# PROGRESS IN THE CONSTRUCTION OF THE MILAN UNIVERSITY CYCLOTRON

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(Presented by F. Resmini)

At the 1962 Los Angeles conference on sector-focused cyclotrons, the project and design studies for a 45 MeV proton cyclotron for the University of Milan were reported¹⁾. In the past year the magnet, its motor-generator set, and the power supply were delivered and installed. In the meantime other components, notably the magnet coils, were built in our shop. Thus, the construction of the cyclotron is now fairly well advanced, and tests of magnet performances are just starting.

In this report the status of the project will be summarized, and a few details added with regard to components modified since the Los Angeles conference.

## The Magnet

It may be recalled that the Milan cyclotron has a pole diameter of 166 cm, and three 60° straight (Thomas) sectors. The magnet assembled, but with the pole tips taken apart, is shown in Fig. 1 and 2. The shallow sectors that can be seen on the poles are grooved to accommodate the trimming coils (of which there will be 8 pairs); they remain outside the vacuum chamber. On these shallow sectors are to be mounted two circular iron plates; they serve as the lids of the vacuum chamber, and also support the inner sectors. One of the plates with the inner sectors bolted on it is shown in Fig. 3. The pole tip configuration is illustrated in the exploded view, Fig. 4, together with the vacuum chamber.

The mechanical construction of the magnet was quite satisfactory. Errors in pole piece parallelism and vertical alignment were measured and found to be well within 0.05 mm.

The 200 kW motor-generator set was installed and tested. Its performance meets the requirement of supplying current constant to $1/10^4$ over 3 minute time intervals.

## Field Measuring Arrangement

The magnet measuring system is designed to record the data taken at any chosen radius with a minimum displacement of 2° in azimuth. The positioning equipment consists of a fixed plate with 180 peripheral slots, and of a radial beam which carries the probe. The azimuthal movement of the beam is driven by compressed air; the radial position is set manually by means of a long precision screw. The positioning error

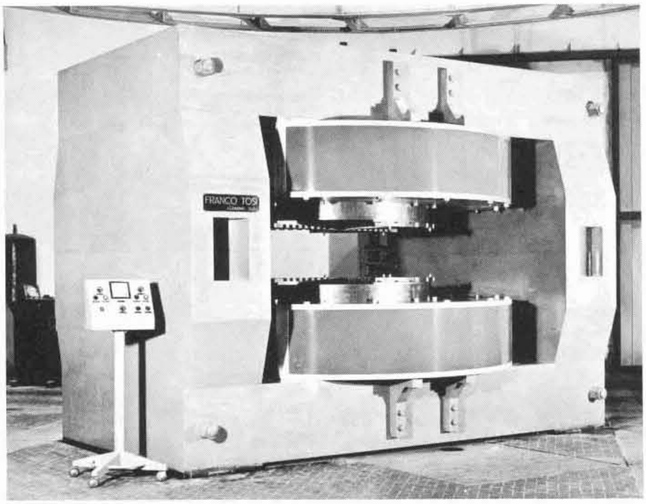

Fig. 1 Cyclotron magnet. Overall dimensions are 442 x 265 x 320 cm height; pole diameter is 166 cm. Niches on frame legs are for jacks to lift the upper half of magnet.

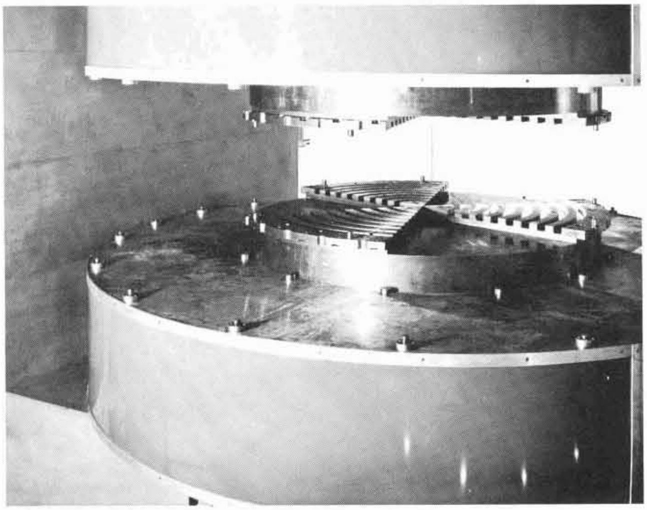

Fig. 2 Magnet gap with grooved shallow sectors.

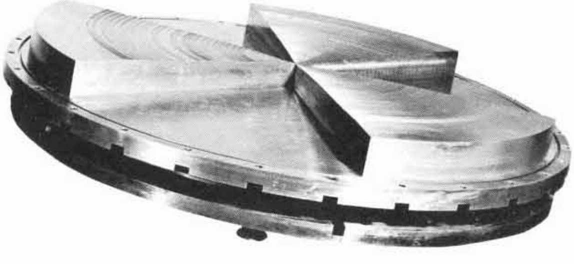

Fig. 3 Inner sectors mounted on circular iron plate which doubles as part of the vacuum tank wall. Pole-tip countouring shown is not yet final.

is expected to be ± 0.01 cm radially and ± 25 seconds of arc azimuthally.

The probe is a Hall generator, Siemens FC 33; its temperature is controlled to within 0.05° C by circulated water. The current through the Hall plate (100 mA ± 0.01%) is supplied by a stabilizer designed in our laboratory. The Hall voltage is amplified and measured by a 5-digit voltmeter (Electro-Instruments, Model 3500) with a precision of 0.01%. The Hall generators are calibrated against nuclear magnetic resonance signals; to provide the reference field our original model magnet has been modified. With new tapered poles of ARMCO iron, up to 21 kG are obtained with field gradients of 0.3 G/cm in the central region.

In making measurements, the probe is to be set manually at the desired radius; then the data is taken automatically, the probe being swept azimuthally. Measured Hall voltages and other relevant information are punched into cards and tape ready for computer evaluation.

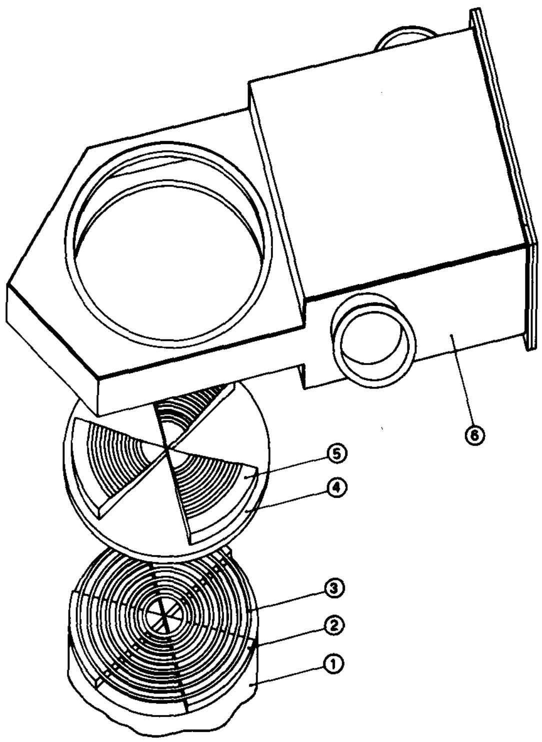

Fig. 4 Exploded view of pole-tip assembly and vacuum tank. 1) lower pole of magnet, 2) shallow sectors, 3) trimming coils, 4) circular iron plate supporting the inner sectors, 5) inner sectors, 6) vacuum tank with pumping ports.

All the parts of this measuring system were tested and found satisfactory, except for the positioning plate the delivery of which was delayed.

## Central Region

A full-scale model of the central region was built to study the electric field patterns by means of an electrolytic tank. The electric field will be measured in the median plane, and approximated with a series expansion outside this plane.

A computer program which integrates the equations of motions, by the Runge-Kutta method, and follows the particles up to the 5th turn was prepared and tested.

The first trials with the electrolytic tank were made to establish the precision attainable; the error in the measurements turned out to be of the order of 2%.

## Resonator and RF Power Supply

The RF resonator is the only major component in our cyclotron where considerable changes in design were made since the Los Angeles report. It was stated then that we proposed to improve the mechanical design of the resonator; for this purpose a second full-scale model was built. The structure of the new resonator retains the basic features of the old one. It consists of a single 180° dee attached to a stem of rectangular cross-section. However, the shorting plane which terminates the RF line

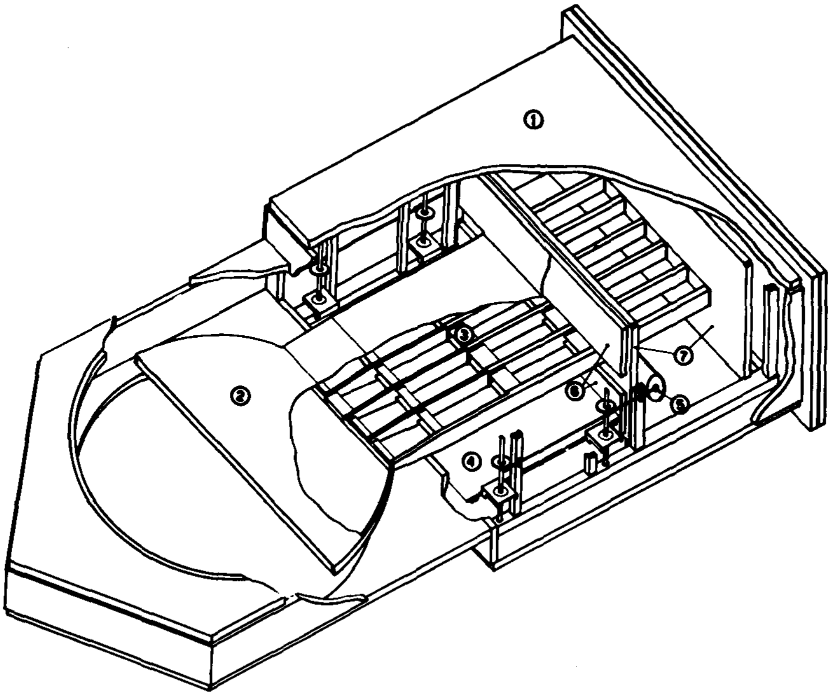

Fig. 5 Cut-away view of resonator box. 1) vacuum tank, 2) dee, 3) dee-stem cantilevered structure, 4) lower movable panel (upper one not shown) 5) panels drive, 6) shorting planes, 7) dee-stem support.

is now fixed rather than sliding. The desired range of resonant frequency variation (from 17 to 22 MHz, as checked with model measurements) is obtained by positioning two panels parallel to the dee stem good electrical connection at the ends of the panels is assured by arrays of fingers. This design reduces appreciably the problems of mechanical construction.

Fig. 5 shows a cut-away view of the resonator box, and Fig. 6 a horizontal cross-section through it. The various parts of the resonator and vacuum tank are now being built.

The RF power set is a commercially produced generator (Marconi Italiana, Model AD 312) originally designed for short-wave broadcasting. It is of the MOPA type, with a final stage using two BR 189 tubes in push-pull to deliver a maximum output power of 120 kW. The set has already been assembled in the equipment annex (Fig. 7).

## Reference

1) A. Luccio, G. Pavanati, F. Resmini, C. Succi and G. Tagliaferri, Nucl. Instr. and Meth. 18-19, 74 (1962).

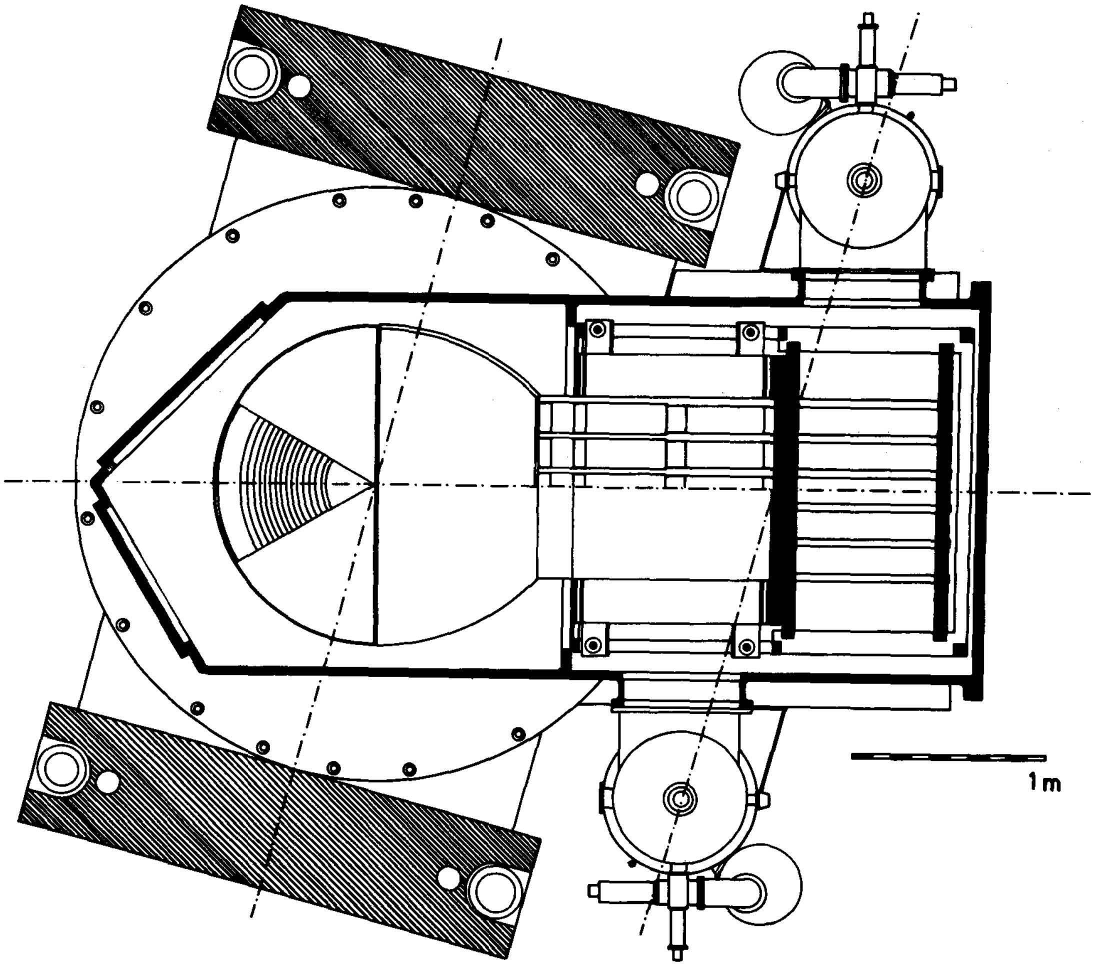

Fig. 6 Horizontal section of resonator.

## DISCUSSION

**BLOSSER :** You mentioned that you plan to integrate axial equations of motion in the electric field obtained from electrolytic tank data. This requires second derivatives of the potential. I wonder if you had considered the effect of your measurement errors on these derivatives and whether the derivatives would be meaningful when such errors are considered?

**RESMINI :** We are now investigating the accuracy of the measurements so I cannot now give the magnitude of the error which we have in field components.

**LIVINGSTON :** When will the machine be finished?

**RESMINI :** The magnet is assembled. The inner pole sectors for producing the correct magnetic field configuration have been calculated from model magnet measurement but, as is well-known, the magnet field can be properly checked only on the full-scale magnet. We intend to spend a few months on magnetic field measurement. Perhaps the machine will be completely assembled in the first months of 1964. Then we shall begin with beam searching.

**TICKLE :** When you use Hall-probe control currents as large as 100 mA, it may introduce an error in the measurements when you go rapidly from a region of strong field to a region of weak field. This is due to the variation in the power dissipated in the probe and to the thermal resistance between the semi-conductor layer and the outer surface of the encapsulation.

RESMINI : Yes, this is true. We have made some tests on our reference magnet by sweeping the magnetic field rapidly from 9 up to 20 kG and vice versa. We have observed a very good reproducibility of a few parts in 10,000.

TICKLE : This must imply that the thermal time constant is rather short. At UCLA, the Berkeley group reported a time constant larger than one minute.

RICHARDSON : In this connection. I might mention that Martin Smith of UCLA has developed a technique of automatically compensating for the change in power and temperature in the Hall plate. This consists of the simultaneous measurement of the Hall voltage and the IR drop in the plate. Feeding this information into a computer program yields B independent of the temperature. This technique has been checked over a temperature change of 10°C.

RESMINI : We plan to check frequently the Hall probe by a nuclear magnetic resonance. Regarding the thermal drift of the Hall plate, we find that our method of keeping the temperature constant works well; from the first measurement we have found that it is not necessary to recalibrate the plate very often.

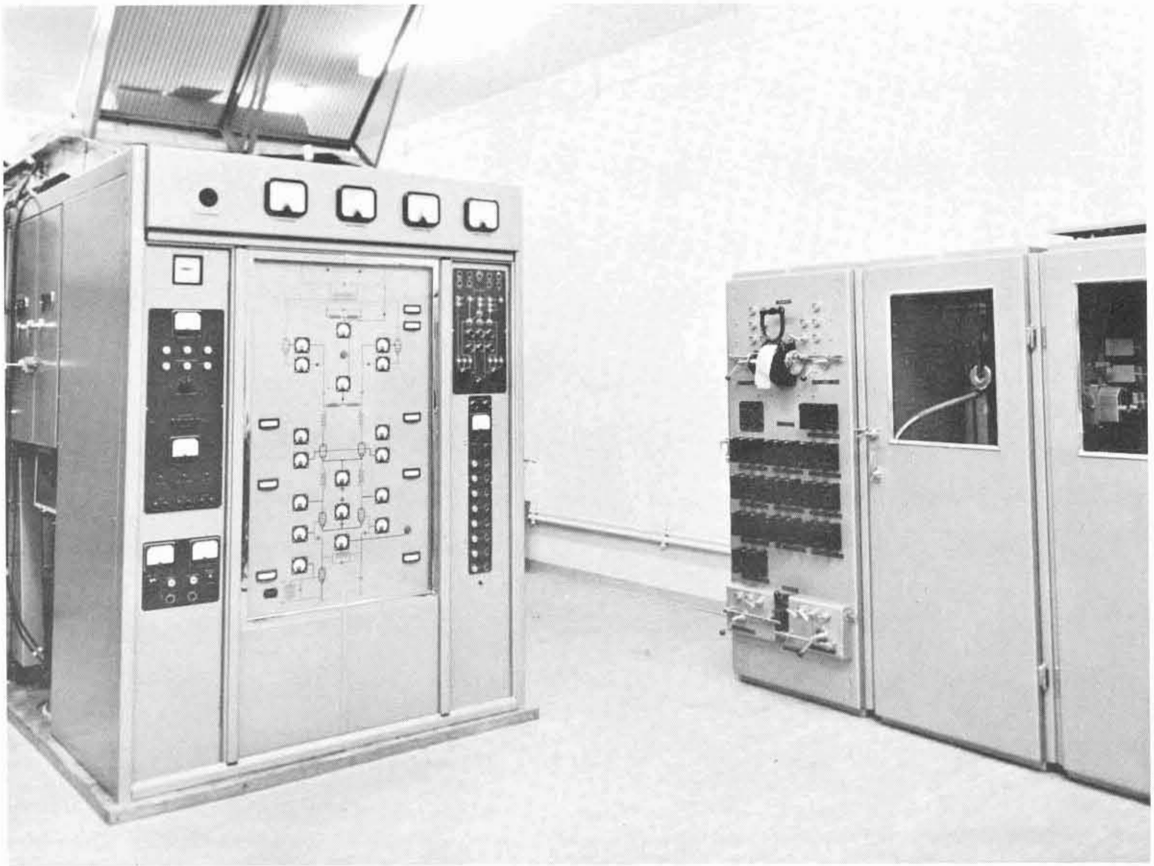

Fig. 7 RF power set. The control panel can be seen in left foreground