechanism partially advanced enough for the cathode contacts to be made, but did not travel to the next detent location. After cooling, operation of the motor would not push the mechanism to the next location. Subsequent disassembly showed that the main platform bearing was locked up. The reason for this happening could not be determined. The slow temperature rise and fall rates had been used during the processing cycle. As a result, a complete test of the MEG system with operating cathodes and electron beam generation was never carried out.

With some additional work, it is quite certain that a complete operating gun could be achieved.

V. ACKNOWLEDGEMENTS

The development of the MEG device was a team effort. The device concept and demonstration of the conceptual model was carried out at the Jet Propulsion Laboratory by Lloyd J. Derr. He also continued in the role of project monitor and contributed extensively to the design modifications as the development progressed. Details of the mechanical design and the design drafting was imaginatively done by David Vaughan. The intricate machining to extremely difficult tolerances in difficult materials was done by Preston Burchard. He also designed and executed many of the jigs, fixtures, and tools necessary to form or assemble many of the parts. The tube assembly, testing, processing and specialty machining was carried out with great patience by Richard Birtwhistle. Additional fixture designing and testing was also done by Paul Sterner. Each of these people made extensive contributions to the final device design.