DEVELOPMENT OF A 25 - 50 WATT HIGH EFFICIENCY, X-BAND, TRAVELING-WAVE TUBE

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ABSTRACT

This is the second Quarterly Progress Report on the development of a 25 - 50 watt, dual mode, high efficiency, X-band space-type traveling-wave tube. During this quarter, the electron gun design was completed, the gun was built and beam trajectory measurements were made, impedance matching design tests were completed, subassembly construction was carried out, PPM magnets were received, the two-stage collector was designed and parts machined, and work was being done on the attenuator design at the end of the period. Technical progress had proceeded to the point where assembly of first tube should take place early in the next quarter.

SUMMARY

The purpose of this project is to develop a dual mode, high efficiency, X-band traveling-wave tube suitable for use as the power amplifier in a spacecraft transmitter for deep space communications systems. The major performance requirements are 42 to 45 percent overall efficiency, 25 to 50 watts power output and an operating frequency range of 8.4 to 8.5 GHz. Cathode design for a lifetime approaching 100,000 hours is required.

The tube design is based upon large overvoltage techniques coupled with two stage depressed collector operation to achieve the efficiency performance. Magnet design is based upon rare-earth-cobalt magnet materials to achieve high performance PPM electron beam focusing. Long life design is based upon Coated Particle Cathode technology.

During this quarter, the electron gun design was carried out using the computer design technique. The gun was then constructed and tested for beam trajectory and perveance in the beam testing system. Impedance match design and testing was completed for the coax to helix transitions. Subassembly construction was carried out to the point where a tube could be assembled. The PPM focusing structure was built and tested with platinum-cobalt magnets. At the end of the period Samarium-Cobalt magnets were received and preliminary tests were made. The two stage collector was designed and analyzed under saturated RF beam condition using computer techniques. Parts were made in preparation for fabrication. At the end of the period, work on the final internal attenuator configuration was underway.

The first tube should be assembled early in the next quarter.

1. INTRODUCTION

Scope and Purpose of the Project

The purpose of this project is to develop a dual-mode, high efficiency X-band traveling-wave tube which can be used as a spacecraft transmitter for deep-space communications systems. It is required to operate at the efficiency level of 42 to 45 percent in the power level range of 25 to 50 watts over the frequency range of 8.4 to 8.5 GHz. The tube is to be designed to meet all requirements of spacecraft operation and launching environment. Life requirements demand cathode design having an ultimate possible life capability of 100,000 hours. Detailed performance requirements are given in Specification No. CS505093 and the environmental requirements are given by Specification No. TS 504550 (Mariner Mars 1971).

Basis of Tube Design

The high efficiency tube design is based upon the technology developed at Watkins-Johnson Company of large over-voltage operation of a traveling-wave tube. Using this technique, a high value of basic beam efficiency can be achieved. The overall efficiency of the tube is further increased through the use of depressed collector operation. Improvement in normal depressed collector efficiency will be accomplished by using a two stage collector system wherein electrons of different velocity classes can be sorted out and collected at optimum potentials.

X-band operation imposes certain restrictions on the TWT design due to the high beam current density necessary for this type of high efficiency operation. In general, this forces the use of lower values of beam perveance in the helix region than can be achieved at lower frequencies. This present design utilizes the higher coercive force of new magnetic materials such as samarium-cobalt to provide the high magnetic flux density in the electron beam necessary to focus the high values of current density. Use of the new rare-earth-cobalt materials allows the use of a high value of plasma wavelength to magnetic period ratio in the periodic permanent magnet focusing structure. This assures good focusing under large-signal, depressed collector conditions.

Long life operation of the cathode of the tube will be accomplished by using Coated Particle Cathode (CPC) technology. This is a special form of the oxide cathode[1]

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1 D. W. Maurer and C. M. Pleass, The CPC: A Medium Current Density High Reliability Cathode, BSTJ Vol. XLVI, No. 10, Dec. 1967.

which overcomes most of the major life limiting factors of the simple oxide cathode. This is accomplished by coating each particle of the basic triple-carbonate cathode coating material with a microscopically thin shell of high purity nickel material. These particles are then coated onto a nickel substrate which provides reducing agents at a controlled rate for converting the barium oxide material to free barium. The CPC cathode combines a high current density capability with low temperature operation and long-life performance.

II. WORK ACCOMPLISHED DURING THIS QUARTER

Additional Phase Velocity Measurements

Additional phase velocity measurements were made on the helix structure. These were made on the helix of a design corresponding to the output section of the 32 watt design described in Table I of Quarterly Report No. 1. This had 100 TPI versus the 75 TPI of the experimental helices measured before. The normalized phase velocity data reduced from these more recent measurements lie within one percent of the data previously shown as Helix No. 2 in Figure 1 of Quarterly Report No. 1. These most recent data were then used as the normalized model for all design and analysis calculations based upon this helix configuration with four BeO supporting rods.

Electron Gun Design

Following the initial calculations on the WJ-251 gun design, modification computations were begun using the electron gun computer program. It was desired to increase the distance from the anode electrode to the point where the beam reached its minimum diameter. It was also desirable to improve beam laminarity. These computations were made in a series of steps starting from the WJ-251 gun design and moving various surfaces of the gun elements to improve the beam trajectory and laminarity. A series of 21 sequential calculations were made to arrive at the final gun element configuration. Some shortcuts were used on the calculations to save computer time by storing space-charge matrix information and using it to reduce the number of relaxations required for the calculations to converge. The final beam trajectory and electrode configuration is shown in Figure 1. This plot does not include the effect of thermal electrons.

The calculations showed that the new design would have several improvements. First the gun perveance increased from the value of 0.177 micropervs for the WJ-251 gun to a value of 0.285 micropervs. This will result in a lower operating anode voltage. Second, the anode to beam minimum distance increased from .115 inch to .410 inch which allows a much better gun polepiece configuration. Third, the current density across the surface of the cathode became very uniform. The following Table gives the pertinent parameters for the 32 watt design.

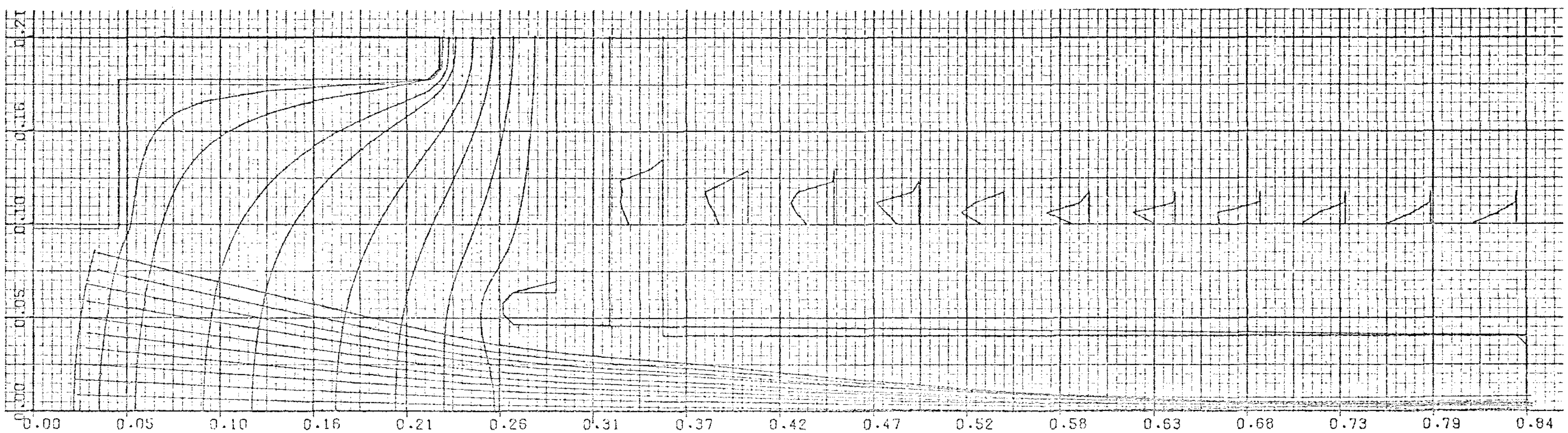

Fig. 1 - Computer plot of electrode configuration and beam trajectory for the initial gun design. Gun perveance = .285 micropervs.

Perveance	.285 micropervs
Cathode Current Density	.340 amps/cm^2
Beam Current	49 mA
Cathode Diameter	.172 inches
Beam Diameter	.016 (without thermal electrons)
Anode to Beam Min. Dist.	.410 inches

The design was then constructed and placed under test in the beam tester bell jar system. In this system, the gun is tested under pulsed conditions to eliminate ion-focusing effects and the current density in the beam cross-section can be scanned with a pin-hole collector system. The pin-hole collector can be moved axially away from the gun anode as well as across the beam which then gives current density profile measurements as a function of distance from the gun. In this way, the position of the minimum beam diameter can be determined as well as the diameter of the electron beam as a function of distance.

Various perturbations of the design positions of the cathode with respect to the focus electrode and the anode with respect to the cathode were tried. It was found that the position of the beam minimum occurred slightly ahead of the design location and that the measured minimum beam diameter, which includes thermal electrons, was somewhat larger than predicted. This was expected. The optimum combination of the electrode positions was determined which gave the smallest beam minimum. This produced a beam diameter of 0.023 inches as compared with the desired value of 0.017 inches. Beam perveance measured to be the value predicted by the computer calculations. Figure 2 shows the measured beam profile for the optimum design.

It is planned to use this gun design in the first tube to evaluate its performance. The additional reduction in beam diameter can easily be accomplished by magnetic convergence in the first few entrance cells of the PPM stack.

Impedance Matching Tests

Helix impedance measurements were made using an HP Network Analyzer. With great care taken to minimize connecting line lengths and spurious discontinuities of connectors, smooth data was measured over the X-band frequency range. Helix impedance varied from 175 ohms to 200 ohms over the 8.2 to 12.4 GHz range.

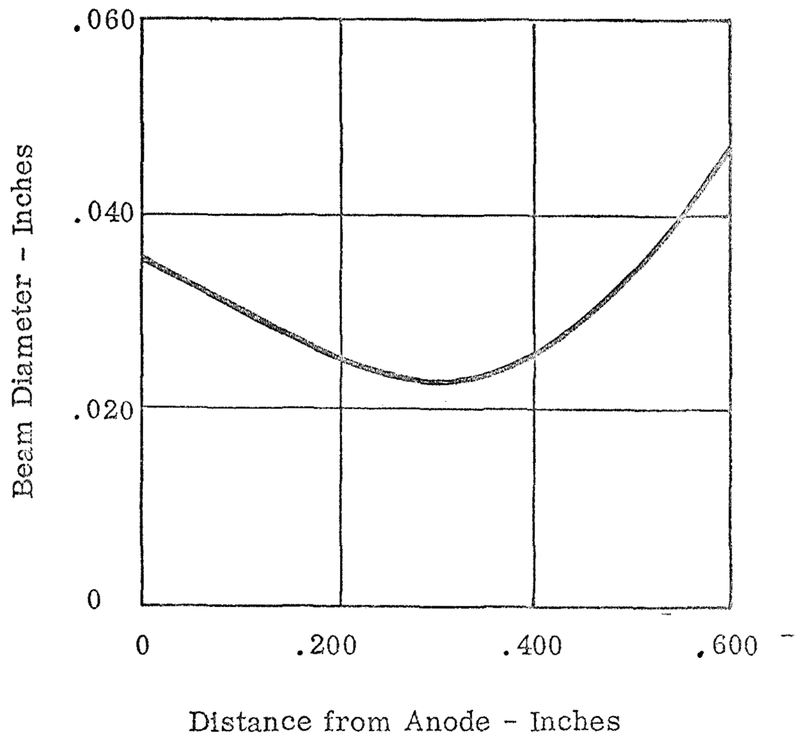

Fig. 2 - Plot of measured beam diameter vs distance from the anode of the electron gun.

The technique used to match the helix impedance to the 50 ohm coaxial line impedance consists of a quarter-wavelength transformer in the coaxial line section between the vacuum window and the beginning of the helix. This technique can be used at X-band because the short wavelength allows it to physically fit into this space. Since only relatively narrow band matches are required for the limited frequency range of this requirement, a single quarter-wave transformer is used. Figure 3 is an expanded Smith Chart plot of this match across the 8.0 to 9.0 GHz range. Over the required frequency range of 8.4 to 8.5 GHz the VSWR is less than 1.07:1. This plot includes the effects of the OSM coaxial connector, the vacuum window, the transformer, and the helix termination.

Subassembly Fabrication

Parts and jigs were received from the machine shop during the quarter and the various assemblies were fabricated and checked for assembly problems and vacuum integrity. An exploded view of the tube assemblies is shown in Figure 4. A view of the parts assembled as they will be in a completed tube is shown in Figure 5. The tube type assignment number is WJ-3703. This view shows the tube with the single-stage collector.

The major difficulty encountered in the assembly has been in drawing the helix barrel tubing to precisely the right inside diameter. The helix supported by four rods inside a deformed barrel requires more critical dimensional control over deformation than a conventional three rod helix. The small barrel size accentuates this difficulty. Our plans were to quantitatively measure the barrel ID before and during deformation with a precision air gauge which can measure dimensional changes accurately to 0.0001 inch. Delivery on this gauge has been delayed until early in the next quarter so alternative ways of controlling deformation have had to be worked out. It has been necessary to draw sets of tubing with the inside diameter increased in steps of 0.0005 inch. The choice of the correct size of tubing to use has had to be made based upon trial and error tests on finished helix assemblies. This procedure has caused some delay.

PPM Focusing Structure

At the design beam perveance value of 0.46 microperv s, it is necessary to use high coercive force permanent magnets to simultaneously meet the requirements for axial magnetic flux density and short magnetic period. At the desired value of the ratio of plasma wavelength to magnetic period, λ_p/L, of 2.8, samarium-cobalt magnets are required. At the lower value of $\lambda_p/L = 2.2$, platinum-cobalt magnets

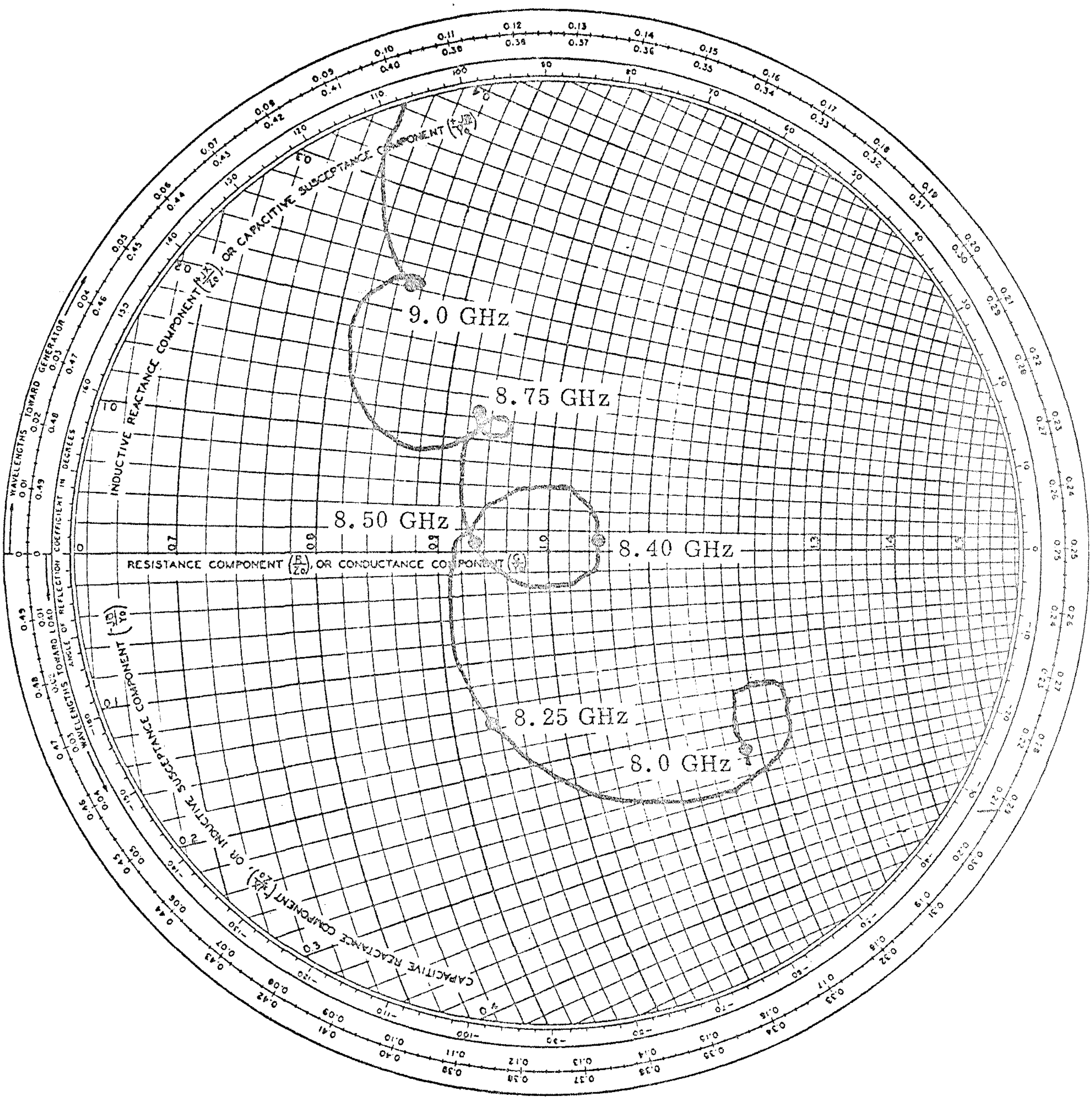

Fig. 3 – Expanded Smith Chart Plot of the coax to helix transition including the vacuum window.

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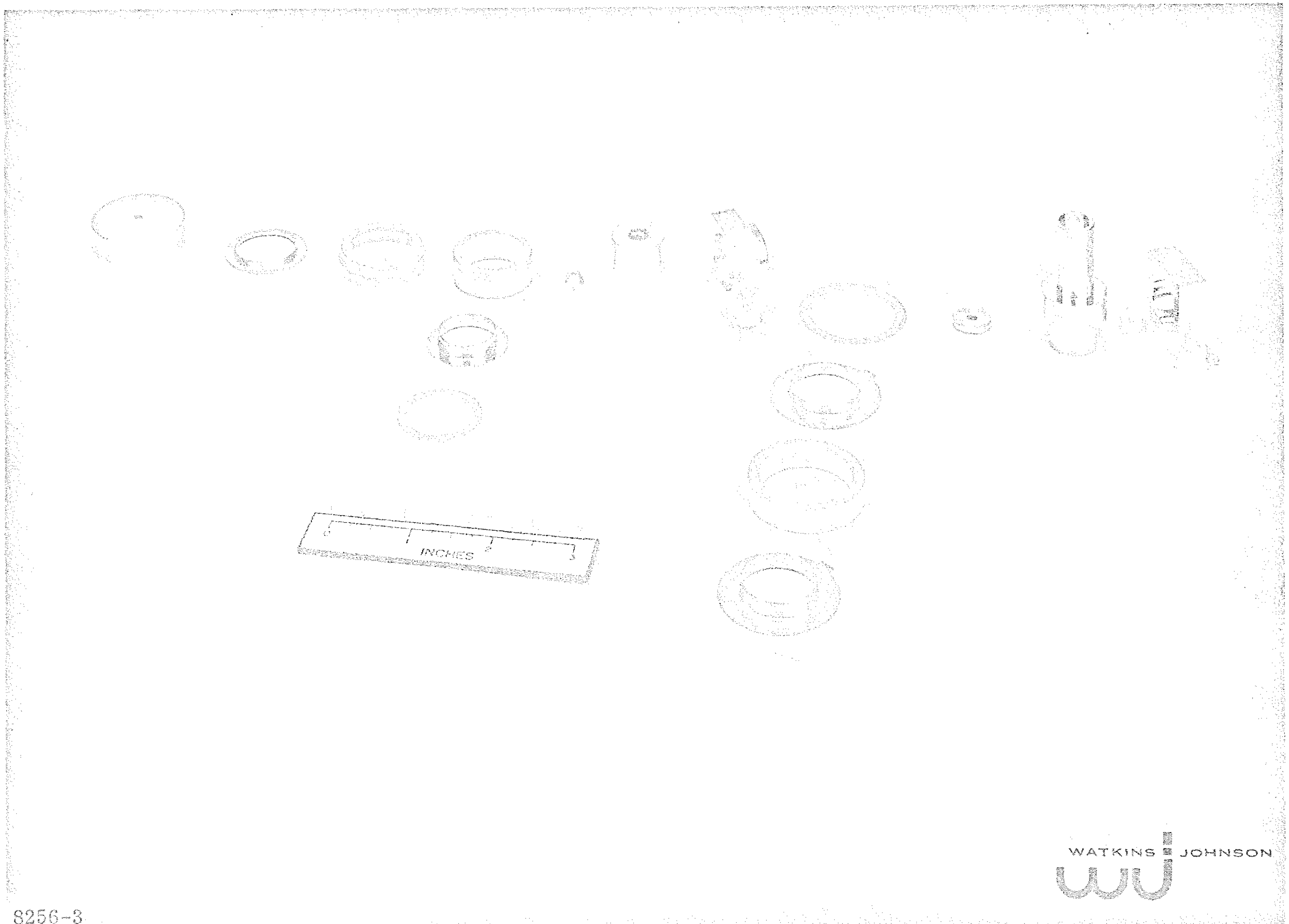

Fig. 4 - An exploded view of the WJ-3703 assemblies.

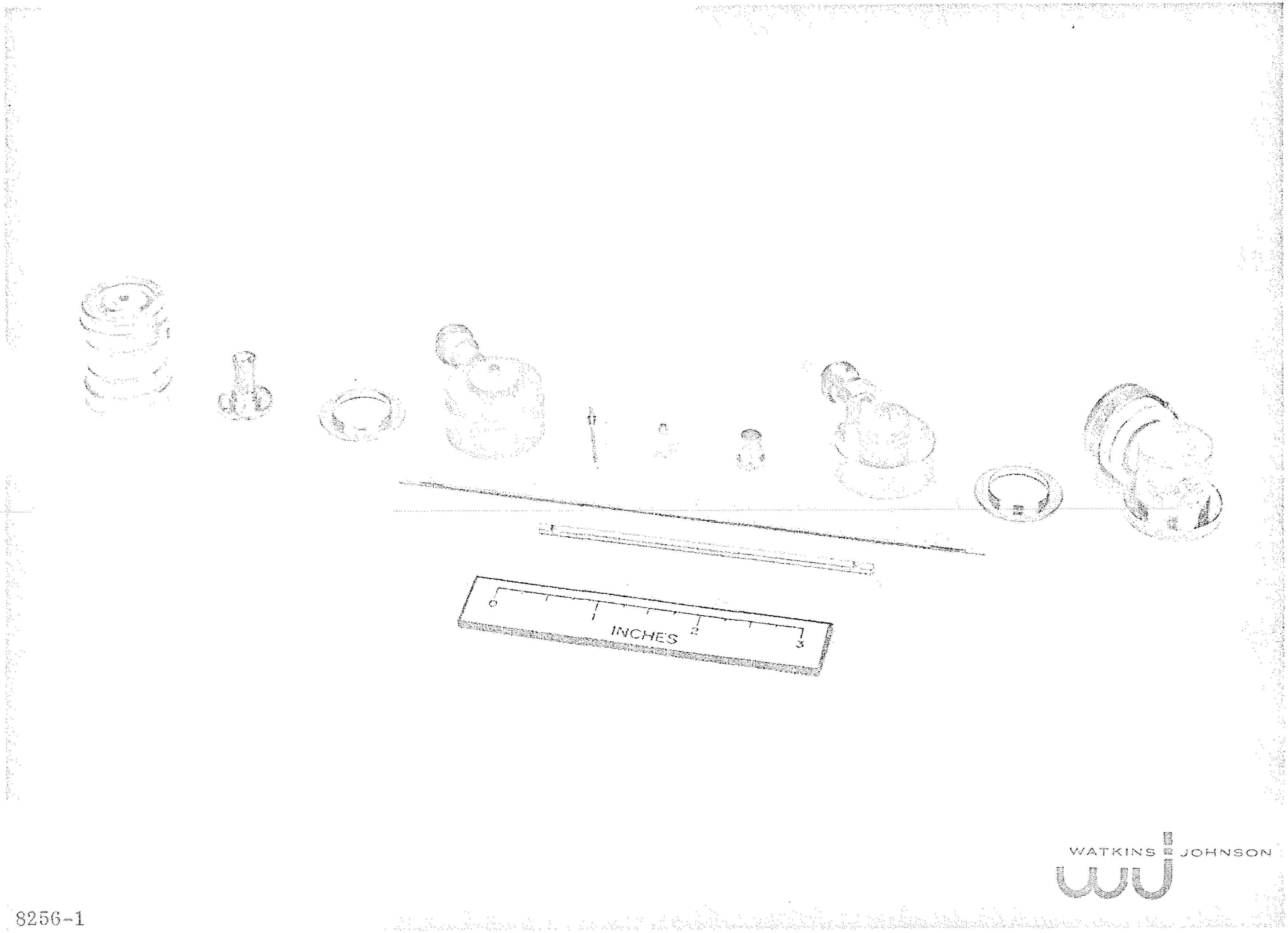

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Fig. 5 - Photograph of the parts assembled as they will be in a completed tube. This shows the single stage collector.

can be used. Both platinum-cobalt and samarium-cobalt magnets were ordered. Cerium-cobalt magnets were also considered as a substitute for platinum-cobalt, but the bid price was higher than platinum-cobalt. Focusing performance will be evaluated with both magnetic period values given above. The possibility of a hybrid stack will also be investigated.

We have recently received delivery of magnetizing and demagnetizing equipment suitable for use with samarium-cobalt material.

Platinum-cobalt magnets were received in the middle of January. A complete magnet stack for the first tube was built up and the field pattern was refined to give uniform peak fields by programming the individual magnet cells. It is ready for the first tube.

The samarium-cobalt magnet material was delivered just at the end of the period. Preliminary checks showed that the magnetizing equipment is capable of demagnetizing the material to one-half magnetization with the automatic system and is capable of knocking the magnetization all the way to zero with manual operation. The magnetization cannot be reversed from the delivered polarity and be completely saturated. The magnets can, however, be remagnetized in the delivered polarity to the saturated value.

Attenuator

The remaining work to be done before assembly of the first tube is to finalize the attenuator configuration. The loss is being deposited on two of the four ceramic supporting rods of the helix. Pattern length, tapers and surface resistivity are being worked out with sprayed carbon coating. When the desired pattern is achieved, it will be duplicated with a pyrolytic carbon deposition.

The attenuator work should be completed early in the next period. The first tube will then be assembled.

Two Stage Collector

The two stage collector configuration was analyzed using a computer program similar to the electron gun program except that it allows the electron beam to be injected into the electrode region with an arbitrary electron distribution and an arbitrary velocity on each electron. The velocity distribution was chosen as the exiting velocity from the helix in the large signal TWT calculations. The radial distribution was chosen as the most pessimistic, that is, the fastest electrons on the axis progressing to the slowest electrons on the outside surface of the electron beam. The trajectory plot is shown in Figure 6.

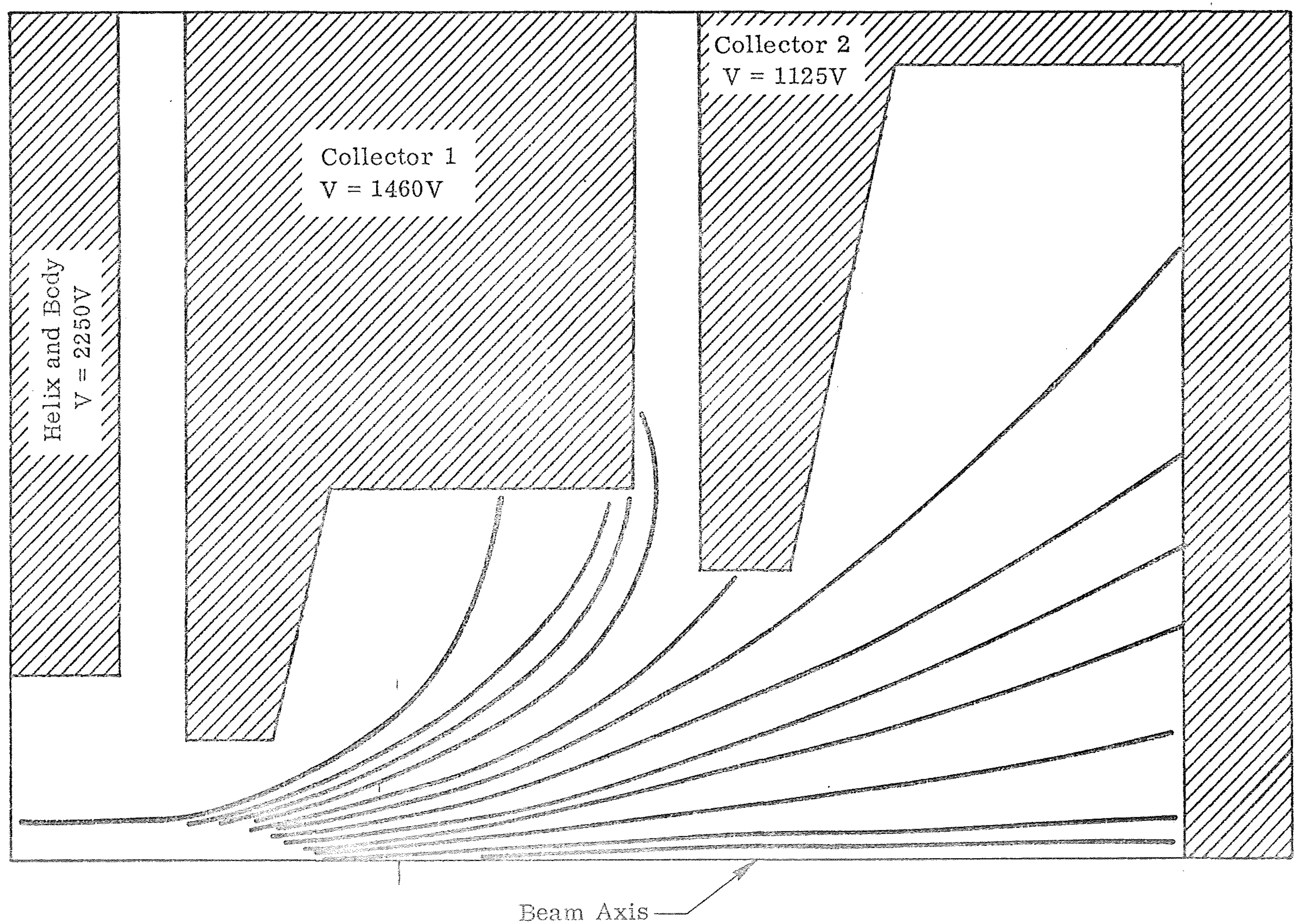

Fig. 6 - Plot of the trajectories of the spent electron beam in the two stage collector.

An exploded view of the collector assembly parts is shown in Figure 7. The two-stage collector is planned for use on Tube S/N 2. The first assembly of parts has not taken place as yet.

Program for the Next Quarter

Tube construction and testing will be the major activity for the next quarter. It is planned to build and test tubes S/N 1, S/N 2, and S/N 3. Modifications to the helix design will be made based upon the measured results. Refinements in assembly procedures will take place as required during this period.

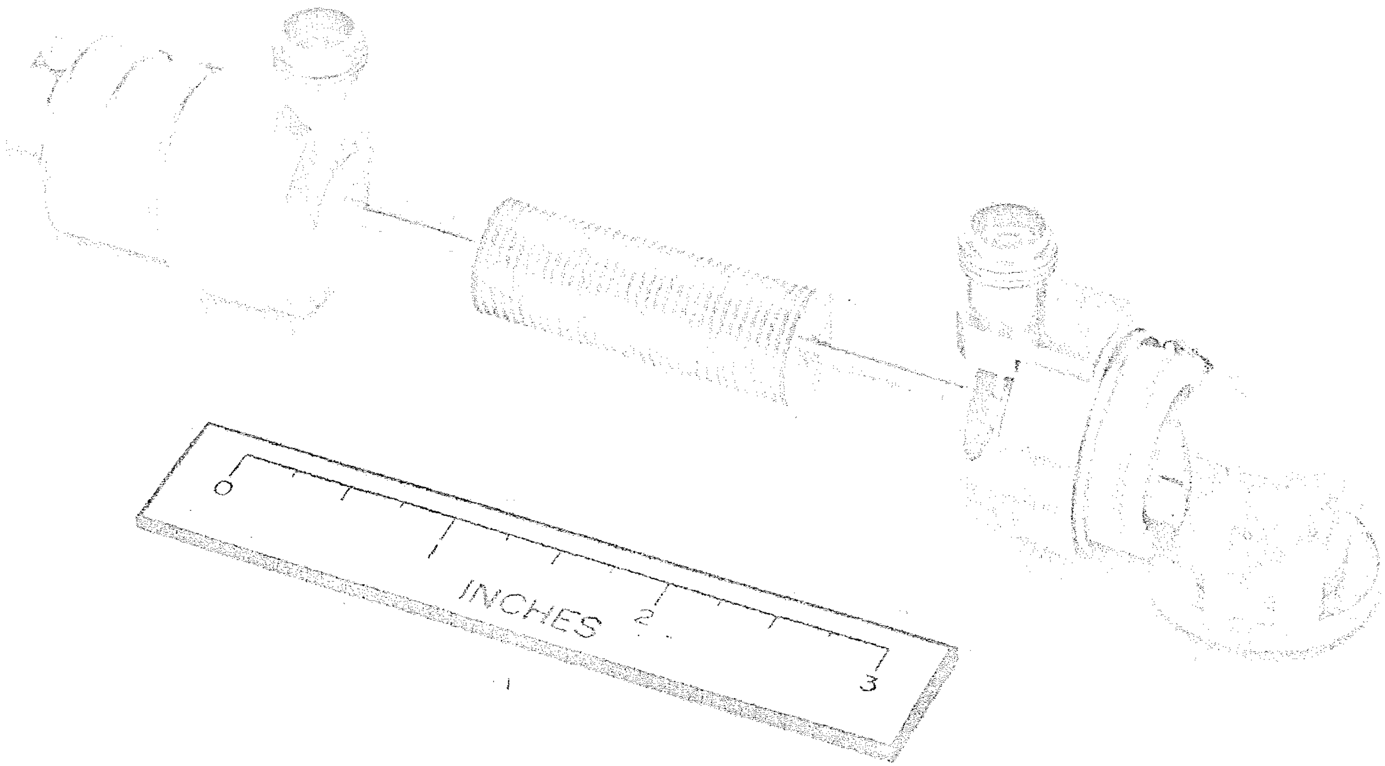

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Fig. 7 - Exploded view of the parts for the 2-stage collector assembly.