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18 Agosto 1982

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STATUS OF THE SUPERCONDUCTING CYCLOTRON PROJECT IN MILAN

Invited talk presented at the "XIX European Cyclotron Progress Meeting", Grenoble, June 10-11, 1982

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INTRODUCTION

This paper is intended to give a comprehensive status report on the Superconducting Cyclotron now under construction at the University of Milan. Since the project was extensively reviewed(1-6) at the time of the International Conference on Cyclotrons held in Caen in Sept. 1981, the emphasis will be on the progress made since then and on the few design changes which have taken place meanwhile.

For the sake of completeness let us just recall that the machine has a K_{FOC} = 200 and K = 800, enabling maximum energies of 100 MeV/n for light ions (fully stripped) and 20 MeV/n for uranium. Both internal ion source operation (Pig-type) and injection from a 18 MV Tandem will be possible. Also axial injection from an external ion source will be implemented, although at a later stage.

The machine has a 3-sectors geometry, with an operating range of the average magnetic field between 22 and 48 Kgauss. The corresponding RF frequency range is between 15 and 48 MHz, for 100 KV peak dee voltage, and harmonic operation from h = 1 to h = 4 will be possible.

In the following we shall review the project status for the different topics in this order :

1. - General design - Injection
2. - Magnet and iron structure - Trim coils
3. - Main coils
4. - Cryostat
5. - RF system
6. - Extraction
7. - Computer control
8. - Building
9. - Summary

1. - GENERAL DESIGN

In order to recall the basic machine design a vertical section and a median plane view are shown in Figs. 1 and 2 respectively. All main parameters of the polar geometry are by now substantially frozen. Repeated calculations, via the program Poisson, of the average magnetic field have given us a sufficient confidence on the overall reliability of the latter. Therefore all the median plane penetrations through the cryostat needed for extraction, injection and all the holes in the pole needed for the trim coils feedthroughs, RF trimming and coupling capacitors will be built in from the start, i. e. without waiting for the measured magnetic field data. This is a considerable departure from the line followed at MSU and Chalk-River(7, 8), and has advantages and risks. Of course the main advantage is a considerable reduction of the time needed to complete the machine. The risks are that the shimming and adjustment of the final magnetic field may be more difficult. However, in light of present experience(9) this possibility seems rather remote and therefore we decided to proceed as detailed above.

The isochronism and focusing properties of the magnetic field seem excellent, as shown in Fig. 3 for fully stripped light ions both at the maximum (100 MeV/n) energy and at the minimum (43. 5 MeV/n). The latter corresponds to the minimum operating field of 22 Kgauss and shows that adeguate isochronism can in any case be reached. The (ν_R, ν_z) working plot for three representative ions is shown in Fig. 4. It does not differ appreciably from the one presented in (1) and we refer to (1) for all comments.

The limits of the injection paths from the Tandem have also been frozen, and they are shown in Fig. 2. A thorough investigation of the space behaviour along the injection path has been carried out, the results being shown in Fig. 5 for two representative ions. The maximum radius at which trajectories are followed is $R \simeq 130$ cm, i. e. well outside the maximum coils radius of $R = 115$ cm. The beam is confined axialy within $\pm$ 4 mm so that a maximum

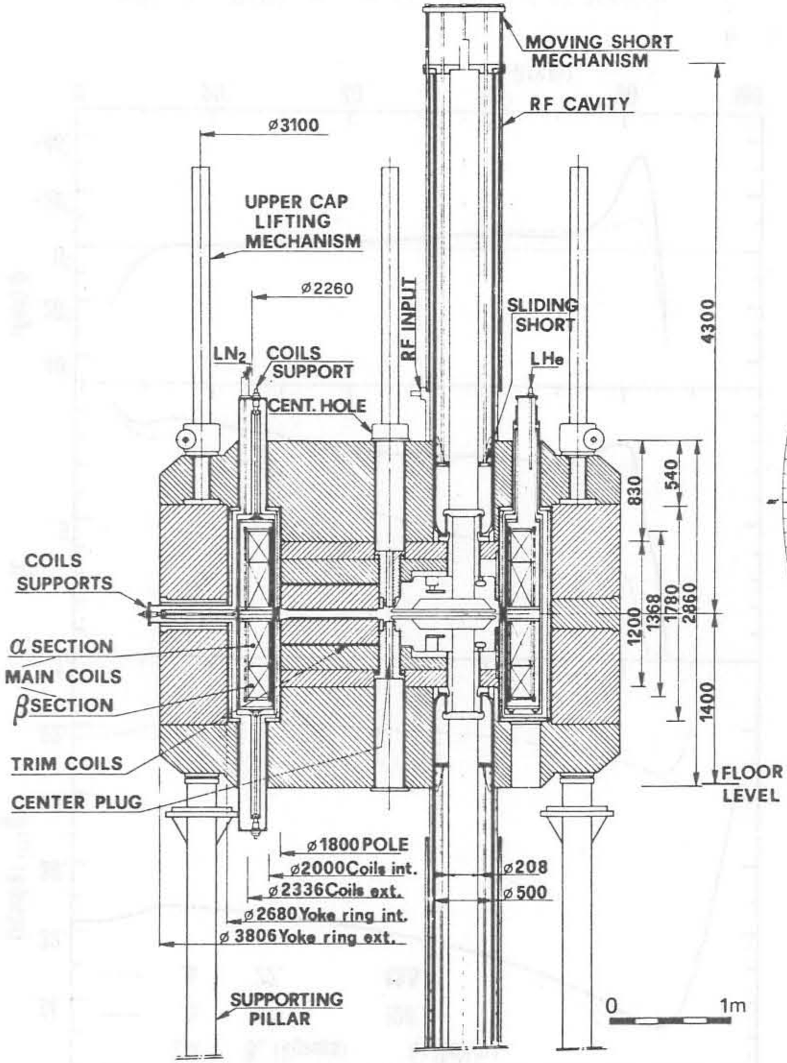

FIG. 1 - Vertical section of the machine.

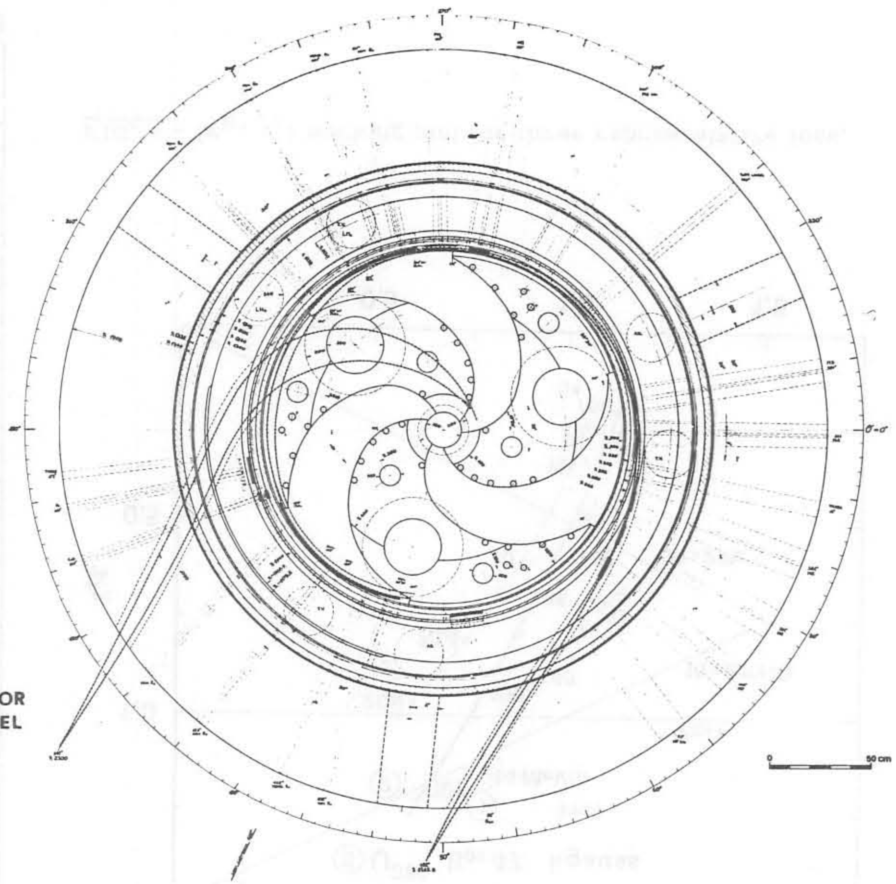

FIG. 2 - Median plane view.

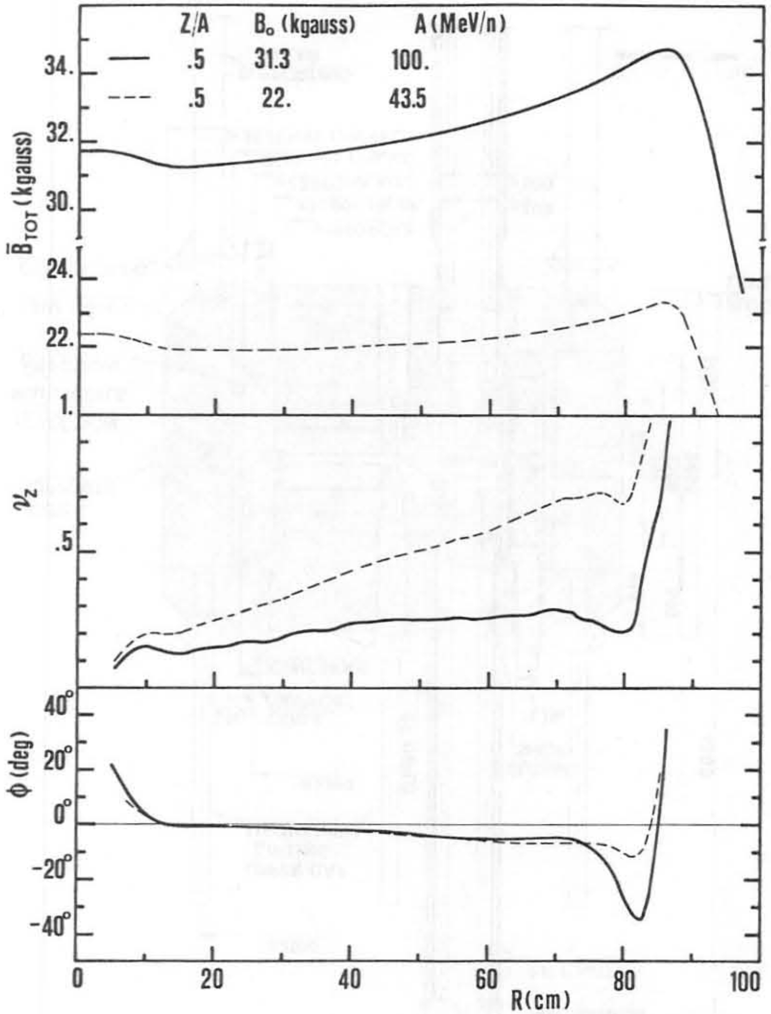

FIG. 3 - B(R), ν_z, φ for 100 and 43 MeV/n.

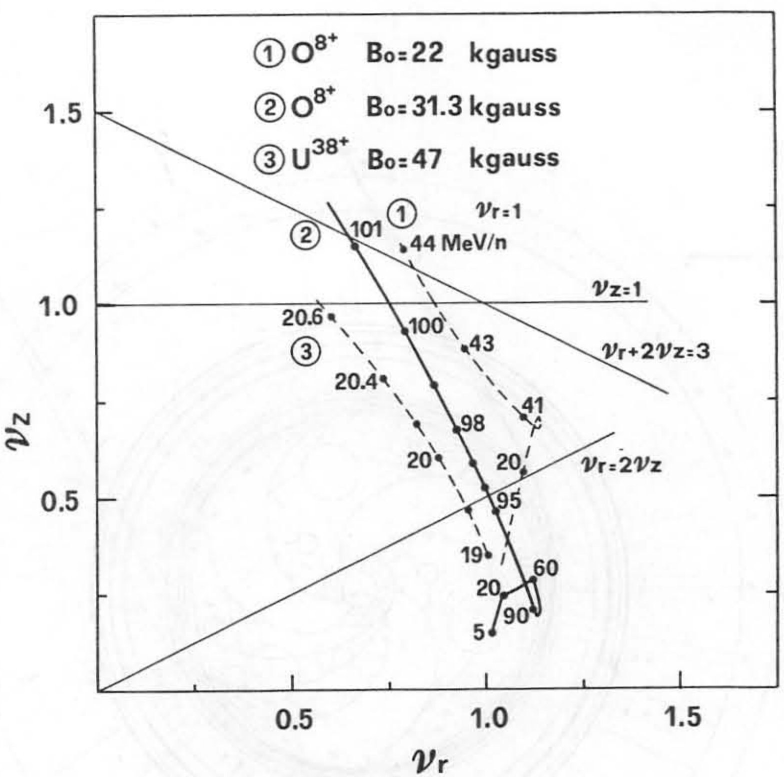

FIG. 4 - (ν_R, ν_z) working plot for three representative ions.

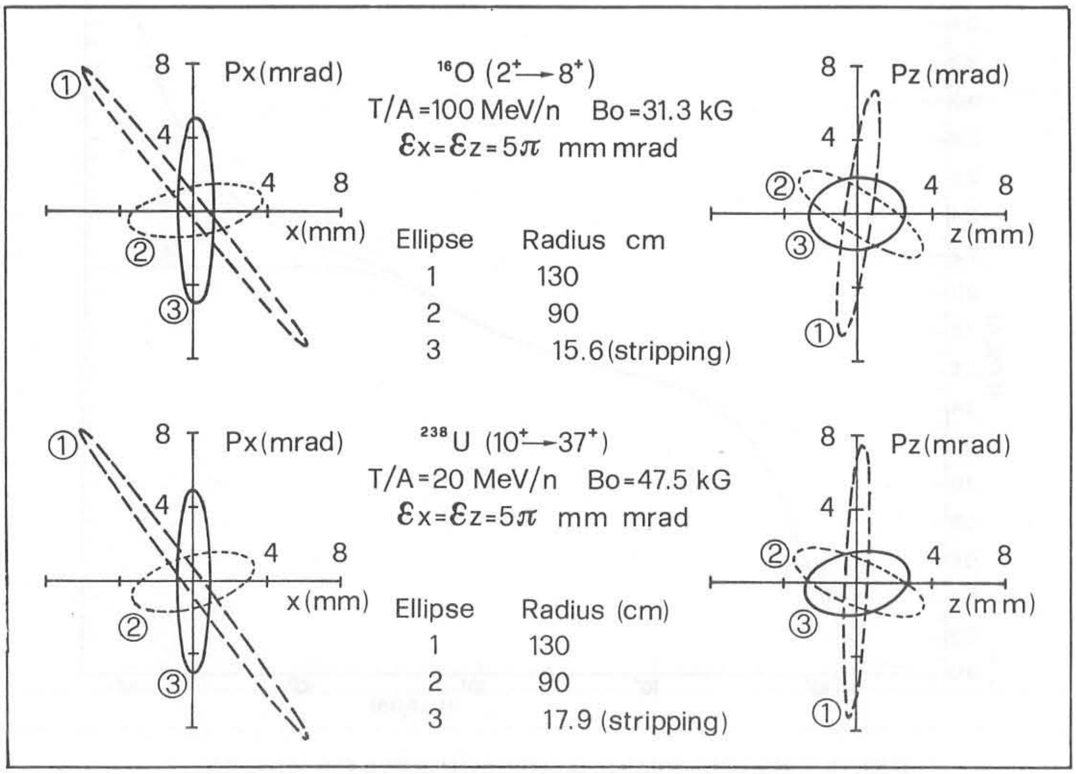

FIG. 5 - Injection phase space for two representative ions.

axial width for the injection hole through the cryostat of ± 12 mm has been selected. This choice allows a considerable margin as apparent from the numbers just quoted. However, it should be noted that the emittance of the beams to be injected may vary considerably from the nominal value of 5 π mm mrad used in the calculations. Besides some margin is needed in order to allow for discrepancies between the calculated and measured magnetic fields.

2. - MAGNET AND IRON STRUCTURE - TRIM COILS

The five pieces in which the yoke iron structure is split, namely upper and bottom caps (including poles), upper and bottom outer rings and central ring, have been cast and are at present being machined. The quality of the iron is excellent, as proved by the magnetization curve of Fig. 6. A view of the outer rings, after machining, is shown in Fig. 7. We needed to provide a good rustfree surface on the upper and lower caps, on which will be mounted the vacuum tight feed throughs for the trim coils, the center plug etc. Consequently we have decided to cover the iron structure with a 2 mm thick layer of stainless steel. The latter is deposited by a special welding technique and is eventually machined to specifications. All tests have shown that a totally vacuum tight and rust-resistent surface is obtained in this way. A

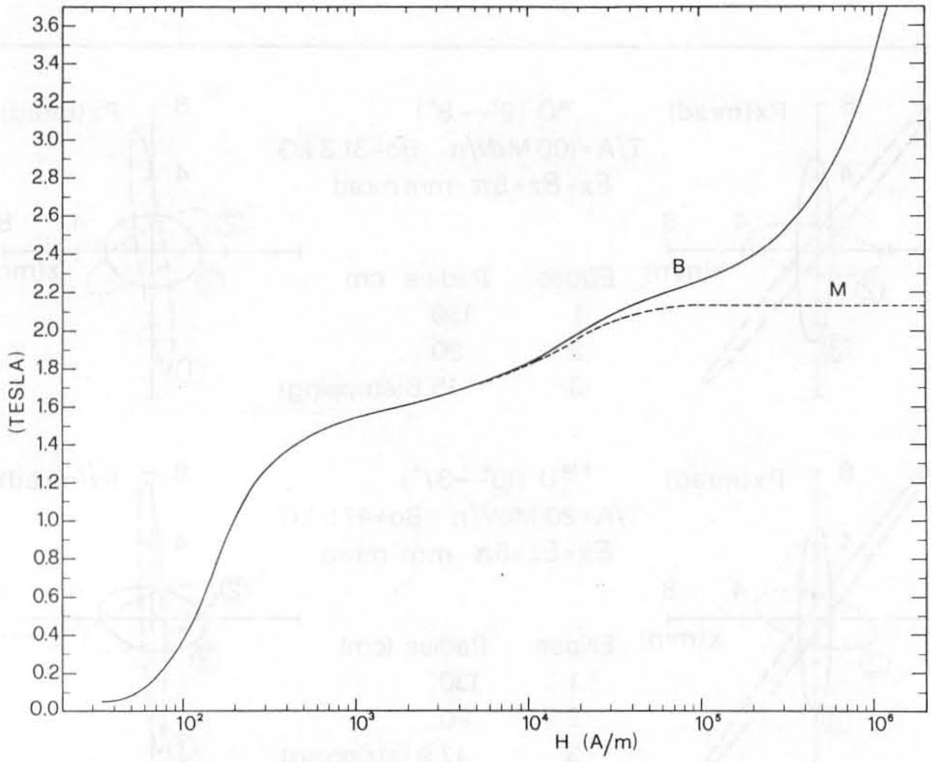

FIG. 6 - Experimental magnetisation curve for the iron.

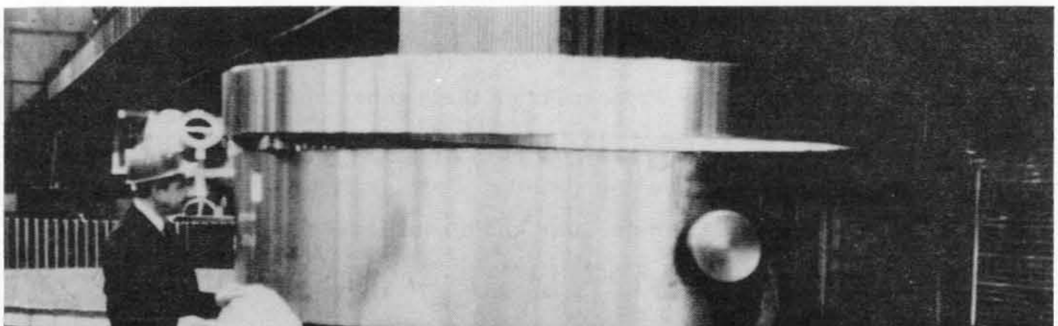

FIG. 7 - Outer rings after machining.

view of the upper yoke cap during this welding process is shown in Fig. 8.

At present the full machining of the poles, which includes the drilling of the trim coils holes is underway. Mechanical tests of the entire structure, including the upper-cap raising mechanism are expected to take place at the end of August. Delivery of the magnet should occour around September 1982.

A full scale prototype of two sectors and one valley has been built, in order to check out the machining procedures and to allow the assembly of a full set of coils. The prototype, shown in Fig. 9, has been cast in aluminum, in order to reduce weight. Machining of the sector profile, including the edge-chamfering according to a curvature radius of 20 mm, has been carried out with a numerically controlled milling machine. The tests have shown that a precision of ± 0.05 mm can typically be achieved, which is deemed sufficient for the cyclotron.

A full set of 20 trim coils has been constructed and assembled on a sector, as shown in Fig. 10. The manufacturing technique uses carefully tailored wood models, each for every trim coil, on which the coil itself is subsequently wound. The results are quite satisfactory and have yielded coils well within the prescribed tolerances. The coils are then impregnated with epoxy like resins. The impregnation is carried out on the sector itself, but using thin teflon covering of the sector. In this way the trim coils can be easily removed from the sectors, for repairing or substitution. A test of this technique has been carried out so far on two coils, as seen in Figs. 11 and 12. The trim coils power supplies which number 28 in total, including those for harmonic coils operation, have been ordered, and delivery of a prototype (400 A, 48 V) is expected by the end of June.

The iron for the sectors, of quality as good as the yoke iron, has been already delivered. This iron which is forged, laminated and successively flame cut according to roughly the sectors profile, is already in the house, as seen in Fig. 13. Final machining will take place in the next 4 to 5 months.

3. - MAIN COILS

The main coils structure is essentially as reported in (1, 2). A drawing of a section, showing the two independently excited parts, the Cu-Be rods which hold the coils together, the LN shield and the vacuum chamber is shown in Fig. 14.

Further development of the superconducting Nb-Ti insert has produced the results for the critical current shown in the left of Fig. 15. At the max field of 5 T the critical current is, in the worst case, well above the 2000 A maximum operating limit. Also the RRR measured values of the copper substrate are rather confortable, as shown on the left of Fig. 16, since a cold work of no more than 3% - 4% is anticipated.

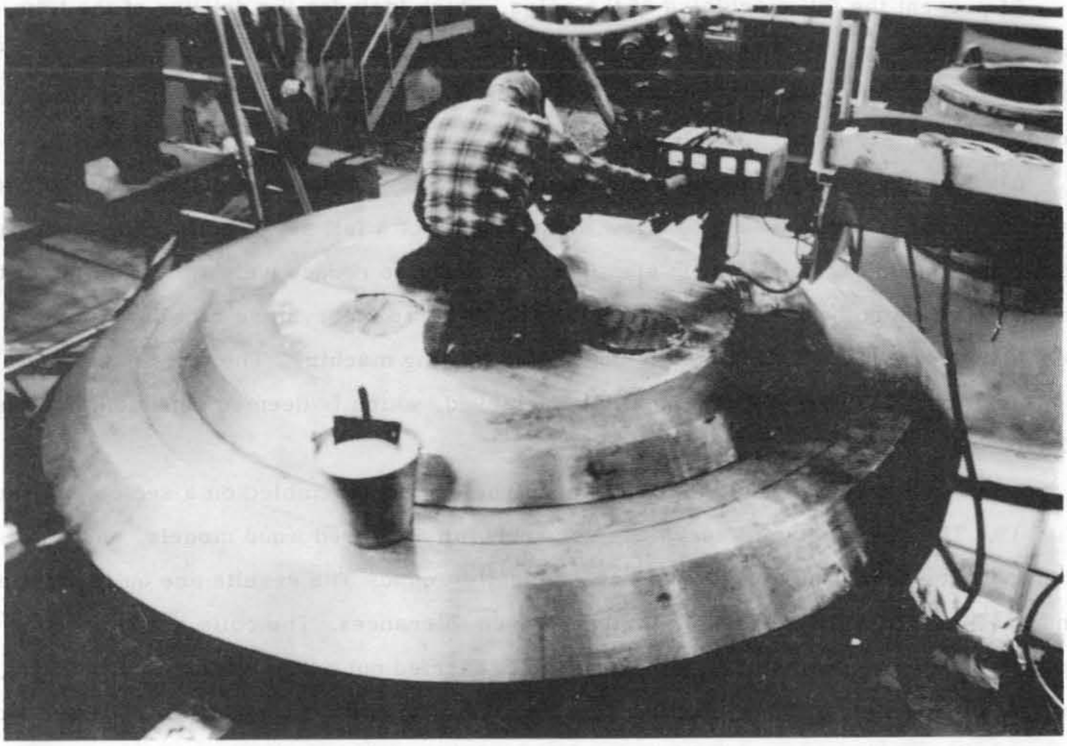

FIG. 8 - View of the upper yoke cap with stainless steel layer being deposited.

FIG. 9 - Full scale prototype of two sectors and a valley.

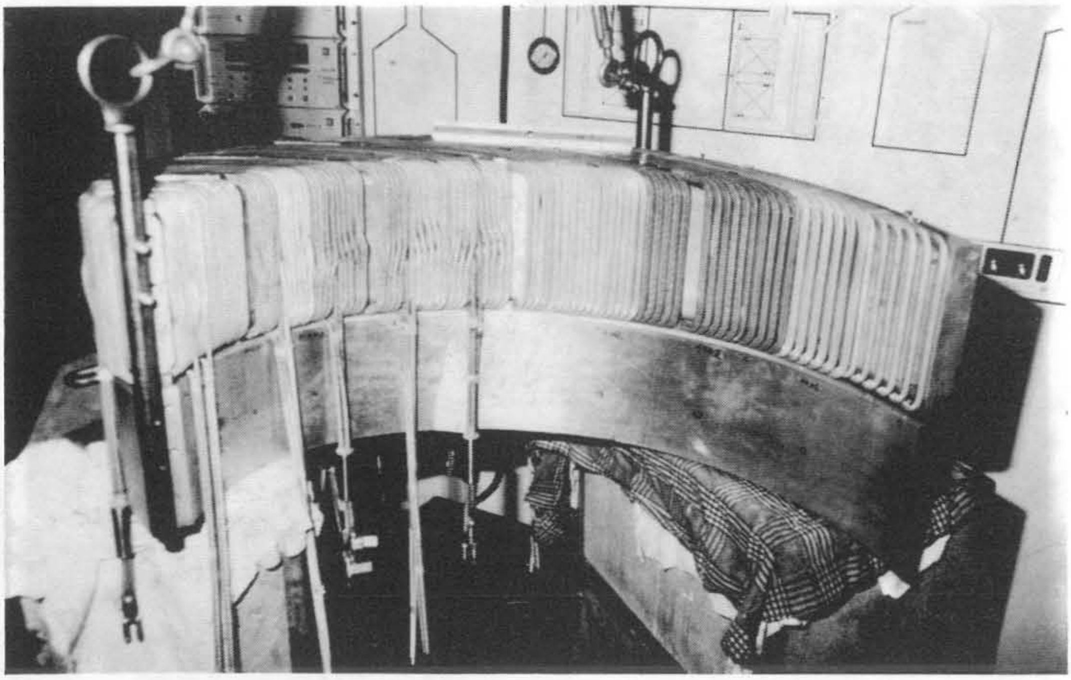

FIG. 10 - Set of 20 trim coils mounted on the sector.

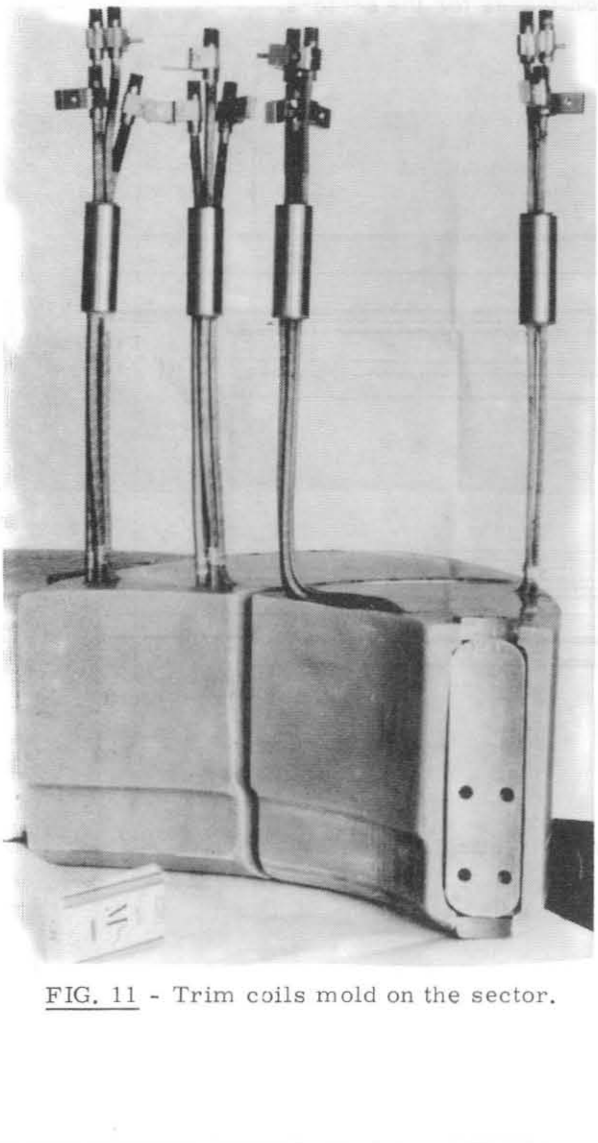

FIG. 11 - Trim coils mold on the sector.

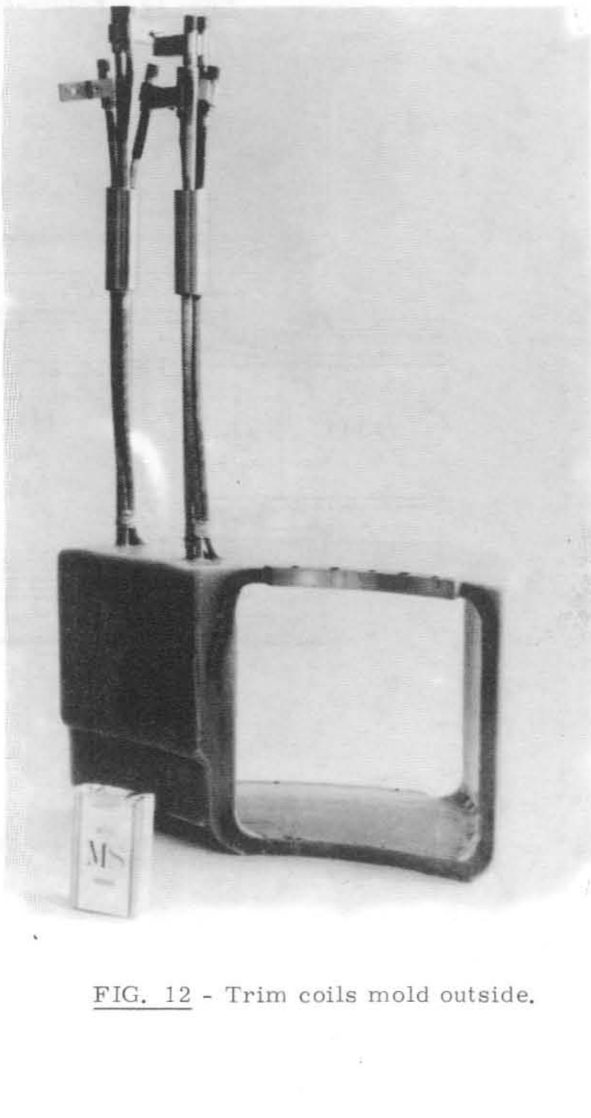

FIG. 12 - Trim coils mold outside.

FIG. 13 - Flame-cut iron pieces for the sectors.

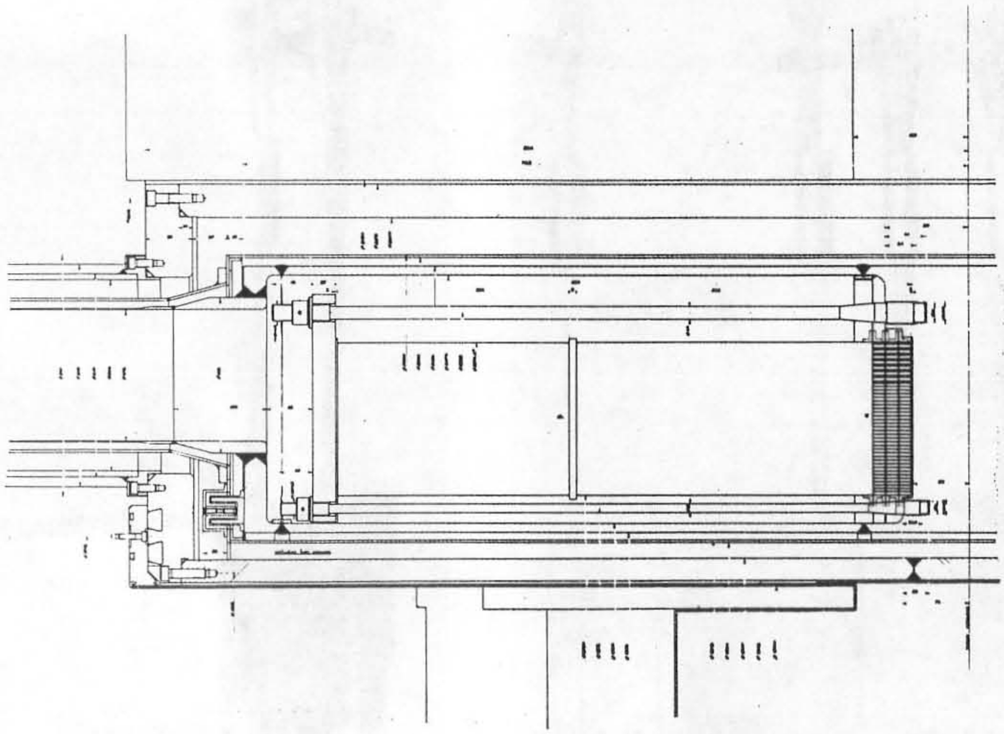

FIG. 14 - Main coils section.

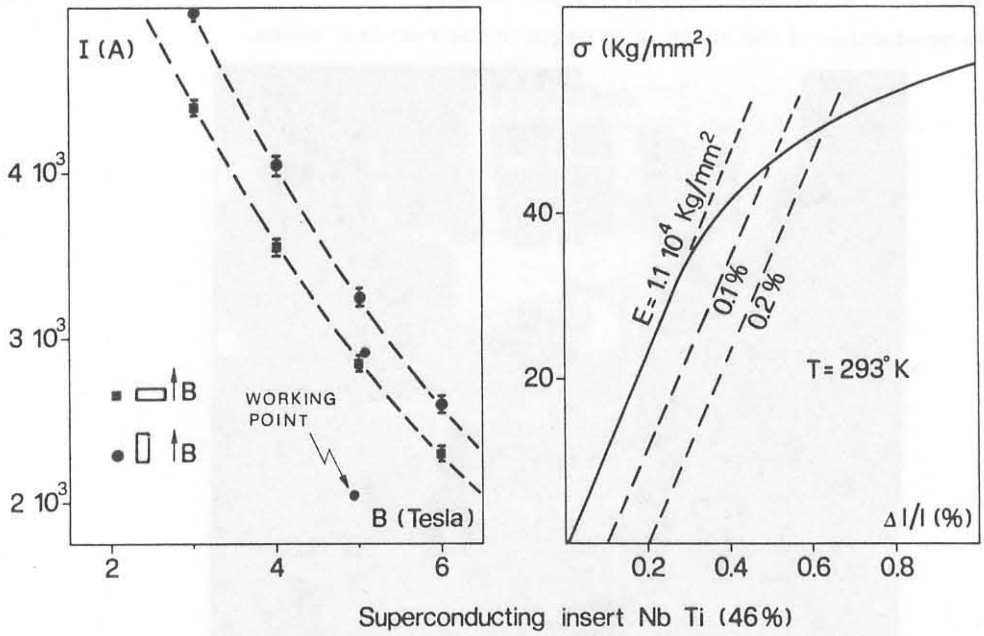

FIG. 15 - Critical current for the Nb-Ti insert (left)

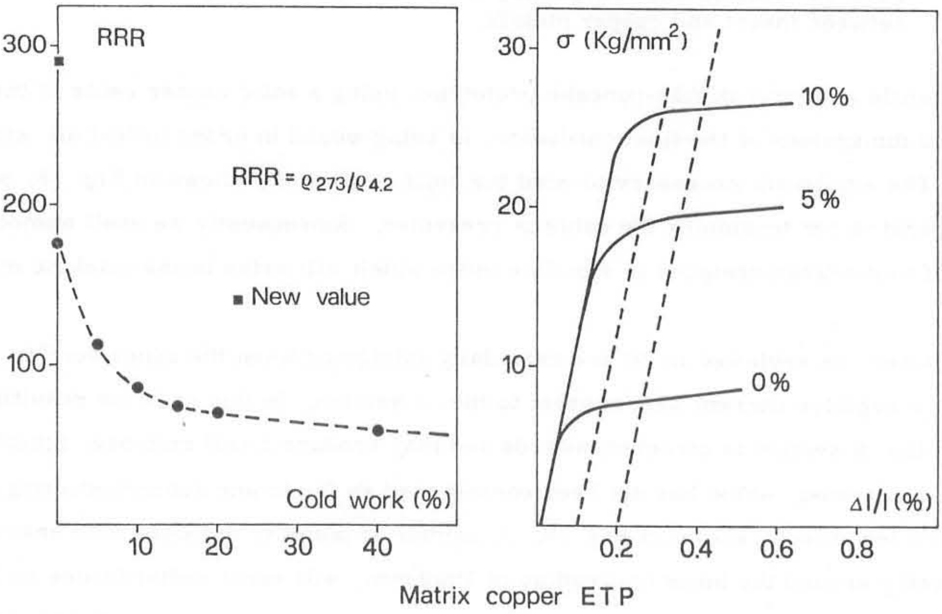

FIG. 16 - RRR of the ETP copper matrix.

An apparatus for testing on-line, via ultrasonic techniques, the quality of the soldering bond between the Nb-Ti insert and the copper substrate has been built as shown in Fig. 17. Full scale production of the cable is to begin in the next few weeks.

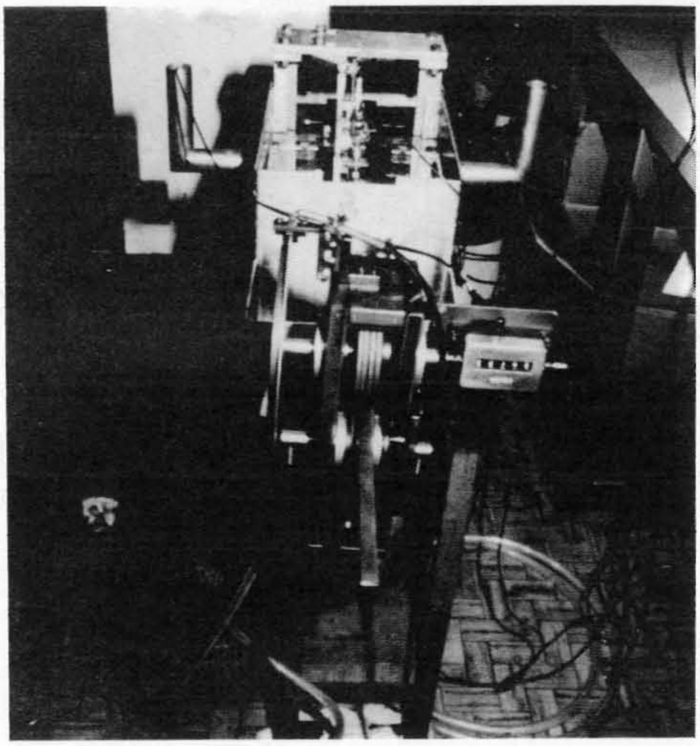

FIG. 17 - Ultrasonic test facility for checking soldering bond between insert and copper matrix.

Meanwhile a dummy double-pancake prototype, using a solid copper cable of the same quality and dimensions of the final conductor, is being wound in order to test all winding procedures. The equipment necessary to wind the coils is partially shown in Fig. 18, where part of the apparat us for tensioning the cable is presented. Subsequently we shall subject the pancake itself to stresses designed to simulate those which will arise in the machine magnetic field.

The latter, as reviewed in (2) are expecially intriguing when the upper section (β) is excited with a negative current with respect to the α section. In this case the resulting radial stress on the β section is directed inwards and may produce a coil collapse. Since this is a rather new situation, which has not been encountered so far in any superconducting coil, we have built a test bench, shown in Fig. 19. A number of pistons, disposed with near cylindrical symmetry around the inner coil radius of 1000 mm, will exert radial forces on the dummy coil pancake. In this way we hope to test the mechanical coil resistance to the inwards compression mentioned above.

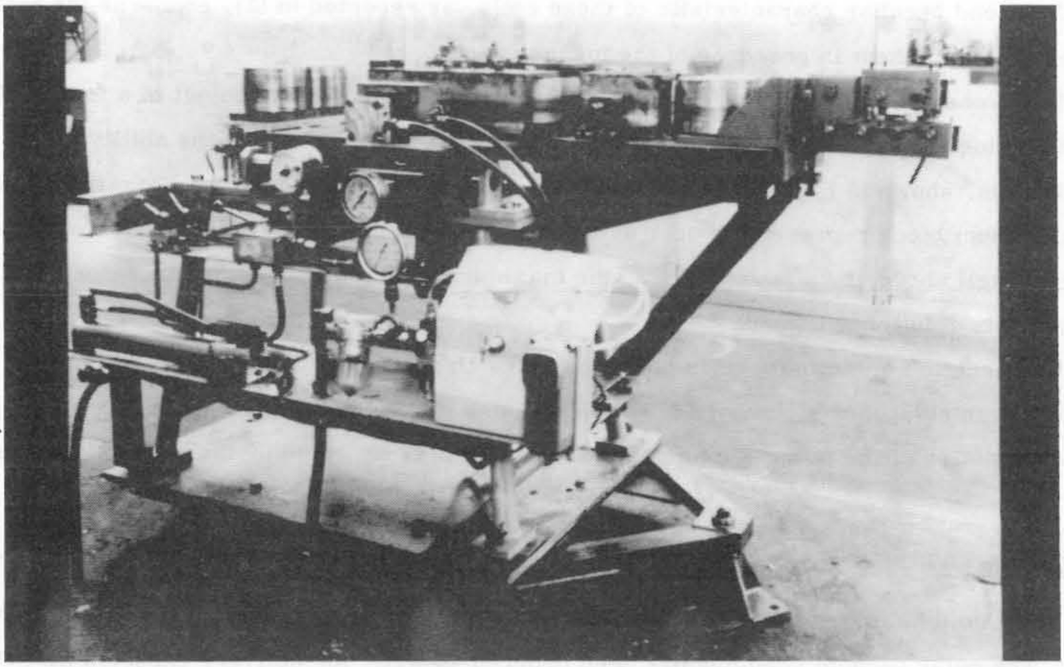

FIG. 18 - Part of the apparatus for tensioning the cable.

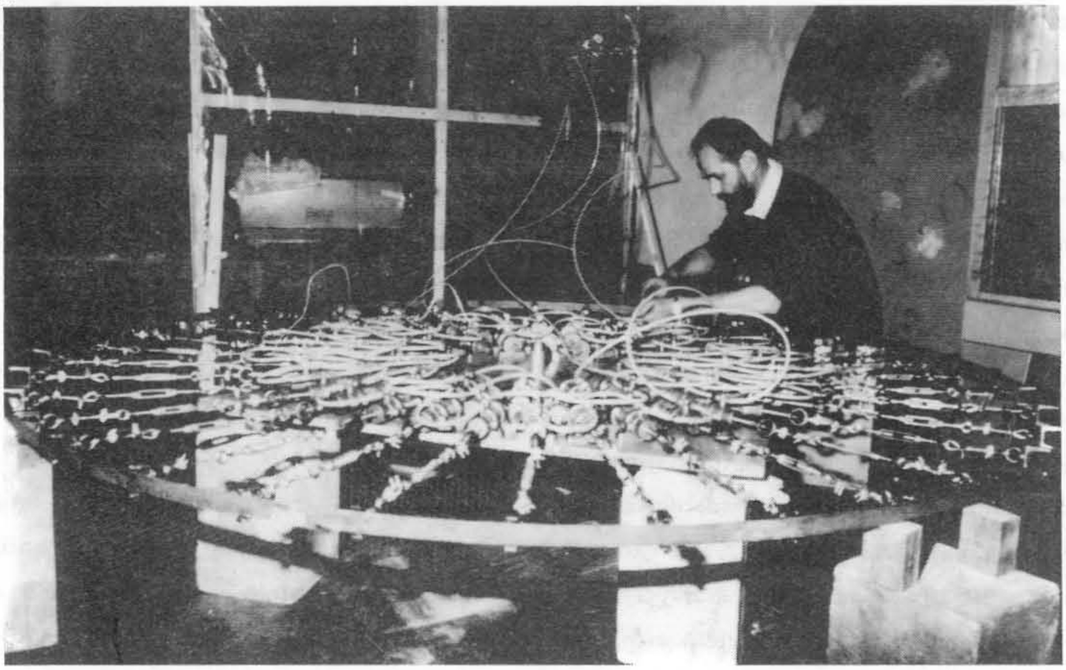

FIG. 19 - Test bench for testing inwards coils stresses.

A second peculiar characteristic of these coils, as reported in (2), concerns the axial forces acting on them in presence of the magnetic field.

In the case of a negative current in the β section, the latter is subject to a force of about 600 tons away from the median plane. We have therefore checked the ability of the Cu-Be rods, shown in Fig. 14, to withstand such stresses. The set-up is shown in Fig. 20, the aluminum block representing on a 1 : 1 scale the coils section. The rods have withstood a stress well above, by a factor of ~ 3, the maximum anticipated. We are therefore confident that this solution will work.

Construction of the main coils power supplies (max current 2000A, 24 V) is in progress. Some components, transistor banks etc, are shown in Fig. 21.

Completion of the power supplies and their testing is expected by the end of this year.

4. - CRYOSTAT

The liquid helium vessel has been ordered, with delivery expected by the end of this year. The outer vacuum chamber has been ordered as well, for delivery expected by Feb. 1983. No major modifications have taken place in the design as reported in (1). The following points are however worth mentioning:

- The central plate of the liquid helium vessel will be carved out of a single forged stainless steel plate. In this way all the holes (for helium, cables etc.) connecting the two (upper and lower) halves of the vessel are simply drilled through, avoiding all problems of vacuum tightness etc. The holes necessary for the insertion of extraction elements like magnetic channels etc. are typically also drilled through the plate radially.
- For the extractor movements and voltage feedthroughs we have decided to use parallel holes, instead of radial ones, as shown in the median plane sketch of Fig. 22. This choice reduces the space available between these elements outside the yoke, but, on the other hand, simplifies considerably the assembly of the extractors and their removal.
- All calculations concerning the pressure arising in the cryostat following a quench, the temperature reached by the coils and the liquid helium boil-off have been completed. The full results are presented as poster paper at this Meeting[10].
- The titanium suspensions of the coils, both radial and axial, are now designed and their procurement will start soon. The radial suspensions consist of three couples of titanium rods, 120^o apart, of 12 mm diameter. The two rods of each couple are at an angle of approximately 5^o, in order to help withstand rotations, although the latter are very unlikely. The axial suspensions consist of three, 18 mm diameter rods, also 120^o apart.

Altogether we expect to be able to mount the coils in the cryostat by next spring, and test the whole system (vacuum, cooldown to LN temperature) before July 1983. The LHe

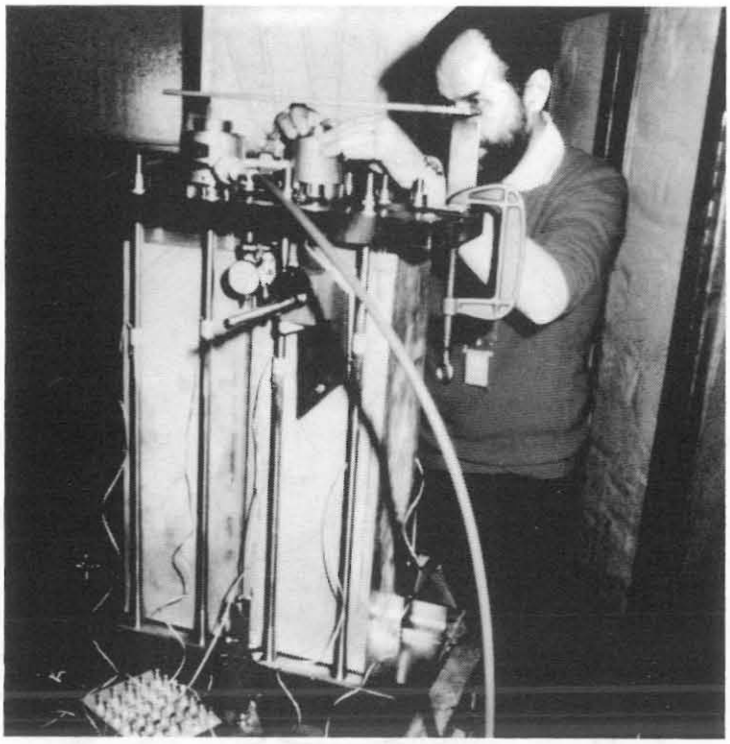

FIG. 20 - Set up for verifying the mech. stress on the Cu-Be rods.

FIG. 21 - Main power supplies components.

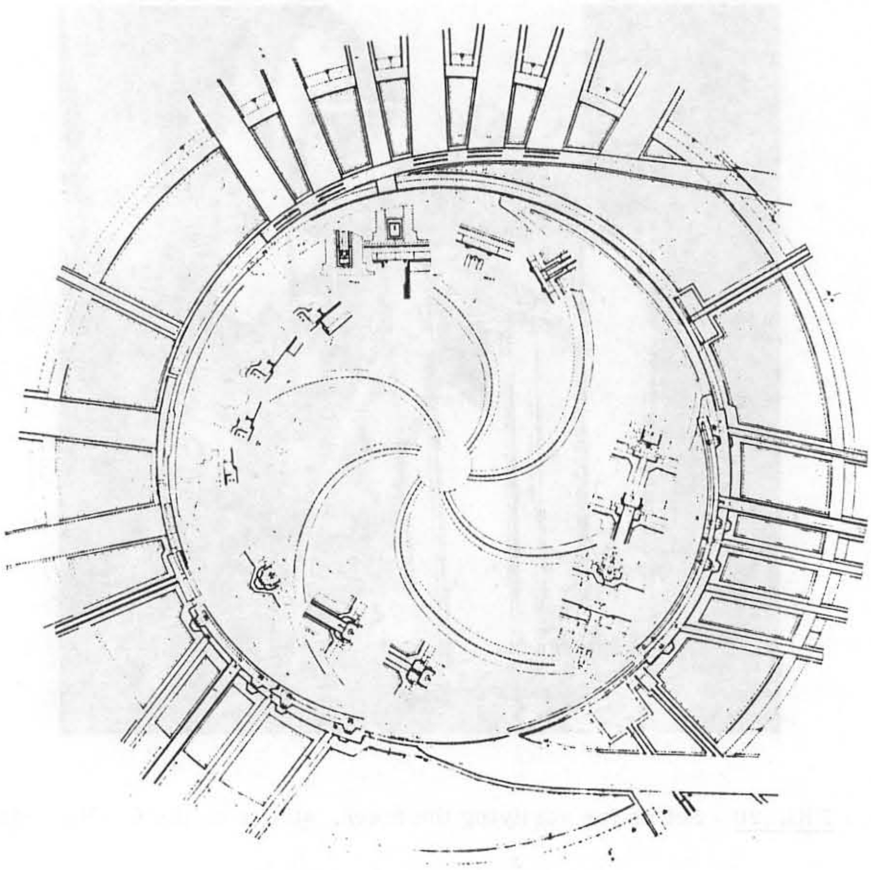

FIG. 22 - Median plane sketch of the cryostat.

liquifier should also be ready by the end of 1982 (TCF 100, Sulzer), with installation anticipated in spring 1983.

5. - RF SYSTEM

5.1. - RF Cavity

The cavities structure is essentially as reported in (1) and (4). At present all technological and mechanical problems concerning the main coaxial structure have been solved and we have already ordered the copper and stainless steel tubes, needed for the cavity prototype. Looking at the two coaxial copper tubes along which the sliding short moves, the internal one is cold-drawn, turned and polished, while the big one is electroformed. Fig. 23 shows the upper half part of the cavity prototype whose fabrication is now underway.

The high voltage ceramic insulator design has been changed because the previous one required metallic vacuum seals which needed for tightness a pressure of ~ 40 Kg/cm and which

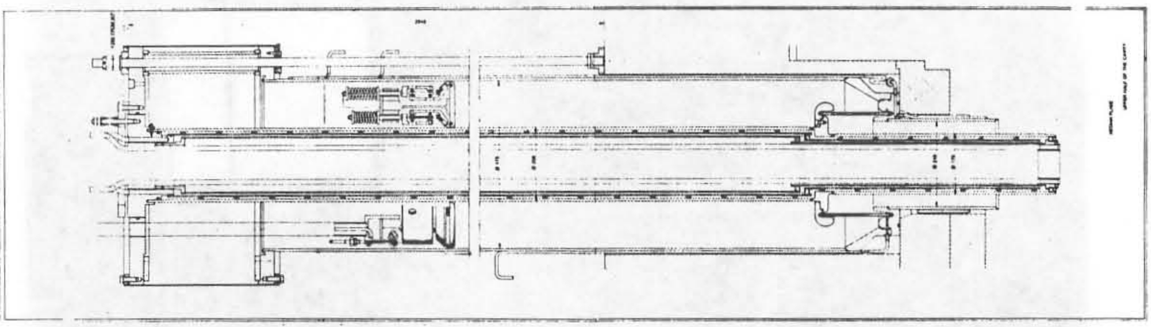

FIG. 23 - Upper half part of the RF cavity prototype.

was deemed too high. The new design, with expecially silver-plated edges, requires only normal viton seals. We expect to receive the insulators by July 1982.

5. 2. - RF Amplifiers

The two stage RF power amplifiers have been completely designed and the manufacturing by Brown Boveri Co. (CH) is in progress. Figs. 24 and 25 show the amplifier status at the end of April 1982. We expect to make the acceptance tests in Baden by the end of October.

5. 3. - Control Systems

A new RF phase and amplitude control system has been designed. The idea and principle of operation, together with expected performances, are presented as a poster paper at this Meeting[11].

5. 4. - Vacuum System

The vacuum chamber for RF cavity prototype tests is presented in Fig. 26. We are now able to use this chamber for testing the actual Superconducting Cyclotron high vacuum system. In the near future we plan to test both a getters solution (SAES-Getters modules UL1250/2) and a cryopump. The comparison of the two systems, and their performance will then allow a decision of the final vacuum system. It is anticipated that several months, and probably up to a year, will be needed before a definite choice is made.

6. - EXTRACTION

Extraction studies have been completed and particle trajectories and phase space tracked up to the yoke exit (R = 191 cm). The previously reported scheme[5] consisting of two electrostatic deflectors and seven magnetic channels is mantained. The following comments are in order :

- Proper fitting of all trajectories with the deflectors does require a variable shape. At Caen

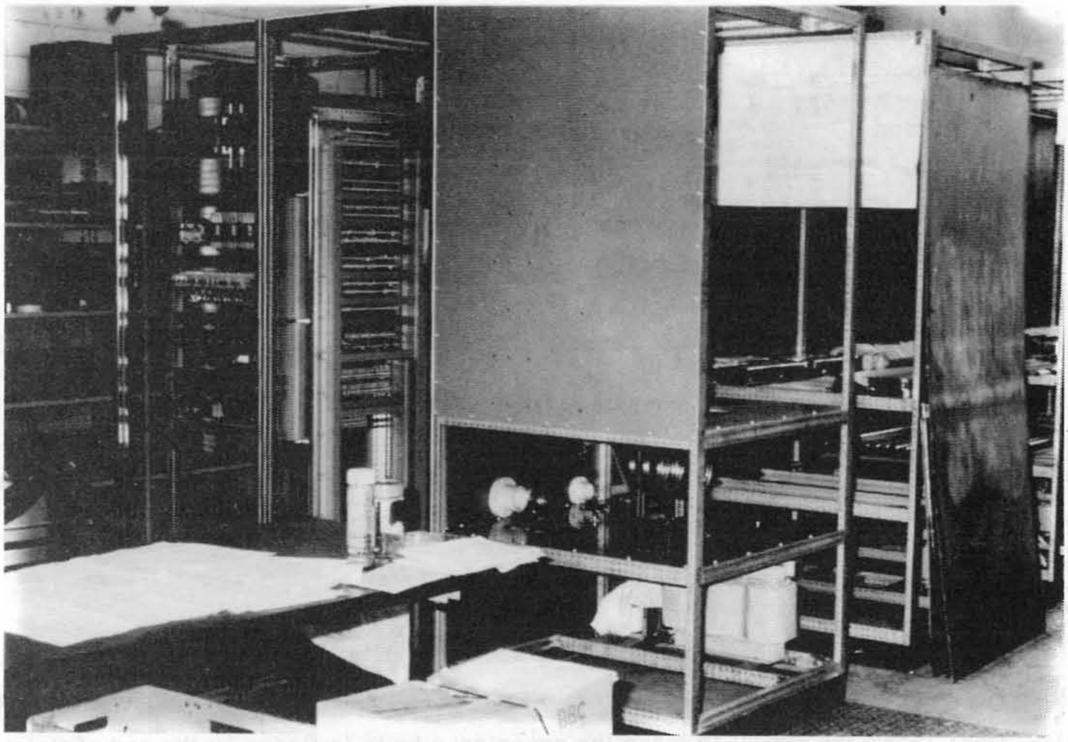

FIG. 24 - RF amplifier while assembling.

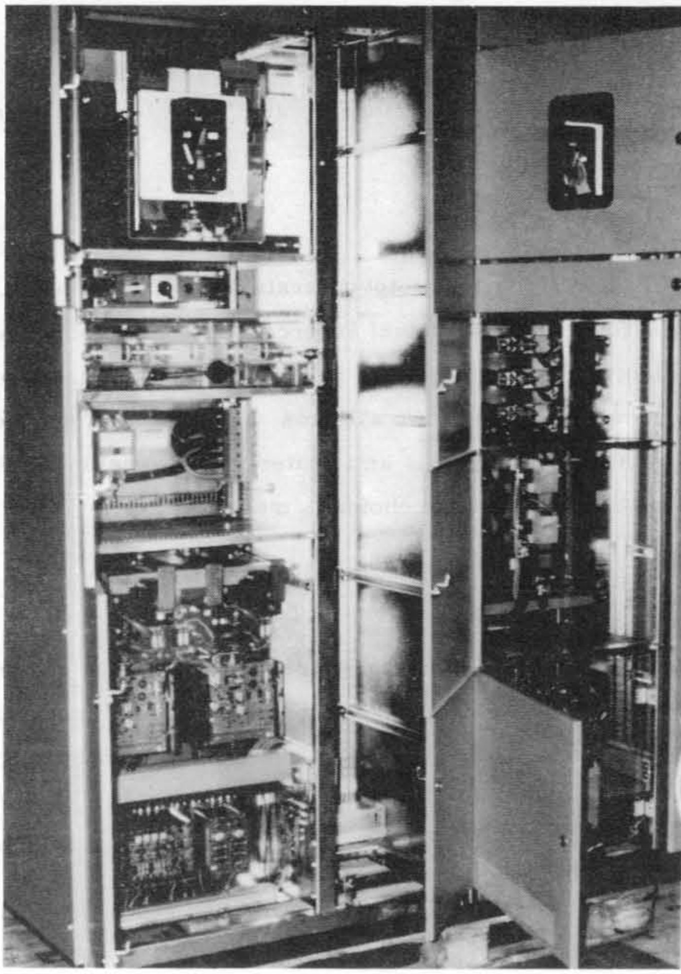

FIG. 25 - Part of the RF amplifier power supply.

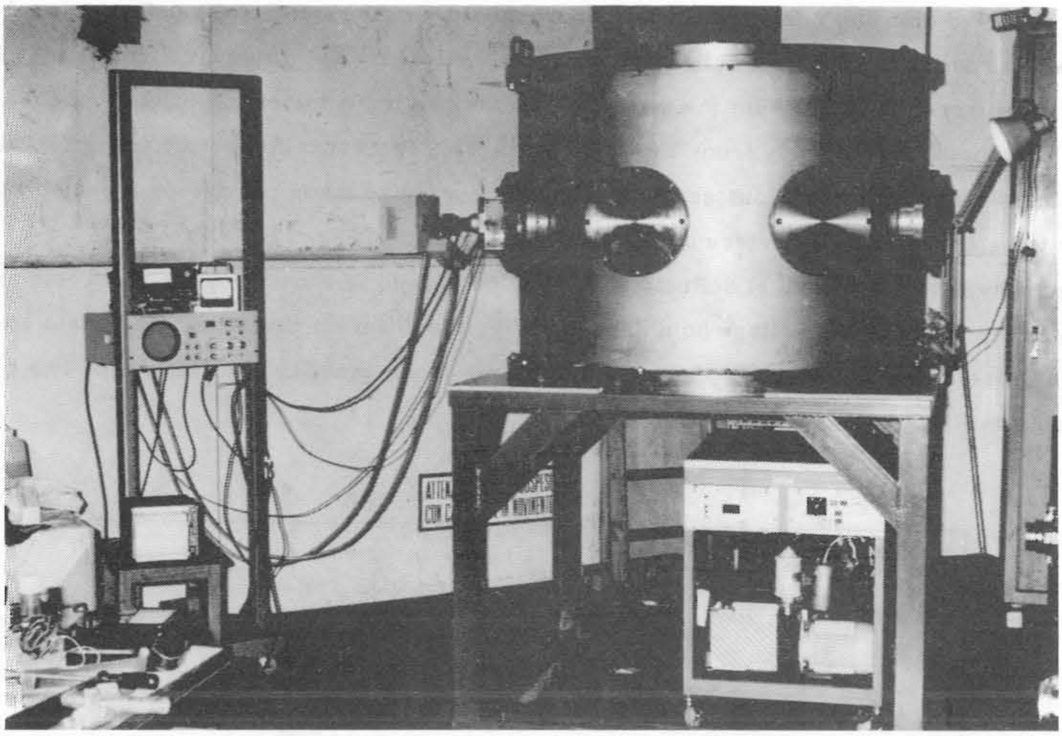

FIG. 26 - Test vacuum chamber.

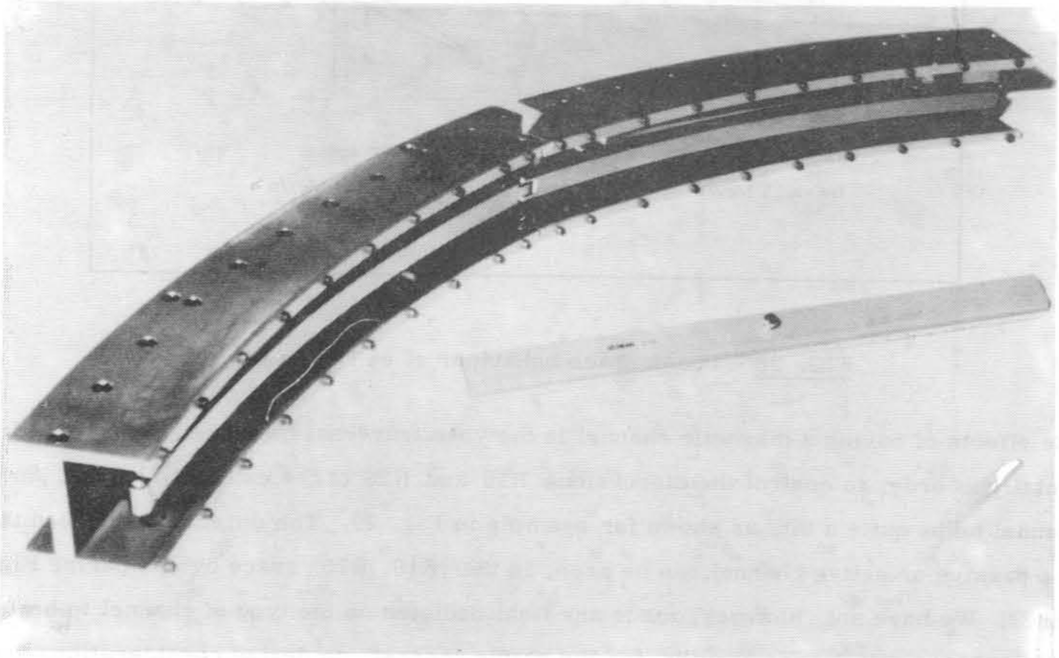

FIG. 27 - Extractor prototype.

we reported that just one swivel point, approximately in the middle of a deflector would suf fice. In reality for the first deflector, which is the longer one, two swivel points may be bet ter. The error in fitting with the deflector the various trajectories would, in this case, drop by a factor of two, namely from 0.8 to 0.4 mm. This fact looks important enough so as to ta ke such possibility in serious account. Therefore we have made provisions for such a deflec tor to be installed in the future as shown schematically in Fig. 22.

- A prototype of a one-swivel deflector has been built, and is shown in Fig. 27. Tests are now underway to check the voltage holding capability, the different insulators materials etc.
- The phase space behaviour of the extracted beams looks excellent, as shown for two typical beams in Fig. 28.

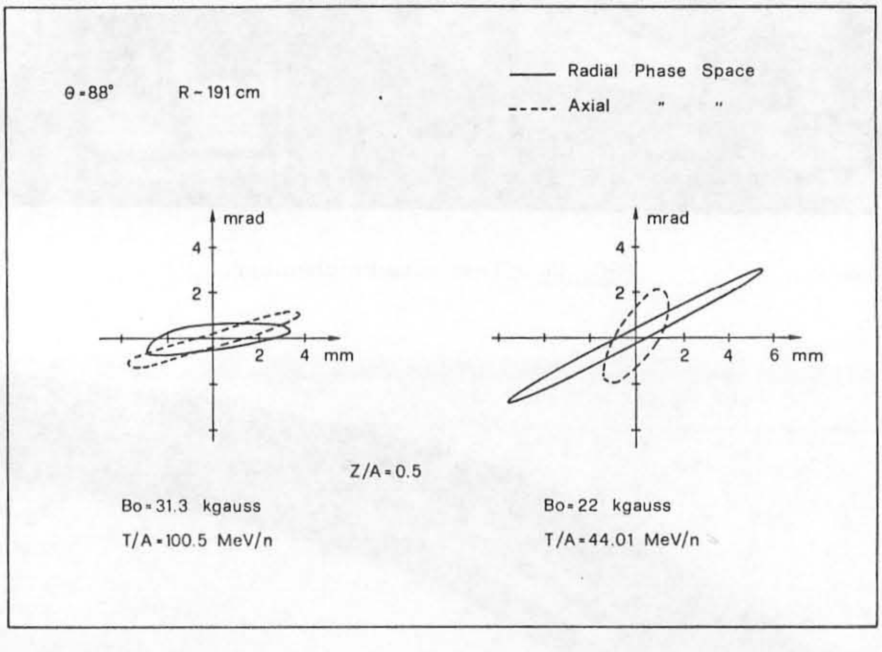

FIG. 28 - Phase space behaviour of extracted beams.

- The effects of having a magnetic channel in the yoke traversal have been investigated, ex- pecially in order to control the dispersions R16 and R26 of the extracted beams. Such a channel helps quite a bit, as shown for example in Fig. 29. The difference between the use of a passive or active channel can be seen, in the (R16, R26) space by comparing Figs. 30 and 31. We have not, however, made any final decision on the type of channel to be used. Such a choice will depend heavily, for the active channel, on design considerations and we will not be able, for at least a year, to put any effort into such a design.

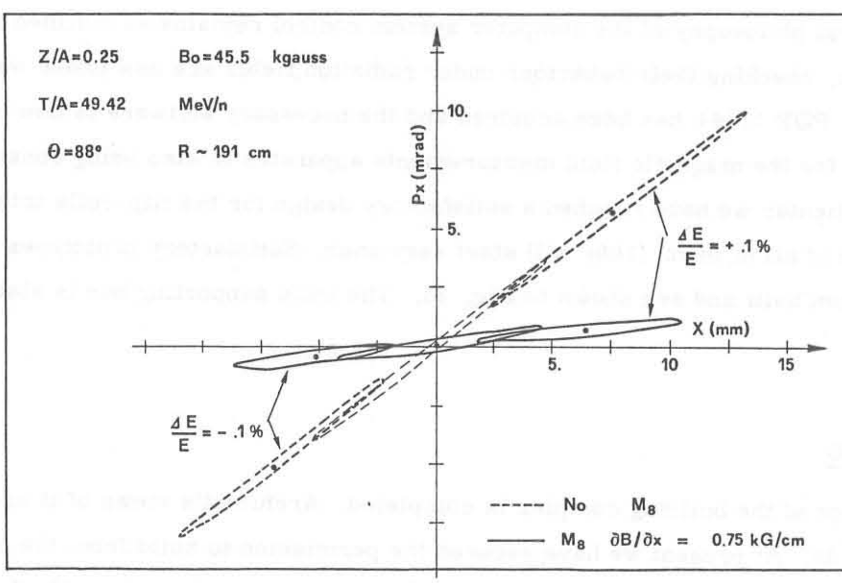

FIG. 29 - Dispersion effects on the extracted beam with channel and no channel.

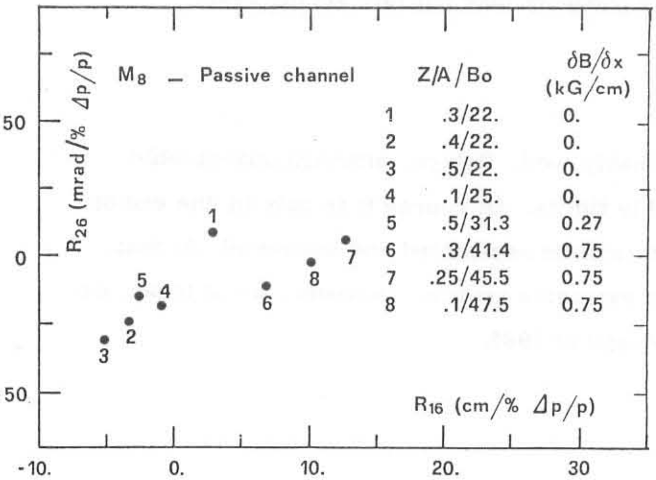

FIG. 30 - R_{26} vs. R_{16} with passive channel.

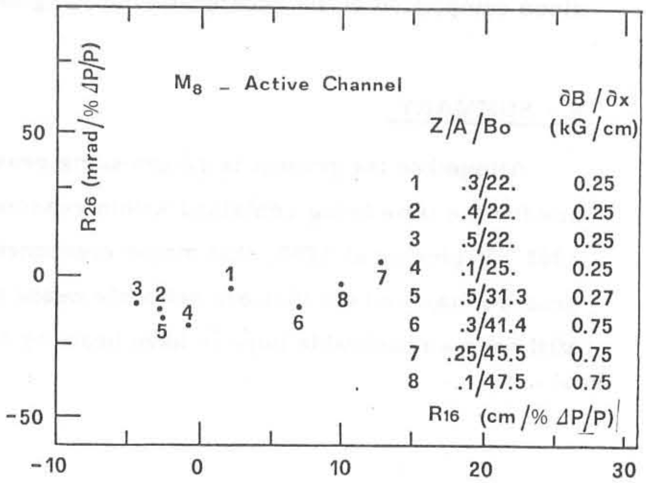

FIG. 31 - R_{26} vs. R_{16} with active channel.

7. - COMPUTER CONTROL

As far as computer control is concerned the main effort is now concentrated on these topics :

- Magnet operation, i. e. c. control of the main coils and of the trim coils ;
- Magnetic field measurements.

The general philosophy of the computer system control remains as outlined in (6). Tests on fiber optics, checking their behaviour under radiation fields are now under way, as shown in Fig. 32. A PDP 11/44 has been acquired and the necessary software is now being developed. Hardware for the magnetic field measurements apparatus is also being constructed and tested. In particular we have reached a satisfactory design for the flip-coils integrators and the production of all of them (100) will start very soon. Satisfactory prototypes of the flip--coils have been built and are shown in Fig. 33. The coils supporting bar is also shown in Fig. 34.

8. - BUILDING

The design of the building complex is completed. Architect's views of it are shown in Figs. 35 and 36. At present we have secured the permission to build from the central authorities and we are waiting for the final permission from local authorities. If all goes well, the building could start by fall of this year.

As a consequence several components of the machine will have to be stored elsewhere, since completion of the accelerator building may probably take till late spring 1983.

9. - SUMMARY

Altogether the project is progressing reasonably well. Delays, although unavoidable, are for the time being contained within reasonable limits. Of course it is only by the end of 1982 - beginning of 1983, that major components will be assembled and delivered. At that time we may find out that our schedule needs an extensive review. However, as of today, we still have a reasonable hope to have beam by the end of 1985.

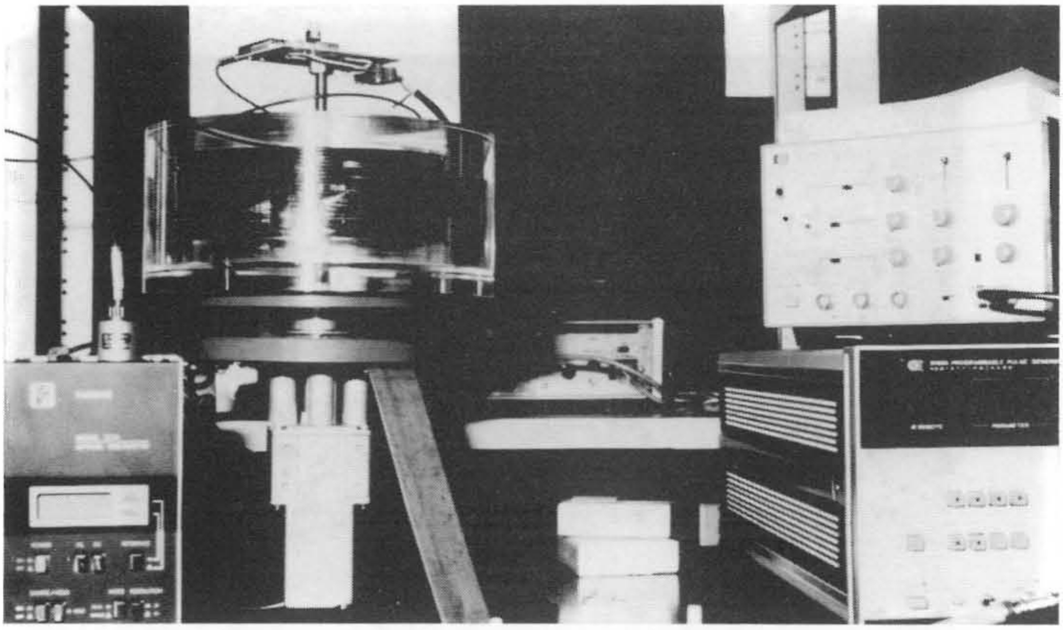

FIG. 32 - Fiber optics test apparatus.

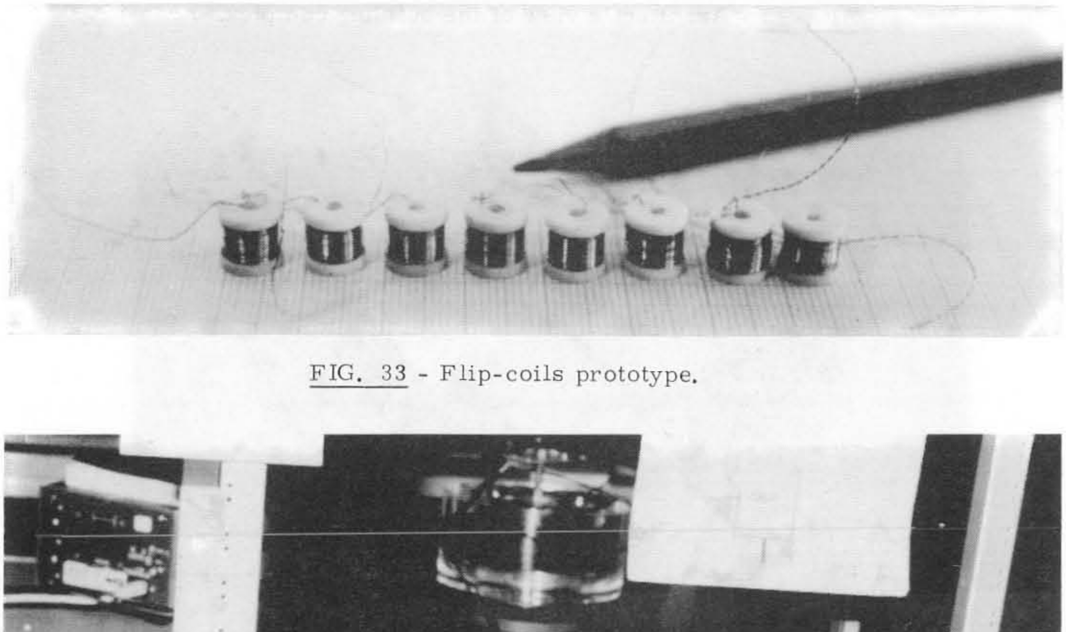

FIG. 33 - Flip-coils prototype.

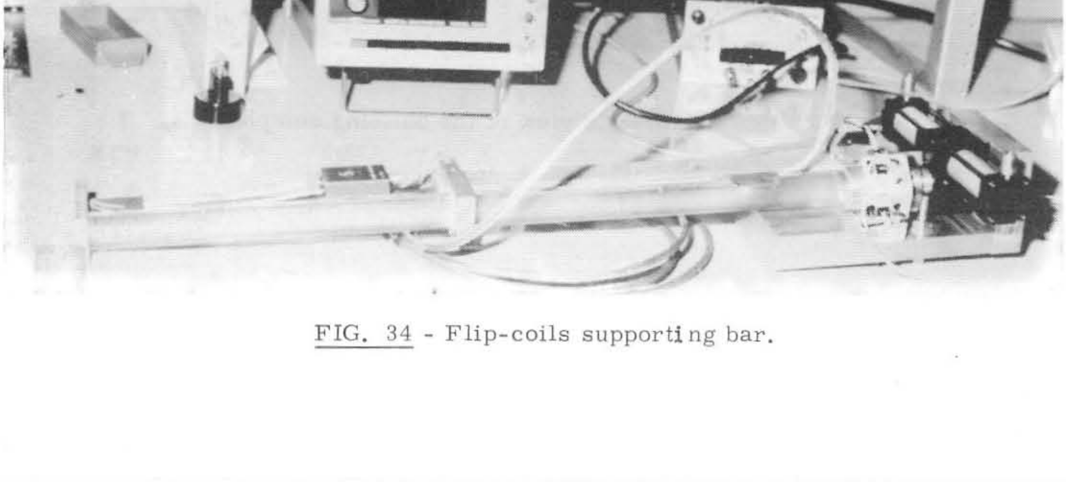

FIG. 34 - Flip-coils supporting bar.

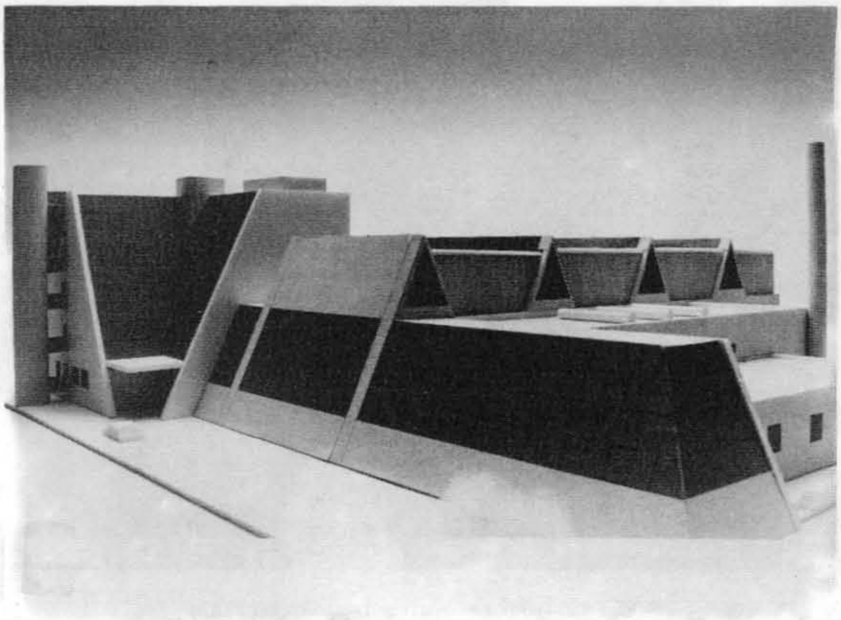

FIG. 35 - Architect's view of the building complex.

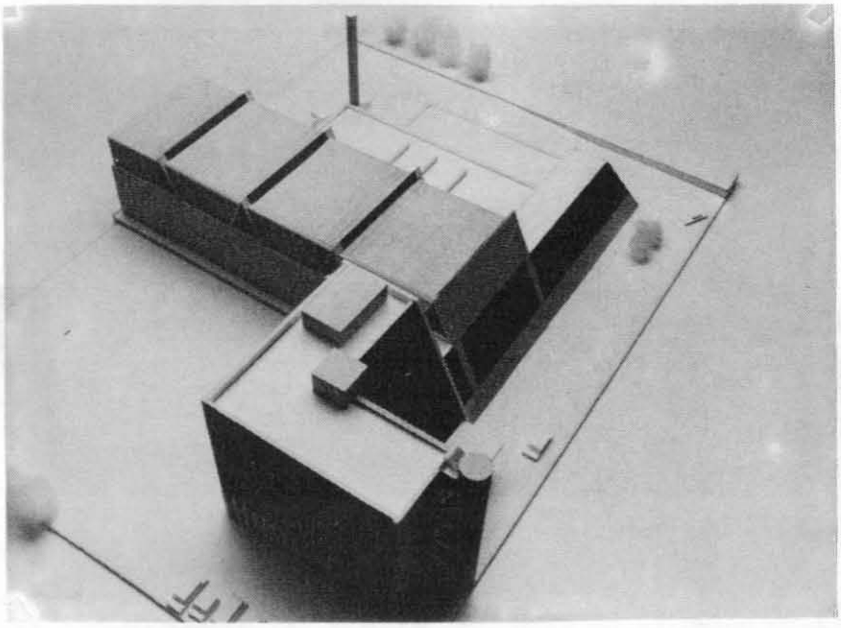

FIG. 36 - Architect's view of the building complex.

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