VI. MAGNETRON DEVELOPMENT

Prof. S.T.Martin   V.Mayper

D.L.Eckhardt   R.R.Moats

S.Goldberg   R.Q.Twiss(guest).

INTRODUCTION

Progress is reported on the following subjects:
1. Results of testing the high-power 10.7-cm magnetron.
2. Design of a ceramic output window for waveguide coupling of the high-power magnetron.
3. Research and design of a sintered thoria cathode for the high-power magnetron.
4. A study of mode stability in magnetrons.
5. A study of the noise generated by 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

1.   Construction

No further construction has been undertaken since the last report. Two tubes have been processed and are undergoing aging and tests on the pressurized test bench. Construction will be resumed when the ceramic output-window design has been altered to reduce the loaded Q, which is presently too high.

2.   Test

Adjustments have been made in the loaded Q of the above tubes by adding inductive irises externally to the windows. This remedied the trouble reported in the October Progress Report, although the loaded Q was inadvertently altered to be too high for optimum performance.

Moding difficulties were also encountered but were resolved by slowing down the rise time of the applied voltage pulse. With these corrections stable, operation could be realized at a peak power output of 3 megawatts. At this output the voltage, current and magnetic field were 40 kv, 200 amp and 2380 gauss respectively. The average pulse length is .6 μsec. Figure VI-1 indicates performance obtained to date. Excessive sparking in the magnetron was the limiting factor in attempting to attain higher outputs. There are indications, however, that this sparking will
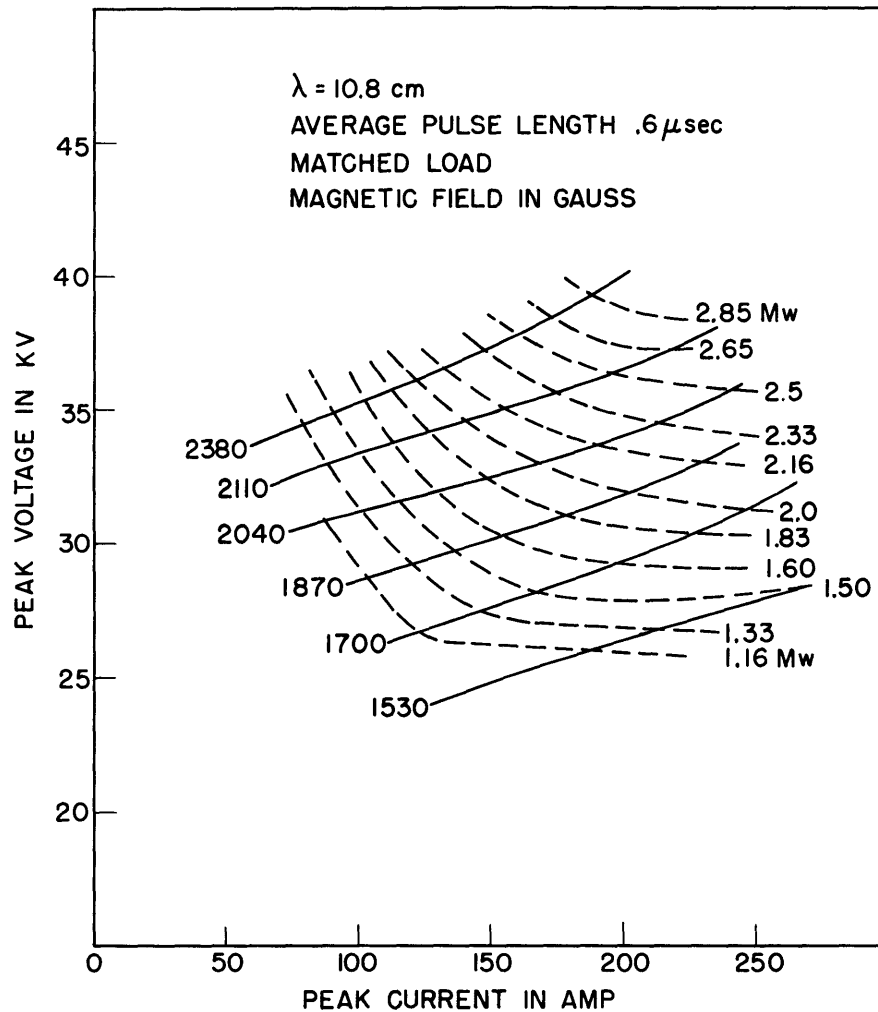
Fig. VI-1. Performance chart, high-power rising-sun magnetron.

reduce as the tube is aged. The total running time to date is 30 hours. Because of interference caused by the modulator and the need for higher pulsing powers, operations were transferred to the modulator vault. The vault modulator can supply a peak power of 20 megawatts into a 20-ohm load at pulse lengths of 1/10, 1, 2, 3 and 5 μsec. Tests are now being run using a 2-μsec pulse. Modulator difficulties have not permitted any accurate power measurements to date.

At power outputs exceeding 1 megawatt, it was found necessary to pressurize the microwave system to alleviate sparking at the iris and the standing-wave probe. At 30 pounds pressure, trouble was found with the conventional water loads due to gas leaking in through the thermocouple connectors. This difficulty was corrected by constructing a load with

vacuum-tight Kovar-to-glass thermocouple connections. The system now functions well at pressures as high as 70 pounds per square inch.

During cold-test measurements on the windows, an unexpected resonance was found at a wavelength 1.5 per cent lower than the π-mode. Its source and effect on tube operation are still unknown.

D.L.Eckhardt. S.Goldberg, R.R.Moats

B. CERAMIC WINDOWS

A redesign of the output window to reduce the coupling of the magnetron to its load has been substantially effected. In the original design first effort was directed to producing a vacuum-tight envelope, in the expectation that the loading could be varied by changing the standing wave with a slug tuner in the test equipment. This scheme led to mode selection problems because of the comparatively long time (10^{-8} sec) required for the reflection to reach the magnetron. This time is of the order of the rise time of the oscillations.

A window 1/8-inch thick by 2 1/2-inch diameter of Coors Body Type ZI-4 gives a loaded Q of about 220 at λ_o = 10.7 cm, where a 3/16-inch thick by 3.4-inch window of the same material gave a loaded Q of 90, in the output section design used by us. The window Q of the former is about 5. Construction of two of these windows for use in the next two tubes will be undertaken.

The requirement of high-pressure operation puts some limitations on window design, but principally on the achievable power-handling capacity (if only flat, plane structures are considered). These factors have been considered qualitatively, but as yet do not appear to put a basic limitation on our immediate objectives. D.L.Eckhardt

C. THORIA CATHODES

1. Development and Design
Constructional difficulties in fabricating the split die have postponed its delivery date. It is expected to be completed within the next week.

No further work has been done on the vacuum furnace. It was found possible and practical, however, to platinum-braze tantalum mounts to a small thoria cathode in a vacuum using a bell jar and induction heating.

A problem yet to be solved is a scheme for supporting a large thoria cathode in the high-powered magnetron. The support must be able to pass

100 amp and be sufficiently insulated from the high (1700°C) temperature of the cathode. When the new die is available, different thoria-tungsten mixtures will be tried to see if a cathode can be made with a higher resistivity than those using the present 70 per cent thoria, 30 per cent tungsten mixture and yet have its resistance characteristics stable. In this way the current requirements of the support may be lessened.   S.Goldberg

D. MODE STABILITY

A study of the mode stability characteristics of the 2J39 magnetron is now under way. Only one mode of oscillation, the π-mode, could be observed. The range of plate voltages which permits stable oscillation in this mode is plotted in Figure VI-2 as a function of magnetic field. Also plotted are the theoretical threshold voltages (Hartree voltages) for n = 4 (π-mode) and n = 3, and the d-c cutoff voltage. Theoretical considerations for a single-ring strapped anode, such as the 2J39 anode, suggest a wavelength of about
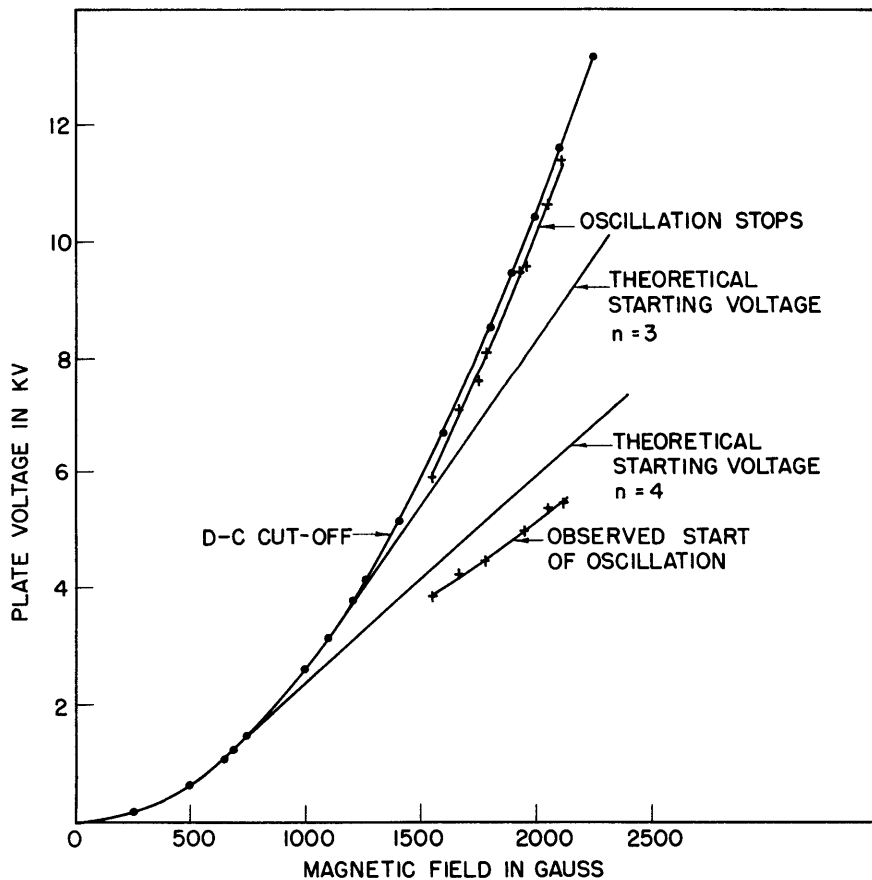

Fig. VI-2. Stable oscillating range for 2J39 magnetron in π-mode.

8.3 cm for the n = 3 mode, since π-mode wavelength is about 9.1 cm[1]. The
next resonant wavelength less than that of the π-mode was found by means of
cold impedance measurements at 7.5 cm. Consequently, this value is assumed
for computation of threshold voltage for n = 3.

The results plotted in Figure VI-1 indicate that the upper voltage
limit for oscillation in the π-mode is determined by the d-c cutoff.
Furthermore, oscillation is observed in the π-mode at voltages far in
excess of the threshold voltage computed for n = 3. For example, at 2100
gauss, oscillation is observed for plate voltages as high as 11.4 kv, as
compared with the computed threshold voltage for n = 3 of 9.0 kv. These
observations lend further support to the conclusion drawn from previous ex-
periments that instability of oscillation in a given mode does not result
primarily from competition of the next possible higher-voltage mode of
oscillation when the threshold voltage of the latter mode is reached, but
rather depends on the stability characteristics of the original mode inde-
pendent of other possible modes. This conclusion assumes that stable oscil-
lation has been firmly established in a given mode, and does not take into
account the problem of which mode will start under a given set of conditions.
It is further assumed that the modes under consideration are far enough
separated in frequency that an r-f field corresponding to one mode will not
excite an appreciable r-f field in the other mode.

In Figure VI-3 are shown a series of synchroscope photographs of r-f
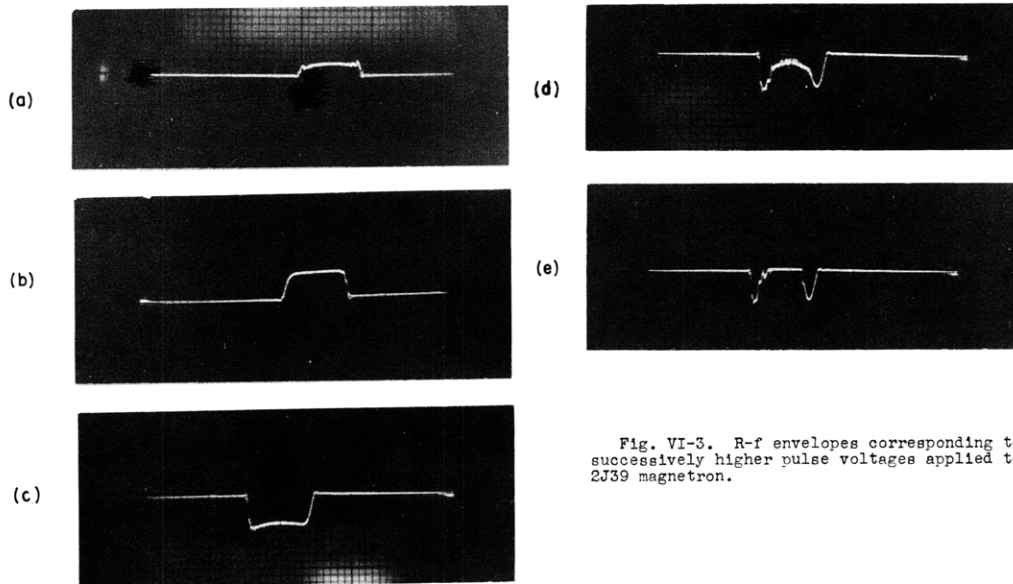envelopes corresponding to successively higher applied pulse voltages. It

Fig. VI-3. R-f envelopes corresponding to successively higher pulse voltages applied to 2J39 magnetron.

1. Collins,G.B.,"Microwave Magnetrons",Chapter 4, McGraw-Hill Book Co.,1948.

will be observed that at first the r-f output increases as applied voltage increases, but after a certain point r-f output falls off with further increase of applied voltage. The dip in the middle of some of the r-f pulses corresponds to the greatest values of the pulse voltage. In the last picture of Figure VI-3, oscillation has ceased completely in the center portion

(a)
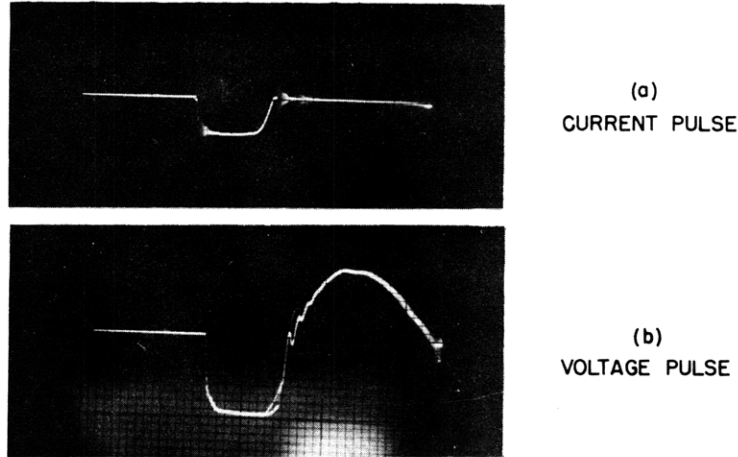CURRENT PULSE

(b)
VOLTAGE PULSE

Fig. VI-4. Current and voltage pulses applied to 2J39 magnetron corresponding to Fig. VI-3(e).

of the pulse. Current and voltage pulses corresponding to this last r-f pulse are shown in Figure VI-4. No current reduction is observed during the cessation of r-f oscillation. This observation is consistent with the data plotted in Figure VI-2 which indicate that the oscillation fails upon approaching d-c cutoff, since it is expected that large currents will flow only upon reaching d-c cutoff in the absence of r-f.

R.R.Moats

E. NOISE GENERATION IN THE PRE-OSCILLATING MAGNETRON

Further mechanical difficulties have prevented the completion of the magnetron with insulated end-caps, mentioned in previous reports. Parts for a redesigned tube are in the process of fabrication. In addition, to ensure a definitely known value of emission and to remove any possible effects of gases from an oxide cathode, a directly heated tantalum-cylinder cathode for this tube (using a 1/8-inch cylindrical sleeve made of .00075-inch tantalum foil) has been designed and tested.

V.Mayper

F. STEADY-STATE SPACE-CHARGE DISTRIBUTION IN A MAGNETRON

An approximate analytic solution for space charge in both the plane and cylindrical magnetron has been obtained, assuming a Maxwellian distribution of both normal and tangential initial electron velocities. It has been established that the electron flow is essentially double-stream, whatever the

ratio of anode-cathode radius. Previous analyses, showing that such a static solution is impossible, have rested on the assumption that the initial velocities are zero.

The principal differences between this solution and the one developed by Hartree and by Slater are:

    (a) The space charge and potential distributions are no longer ambiguous in character;

    (b) The average electron transit time is appreciably decreased;

    (c) As a consequence of (b), the current crossing the potential minimum is correspondingly increased, since the total space charge in either case is primarily determined by the plate voltage and the magnetic field.

There are strong reasons to suspect that this space-charge distribution is inherently unstable.

R.Q.Twiss (guest), Prof.S.T.Martin

G. NOISE PROPERTIES OF THE "NON-OSCILLATING" MAGNETRON

An exact theory has been obtained for the noise properties of a temperature-limited cylindrical magnetron. The noise produced by such a tube is some 40 decibels less than that observed in a presumably space-charge-limited tube. The presence of the excess noise is attributed to an internal space-charge amplification. The existence of similar effects has been recently discovered by A.V.Haeff who suggested, in a Letter to the Physical Review, that they might be responsible for the excess noise in magnetrons and for the excess plate current found by many observers. These suggestions have been confirmed. Considerable amplification will take place between ingoing and outgoing electron streams.

When a potential minimum exists, as is the case in a space-charge-limited tube, there is a mechanism for positive feedback at frequencies equal to the inverse transit time or its harmonics. This mechanism can result in a zero-mode oscillation of the space charge, the amplitude of which is limited by the depth of the potential minimum and the circulating current density.

It has also been shown that the noise generated by the space charge in a mode of the magnetron is statistically independent of that generated in any other mode. The amplitude of the noise within a given mode depends on the geometry of the tube and the operating conditions, and varies considerably from mode to mode. It is probable that this fact has much to do with the mode-selection properties of magnetrons.

R.Q.Twiss (guest)