A 3 MeV EXPERIMENTAL PROTON LINAC :
DESIGN, CONSTRUCTION AND PROPOSED EXPERIMENTS

E. Boltezar, H.F. Malthouse and D.J. Warner

European Organization for Nuclear Research
Geneva, Switzerland

Introduction

During the next five years as the CERN PS improvement programme [1] and the construction of the Intersecting Storage Rings near completion, the 50 MeV linac injector will certainly need to produce an improved proton beam with :

a) More accelerated protons per main machine pulse which would come mainly from an increase in beam pulse length (from 10 μs to 50-100 μs).

b) A more predictable and hence it is hoped a better beam quality, i.e. reduced emittance

In concept, (a) is straightforward though it needs much design effort. Concerning (b), the 50MeV linac can produce the beam quality originally specified for the future 800 MeV booster synchrotron but a factor two reduction in emittance would be welcome. Also much experimental evidence indicates that we are approaching a limiting current either before or in the early part of the linac [2] and this makes the setting-up of the proton beam difficult and critical. To control and predict the beam quality one thus requires a better knowledge of beam behaviour under high current density conditions. This knowledge can come only from thorough experimental and theoretical studies which, in turn, could lead to improved acceleration geometry and also to new pre-injection bunching and matching schemes. However the detailed practical work required could not be done on the PS linac without causing unacceptable interference with the High Energy Physics programme.

Thus one is led to consider a low energy experimental linac as a research facility leading eventually to an improved linac design.

Choice of Accelerating Structure

An experimental linac with a structure from 0.5 to 3 MeV based directly on the drift tube geometry of the present 10 MeV section and using the present quadrupole focusing magnet design (with the exception of the first three magnets) is being built. It was considered when choosing this structure that the time, effort and money required to produce a completely new and better RF and focusing system designs, are not justified when there are so many experimental possibilities with the original design. Among these possibilities is the quantitative evaluation of the supposed limitations or weaknesses in the present linac (e.g. inadequate prebunching and matching, short non-linear quadrupoles, radial and longitudinal position errors of drift tubes, dirty vacuum, low transit time factors) with respect to their perturbing effect on the linac performance. Also the compatibility in design allows some types of improvements verified on the 3 MeV model, e.g. in the 0.5 MeV matching to be applied directly to the present injector linac.

Thus with this 3 MeV accelerator one wants to study experimentally why one obtains the present beam quality from the 50 MeV injector linac. Meanwhile theoretical work continuing at CERN and elsewhere on such topics as beam dynamics with space charge and compensated RF structures can perhaps be tested up to 3 MeV and modifications shown to affect the RF structure, eventually incorporated into future designs.

Some General Features of the Project

A proton linear accelerator is much more than the accelerating structure alone so one must acknowledge that the project would not have commenced without the availability of the experimental pre-injector (a short column [3] and duoplasmatron source [4] identical with the 50 MeV linac pre-injector) and the experimental RF drive chain which has been used for full power testing of the French Thomson-Houston (FTH) high power amplifiers. In its initial form then this accelerator will consist of

a) Systems which are available in their entirety : the pre-injector and the RF power supplies,

b) Systems using spare PS linac components or designs based directly on existing components : the low energy matching and bunching at 0.53MeV, the 3 MeV transport and experimental region, the overall control system, the drift tube quadrupoles and their power supplies, the pre-injector support stand,

c) Systems where new concepts have been developed : the mechanical design and fabrication methods for the complete RF structure, and the vacuum system.

The choice of 3 MeV for output energy is not critical but is a fair compromise which leads to a linac long enough at normal operating RF levels for the radial and longitudinal acceptances to be defined, yet short enough for beam memory between input and output to be important i.e. with $\varphi_s = 30^o$ and q = 0.75 for the + + - - focusing, one can show (linear approximation) that there are ~ 1.3 phase oscillations and ~ 1.0 radial oscillation in the 3 MeV accelerator. Also of practical operational importance is the fact that for the common linac structural materials, copper, iron, chromium and nickel, the cross-sections for neutron production at 3 MeV are either zero or very small (<1/20th that at 10 MeV) so that with a correctly chosen beam stopper material (e.g. Aluminium) the radiation hazards when protons are being accelerated, should be tolerable.

The input energy, 0.53 MeV is dictated by the present pre-injector ; the accelerating structure could however be fairly readily modified to accomodate a higher energy pre-injector (<1 MeV).

The major changes associated with the RF structure are in the method of fabrication. In fact copper clad steel is used for the RF cavity and this leads logically to tuning and field flattening with ball-tuners and to support stems with external alignment mountings. A major innovation is the support girder for the complete set of drift tubes which can be raised en bloc for alignment and inspection. Modern high vacuum techniques are introduced with metal vacuum seals and turbomolecular and ion pumps designed to give a short pump-down time so that opening the cavity is not a serious job.

The remainder of this report describes the accelerator with emphasis on components which are especially significant in the experimental context or where the fabrication techniques differ markedly from those of the present 50 MeV linac. Details of the latter accelerator have been reported elsewhere (Regenstreif [5] and subsequent conference reports [6], [7]).

The Layout of the Accelerator (Figs. 1 and 2)

The pre-injector will be mounted on a new axially movable support stand so that the horizontal beam axis is approximately central in the Faraday cage wall at 3.25 m above the load bearing concrete floor and 0.19 m above first floor platform level. To support the accelerating cavity, the vacuum pumps and some beam transport elements immediately before and after the cavity, a reinforced concrete block has been made. There is access to these components from above via a two metre wide slot cut in the first floor platform and access from below which will be convenient for work on vacuum pumps and RF feed lines. Three FTH final RF amplifiers stand close to the accelerator with the low to medium power RF stages (Siemens' chain), the modulators and their associated local controls in adjacent ground floor laboratories. An electronic equipment and control room is at first floor level next to the accelerator proper.

The Accelerating Cavity

The cavity internal diameter is 1075 mm and its internal length 1510 mm. Using the formula $L_n = 46.76 + 3.907\, n$ (mm) one obtains the manufactured length of the n^{th} cell to within ± 0.07 mm ($3 \leq n \leq 18$) with $\frac{g}{L}$ constant at 0.25. The range of values of some of the drift tube dimensions along the 3 MeV accelerator : (a) Drift tube diameters 140.3 mm to 120.9 mm (b) Bore hole diameter, (2a), 16.5 mm to 27.9 mm (c) Small radius which joins the bore to the face of the drift tube, (rhc), 1.5 mm to 2.5 mm. The section of the drift tube between the front face of the drift tube, and the maximum diameter can be closely approximated by a quarter of an ellipse and this fact was used when calculating the electromagnetic quantities for individual cells with the CLAS program [8] [9]. For the 3 MeV accelerator some small changes were made in the accelerating geometry (compared to the first 18 cells of the 10 MeV PS linac tank) essentially to ensure that the drift tube bore radius, (a), and the hole corner radius,(rhc), increase regularly as one passes along the accelerator. As it is hoped to compare practical observations and theoretical predictions of the proton dynamics it seemed useful to remove the more obvious discontinuities from a system which as shown above is basically regular. Some preliminary calculations of proton dynamics have shown that with an accelerator of known geometry one can use an inverse procedure to that usually used in linac design [10] and obtain electric field as a function of the given cell lengths (φ_s assumed constant at -30^o). To adjust the electric field to the required law there are five ball tuners (100 mm diameter); in practice the gross errors are best eliminated with a tuning bar fixed to the cavity wall leaving the fine tuning to the ball tuners. As frequency tuners the five balls will give a total frequency swing of 280 kHz for ± 25 mm radial movement about their normal positions. The calculated range of frequency perturbations of the unit cell frequencies due to the single drift tube support stems (diameter 27 mm) is from -430 kHz to -160 kHz. Compared to the power available, the RF requirements of the accelerator are modest i.e. with half the theoretical Q, only ~ 300 kW is required for copper losses and another 250 kW for beam loading compensation (100 mA proton beam).

Some Mechanical Engineering Aspects of the 3 MeV Accelerator

The Accelerating Tank (Fig. 3)

This is manufactured from copper clad steel plates of nominal overall thickness, ½ inch and copper thickness, 1/16th inch. The cavity is essentially a cylinder (dia. = 1075 mm) reinforced at both ends by flanges, each with a circular opening of 700 mm diameter. The long slot on the top of this tank is closed by the drift tube support girder. Four dowel pins ensure precise positioning of this girder and give the tank shell the necessary stiffness. The half drift tubes are bolted onto the circular end covers which are again made of copper clad steel. Various input flanges are provided on the tank ranging in size from openings for field monitor loops (dia. = 15 mm) to four vacuum ports (dia. = 200 mm). These latter ports are provided with grids formed by a series of holes drilled through the cavity wall. The deformation of the tank when it is evacuated is reasonably small : ~0.005 mm radially and 0.2 mm longitudinally as measured on the end covers.

The welding of the copper clad steel was made by argon arc as follows. First a V-weld in the steel part which was chipped out to sound metal from the copper side and then rewelded on this side with a filler rod of copper-iron. This weld was chipped out again to the depth of the copper cladding and finally closed with a pure copper weld. To obtain a continuous copper surface around the opening for the drift tube support girder, the end covers and the feeder lines, collars have been machined from solid copper and then welded and brazed onto the copper cladding of the tank. After welding and stress stabilization these collars have been precisely machined for centering and providing good sealing surfaces for the matching pieces. Incidentally, the vacuum seals (except on the injection system) are made with 1 mm gauge aluminium wire gaskets.

The Drift Tube Assembly (Fig. 4)

The drift tube, the quadrupole magnet and the outside part of the stem (including flexible bellows and sealing block) are brazed and welded to form a permanent and vacuum tight unit.

The drift tube proper consists of three parts: body, lid and bore tube. The body and lid are turned out of solid copper with a diamond tool; the bore tube which consists of three sections is manufactured from 0.2 mm and 0.8 mm gauge stainless steel sheets by rolling and brazing. To assemble the drift tube, a short piece of the copper support stem is brazed to the body and one end of the bore tube to the lid. The quadrupole magnet is then simply placed in a cylindrical housing in the body and fixed in the correct azimuthal position by a key. Finally all drift tube pieces are sealed by electron beam welding. During the welding the mean temperature inside the drift tube body does not exceed 80°C. After the sealing, traces of the welding material are machined away and the tube receives a final polishing using diamond cloth and distilled water. The last operation is the brazing of the rest of the copper stem; this is done by induction heating with careful cooling of the drift tube to prevent damage to the quadrupole. All brazings are done in vacuum using solders of different melting points. No changes in dimensions due to the brazing have been observed. The electron-beam welding, however, tends to shrink the drift tube in length by up to 0.1 mm; this can be nearly corrected by making the lid and the bore tube slightly longer. No deformation of the drift tube under atmospheric pressure could be measured.

The drift tube is cooled via the stainless steel supporting part of the stem inside which two further concentric stainless steel tubes are provided for water circulation. (Fig. 4). One end of the outer stainless steel tube is screwed into the body of the drift tube, the other end is clamped into the adjustment device. The leads of the quadrupole magnet pass up through the inner tube. Each half drift tube is bolted onto its respective tank end plate and sealed there-on by an aluminium gasket.

Alignment

From the mechanical point of view the accelerating system excluding the experimental area is four units, each having its own adjustable support and also having two outside targets on each end for checking and adjusting the alignment without opening the system. For interconnection of the units flexible metal bellows are used. The pre-injector support stand rests on the floor of the Faraday cage while the buncher, the input focusing triplet and the accelerating tank are mounted on a reinforced concrete block. For this comparatively short system the standard method using the micro alignment telescope to view optical targets is entirely adequate.

The drift tubes are mounted on a rigid girder which closes the slot on top of the accelerating tank. This girder can be lifted and fixed at 800 mm above the tank for mounting and aligning the drift tubes. Each drift tube stem is provided with clock-gauges touching an invar bar mounted on two supports on top of the girder. The bar itself is aligned with the targets on the tank. With this arrangement it is possible to check and if necessary readjust the position of each drift tube without necessarily breaking the vacuum. For horizontal positioning, the adjustment system for the drift tubes uses a spring loaded spherical thrust bearing to pivot the drift tube stem around a fixed point (Fig. 4). For vertical adjustment the stem can slide along a pivoting sleeve which is pressed against the adjusting screws by springs. Experiments have shown that this arrangement guarantees a stability of the drift tube position inside 0.012 mm.

To ensure mechanical and frequency stability the tank, the drift tubes and the buncher are kept at a constant temperature (within 1°C) by a water cooling system which operates at a few degrees above the maximum ambient temperature. The accelerating cavity is protected from excessive heat irradiation by being wrapped in an aluminium sheet.

Ancillary Systems and Components

The Injection System

The existing experimental pre-injector will be used to provide dense proton beam (> 0.5 Amps) at energies up to ~ 560 keV [3], [4]. A new rigid supporting frame has been built for the accelerating column. In addition to limited mechanical movement in the transverse directions the support has a range of axial movement of 1 m which will eventually allow us to make substantial modifications in the matching, bunching and diagnostic equipment between injector and accelerating cavity. Initially, however, the same basic input matching system as for the 50 MeV linac will be used to make the 3 MeV accelerator operational. To restrict the flow of hydrogen which comes from the Duoplasmatron source into the low energy drift space, a rapid acting mechanical gate synchronized to the beam pulse rate, is being considered, i.e. at 1 p.p.s.

The Vacuum System

The main cavity vacuum system will consist of a 260 l/s turbomolecular pump and two 500 l/s triode ion pumps with the backing pressure provided by a two-stage rotary pump. It is hoped that pump-down time to operational level from atmospheric pressure will eventually be ~ 1 hour and that the cleanliness of the system will be such as to allow experiments with RF accelerating fields appreciably greater than those possible in the 50 MeV linac.

The RF Power System

The experimental RF system, currently used for testing FTH triode amplifiers will be modified for use on the 3 MeV accelerator. Two output stages, one normal and one for beam loading compensation, will feed the cavity via two coupling loops. Note that peak power required for cavity excitation will be < 300 kW and for beam loading compensation < 500 kW so that the system will run well below its normal (2 × 2 MW) outputs. The cavity servo tuning system will operate on any chosen combination of the five ball tuners. To obtain reliable experimental results it will be essential to have stable and reproducible RF powering combined with precise monitoring of RF levels in the accelerator and buncher cavities. Ten identical monitoring loops will be spaced along the main cavity, each one feeding a matched detector (followed by a gated analogue to digital converter) so it will be possible to check field level and tilt continuously.

A Tentative Experimental Programme

The general theme of the experimental programme will be to study the evolution of a proton beam in the low energy part of a linac, i.e. the acceptance at 530 keV and the corresponding emittance at 3 MeV in the six dimensional phase space. This will be done over a wide range of currents and current densities, from levels where space charge effects are negligible right into the space charge limited region. It is hoped to fit the experimental results obtained with the most recent computational methods available. Put in the above form, the experimental plans seem rather ambitious but one can demonstrate that they are feasible without relying on untried measuring techniques. In fact all the methods outlined below are based on or analogous to experiments previously attempted at CERN, the Rutherford Laboratory and/or BNL. Compared to other linacs which are used as injectors or for nuclear physics research, the 3 MeV accelerator will have the following important advantages as a tool specifically for accelerator research :

i) The output beam is obtained after only 18 unit accelerating cells and this will give much less possibility of ambiguity when comparing experimental results with the theory. (Compared, for example, with CERN Tank I, 10 MeV).

ii) Normal linacs are available for only a small percentage of their time for accelerator research. With the 3 MeV linac a wider range of experiments will be possible merely because the accelerator does not need to be returned to some standard condition after a very limited time.

iii) The 3 MeV accelerator is more flexible in its design.

In the following sub-sections some of the proposed diagnostic apparatus is briefly described and some experimental methods suggested for the principal studies of the proton beam dynamics. Other future possibilities,e.g. conversion of 3 MeV linac for higher pre-injector energy, the acceleration of deuterons and development and testing of systems to be used on the 50 MeV linac,are not treated here.

The 3 MeV Experimental Region

Directly after the accelerator will come the beam transport system and diagnostic apparatus for the 3 MeV proton beam. The quantitites to be measured are current, emittance, energy, energy spread, with phase and phase spread of the proton bunches considered useful indicators of performance with a dense beam, but difficult to measure with present techniques.

Current. In principle, beam transformers will be as on the 50 MeV linac but will be used with energy discrimination, desirable at the 3 MeV output to eliminate low energy protons. The same transformers are proposed as detectors for the emittance, energy and energy spread measurements with Faraday cups as an alternative below 50 μA proton current. It is important to have the possibility of sampling and converting the measurements to digital form.

Emittance. For the initial experiments the standard CERN two slit method [11] will be used for measurements before and after the linac. Though at present rather time consuming, the method has the merit of producing reliable quantitative results. With 2 mm wide slits and a pulsed quadrupole triplet (focal length 0.75 m) one obtains phase area resolution of 2 mm × 2.7 mrad compared to the expected output emittance area ~ 150 π mm mrad.

Energy, Energy Spread, Phase and Phase Spread. Use of a DC analysing magnet is proposed for energy spread measurements (Resolution $\frac{\Delta E}{E} \simeq 0.2$ %, i.e. $\Delta E \simeq 6$ keV compared to estimated full width at half height ~ 40 keV). In principle an analysing slit or a Faraday cup is moved across the image plane of the single vertical defining slit and the transmitted current is recorded. For absolute energy two defining slits should be used before the magnet and with considerable care one can obtain 0.2 % precision. However, it may also be possible to develop an elegant method of energy measurement via the time of flight method either with a beam fine structure monitor [12] as pick-up or with some resonant and transparent detector [13]. Both detectors would compare the phase of the 202 MHz structure of the beam with a standard RF phase and thus would be also useful for relative phase measurement. The fine structure monitor could also measure the time structure of the proton beam, i.e. the phase spread at the end of the accelerator (resolution ~ 15^o) and the energy spread after a drift distance of a few metres.

Some Proposed Experimental Methods

In the following sub-sections an approach is outlined which it is suggested could help us obtain an acceptably complete and self consistent description of the acceleration process. Basically one builds up families of characteristics for the accelerator which enable one to calibrate, for example the RF levels, which are usually measured on an arbitrary scale, as a function of the corresponding stable phase angles of proton acceleration. The simple paraxial type of ray tracking must correlate well with our dynamics computations if we are to expect any success when radial motion, non-linearities and space charge become successively important. Undoubtedly with the 3 MeV model one will also attempt to optimize all variable parameters to obtain the maximum current, maximum brightness, minimum energy spread or whatever output parameter or group of parameters is taken as a criterion of optimization. One must accept however that such optimization techniques can only lead indirectly to consistent explanations for the dynamics.

Investigations of Longitudinal Phase Space. For all experiments under this heading it is proposed to use a fine paraxial beam of low current density so that radial and space charge effects are reduced. Correlation of results with axial calculations should be good.

Expt. 1 Axial motion characteristics :
Measure input current, output current, energy, energy spread as function of accelerating RF level and injected beam energy (without pre-buncher).

Expt. 2 Buncher characteristics :
Measure input current and output parameters versus phase and RF level of the buncher, other parameters constant at some levels defined by Expt. 1. Hence it should be possible to deduce settings of buncher excitation for narrowest bunch phase width.

Radial Phase Space. Here it is more difficult to separate the radial and phase motion. Note that the current density used is still small.

Expt. 3 Radial acceptance by ray tracing :
Use slits to define a beam of small phase area and measure input current, output current, energy, energy spread and emittance as function of position of input beam in phase space. This experiment should enable one to measure the input transverse acceptance and to detect emittance blow-up (given the necessary current measurement sensitivity).

Expt. 4 Radial-phase coupling :
Use slits to define an axial beam and measure input current and output parameters as a function of quadrupole focusing q value. The aim is to investigate the q = 0.5 resonance.

Expt. 5 Emittance blow-up :
Use slits to define progressively increasing emittances and measure input current, input emittance and output parameters. This will provide information on the beam evolution in transverse phase space.

Expt. 6 Output emittance as a function of input phase :
Adjust 0.53 MeV transverse matching to give maximum output current at 3 MeV (without bunching). Set buncher RF level for minimum phase spread at accelerator entrance. Measure the output emittance as a function of buncher phase.

The results of the experiments in 'Radial Phase Space' may be difficult to correlate with computations. This arises from the increased complexity of the processes and from the perturbing effects not normally included in the calculations e.g. non-linear lenses, alignment errors and RF field errors. However a basis of comparison has been established for the results obtained when space charge becomes important.

Space Charge Effects. Here it is often important to measure the beam before it enters the linac especially when it is bunched. Buncher computations have been done for this region [14]. Note that an important source of error in high beam current experiments at low energy is that the beam may be partially neutralised. Essentially one can attempt to repeat experiments of type 1,2,4,5 and 6 but with high current density beams. The explanation of the results of these experiments will severely test any theories or computational methods.

The above list of experiments is given merely to show the range of measurements possible with the proposed diagnostic equipment. In practice experiments will also be done in which one varies other important parameters, e.g. RF field, quadrupole focusing field law, input matching and drift tube alignment. Another important part of the research will be to confirm or extend results already obtained on the 50 MeV injector linac.

Conclusions

From the above it can be seen that this 3 MeV experimental proton linac, which will soon be operational, can be used to make many crucial experimental tests of the acceleration process in low energy linacs. Meanwhile it is hoped that computational methods under development for the low energy proton dynamics (including space charge effects) will be available to guide the direction of the experiments and explain the experimental results. Towards this end there are already available reliable computations of the form of acceleration field via the CLAS program [9] and some computations and interpretations of the bunching process including space charge and quadrupole focusing [14], [15] .

Concerning the state of the construction of the Alvarez section, the cavity shell and support girder are complete and vacuum tight while the drift tubes, ball tuners and other ancillary parts are well advanced. It is hoped to be able to close the cavity and start putting in RF power during the Autumn.

We wish to acknowledge the encouragement and support for this work given by Mr. C.S. Taylor and to thank many other members of the Linac Group and MPS Mechanical Section for their willing and active cooperation.

References

[1] The Second Stage CPS Improvement Study, MPS/Int. DL/B 67-19.

[2] C.S. Taylor, D.J. Warner, F. Block and P. Têtu
Progress Report on the CERN-PS Linac, Proceedings of the 1966 Linear Accelerator Conference LA-3609 (Oct 1966), p. 48.

[3] J. Huguenin, R. Dubois, G. Visconti and R. El-Bez
The New 500 keV Single-Gap Pre-injector Tube for the CERN PS Linac , Ibid, p. 355.

[4] B. Vosicki, M. Buzic and A. Cheretakis,
The Duoplasmatron Source for the CERN PS Linac, Ibid, p. 344.

[5] E. Regenstreif
The CERN Proton Synchrotron, (3rd part) CERN 62-3, Jan 1962.

[6] C.S. Taylor
High Current Performance of the CERN PS Linac International Conference on High Energy Accelerators, Dubna (1963).

[7] C.S. Taylor
Performance of the PS Linac, Minutes of the 1964 Linear Accelerator Conference MURA 714 (1964), p. 353.

[8] M. Martini and D.J. Warner
Numerical Calculating of Linear Accelerator Cavities, CERN 68-11, (March 1968).

[9] M. Martini and D.J. Warner
An Improved Method for Calculating Proton Linac Cavities, this Conference, p. 512.

[10] A. Carne and P.M. Lapostolle
Design Equations in an Alvarez Type Proton Linear Accelerator, Proceedings of the 1966 Linear Accelerator Conference, LA-3609 (Oct.1966), p. 201.

[11] P. Têtu
Emittance du Faisceau Linac, MPS/Int LIN 63-5 1963.

[12] D.J. Warner
An Approach to 200 MHz Bunch Measurements, Proceedings of the Vth International Conference on High Energy Accelerators (Frascati 1965) p. 612.

[13] D.C. Hagerman and M. Jakobson
A Device for Absolute Velocity Measurement of RF Modulated Beams, Nuclear Instruments and Methods 30 (1964), p. 154.

[14] F. Vermeulen
Computer Simulation of Beam Bunching with the Inclusion of Space Charge Forces and Quadrupole Lenses, MPS/Int. LIN 67-5 (1967).

[15] P.M. Lapostolle
Bunching, this Conference, p. 317.

DISCUSSION

(D. J. Warner)

PROME, SACLAY: What is the computing time for a standard cell with the program?

WARNER, CERN: For the "CDC 3800" computer (similar to the 7094 computer) the typical time for a cell in tank one is four minutes. This is central processer time after everything is on tape. A thousand points require 20 seconds and we typically have 12,000 to 20,000 points.

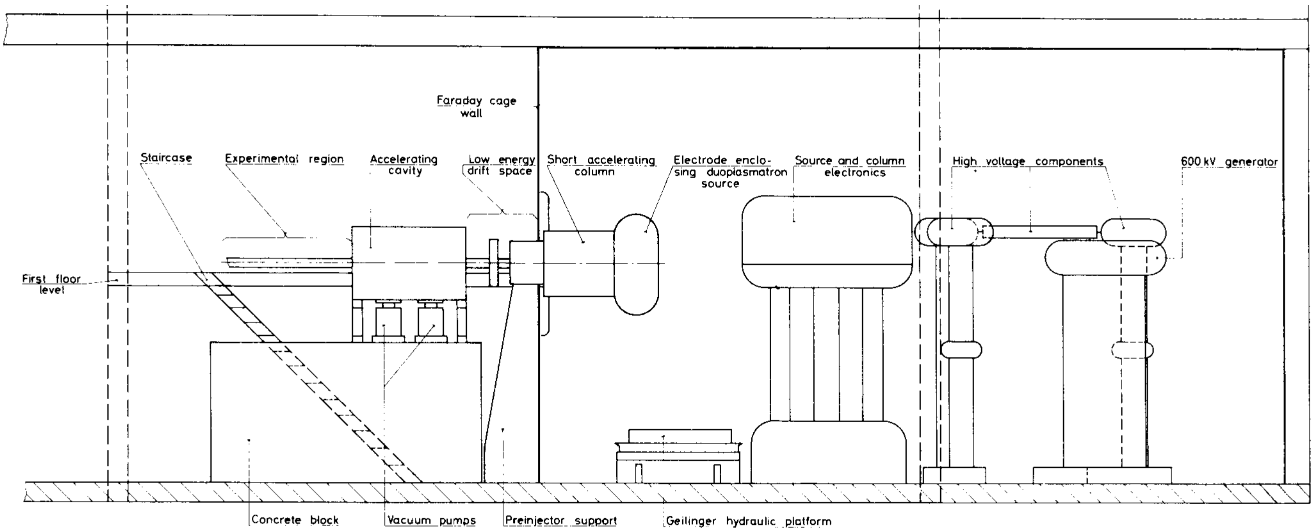

FIG. 1 Schematic elevation showing 3 MeV experimental accelerator and faraday cage layout

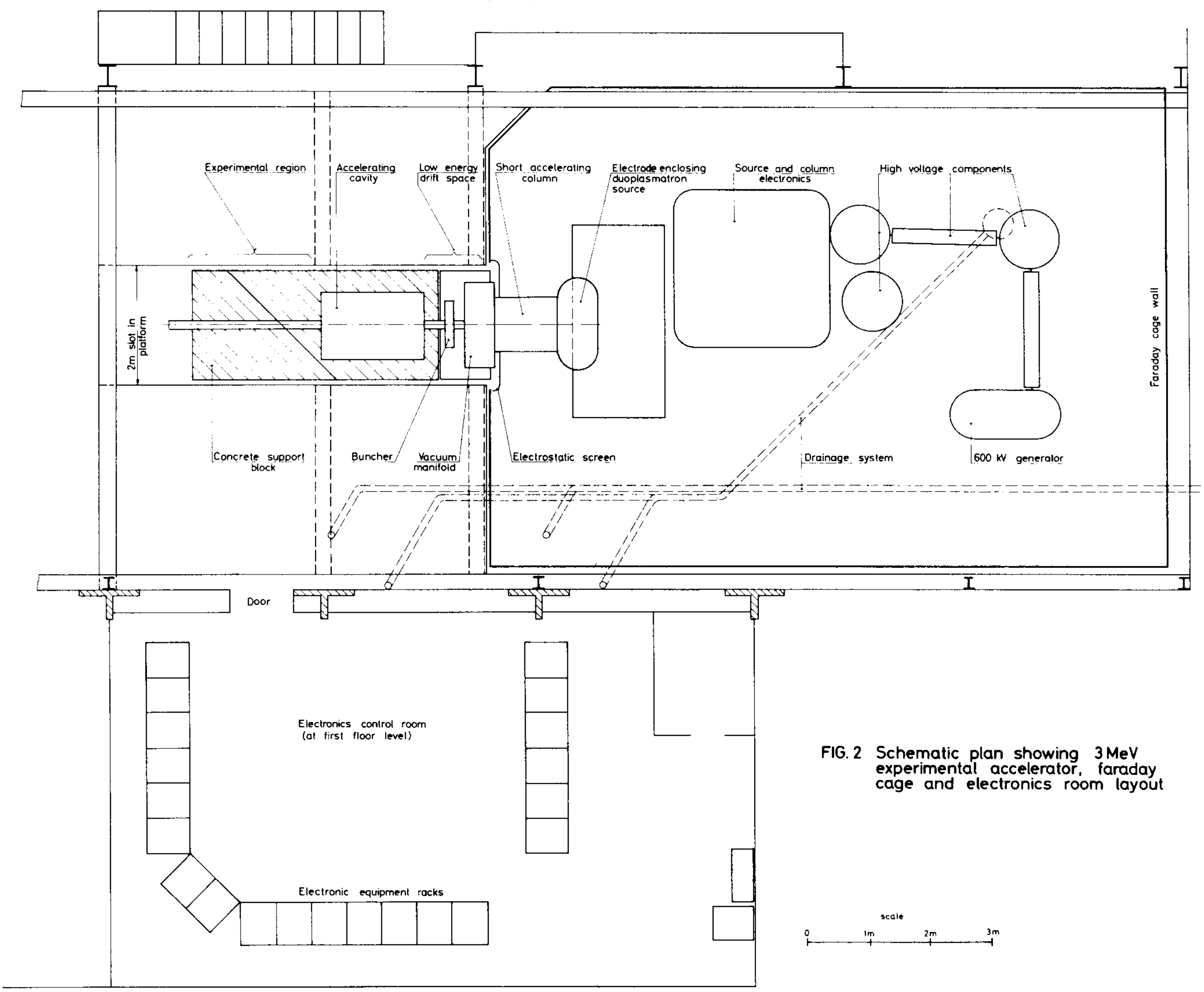

FIG. 2 Schematic plan showing 3 MeV experimental accelerator, faraday cage and electronics room layout

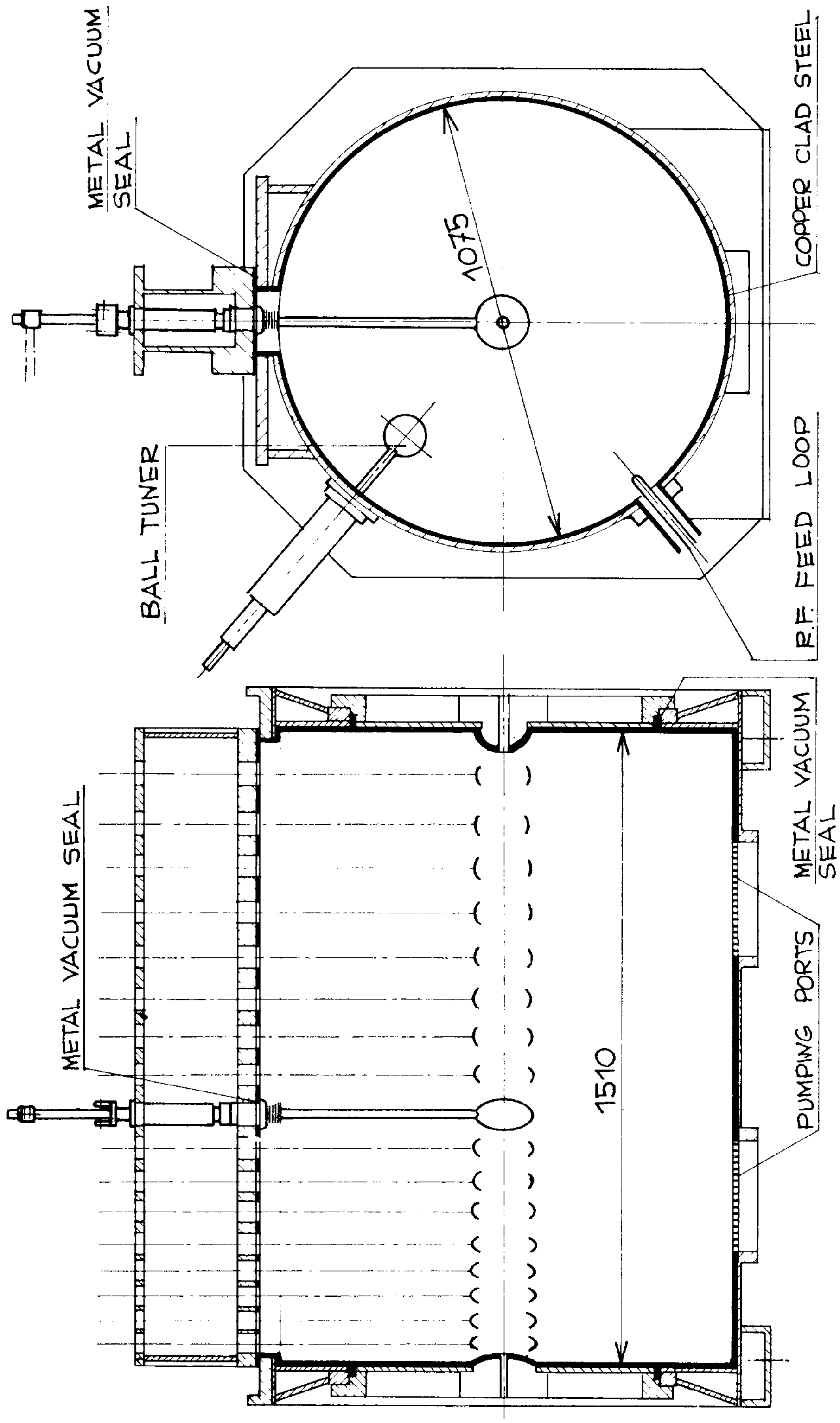

Fig. 3 General view of Accelerator Cavity.

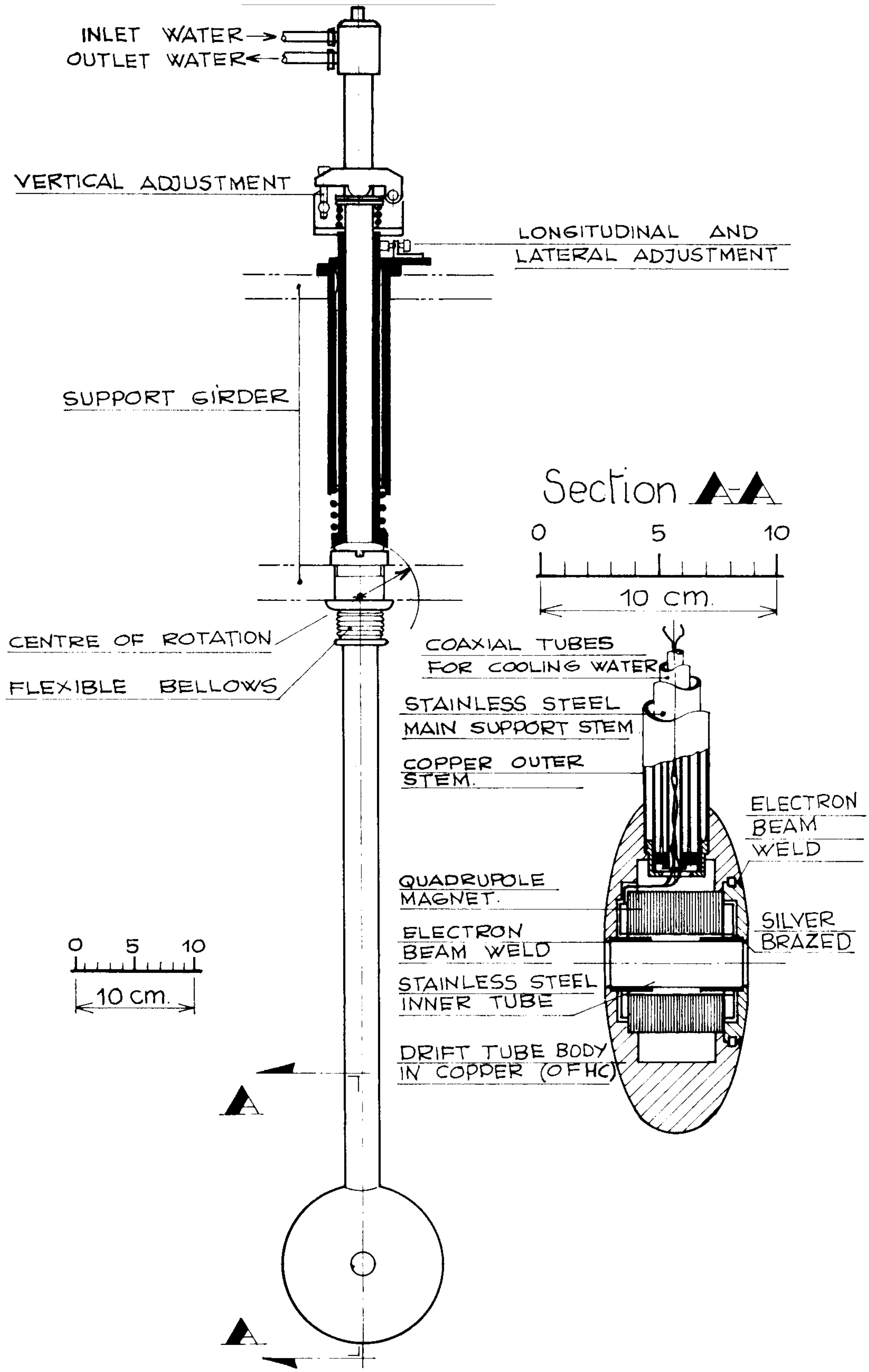

Fig. 4 Typical Drift-Tube and Support System.