INITIAL TESTS OF A HIGH-GRADIENT 550 kV ACCELERATING TUBE WITH A DUOPLASMATRON EXPANDED PLASMA PROTON SOURCE

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(Presented by D. J. Warner)

The general trend in the last few years in the design of high current high brilliance preinjectors has crystallised towards the use of duoplasmatron sources combined with short accelerating columns. This approach facilitates the problems of space charge repulsion and aberrations but introduces new problems of matching the beam, from an ill defined plasma boundary of inconstant density to the column, and of HT breakdown in vacuum and in air and X-ray radiation.

Construction principles and preliminary results obtained with a reentrant accelerating structure are described in this paper (Fig. 1). Anode contains the DP source and the cathode the matching quadrupoles. Clearance between the two electrodes can be varied between 7.5 to 12.5 cm. Those two electrodes are carried by a 14 section porcelain column of classical construction, with external resistance potential dividers (two parallel chains 2600 $\mathrm{m}\Omega$ each). Porcelain rings are

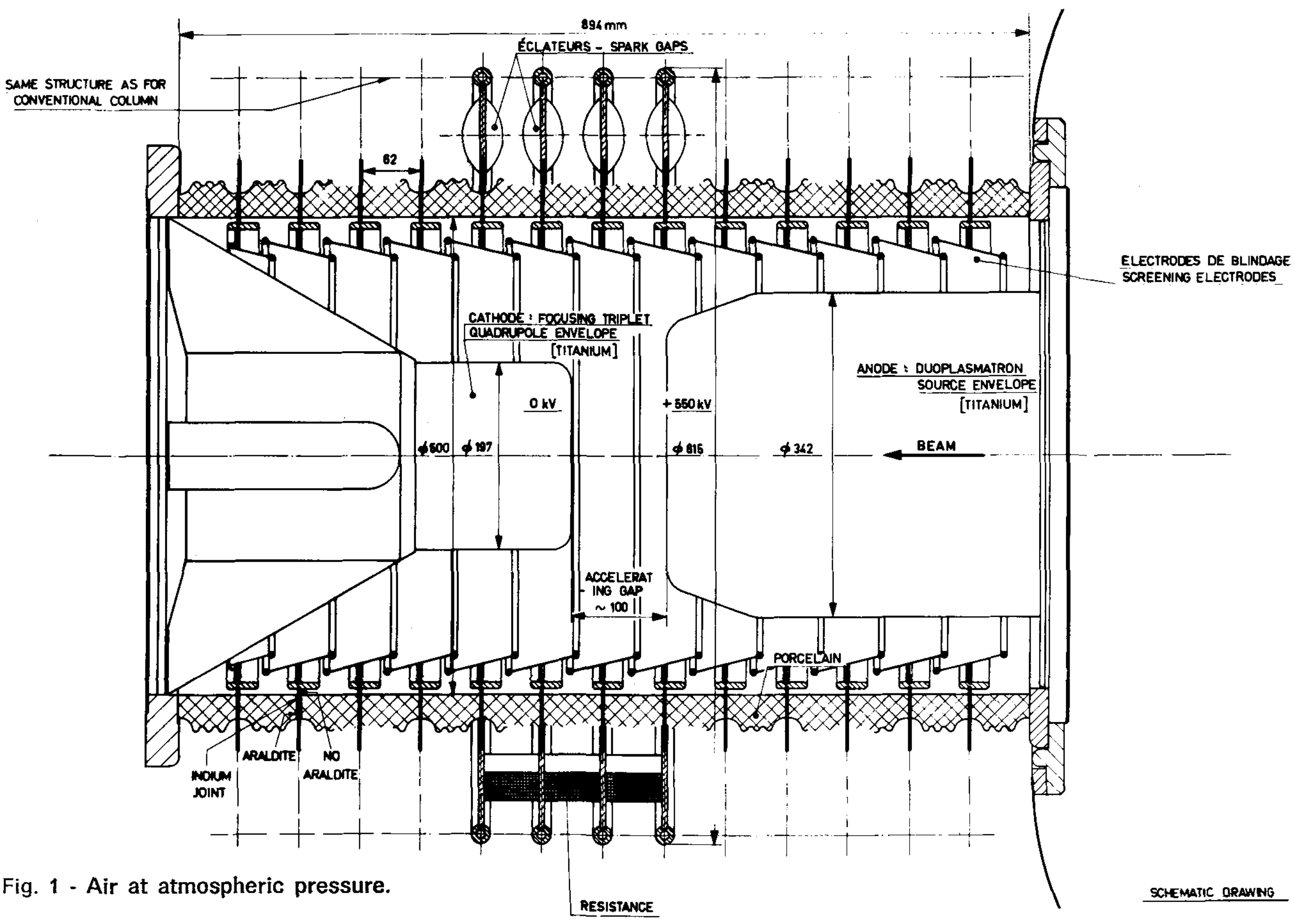


Fig. 1 - Air at atmospheric pressure.

protected from bombardment by shielding electrodes which were designed so that they

a) reduce the field at the porcellain/metal junction (particularly on the negative side eof each porcelain ring),

b) are of the form that the secondary electrons, which are created by the bombardment of exposed metal surface, cannot reach the nearby positive protection ring and so cause an eventual breakdown (Fig. 2) and,

c) present small impedance for pumping the porcelain region (1, 2).

Porcelain rings, stainless steel discs carrying anticorona rings and shielding electrodes were assembled by glueing with araldite. Special precautions were taken to prevent araldite entering the accelerating column, and the degassing of araldite was reduced by insertion of an indium ring (Fig. 3).

The choice of material for the reentrant electrodes and the porcelain protection has attracted special attention. After extensive research (Figs. 4, 5, 6) titanium was selected as the best material both for its excellent voltage holding capabilities and its extremely low electron currents, which give very low X-ray radiation level (3).

Ti, Va, Al and Ti, Al, Mn alloys were better than pure Ti from the points of view mentioned above, but they are more difficult to machine, to bend and to weld. A set of electrodes of pure Ti were fabricated and tested immediately, and a set of electrodes made of Ti alloy (Ti 30, Al 6, Va 4) is being manufactured and will be tested subsequently.

Tests on the column (but without the source and matching triplets) with a gap of 100 mm were performed. After forming for about two weeks 640 kV was reached. The breakdown rate was reasonable and electron current negligible. After a month's operation at 600 kV the tube was opened and inspected. The porcelain rings were intact. The cathode alone showed some pitting. After further conditioning which took three days, the breakdown rate was 1 ÷ 2 per day at 580 kV. Superconditioning of 50 kV made it

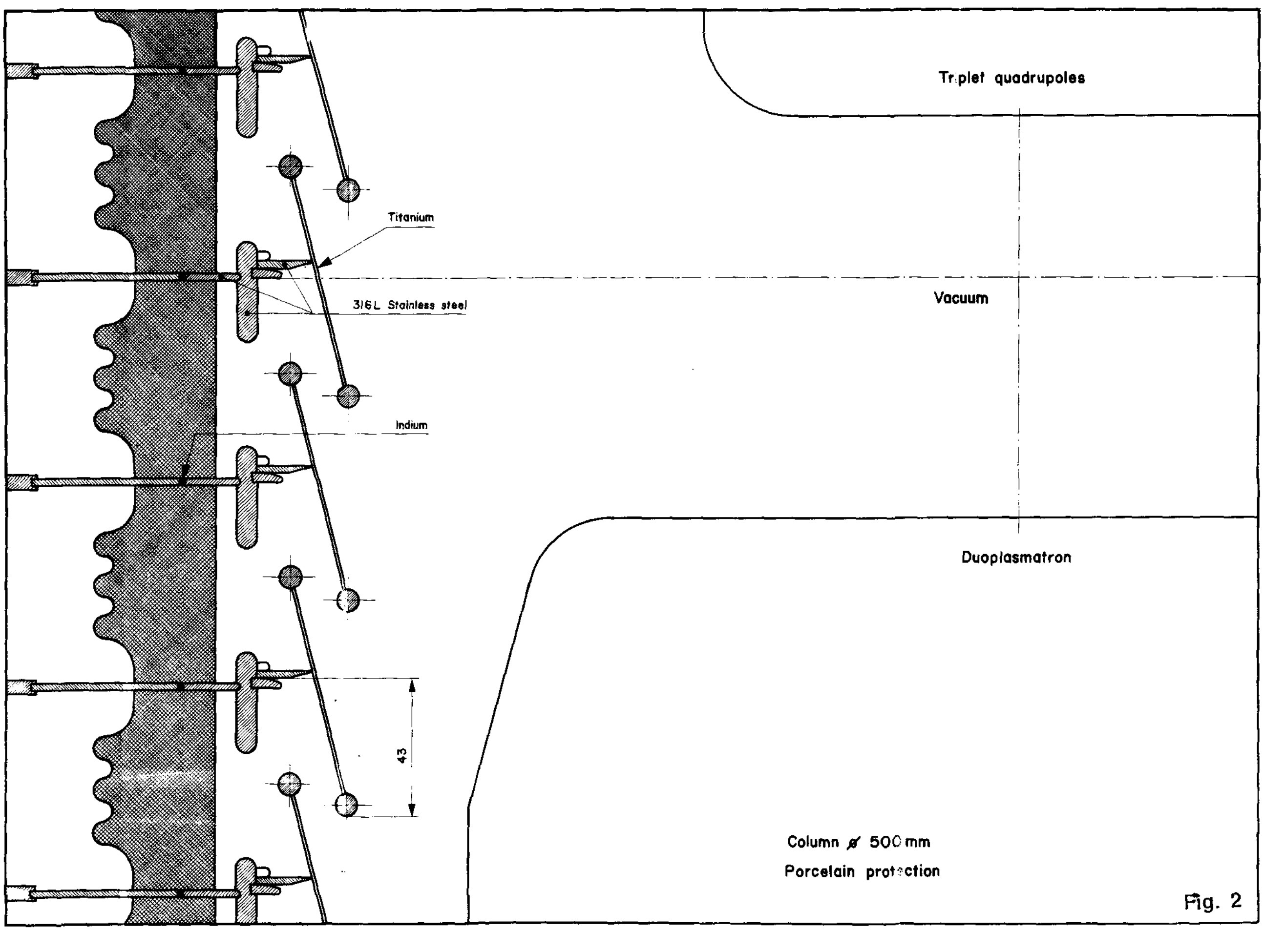


Fig. 2

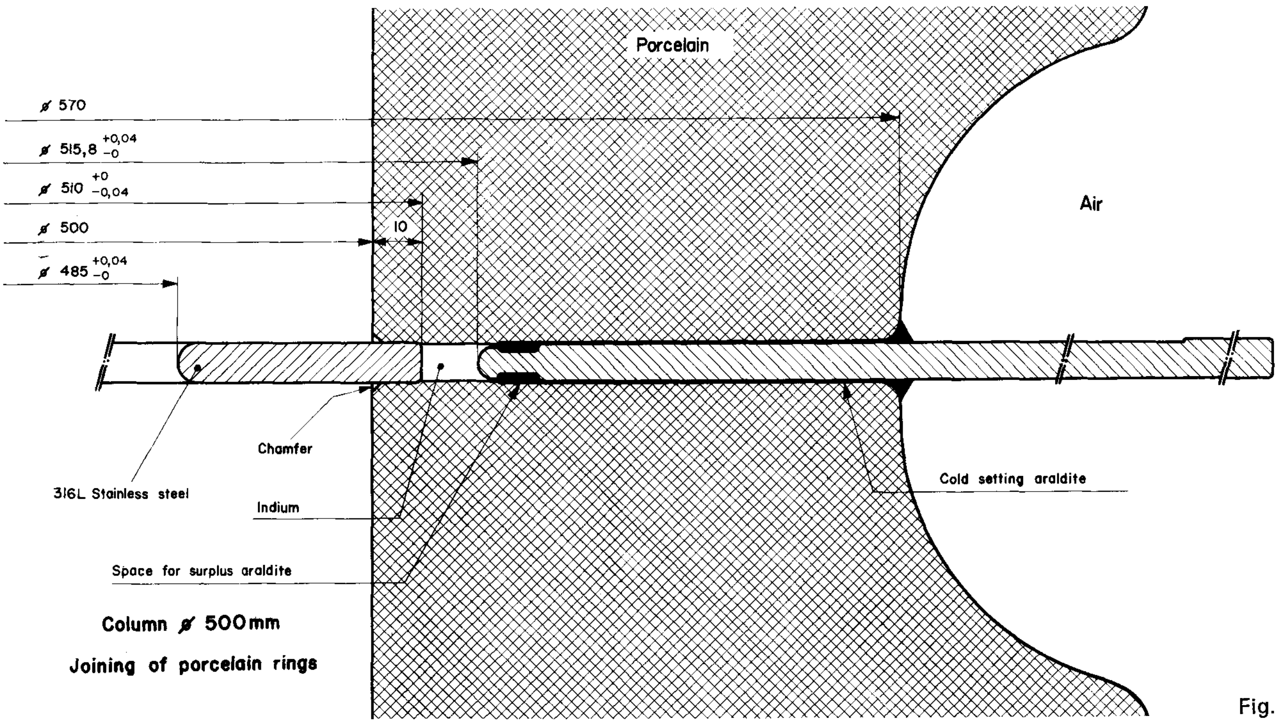
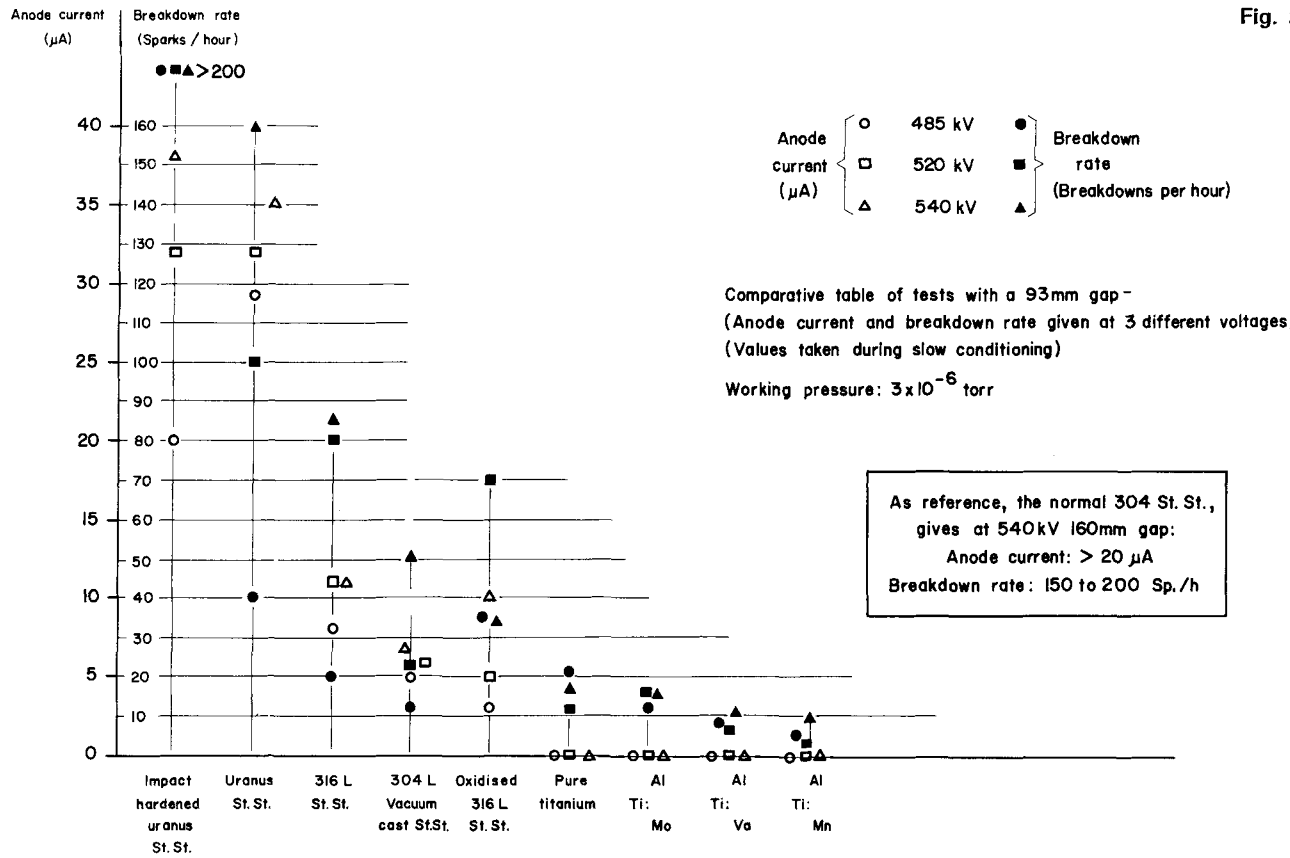


Fig. 3

Fig. 4 - Table of materials tested.

Name	Trade-Name	Maker	C	Ni	Cr	Si	Mn	S max.	P max.				Others	Micro-Hard. Vick. (100gr.)
Stainless Steel	URANUS 15-C	UGINE France	0,02	14-15,5	16,5-18	0,3	0,85	0,015	0,02					150
Stainless Steel (impact hardened)			"	"	"	"	"	"	"					470
Stainless Steel 316 L			0,03	10-14	16-18	1 max.	2 max.						2-3 Mo	
Stainless Steel 316 L (oxidised)			0,03	10-14	16-18	1 max.	2 max.						2-3 Mo	
Stainless Steel 304 L	ICN 472 Bc		0,03	11,5	18,5	1 max.	2 max.							
Stainless Steel 304 L (vacuum cast)	NS 22.5	UGINE France	0,022	9,93	18,87	0,340	1,34	0,012	0,014					
			Ti	Al	Mo	Mn	V	N_2 max.	H_2 max.	C max.	Fe max.	O_2 max.		
Titanium (pure)	UT 40	UGINE France	~99,5	—	—	—	—	0,06	0,0125	0,08	0,25	0,25		150 to 200
Allied Titanium		PECHINEY France	~89,5	6	—	—	4	—	—	—	—	—		~400
Allied Titanium		PECHINEY France	~91,5	4	—	4	—	—	—	—	—	—		~400
Allied Titanium		Reactiv Metal Inc. U.S.A.	~88,5	7	4	—	—	—	—	—	—	—		~400

Fig. 5



possible to run for over 24 hours with less than 10 breakdowns (Fig. 7).

Installation of the source and matching triplets impaired the voltage stand-off and increased the breakdown rate. The exact origins of this behaviour are not yet completely known, but indication of adverse effects of oil, welding flux, resin flux and PVC insulating sleeves on breakdown rate is clearly present.

After removing some of the sources of pollution mentioned above, conditions improved (550 kV at 85 mm electrode distance, breakdown rate: 5/hour, conditioning loss 15 kV/h, but they did not quite attain the values of the column without the source and quadrupoles. Full beam current (0.7 A) did not cause any breakdown unless the extraction voltage was adjusted so as to spray the downstream electrode. Above results refer to the laboratory set up.

When the column and the source were mounted in the Linac it was much more difficult to hold-off the voltage. The working voltage (540 kV) could only be maintained when the column was filled with helium $7 \cdot 10^{-5}$ mm. Probable reasons for this behaviour are: many greased joints in the column-Linac space, and also secondary electrons coming from the Linac. Fig. 8 shows the titanium electrode containing the source, and Fig. 9 shows the interior of the column with the protection rings and the grounded electrode containing the matching triplet.

DUOPLASMATRON SOURCE (4, 5, 6, 7)

The DP source is of the plasma expansion type. This type was adopted as it makes the voltage hold off easier between the extractor and the source, and also permits the shaping of the potential field in the region of extraction. It is known that the density of plasma escaping from the source is largest on the axis. A flat extraction electrode opposite the expansion chamber gives a field which is not intense enough on the axis to give a smooth plasma boundary. The boundary is convex in the central region, then concave or flat. The emittance of a beam coming from such a boundary is contorted and the brightness of the beam is low. By making the inside of the expansion chamber conical, Rose et al succeeded in over-coming this difficulty (4). In the CERN source a cone of 15° was used and gave satisfactory result as far as emittance was concerned. A small coil is fitted inside the expansion chamber for shaping of the plasma boundary. Extraction elec-

Fig. 6

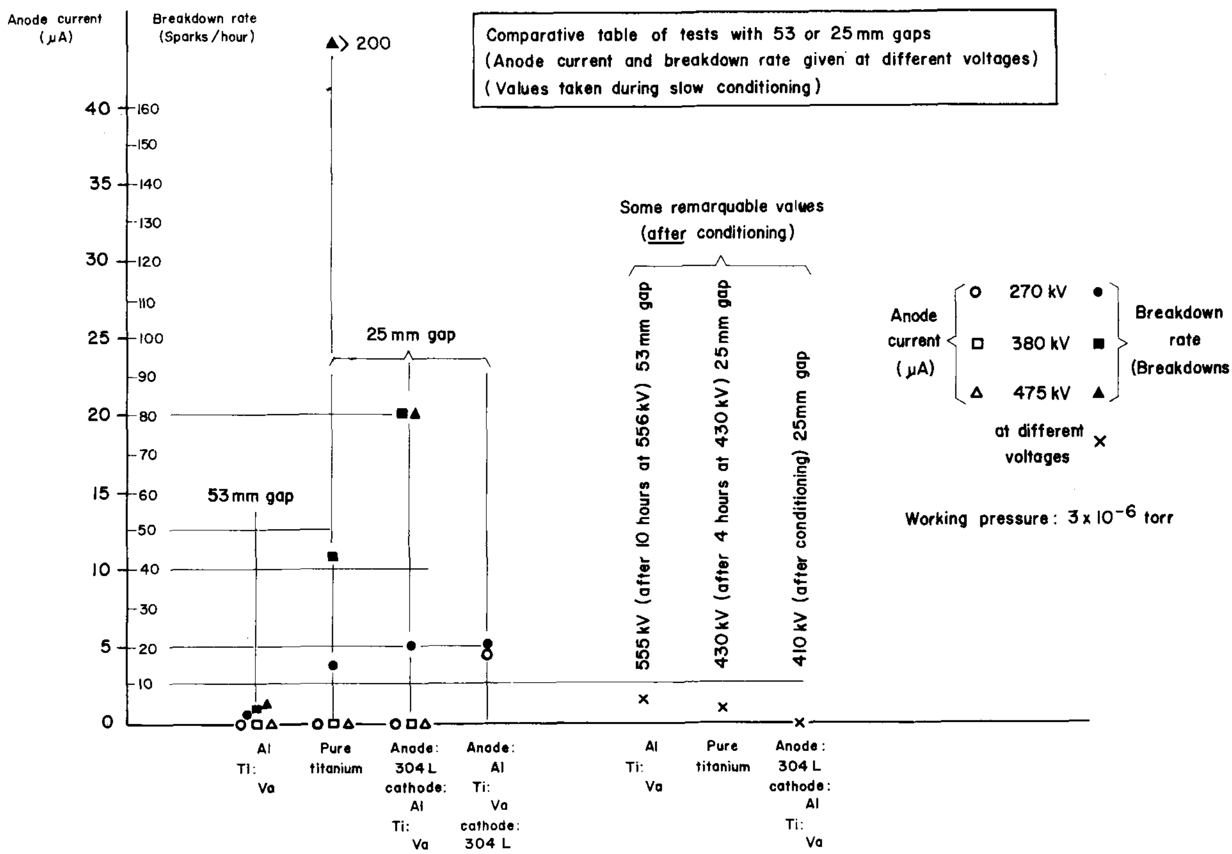
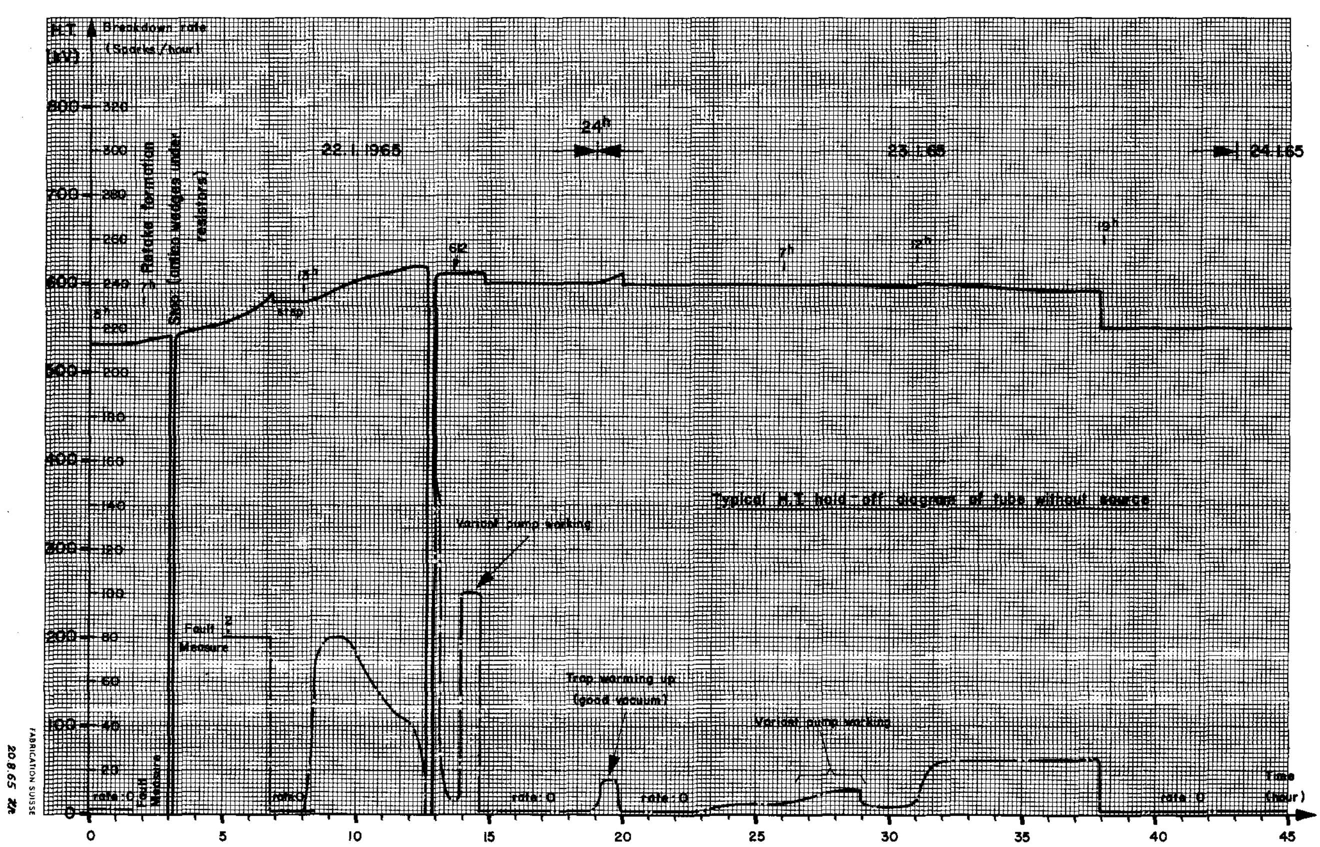


Fig. 7 - Typical H.T. hold-off diagram of tube without source.



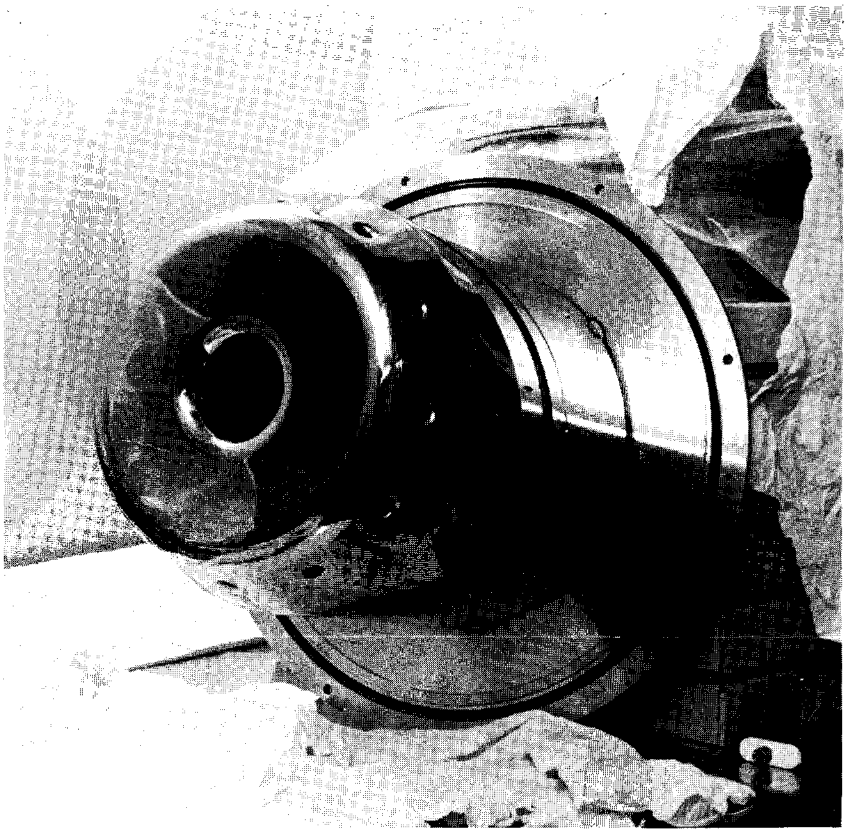
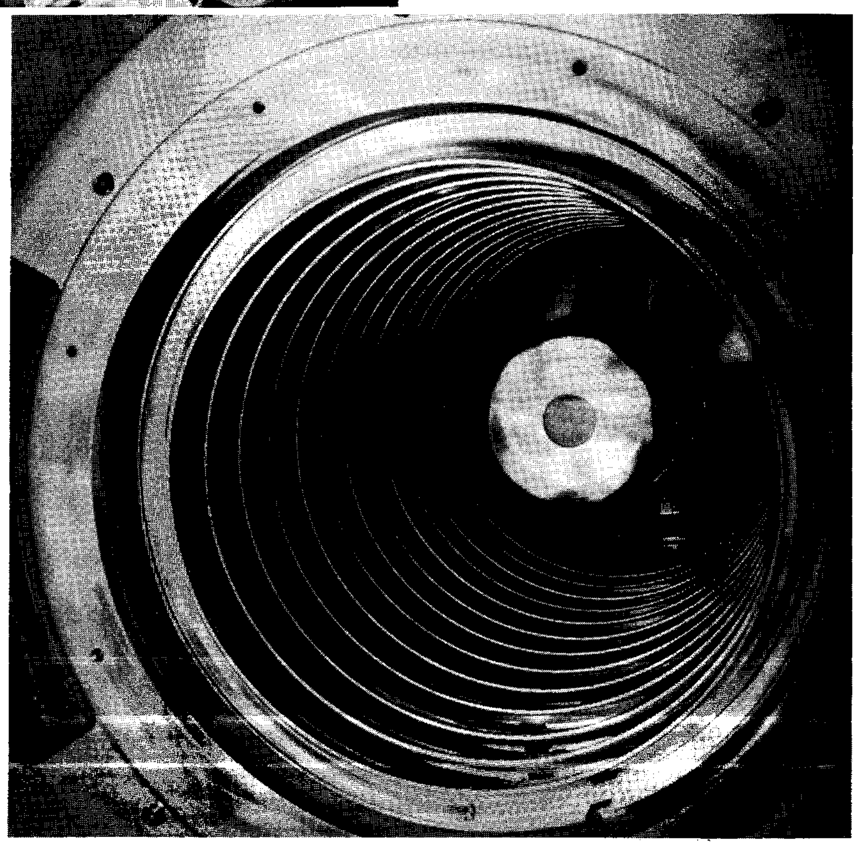


Fig. 8

Fig. 9



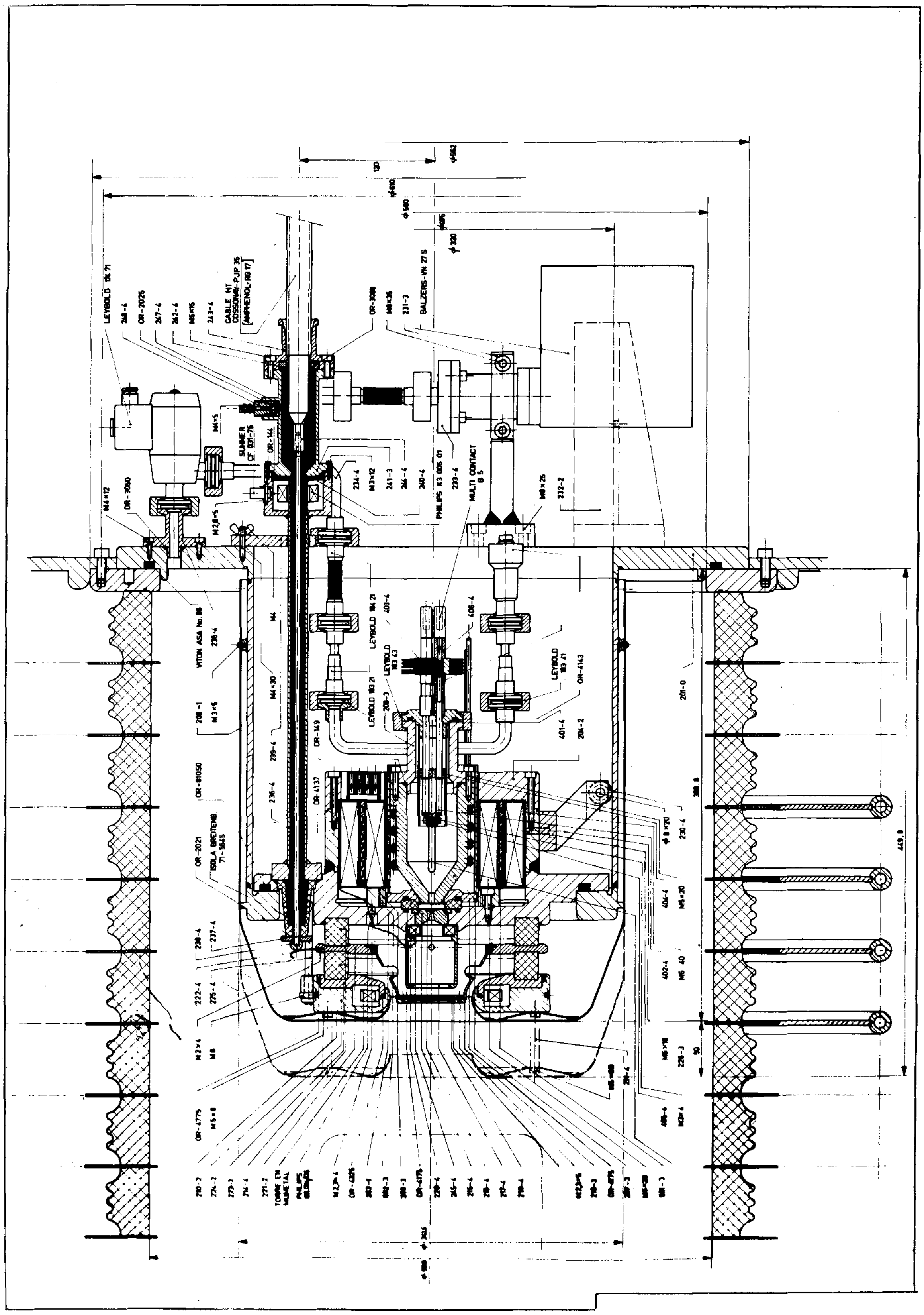


Fig. 10

trode was made of titanium with a flat grid made of molybdenum wire (0,1 mm ∅, 1 mm # mesh). Extraction voltage is produced by a hard valve pulser (pulse length 50 μs) which has a low internal impedance so that the voltage does not drop when beam arrives, and at the same time has a low stored energy (~ 1 Joule) in order to prevent excessive damage to the electrodes.

The pulser which supplies the arc current is hard tube, current stabilised. It can supply up to 1600 V at the beginning of the pulse to strike the arc quickly, and up to 80 A of arc current during 10-25 μs.

The cathode used in this source is made of nickel wire mesh painted with a paste (80% Ni, 10% $BaCO_3$, 10% $SrCO_3$ mixed with some amylacetate). This type of cathode can be exposed to air several times if one takes precaution to fill the source with dry N_2 before exposure. Cathode heating current was stabilised, but a temperature stabiliser would be preferable as variations in hydrogen pressure during tests, change the cathode temperature quite markedly. This will be done in the future.

The pieces of the DP which are parts of the magnetic circuit were made of Armco steel, others of stainless steel, and the anode of molybdenum. The intermediary electrode and the main magnetic coil are oil cooled, the heat being removed by an oil-air heat exchanger. Cathode is easily demountable to facilitate servicing and a new type of cathode holder with two cathodes is developed, to increase the time between servicing (Fig. 10).

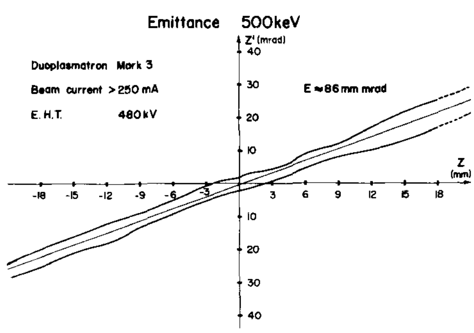


Fig. 11 - Emittance, 500 keV.

TESTS

Tests performed with the duoplasmatron and the short column have shown that a high current (> 700 mA) can be accelerated without breakdown of the column. For a particular set of parameters (I arc = 65 A, B ~ 0.5 T, U extr. = = 30 kV) a beam of > 250 mA was accelerated with an emittance (normalised) of 0.27 cm m rad (Fig. 11). The accelerated current at 10 MeV was only 55 mA. To explain this, the emittance was transformed back to the entrance of the quadrupoles and it was found that the beam had a neck there, so that proper matching to the Linac was impossible. By plotting of the electrostatic

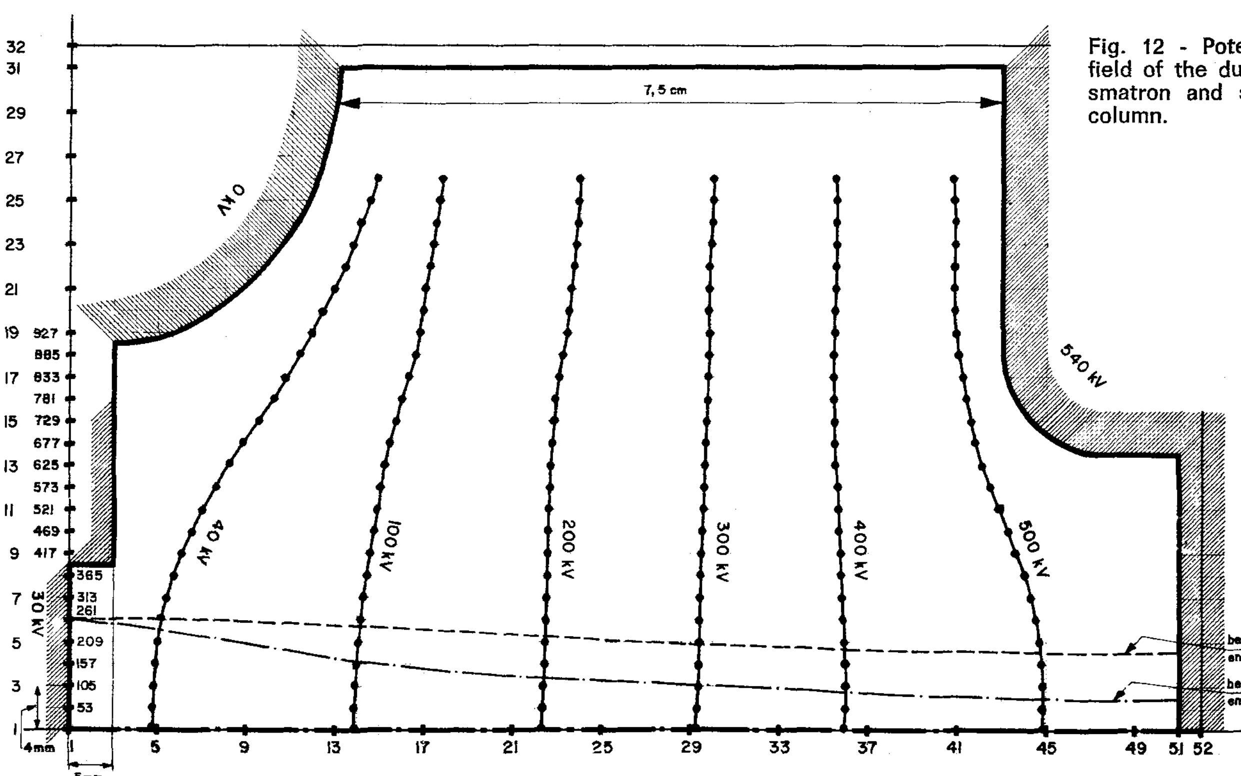
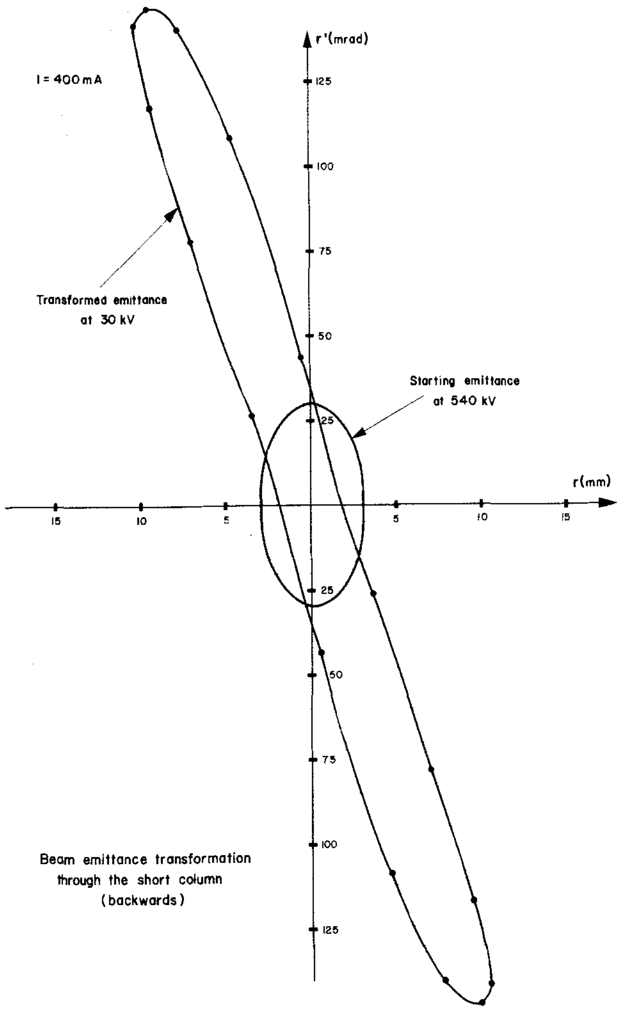


Fig. 12 - Potential field of the duoplasmatron and short column.



· Fig. 13

field in the column and transforming the beam back to the extraction grid it was found that the beam at this place is focused (Figs. 12 and 13). In order to match the beam to the Linac two solutions are possible: to displace the matching triplet downstream, or to decrease the convergence of the beam at the source by an appropriately shaped expansion chamber.

A further difficulty which was found was that the beam pulse had a peak in the beginning about

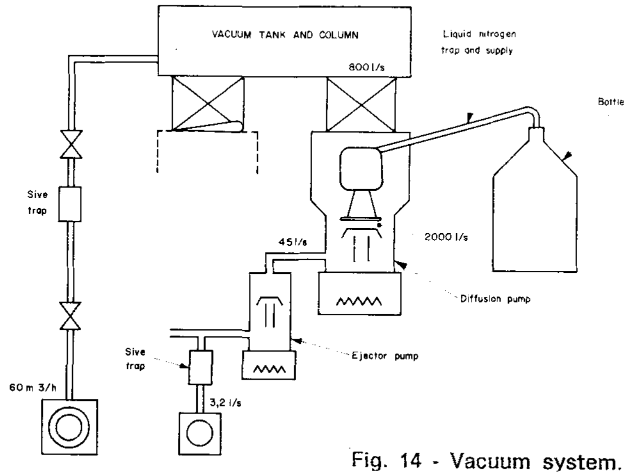


Fig. 14 - Vacuum system.

twice as big as the rest of the pulse. At the beginning of the experiments we thought they were sonic plasma oscillations (f ~ 100 ÷ 150 kHz) but when the beam pulse was made appreciably longer (25μs) this oscillation did not appear on the rest of the pulse. We still have not found the reason for this behaviour.

The voltage hold-off of the column was worse when it was mounted on the Linac, as already mentioned, and this we believe is due to many greased O-rings. The extreme cleanliness in manufacture, installation and cleaning is of utmost importance for reliable operation of a high gradient column. A clean vacuum, free from all organic oils dictated to us the use of mercury diffusion pumps (2 × 2000 l/s, after baffling 2 × 800 l/s) with liquid nitrogen cooled baffles. The filling of baffles is automatic, and governed by temperature sensing resistors. This system, after initial difficulties, has proved reliable (Fig. 14).

Acknowledgement

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Remark: A more detailed report will be issued in due course.

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AN APPROACH TO 200 MHz BUNCH MEASUREMENTS AND LIMITATIONS ON LONGITUDINAL PHASE PROBES

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A. AN APPROACH TO 200 MHz BUNCH MEASUREMENTS

The aim of this investigation was to find a simple direct way of studying the form of the output beam from a proton linac in the longitudinal phase plane. This type of work has been done previously by a time of flight method (1) which integrates information from about 2000 beam pulses i. e. requires a high repetition rate (50 pps) accelerator. Normally, for the Faraday cup method of beam monitoring the pick-up and display system bandwidth is < 5 MHz even on pulsed accelerators. To study individual proton bunches from a linac requires a bandwidth orders of magnitude greater. For example, the bunch length at 10 MeV is ≈ 35° (≈ 0.5 ns at 200 MHz) and the simplest shape will require up to the tenth harmonic of the accelerating frequency to give a good representation of the incident current pulse. The finer structure of two or more current peaks in the energy spectrum which arises from the non-linear nature of the acceleration process, has been observed (1), even when no prebunching was used. Thus there is probably useful information to be obtained up to 10 GHz (50th harmonic) for a 200 MHz accelerator. The apparatus was developed to solve some of the problems set by such a broad band system.

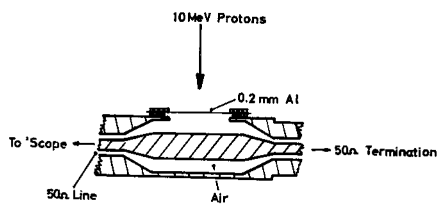

Fig. 1 - Section through beam monitor.

The design of the current monitor

Basically, protons are collected on the inner of constant impedance coaxial line terminated correctly at both sending and receiving ends. This monitor was installed at 10 MeV on the CERN linac, was made retractable and was compatible with the available low loss matched connectors and cables. These factors had most influence on the original geometry (Fig. 1). The

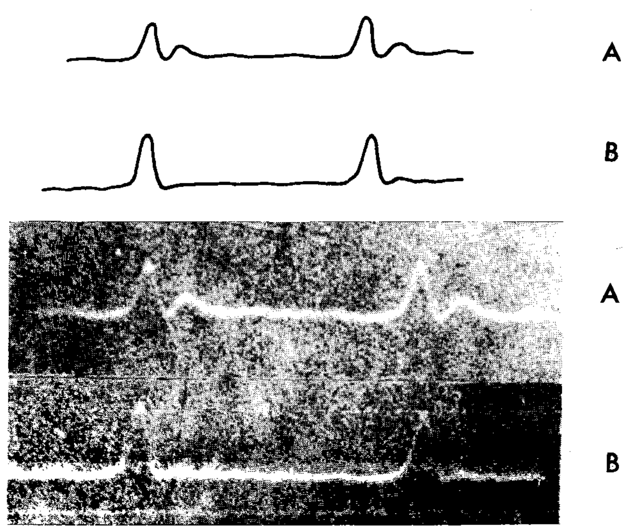

Fig. 2 - Recorded signals with vacuum (A) and air dielectric (B); 5 ns between main peaks.