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MAGNETO-OPTICAL METHOD TO LOCATE SC QUADRUPOLE MAGNETIC AXIS AT ROOM TEMPERATURE

K.F. GERTSEV, JU. A. LUGIN, V.P. NOVIKOV, E.V. SERGA,
V.L. GRIBKOV, N.N. KIRYUKHIN and A. JA. CHERVONENKIS

Institute for High Energy Physics, Protvino,
Moscow Region, 142284, Russia

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The magneto-optical film and computer system for measurement of the quadrupole magnetic axis position are described. The calibration results of the high sensitivity film sensors and magnetic axis measurements of the UNK SC quadrupole coil at room temperature are presented.

KEY WORD: Magnetic measurements

1 INTRODUCTION

The iron garnet technology was applied earlier by the authors of this report for magnetic axis position measurements of conventional and superconducting (SC) quadrupole magnets with gradients of 5–100 T/m.[1] Recently, technology progress has allowed one to decrease the lower level of the measured gradients to 0.3 T/m, providing a good opportunity to measure the magnetic axis position of SC quadrupoles at room temperature. We have investigated magneto-optical (MO) sensors of high sensitivity based on Bi-substituted garnet films. Some pieces of such films were placed inside the quadrupole in two orthogonal planes (X-Z, Y-Z), while the location of the zero magnetic field was determined by the position of the boundary between two areas of the film having opposite magnetization directions. The structure of the magnetic field, visualized by means of the magneto optical Faraday effect, was transferred from the quadrupole by a fiber-optic lightguide with a polarizer. This measurement method was based on the use of highly anisotropic uniaxial films. A measurement computer system was constructed for investigation of the film sensor and for future use in the test facility. The calibration results of the film sensors and magnetic axis measurements of the UNK SC quadrupole coil are presented.

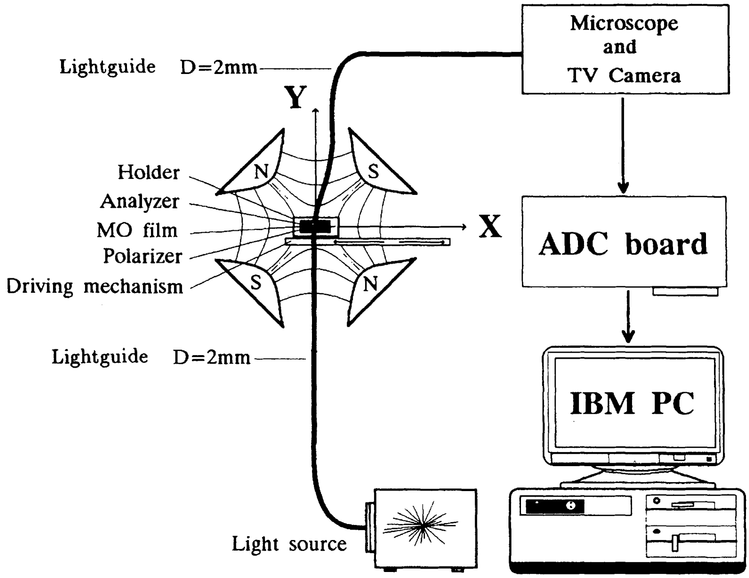

FIGURE 1: Schematic diagram of the system.

2 FILMS AND MEASUREMENT EQUIPMENT

The typical composition of films investigated is Y $Bi_2Fe_{3,7}Ga_{1,3}O_{12}$(III). The typical magnitude of specific Faraday rotation is $2^\circ/\mu$m in our measurements. The film thickness was about 10 μm on a substrate 0.5 mm thick. The magnitude of the one-axis anisotropy film was $Hk = 10^4\ Oe$.

In order to get high magnetic sensitivity in the films we used local diffusion heat treatment. As a result, a single domain is formed on the background of labyrinth domain structure. The critical field gradient of this monodomain structure may be decreased to $G \leq 0.3$ T/m while the coercivity is limited by the value of $Hc\ <\ (1-2)\ Oe$. The effective coercivity was decreased even more by applying a weak alternative magnetic field ($H \approx Hc$).

A schematic diagram of the measurement system is shown in Figure 1. The film is inserted between the polarizer and analyzer. This sandwich is placed into the holder together with the demagnetization coil. The film has a 2 mm diameter working area. Two lightguides of the same diameter, having fibers 20 μm thick, are attached to the polarizer and analyzer. The first lightguide is used to transmit the light from the source to the film. The magnetic field picture is transmitted to the microscope through the second lightguide.

The microscope image is observed directly or by TV camera. We use vidicon TV camera, since its spectral characteristics coincide with the transmitted light spectrum of the film. The TV camera has a standard TV signal CCIR. It is linked with an ADC board, which can digitize the image consist of 512×512 pixels with amplitude resolution of 6 bit. The ADC board is connected to an IBM PC.

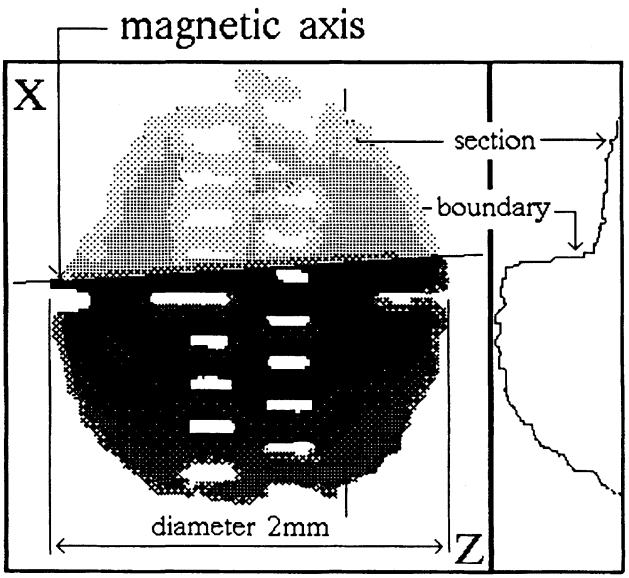

FIGURE 2: Picture of the gradient magnetic field on the film.

3 CALIBRATION

Calibration measurements were carried out in a warm quadrupole of 0.4 m length with an aperture of 80 mm and a transfer function $G/I = 0.25$ T/m$\cdot A$. The MO film holder was placed on the driver mechanism which moved along the X axis in the main horizontal plane of the quadrupole. The positioning accuracy was about 10 μm.

A typical film picture of the gradient magnetic field is shown in Figure 2. There are the position markers on the surface of the MO film. In all the cases the field gradients were more than the critical gradients of the film. Therefore we had only a smooth boundary, which corresponded to zero magnetic field. The magnetic axis was visualized by the line which split the bright and black areas.

The computer program was developed for reading and processing the image data. This program chose the vertical section of the image and calculates the boundary position between bright and black area. There was nonuniform illumination on the film surface and the lightguide had also some defects. In order to eliminate such effects, we measured the light background on the film. Then the background was subtracted from the film picture. To determine the position of the boundary we used a differentiation method.

First we estimated the reproducibility of the boundary position by means of reading and analyzing a single film picture without demagnetization processing. The RMS deviation was 2 μm. This error was caused by the electronic noise and the method of calculation.

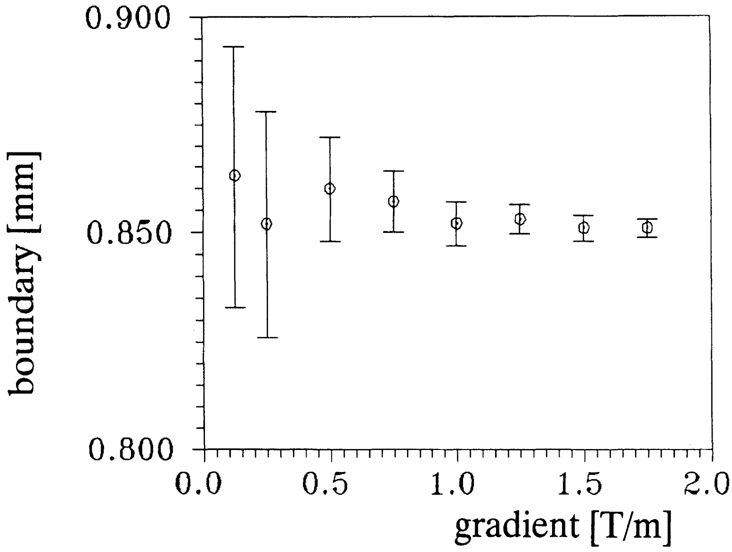

FIGURE 3: RMS deviation of the boundary position depending on the magnetic field gradient.

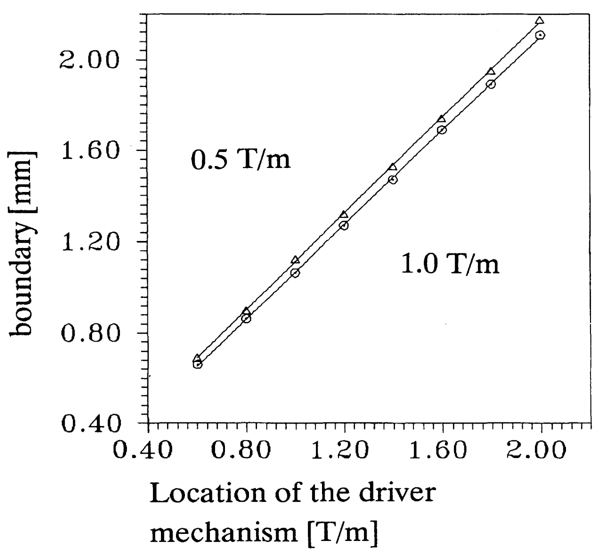

FIGURE 4: Boundary position versus sensor location.

Since the films have coercivity, the real position of the boundary may be different from the true position of the magnetic axis. In the case of applying pulse alternating demagnetization, the film coercivity is reduced and the random phase of the alternating field leads to the deviation of the final boundary position.

Figure 3 shows this RMS deviation in the demagnetization repeating process at different magnetic field gradients. The RMS deviation multiplied by the gradient of the field is approximately equal to the constant $\sigma \times G \sim (0.12\text{–}0.14) \times 10^4$ T in terms of the magnetic field. At the same time we see a systematic displacement of the visible boundary depending on the field gradient. It may be a real movement of the magnetic axis caused by the quadrupole excitation current. But the influence of the film defects and film edges will have the same result. In order to select the measurement error in the entire working film area, the magnetic axis was being displaced on the film by the transverse movement of the film sensor.

Figure 4 shows the boundary position depending on the sensor location. For each location there was a demagnetization process. We have not observed any difference between boundary position in the forward and backward directions. The straight line was drawn through the measurement points by the fitting method. The X range of the film was 1.4 mm. For the gradient of 1.0 T/m the full band of the errors with respect to the straight line was about ± 8 μm; for 0.5 T/m gradient it was about ± 12 μm. For the gradient of more than 1.0 T/m the main part of the calibration error is associated with the moving driver mechanism.

The boundary on the film was measured at different current polarities of the quadrupole. For gradients of 1.5–1.75 T/m, the boundary was displaced 6 μm.

We measured the boundary on one section of the picture. The precision may be improved by measuring several sections. We used neither a very precise driver mechanism nor a very good TV camera, but the results obtained show that MO films have unique properties for the measurement of the quadrupole parameters.

4 SUPERCONDUCTING QUADRUPOLE MEASUREMENTS AT ROOM TEMPERATURE

The SC coil of the UNK quadrupole has an inner diameter of 80 mm and transfer function of 12 T/m·kA without iron. The scheme of the experiment is shown in Figure 5. The film sensor moves along the Z axis of the quadrupole coil. The film is located in the main X-Z plane. Then the film is turned 90° to the main Y-Z plane. The bubble level keeps the angular position of the sensor in each Z point. The transverse displacements of the film sensor are taken into account by means of Taylor-Hobson optics. The TV camera reads the boundary position on the film.

In the direct current mode, the coil warms up, which leads to inconvenient conditions for the film and for the optical measurements (refraction). Therefore, the measurements are carried out in the pulse current mode having a flat-top of a few seconds.

The results of one measurements run are shown in Figure 6. The field gradient was 0.6 T/m, and we could estimate part of the measurement errors in accordance with the calibration results. As for optical measurements, their accuracy was about 20 μm.

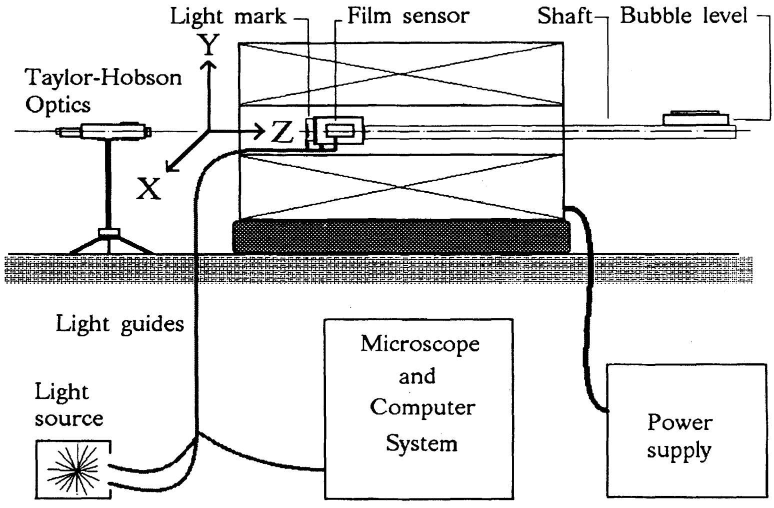

FIGURE 5: The layout of the experimental facility.

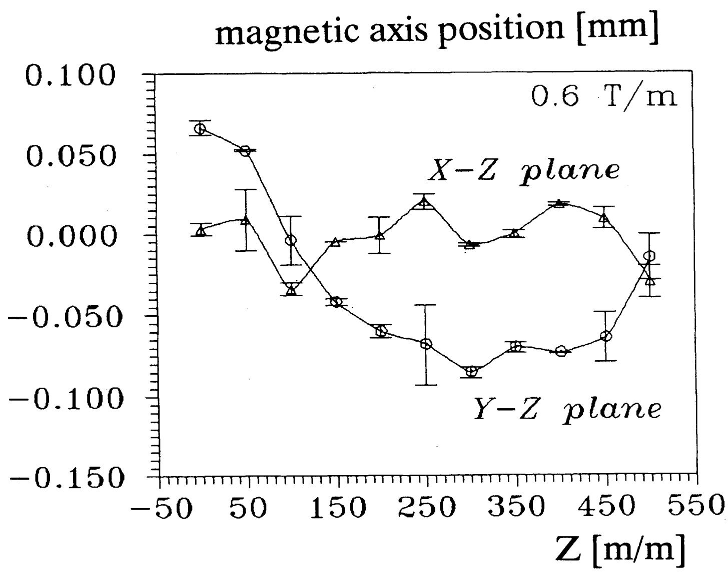

FIGURE 6: Results on measuring magnetic axis position along the geometrical Z axis of the quadrupole coil.

The magnetic axis position in each Z point was measured twice, during the forward and backward sensor movement along the Z axis of the coil. As a result, we have 11 pairs of digital data for both X and Y directions. For X-Z and Y-Z planes, the RMS deviations were 15 μm and 21 μm, respectively. The forward and backward directions had the deviations of the integral magnetic axis position, typically in the range of 4–7 μm. The vertical sag of the magnetic axis appeared to originate with the mechanical sag of the coil, which was placed on two supports.

5 CONCLUSION

The present results show that magneto-optical method, based on garnet iron film of high sensitivity, is very convenient for the room temperature measurements of SC quadrupole magnetic axis along the Z axis and it gives a good opportunity for production quality control of SC quadrupoles. This method allows one to measure, with good accuracy, the geometrical parameters of the conventional and superconducting magnets in a wide range of magnetic fields.

REFERENCES

1. K.F. Gertsev *et al.*, High resolution method for the magnetic axis localization of multipole magnets based on the garnet film technology, Proc. IISSC-4, edited by J. Nonte, Plenum Press, New York 1992, pp. 1103–1109.