WAVE GUIDE FEED SYSTEM FOR A MICROTRON

THESIS FOR THE DEGREE OF M. S.
MICHIGAN STATE UNIVERSITY

JOHN HARRY MACROPOL

1955

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FOR A MICROTRON

By

JOHN HARRY MACROPOL

A THESIS

Submitted to the School of Graduate Studies of Michigan State University of Agriculture and Applied Science in partial fulfillment of the requirements for the degree of:

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AN ABSTRACT

This thesis describes the construction of a wave guide feed system for a microtron, or electron accelerator, in the 10 centimeter band. All the component parts are described in detail.

The reason for introducing a wave guide feed system was to obtain better impedance matching, gain a higher degree of frequency stabilization by introducing a load in series with the resonating cavity, and to reduce line losses due to sparking by evacuating the entire feed system.

The purpose of the experiment was to determine if the microtron will operate with stable orbits with the low power input available (approximately fifty kilowatts peak power) when line losses are minimized and frequency stabilization is maximized, utilizing the new wave guide feed system.

No orbits were detected with the low power input. A probable reason is electronic loading of the cavity which limits the current that can be accelerated by a given power input into the accelerating cavity.

C. D. Hause
for R. D. Spence

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INTRODUCTION

The microtron, or electron cyclotron, has certain distinctive advantages over other types of accelerators. Some of these advantages are:

a. Extreme simplicity and compactness.

b. Only a simple static magnetic field is required.

c. Vertical focusing is not required due to a very short accelerating time.

d. Extraction of the electron beam is simplified because of wide spacing of the electron orbits.

e. No special source of electrons is required; an ample supply of electrons is produced by field emission.

This paper deals with the construction of a wave guide feed system for a microtron which previously utilized a co-axial line feed system. The operation of the microtron with the co-axial line system was erratic and unstable with the low power input that was available. It was suggested that this was due to line losses, poor impedance matching, and lack of an adequate stabilizing load in series with the resonant cavity. Sparking also occurred in the coaxial line, and to remedy this condition, a new feed system was proposed which was to be evacuated completely. A tunable stabilizing load was proposed together with a phase shifter for line adjustment.

The purpose of the experiment was to determine if the microtron will operate with stable orbits with a low power input to the accelerating cavity (approximately fifty kilowatts peak power) with all power losses minimized and frequency stabilization maximized, utilizing the new wave guide feed system.

DESCRIPTION

The description and theory of operation of the microtron has been described in detail elsewhere (1). A brief review will be given here.

Generally, in outward appearance, the microtron resembles other cyclic particle accelerators. Basically it consists of a cylindrical vacuum-tight accelerating chamber which is placed between vertical pole faces of a magnet. The microtron differs from other accelerators by utilizing a constant magnetic field and a radio-frequency resonant cavity as the accelerating element whose electric field is placed tangential to the electron orbits. The electrons are produced by field emission from the inside surface of the resonant cavity and are accelerated across the gap in the cavity. Some of these electrons emerge from the hole in the pole of the cavity and describe a circle in the perpendicular magnetic field. At the proper magnetic field strength, these electrons will complete an orbit in an integral number

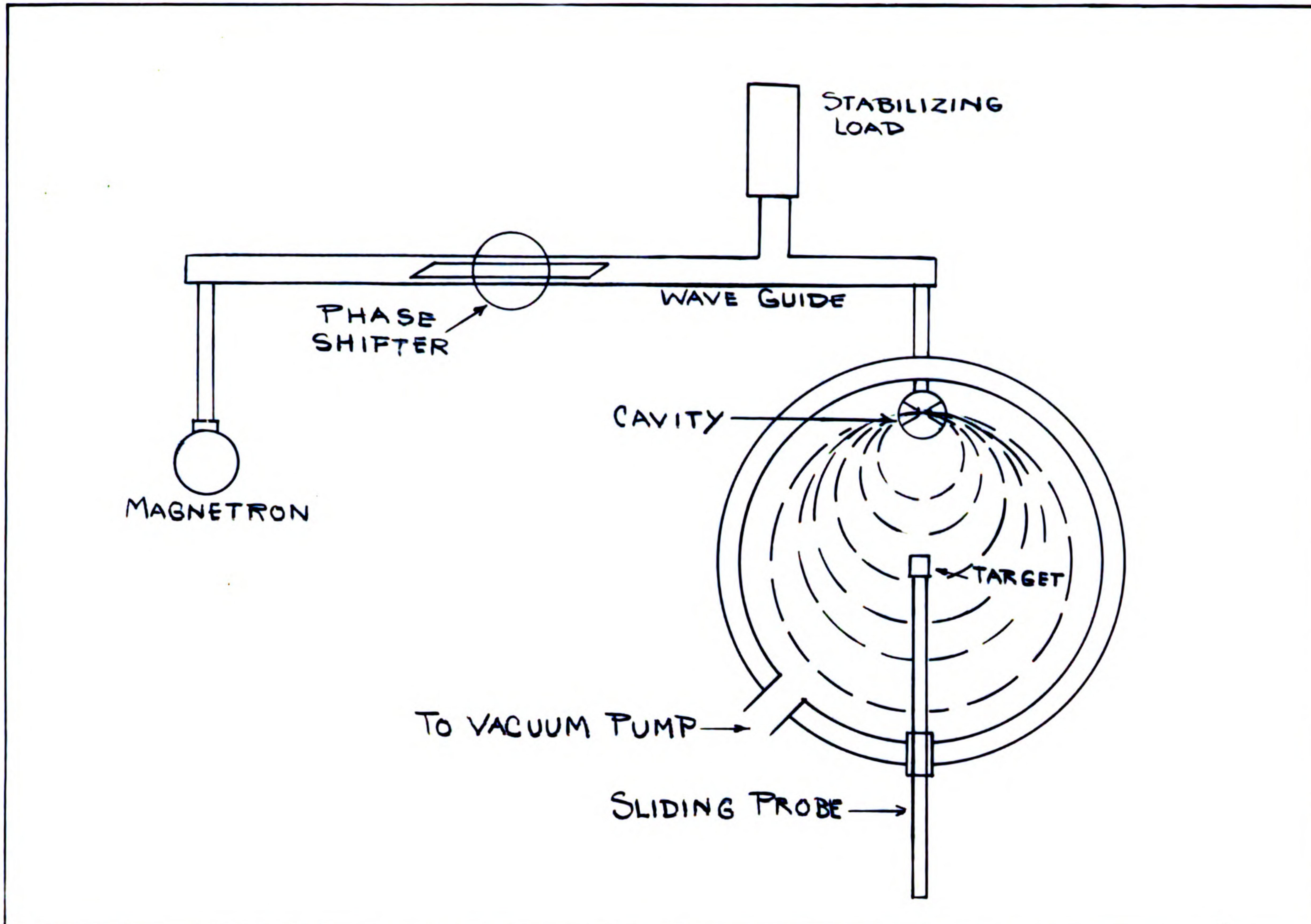


Figure 1. Simplified plan of the microtron through the median plane.

of radio frequency periods and thus return to the cavity to be given a further accelerating push across the gap. Each succeeding orbit has a larger radius due to the added kinetic energy the electrons acquire during each acceleration, but they are all co-tangential at the accelerating gap. In the microtron, the difficulty which arises from the relativistic increase in mass of the accelerated electrons as they gain in energy, is overcome by making the time lag per revolution of the electron, caused by this relativistic effect, equal to an integral number of periods of the radio frequency field. The time of revolution of each successive orbit is an integral number of radio frequency periods longer than the preceding orbit. Thus the electron always returns to the accelerating gap in phase for further acceleration. Also, the period of the first orbit is made an integral number of radio frequency periods.

The microtron has inherent phase stability for electrons that enter the accelerating gap before or after the resonant phase (2). Suppose an electron crosses the accelerating gap at a phase p_o after the maxima of the radio frequency cycle (Figure 2). This electron

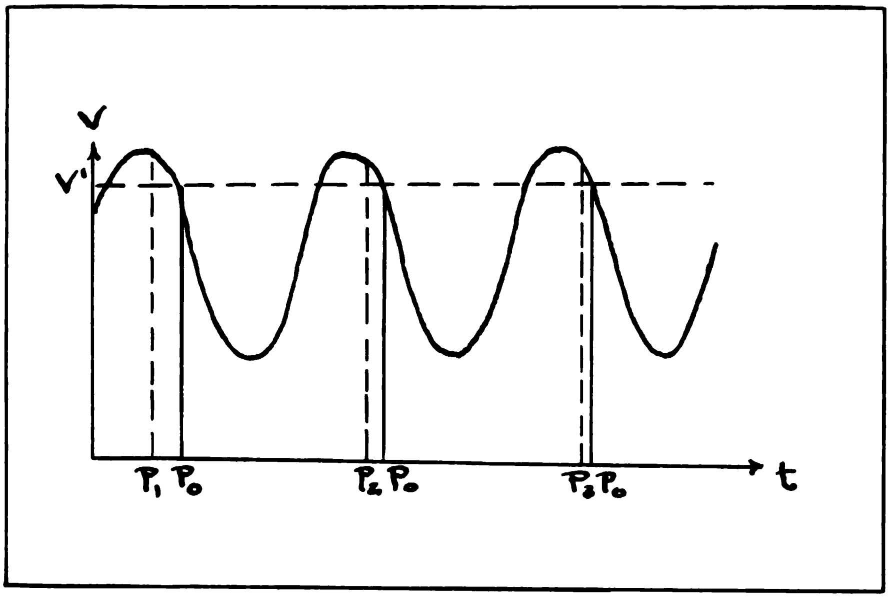


Figure 2 Phase stability

will be accelerated, and for the proper magnetic field strength will return to the gap at the same phase p_o to be accelerated again. This is the resonant electron. If an electron traverses the gap slightly ahead of the resonant electron at a phase p_1, it will gain more energy than the resonant electron and thus describe a larger orbit with a larger time of revolution.

Thus its phase p_2 at the next gap crossing will be closer to the phase of the resonant electron. After the next acceleration, it will cross the gap at the resonant phase but will have acquired a greater energy than the resonant electron which will cause its phase to shift to the other side. This process will be repeated with succeeding accelerations until the electron crosses the gap at the resonant phase. Thus in a region about the resonant phase, electrons will remain in a stable orbit. All other electrons have unstable phases and will be lost from synchronism.

FREQUENCY STABILIZATION

When a high Q cavity is tightly coupled to a magnetron resonator system, it tends to stabilize the frequency of oscillation of the magnetron and makes it oscillate with a frequency equal to the resonant frequency of the cavity (3), providing the resonant frequency of the cavity is within the frequency range of the magnetron. This frequency stability is the effect of the increased energy storage of the system. However, since the cavity must be coupled by means of a transmission line (wave guide or co-axial line) that is in itself resonant, the system will have three modes of resonance which differ slightly in frequency. The middle mode is the "principle" mode and the outer ones are "extraneous" modes. Because the stabilization is higher for the principle mode, oscillations build up more strongly in the extraneous modes because the effective value of resonator capacitance is higher for the stable mode and the rate of build-up varies inversely with resonator capacitance. This causes the magnetron to oscillate in one of the extraneous modes instead of the highly stable principle mode. This is particularly true if the frequency stability of the principle mode is more than about three times that of the unstabilized system. To avoid this difficulty, the attenuation of the transmission line between magnetron and cavity may be increased by introducing an auxiliary load in series with the transmission line.

For our case, since the transmission line was wave guide, a sand load was utilized. This consisted of a section of wave guide filled with sand and placed in series with the main transmission line by means of a tee coupling.

During normal operation, heat will be generated in the resonating cavity, especially if a large amount of r-f power is applied. This causes expansion with a subsequent volume increase and change of resonant frequency. To avoid this effect, some means of temperature control such as water cooling is desirable. The cavity used with the new feed system was water cooled.

CONSTRUCTION OF THE WAVE GUIDE FEED SYSTEM

Co-axial Line to Wave Guide Transitions

Because the 2J22 magnetron that was used for the r-f power is designed to couple to a co-axial line, a transition from co-axial line to wave guide was necessary in order to introduce the r-f power into the wave guide system. On the terminal end of the wave guide system, a wave guide to co-axial line transition was used as a take-off to introduce power into the cavity. This was necessary because the distance between pole pieces of the microtron magnet was not great enough to allow a wave guide coupling to the accelerating cavity.

Crossbar transitions (Figures 3 and 4) were utilized because of their simplicity of construction and because they permit a more accurate support of the center conductor of the co-axial line. This is important because the position of the center conductor is critical for adequate impedance matching. A graph of voltage standing-wave ratio versus wave length for the crossbar transition, based on data by G. L. Ragan (4),

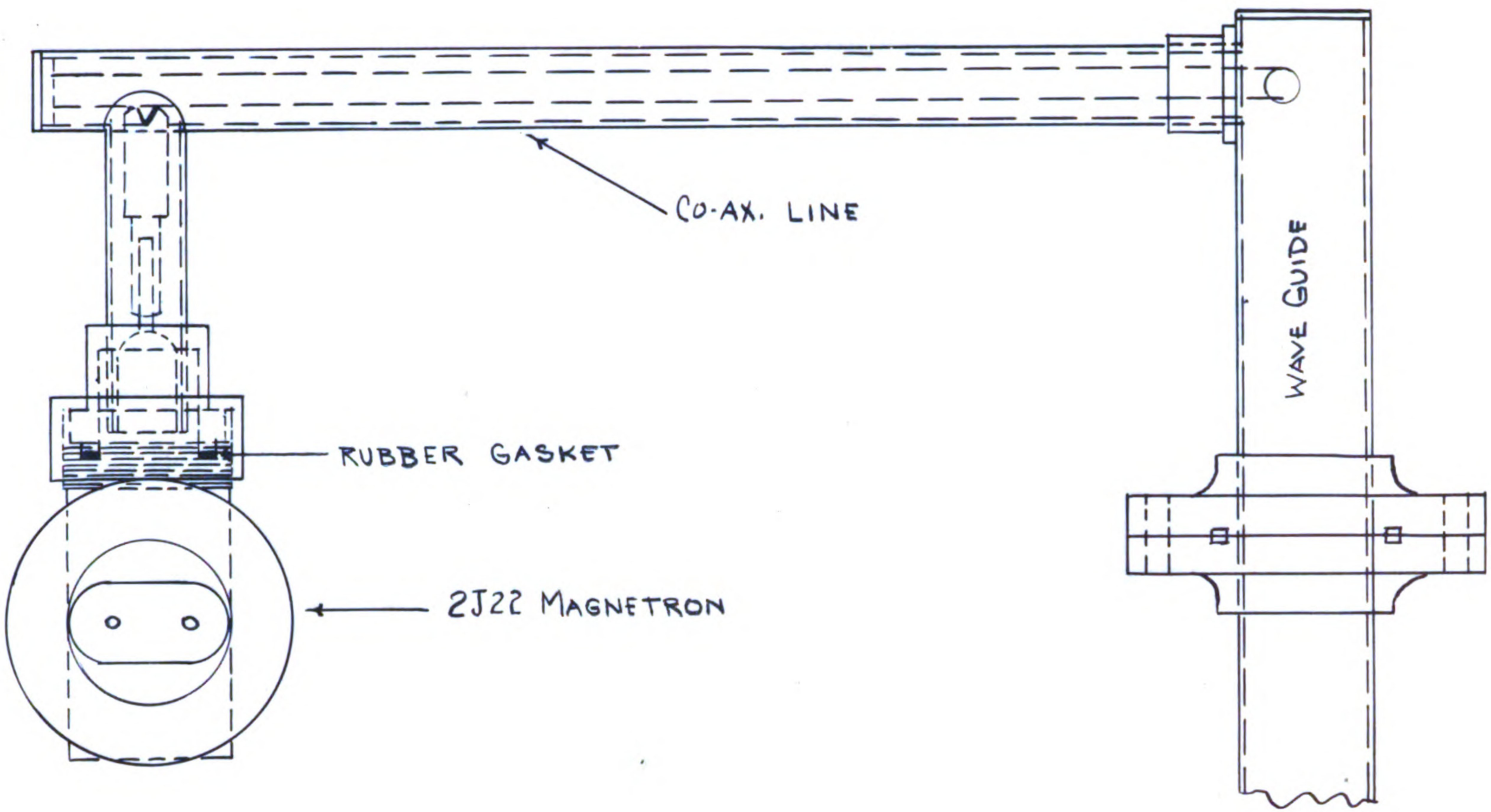


Figure 3. Method of coupling magnetron and co-axial line to wave guide transition.

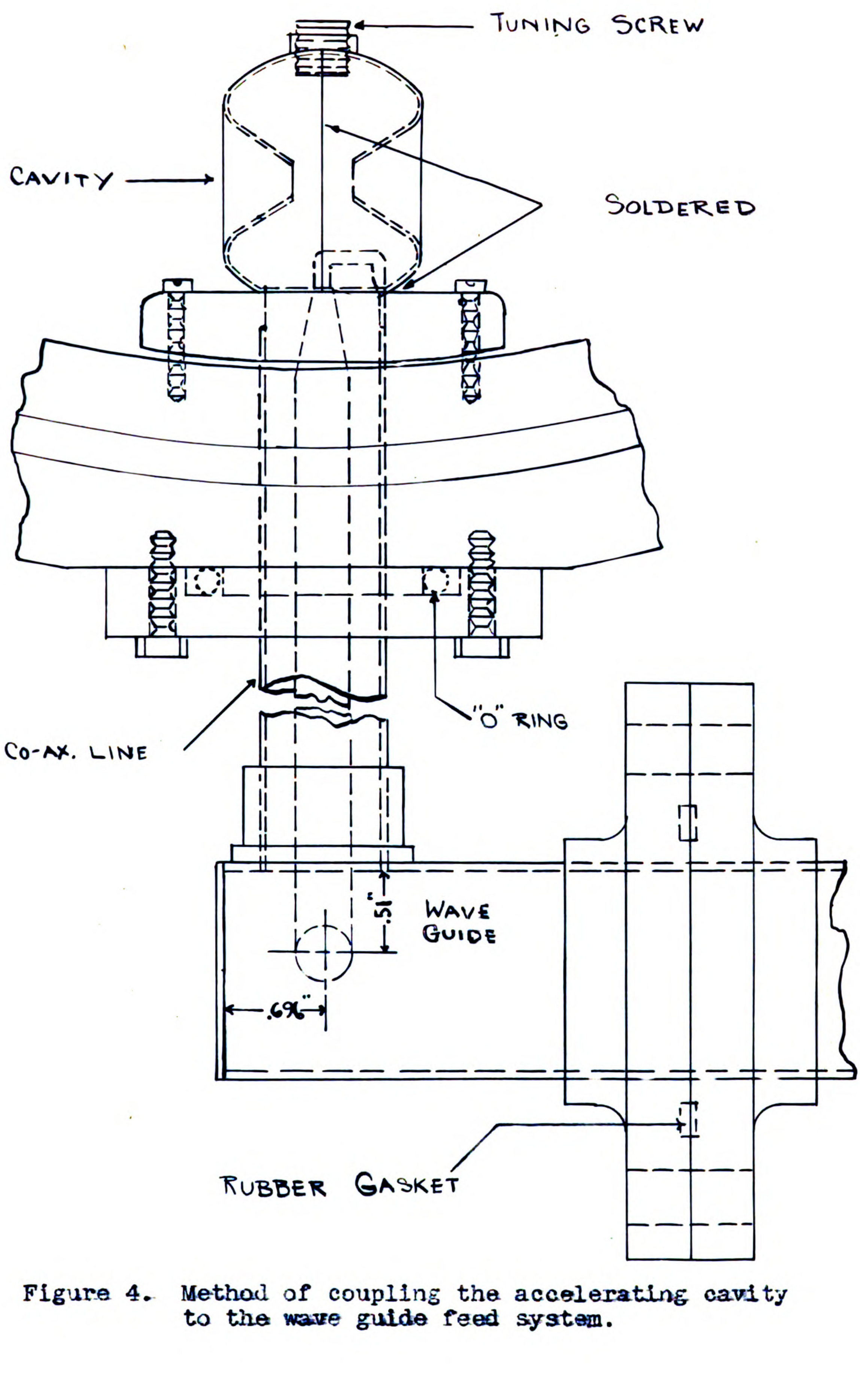


Figure 4. Method of coupling the accelerating cavity to the wave guide feed system.

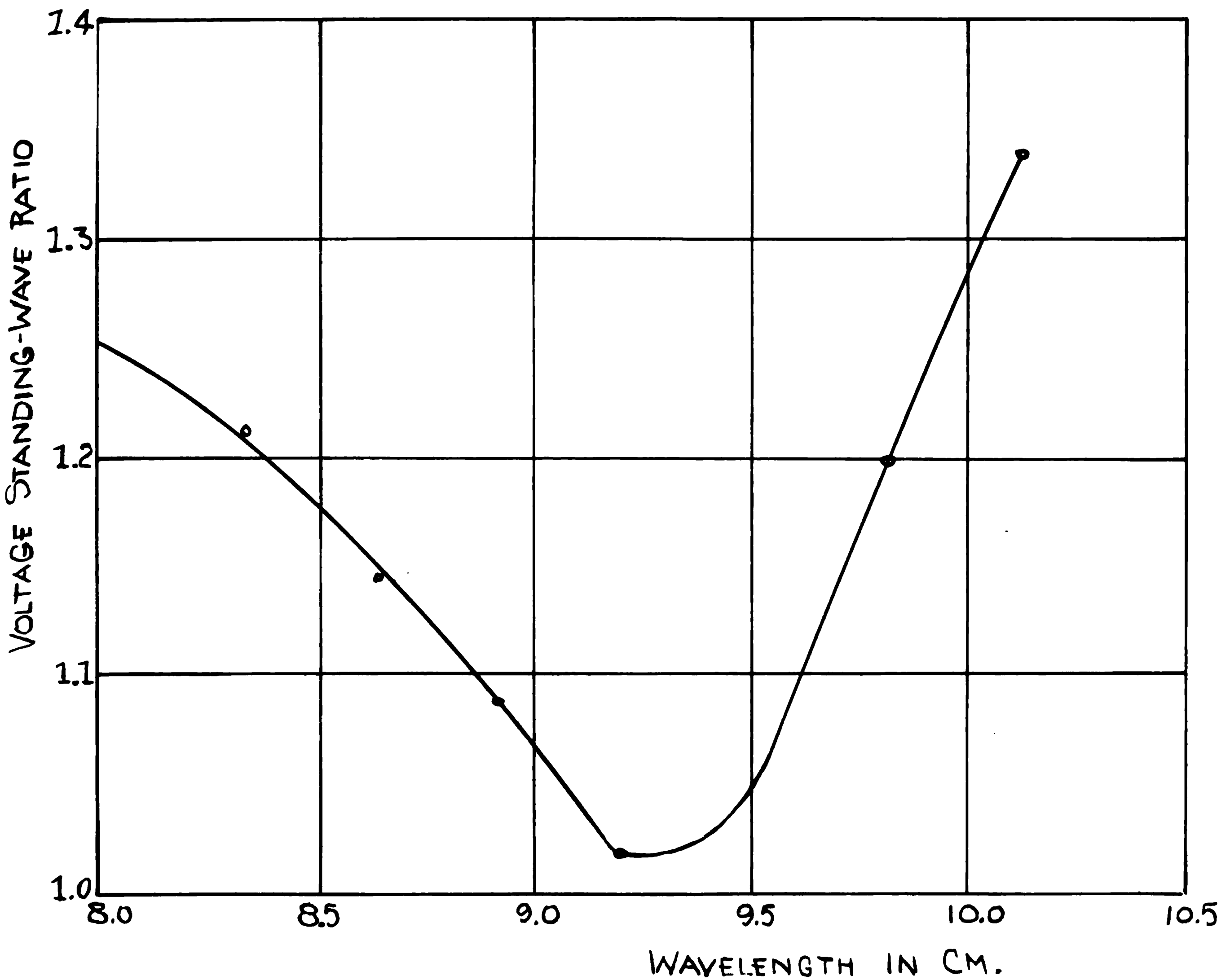


Figure 5. Voltage standing-wave ratio versus wavelength for the crossbar co-axial line to wave guide transition.

is shown in figure 5.

The cavity was coupled to the co-axial line by means of a loop coupling.

Phase Shifter

Since the separation between magnetron and cavity must be kept very close to an integral number of wave lengths, some means had to be provided for adjusting the effective separation. This was accomplished by constructing a phase shifter, the details of which are shown in Figure 6. Essentially, the change in guide wave length is brought about by moving a dielectric slab laterally across the interior of the wave guide. The effect of the dielectric becomes much greater when it is in the region of the strong electric fields in the center of the wave guide than in the region of the weak fields near the walls. The ends of the dielectric slab were tapered in the manner indicated, the length of the taper being half a wave length. Because the entire wave guide system was to be evacuated, the problem of constructing the phase shifter so that mechanical adjustment could be made under

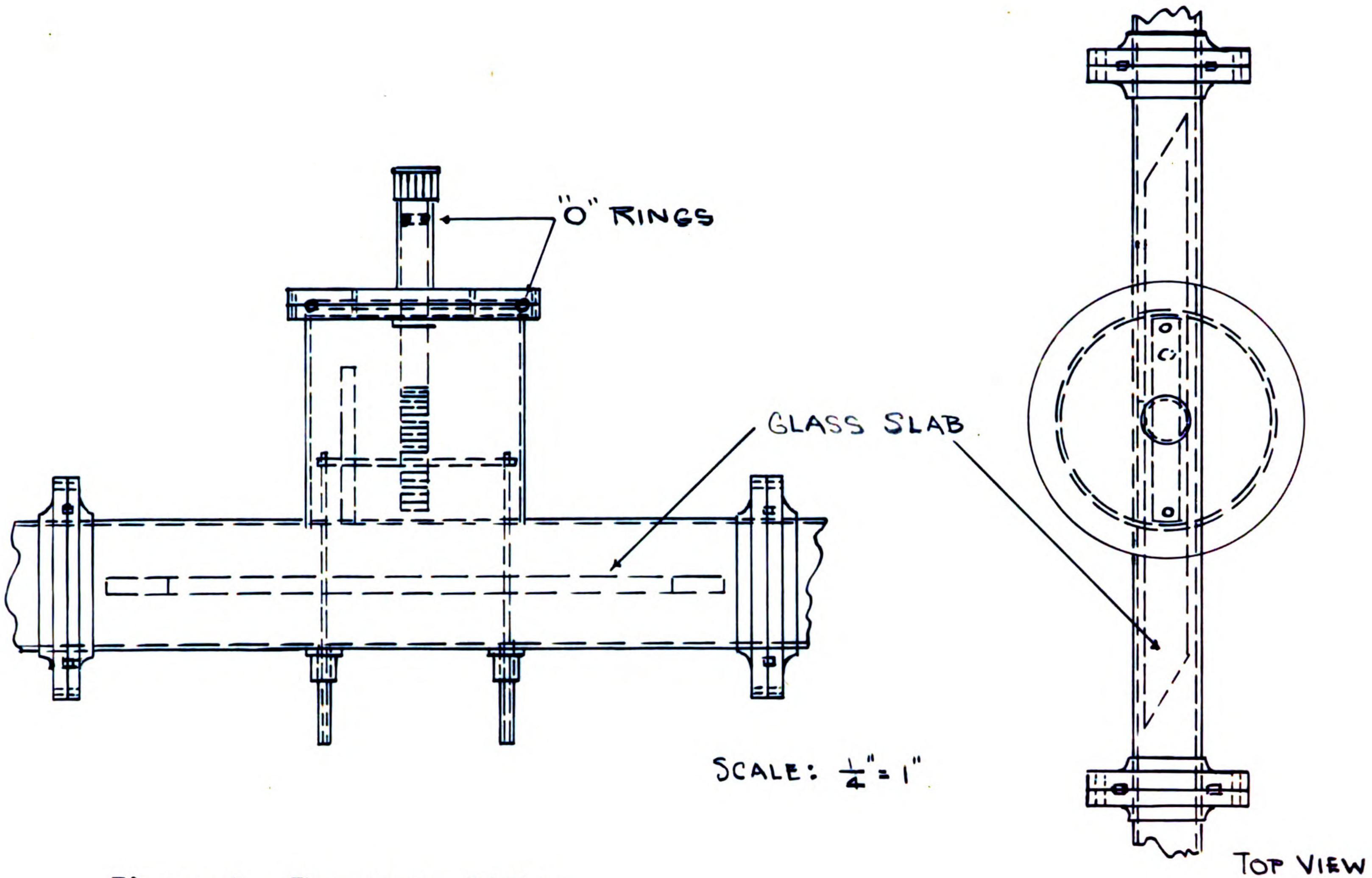


Figure 6. The phase shifter.

vacuum was solved with rubber "O" ring seals as shown. The slab was supported by means of two brass rods spaced in such a way that cancellation of reflections was achieved. Three-eighths inch glass plate was chosen for the slab material after unsatisfactory results with polystyrene which broke down under vacuum when r-f power was applied.

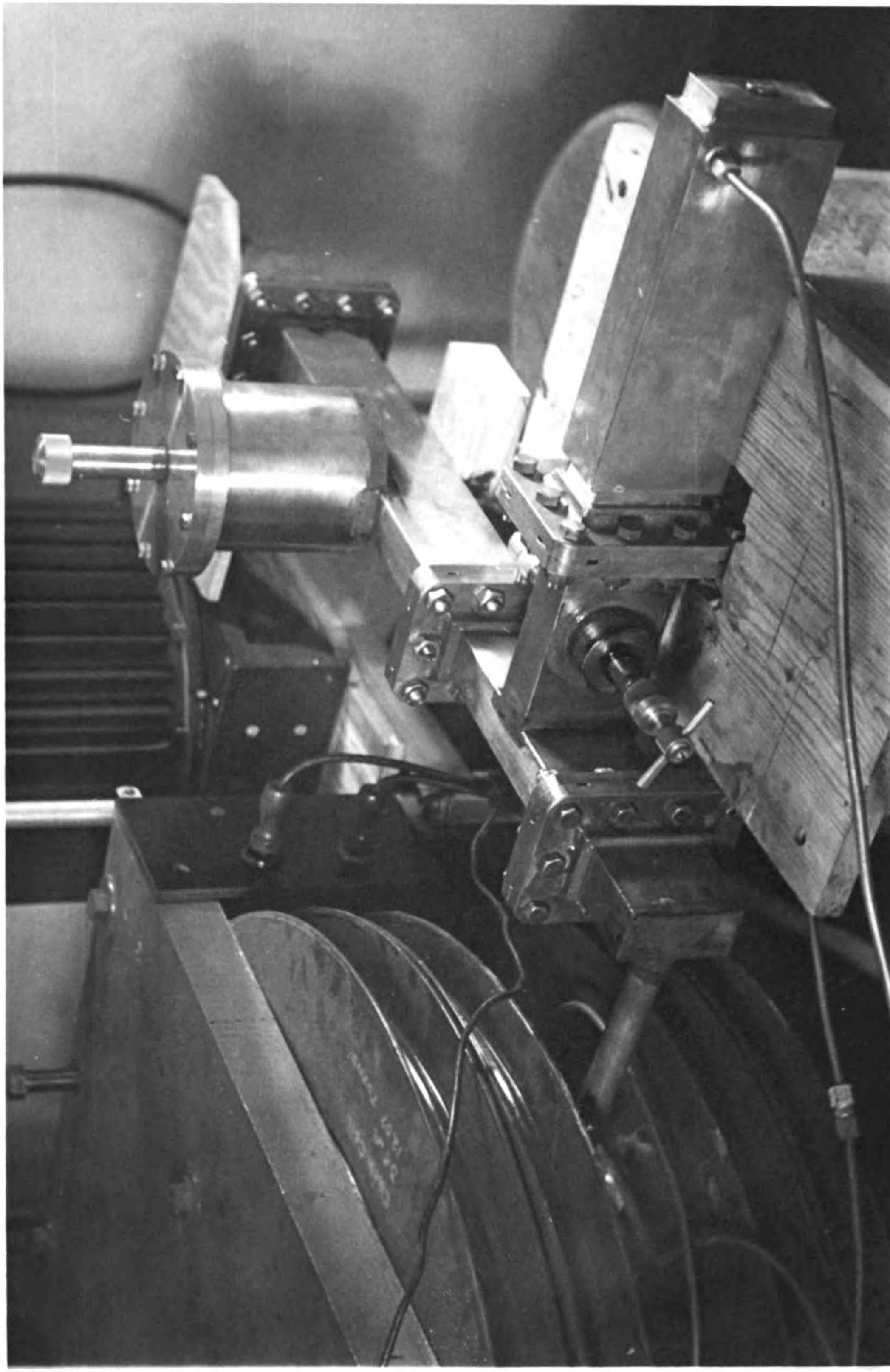
The Stabilizing Load

The sand load which was used as a resistance in series with the cavity to stabilize the frequency of operation of the magnetron is shown in Figure 7. Finely screened sand was stirred in a fluid suspension of Aquadag and water, drained, and dried. A fifty-fifty mixture of the coated and uncoated sand was used as the filling material for the load in a section of wave guide eleven inches long. To facilitate impedance matching, the input end of the sand load was tapered from narrow wall to narrow wall of the wave guide for a length of twelve centimeters. The sand was held in the tapered position by a one-eighth inch thick Transite plate which was cemented in place with Insalute Cement. Water cooling was provided by a copper jacket surrounding the length of wave guide. The sand load was separated from the evacuated section of wave guide by means of a vacuum-tight mica plate inserted between the coupling flanges and sealed tight with Picein.

Tuning Screws

Two tuning screws, two inches in diameter, were properly placed on the tee which held the sand load one-eighth of a guide wave length apart on the opposite broad sides of the guide to allow independent adjustment of the resistive and reactive impedances. Since the entire system was to be evacuated, it was necessary to construct the tuning screws so they could be adjusted under vacuum. Rubber "O" ring seals were used to seal each unit. The arrangement is shown in the photograph and the details of the construction are shown in Figure 7. The tuning screws control the amount of power distribution between load and cavity and cancel any stray reactances in the tee and side arm circuit (5).

The use of tuning screws with large diameters is preferred because a greater amount of inductive susceptance may be obtained with a smaller insertion



The wave guide feed system

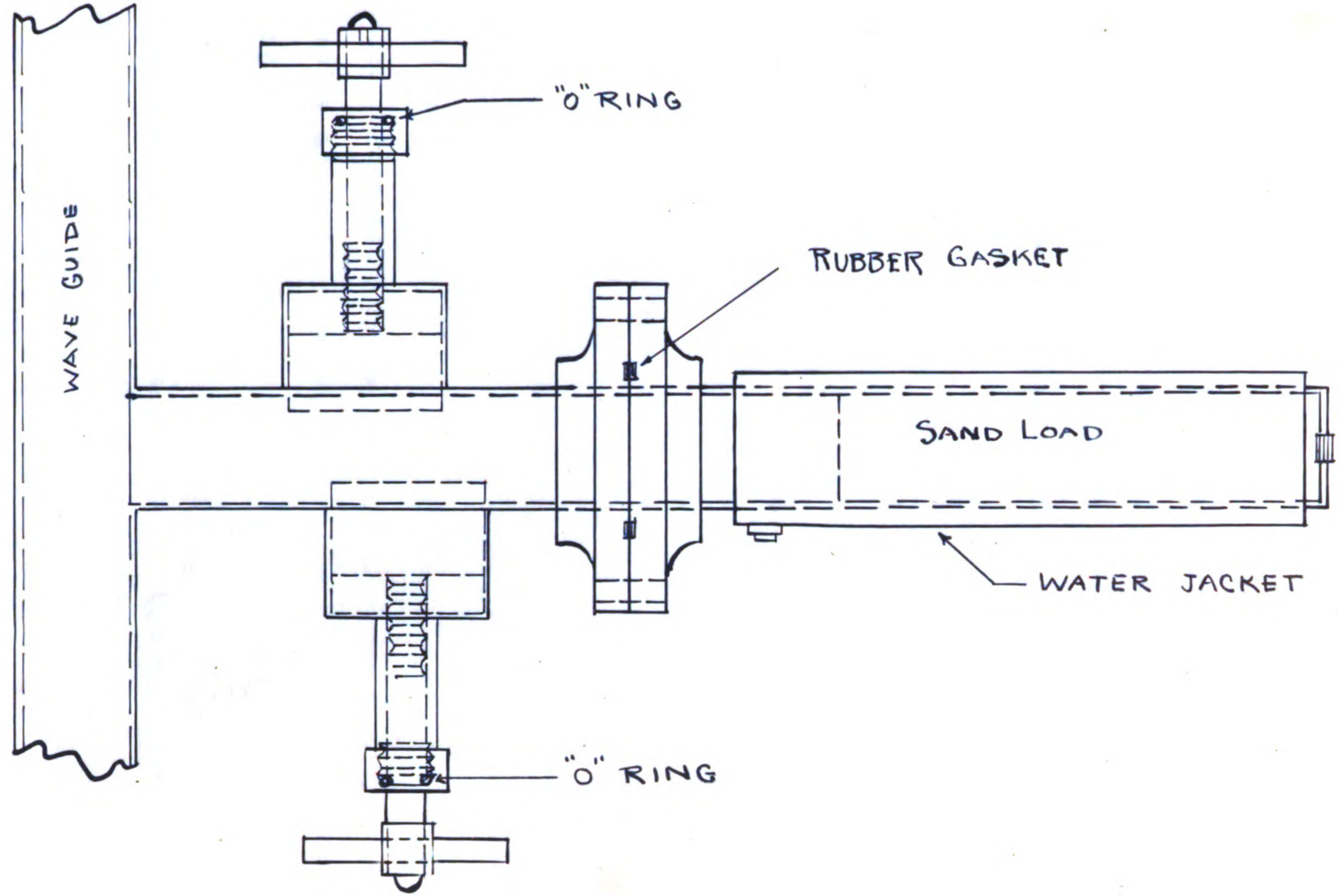


Figure 7. The stabilizing load and tuning screw arrangement.

or retraction. An admittance plot for this type of tuner, based on data by G. L. Ragan and F. L. Niemann (5), is shown in Figure 8. The admittance at the center of the input screw is plotted for each screw separately; that is, one screw is varied with the other set flush with the inside of the guide.

A plot of voltage standing-wave ratio as a function of screw setting for a two inch diameter tuning screw, from information by F. L. Niemann (5) is shown in Figure 9.

The Accelerating Cavity

The cavity resonator chosen was of the spherical type made of spun copper with 67° re-entrant cones. This shape was chosen because of its considerably higher Q and its high shunt resistance. Also, since all the surfaces inside this type of cavity are well rounded, the possibility of sparking is minimized. The cavity was spun in two halves which were then soldered together. A flange was then attached which clamped on the co-axial transmission line and assured a good electrical contact.

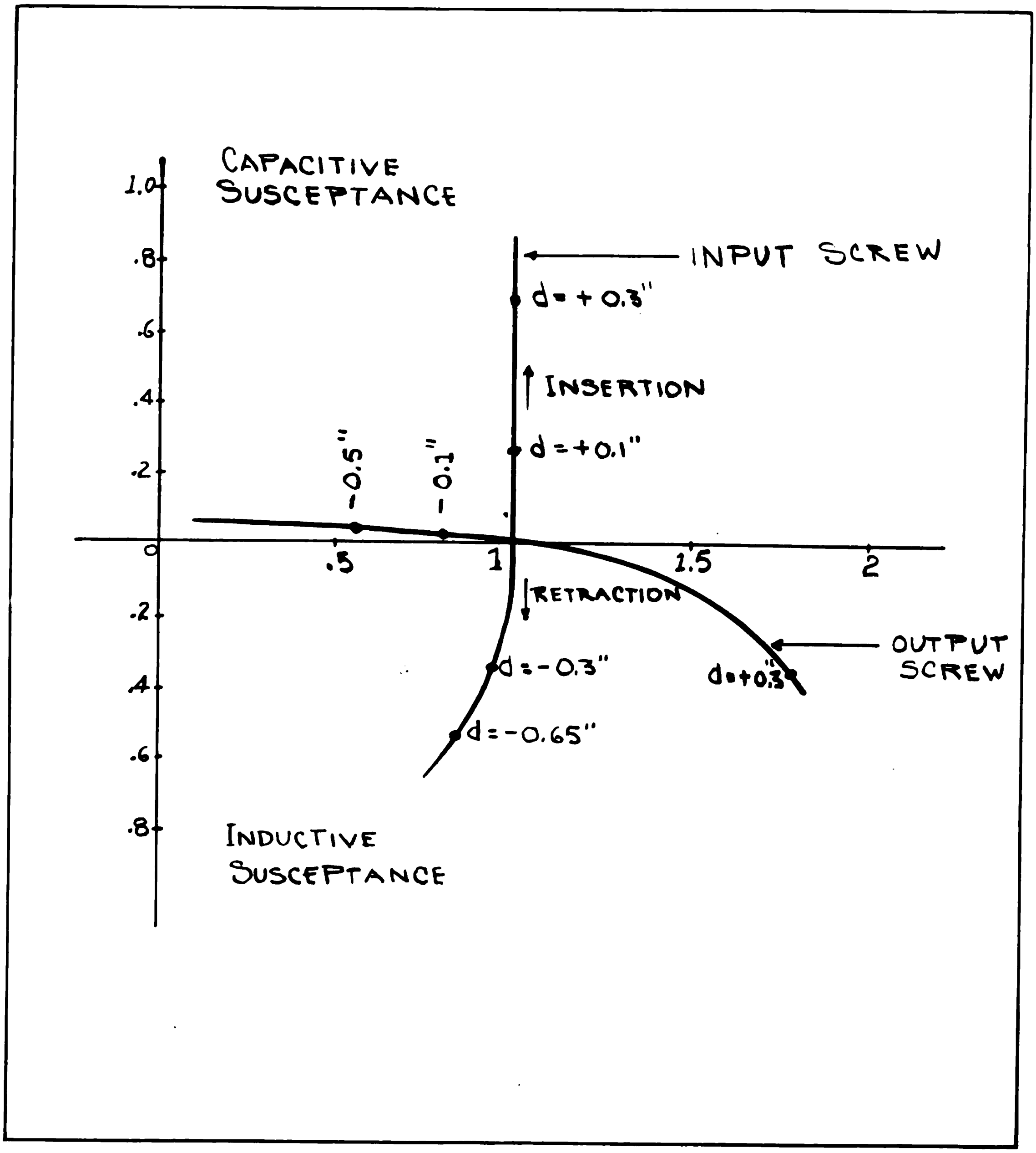


Figure 8. An admittance plot for the two inch diameter tuning screws.

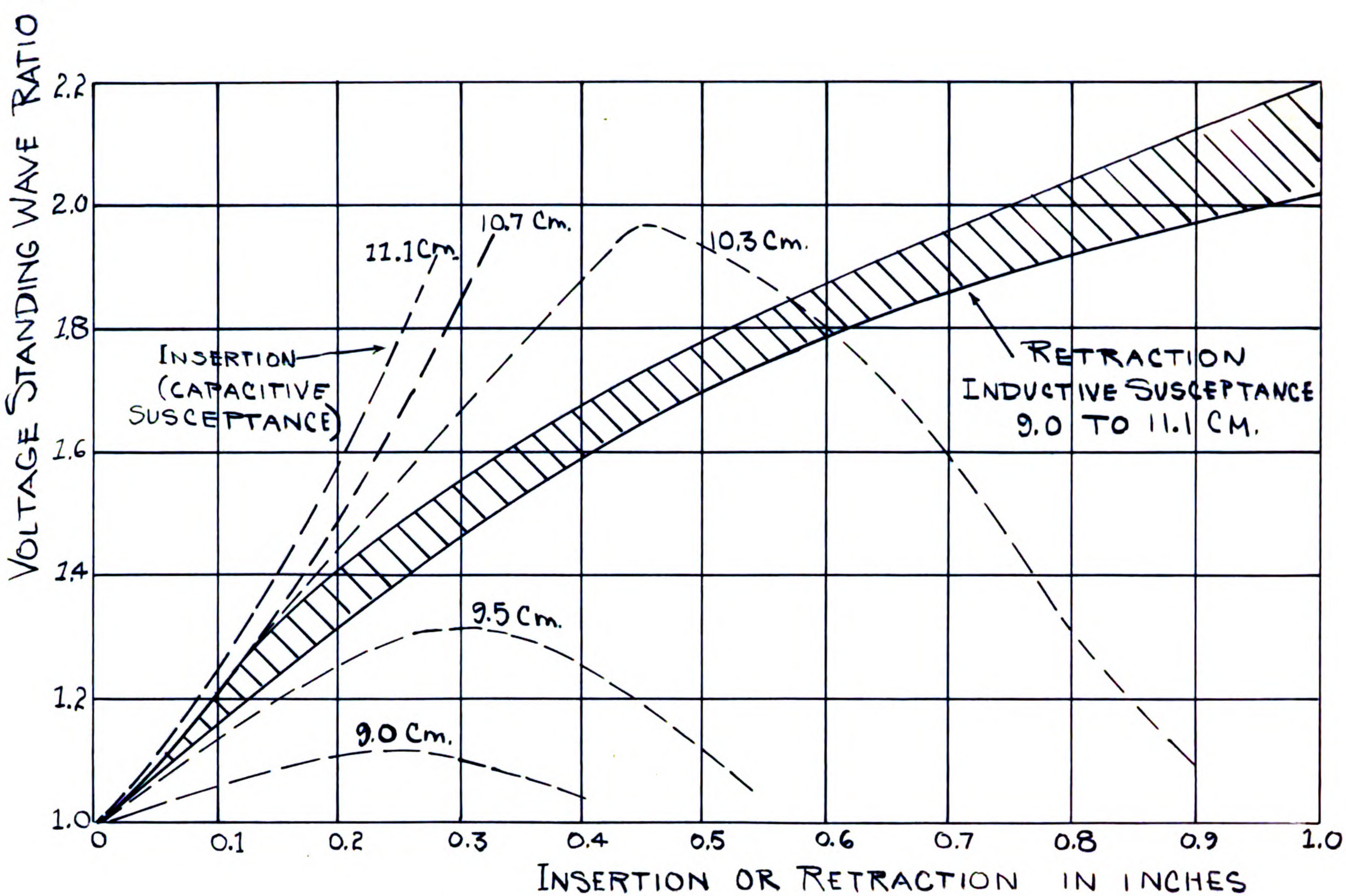


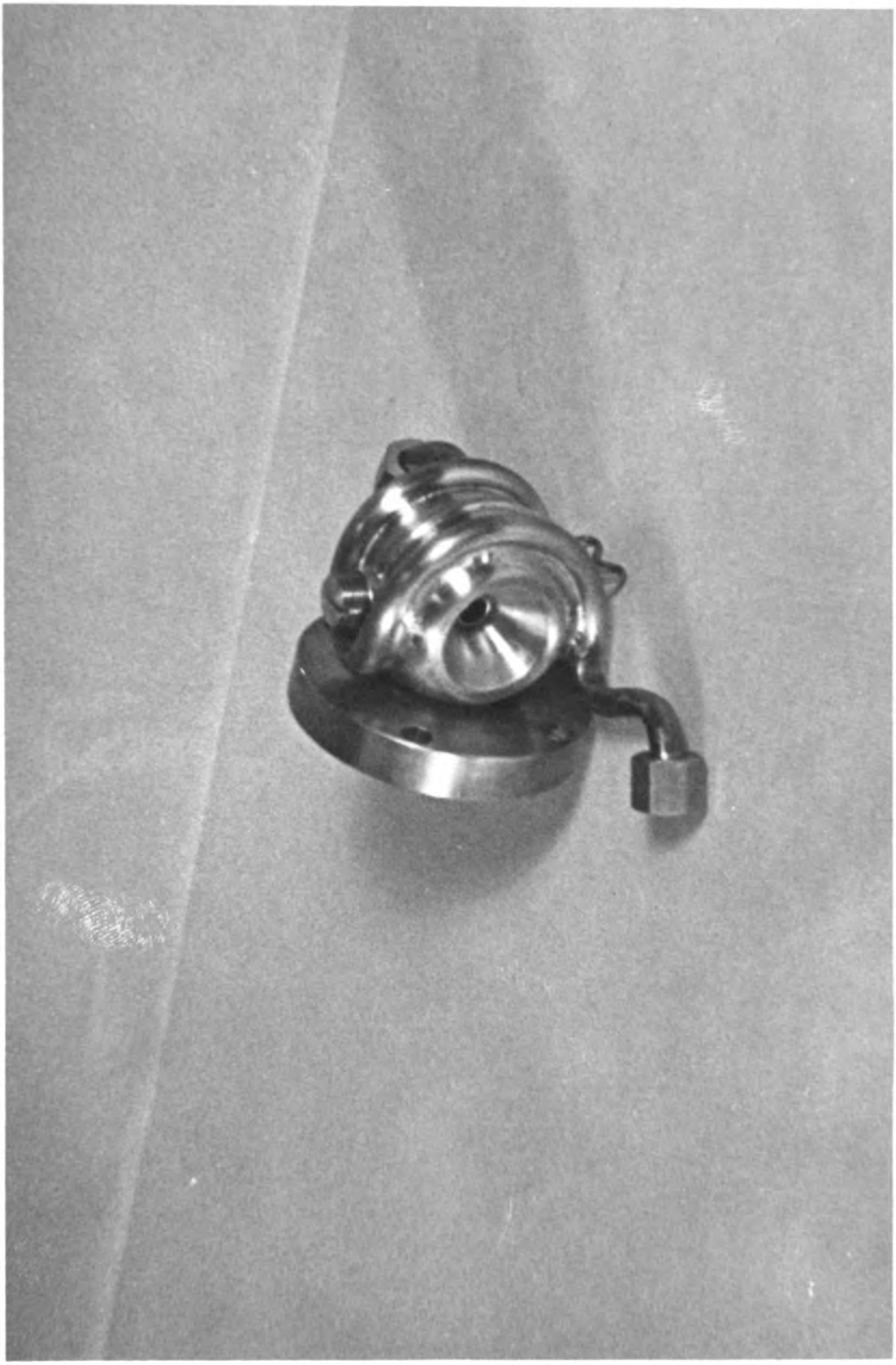
Figure 9. Voltage standing-wave ratio as a function of screw setting for a two inch diameter tuning screw at wavelengths ranging from 9.0 cm. to 11.1 cm.

For a spherical cavity, the theoretical resonant wave length (6) is:

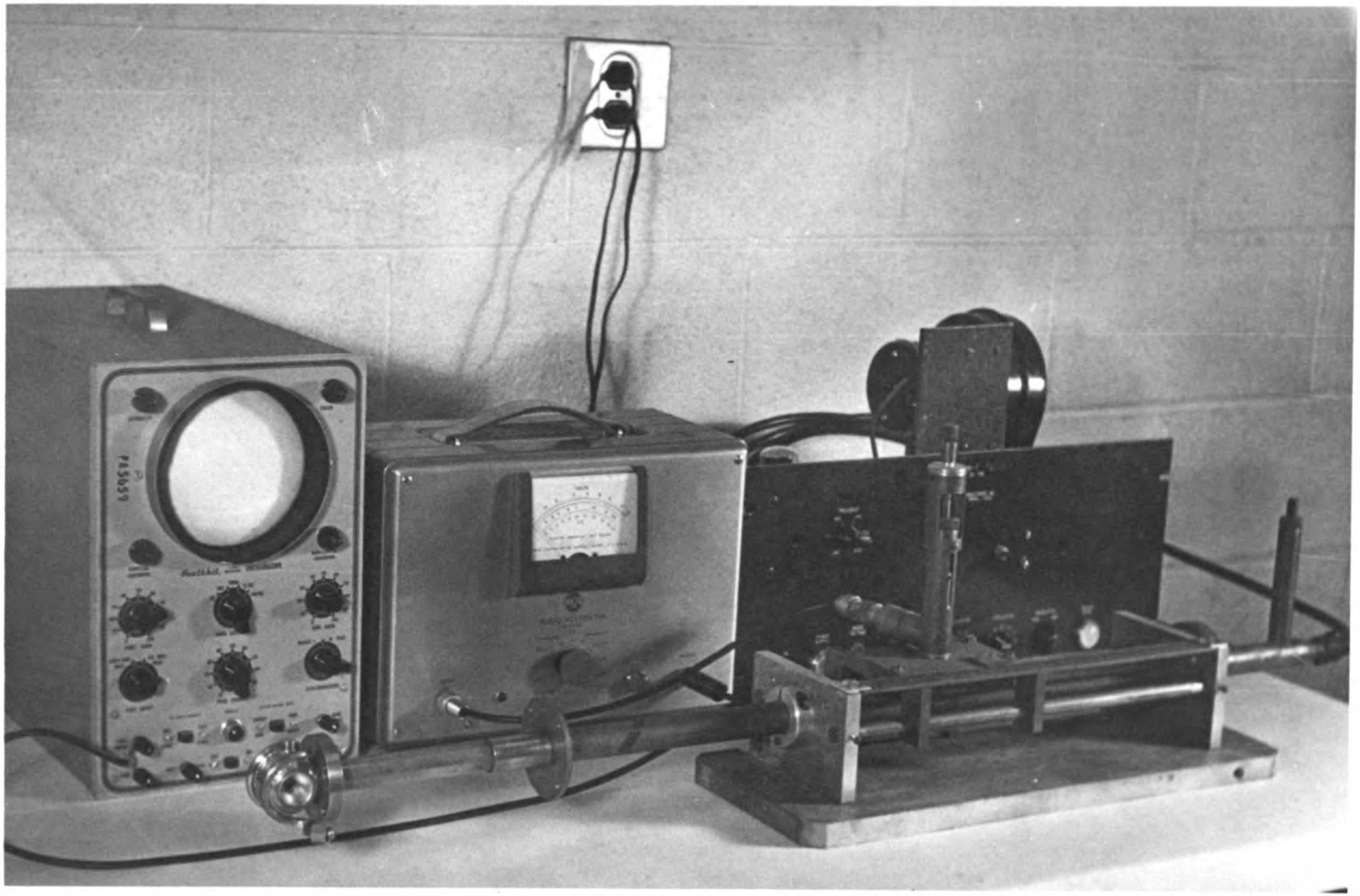
$$\lambda = 4r \text{ where } r \text{ is the radius}$$

When the configuration is altered by holes and coupling loops, as it must be if it is to have any practical application, the total volume to surface ratio is changed, thus the resonant frequency changes from the theoretical value. The cavity used was constructed with dimensions slightly smaller than theoretical dimensions and its resonant frequency was measured to see that it was within the range of frequency of the magnetron that was used to supply the r-f power.

The set-up for measuring the resonant frequency of the cavity is shown in the photograph. The cavity is coupled to the terminal end of a co-axial line which in turn is connected to a standing-wave detector. A Browning TVN-7 power supply feeds a K 417 tunable reflex Klystron whose output is connected to the standing-wave detector by means of a flexible co-axial cable. The crystal pickup on the probe of the standing-wave detector is connected to the vertical input terminals of the oscilloscope. The Klystron frequency can be adjusted until resonance is obtained.



The accelerating cavity with cooling coil



Set-up for determining the resonant frequency of the accelerating cavity

The wave form which appears on the oscilloscope when the cavity is in resonance has the shape shown in Figure 10.

Water cooling of the cavity was achieved by means of a copper tubing soldered around the outside surface. The tubing was connected to air-tight fittings on the walls of the accelerating chamber.

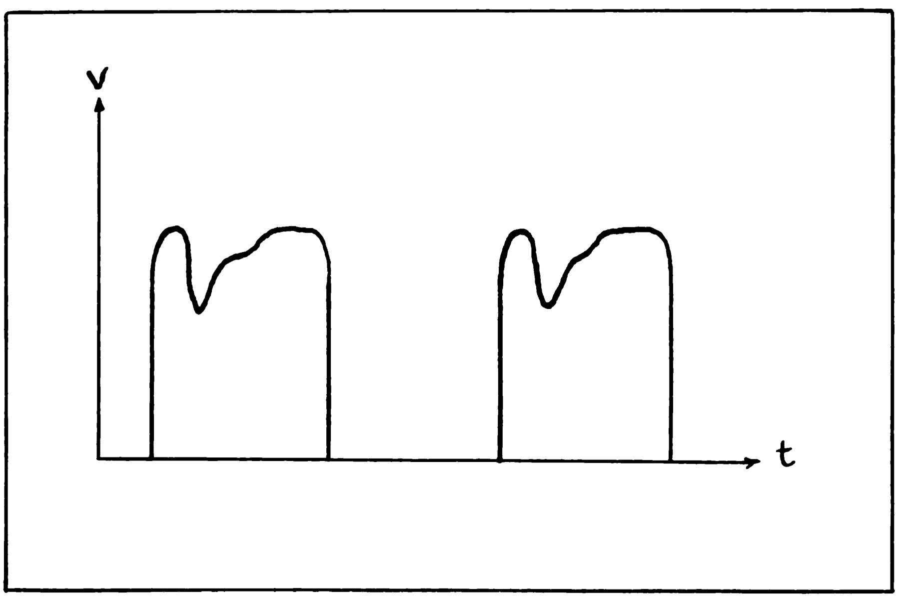


Figure 10 The wave form when cavity is in resonance

SUMMARY

Orbit Detection

Two methods of orbit detection were used. The apparatus first used consisted of a Geiger Muller tube and counter. The tube was mounted on the end of a vacuum-tight sliding probe. This method proved unsatisfactory because of the high rate of background count, caused by the r-f field, which made it difficult to detect any weak orbits that may have been present.

The second method consisted of a Faraday cage mounted on the end of the sliding probe. The Faraday cage was connected through an amplifier to the vertical input of an oscilloscope.

No stable orbits were detected with either method. It was suggested that the power input was insufficient to cause a great enough potential across the accelerating gap for electron field emission. A filament was placed at the cavity throat to supply electrons in the vicinity of the accelerating gap. After failure to detect any stable orbits after repeated attempts to do so, it was concluded that none existed.

A probable explanation for the lack of stable orbits, is electronic loading of the cavity due to

View of cavity attached to accelerating chamber with filament arrangement shown an insufficient power input. As stated by Henderson and Redford (8), the accelerated electrons present a conductance in parallel with the cavity shunt conductance. This causes an increase in the effective conductance of the cavity and a decrease of the gap potential. Thus for a given power input to the cavity, the current which may be accelerated is limited.

Suggestions for Improvement

A larger power supply (500 kilowatt peak power or greater) is necessary to supply an adequate potential across the accelerating gap and to overcome the effects of electronic loading of the cavity. A tunable magnetron would be desirable and would give one more dimension for tuning to the cavity resonant frequency.

Keeping the magnetron adequately cooled presented a problem. The heat generated in the inner conductor of the co-axial line at the magnetron coupling could not be conducted away fast enough since the entire system was evacuated. This difficulty could be eliminated by utilizing a magnetron that couples directly to a wave guide instead of a co-axial line. Thus the inner conductor could be eliminated entirely.

BIBLIOGRAPHY

(1) Kaiser, H. F., Journal of the Franklin Institute, 257, Number 2, pp. 89-107, 1954

(2) Henderson, W. J. and Redford, R. A., Nucleonics, 5: pp. 60-67, 1949

(3) Reich, H. J., Ordung, P. F., Kraus, H. L., Skelnik, J. G., Microwave Theory and Techniques, D. Van Nostrand Co., pp. 776-778, 1953

(4) Ragan, G. L., M. I. T. Radiation Lab. Series, Microwave Transmission Circuits, Ragan, G. L., Editor, McGraw Hill Book Co., Chapt. 6, pp. 346-349, 1948

(5) Ragan, G. L., Niemann, F. L., M. I. T. Radiation Lab. Series, Microwave Transmission Circuits, Ragan, G. L., Editor, McGraw Hill Book Co., Chapt. 8, pp. 502-505, 1948

(6) Spence, R. D., Principles of Radar, Reintjes, J. F., Editor, McGraw Hill Book Co., Chapt. 10, pp. 10-48 - 10-54, 1946