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ИНСТИТУТ ЯДЕРНОЙ ФИЗИКИ СО АН СССР

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LOW APERTURE MAGNETIC ELEMENTS MEASUREMENTS

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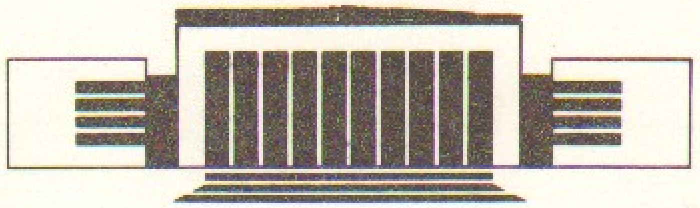

НОВОСИБИРСК

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ABSTRACT

In this paper two new methods of magnetic field measurements in low aperture elements are discussed. The first method uses thin magnetoresistive bismuth wire and the second - strained wire with AC. Principles of measuring used in the last technique are different from well known SLAC method of vibrating wire. Results of testing 0.38 T/mm quadrupole and VLEPP final focus test 3 T/mm lens are presented. Brief comparing of the lens axis determination precision of these methods is also discussed.

МАГНИТНЫЕ ИЗМЕРЕНИЯ МАЛОАПЕРТУРНЫХ ЭЛЕМЕНТОВ

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АННОТАЦИЯ

В данной работе обсуждаются два новых метода измерений в малоапертурных элементах магнитной оптики. В первом из методов используется эффект зависимости сопротивления висмутовой проволочки от магнитного поля. Во втором измеряющим элементом является натянутая проводящая нить по которой пропускается переменный ток. Следует отметить, что метод натянутой нити не сходен с развиваемым в SLAC США методом вибрирующей нити. Приведены результаты измерений тестовой квадрупольной линзы с градиентом 0.38 Т/мм и тестовой линзы для системы финальной фокусировки ВЛЭПП с градиентом около 3 Т/мм. Обсуждены предельные точности определения магнитной оси линзы обоими методами.

INTRODUCTION

For TeV region of linear colliders the problem of magnetic element construction of highest strength is very important. For example, in quadrupole lenses gradient of about 3 T/mm should be received. If the magnetic field in the lens would be formed by iron poles then the aperture of the lens should be equal or less than 1 mm. For such apertures traditional methods of field measurements can not be used. Two relatively new methods suitable for the situation will be discussed in this paper. The first method is based on dependence of bismuth wire resistance on magnetic field amplitude. The second method is based on measurements of vibration amplitude of wire in the lens, when alternate current is passed through the wire.

1. BISMUTH WIRE FIELD MEASUREMENTS

In this method we used the Gauss effect - magnetic sensibility of the resistance (of bismuth wire in this case). The one of it attractive peculiarities is a possibility to get the integral characteristic of magnetic field in low aperture magnetic elements. Indeed, the minimal aperture is determined by the diameter of wire. Using of the bismuth wire is very suitable for lens magnetic axis searching. And by the parallel movement of the wire the transverse distribution of the field may be received [1]. In low fields bismuth resistance has a squared dependence on field, and in strong one - linear dependence. For example in quadrupole lens with constant gradient $B=G\cdot r$ the resistance of the wire placed at the center of lens is equal to :

$$R^{-1}=\frac{\pi}{\rho_0\cdot l\cdot A\cdot G^2}\ln(1+A\cdot G^2\cdot a^2) \qquad (1)$$

where ρ_0 - specific resistance without field, l - length of wire, a - diameter of the wire.

At fig.1 one can see the wire resistance vs magnetic field. With the help of fourth order polynom approximation value of constant A for the expression (1) is determined $A=7.0\cdot10^{-9}$ $1/G^2$. However, the resistance of the bismuth wire also has a strong dependence on the temperature. It's thermosensibility is equal to $4.2*10^{-3}$ 1/degree. We tried to overcame this obstacle by the help of impulse feeding with stabilization of the average power, using measuring resistance and taking into account nonlinear dependence from field.

A construction of the probe that was used in test experiments is schematically shown at fig.2. Wire with diameter 0.1 mm was made from polycrystalize bismuth and placed into the glass tube. After stretching the wire has been pressed and soldered at metallic ends of tube. For the soldering Rous's low temperature alloy was apply. In general, measurement has realized according to following scheme. Bismuth wire was inserted at one of the arms of the bridge scheme. Measuring lens, wire and also heat element, which provide the initial value of the wires temperature, are placed at the thermoisolated container. Impulse voltage from the stability source is supplied to the bridge scheme. After the delay time for the elimination of contact's noise (approx. 2 ms) bridge signal is measured. The total impulse time is 80 ms, time between measurements is 5 s.

Transverse field distribution in test lens is shown at fig.3. Two constant SmCo magnets and four iron poles are used in the lens construction. Diameter of the lens aperture is 2 mm, length- 40 mm.

2. FIELD MEASUREMENTS BY STRAINED WIRE

If electric current I is passed through the strained wire and if

part l of wire is placed in the magnetic field B, then Lorentz force $F=I\cdot[l\times B]/c$ would act on the wire, leading to its displacement. This displacement contains an information about value and direction of magnetic field. Another way is to measure the wire resonant frequency shift in magnetic field which is proportional to magnetic field gradient [2].

For the test lens field measurements thin (diameter 28 microns) tungsten wire with length of dozens times grater than lens size was pass through the lens parallel to it's axis. An alternate current with low frequency Fw (20 Hz, 10 μA) was passed through the wire. In magnetic field of the lens this current leads to vibration of wire. Value of vibration amplitude in x direction (for example) is proportional to the integral of field B_y along the lens.

The wire vibration can be measured with accuracy better than 0.01 micron [3] by the next way (see fig.4). On the wire a voltage with high frequency Fc (few hundreds of kHz) was supplied. The wire was passed through horizontal and vertical pickup-electrodes. The pickup signals have been multiplied at first with high frequency Fc and then with low frequency Fw reference signals. This procedure gave us value of vibration amplitude at frequency Fw and thus the integral of magnetic field along the lens.

Calibration was carried out by using magnet with constant field. Moving the lens we could measure field B_y versus coordinate x.

Field B_y distribution in x-z plane of the test lens is shown at fig.5. One can see, that field distribution is slightly unsymmetrical due to errors in poles mounting.

This technique was used for measuring another 3 T/mm quadrupole lens for linear collider VLEPP final focus system [4].

3. VLEPP FINAL FOCUS TEST QUADRUPOLE

The test lens with high gradient was designed and constructed (see fig.6). This lens has Bore radius and a gap equal to 0.5 mm. The lens was 10 cm long. It was constructed using low carbon steel. The lens has two copper coils. It seems to us that coils rather then permanent magnets are more suitable for the final lens because the precise tuning of gradient in wide range does not demand mechanical efforts. The lens has four correction coils that gives possibility to displace quadrupole axis in some limits.

The measurements of lens fields by using of strained wire technique have been performed. During the measurements the vibration amplitude of wire was about of few micrometers.

At the fig.7 field B_y in the plane z-x versus x when current feeding the lens was 0.13 A and 0.52 A. The maximum gradient of about 2.83 T/mm was reached in the lens (see fig.8). Nonlinearity of magnetic field in this lens doesn't exceed the value of :

$$\sum(\delta B_n/B_4)_{0.7aperture} \simeq 15\ \%\ ,\ n>4$$

It is big but not vary dangerous value because transverse beam sizes in the FF lens will be smaller than 10% of the lens aperture.

4. ULTIMATE ACCURACIES OF LENS AXIS MEASUREMENTS

For low aperture elements of future linear colliders the problem of axis position definition is very important. What accuracy can these two methods of field measurement give?

For the bismuth wire method there are some effects which result accuracy limitation. At the first, diameter variation along the wire an leads to uncoincidence of it's effective and geometric axises. If diameter variation $\delta a/a \simeq 1\%$, displacement of axis can reach $0.01 \cdot a = 1$ microns.

At the second, if we are measuring lens with gradient G and sextupole S, then effective axis would be displaced on $\delta X \simeq a \cdot (S/G)$ from the true lens axis. Suppose, quadrupole lens poles is installed with error Δ, then sextupole harmonic $S \simeq G \cdot \Delta / R^2$ should appear, leading to axis shift $\delta X \simeq \Delta \cdot a^2 / R^2$, where R - lens aperture. This effect, however, is not strong: for $\Delta = 1$ micron, $a = 100$ micron, $R = 500$ micron we get $\delta X \simeq 0.04$ micron.

At the third, dependence of bismuth resistance on temperature $\alpha = 4 \cdot 10^{-3}$ 1/degree made us to keep stable average temperature of wire. Variation of temperature $\delta T/T \simeq 10^{-2}$ results resistance deviation $\delta R/R \simeq 4 * 10^{-5}$. For lens with G=3 T/mm wire resistance versus position is determined by expression $\delta R/R \simeq A \cdot G^2 \cdot (x/a)^2$, thus error in axis definition would be about 2-3 micron.

As to vibrating wire method, it accuracy of axis definition depend on size variation along the wire only. Using wire with diameter $2a = 30$ micron and $\delta a/a = 1\%$, the precision can be made as low as 0.1 - 0.3 micron.

CONCLUSION

Bismuth wire and strained wire methods are very suitable for low aperture element measurement. By these methods lens axis can be found with micron accuracy or better.

The authors are gratefully acknowledge Yu.N.Rasskazov for his help in 3 T/mm test lens design.

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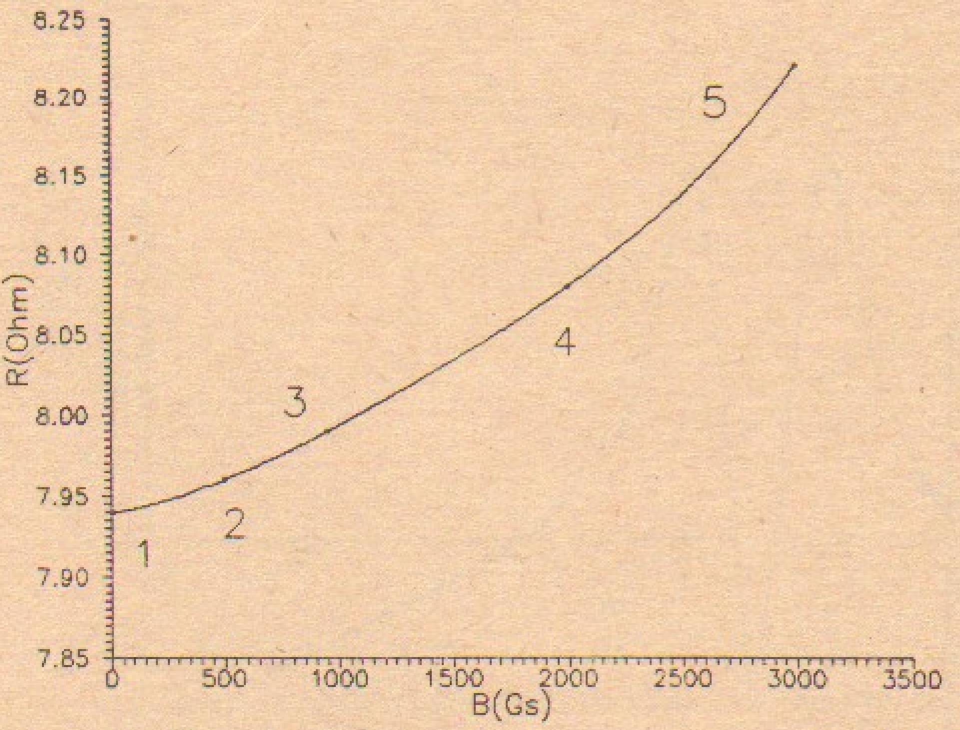

Fig.1 Bismuth wire resistance vs magnetic field

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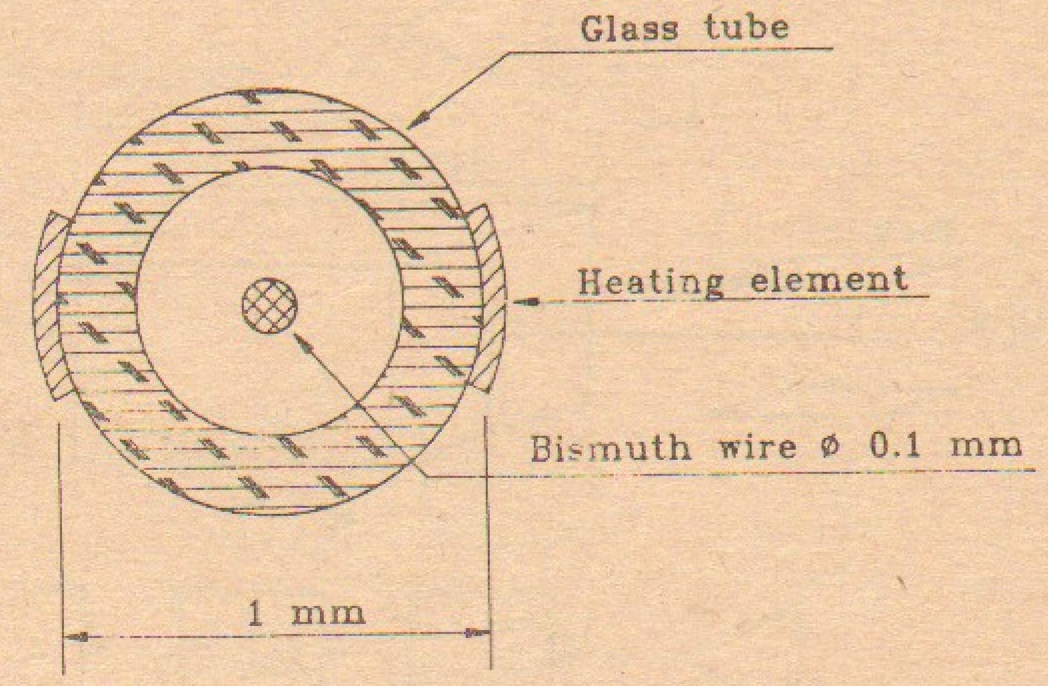

Fig.2 Cross section of bithmuth wire probe

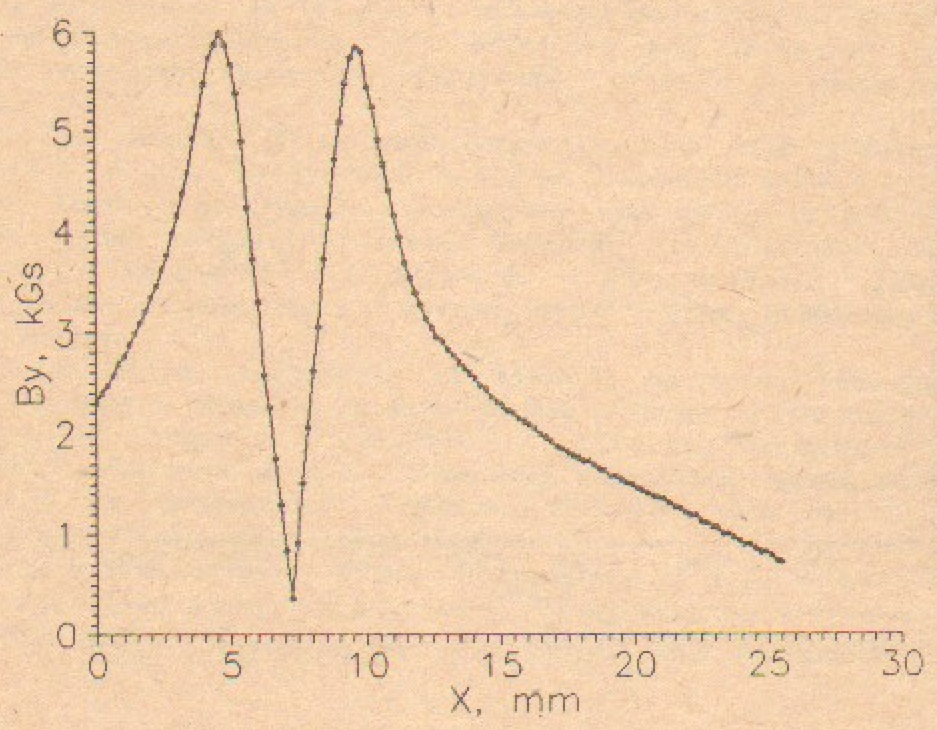

Fig. 3 Transverse field distribution in 2 mm aperture test lens measured by bismuth wire

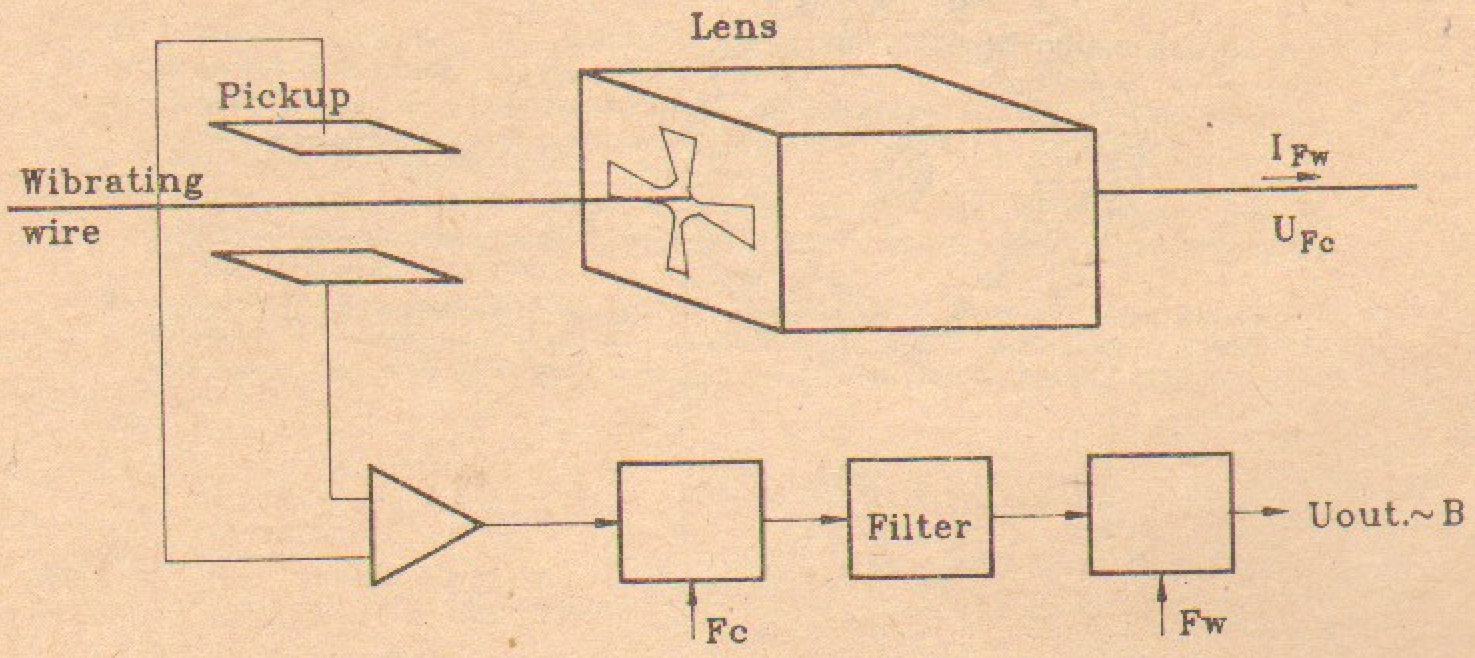

Fig. 4 Scheme of strained wire technique

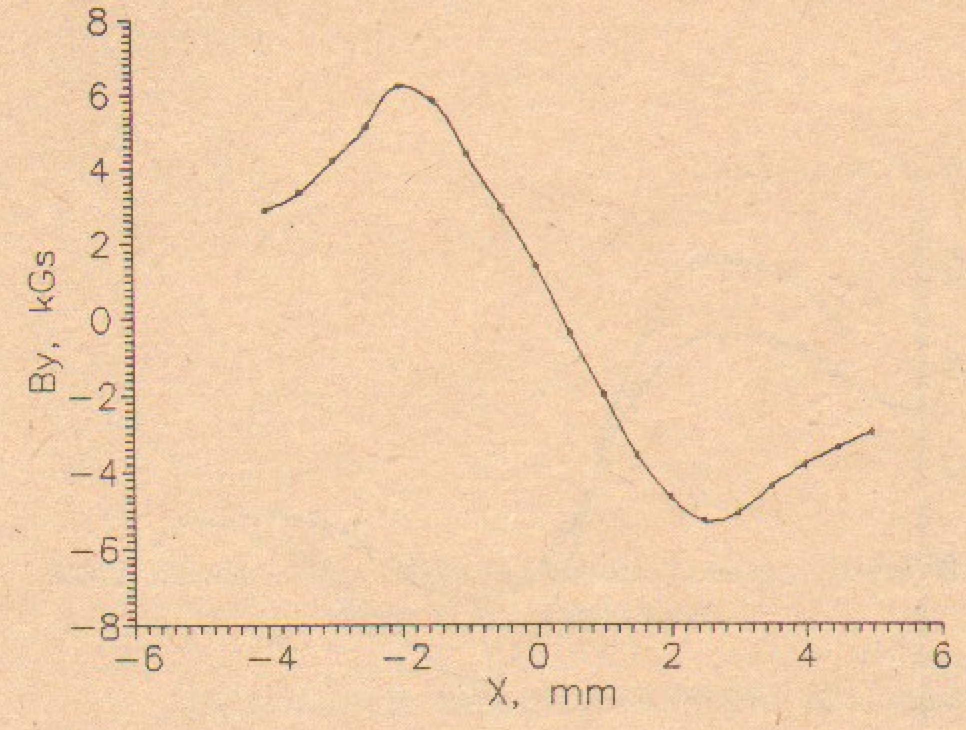

Fig. 5 Transverse field distribution in 2 mm aperture test lens measured by strained wire method

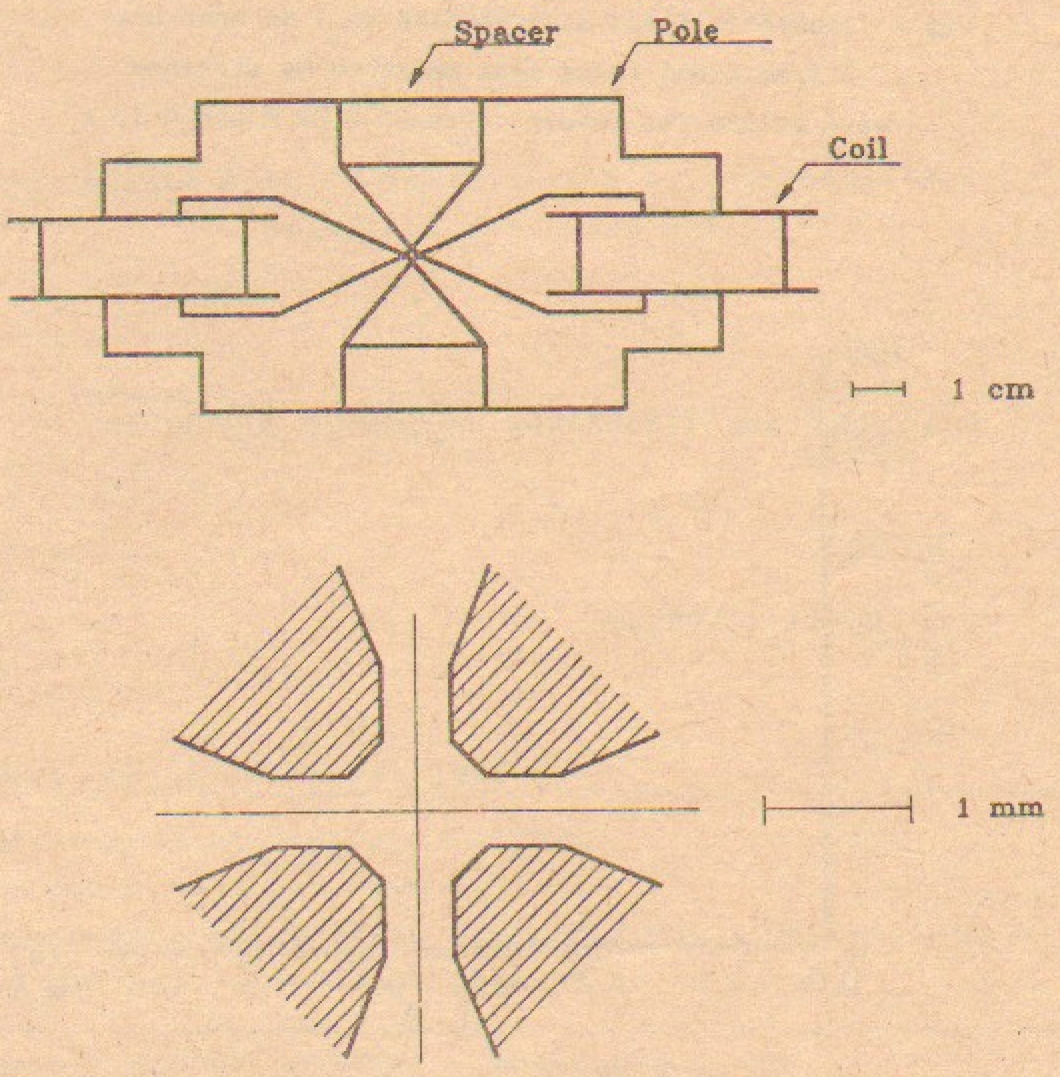

Fig. 6 The 3 T/mm final focus lens layout

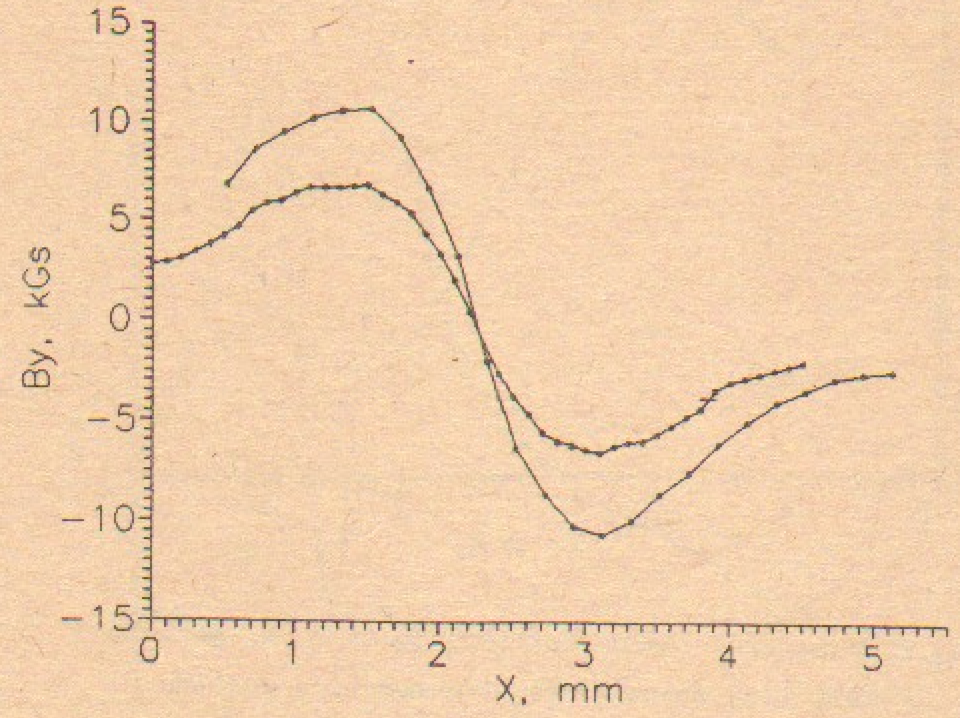

Fig.7 Transverse field distribution in 1 mm aperture
3 T/mm final focus lens measured by strained
wire method for feedig currents 0.52 A and 0.13 A

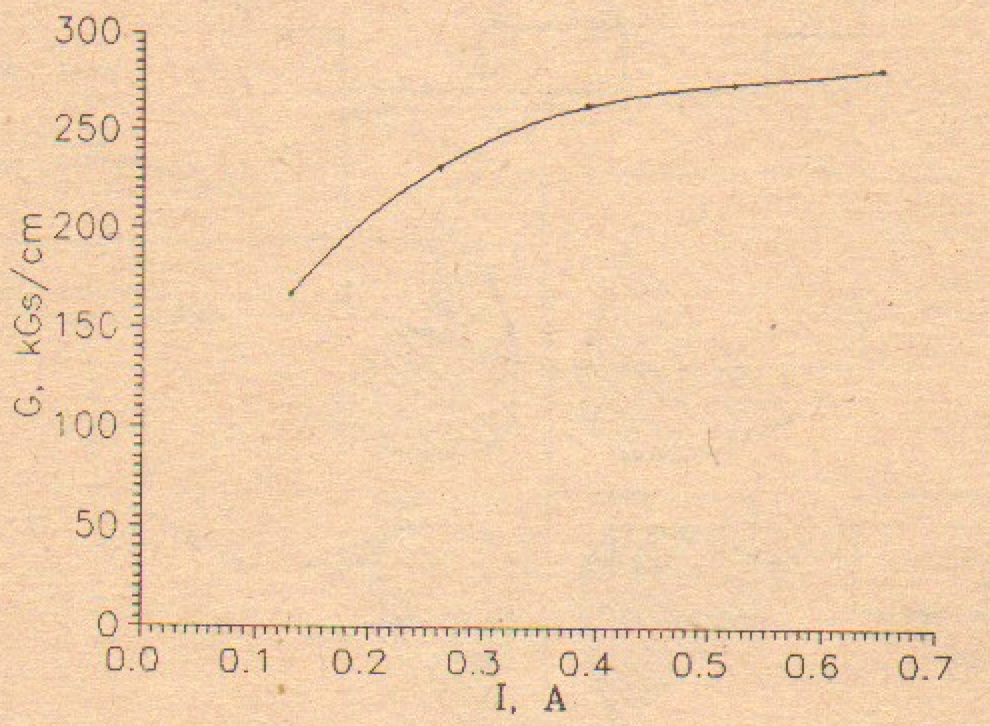

Fig.8 Final focus test lens gradient vs. feeding current

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