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Notes on Magnetron development programme (I).

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1. Data on standard types.

E.1189. (a) 6 - segment type, now replaced by (b).(opt.H = 1400 g.)

(d_a = 12.0, d_c = 12.0, l_a = 20, s.w. = 2.0, s.d. = 2.0, d_k = 4.5; λ = 9.8 cm.) *

15 valves made including experimental variants (see below).
Life data: 1 emission failure 225 hours (poor emitter initially). 3 between 50 and 100 hours. (2 had poor contacts in heaters initially, were repaired as soon as replacements became available and are now in service again; the third was accidentally broken; none showed any deterioration in performance). The remainder have been run for periods between 5 and 30 hours; all OK except 1 heater failure at 30 hours.

(b) 8 - segment type.(opt.H = 1050 g.)

(d_a = 16.0, d_c = 10.0, l_a = 20, s.w. = 1.6, s.d. = 3.3, d_k = 6.0; λ = 10.0 cm.)

4 valves made: 3 O.K. at 20, 30 and 60 hours respectively,
1 heater open-circuited at 210 hours.

E.1198.

(p = 4, d_a = 16.0, d_c = 10.0, l_a = 20, s.w. = 2.0, s.d. = 3.05, d_k = 6.0; λ = 9.1 cm.; opt.H = 1150 g.)

4 valves made: 3 O.K. at 25, 10 and 4 hours; 1 accidentally broken at 85 hours then repaired; now O.K. at 75 hours.
3 further samples are approaching completion for A.M.R.E.

The general position on life and stability of performance appears to be satisfactory, though heater failures have been too numerous. It has been found that the insulating coating on the heater spirals has not been up to normal standards and this is being attended to. Life test gear will shortly be available for continuous operation, independent of the experimental programme. A total of 35 valves (including repairs) has been made with the gold seal technique without a failure of the seal.

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* Symbols used:
p = no.of pairs of segments,
d_a = anode diameter,
d_c = circuit hole diameter,
l_a = anode length,
s.w. = slot width,
s.d. = slot depth,
d_k = cathode diameter,
H = magnetic field strength,
E_a = anode voltage,
I_a = anode current,
λ = wavelength; dimensions in mm.

2. Valves for shorter wavelengths.

(a) E.1218. (aimed at 7.5 cm.)

($p = 5$, $d_a = 16.0$, $d_c = 8.0$, $l_a = 20$, s.w. = 1.6, s.d. = 2.8, $d_k = 6.0$; $\lambda = 7.9$ cm.; opt. H = 1120g.).

2 valves made: both O.K. at a few hours. (1 sent to A.M.R.E.) On oscillation test at 9 kV. 6A. peak input, H = 1100 g., the output was of the same order as for E.1198 (accurate measurements not yet made but the efficiency is certainly of the order of 10%).

If further valves are required the wavelength will be adjusted to 7.5 cm. or whatever exact figure is decided on in that neighbourhood.

It is satisfactory to note that the wavelength range of 12 to under 8 cm. has now been covered without any indication of reduction of efficiency with decreasing wavelength.

(b) Study at about 10 cm. of constructions adapted to shorter wavelengths.

(i) Coupling methods.

Variations from the central coupling loop are being tried out in C.W. designs (q.v. below). The first of these, coupling loop of the same size placed just outside the end of one circuit hole, has given approximately the same output and efficiency though the coupling coefficient was considerably reduced. Coupling and tuning conditions (on the coupling line) are more critical and this made it appear on a first trial that the available output was less.

The second variation, which would probably be the most convenient for the shortest wavelengths, namely direct tapping of the inner of the coupling line on one of the resonent elements, is included in a valve now being made. The analogue of this in a glass receiving magnetron (E.1210) with resonant strip segments is being used with complete success at about 10 cm.

(ii) Form of resonant cavities.

The "hole and slot" construction has been extended in the direction of deeper slots to the point at which the slot depth is about equal to the hole diameter without any difficulties arising. Two C.W. valves are now in hand with resonent elements formed by radial blades ("commutator valve"), one valve with a central coupling loop and one with the direct tap referred to above. The important dimensions are the same as those of the C.W. valves already made.

It will be clear that the aim in all this has been to avoid indefinite conclusions by making only one change at a time.

(iii) Effect of increasing p.

Valves have now been made with p = 2,3,4,5 and 6. There is some indication of an improvement in efficiency between p = 2 and p = 4 and there appears to be little change between p = 4 and p = 6, though in the last case there is some evidence that the efficiency curve against H has two peaks just below and just above the calculated opt.H. This may

may perhaps be a function of the ratio of slot width to segment width rather than of p; further trials are required to clear this up and will be made in due course. It appears that the width ratio (slot/segment) is otherwise not a critical variable at least for values between about 0.2 and 0.4.

(c) Valves with structure similar to E.1198 for shorter wavelengths.

A design for $\lambda = 4.5$ cm., pulse operation, is being made to which the following data apply:-

$\lambda=4.4$ (measured) $p = 8$, $d_a = 16.0$, $d_c = 4.0$, $l_a = 20$, s.w. = 1.0, s.d. = 2.7, $d_k = 6.0$; opt.H = 1150g., opt.E_a = 9 kV.; central coupling loop.

The difficulties of proceeding farther in this direction are purely geometrical; as p is increased with decreasing λ to keep opt.H constant, d_c has to be reduced by a factor greater than that by which p is increased, so that the tendency is towards small circuit holes with deep slots and mechanical problems arise in the coupling loop design. Hence the desire to change the form of the coupling and of the resonant cavities. These difficulties are increased in C.W. designs where even greater values of p are necessary to give a reasonably low anode voltage without excessively small anode diameter.

The design detailed above certainly does not represent the limit, but it is proposed to complete the exploratory experiments at about 10 cm. before attempting what may prove to be an unnecessarily difficult construction for still shorter wavelengths

If the "commutator valve" with direct coupling does succeed at 10 cm. (the disappointing though perhaps inconclusive results of the first Birmingham experiments show that its success is not a foregone conclusion), and there is as little variation of efficiency with p in going from p = 6 to p = 16, say, as there has been between p = 2 and p = 6, then the prospects of satisfactory valves for aircraft use at wavelengths down to 2 or 3 cm. are good.

3. Designs for higher power.

(a) 10 cm. valve similar to E.1189.

$\lambda=10.66$ ($p = 4$, $d_a = 25.0$, $d_c = 10.0$, $l_a = 46$, s.w. = 1.6, s.d. = 3.3, $d_k = 10.0$; opt.H = 1070 g., opt.E_a = 19 kV., anode dissipation about 1 kW., air cooled).

This design, of which a first sample is approaching completion, is expected to give a peak output of the order of 100 kW. Difficulties with external spark-over are quite likely to arise if this is achieved. The purpose of this design is to explore the possibilities in the direction of higher power rather than to meet any specific Service requirement. A suitable modulator has been designed.

(b) 50 cm. valve.

(See below).

4. Designs for longer wavelengths.

(a) 25 cm. valves.

A first attempt to produce a valve for about 25 cm., made some time ago, was chiefly remarkable as the only case so far of gross disagreement between the calculated and the actual wavelength. The valve data were:

$p = 2$, $d_a = 13.5$, $d_c = 23.0$, $l_a = 20$, s.w. = 1.0, s.d.= 2.9, $d_k = 2.9$; calculated $\lambda = 27$ cm.; calculated operating conditions: opt.H = 1000g., opt.E_a = 7 kV. for precessional resonance oscillations, or opt.H = 735g., opt.E_a = 3.3 kV for tangential resonance oscillations.

The valve operated roughly as expected under both sets of conditions (no detailed study was made) but the wavelength was in the neighbourhood of 18.5 cm.

A radiograph revealed nothing abnormal; the valve has not yet been opened up to make sure. It is possible that the assumptions made in the wavelength calculation do not hold for large ratios of d_c/l_a. Only pressure of work on more urgent designs made us transgress the rule that in valve work experiments should never be confined to a single sample. The uncertainty as to the significance of the results which we have here is the usual penalty.

Another design, which departs less far in relative dimensions from previous valves, is now being made. ($p = 3$, $d_a = 30.0$, $d_c = 20.0$, $l_a = 40$, s.w. = 1.5, s.d. = 5.1, $d_k = 10$; opt.H = 525g., opt.E_a = 7.6 kV.; designed $\lambda = 25.1$ cm.) The expected output is 5 - 10 kW peak.

Owing to the recent success of the oxide cathode triode E.1190 (about 20 kW peak output from a pair at 25 cm.; life data very scanty as yet but hopeful), this magnetron design is not regarded as very important from the application point of view. It is of some importance as a second string until we know more of the life and production position on the triodes. Its primary purpose is, however, as part of the experimental programme.

(b) High power design for 50 cm.

At the request of the C.V.D. Committee a design for 100 kW. peak output or more at about 50 cm. is being considered. Straight forward extension of the E.1189 design leads to clumsy structures which are also very wasteful of material unless extremely high anode voltages can be contemplated and very large powers are required.

A design is being prepared on the basis of a system of resonant copper bars each connected at one end to an enclosing copper cylinder. This looks much more reasonable but the details of the design have still to be completed. As a low field (300 g. for $p = 3$) is required in a large volume (probably $d_a = 100$ mm. for E_a about 22 kV) a solenoid or a pair of Helmholtz coils may be preferable to a permanent magnet.

5. C.W. Valves.

Two valves have been made, with standard oxide cathodes, for which the data are:

$p = 6$, $d_a = 10$, $d_c = 6$, $l_a = 20$, s.w. = 1.0, s.d. = 5.5, $d_k = 4.5$; opt.H = 750g., opt.E_a = 1.3 kV., $\lambda = 9.8$ cm. all calculated.

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The observed λ was 8.8cm.; some of this discrepancy may be accountable to slight inaccuracy in the width of the rather deep slots used; unfortunately an exact measurement of s.w. was not made during manufacture. The curve of efficiency against H showed two maxima of about 10 and 13% respectively (data for the second valve are not extensive but the two appear to agree); these occur at about 600 and 900 g. with a minimum (about 5%) near the calculated opt.H of 750g. The corresponding anode voltages were about 0.8 and 1.9 kV. An output of the order of 25W.continuous has been obtained at the higher condition but with the 200W.input required the cathode was bombarded up to far above normal temperature. The emission fell fairly rapidly during the C.W. tests but the anode current remained space-charge limited. One valve completed about 35 hours and then would not start oscillating even with over normal heating watts. The other at rather shorter life showed rapid deterioration of efficiency. On opening up both valves were found to have the central part of the nickel cathode cylinder melted and appreciably distorted. While exact figures are not available it would appear that the cathode bombardment in these valves was worse than it has been in pulse valves with the same cathode and similar mean input.

The coupling loop trial made with these valves is reported above.

Some measurements of frequency stability were made, using an H A.I. oscillator on about 50 cm. to produce an I.F. beat which was applied to a normal C.W. receiver. The method worked very well when precautions had been taken to exclude the carrier frequency from the receiver. On a rectified A.C. anode supply with a ripple of a few per cent, the frequency spread was less than 1 Mc/s (a few parts in 10^4 frequency modulation) at 1.9 kV. 70 mA input. The variation with anode voltage in the region of maximum efficiency appeared to be of the same order as that indicated by the point-by-point measurements made on E.1189 with pulsed anode voltage. Variation of frequency with anode temperature corresponded approximately to the temperature coefficient of linear expansion of copper.

The valves are now being re-made with thoriated tungsten spiral filaments (to be operated as dull emitters if the emission is stable, otherwise they can be run up to bright emitting temperature).

More complete frequency measurements will be made later.

By designing valves to work at the lower efficiency maximum observed on these samples it would appear possible to increase both anode and cathode diameter which would reduce bombardment difficulties for a given mean output.

The two C.W.valves of the "commutator" structure mentioned above are being made with oxide cathodes.

The design of indirectly heated tantalum cathodes for C.W. valves is being considered. Outgassing on the pump may present some difficulties.

6. Frequency modulation.

(a) Use of external stabilising resonators.

Preliminary experiments have shown that an appreciable reduction in frequency variation with anode voltage is possible by the use of a concentric tube resonator coupled to the tuned output circuit in the way which has been used successfully at longer wavelengths. More detailed investigation will be made later on the C.W. valves with which precise heterodyne frequency measureme is possible.

(b) Use of internal stabilizing resonators.

Possible designs have been considered but the method has same practical drawbacks as compared with (a) and will not be pursued at present.

(c) "Squaring" of modulator wave-form.

Considerable success has been achieved in modifying the waveform of the ignition thyratron modulator in this direction. It appears, however, that with proper design of the modulator output circuit considerable squaring of the output voltage is produced by the steep rise of anode current in the operating region of the magnetron characteristic and that it is difficult to obtain much further improvement. The problem is being reconsidered from the point of view that what is required is a constant current rather than a constant voltage generator.

Tests on an actual transmitter (E.1198) and receiver have been made with both gas-filled and hard valve modulators. The results were that there was no substantial difference in frequency spread or in received signal amplitude (ground return) between the peaky and the "square" wave ignition thyratron circuits; the hard valve circuit gave an appreciable reduction in frequency spread (by a factor of rather less than 2) but the received signal was reduced rather than increased. This result is not necessarily final and the tests are continuing. The frequency spread was measured (between extinction points) by variation of the receiver local oscillator frequency. The original figure was in the neighbourhood of 40 Mc/s. Most of the radiated energy was of course contained in a considerably smaller frequency band; 1/7 of it (on a rough estimate) was contained in the 4 Mc/s pass band of the receiver I.F. amplifier.

(d) Calculation of the effect of combined amplitude and frequency modulation on a pulse signal.

A report covering this work (E.C.Cherry) will be issued shortly. In very brief summary, the result of this analysis (which is backed by some experiments at relatively low frequencies), that for the conditions which arise in the magnetron transmitter as now used the effect of a frequency modulation of the order of several times the receiver band-width is to produce a slight **increase** in the peak amplitude of the received signal accompanied by some reduction of its width. A large increase in the frequency modulation would eventially so narrow the received signal as to cause loss of amplitude in the I.F. channel.

The experimental work described in (c) is now mainly directed towards getting an adequate experimental check on these predictions under working conditions. It is too early to be dogmatic but the indications are that the significance of frequenc modulation in pulse transmission has been over-estimated and that the causes of discrepancies attributed to it may lie elsewhere.