VI. MAGNETRON DEVELOPMENT

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Introduction. Work on the following closely related subjects is now in progress.

(1) The construction of a 10-Mw pulsed magnetron at 10.7 cm.

(2) The fabrication of a suitable output window for waveguide coupling of the magnetron, capable of sustained operation at an average power of 10-20 kw.

(3) The design and construction of a cathode free from the sparking or arcing troubles encountered with oxide cathodes at high voltages and high currents.

(4) A study of the mechanism of mode jumping observed as the voltage applied to a magnetron is increased.

(5) A study of the noise generated by the space charge in a cavity magnetron at voltages and currents below which coherence in the space-charge structure may be observed.

A. TEN-MEGAWATT MAGNETRON

Staff: Professor S. T. Martin
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To date two high-power magnetrons have been constructed and evacuated out of three starts. In one a cathode-heater short circuit developed. The third was sealed off successfully and placed on the test bench. With no magnetic field a pulse current of 150 amperes was drawn for a pulse duration of 1.7 μsec and a PRF of 500 cps.

This tube performed very satisfactorily and stably at low powers. During the early aging a power level of one-half megawatt was reached at a wavelength of 10.8 cms. At this point an accident produced a leak in a kovar weld, terminating the test. The observed efficiency at these low-power levels was well over 50 per cent. Construction of two anodes is proceeding, and the two defunct tubes are being reprocessed.

The ceramic output window discussed below has performed so successfully that a serious effort will be made to replace the glass cathode lead supports with ceramic tubes, now on hand. Taken together with a hydraulic pinch-off tool capable of pinching off 5/8 in. copper tubing which has been successfully tested, this will allow the fabrication of tubes which may be processed at temperatures well above the 450°C limit now necessary.

VI. B. CERAMIC WINDOWS

Staff: D. L. Eckhardt

As stated in the last progress report, successful vacuum-tight silver-soldered ceramic windows $3\frac{1}{2}$ in. in diameter have been made. Since then several more have been made, all of them being free from leaks when vacuum tested.

Until recently considerable difficulty was experienced in mounting the ceramic window, in its metal flange, on the magnetron. This problem was solved with oxy-acetylene welding and has proved the most satisfactory method, by far, of several attempted.

The problem of making the window resonant at the operating frequency will be deferred until the construction and test of additional tubes have been accomplished.

C. THORIA CATHODES

1. Physical Research

For work on the physical processes involved in the thermionic emission from these cathodes, refer to Sec. I. 1.

2. Design

Staff: S. Goldberg

A die for the pressing of thoria cathodes, 0.87 in. in diameter and 2.7 in. long, together with the necessary jigs for firing them, is in process of construction.

D. MODE STABILITY

Staff: R. R. Moats

One of the limitations upon the maximum power of a magnetron is the stability of the particular mode in which it is designed to operate. Therefore a study of mode stability and mode change has been carried on in connection with this project.

The principal conclusion which has been reached is that mode instability and mode changes are a result of inherent instability of the initial mode of oscillation, and are not influenced by the presence of any other mode of oscillation which may arise after the initial mode ceases. Therefore separation in frequency or in range of operating voltage between the desired mode and the next higher-voltage mode is not critical in extending the stable operating range of the desired mode to higher voltages and currents. These conclusions are subject to the following possible limitations:

1. Operation in the initial mode must not excite oscillation in any other mode. The frequency of the initial mode must therefore be separated from the frequency of any other possible mode by an amount much greater than f/Q_L (where f is the frequency of, and Q_L is the loaded Q for, the other possible mode) in order to avoid coupling between modes through the r-f circuit.

2. The rise time of the applied voltage must be relatively long compared with the buildup time for the oscillation. If the rise time were very short, the applied voltage could rise to a value at which some other mode could build up before the lowest-voltage mode had had time to build up.

The analysis of the problem of mode change has been clouded by the fact that in most magnetrons, when oscillations cease in one mode, oscillations begin in another mode immediately. It has not been entirely clear as to whether the primary event was the cessation of oscillations in the original mode, or whether the mode change took place as a result of some kind of competition between the two modes. This problem was investigated experimentally by the use of a low-power rising-sun magnetron, scaled in current and voltage from the high-power magnetron now under construction in this project. (See RLE Progress Report, July 15, 1947, p. 6.) The steady-state voltage-current curve for this magnetron is shown in Fig. VI-1. Since mode identification was not conclusive, the three

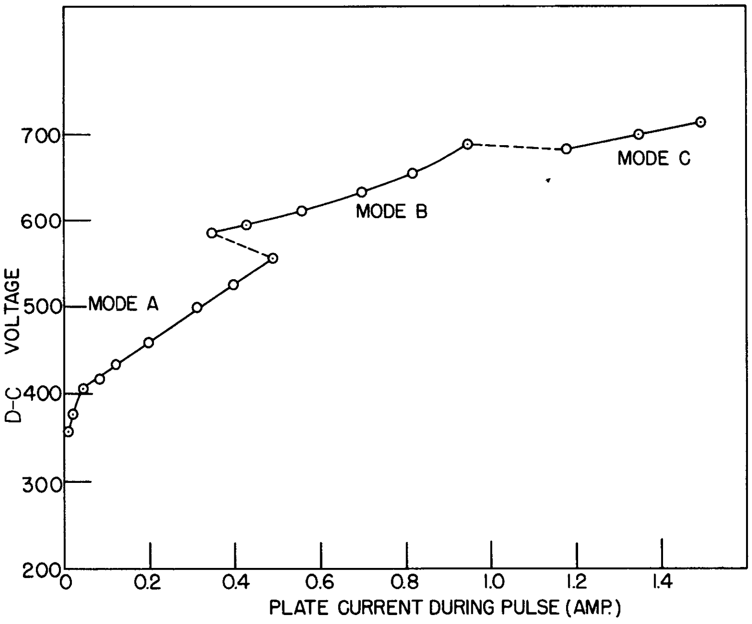

Fig. VI-1. Steady-state V-I curve: Low-power rising sun magnetron.

observed modes of oscillation are simply referred to as A, B, and C. A wavemeter cavity was connected in parallel with the r-f line, so that it was possible to alter the operating characteristics of one mode without affecting the characteristics of any other mode. The effect of loading upon mode stability was discussed in the Progress Report of October 15, 1947, pp. 6-7.

The results of this test involving selective loading of modes are illustrated by Fig. VI-2. The applied voltage pulse shown here requires 20 μsec to rise from zero to its maximum value. When the wavemeter cavity was tuned to Mode A, the boundary between Modes A and B was changed from the position shown by the solid line to that shown by the dashed line. No effect, however, upon the boundary between Modes C and A was produced thereby. Tuning the cavity to Mode B affected the ending of that mode in a manner shown by the dashed line, but did not affect its starting. Likewise, tuning the cavity to Mode C affected its ending, as shown by the dashed line, but not its starting. These results indicate that the conditions for shifting from one mode to another are determined by the characteristics of the mode initially oscillating, and are not affected by the mode which is found immediately after the initial mode has become unstable, no matter whether the voltage shift accompanying the mode change is upward or downward.

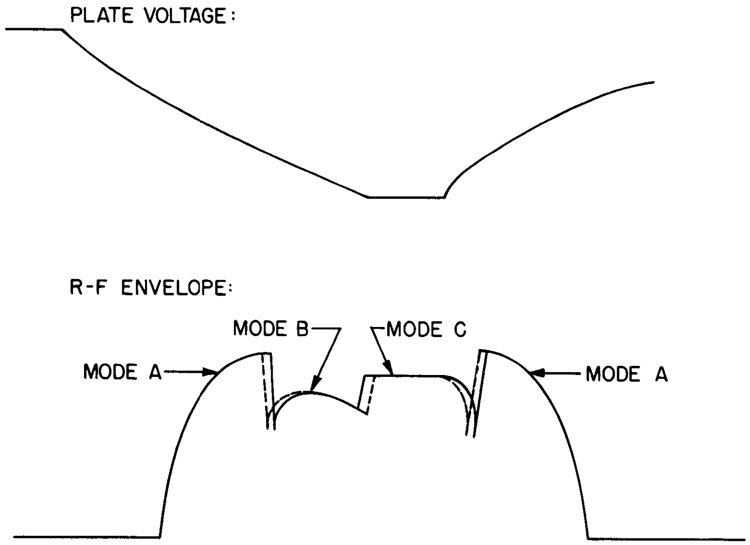

Fig. VI-2. Effect of load on mode change.

The conclusions set forth above agree with those described by Rieke[1] for the case where the mode change is accompanied by an upward

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[1] F. F. Rieke, "Microwave Magnetrons", G. B. Collins, Editor, McGraw-Hill 1948, p. 349.

shift in voltage, as from Mode A to Mode B (Figs. VI-1 and VI-2). But in the cases where the mode change is accompanied by a downward shift of voltage, as from B to C and from C to A, Rieke says, "These transitions can arise only from an interaction between modes; for if the primary event were simply the cessation of oscillations in the initial Mode A, the current (which can flow only because of the oscillations, since the voltage remains well below cutoff throughout) should tend to decrease and the voltage to rise <u>during the transition</u> - - which is opposite to what is observed. Evidently, while the tube is in Mode A, a condition is reached that permits B to build up, and eventually the oscillations in B reach a great enough amplitude to suppress A."[1] (Rieke's Mode A is the higher-voltage mode, B the lower-voltage mode, and the mode change is from A to B.) This last statement is in direct conflict with the conclusions set forth above. Here Rieke had failed to observe any reduction of current between modes, and instead observed only the current rise accompanying the oscillation of Mode B. Figure VI-3 shows the pulse of applied current as observed in connection with operation of the low-power rising-sun magnetron under conditions illustrated in Fig. VI-2. The sharp vertical spikes occur at the mode boundaries, and show a sharp reduction of the value of current after one mode collapses and before the next builds up. This last observation is consistent with the idea that mode change takes place as a result primarily of cessation of oscillations in the first mode, and not with Rieke's suggestion of mode competition.

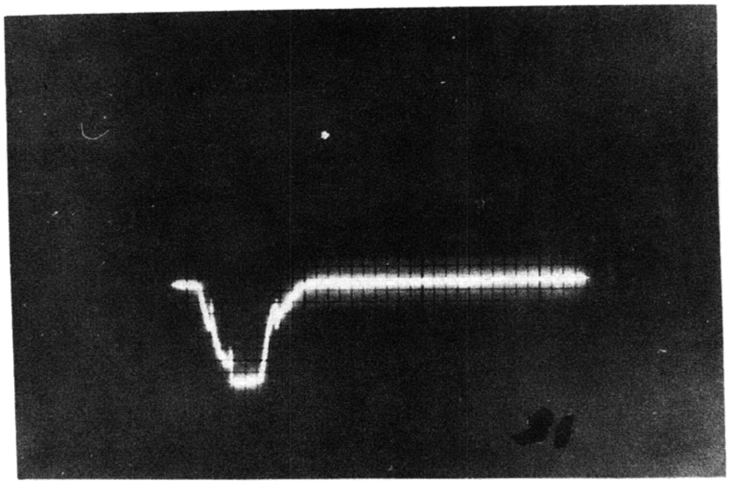

Fig. VI-3. Current pulse: Low-power rising-sun magnetron.

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[1] F.F. Rieke, op. cit, p. 350.

A set of measurements of the electronic admittance in the QK-61 magnetron has been completed, (see RLE Progress Report, April 15, 1948, p.40). Figure VI-4 shows these results in the form of curves of constant d-c voltage in the admittance plane. Changes of loading have been represented in terms of electronic conductance g, and "frequency pushing" in terms of electronic susceptance b. The line to the right of, and parallel to, the vertical axis represents the value of g corresponding to a matched load. Other loads, if insensitive to frequency, can be represented as other vertical lines. If a particular line of d-c voltage fails to intersect the vertical line corresponding to a given value of g, it represents a voltage outside the possible operating range for that load.

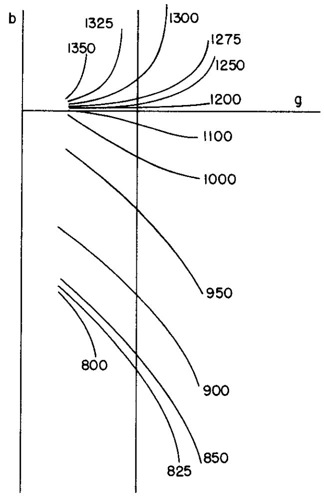

Fig. VI-4. Curves of constant d-c voltage for QK-61 magnetron.

E. NOISE GENERATION IN THE PRE-OSCILLATING MAGNETRON

Staff: V. Mayper

Construction of a magnetron with insulated end caps for measurements of pre-oscillating anode current is not yet complete because of mechanical difficulties. However, a tube is at present under construction which seems to have resolved most of these difficulties.

Measurement of internal Q (including the effects of electronic loading, negative and positive) as a function of plate voltage below oscillation is still in progress. In the region just below oscillation, the results given by Rieke[1] have apparently been confirmed for the QK61; at V = 500 volts the internal Q is just about the cold value, while with increasing voltage it increases, becoming "infinite" at 765 volts, then

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1. F. F. Rieke. "Microwave Magnetrons", G. B. Collins, Editor, McGraw-Hill 1948, p. 392.

coming up from "minus infinity" until it attains a small enough negative value to balance out the positive losses in the load circuit (i.e., $Q_o = -Q_e/g$), at which point oscillation commences. (As has previously been observed, by others and ourselves, the beginning of oscillation is not discontinuous with voltage, but rather the random noise output becomes more and more concentrated in bandwidth and of greater and greater amplitude until finally the output is the normal negligible-bandwidth c-w signal. The transition is of course quite rapid, so that the "starting voltage" is only slightly ambiguous.) At much lower plate voltages, however, there seem to be positive electronic loading effects, which are now being investigated.

Some further measurements of noise output have been made, as a function of plate voltage, but their meaning will remain doubtful until the dependence of internal Q on plate voltage is more thoroughly investigated. So far as can be told, in the region around 400-600 volts where the internal Q does not vary greatly with plate voltage, the noise varies almost exponentially with the plate voltage. This gains some support from previous results which used plate leakage current as the independent variable, but the current-voltage relationship was of doubtful linearity, so that the question of exponential dependence of noise on plate voltage is still open. In any event, it would only hold before the feedback mechanism, starting at about 600 volts, became effective.

F. STATIC SPACE CHARGE IN THE PLANE MAGNETRON AND CYLINDRICAL MAGNETRON

Staff: R. Q. Twiss
Professor S. T. Martin
W. Rotman

As a part of the investigation in the generation of noise in the magnetron, a study of the space charge, including the effect of Maxwellian distribution of initial electron velocities, has been undertaken.

In the case of the plane magnetron, results have been obtained yielding space-charge densities and transverse-current densities as functions of position, with applied magnetic field and anode voltage as parameters. It seems likely that the very large transverse-current densities will do much to explain the tremendous observed noise power in the pre-oscillating magnetron. A major mystery, however, is still the appearance of the relatively large currents in the cut-off region which are observed experimentally. The observed currents are astronomically larger than the theoretical values.

A few selected solutions of the cylindrical case will be computed on the differential analyzer for comparison with the plane case.