THE NEW SATURNE INJECTOR
STATUS REPORT ON THE 750 keV PREINJECTOR

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This paper reports on the new 20 MeV linac 750 keV preinjector named "Amalthee".[1]

This preinjector provides a 100 mA proton pulsed beam at the linac entrance. The pulse duration is 200 µs and the beam emittance value at the output of the preinjector itself is, so far, 2.5 x 10^{-6} m-rad (normalized value).

First, the preinjector will be described. Then emittance measurements will be given and discussed.

Finally, a few words will be said about ion optics between Amalthée and linac.

1 - Preinjector

1.1. - Basic principles

From initial studies of the project, a pressurized structure was chosen. Indeed this technique is, for us, well-known and has many advantages:

The danger of flashover is effectively eliminated along the accelerating column for an average electrical field up to 20 kV/cm;

the structure is compact;

the high voltage generator leakage current is very low. Its magnitude order is one microampere.

Once the maximum electrical field had been selected the focusing system, matching the ion source beam to the accelerating tube entrance, was calculated.

It is a classical focusing system (see Figure 1) incorporating:

Extracting probes with a Pierce-like geometry;

an electrostatic lens;[2]

a 15 kV/cm gradient accelerating tube.

The preinjector has been built around this focusing setup.

Let us notice that whole compactness provides the possibility of using a liner to compensate for the voltage drop during the pulse duration.

1.2 - Description

1.2.1 - Pressurized tank

The tank diameter is 2 meters and the total length is 2.7 meters. Its volume is 7 cubic meters.

The maximum electrical field on the insulators is about 30 kV/cm. To avoid voltage breakdown, a dielectric strength of 180 kV/cm (i.e. 6 x 30 kV/cm)+ is necessary. We use a pressurized gas mixture: nitrogen (73%) and carbon dioxide (27%) and the pressure is 10 kg/cm^2.

1.2.2. - Accelerating column (Figure 2)

Since the electric strength of the Cockcroft-Walton generator is lower than that of the accelerating tube, the column is composed of two electrically insulated parts. This is possible owing to the focusing lens (5) that increases the distance between the terminal and the support flange. Inside one of these columns, is located the Cockcroft-Walton generator (9) and the shaft (11) transmitting power from the motor (12) to the alternator (10). Inside the other column is the ion source (6), the focusing lens (5) and the accelerating tube. The terminal electrode and the two columns are supported by "Makrolon" ++ tubes (14). Shielding rings divide the voltage along the column.

A liner, supported by insulators (15) surrounds the terminal electrode and an important part of the column.

1.2.3. - The Cockcroft-Walton 750 kV generator[3]

A dc current of 70 µA, is required by measuring resistor. The generator is made of 16 stages, its equivalent capacity (see Fig. 3) is 2.10 pF and its power is 300 W.

Each condenser, a ceramic cake of 8.5 cm diameter and 3.7 cm long, has a capacity of 3500 pF and can hold 130 kV.

+The flashover of a good insulator occurs for half the breakdown voltage in the gas itself (experimental data). For a spark on a gap, the voltage across the other gaps increases by a factor of 2. If we want a safety factor of 1.5 to take into account dispersion among insulators, we find 2 x 2 x 1.5 = 6.

++Makrolon is a polycarbonate manufactured by the Bayer Company.

Rectifiers are made of selenium. Each of them can stand a 64 kV inverse voltage and 10 mA direct current.

A 54 MΩ bleeder connects the high-voltage generator to the terminal and limits the rectifier current in case of sparking. It also acts as a 1000 Hz filter.

The Cockcroft-Walton is supplied by a 30 kV transformer fed from a 1000 Hz, 3 kW alternator.

The voltage ripple value measured on the high potential electrode (i.e. taking into account the 54 MΩ resistor) is 2.5 kV peak to peak. This fluctuation is slightly over the limit that the linac can accept. It comes from the rectifiers' stray capacitances.

1.2.4 - Liquid resistor (see Figure 4)

The measuring resistor is a teflon tube, divided by regular spaced electrical probes, and forms a closed circuit in which a liquid is circulated.

The liquid is an organic mixture, the components of which have very stable electrical properties, (the resistivity variations are less than 1% over a 500 hours period). The resistivity value is 2×10^{8} Ω-cm. The dielectric strength is much better than 40 kV/cm. The total resistor value is 100 MΩ.

The dividing electrodes are connected to the accelerating tube probes to distribute the voltage.

On the same circuit is located the high voltage measurement and regulation unit.

1.2.5. - Slow regulation

The purpose of the slow regulating system is to regulate high voltage from pulse to pulse.

One can see, in Figure 4, the regulation scheme.

The current intensity (i_1) is compared with the current intensity (i_2) delivered from a 20 kV generator across another branch of the liquid resistor. The cell geometry is such that if $i_1 = i_2$, the high voltage value is 750 kV.

If i_1 is different from i_2, an error signal reacts on the exciting current of the 1000 Hz ac generator supplying the Cockcroft-Walton generator.

As we use the same liquid to measure i_1 and i_2 we do not have to take into account the liquid resistivity value. The average liquid temperature is not exactly the same inside the two parts of the liquid resistor ($\Delta\theta^{o} \simeq 1^{o}$). But the liquid flow rate is constant enough to give no trouble.

1.2.6 - Fast regulation

The capacity value of the terminal with respect to ground is C_1 = 290 pF. If the pulse current of the ion beam is 100 mA during 210 μs, we get a voltage drop equal to 75 kV. To compensate for this voltage drop and for the 1 kHz ripple, we apply a correcting signal on the liner. For the moment the regulation is programed and the correcting signal is provided by an oscillating circuit. A fast regulation taking into account the instantaneous current variation will be set up in 1969.

1.2.7. - Accelerating tube (see Figure 5)

This accelerating tube is made of 15 elements, each consisting of:

one insulating ring made of ceramic material "Durelcer". Its outside diameter is 39 cm, inside diameter 34 cm and its thickness is 3 cm;

one stainless-steel probe riveted on a flange made of iron nickel alloy.

The components are glued with vinyl acetate.[4]

1.2.8. - Miscellaneous

- Shaft -

Electrical power inside terminal electrode is provided by a 400 Hz, 3 kVA alternator. This alternator supplies power to the ion source and high voltage focusing system supplies. The ac generator is driven by an insulating shaft activated by a motor. Two versions of this shaft exist. One is made of Makrolon and the other one is made of epoxy resin. These two versions work very well.

- Pumping system -

A mercury pump is used, the pumping speed of which is 1730 l/s for hydrogen at 10^{-4} torr. The ultimate pressure is better than 10^{-6} torr in the accelerating tube with the ion source off. The operating pressure is 8.10^{-6} torr with a hydrogen flow rate of 49 cm^3 atm/hour.

1.3. - Results

The terminal electrode itself (ion source, focusing system and accelerating tube not being setup) holds 1 MV without any sparking.

The accelerating tube has been tested at 750 kV (its operating voltage is 600 kV, the beam energy being 150 keV after focusing). The first time, we increased the voltage on the tube step-by-step over four hours. We controlled it by observation of the outgassing. Before each step, the vacuum was allowed to reach its limiting value.

Since January 1968, we have had a 100 mA ion beam and we have never had any sparking. Now, we are able to set up the voltage within 10 seconds. After 10 minutes, we have a 100 mA ion beam. This delay corresponds to the time necessary to heat up the palladium leak which regulates the hydrogen flow.

2 - Optical properties of the beam

2.1. - Short survey of the previous results

The focusing principles were pointed out at the Los Alamos Conference in 1966.[5] The results of a 100 mA, 350 kV accelerated beam were communicated. The accelerating tube of the test bench provided 200 kV acceleration after beam extraction and focusing.

The Amalthée accelerating tube provides a 600 kV acceleration. Figure 6 summarizes the two setups.

In 1966, we noticed disagreement between calculated voltages and experimental values when tuning the 350 kV accelerator. The explanation was the nonuniform beam density at the output of the ion source.

A uniform density is necessary if one assumes linear focusing forces along the transport system between ion source and the accelerator output. As the differences were unfavorable (high electrical field on probes), we tried to get a density as uniform as possible in the plasma expansion cup.

Another important argument was a brightness lost with respect to the previous results on low intensity beam.

In 1967, at the last International Conference on High Energy Accelerator in Boston, we reported beam optics and density distribution improvement at the exit of the source by insulating the walls of the cup with sprayed alumina.[6]

A test on the 350 kV setup gave us the confirmation that this method made the tuning voltages agree with the calculated ones and increased beam brightness.

However, we shall see that the results we get on the Amalthée beam are not as satisfactory.

2.2. - Optical properties of the Amalthée beam

2.2.1. - Experimental setup

One can see, in Figure 7, the emittance measuring setup. It is included inside the focusing system transporting the beam from Amalthée to the linac and can be used permanently.

An insulated biased target, used to measure the beam intensity, contains a set of 0.2 mm diameter sampling holes. Its location is 85 cm from the waist of the beam. The pencil beams are analyzed by a wire moving perpendicularly to the line of holes, one meter further downstream.

2.2.2. - Ion source beam measurements

Before installing the source on Amalthée, we tested it on a 25 kV test bench.

The expansion cup had an alumina deposit (see Figure 8).

Figure 9 shows a recording of the density distribution and the emittance, we deduce from it.

The emittance value is 1.2 10^{-6} m-rad (normalized value) and one can see that the density is not perfectly uniform. We had better results previously, with respect to the density distribution, but some difficulties appeared when we wanted to duplicate the ion source. Fasolo[7] noticed that magnetic parameters are somewhat unknown. We continue to experiment in order to understand phenomena inside the plasma expansion cup. It seems that the influence of the wall surface conditions should be studied.

2.2.3. - 750 kV measurements

In Figure 10, one can see wire recordings and emittance patterns for 68 and 104 mA beams.

We notice that:

1) Experimental focusing voltage values agree with calculated ones.

2) The extracting voltage is slightly higher than Pierce's theory predicts: 52 kV instead of 44.5 kV (Pierce's value). However, if one compares this with the 1966 results one can see that the difference is now 7.5 kV instead of 30 kV.

We can conclude that the density improvement is a good criterion for optimizing extraction and focusing voltage values.

3) For a 104 mA beam intensity, the emittance pattern shows aberration effects. The area is 1.2 10^{-6} m-rad (normalized value). But the apparent envelope is 2.5 10^{-6} m-rad.

These aberrations and the effects of 2) can be the consequence of the nonuniformity of the plasma density at the source output. These space-charge aberrations added to lens aberrations deteriorate beam quality.

3 - Ion Optics system between Amalthée and Linac

3.1. - Description

In Figure 7 one can see that two triplets are used to transport and focus the beam at the linac entrance.

We will not give details but only the principles that have directed the realization of the transport system:

1) The intervals, separating the triplets located between Amalthée and the linac provide possibility of installing beam monitors and pumping system.

2) To align the beam, we move Amalthée to make the

beam-line coincident with centered targets.

These targets are defined with an accuracy equal to 1/10 mm. This insures beam position stability when a triplet's focal length is varied.

3) Triplets have been calculated taking into account third order aberrations, due to leaking field of the quadrupoles, and space charge.

3.2 - Results

During transport from preinjector to linac, the beam loss is less than 5%, at a beam intensity of 100 mA and the coil current of the quadrupoles are the calculated ones within a 2 or 3% error.

4 - Conclusion

Amalthée provides the calculated beam intensity and the transport system is able to focus this beam at the linac input without loss.

Beam optical properties, although sufficiently good for first experiments on the linac, have to be improved in order to understand plasma expansion phenomena, and to have an aberration-free beam for making measurements on the linac transport properties.

References

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2. J. Faure, "Focalization dans le préinjecteur 750 kV Amalthée" - (GES. 64/26 - Pre-I. 01)

3. P. Bernard, "Projet de générateur cascade pour le préinjecteur" - (SEFS TD 64/4)

4. P. Bernard, "Technologie d'assemblage d'un tube accélerateur - Procedé de collage metal-ceramique à l'acétate de vinyl" (SEFS - TD 66/56)

5. P. Bernard, J. Faure, R. Vienet, "A 100 mA Ion Beam with a Large Brightness" - 1966 Linear Accelerator Conference (Los Alamos) Page 395, Proceedings of the 1966 Linear Accelerator Conference, Los Alamos.

6. P. Bernard et al., "New 20 MeV Saturne Injector Studies on Ion Sources and Particles Bunching" Page A-8, Proceedings of the Sixth International Conference on High Energy Accelerators 1967, Cambridge, Mass.

7. J. Fasolo, "A proposal for a Study of Plasma Boundary and Beam Formation in a New Class of Ion Sources" ANL Accel. Div. Int. Rpt. JF-1, 1967.

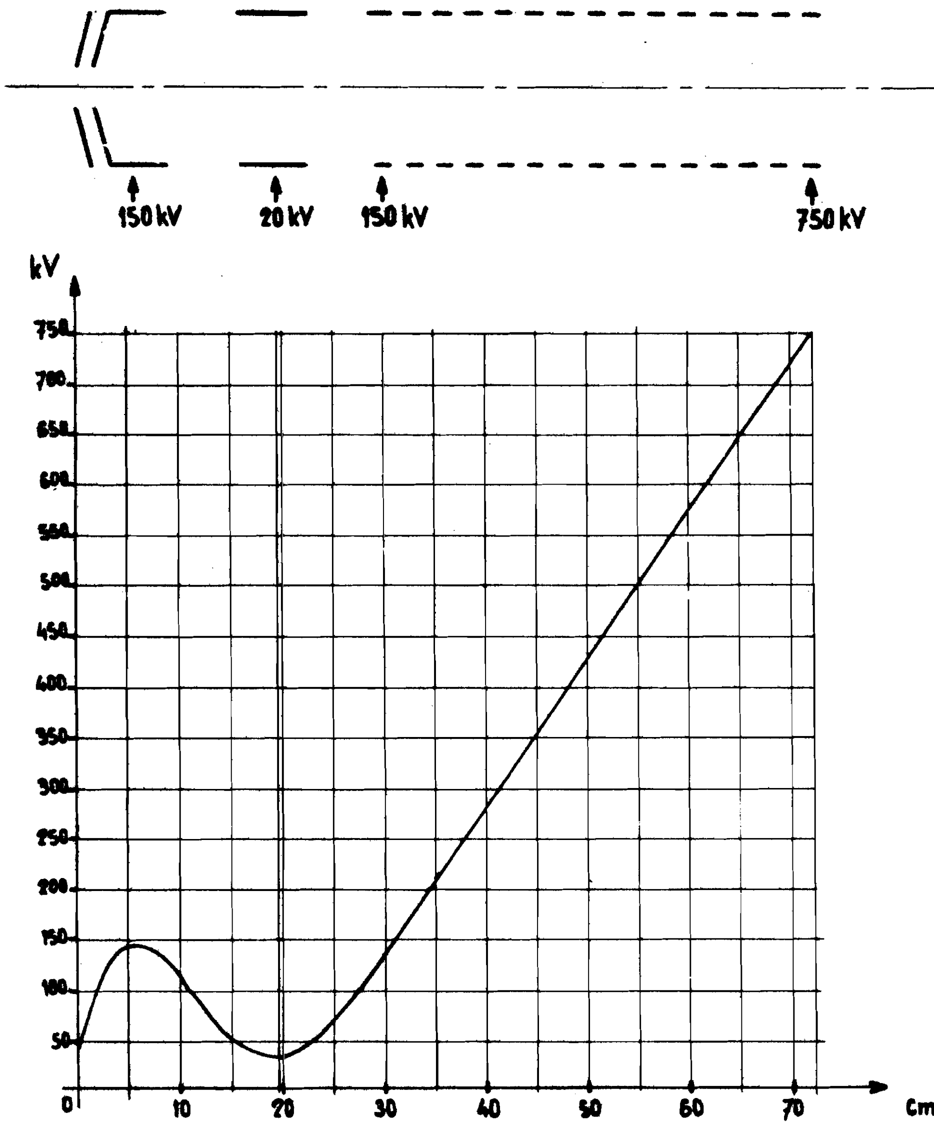

Fig. 1 - Beam extracting, focusing and accelerating system.

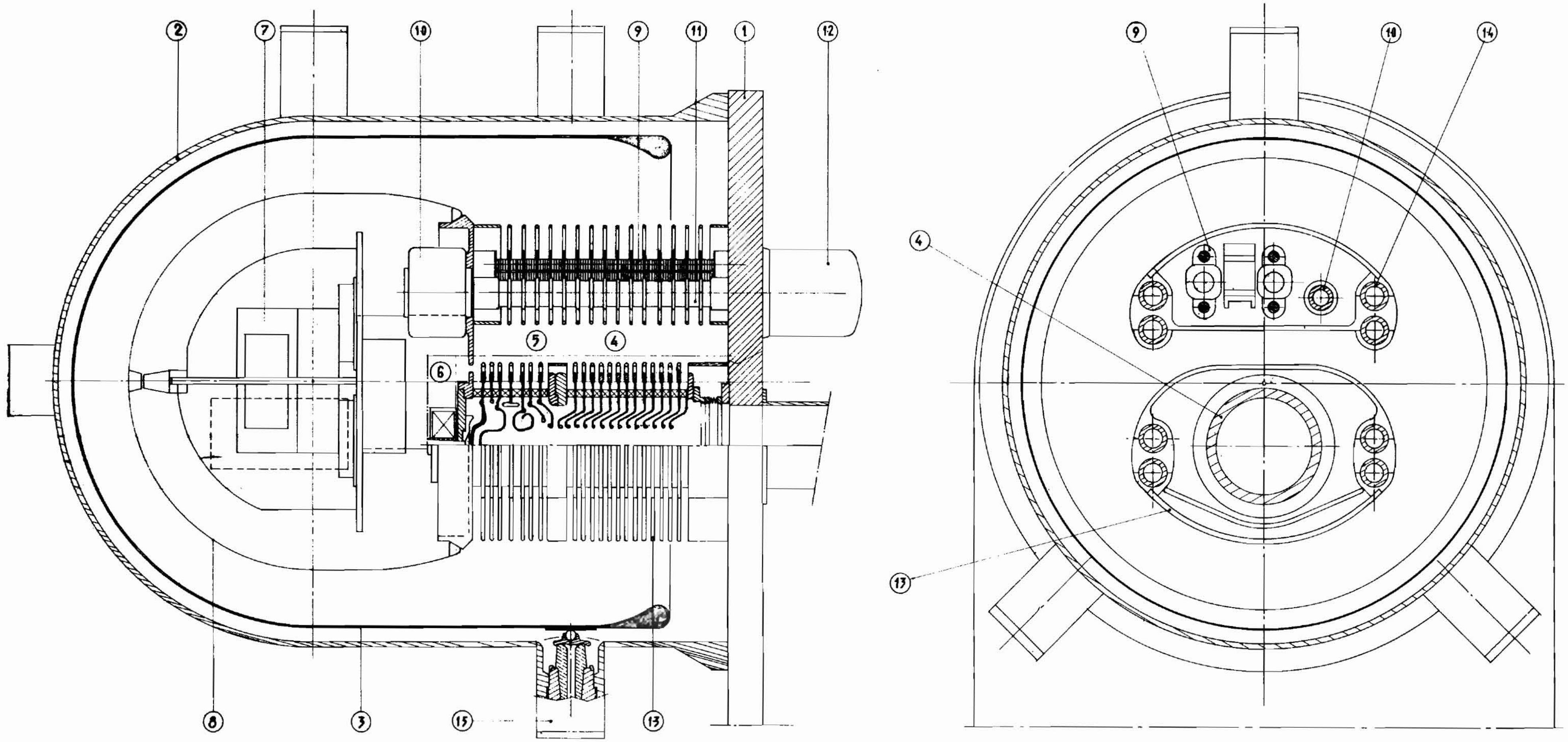

Fig. 2 - AMALTHEE - the preinjector.

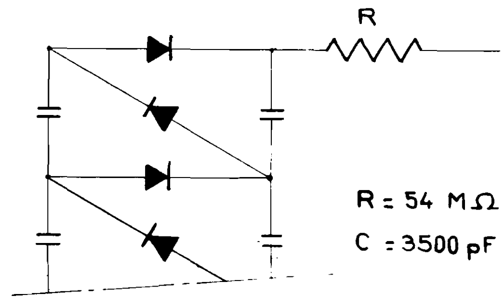

Fig. 3 - Cockcroft-Walton scheme.

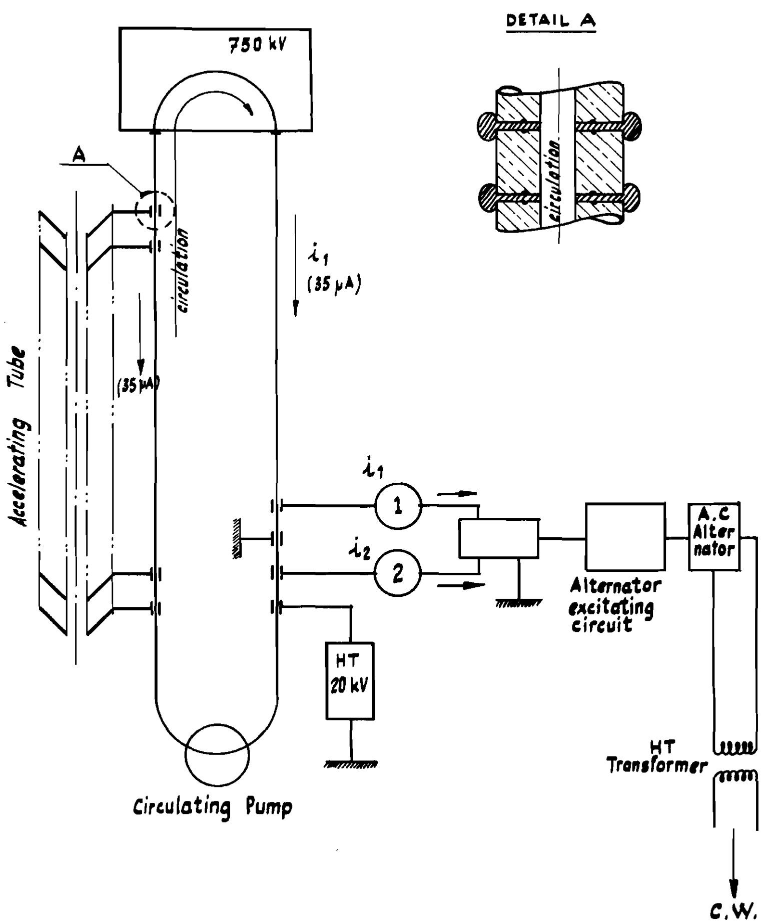

Fig. 4.- High voltage slow regulation scheme.

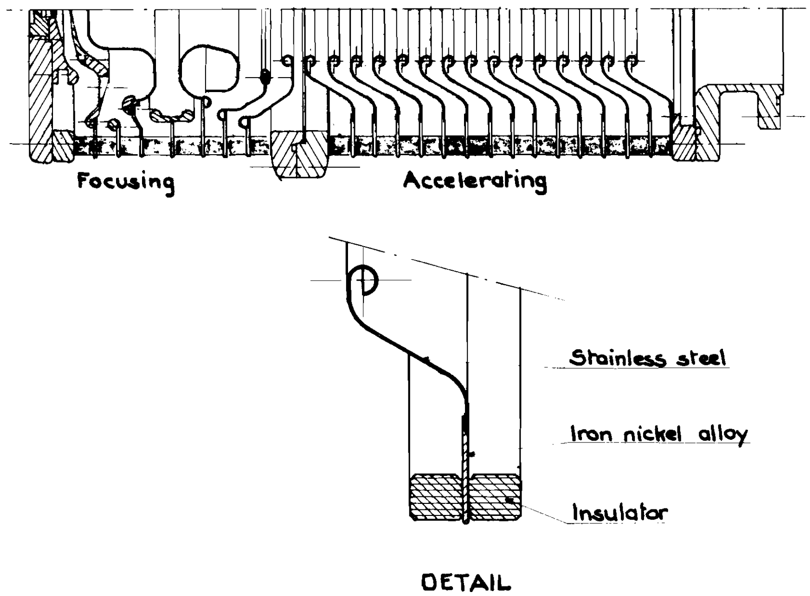

Fig. 5 - Accelerating tube.

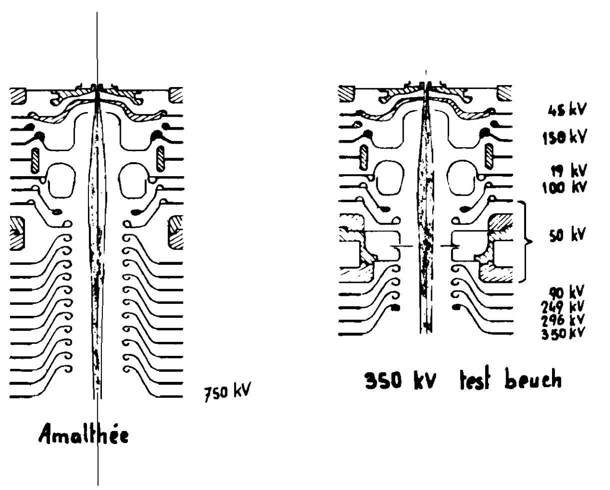

Fig. 6 - Accelerating tube of Amalthee and 350 kV test bench.

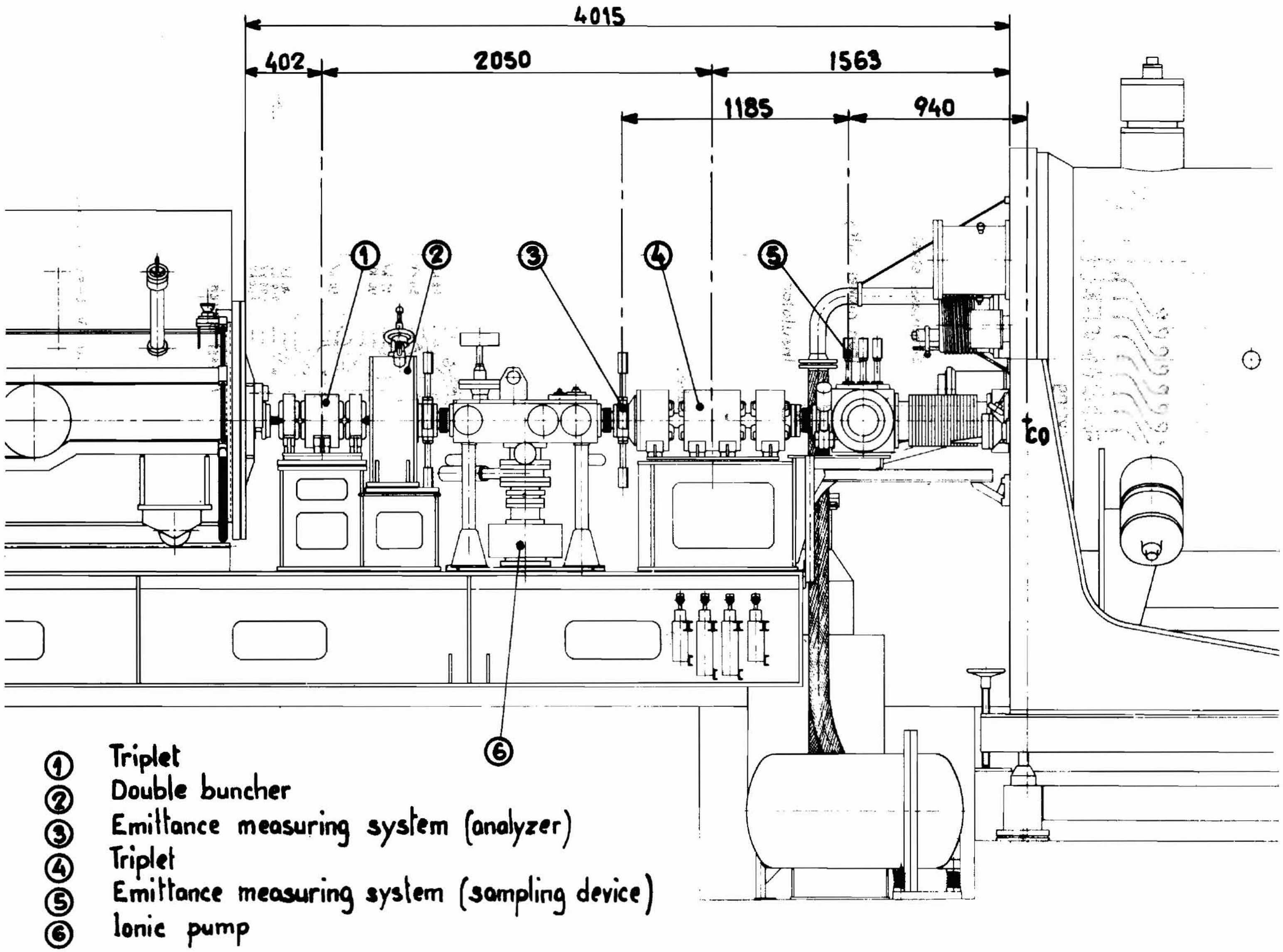

Fig. 7 - Ion optics system Amalthee and the linac.

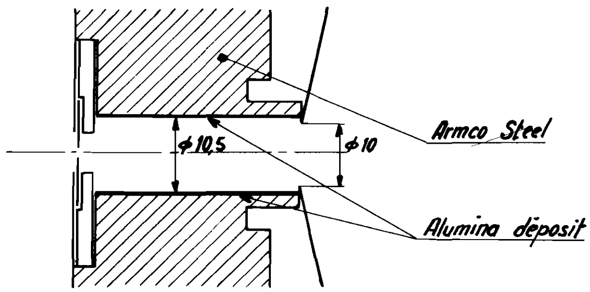

Fig. 8 - Insulated plasma expansion cap.

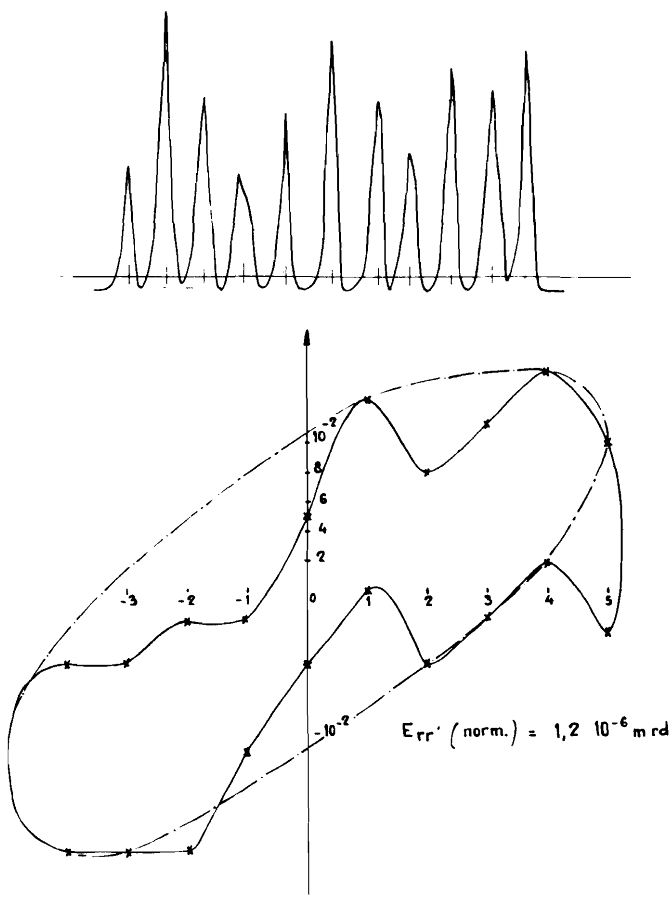

Fig. 9 - Emittance and density measurements at 25 kV.

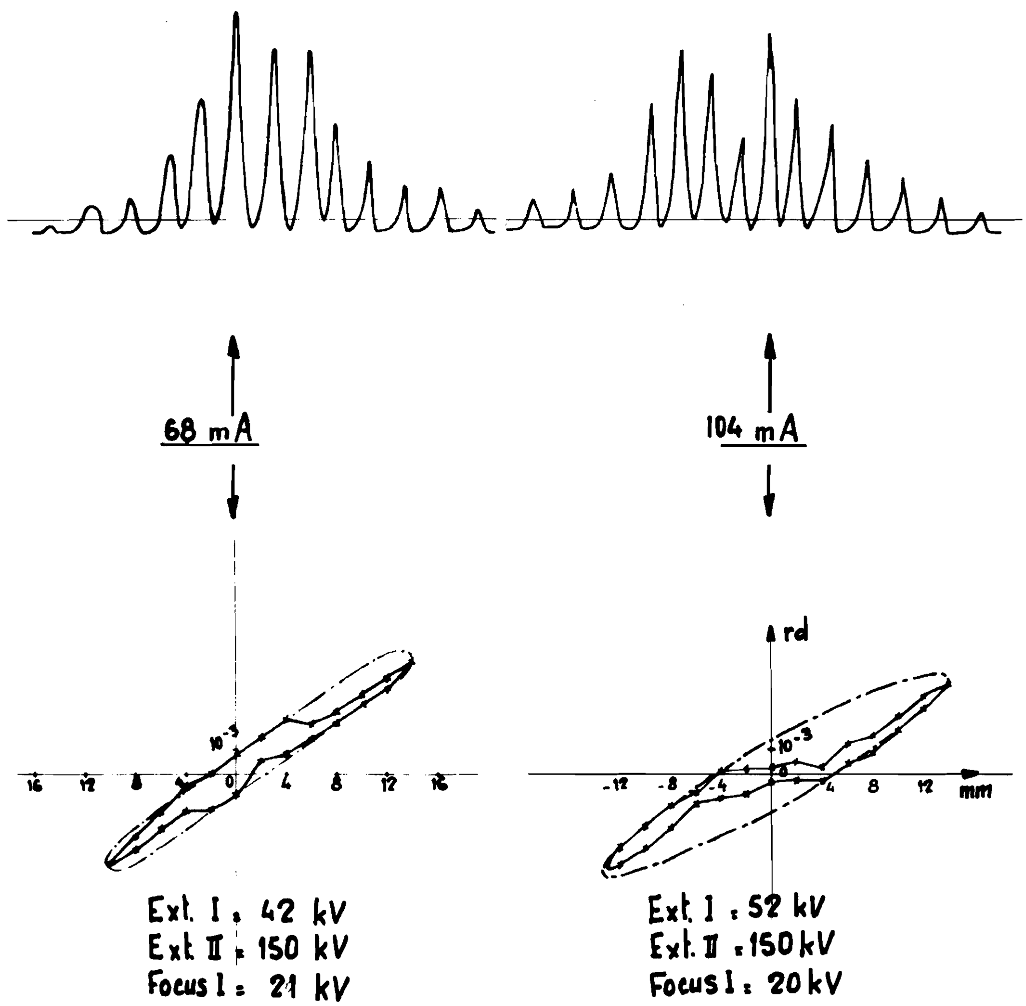

Fig. 10 - Emittance and density measurements at 750 kV.