PRELIMINARY REPORT ON THE FES BEAM PROFILE MONITORS

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Abstract

The problem of obtaining the profile of the fast (and eventually slow) ejected beams at the Serpukhov accelerator is studied. In part 1 a review is made of possible beam detection methods, of which the secondary emission mechanism is retained. In part 2 the location of the monitors and the special problems connected to them are studied and in part 3 some solutions are proposed.

1. REVIEW OF POSSIBLE DETECTION MECHANISMS

1.1 Standard bunch

In order to compare the performance of different mechanisms, we introduce a "standard beam", divided into 30 "standard bunches". The standard beam is circular with a diameter of 2,5 cm (section $S = 5\ cm^2$). The protons are uniformly distributed over the cross-section. Each bunch contains 5×10^{10} protons.

1.2 Energy loss of the beam in interposed material

We suppose a high energy proton loses 2MeV per g/cm^2 of interposed material. The energy lost per bunch and per gram exposed material is then :

$$\Delta E = 3{,}2\times10^{-3}\ \text{Joule/g} = 320\ \text{rad.}$$

1.3 Detection of the E.M. field of the beam

The E.M. field of the beam can be used to measure the intensity and position of the beam but, up to now, no means is known to derive the beam profile (B.P.) from the E.M. field.

1.4 Detection of the termal effect

As calculated in paragraph 1.2, a standard bunch loses about $3{,}2 \times 10^{-3}$ Joule or $0{,}75 \times 10^{-3}$ cal per gram exposed material. The resultant temperature-rise could be detected by measuring the resistance change of a wire. A material with a low heat capacity and a large temperature coefficient of resistivity is necessary. With Tungsten, one of the best suited metals, the temperature rise is $2{,}4 \times 10^{-2}\ {}^oC$ and the resistance change is 10^{-4}. This change is difficult to detect at a distance and the real change will be smaller because only part of the wire is exposed to the beam. Moreover, a wire has too low a resistance; thin-film resistors will be necessary with still smaller results because of restrictions in the choice of materials.

1.5 Chemical and activation effects

These effects can usually only be detected after removing the test specimen out of the vacuum chamber and thus are not useful to our purposes.

1.6 Luminescence effect

Screens of certain materials will light up when exposed to the beam. They can be monitored by T.V. cameras. This is a very useful effect but gives no quantitative results and is not very sensitive[1].

1.7 Conduction effect in semiconductors

The conductivity of semiconductor materials is heightened by several orders of magnitude in the presence of a high-energy beam. Both the bulk effect and the effect on back-biased junctions can be used. However, this effect can only be exploited practically if the semiconductor is in the form of a monocrystal with few defects. A large radiation dose will rapidly deteriorate the performance. The effect is thus of limited use for B.P. measurement[2].

1.8 Conduction effect in insulators

High energy protons will form electron-hole pairs. The electron will drift under influence of an electric field until it is captured. The mean free path of the electron will, in general, be small compared to the thickness of the insulator but the general displacement of the electron cloud will be equivalent to a current.

Again, the effect will be larger in single crystals, such as sapphire, where the life-time of the electrons is long, but it will rapidly deteriorate with the radiation dose. On the other hand, in amorphous material the effect will be small but it will mount with the radiation dose, as some short-range order will be produced. In between, materials can probably be found which change little with the dose and where the effect is still useful.

According to the (scarce) literature the effect is linear with the rad. dose in wide limits but some memory effects are possible due to charge distributions in the insulator. Anyway a great deal of research will be necessary in order to make a practical device.

To conclude, some measured values of conductivity change[3,4] :

	no radiation	320 rad in 20 nsec
single crystal sapphire	$< 10^{-10}$	6×10^{-3} $(\Omega\text{-m})^{-1}$
mylar sheet	$< 10^{-10}$	10^{-6}

1.9 Residual - gas ionisation

The beam-protons ionise the residual gas molecules. Free electrons and ions are formed, which can be collected by charged strips or wires. The collected charge is proportional to the residual pressure. The device is very sensitive to magnetic fields and difficult to shield. It does not intercept the beam, however, and it is the only beam profile monitor (B.P.M.) that can detect the internal beam.

The same principle can be used in air but then the collecting wires must be placed in the beam. Secondary emission will occur and the device becomes rather unreliable[5,6,7,8,12].

1.10 Secondary - emission effect

When high-energy protons strike a conductor, electrons are displaced and some escape the material. As most electrons have an energy of only a few eV, this is mainly a surface effect.

For the same effect, foils give less disturbance to the beam than wires and are thus preferred. An efficiency of 5°/o secondary electrons per proton can be obtained with the foils (both sides together). Positively charged electrodes in the vicinity are necessary to collect the electrons.

The monitors have to be shielded because, in the presence of a magnetic field, the electrons fall back on the foil.

A foil, 1,5 mm wide, exposed over 25 mm of its length to a standard bunch, will collect a charge $\varphi = 3\times10^{-11}$ Coulomb. This is enough to charge a 100 pF capacitor to 0,3 Volt.

The secondary emission effect, in spite of its sensitivity to magnetic fields is the most useful effect studied and a B.P.M. using this effect will be developed in the second and third parts[1,9,10,11,12].

2. SOME GENERAL CONSIDERATIONS ON THE SERPUKHOV B.P.M.

2.1 Possible mounting places

B.P.M. can be mounted in the ejected beam :

a) In SS 24, just before the mobile septum magnet (M1).
b) In SS 26, just before the fixed septum magnet (M2).
c) In SS 27, on beam A (M3).
d) Eventually further down the beam transport.

2.2 Influence of magnetic fields

In the presence of a magnetic field, the secondary electrons leaving the Al strips move in a circle and may fall back on the strips. In order to prevent this, collecting electrodes are placed at a distance less than the radius of the electron trajectory. This radius is function of the electron energy and the magnetic field.

$$R = 3{,}3 \times 10^{-6} \frac{\sqrt{\mathcal{E}}}{B}$$

R in m
$\mathcal{E}$ el energy in eV
B magn. field in Tesla

Electrons with energy less than 0,5 eV are less than 10 % of the total. To collect electrons of 0,5 eV with a collector placed at 2 mm, the maximum tolerated field is :

$$B_{max} = 12 \text{ Gauss}$$

M2 and M3 have to be placed between the magnet windings where the stray field is about 1000 Gs. M1 can be placed in the septum magnet tank where the field is about 50 Gs. Consequently, all monitors have to be shielded.

The shielding of M2 and M3 has a special consequence. When these monitors are placed on the ejected beam, the stray magnetic field is shielded over a distance of about 7 cm (the length of the shielding). If these monitors are removed after the measurement, this field is active again and equivalent to a kick of 10^{-2} Tesla or 0,5 °/o of the kick of the mobile septum magnet. Consequently, these monitors have to stay fixed on the beam. This is no disadvantage because their influence on the emittance of the beam can be made negligible as we shall see.

There are no theoretical objections to the removing of M1 but it would be technically very convenient if this monitor too could stay fixed.

M1 and M2 are close to the beam envelope at injection. The stray field is distorted by their shielding and we have to check that this does not disturb the internal beam.

2.3 Multiple scattering angle due to the B.P.M.

In the focusing sections of the Serpukhov accelerator, the actual mean scattering angle is about 0,3 mrad. If we add to this another 0,14 mrad, the beam radius becomes only 10 °/o larger because those scattering angles add quadratically. Those 0,14 mrad correspond to 1,9 g/cm^2 material in the beam or 7 mm Al sheet (at 70 GeV). The beam diameter increase (in °/o) is proportional to this thickness for small increases.

As we shall see in part 3, the total thickness of Al sheets for the 3 B.P.M. together is 0,36 mm, which corresponds to a beam diameter increase of only 0,6 °/o. Consequently the monitors can be left in the beam without harm.

2.4 Other problems

M1 has to move in and out the beam, synchronous with the mobile septum magnet and with the same precision. The simplest way to do this, is to mount the monitor on the septum magnet chassis. A difficult point is the connection of about 40 wires to the outside world by means of flexible strips.

M1 and M2 must not hinder the internal beam. The supporting frame of M1, towards the interior of the vacuum chamber, must not be thicker than the septum (3 mm). It may be up to 15 mm for M2. Consequently M2 can have a heavier magnetic shield than M1, which is a happy coincidence.

2.5 Size and resolution of the monitors

A window 40 mm high and 50 mm wide will accommodate all beams. With strips 1,5 mm wide and a space between of 1 mm, a resolution of 2,5 mm' can be obtained. In that case 16 horizontal and 20 vertical strips are needed to fill the window.

3. SOME SUGGESTIONS FOR CONSTRUCTION

3.1 Construction of the B.P.M.

The general layout is given on fig. 1. The magnetic shield in armco iron serves as support for the whole assembly. The horizontal and vertical strips are made of 1,5 mm wide and 50 μ thick aluminium sheet. They are clamped on the outside under a soldering pin and glued or bonded on the other side to a ceramic support. These strips are sandwiched between Al sheets 20 μ thick. The space between two strips is 1 mm. Between the strips and the sheets there is 2 mm space. Fig. 2 gives a view of the strips and sheets. The sheets are clamped under copper strips.

For ease of mounting the shield is composed of two parts. The horizontal strips with outside contacts and two sheets are mounted on the left part (fig. 2) and the vertical strip with their contacts and the remaining sheet on the right part.

Fig. 3 gives an inside view of the shield (left and right part separated). The numbers on the planes indicate the level (in mm) with respect to the reference plane A - A' (fig. 2).

The accurate positioning of the strips will be a problem. This can be made easier by making guiding identations on the ceramic and iron supports.

Machining the ceramic parts is another problem. Perhaps the new machineable ceramics can be used. They must be baked afterwards and then shrink about 12 $^{o}/o$.

3.2 The magnetic shielding

Fig. 4 gives the magnetic field distribution around the shield. For an outside field of 0,1 Tesla, the maximum induction in the iron will be about 1 Tesla. The corresponding field in armco iron is about 2 oersted. Consequently, the maximum field inside the shield will be less than 5 gauss, which is adequate.

For the same outside field of 0,1 Tesla, the maximum induction in the "septum" shield is about 1 Tesla for a shield of 1 mm thickness. For monitors working in a high field, a thicker septum will be used, however (3 mm).

The total weight of the shield is about 4 kg.

3.3 Mounting of the B.P.M. on the mobile septum

Fig. 5 gives a possible mounting method. The B.P.M. is fixed on the septum magnet chassis. Connection to the bottom of the tank is made by two rows of 20 flexible strips in berillium - copper. They allow the monitor to move 45 mm in either direction. The strips are 7 mm wide, with 3 mm space between. The total length of a row is then 20 cm.

3.4 Input multiplexing

The charge, collected on the strips, is stored on 36 coaxial cables, 5 m long. These cables are switched one by one into a low-loss cable (1 cm outer diameter is sufficient), which guides the resultant pulse to the local control room where it is processed. This pulse will be 50 µs long and, for a standard bunch centered on the strip, it will be about 0,1 V high.

The switching is done by means of mercury reed-relay switches[12]. An existing design accepts 20 input cables. If this design is used, two units, switching into 2 output cables will be necessary.

The time between two successive switchings is 5 msec. The total read-in takes consequently 100 msec. For a $4^{0}/o$ accuracy, the time constant of the storage cable has to be better than 2,5 sec. This means an insulation resistance of at least $10^{10}\Omega$, and this in a radiation environment.

The electron-collecting sheets cause a special problem. In order to collect all electrons, they must be at +50 to +100 Volt. They are not insulated from the shielding and, consequently, the whole shielding will be at this voltage and it has to be insulated from ground. In order to prevent charge-up of the strips via leakage paths, this voltage is pulsed on only for a few µ seconds, centered around the moment of ejection.

3.5 Electronics

Fig. 6 gives a possible configuration. All signals are routed through the computer which commands the display. Fig. 7 gives a possible display. Calibration marks are generated every cm.

3.6 Immediate action to be taken

It is suggested to construct a prototype B.P.M. to put it into a small vacuum tank with thin input and output windows and to put.the whole thing in an ejected beam.

Roughing of the vacuum tank can be done with an auxiliary pump and only a very small ion-pump will be needed to maintain a vacuum of 10^{-5}.

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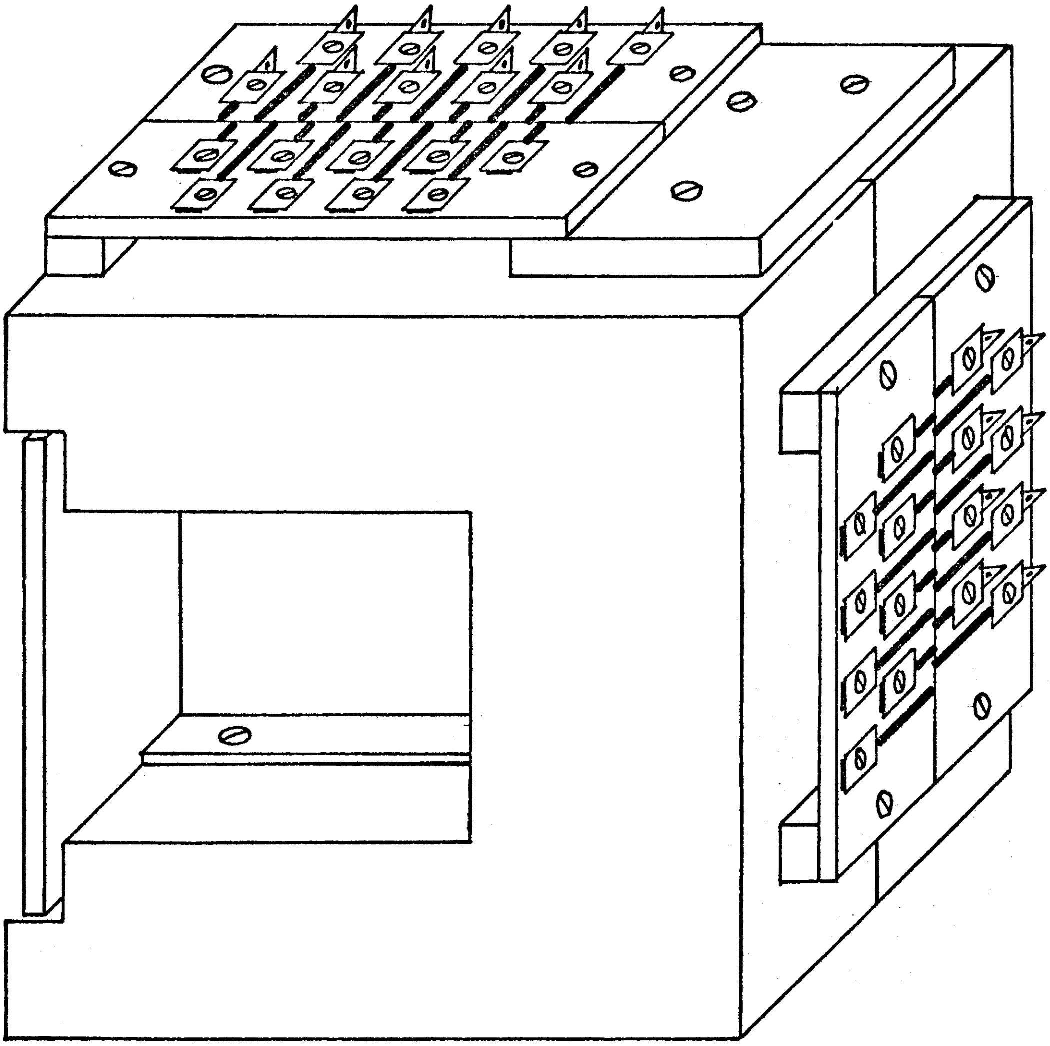


Fig. 1 : General view of the beam profile monitor

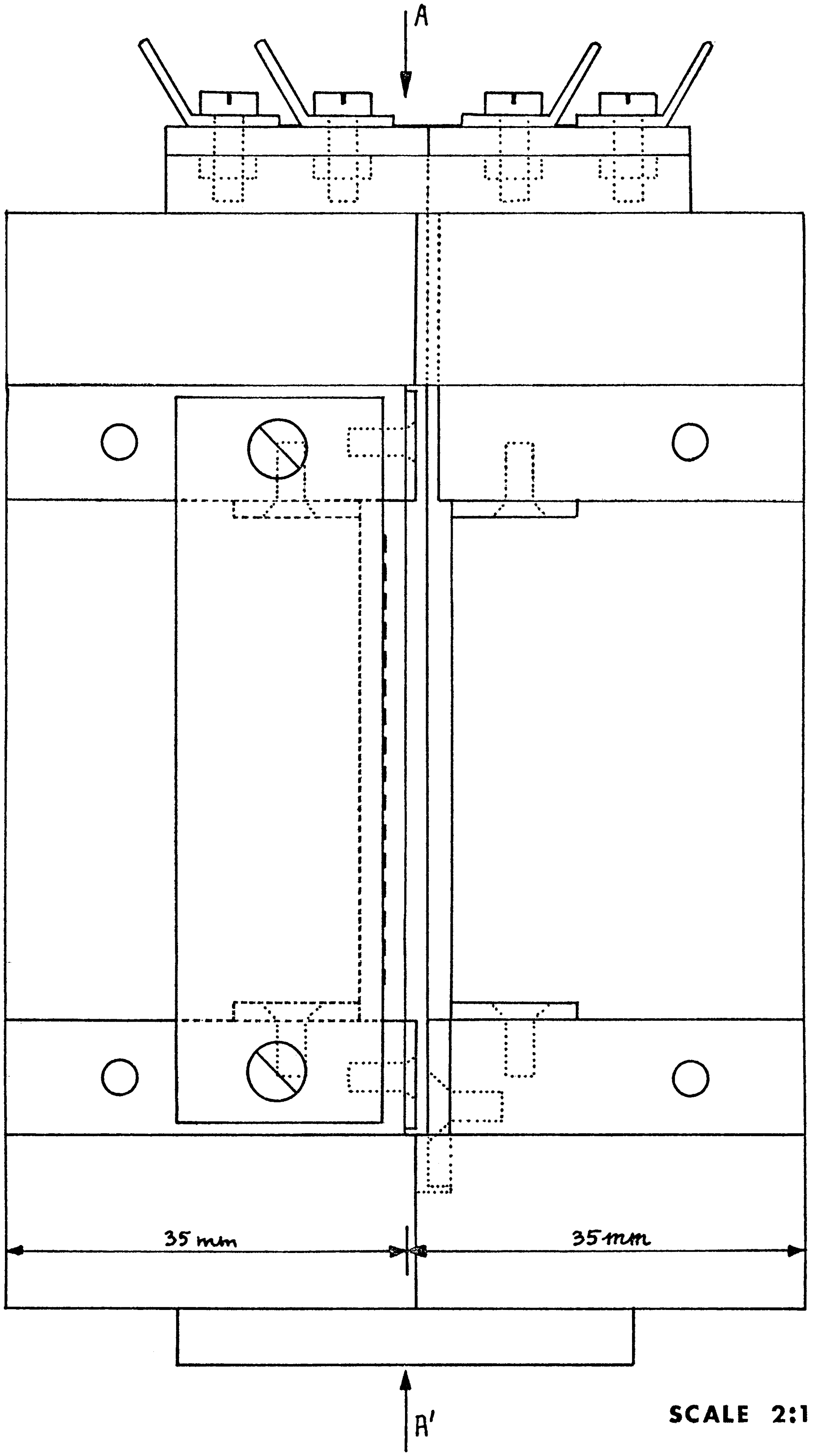


Fig. 2 : Side-view of the B.P.M.

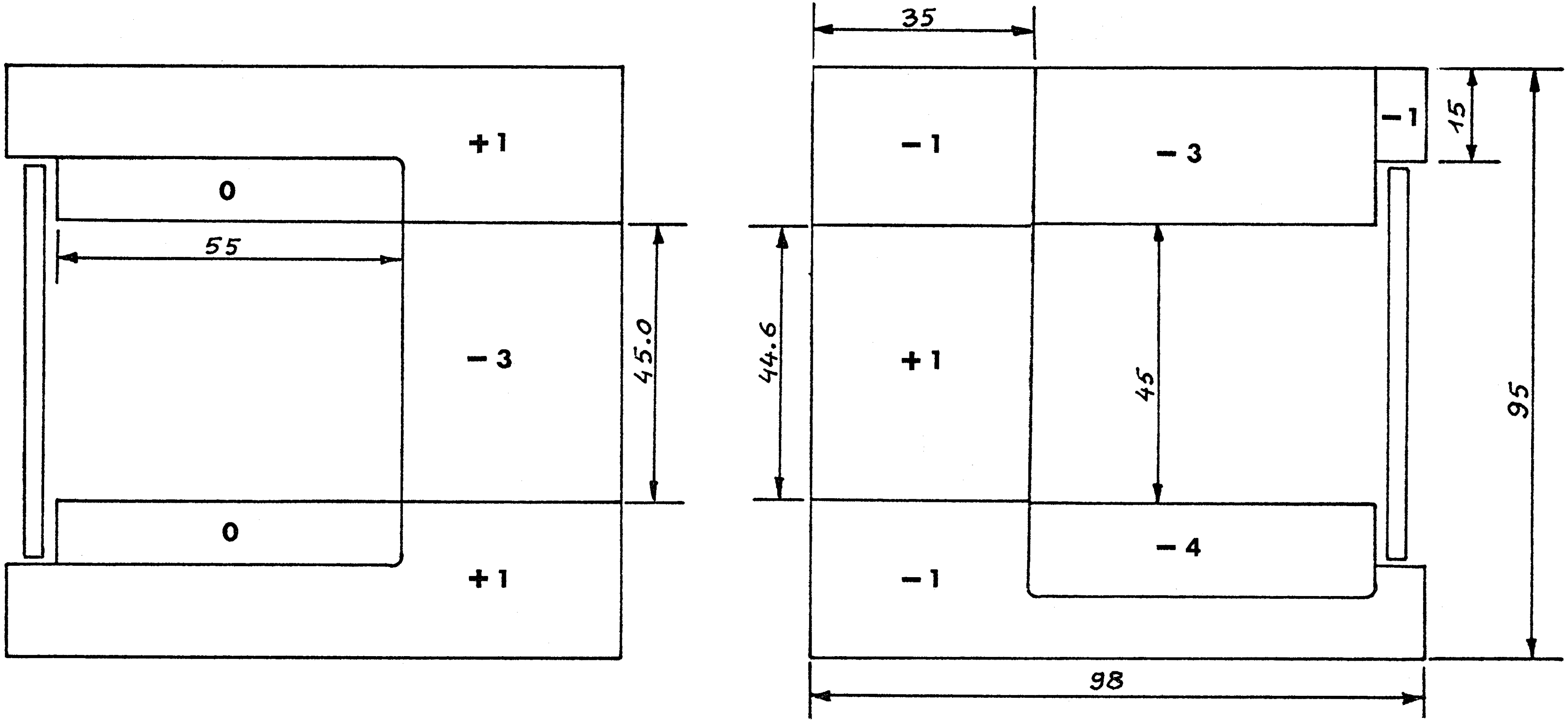


Fig. 3 : Inside view of the magnetic shields

SCALE 1:1

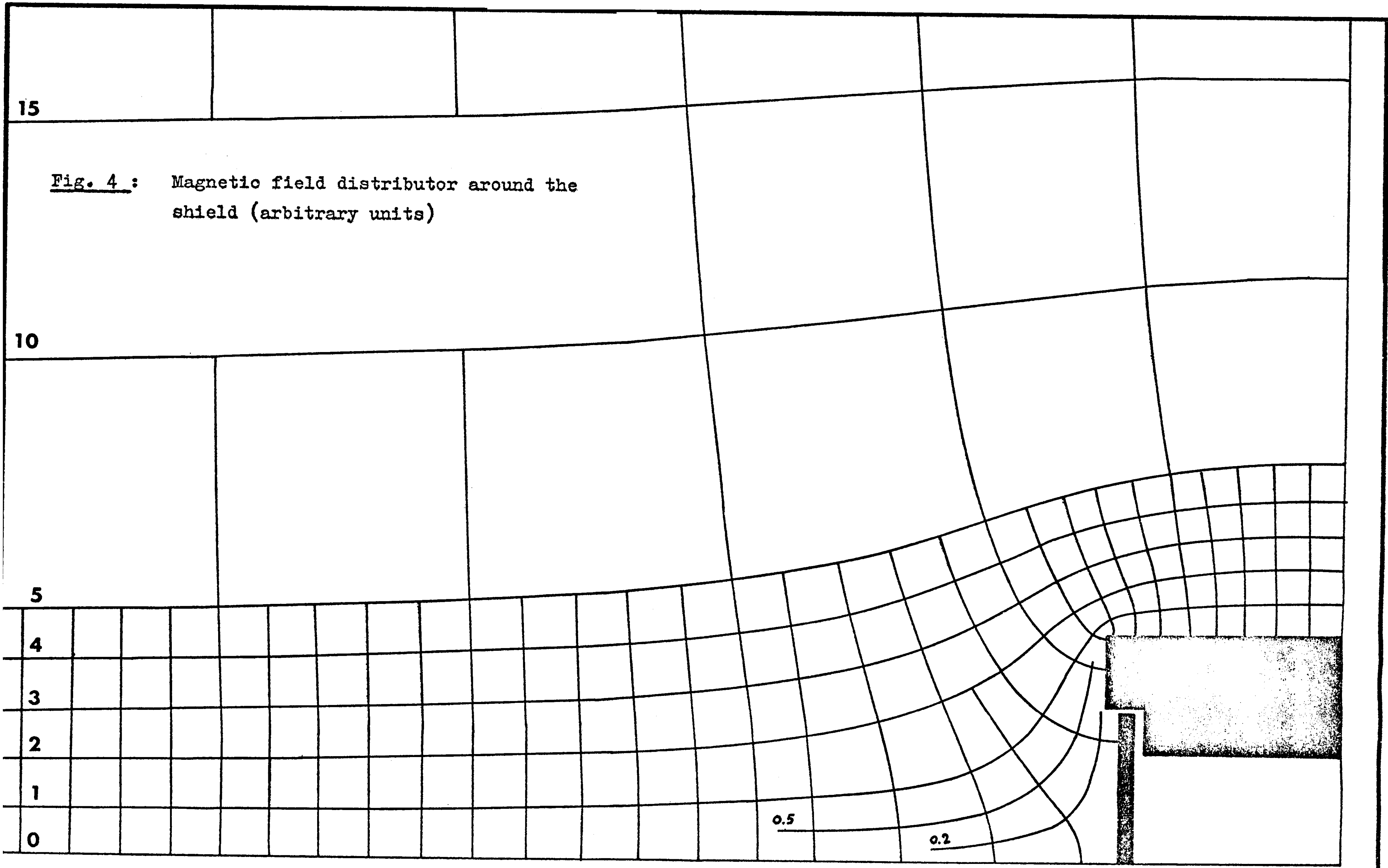


Fig. 4 : Magnetic field distributor around the shield (arbitrary units)

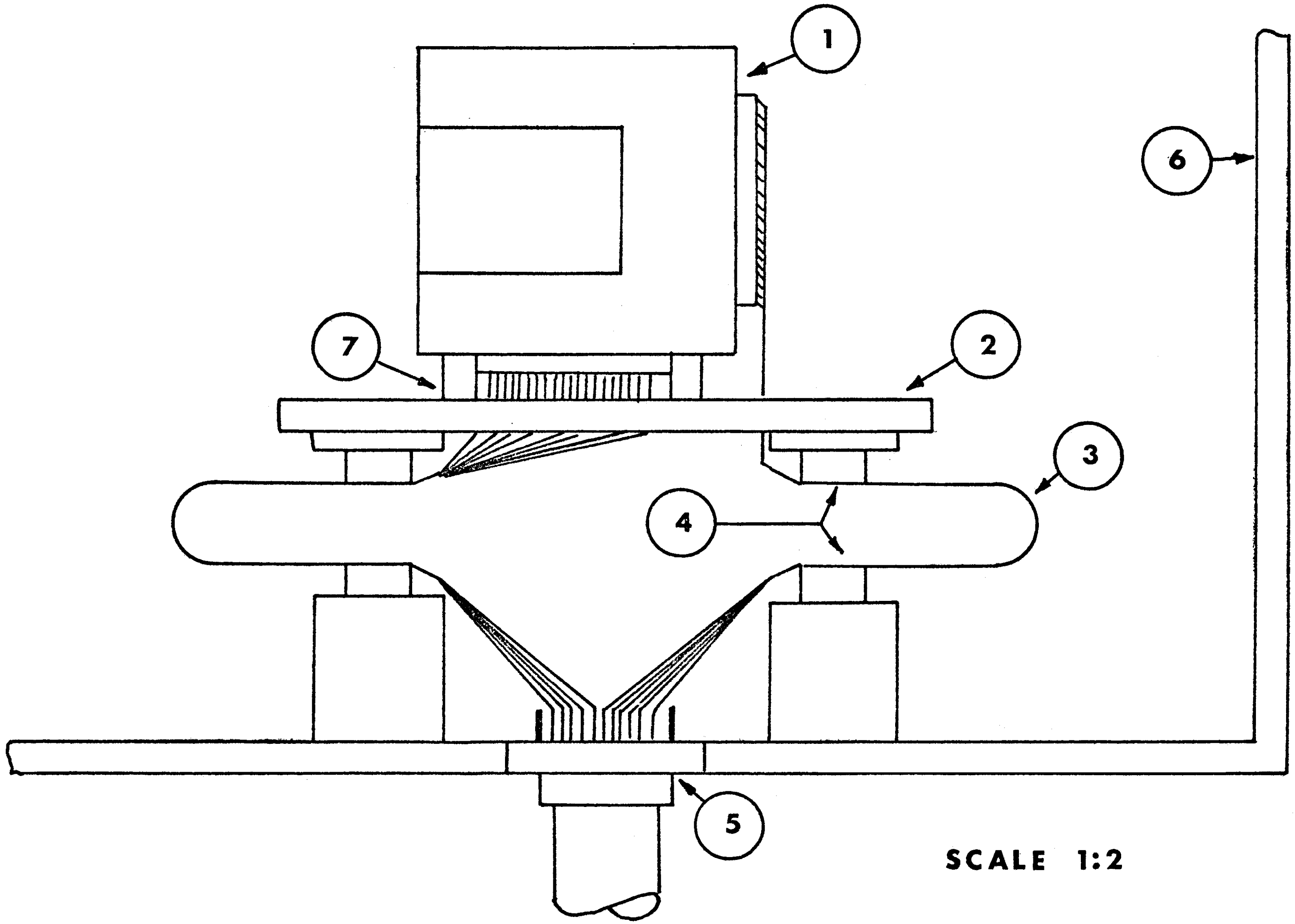
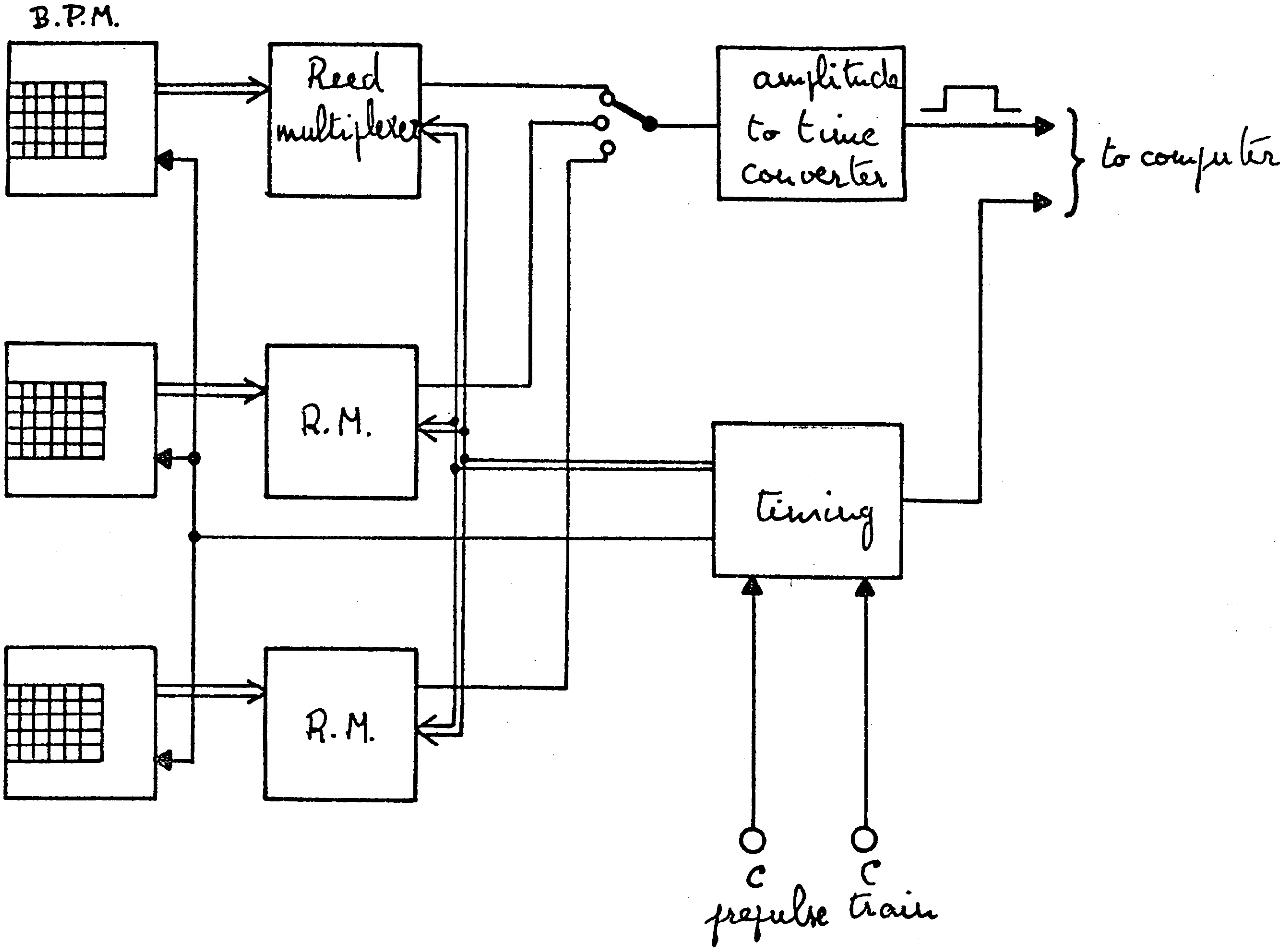


Fig. 5 : Mounting of the B.P.M. in the tank of the mobile septum magnet.

(1) B.P.M.
(2) Al plate connected to the S.M. chassis
(3) flexible strips
(4) ceramic supports
(5) vacuum feed-through
(6) wall of vacuum tank
(7) insulating supports



<u>Fig. 6 :</u> Electronic configuration for the B.P.M.

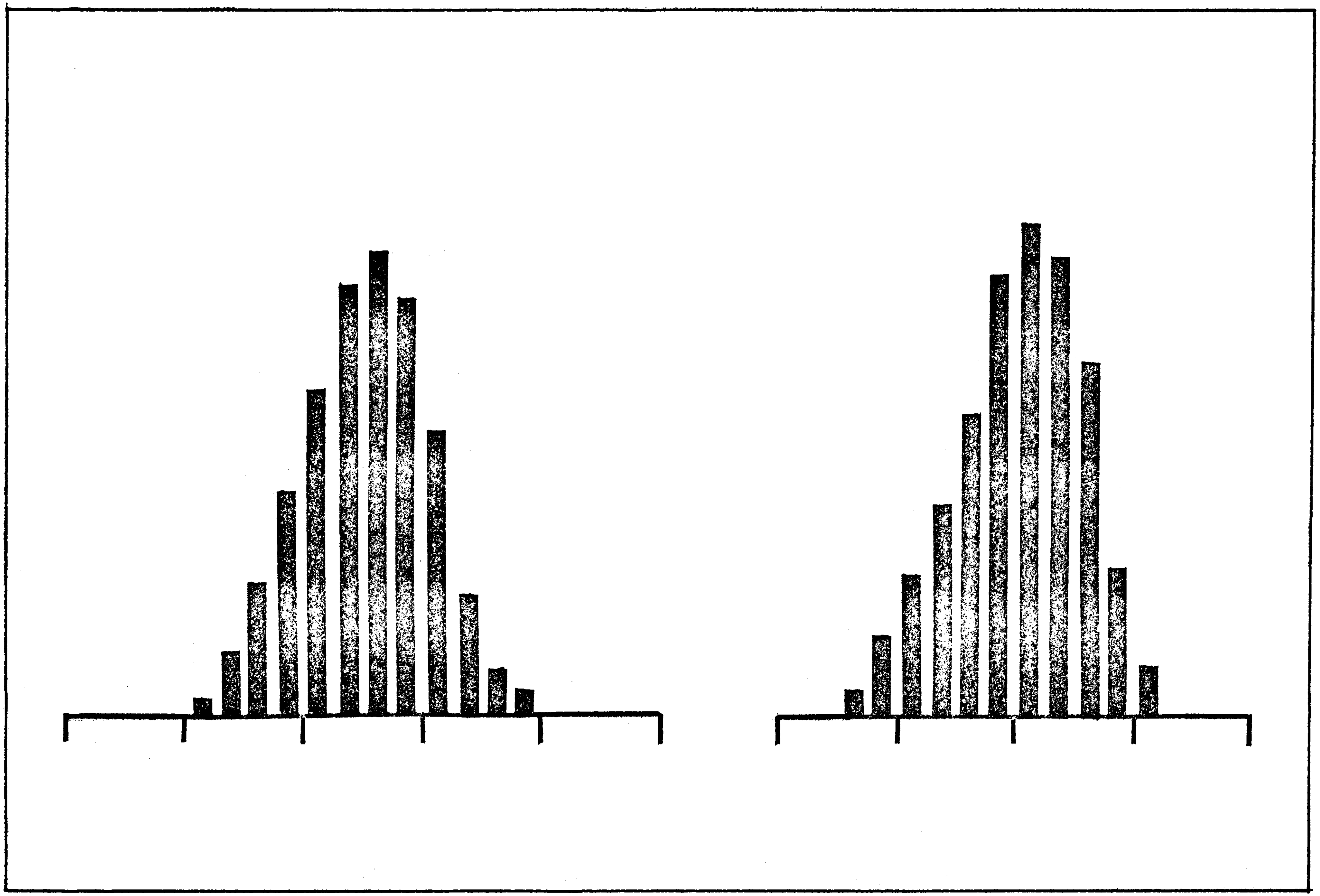


Fig. 7 : Cathode-ray tube display of the beam profile