THE RESNATRON

by

G. E. SHEPPARD

Westinghouse Electric Co.

The word "Resnatron" is used to denote certain types of ultra-high-frequency generating devices. In general, a Resnatron is an ultra-high-frequency tube capable of handling large amounts of power, in which the electrode system and circuit are incorporated into the same vacuum system. An overall view of a Resnatron is shown in Figure 1. These devices are usually, though not always, tetrodes. Resnatrons are distinctly different devices from Klystrons and Magnetrons in that the principles of Resnatron operation are similar to ordinary Class C vacuum tube operation, except for conditions imposed at high frequencies.

In the field of continuous high-power output at ultra-high-frequencies, the Resnatron outperforms all other power generators. The wartime Resnatron development resulted in a device, which was capable of producing 50 to 85 kW of continuous power at a frequency of 600 megacycles. This amount of power was produced at efficiencies ranging from 40 to 70 percent. During the war, mobile Resnatron radar jamming units were operated against the use of German airborne radar at frequencies of 350-650 Mc. These units were mechanically tunable and noise modulated and capable of operating at 50 kW continuous power output at these frequencies.

Some typical Resnatron operation data at a frequency of 600 megacycles is as follows:

140 kW	Input Power
8 Amperes	Plate Current
17.5 kilovolts	Plate and Accelerator Voltage
1–1.5 Amperes	Grid Current
2500 Volts	Grid Voltage (D–C average)
85 kW	Output Power
60 %	Efficiency

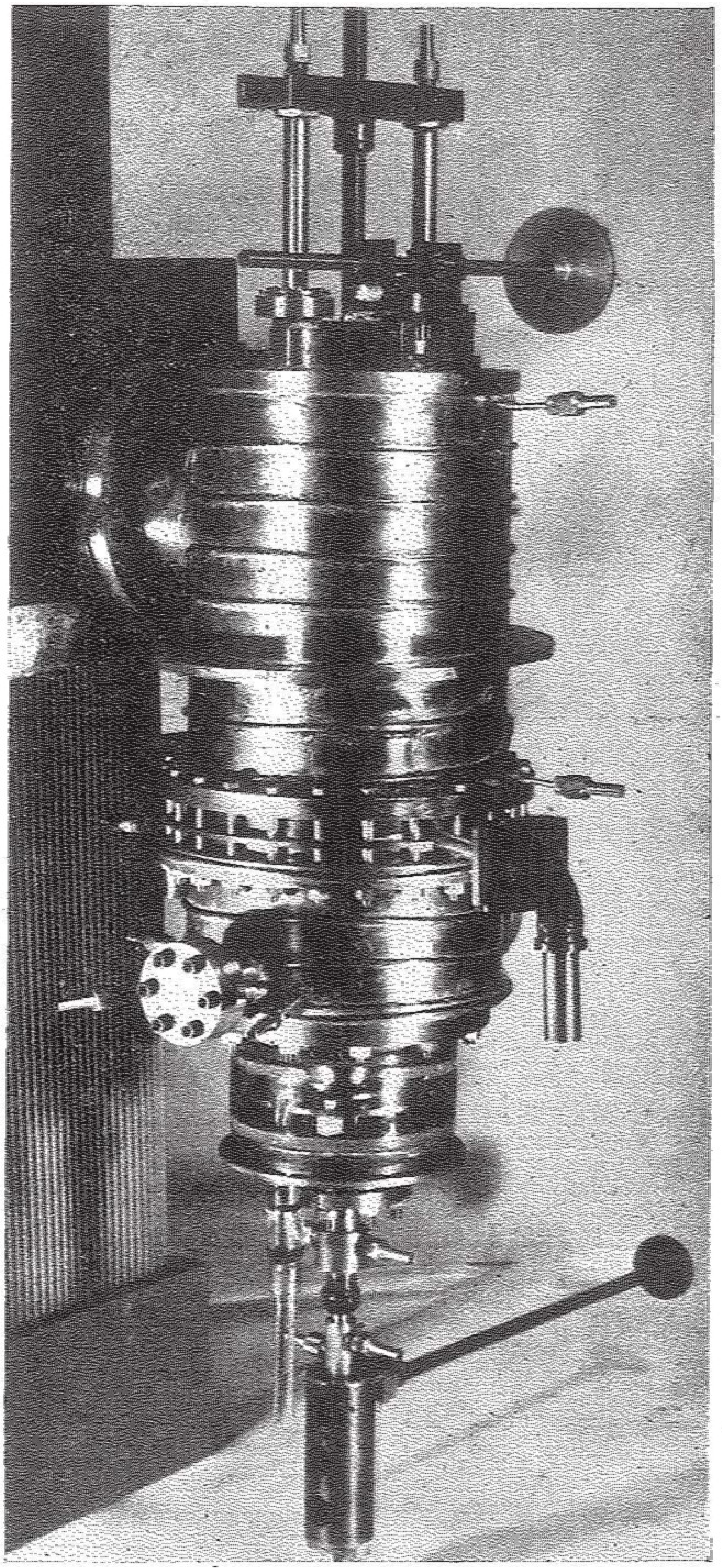

Fig. 1. – The resnatron in detail. The lower horizontal rod is the cathode tuning drive; the upper is the "Daisy" tuning drive.

The principles upon which the Resnatron is based were investigated by Dr. David H. Sloan and Dr. L. C. Marshall at the University of California, in search of a source of high frequency and power for electron acceleration. Their first successful Resnatron was made in 1938. During the war, the Resnatron was developed for radar jamming at Westinghouse Research Laboratories by Dr. Sloan and Dr. W. B. Fretter and their co-workers. The work of adapting the Resnatron for operational use was done under Division 15 of N. D. R. C. at the Harvard Radio Research Laboratories.

In view of the performance of conventional tubes at ultra-high-frequencies, the Resnatron performance shows great improvement in power output and efficiency. It may be of interest to survey the limitations to ultra-high-frequency power output, which exist in vacuum tubes of conventional design. Then, by comparison with the design principles of the Resnatron, an insight into the reasons for its performance can be gained.

As the frequency of operation is increased, the time of transit of the electrons across the inter-electrode space of a vacuum tube becomes an important limiting factor to power output and efficiency. The obvious method to circumvent this effect is to reduce the spacings between electrodes in a given tube. However, when the limiting spacings are reached physically, nothing more can be done in this direction.

As the frequency is increased, it is also found necessary to reduce the circuit capacitance and inductance. When these circuit elements are reduced to the capacitance and inductance of the tube itself, the upper limit to frequency of operation is reached.

By the conventional approach, then, the limit to frequency is set by the spacing between electrodes and the capacitance and inductance of the tube itself. The inevitable result of approaching these limits is a small tube. This limit on the size of the tube limits the power dissipating capabilities of the tube elements and consequently the power output.

Another factor, which enters into the design of ultra-high-frequency tubes, is the cathode emission. As the frequency is increased, the pulse or "bunch" of electrons which is emitted from the cathode during a portion of each cycle must occur in a shorter time interval. Hence, for a given power output, as the frequency is increased, the peak electron emission must increase. Since the

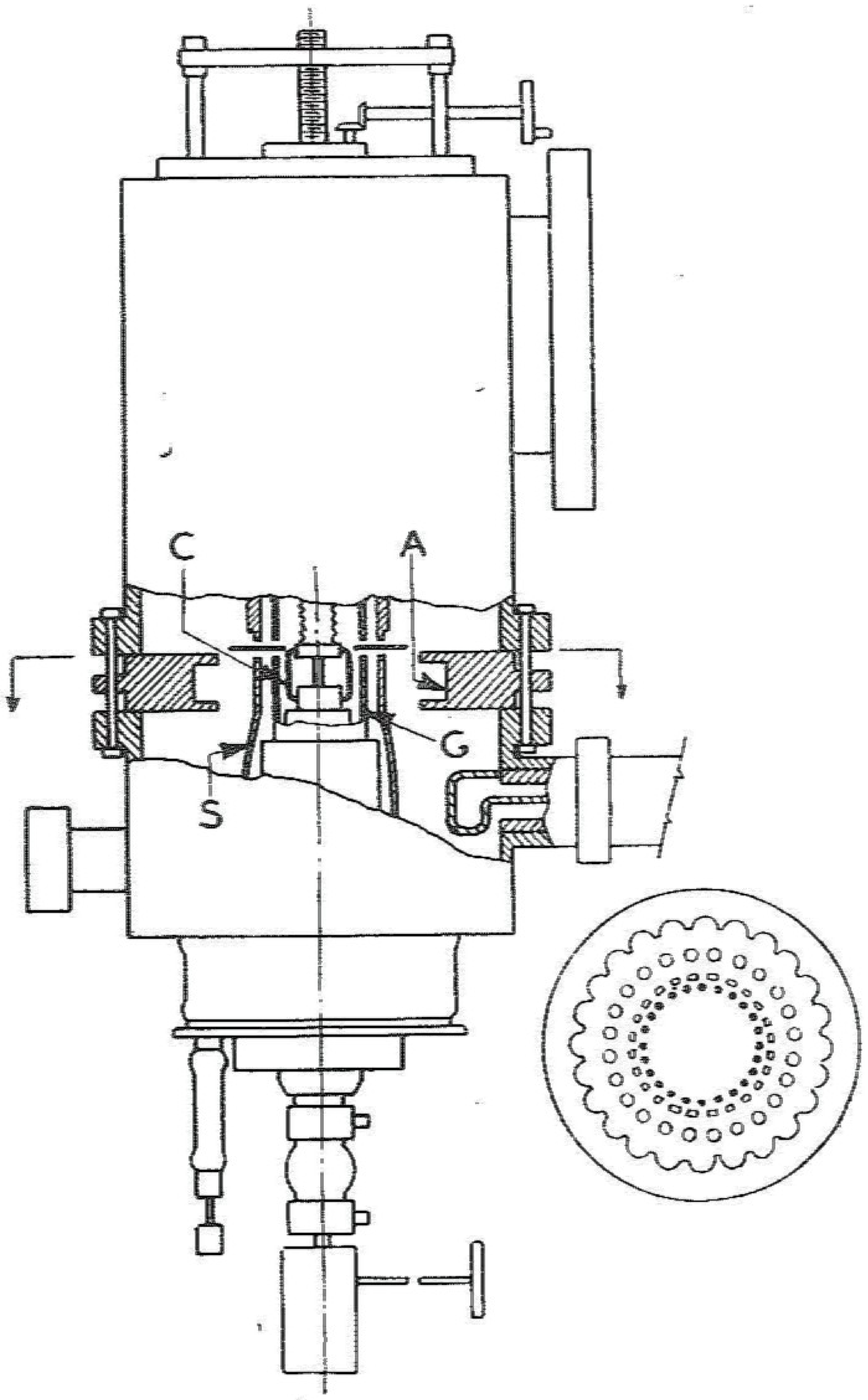

Fig. 2. – Cut-away view of resnatron and cross-section (at arrows). A-is the anode, C-catode, G-grid, S-the accelerator or screen. The close positioning of grid and cathode will be noted.

cathode must be physically small in order to minimize capacitance, another limit is thus set on the power output.

By following the design principles just discussed, many vacuum tubes have been designed for ultra-high-frequency use. However, no vacuum tubes of conventional design exist for more than a few hundred watts power output above three or four hundred megacycles in frequency.

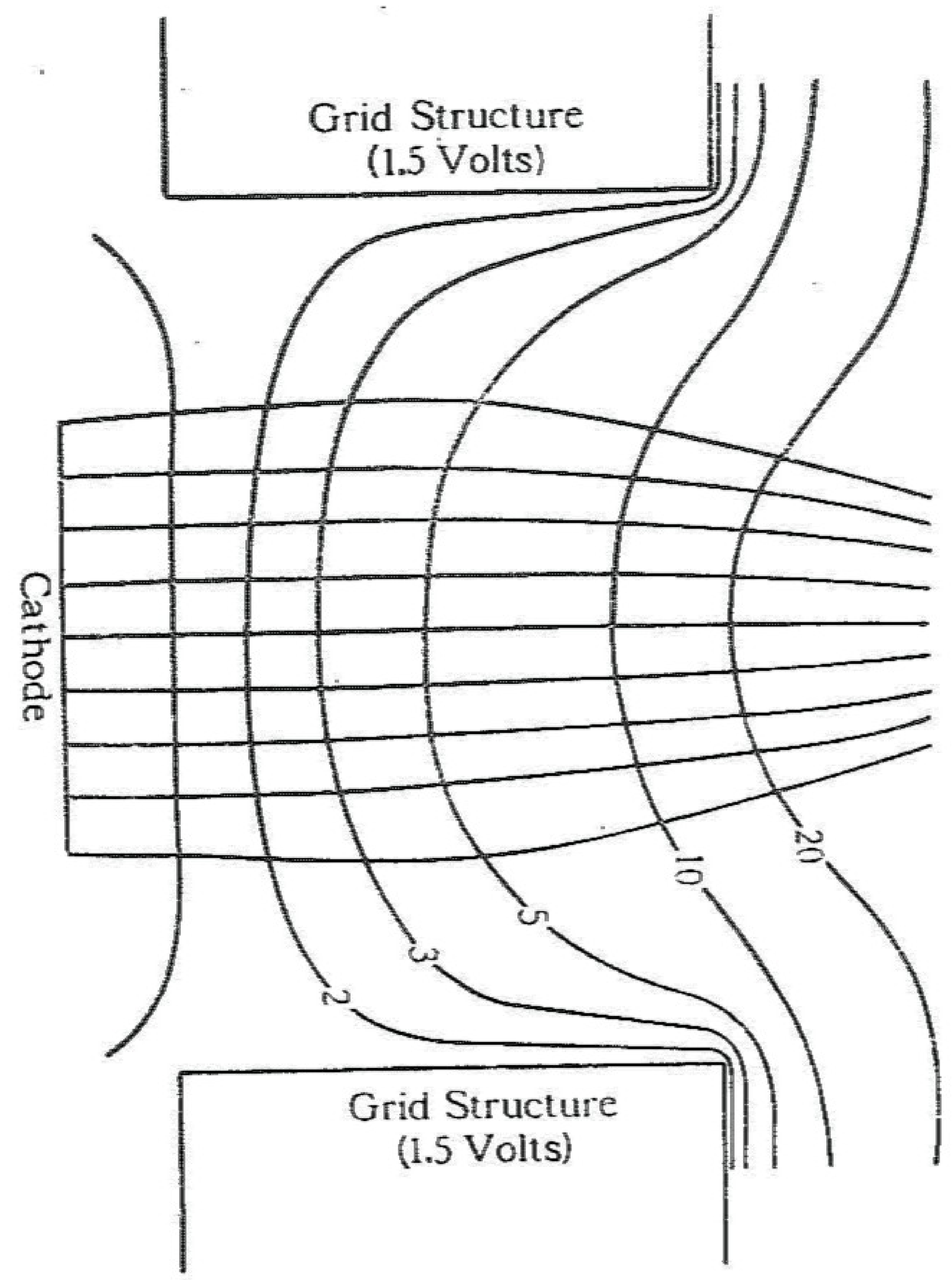

Fig. 3. – Electron path based on a calculation of the equipotentials and stream lines on the grid. Design efficacy in minimizing electron-grid collisions is at once apparent.

Devices such as the magnetron, klystron, and disc-seal tubes greatly extend the available frequency range and each device has its own advantages and uses. However, none of these devices, with the exception of the CW magnetron, has the ability to generate CW power in tens of kilowatts at ultra-high-frequencies.

The wartime Resnatron was a tetrode. Its operation resembles somewhat that of a grounded grid triode, except that with the Resnatron the output circuit is connected between the second grid — called the accelerator grid — and the anode, instead of being connected between the control grid and anode. The accelerator grid is strongly by-passed to the control grid, and since the control grid is operated at RF ground, the circuit operates as a grounded grid and accelerator circuit, as regards RF.

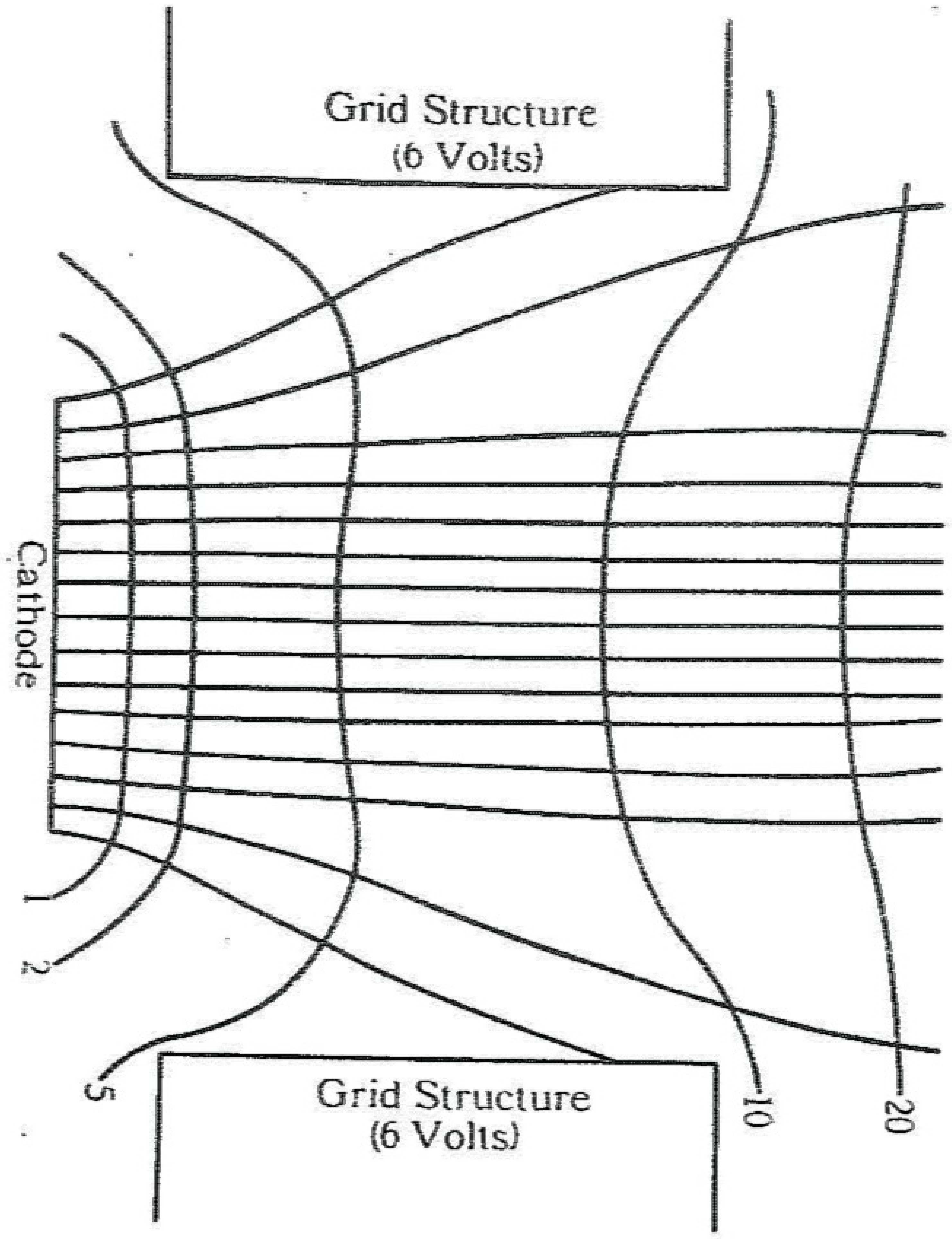

Fig. 4. – Shown is the same grid structure as for Fig. 3, but with a much higher grid potential. Even with this increased voltage, few electrons strike the grid.

Since lumped circuits are out of the question, the Resnatron utilizes coaxial cavity-type circuits. The electrodes of the Resnatron consist of filament (C), control grid (G), accelerator grid (S), and anode (A), as shown in cutaway view Figure 2. These electrodes are connected to two resonant coaxial type cavities, one between the filament and control grid, the other between the accelerator grid and anode. In order to minimize circuit difficulties, the two resonant cavities form a part of the vacuum system.

As a means of minimizing power dissipation in the electrodes, particularly the control grid, the electrode configuration utilizes electron optical principles to produce focused electron beams, as is shown in Figures 3 and 4. The electron optics involved in the electrode design make possible a rather massive control grid which is effectively very close to the filament. The control grid consists of slots milled in a copper pipe which surrounds a radial filament structure. The physical spacing between the control grid and filament is .040″. However, because of the field distribution of grid and filament, the effective spacing is .015″ grid to filament. Thus a closely spaced grid filament structure is obtained, having a large grid which can be effectively cooled. The accelerator and

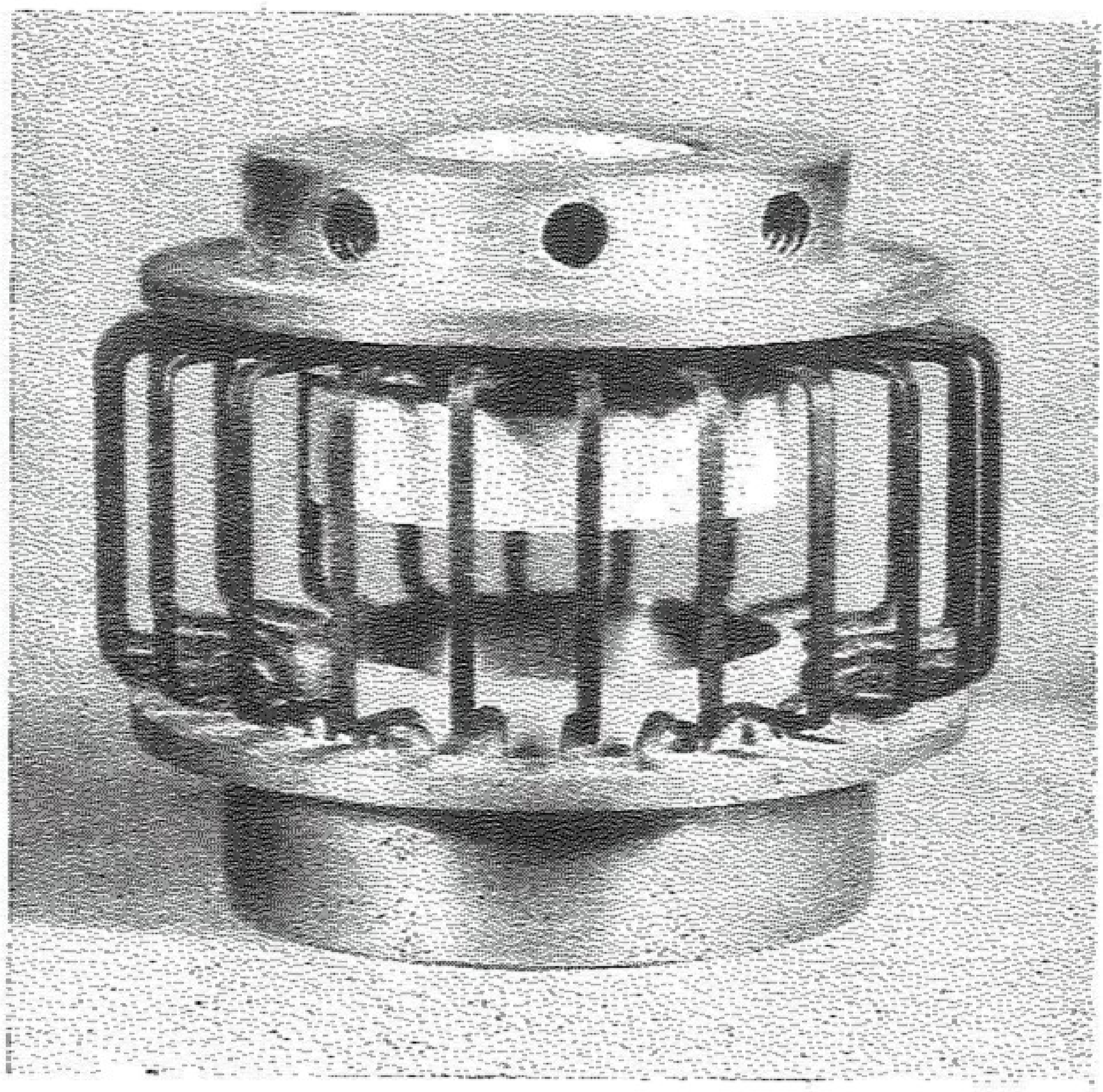

Fig. 5. – The cathode consists of 24 tungsten strips, each size 50 mil - ground flat. The rating is 1800 amperes, 2.0 volts.

anode are also rather closely spaced, and the design is such that all electrodes can be effectively water-cooled.

The distance between the control grid and accelerator is such that transit time would be a quite important limitation. However, this effect is diminished by applying a high D. C. potential between the accelerator and control grid. This potential provides a steady accelerating field for the electrons leaving the control grid toward the accelerator. As a result, the electrons in any given bunch reach the accelerator grid with practically the same velocity. Hence, when the bunch of electrons enters the accelerator-anode space, it has done so in a short time compared to a cycle and as a coherent bunch. Presumably the same effect could be obtained for longer transit times, provided the electrons remained closely bunched. Thus the conventional limitation upon electrode spacing because of transit time is avoided.

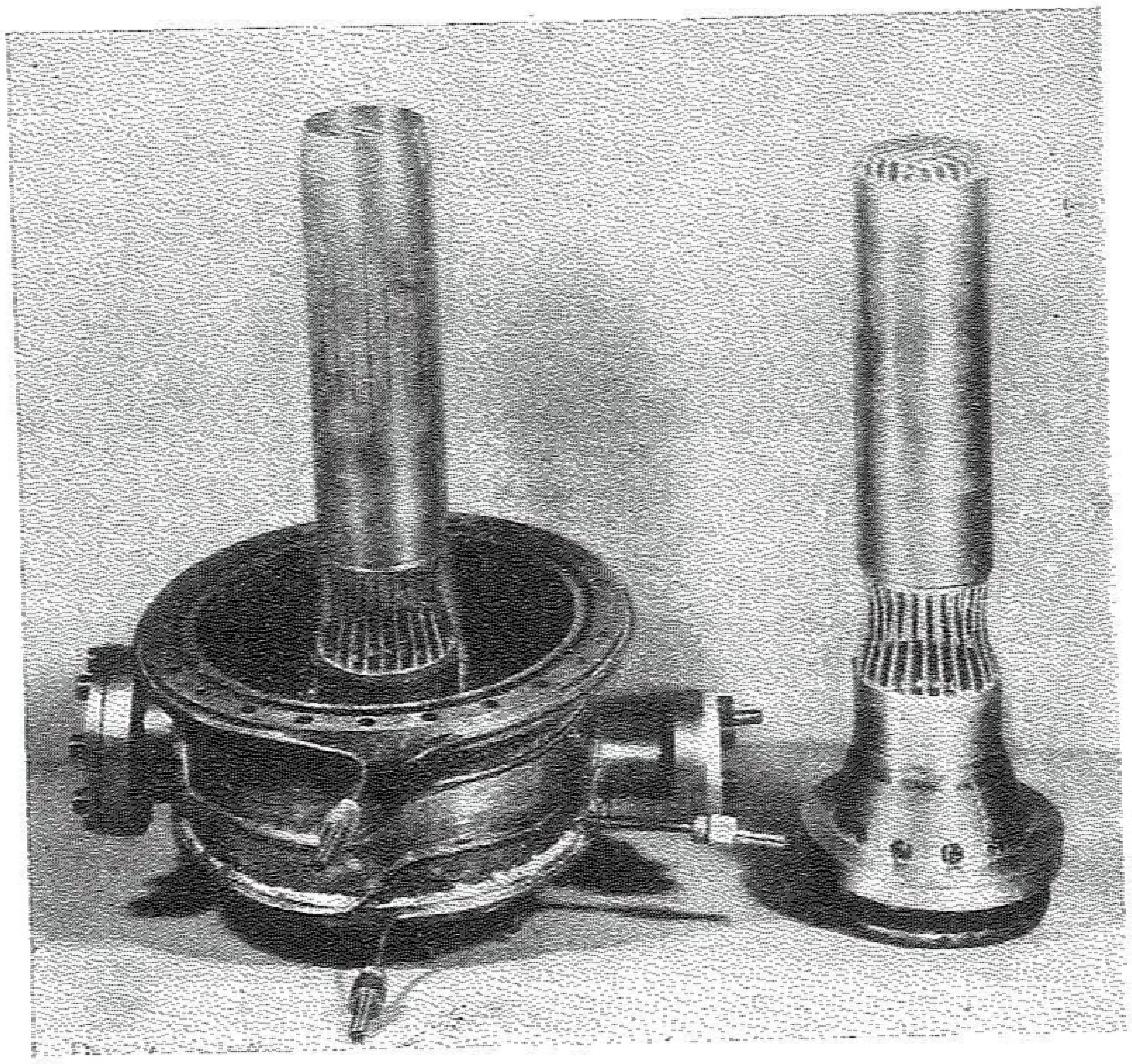

Fig. 6. – The screen grid installed in its housing. Another type type of grid structure is shown beside it.

The filament structure is built of 24 individual filaments of .050″ diameter pure tungsten wire ground flat on the face nearest the grid. The filament emitting length is about one inch. This structure is shown in Figure 5. In order to get the peak emission necessary, the filament is operated at a temperature such that its life is only a few hundred hours. However, the requirement of high peak emission is met in a small size emitter.

From the foregoing discussion, it is seen that the principles of Resnatron design make possible the elimination of the conventional limitations to high-power output at ultra-high-frequencies. A serious limitation to the power output of a resnatron is secondary electron emission from the anode, if left uncorrected. This limitation is alleviated by a slotted anode design, whereby the secondary electrons are trapped and do not interfere seriously with the power output.

Mechanically Resnatrons are quite different from most other ultra-high-frequency generators in that the electrode system and circuit are closely joined and part of the vacuum system. A three quarter wavelength coaxial cavity is connected between the filament and control grid. Surrounding this is a half wavelength coaxial cavity, connected between the accelerator grid and anode. In the outer wall of the grid-filament resonator opposite the filament, are milled 24 slots which serve as the control grid. Surrounding the control grid in the inner conductor of the accelerator-anode resonator are lengths of one-eigth inch diameter copper tubing, which are properly aligned with respect to the control grid. This structure is the accelerator grid and is shown in Figure 6. The outer cylinder of the accelerator-anode resonator contains the anode. Each electrode is insulated from the other by insulation outside of the RF field, so that the insulators are used for D. C. Only the output seal has to withstand the RF power on a glass insulator. All of the electrodes are water cooled, either by direct flow of water through the element, or by end cooling.

In operation the power output is taken from the accelerator-anode resonator by means of a coupling loop into a coaxial transmission line. A section of this line is a kovar-to-glass seal in the outer conductor which serves as the output seal. The length of this seal is such that it matches the short dimension of a rectangular waveguide. Proper matching to the waveguide is obtained by a tuning stub in the coaxial line past the output seal.

A waveguide is used beyond the output seal, for ease of handling the high powers involved.

Feedback is obtained for operation as a self-excited oscillator, by means of wire probes which extend from the grid-filament resonator into the electron interaction space of the accelerator-anode resonator. The proper phase is obtained by cutting the probes to the correct length.

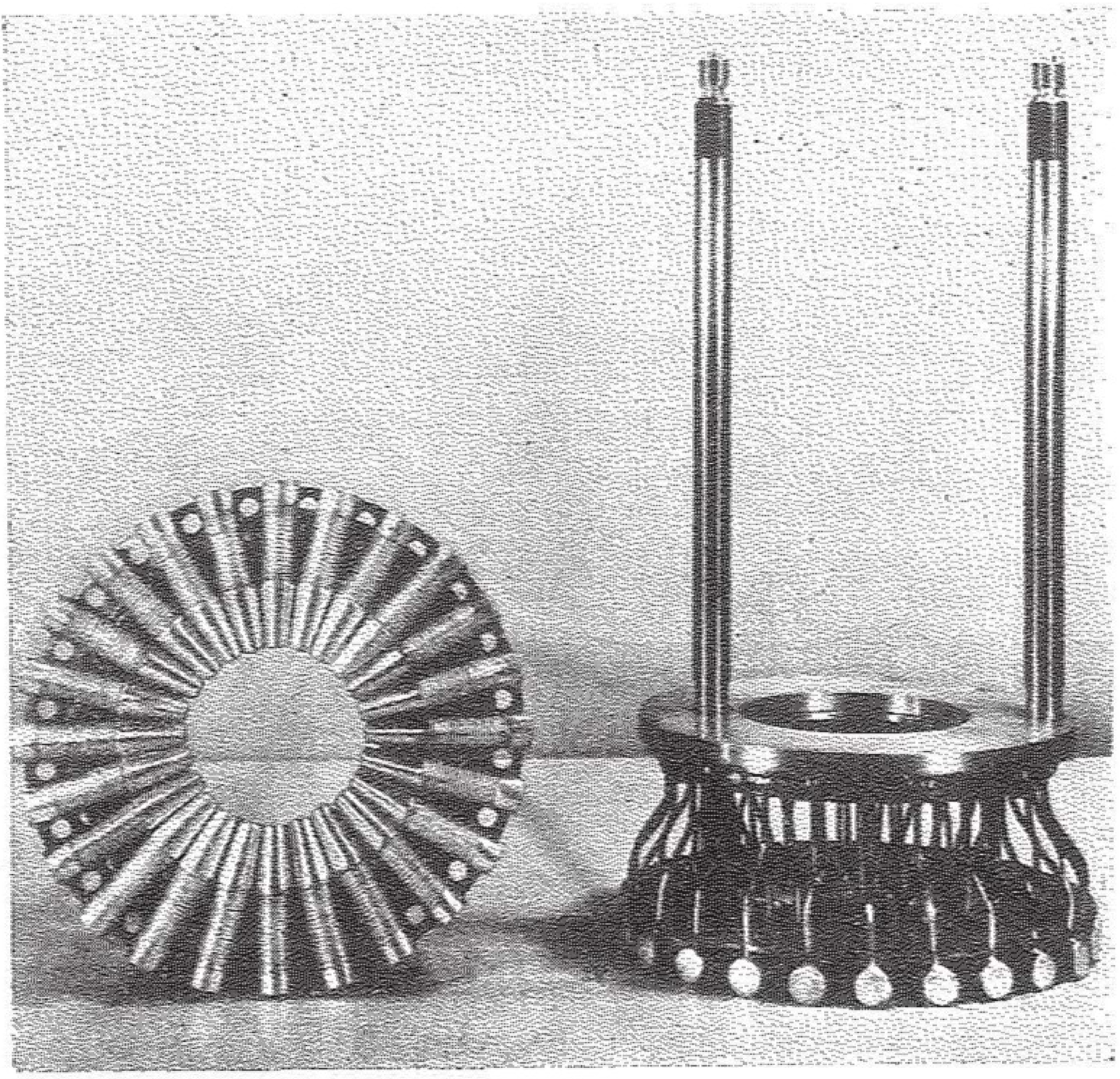

Fig. 7. – The "Daisy", an ingenious screen grid-anode tuning device. Twenty-four Sylphons maintain an equal pressure.

Tuning is obtained in the grid-filament resonator through variable capacitative termination of the three quarter wavelength cavity. In the accelerator-anode resonator, tuning is accomplished by changing the length of the cavity by means of a movable short. This shorting system was held in contact with the cavity walls by water pressure activated metal bellows. A view of this structure is shown in Figure 7. Mechanical motion is introduced into the vacuum system by Wilson seals and metal bellows connections.

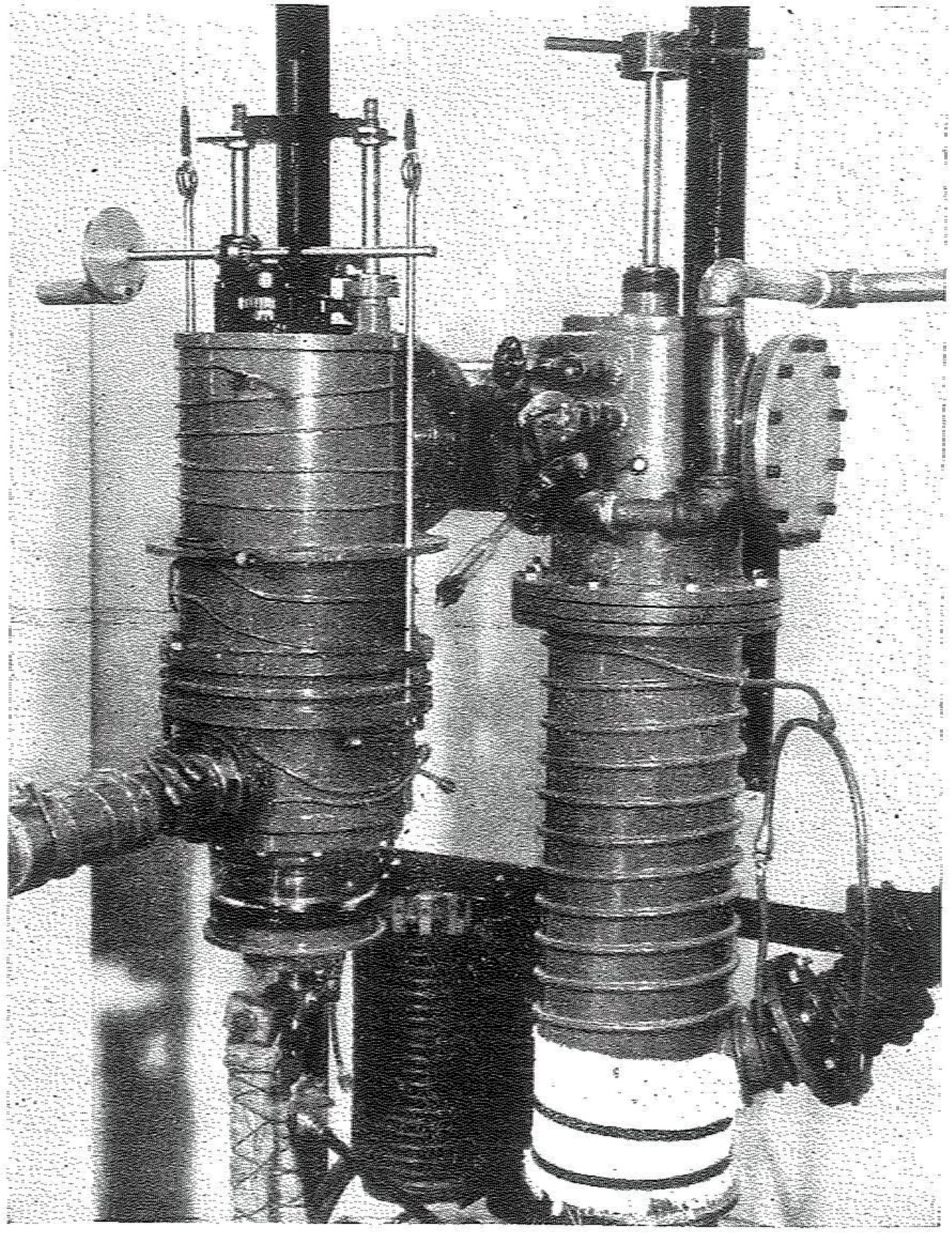

Fig. 8. – The resnatron assembled for operation. Its associated diffusion pump is at the right.

The tube structure is demountable to allow for filament replacement and is continuously pumped. A high-speed pumping system, consisting of a three stage oil diffusion pump backed by a mechanical pump, is used. The Resnatron is mounted directly on the diffusion pump throat. Continuous pumping has the advantage that voltage flashovers cannot permanently increase the pressure in the tube. A Resnatron connected to an oil diffusion pump is shown in Figure 8.

Undoubtedly the capabilities of the Resnatron will be applied to television and frequency modulation transmitting and other high-frequency services. Further development will extend the frequency and power range of the Resnatron and will result in many new fields of application, especially high-frequency industrial heating.