Automatic Bench for Precise Magnetic Measurements of Linac Multipole Focusing Elements

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Abstract

Automatic Hall-type magnetometer for magnetic measurements of focusing channel elements with arbitrary field configuration is described. Hall probe housing supported around periphery provides 3D precise movement in 75% of aperture space. The measurement technique and mathematical treatment developed to create the spatial model of the field are given. The magnetometer ensures the accuracy 0.3% of maximum field value in a whole magnet working space. Measurement runs for quadrupole lenses of ISTRA linac focusing channel are presented.

1 MAGNETOMETER PARAMETERS

The experience of focusing channels development for linear accelerators with given kind of charged particles shows preferable permanent magnet quadrupoles (PMQ) [1,2]. Such magnets require to be careful on a manufacturing stage to ensure tolerances because of wide initial spread ($\simeq 20\%$) of its magnetization like both piece-to-piece differ-

Table 1: PMQ main parameters for ISTRA accelerator.

N	Parameter	1 tank	2 tank	
		DT $1\div33$	DT $1\div33$	DT $35\div54$
1.	Aperture, $2r_o$, mm	$18^{+0.01}$	$18^{+0.01}$	$18^{+0.01}$
2.	Lens length, l_{lens}, mm	50	100	150
3.	Top field, B_m, T	0.50-0.54	0.29	0.22
4.	Gradient, G_o, T/m	56-60	32	24
	Tolerances on			
5.	Gradient, %	±0.5		
6.	Magnet axis displacement, mm	0.030		
7.	$\frac{\Delta B}{B}\|_{r^*=0.75r_0}$, %	0.7		
8.	$\frac{\Delta G}{G}\|_{r^*=0.75r_0}$, %	3		
9.	Median displacement	$\pm 30'$		

ences and within volume limits of each magnet element. The main parameters of PMQ for ISTRA proton linac are shown in the Table 1. The tolerances given can be considered typical for such kind of machine.

2 MATHEMATICAL APPARATUS

We describe the field $\vec{B}(r,\varphi,z)$ in a multipole lens working space by a scalar potential function U: $\vec{B} = -\text{grad}U$, which satisfies Laplace's equation in closed volume limited by cylindrical surface. The solution of this equation and hence a field $\vec{B}$ can be written in terms of Fourier-Bessel series with coefficients depending on boundary conditions.

According to our technique the longitudinal size l_m of cylinder where the field is measured must be chosen to be long so much that the field value on both sides ($z = \pm 0.5 * l_m$) of cylinder is less than required accuracy (Fig.1). In this case all three spatial components of the field can be calculated in each internal point if we measure only the radial component on cylinder surface. In practice l_m is greater than geometric lens length l_{lens} by approximately 2a. To meet the homogeneous conditions on sides we cut out measured data lower accuracy level (Fig.2) and join a pieces of some simple curve (parabola or some other) following down to zero at z_o (on the left side) and z_e (on the right side) instead of infinite long actual tail with very small field value. The piece $l = z_e - z_o$ is the length of a

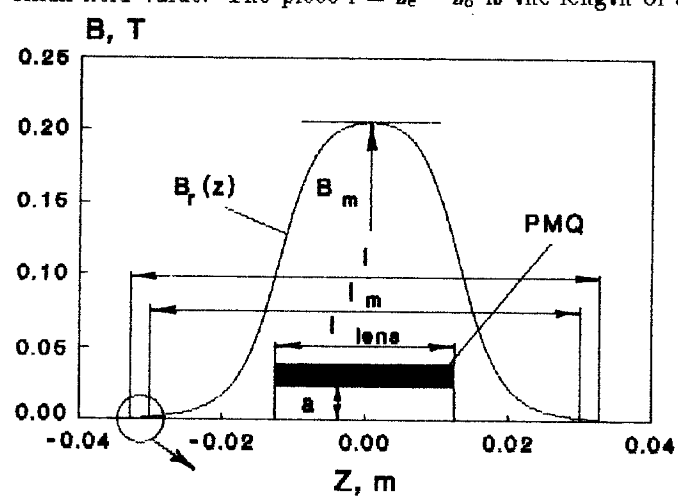

Figure 1: Choice of field expansion length. $B_r(z)$ - field radial component in a PMQ pole plane at $r = $ const.

field expansion into double Fourier-Bessel series.

Representing measured field distribution $B_r^*(r,\varphi,z)$ on the cylinder surface $r = r^*$ by corresponding series and on the base of equality

$$B_r^*(r^*,\varphi,z) = \sum_{k=1}^{\infty}\sum_{n=0}^{\infty} R_{k,n}(r^*) \times$$

$$\times (\overline{A}_{k,n}\cos n\varphi + \overline{\overline{A}}_{k,n}\sin n\varphi)\sin\frac{\pi k(z-z_o)}{l}, \qquad (1)$$

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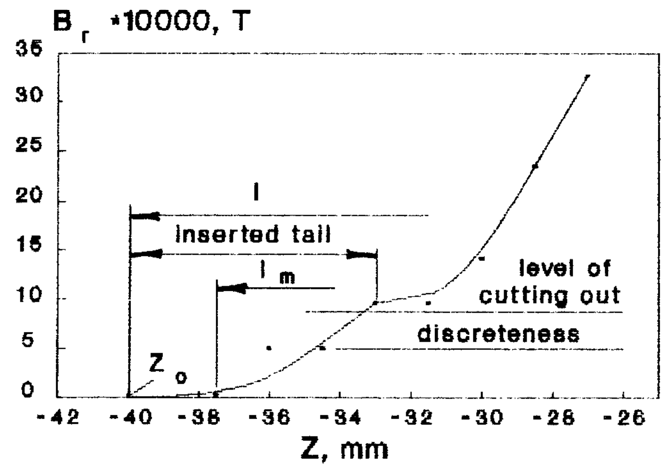

Figure 2: Tail joining. Points - experimental B_r data, curves - approximating lines.

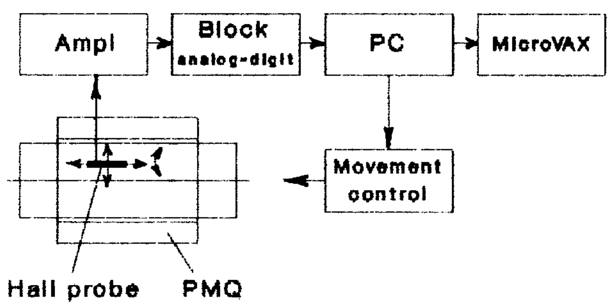

Figure 3: Block diagram of magnetometer.

where

$$R_{k,n}(r) = \frac{d}{dr}\left(\frac{I_n(\frac{\pi k r}{l})}{I_n(\frac{\pi k r_a}{l})}\right) = \frac{\frac{n}{r} I_n(\frac{\pi k r}{l}) + \frac{\pi k}{l} I_{n+1}(\frac{\pi k r}{l})}{I_n(\frac{\pi k r_a}{l})}$$

we determine coefficients $\overline{A}_{k,n}$, $\overline{\overline{A}}_{k,n}$ of scalar potential U.

In our case it is

$$U(r,\varphi,z) = \sum_{k=1}^{\infty}\sum_{n=0}^{\infty} \frac{I_n(\frac{\pi k r}{l})}{I_n(\frac{\pi k r_a}{l})} \times$$

$$\times\ (\overline{A}_{k,n} \cos n\varphi + \overline{\overline{A}}_{k,n} \sin n\varphi) \sin \frac{\pi k (z - z_0)}{l}, \qquad (2)$$

and defines the complete distribution of the multipole lens field $\vec{B}(r,\varphi,z)$ in the whole working space.

3 MAGNETOMETER

The 3D movement of Hall probe is carried out by automatical power-driven system which operates in correspondence with control program from computer (Fig.3). Analog signal from Hall probe through amplifier and analog- digit (1024 bit) block comes to PC hard disk. When measurement cycle is completed all information from PC memory is directed to MicroVAX computer where the mathematical treatment is fulfilled.

Table 2: Instrument parameters

N	Parameter	Coordinate		
		R	φ	Z
1.	Movement range	7 mm	395°	300 mm
2.	Instrument discreteness	10μm	0.08°	15μm
3.	Speed max	5 mm/s	90°/s	10 mm/s
	Speed min	40 μm/s	3°/s	40 μm/s
4.	Hall probe housing OD	18 mm		

The main unit of magnetometer is shown in Fig.4; its main parameters are given in Table 2.

A multipole lens is fixed in the left-side support in such

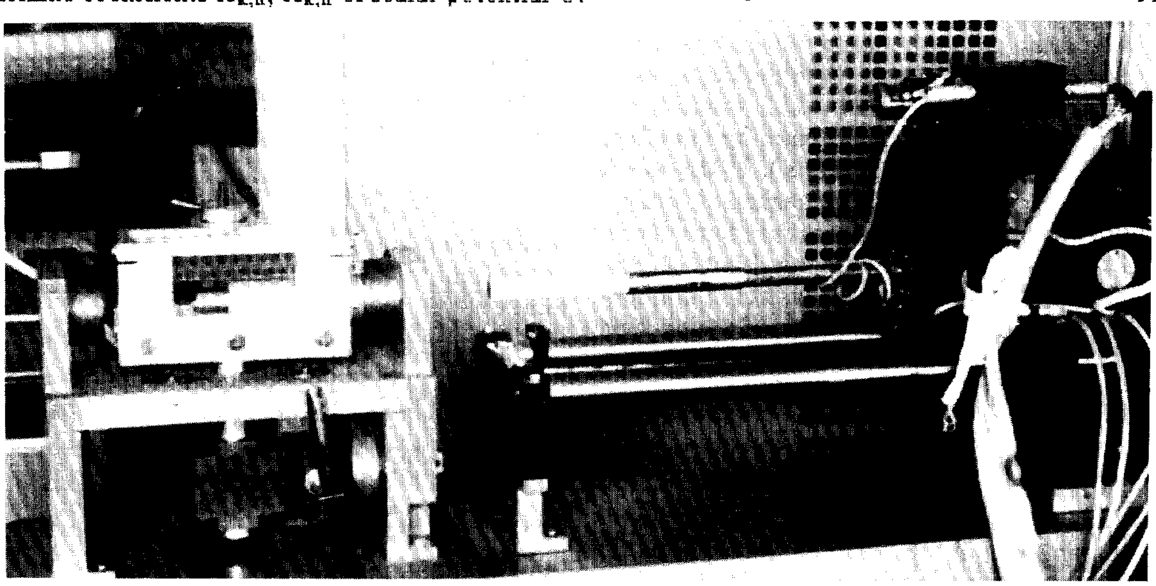

Figure 4: The main unit of automatic bench for multipole lens measurements.

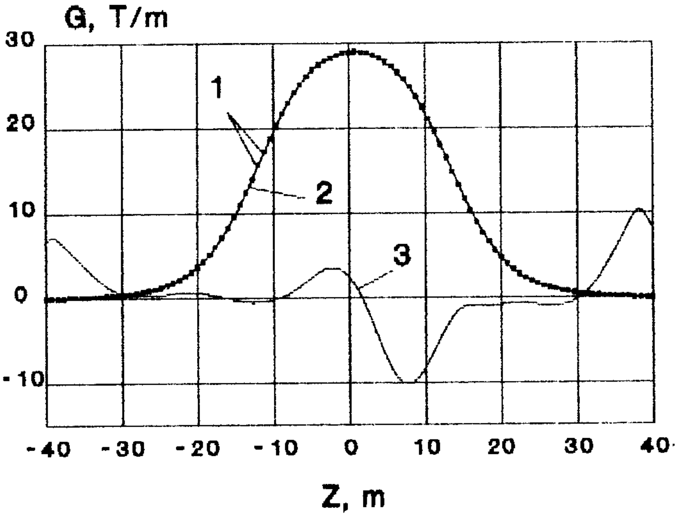

Figure 5: Gradient distribution in 25 mm long rod-type Sm-Co PMQ for ISTRA accelerator. 1 - calculated values (points) from experimental data, 2 - theory dependance, 3 - curve of difference (*100). r.m.s. deviation= $6.4 \cdot 10^{-3}$(0.02%).

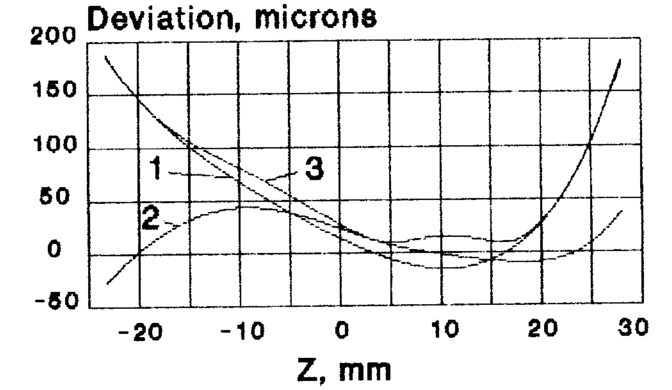

Figure 6: Magnetic axis displacement from geometrical axis. 1 - deviation along x-axis, 2 - deviation along y-axis, 3 total deviation.

a way that its longitudinal axis coincide with axis of two coupling holes by ground finger with accuracy 10μm. The Hall probe is mounted inside the long rod of 18 mm OD 70 mm far from its left end and is oriented with its normal along radial direction. In the right side one can see the movement system with position pickups and the Hall signal preamplifier box.

The measurement procedure runs in following sequence

- Instrument calibration.
- Routine loading into PC memory.
- Field sampling in points of cylindrical surface.
- Data processing and producing of main result.
- Checking the lens measured for quality.

On the instrument calibration stage the special dipole magnet with homogeneous field and NRM device are used. Within 0.3T range of field values it is possible to substitute the real voltage-field Hall probe dependence by linearized one due to small deviation of 0.5 mT (r.m.s.). In the case of wider field range the program simulated regime of voltage-field conversion is provided in accord with real dependence.

Before measurements the necessary sensitivity is chosen by appropriate selection of attenuation factor in amplifier channel to match the maximum loading of analog-digit transformation range at maximum field value in a lens to be measured.

The total running time depends on number of points where the field is measured. It is usually 15 minutes and is provided due to short time response (25μs) through Hall probe signal channel. During that period the information in about 10^5 points on cylinder surface is accumulated. It gives a possibility to fulfil a statistical treatment of accidental errors on one hand and to provide a detail description of field distribution on the other.

The total error of absolute measurements does not exceed $\pm 0.3\%$ of maximum field value. It contains in general digital transformation uncertainty being ± 1 bit.

4 APPLICATION

The described magnet measurement complex was used as a bench during manufacturing of focusing channel for ISTRA accelerator. It provided both to eliminate errors in magnetization distribution and to carry out computer simulation of beam dynamics. But probable applications of that device are much more wider. It can be used for magnets with arbitrary field configuration as well as for precise field tuning when observation of continuous field changes is desirable. The developed method of spatial modeling gives a possibility to determine all required performance characteristics from spatial harmonics spectral description to integral distributions of a field. On Fig.5 and Fig.6 the longitudinal distribution of gradient and magnetic axis displacement for short PMQ are given respectively. It shows a possibility to detect and localize significant imperfections at low level of values.

5 ACKNOWLEGMENTS

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6 REFERENCES

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