COMPASS FOR MEASURING THE MAGNETIC LINES STRAIGHTNESS AT THE COOLING SECTION IN VACUUM

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Abstract

The 2 MeV cooler is currently under construction at the COSY synchrotron. Due to high energy it is a very strict requirement for the magnetic field homogeneity at the cooling solenoid. Since the magnetic field has to be adjusted during the accelerator operation, the measurement system is installed inside vacuum chamber. The design and features of this system are described in the article, as well as preliminary results are discussed.

INTRODUCTION

Magnetic field homogeneity at the cooling section is quite important for electron cooling as it increases effective velocity of electrons. For high energy electron cooling transverse temperature of electrons is strongly depended on magnetic field nonstraight linearity [1].

In the first experiments on determination of the quality of magnetic field at BINP [2], an optical automatic autocollimator was used as the measuring system. As the magnetic sensor it was used a construction composed of the mirror, laid down in the gimbal suspension with jewels from clock as the bearing supports, and of steel rod penetrating the mirror axis. In 2000, a measurement system for a prototype of electron cooling system for the Tevatron (Fermilab, USA) was designed [3]. The magnetic sensor was made of two cylinder of NdFeB material that provided required sensitivity at relatively low guiding magnetic field. Electronic circuit contained a low power semiconductor laser as light source, four quadrant photodiode, source of compensating current and the feedback loop, allowing return reflected from the mirror compass beam to the starting position for fixing the value of the compensation current.

This scheme with no significant changes was used in future for setting up solenoids of produced at the BINP coolers for IMP (Landzhou, China) and for CERN. Only design of compasses was improved.

All those designs of the sensors showed very high sensitivity and were successfully used for different coolers commissioning. But such a type of compass can not be used in the COSY cooler because of following disadvantages:

- The suspension wire is rather weak to overcome the tension caused by transverse field. This is important as long as sensor must be hidden inside special parking place to release accelerator's aperture. Increasing the strength of wire by increasing its thickness is also limited because of rapid growth of the elastic forces.
- The sensors contain incompatible to UHV materials those determine some of their features.
- Some of details are not heat resistant that doesn't correspond to the requirement that all components have to be back able up to 300°C

So a device which meets UHV requirements and allows to measure straightness without disassembling of vacuum chamber was constructed. The sensor design is similar to the device which was used on electron cooler for NAP-M storage ring [2] except some peculiarities. On the other hand measurement system is based on the same ideas, used in "air type" measurements [4].

SENSOR DESIGN

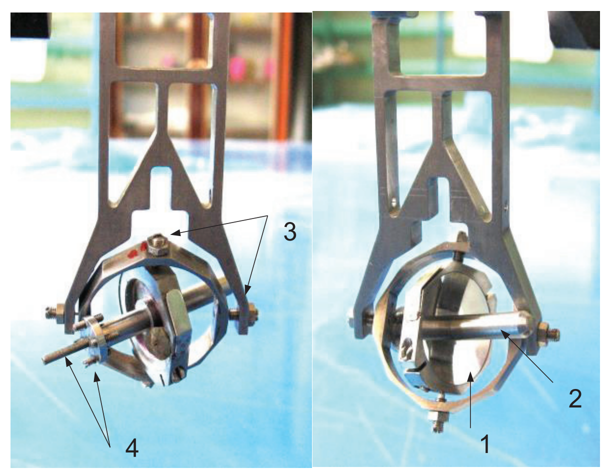

Figure 1: Compass with gimbals suspension. (1 – mirror, 2 – compass needle, 3 – jewel bearings, 4 – balancing screws).

Compass needle (fig. 1) is made from low carbon steel with high permeability to provide its complete saturation. It is attached to the mirror which is made of polished tantalum disk. Gimbals suspension has two axes formed by two couples of precise jewel bearings. The bearings type was chosen as conical bore that provide low friction in it. On the other hands this type requires precise alignment of the bearings axis in the bore to avoid any backlash which may result in measurement hysteresis [5]. On the needle back part five balancing screws are placed, one at the compass axis and two couples along bearings axes. One couple is made from low carbon steel but another one from stainless steel. The idea is to eliminate misbalance of the compass in gravity force as well as in magnetic force due to needle discontinuity since it has a screw

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thread inside. Compass with gimbals are attached to the titanium frame which is a part of the driving cart to provide the longitudinal motion of the device.

CALIBRATION

Before installation in the cooler the compass should be tested and the deviation from the norm of the parameters should be minimized. All parameters are recorded as a passport data of the device.

Special test bench was designed and constructed to perform the compass calibration [5]. Compass is installed in center of the solenoid, which contains block of correction and calibration coils. Components of the transverse magnetic field in the compass region are proportional to the currents in correction coils. The solenoid can be rotated to 180 degrees without correction and calibration coils.

Briefly, the idea of the method is as follows [5]. The signal recorded by the instrument in some point includes several components. Some of them depend on the solenoid's longitudinal magnetic field B_z, and the others are field-insensitive. This signal can be represented by the following expression:

$$B_j = B_{1j} + B_{0j} + \delta B_j = B_j[\alpha_j + \beta_j + \gamma_j] + \\ + [B_j^{ext} + B_j^{sh} + B_j^{sen}] + \delta B_j \quad (1)$$

where j is the x or y coordinate; α_j are the imperfections of the solenoid's magnetic field; β_j is the angle between the magnetic axis of the compass and the perpendicular to the mirror; γ_j is the angle between the solenoid's axis and the laser beam, B_j^{ext} is the external (with respect to the solenoid) magnetic field; B_j^{sh} is the residual field of the magnetic shield; B_j^{sen} are the additional z-independent components due to the magnet's unbalance etc.; and δB_j are the random noises.

Rotation of the solenoid about its axis through 180 degrees reverses the signs of its own transverse components. Making three measurements for each of components x and y in order to determine $B_{j1}(B_{z1})$, $B_{j2}(B_{z2})$, and $B_{j3}(B_{z3})$ for the fields B_{z1}, $B_{z2} = 2\ B_{z1}$, and $B_{z3} = -B_{z2}$ (i.e., with the solenoid turned over) allows all of the values characterizing the quality of the compass to be calculated:

$$B_j^{sen} = 2B_{j1} - B_{j2}, \alpha_j = (B_{j2} - B_{j3}) / 2B_{z2}$$

$$\beta_j = (B_{j2} + B_{j3} - 2B_j^{sen}) / B_{z2}. \quad (2)$$

After adjustment of parameters we reached next values: B_x^{sen}/B_y^{sen}=-5.4·10^{-4}/4.4·10^{-4}; α_x/α_y=1.1·10^{-4}/5.7·10^{-4}; β_x/β_x=8.6·10^{-4}/-8.1·10^{-4}. Such values are appropriate to use the compass for measurement of field line straightness [5].

To measure the sensor sensitivity the calibration coils were used [5]. Sensitivity of the compass is about 1 mG. For the field in cooling section of the COSY cooler of 1÷2 kG that means that we can measure angle of field line with accuracy of 0.5÷1.0×10^{-6}.

MEASUREMENT SYSTEM DESIGN

Mechanical In-vacuum Assembly

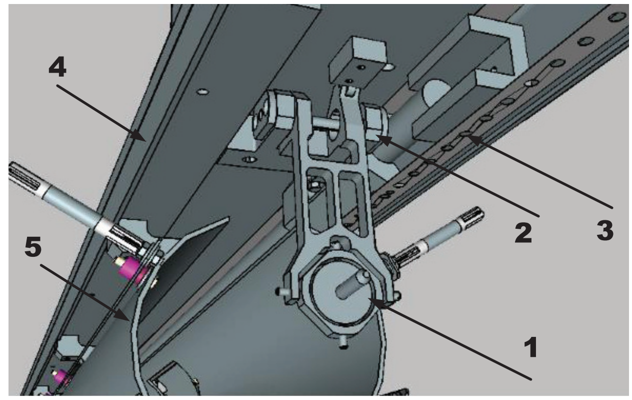

Figure 2: Compass assembly. (1 – mirror, 2 – compass driving cart, 3 – perforated tape, 4 – titanium rail, 5 – false tube).

The measurement system is assembled inside the vacuum chamber of the cooling section with the help of the 3.5 meter long titanium rail (fig. 2). It serves as a support for the driving mechanism, false chamber and BPM monitors. Driving chart with the compass slides along guiding rod attached to the rail. The motion chain consists of following units: rotary motion feedthrough with the step motor, connecting rod, 90° pinion drive, titanium perforated tape. The in-vacuum end of the rotary drive is connected to the pinion drive with long rod so that rotation can be transmitted to the unit which transforms it to the longitudinal motion of the cart with the help of the perforated tape.

The titanium rail has a special parking space for the sensor where it is kept during accelerator operation to release its aperture. During the magnetic measurements the compass goes out this place and occupies the proton beam orbit.

Since the rail has definite thickness it also sits above the synchrotron aperture. This means, that the design is not axially symmetric system that leads to the vacuum chamber impedance mismatch. To improve the impedance the false chamber was constructed as a sufficient part of the measurement assembly.

Air-side Equipment

Magnetic measurement system contains various optic and electronic devices those are functionally similar to previously used for different coolers commissioning [4]. The difference is in a presence of special equipment for the introducing the laser beam inside the vacuum chamber.

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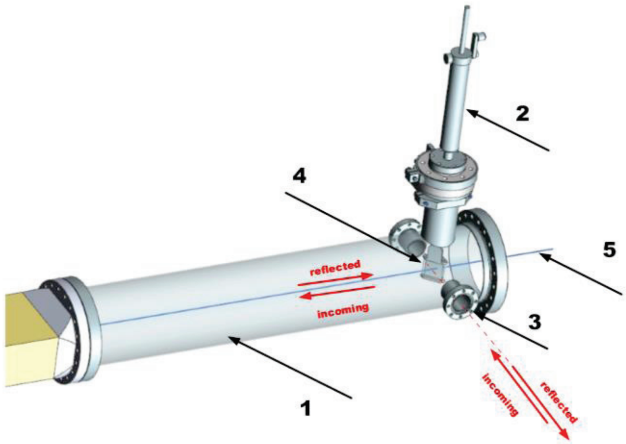

Figure 3: Laser beam input-output. (1 – vacuum chamber, 2 – push-pull manipulator, 3 – vacuum glass window, 4 – prism, 5 – proton beam axis).

Laser Beam Input-output Units

The peculiarity of the measurement system is vacuum – air transition of the laser beam. As usual, there is no enough space especially along the proton beam so the input-output chamber sits at nearest to the cooler quadrupole triplet. As shown in fig. 3, the vacuum glass windows are used to introduce the laser beam in vacuum chamber. Incoming beam goes into, then reflects with prism and goes towards sensor mirror. Being reflected from the mirror it follows the same path in opposite direction to the registration equipment. Push-pull manipulator provides required position of the prism (bearing in mind that prism must be out of aperture during the accelerator operation).

MEASUREMENTS RESULTS

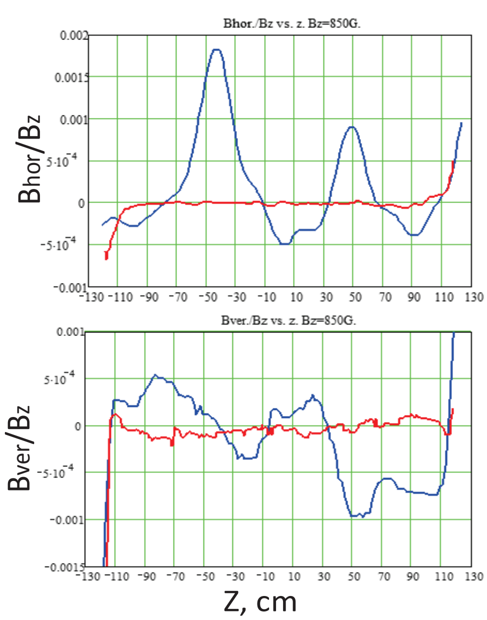

Figure 4: Magnetic measurements results.

Some of the results obtained during the commissioning at BINP are presented in fig. 4. Transverse magnetic component was measured at the cooling solenoid before (blue) and after (red) coils adjustment. One can see that finally the transverse components are within requirements. On the other hands, the noise of the vertical component measurements is higher most likely due to different sensitivity of the compass to vertical and horizontal mechanical oscillations.

SUMMARY

The measurement system based on compass with gimbal suspension was constructed and tested for COSY cooler to measure magnetic field line straightness with accuracy better then 10^{-5} for field 1-2 kG. It is a compromise between lower sensitivity and accuracy in comparison with compass on wire suspension and strict UHV requirements.

REFERENCES

[1] V.V. Parkhomchuk, A.N. Skrinsky, "Electron cooling: 35 years of development", *PHYS-USP*, 2000, 43 (5), 433–452.
[2] L.N. Arapov, N.S. Dikansky, V.I. Kokoulin at al,, Precise solenoid for the electron cooling, Proceedings of the XIII international conference on high energy accelerators. Novosibirsk, 1986, p.341-343.
[3] C. Crawford, E. Mc-Crory, S. Nagaitsev et al, Fermilab Electron Cooling Project: Field Measurements in the Cooling Section Solenoid. Proc. of the 2001 PAC, Chicago.
[4] V.N. Bocharov, A.V. Bubley, S.G. Konstantinov et al, Precision Measurements and Compensation for the Transverse Components of the Solenoids Magnetic Field. Instruments and Experimental Technique, Vol.48, No. 6, 2005, p.p. 772—779.
[5] V.N. Bocharov, M.I. Bryzgunov, A.V. Bubley, et al, System for measurement of magnetic field line straightness in solenoid of electron cooler for COSY, COOL'11 proceedings.

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