EXPERIMENT ON EXCITATION OF POWER OSCILLATIONS ON METER WAVES IN A TOROIDAL CAVITY RESONATOR PLACED IN VACUUM

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INTRODUCTION

For a rational choice of accelerating voltage gradients in a proton linear accelerator it is necessary to have information on the electrical strength of accelerating gaps. Too careful choice of accelerating voltage gradients may lead to an unreasonable increase of both accelerator dimensions and the power supplied by high-frequency oscillators.

Since the mechanism of high frequency discharge in vacuum remains unstudied and the semi-empiric criterion of discharge [1] does not take into account the effect of electrode ageing, the results obtained under conditions comparatively similar to those found in linear accelerators may be of interest. The experimental device used a cylindrical toroidal resonant cavity with a 4 cm gap between the drift tubes. The cavity is excited by oscillations at a frequency of 99 megacycles running at 750 μs pulses.

The first attempt to obtain oscillations in the cavity failed because of discharges which took place at relatively small voltage amplitudes in its ring space as well as in the accelerating gap. In further experiments stable oscillations of more than 1.2 MV amplitude were obtained.

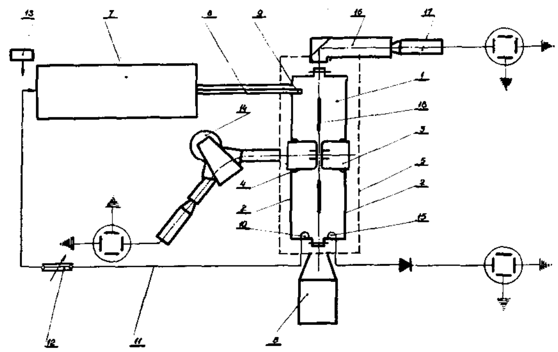

Fig. 1 Diagram of experimental device.

EXPERIMENTAL ARRANGEMENTS (Fig. 1)

1. The toroidal cavity (1) consists of two brass (copper covered) cups (2) 1 600 mm in diameter with 200 mm diameter drift half-tubes moving in clamping tubes (4). The cavity is placed in a steel vacuum-tight housing pumped out to a pressure of 2 to 3×10^{-6} mmHg by an oil diffusion VA—5 pump (6) with nitrogen and freon traps. Interelectrode gap d = 40 mm; cavity natural frequency $f = 99$ megacycles; quality $Q = 20\,000$; shunt resistance $R_s = 2\times10^6$ Ω.

2. A pulsed oscillator (7) of a maximum output power up to 1 MW [2], the three last stages of which used grounded-grid circuits, has a total power gain of the order of 10^6.

The oscillator feeds the cavity through a 40 Ω coaxial feeder (8) (2.2 m long) ending in a coupling loop (9). The oscillator was excited either by a master generator (13) or by connecting its input to a feedback circuit (11) of the cavity (self-oscillating conditions). In the last case a continuously variable line (12) provided suitable phase adjustment. Measures were taken to prevent parasitics of the oscillator.

3. Some specially built measurement devices—a β-spectrometer (14) and a measuring loop (15) to measure gap voltage etc.—were added to the standard measuring instruments.

LOW VOLTAGE DISCHARGES

a) Resonant high frequency discharge or multipactor effect [3,4] took place in the gap between half-tubes in the continuously operated cavity or, if pulsed, at more than 25 cps pulse repetition frequency. In this case the RF amplitude in the gap did not exceed 0.5—1.0 kV, which is in a good agreement with calculated data [3,5]. With a pulse repetition frequency decreased this type of discharge made no observable appearance and there was no difficulty in increasing voltage even when tube surfaces were specially covered with pump oil.

b) Serious obstacles to the excitation of power oscillations in the cavity were discharges appearing at 12-30 kV voltage amplitudes. The high frequency envelope had a sawtooth shape in this case and flashes of light corresponding to abrupt falls of the oscillations were registered by a photomultiplier (Fig. 2).

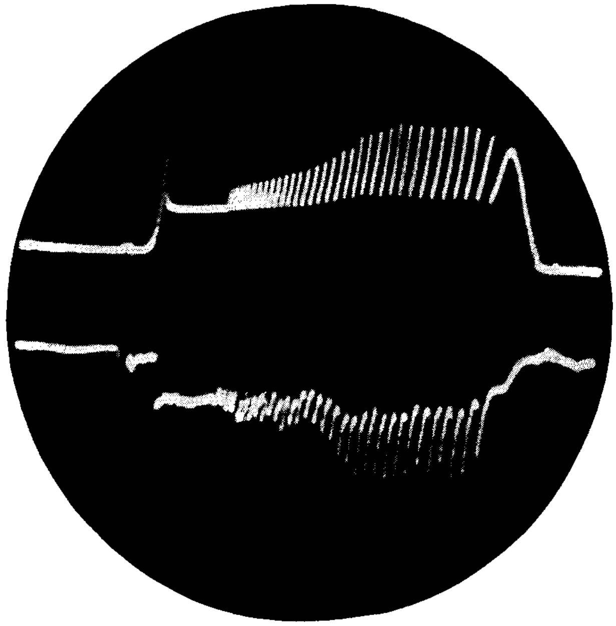

Fig. 2 High-frequency envelope (above) and light signal at low voltage discharge.

With pressure in the cavity increased, one could clearly see that the flashes took place over the whole ring space of the cavity (where the distance between face walls is 40 cm). The pressure increase was accompanied by a decrease of discharge voltage.

Measured results are given in the Table I.

At a 5-7 kV/μs rate of voltage rise corresponding to a 500-800 kV pulse amplitude, the oscillator being independently excited, discharges were not frequent. With a lower rate of voltage rise, discharges usually stopped normal oscillations.

With the oscillator input connected to the cavity feed back loop, discharges in the cavity appeared during the first part of a pulse (100-300 μs) followed usually by normal voltage build-up. In this case oscillations frequencies within the pulse changed by 100-200 kilocycles.

A wide flat ring insulated from the walls was placed coaxially in the symmetry plane of the cavity (Fig. 1, (18)) to suppress discharges. This done, the cavity natural frequency suffered practically no change. With a positive potential of approximately 4 kV fed to the ring, no low voltage discharges appeared, thus enabling stable operation at any amplitude up to 200 kV. With greater amplitudes, discharges occurred at the ring edge.

HIGH VOLTAGE DISCHARGES

Electrical strength of the accelerating gap was investigated at large voltage amplitudes, the ring (Fig. 1, (18)) having been removed. Immediately after beginning operation high, voltage discharges

TABLE I

Pressure (mm Hg)	3×10^{-6}	3×10^{-5}	3×10^{-4}	5×10^{-4}	1×10^{-3}	5×10^{-3}
Voltage amplitude (*) (kV)	12-30	12-30	12-16	9-14	4-14	1-5

(*)Minimum value of voltage corresponds to the amplitude at which a discharge appeared, while larger value of voltage corresponds to the highest attainable amplitude value.

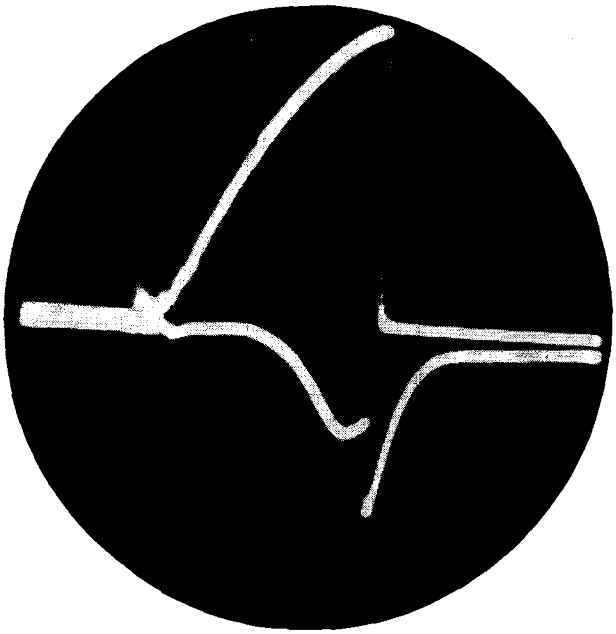

Fig. 3 High-frequency envelope (above) and light signal at high voltage discharge.

appeared usually at a voltage amplitude of 500-600 kV. The discharges were accompanied by very fast attenuation of oscillations in the cavity, the photomultiplier registered a flash of light (Fig. 3) and, when connected to a naphthalene crystal activated by anthracene, registered also a sharp increase of X-ray intensity (Fig. 4). After some time of operation, discharges became very rare and the voltage was increased by steps of 100-200 kV. Sparking almost disappeared after short ageing at each step.

The data gained at 1.300 kV and 6 cps pulse repetition frequency are given below as an example of ageing dynamics:

TABLE II

Time elapsed after beginning of ageing (min)	1	2	3	4	5	6
Number of discharges per 1 min	16	15	20	11	5	2

Several hours ageing would lead to stable discharges less operation. Thus, after 3 hours ageing at 1 000 kV, only one discharge per 3000 pulses appeared. Control tests during next days showed no discharges at this level.

In three series of experiments, copper or chromium covered half-tubes 200 mm in diameter with curvature radii of 3 or 16 mm were used. No essential influence of the variation of the curvature radius and of covering material on electrical strength within amplitude values up to 1.200-1.400 kV reached during the experiments was found. In this case the average field intensity was 300-350 kV/cm and maximum intensity at curvature surface 450-500 kV/cm which was 3 times higher than the values corresponding to the criterion [1]. Electrical fields measured by means of the loop, the β-spectrometer, as well as by absorption in aluminium of electrons accelerated across the gap differed by 10%.

It should be mentioned that an increase of pressure in the cavity up to 1×10^{-5} mm Hg was followed by no reduction of its electrical strength. X-ray intensity growing approximately proportionally to the 7th power of voltage at more than 1 MV, further increase of voltage was inexpedient.

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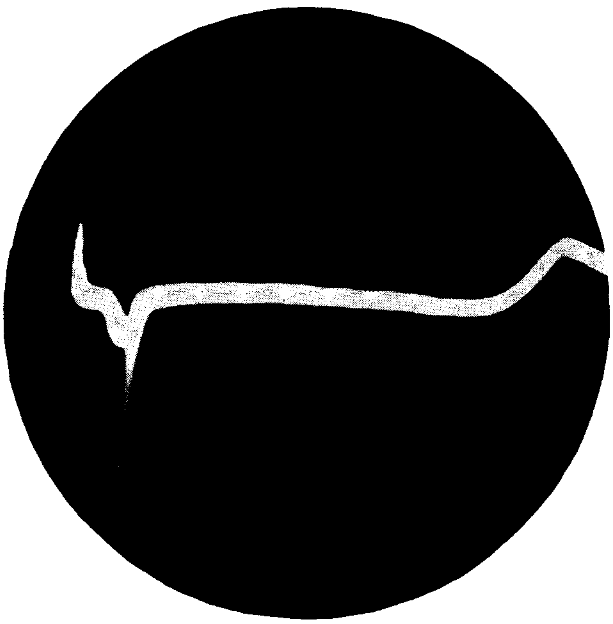

Fig. 4 Oscillogram of X-ray pulse during discharge.

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COHERENT FORCES IN A BUNCH OF RELATIVISTIC ELECTRONS

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Coherent radiation of electrons in a synchrotron was first considered by McMillan [1] and then by Schiff [2]. In these works as well as in other ones, they were interested mainly in the intensity and the spectra of coherent radiation.

A. M. Prokhorov [3] was the first who studied experimentally coherent radiation. In particular, he showed the possibility of the use of coherent radiation for diagnostics of the behaviour of accelerated electron bunches. This problem is also considered in another paper by the same authors [4].

Later on the interest in coherent radiation diminished, since in usual accelerators the intensity of coherent radiations is supressed because of the shielding effect of the chamber walls.

However, the coherent radiation is connected with the presence of the force of interaction between electrons, which changes sharply along the electron bunch, and in the first place it may break the phase stability of the bunch. This phenomenon is of great interest, mostly because it is closely connected with attempts to create a powerful storage system.

The calculation of interaction forces in a coherent radiating bunch of relativistic electrons in free space was firstly done by I. E. Tamm [5] for a particular case. Analogous results were obtained by S. M. Ritov [6].

In more general assumptions, calculation of the coherent interaction forces for a non-shielded bunch had been made by the authors [7]. Besides, the influence of these forces on the phase movement of electrons in a storage system has been considered [8].

This paper deals with the calculation of electron interaction forces and the power of coherent radiation for revolving relativistic bunches taking into account the shielding effect of the chamber walls. The effect of shielding is approximately taken into account, since it is assumed that the bunch moves between two perfectly conducting infinite planes. In a number of cases we restrict our considerations to one of the shielding planes only.

It follows from the performed calculation that the shielding diminishes the mean power of coherent interaction. However, near the ends of the bunch these forces remain very great and often exceed the

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(*) See note on reports, p. 696.