LETTERS TO THE EDITORS

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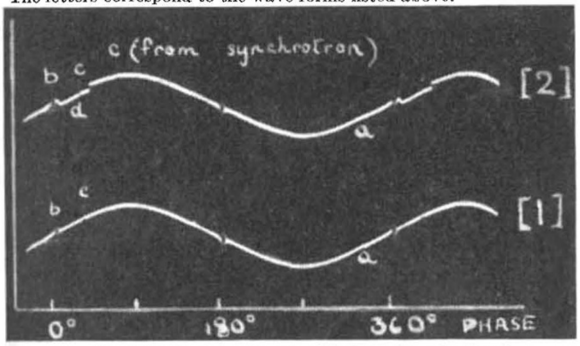
Experimental 8 MeV. Synchrotron for Electron Acceleration

THE synchrotron principle has been suggested by Veksler[1] and McMillan[2] as a possible means of accelerating electrons to high energies. This letter describes modifications which have been made to a 4 MeV. betatron to convert it to an 8 MeV. synchrotron. The experiments prove that the synchrotron principle is a valid one for electron acceleration.

The betatron chosen for modification[3] was one of Kerst's early models, similar to that described by him[4]. It accelerates electrons to 4 MeV. when unmodified, and X-rays are produced by allowing the orbit to collapse so that the electron beam strikes a tungsten target. The equilibrium orbit is at 7·5 cm. radius and the target is at 4·6 cm. radius, so that there is a considerable delay between the time when the central core saturates and the emission of the X-rays. In operation as an unmodified betatron we have the following conditions: peak field at equilibrium orbit, 2,000 gauss; 50 cycle R.M.S. current in field coils, 35 amp.; central core saturates at a phase of 24° relative to the minimum field; electrons strike the target at a phase of 90°, that is, when the field is maximum. The current in the exciting coils was now stepped up to 70 amp., the maximum permissible without breakdown. This did not increase the energy of the electrons, since saturation of the core now occurred earlier and consequently the electrons struck the target well before the exciting field reached its maximum. The following conditions now pertained: peak field at orbit, 4,000 gauss; central core saturated at phase of 12°; electrons struck target at phase of 30°. To demonstrate synchrotron action it was only necessary to show that, with the betatron thus over-run, the electrons could be made to strike the target at a phase of 90° by suitable application of radio-frequency acceleration. Then it would follow that the energy had been doubled (to 8 MeV.).

To indicate this experimentally the following wave-forms were superposed on an oscilloscope: (*a*) the current in the field coils (which is proportional to the magnetic field), (*b*) the voltage applied to the injector gun, which was a very heavily damped oscillation produced by a peaking transformer, (*c*) the response from a Geiger-Muller counter placed in the X-ray beam, (*d*) the rectified envelope of the R.F. voltage across the resonator. The traces obtained with and without the R.F. voltage are shown in the photographs 1 and 2. The letters correspond to the wave forms listed above.



1, No R.F. (betatron); 2, with R.F. (synchrotron)

It will be seen that with the R.F. off there was only a single counter response at a phase of 30°. With the R.F. on, the expected counter response due to the synchrotron was obtained at 80° (showing 8 MeV.) as well as a response persisting at 30° showing that all the electrons were not caught. The synchrotron response could be moved about in phase by alteration of the R.F. pulse width, keeping its starting point constant.

The fact that a considerable proportion of the electrons were being accelerated to high energies was confirmed by placing an ionization chamber in the X-ray beam. The ionization produced was increased by a factor of 4 times on switching on the R.F. voltage. This is in agreement with an expected increase in conversion efficiency at the target for higher energies. If all the electrons could be accelerated to 8 MeV. the increase factor would probably be about six times[5].

The R.F. apparatus used was chosen for availability and ease of construction, and no attempt was made to remove many obvious deficiencies. The accelerating voltage was produced by a quarter-wave long resonator of the coaxial line type[6] excited at 640 Mc./s. by a small loop. The electrons passed up the hollow inner conductor of the resonator and were accelerated at the gap. The resonator could not be solid, or eddy currents would have disturbed the electron orbits. It was therefore constructed from 26 S.W.G. wires, 1/16 in. apart, mounted on distrene spacers. The wires were shorted together at the current antinode only. The whole was bent into a quadrant round the circumference of the 'doughnut' and was completely external to it. The R.F. field produced was markedly inhomogeneous, since only those wires which were of resonant length were strongly excited. In addition the field was reduced by the presence of the porcelain doughnut and its 'Aquadag' coating, and by the proximity of the magnet. These disadvantages were outweighed by the ease of construction of the resonator. The R.F. power was produced by a small C.W. oscillator, feeding a buffer amplifier which was modulated to give an R.F. pulse of variable length and phase, reaching its full value in 10 microsec. The mean power supplied was about one watt and the peak accelerating voltage across the resonator was appreciably less than 100 volts. It appeared that an increase in the power supplied would have increased the X-ray yield, as also would steepening the leading edge of the R.F. pulse.

The results we have so far obtained certainly indicate that the synchrotron is a powerful means of accelerating electrons, and show clearly its advantage over a betatron in giving much greater energy and X-ray yield without increase in magnet size.

This work was carried out as part of the programme of the Telecommunications Research Establishment of the Ministry of Supply. Acknowledgment is made to Mr. A. R. Greatbatch for facilities provided in his Department to use the betatron, and to the assistance given by our various colleagues at Telecommunications Research Establishment and the Armament Research Department. We also thank the Directorate of Atomic Energy for permission to publish these results.

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Space-diversity Reception and Fading of Short-wave Signals

IT is well known[1,2] that fading patterns of short-wave signals as received on two or more aerials spaced a few wave-lengths apart are independent of each other; and this fact has been utilized in space-diversity reception, where the outputs from separate receivers connected to such aerials are mixed together in order to obtain a fairly constant signal level. It is generally assumed, however, that the variations of intensity of signal on a single aerial are of random nature caused by scattered waves from diffracting centres in the ionosphere[3,4].

As a preliminary to the investigation of the various modes of diversity reception within a limited space, we have recently made a large number of visual[5] and automatic ink records of fading of short-wave signals received from All India Radio, Delhi, situated at a distance of 678·4 km. It has been observed that there are occasions when the nature of fading of the signals rapidly changes from random variations of peaky type to a smooth and quasi-periodic nature, often accompanied by slow changes of a few minutes. Observations have been made on 41, 31, 25, 19 and 16-metre bands, with vertically polarized waves, mostly during the day-time. The slow variations associated with the quasi-periodic nature of the fading suggest that purely random variation, agreeing with Rayleigh intensity distribution, may occur so long as the wave suffers single-spot reflexion in the ionosphere; but, as soon as the signal undergoes two or more reflexions, either from one

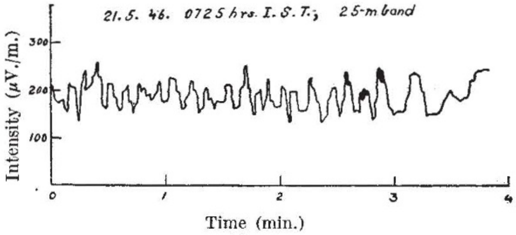

Fig. 1

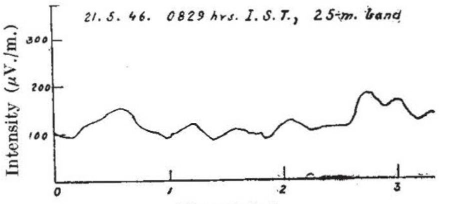

Fig. 2

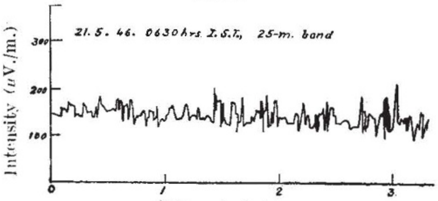

Fig. 3