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M. Placidi : MAGNETIC CENTER LOCATION IN QUADRUPOLE LENSES. -

(Nota interna : n. 371)

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(Presented to the "Second Intern. Conf. on Magnet Technology, Oxford, July 1967")

In this paper it is shown how the magnetic center and axes location in a quadrupole lens can be rapidly and rather precisely achieved by means of the technique of peaking strips[1] excited by a sinusoidal, fixed frequency magnetic field, oriented along the peaker axis.

Two peakers conveniently placed and oriented in the lens determine the position of the magnetic center with respect to the mechanic one, together with the configuration of the axes of the field distribution.

Among the methods for magnetic center location commonly used for gradients in the range (300 ÷ 700) Gss/cm, the current carrying wire placed along the lens can be mentioned; every element of the wire, at a distance ΔS from the axis, is subject to the Lorentz force, that is compensated with a tension T proportional to the local value of the induction and to the current i in the wire.

The attainable accuracy of this method is of the order of $\pm 10^{-1}$ mm.[2]

As a second example, the procedure based on the Cotton-Mouton effect can be mentioned, in which a white, plane polarized light beam, going through a colloidal suspension of particles of ferroso-ferric oxide undergoes an anisotropic scattering with patterns the configuration of which is determined by the n-polar field distribution in which the suspension is placed.

This method has been succesfully used at SLAC[3] and gives for the attainable accuracy a value of $\sim 3 \times 10^{-2}$ mm.

Location of the magnetic center can be achieved using a rotating coil.

The contribution from the quadrupolar field can be minimized if the loop is symmetric; in this case the induced f. e. m. is proportional only to the bipolar field, that is a function of the distance ΔS between the rotation axis of the coil and the magnetic axis.

The accuracy allowed can be estimated to be of about $\pm (1 \div 2) \times 10^{-1}$ mm.

The adopted method allows accuracies of the order of $\pm 2 \times 10^{-2}$ mm.

The suggested procedure. -

The ferromagnetic material, used for peaking strips has a static hysteresis loop almost rectangular and narrow, with a maximum permeability value, for infinitely long wire, of the order of 10^5, and low coercitive field, Hc (~ 10 A/m).

An external field parallel to the wire axis with an intensity of the order of 10^{-1}oersted is then sufficient to reverse the magnetic polarization vector inside the wire. As a consequence of this fact an induced voltage signal is available in a pick-up coil; the time duration of the signal depends upon $\dot{H}$, the geometrical dimensions of the peaker and the properties of the material, and its amplitude is proportional to the exciting magnetic field derivative $\dot{H}_e$, according to the approximate relation:

(1) $$v_{pick\text{-}up} \simeq 2NS \frac{B_s}{H_c} \dot{H}_e$$

where B_s is the saturation value of the induction in the wire, S its cross section and N the number of turns in the pick-up coil.

The operating principle is illustrated in Fig. 1.

If the exciting coil produces a sinusoidal field H_e with frequency ν, amplitude $\gg |H_c|$ and zero mean value, the time distance between the induced voltage peaks is:

(2) $$\tau_o = 1/2\,\nu$$

The pulses are induced in the time interval in which the condition:

(3) $$H_t \pm H_c = o$$

is valid, where H_t is the total field in the region occupied by the wire.

If an external field parallel to the peaker axis, $H_{\parallel}$, smaller than the maximum value of H_e, is superimposed to H_e, a variation takes place in the time separation between the peaks: the derivative $\partial\tau/\partial H_{\parallel}$ is a characteristic of the wire used, and it is proportional to $(\dot{H})^{-1}$. (Fig. 2).

If the value of $\partial\tau/\partial H_{\parallel}$ for the peaker used is known, the measurement of $\Delta\tau$ gives the amplitude of the external field component parallel to the wire axis.

Our apparatus consists of two peakers located in a support which can be aligned with the mechanical center of the lens, and an electronic magnetometer[4] working as time-amplitude converter, for the measure of $\Delta\tau$.

The two peakers were set magnetically normal one to the other by means of an external field with known direction.

The component $H_{\parallel}$ parallel to the peaker axis can be measured provided that the normal component $H_{\perp}$ is smaller than a critical value $H^{x}_{\perp}$ which depends from the dimensions and quality of the wire. In our case this value was found to be of the order of 10^3 Oe.

With our device the magnetic center position can be measured either translating the peakers using the instrument as a null meter, or reading its deflection with the peakers aligned on the mechanical center, using the calibration curve to determine the field; for a given gradient one can then derive the center position.

If a peaker is placed in the lens so that its vertical axis is aligned with the geometrical one, the variation in the time separation of the peaks is a function, for a given gradient, of the distance ΔX between the vertical mechanic and magnetic axes (see Fig. 3):

(4) $$\Delta\tau \simeq \frac{G}{\mu_o} \left(\frac{\partial\tau}{\partial H_{\parallel}}\right) \cdot \Delta X.$$

In the same way an horizontal peaker gives a measure of the value ΔZ of the displacement between the axes.

The position of the center of the peaker is not critical, provided the transverse component of the field along the peaker is less than $H^{x}_{\perp}$. With the notations of Fig. 3, this means, if ξ is the vertical coordinate of the center of the wire

(5) $$\xi \lesssim \frac{\mu_o H^{x}_{\perp}}{G}$$

For $G = 10^2$ Gss/cm and $H_{\perp}^{x} = 10^3$ Oe, ξ must be less than 10 cm.

In order to measure ΔX and ΔZ with an accuracy ΔY, it is necessary to read a deflection Δi of the instrument

(6) $$\Delta i = \sigma_t \ \Delta Y = G \Delta Y \sigma_B$$

where σ_t and σ_B are the sensitivities of field and displacement measurements.

Their values, after proper adjustments of the electronic apparatus and fixing the excitating field parameters (ν = 1 KHz, H_e^{max} = 60 Gss), were, at $G = 10^2$ Gss/cm:

(7)
$$\sigma_B = \frac{1}{\mu_o} \frac{\partial i}{\partial H_{\parallel}} = 72 \ \mu A/Gss$$

$$\sigma_t (G) = \frac{\partial i}{\partial Y} = 7.2 \times 10^2 \ \mu A/mm$$

The values (7) represent the slope of the calibration curve in correspondance of the linear region of the sinusoidal exciting field.

The sensitivity of the instrument was:

(8) $$\delta i = \pm 0.4 \ \mu A$$

so that the minimum detectable value of the external field turns out

(9) $$H_{\parallel}^{min} = \pm 5 \times 10^{-3} \text{ Gss}$$

and the minimum value of the displacement ΔY is limited by the mechanic sensitivity of the apparatus, that is of the order of $(1 \div 2) \times 10^{-2}$ mm.

The upper limit $H_{\parallel}^{max}$ for an external field, measurable with a non biased peaker, is lower than the maximum value H_e^{max} of the exciting field, because the pulses deteriorate when the derivative $\dot{H}_e$ decreases.

The value of $H_{\parallel}^{max}$ was determined during the calibration of the instrument with a known field at different values of $H_{\perp}$. The calibration curve is linear in the range $\pm$ 15 Gss, while the value of $H_{\parallel}^{max}$ was found to be

(10) $$H_{\parallel}^{max} = \pm 34 \text{ Gss}$$

independently from $H_{\perp}$ up to about 1 KGss.

The maximum value for the displacement, ΔY^{max}, is then, for $G = 10^2$ Gss/cm:

(11) $$\Delta Y^{max} (G) = \mu_o \frac{\sigma_B}{\sigma_t} H_{\parallel}^{max} = \pm 3.5 \text{ mm}$$

The peaker magnetic axis can be determined with respect to the external reference on which the peaker itself is aligned, rotating by 180° the whole apparatus around a direction parallel to the wire (Z axis in Fig. 4 for the case of a vertical peaker). In the Fig. 4a) configuration the output of the instrument in a function of the distance between the wire and the magnetic axis

(12) $$\Delta i^{(a)} = G\,\sigma_B\,(\Delta X + \delta X)$$

being δX the position of the wire with respect to the external reference.

The output $\Delta i^{(b)}$ in the Fig. 4b) configuration is proportional to $(\Delta X - \delta X)$, so that we have

(13) $$\binom{\Delta X}{\delta X} = \frac{1}{2G\,\sigma_B}\left\{\Delta i^{(a)} \pm \Delta i^{(b)}\right\}$$

After this calibration in the two planes, the magnetic position of the axes can be determined within the mechanical errors of the apparatus (in our case about $\pm$ 0. 02 mm).

Results. -

The described procedure was used to locate the magnetic center of the Adone Storage Ring quadrupoles(5) and to control their dependence from the gradient strength.

First the position of the magnetic center with respect to the mechanic one was determined, at a fixed value of gradient, G^{*}, in one of the lenses taken as reference, using the mentioned calibration system to avoid sistematic errors.

The magnetic centers of the other lenses were then determined measuring their displacement with respect to the magnetic center of the reference lens; during the measurements each quadrupole was connected in series with the reference one. Fig. 5 shows the dependence of ΔX and ΔZ from the gradient strength in one of the lenses (Fig. 5a) and the distribution, over the 49 lenses, of the same quantities, at $G = 4 \times 10^2$ Gss/cm.

As said in ref.(5), the Adone quadrupoles an rather unconventional having not circular simmetry around the optical axis to get an elliptic useful region as required, and having amagnetic yokes on the sides to avoid a large background due to lost electrons in the median plane of the ring. This fact gives some explanation of the relatively flat distribution in ΔX shown in Fig. 5b.

All the measurements were performed with peakers using Nilomag 771, 0.1 mm diameter wire. With the mentioned exciting field, $\dot{H}_{max} = 3.8 \times 10^4$ Gss/sec, the pulses width was of the order of $8 \div 10$ μsec.

Aknowledgements. -

The use of peaking strips for quadrupole center location has been suggested by F. Amman; the electronic has been built by S. Tazzari and myself.

I am glad to aknowledge the valid help of M. Vescovi in the preparation of the apparatus and during the measurements of the quadrupoles.

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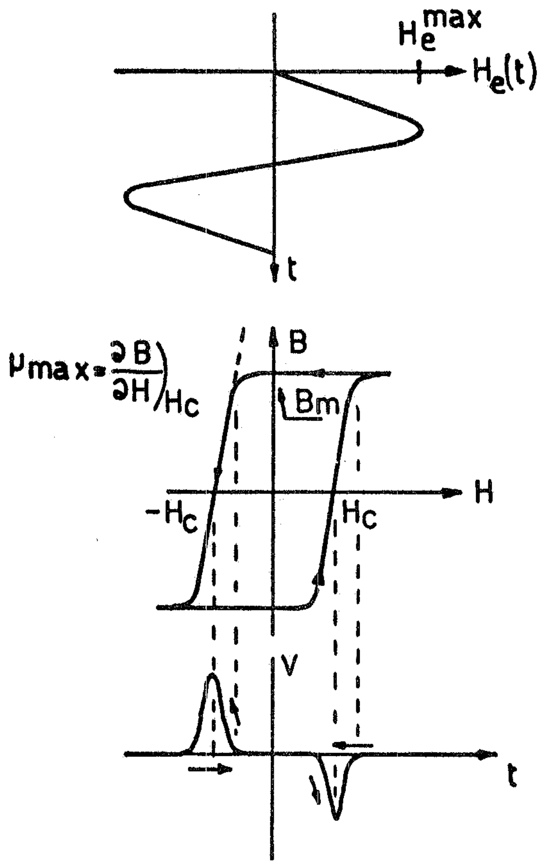

FIG. 1 - The working principle of a peaker.

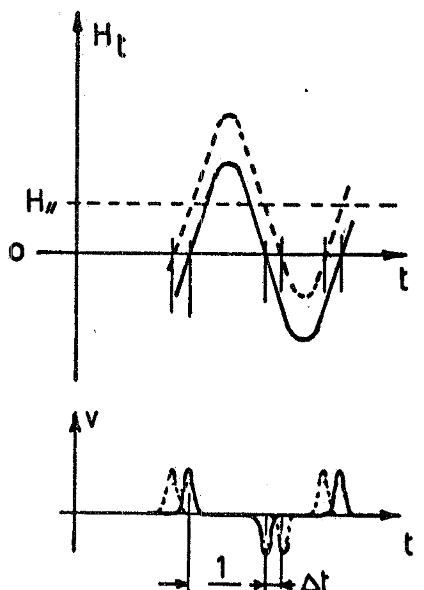

FIG. 2 - Showing the effects on the time separation due to an external constant field.

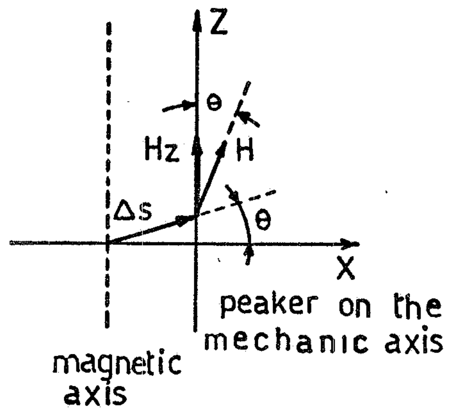

FIG. 3 - Peaker aligned on the geometrical axis non coincident with the magnetic one.

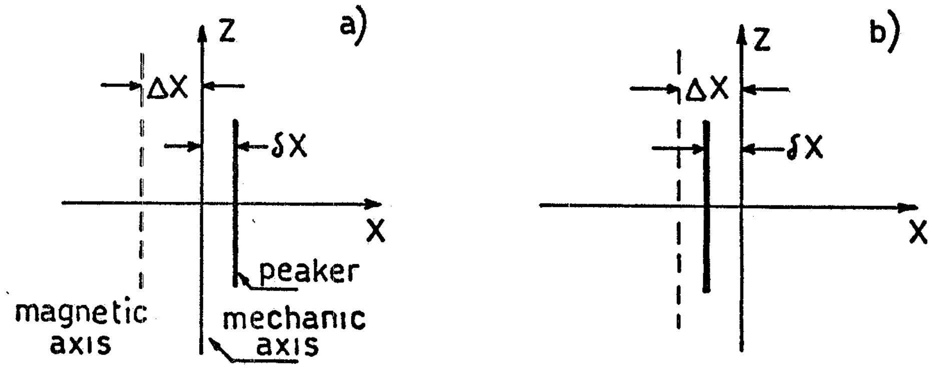

FIG. 4 - Showing the calibration procedure.

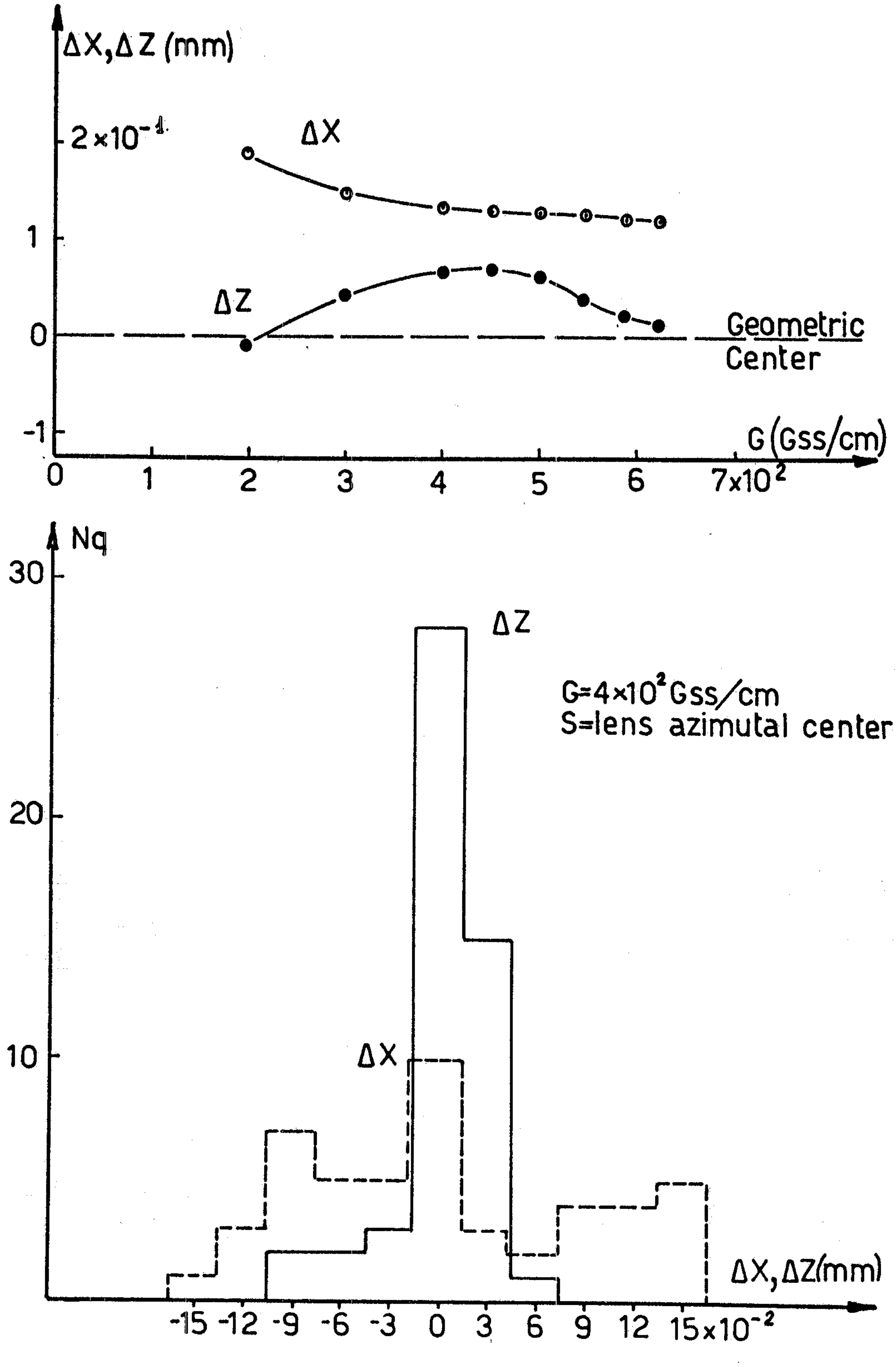

FIG. 5 - Experimental results.

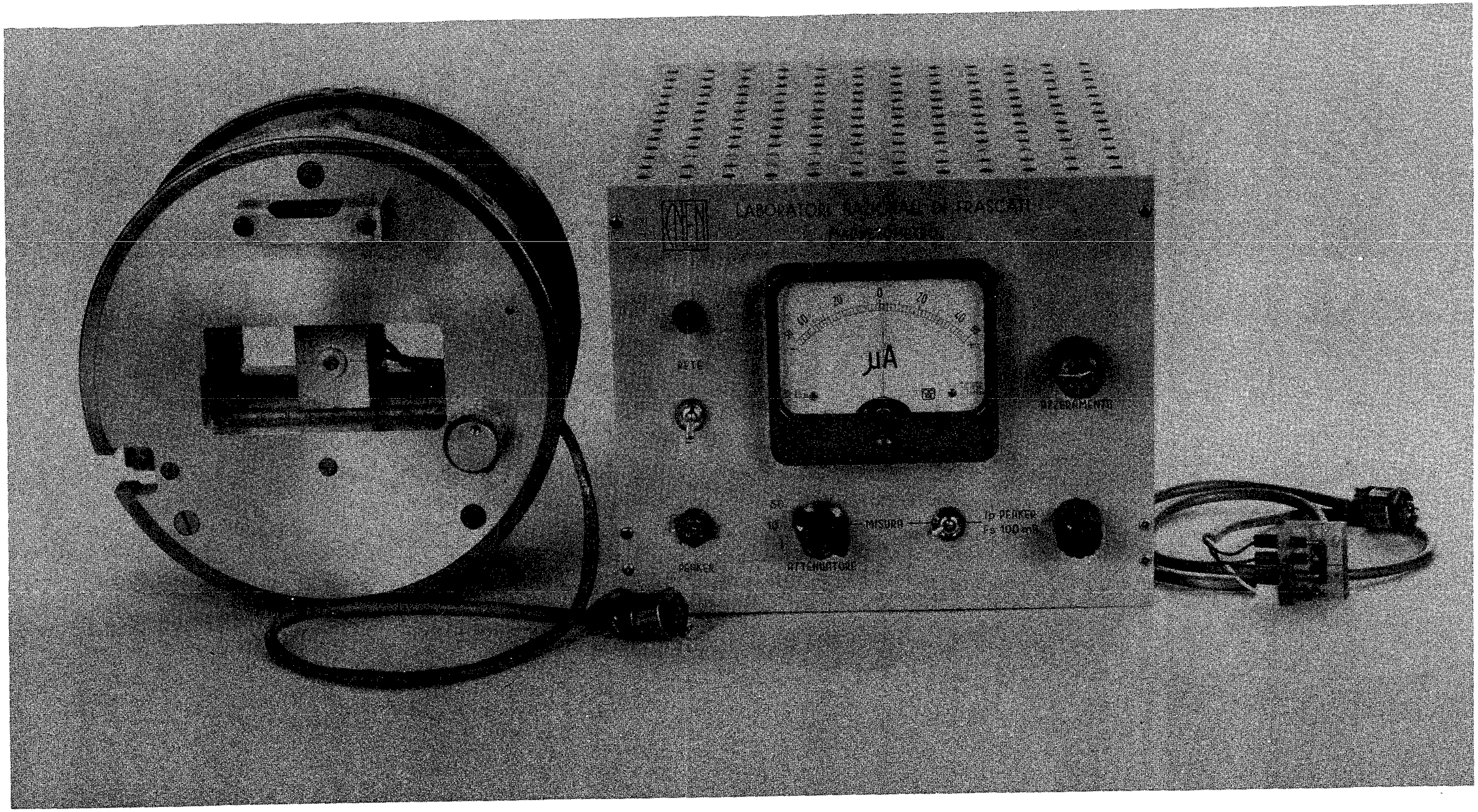

FIG. 6 - Experimental apparatus.