MEASUREMENT OF GEOMETRY OF PARTS OF MAGNETIC SYSTEM OF NICA COMPLEX COLLIDER

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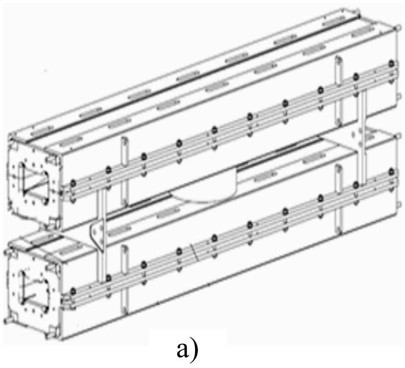
Abstract: The report deals with issues related to the measurement of geometry and the estimation of the geometric accuracy of parts of the magnetic structure of the collider of the NICA complex, Dubna, Russia. The methodology of measurement of dipole lens semi yokes which are part of Collider magnetic structure is briefly described. Special attention is paid to the influence of the choice of metrological datum features on the adequate assessment of the geometric accuracy of the object being measured.

Key-Words: measurement, methodology, metrological datum features.

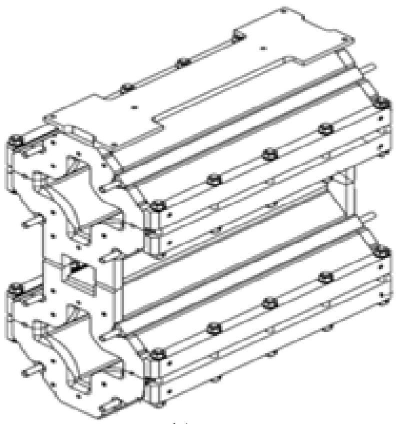
1. Introduction

The Nuclotron-based Ion Collider fAcility (NICA) is the new accelerator complex being constructed at JINR aimed to provide collider experiments with heavy ion [1]. The NICA layout includes Electron String Ion Source, Linac, Booster, Nuclotron and Collider.

The Nuclotron-type design is chosen for the NICA collider. Collider ring lattice is based on FODO (focusing lens, dipole magnets, defocusing lens, and dipole magnets) periodic cell in arc [2, 3]. Two collider rings are placed one above the other. Each ring is a racetrack consisting of two bending arcs and two long straight sections. Long straight sections are matched to the arcs. The beam superposition/ separation is provided in the vertical plane. That is achieved with dipole and quadrupole magnets having two apertures in one yoke (Fig. 1).



a)



b)

Fig. 1 Yoke of twin aperture dipole magnet (a) and quadrupole lens (b)

One of the factors that affect the quality of the magnetic field inside the aperture is the geometric accuracy of the yoke.

The methodology of measurements of geometrical features (sizes, form, location and orientation of surfaces) of yoke of dipole lens of the Collider of the NICA complex by a Portable Coordinate Measuring Machine (Portable Measuring Arm) proposed in this paper complies with the prescribed tolerances of deviation from nominal sizes, form, location and orientation of surfaces according to technical documentation.

2. Methodology of Measurement

The yoke of dipole lens consists of three parts - the upper, the lower and the central part. of yoke (Fig. 2) made of laminated electrical steel. They are held together by longitudinal steel plates welded with laminations and frontal plates. As the parts have the same geometry of aperture a common methodology is developed for their measurement.

Geometrical features of the object are determining by coordinate measurements of number of points of its plane and hyperbolic surfaces and holes. Measurements are performed in a Cartesian coordinate system related with the Portable Coordinate Measuring Arm (PCMA).

Estimation of geometrical accuracy of each part of the yoke includes the evaluation of deviations of linear dimensions from the nominal values and

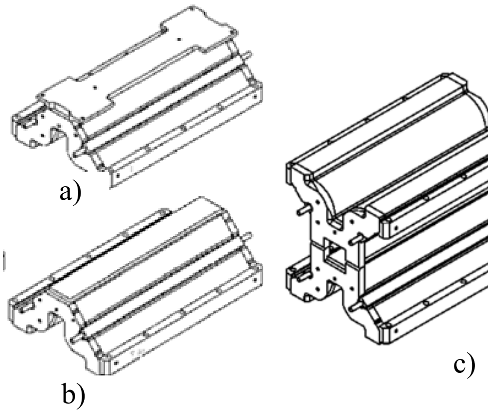


Fig. 2 Upper (a), lower (b) and the central (c) parts of yoke of lens

deviations of extracted geometrical features (lines, planes, hyperbolic surfaces, holes, axes) from prescribed form, location (position and symmetry) and orientation (parallelism and perpendicularity).

2.1. Measurement of Geometric features

In Fig. 3 the central part of the dipole lenses yoke with the surfaces to be measured is shown.

Cartesian coordinates of number of points of flat surfaces L_i, L'_i (i=1…4), K_j, K'_j and end surfaces P_j (j=1…4) are measured.

Cartesian coordinates of points of hyperbolic surfaces H_1, H_2 and H_1' and H_2' are measured in at least 3 cross-sections (Fig. 4) to assess the accuracy of profile form. It is preferable to use PUMP with point probe to avoid offset problems.

2.2. Construction of Reference Features

Construction of reference features (planes, axes, lines and points) is based on the measurement results for coordinates of points of geometrical features (points of extracted features).

All metrological datum features for estimation of yoke parts geometrical accuracy are constructed using specialized software for the Portable Measuring Arm.

The planes associated with the extracted surfaces are constructed as mean planes.

Centers of holes O_1 and O_2 in plane P are constructed as centers of mean associated circles.

In the drawings, the following planes are designated as datum planes to determine position and orientation of the other features: the planes associated with the surfaces K_1 (datum D), K_1' (datum E) and K_4 (datum A) and datum plane B, which is

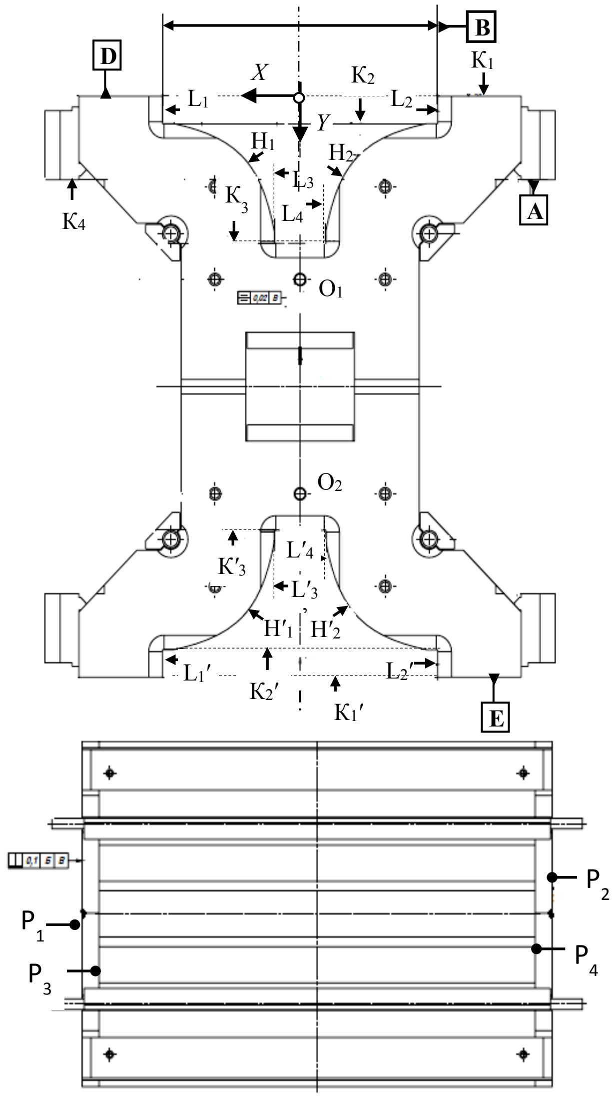


Fig. 3 Central part of dipole lens yoke

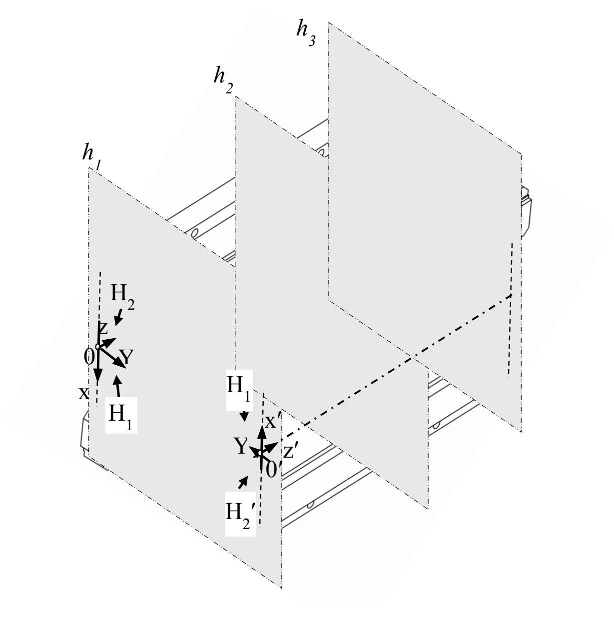


Fig. 4. Measurement of hyperbolic surfaces H_1, H_2, H_1', H_2' in cross-section h

constructed as a mean plane of surfaces L_1 and L_2.

As a result of metrological analysis of the drawings of the yoke and its parts, some inconsistencies in the choice of datum planes were discovered:

- Orientation and position deviations of inner surfaces relatively to the contact surfaces K_1 and, respectively $K_{1'}$ more strongly influence on the quality of electromagnetic field than the orientation relatively to the flange surface K_4. So, it is not appropriate to use K_4 as a datum plane.
- Tolerance of perpendicularity of surfaces L_1, L_2 ¬ to datum *D* is actually the tolerance of perpendicularity of their mean plane (datum *B*). This tolerance is 2.5 times greater than, for example, symmetry tolerance for holes O_1 and O_2 with respect to datum *B*.

Therefore, it is not advisable to consider *B* as the plane of symmetry of the measured part of yoke and as a datum for assessing the position of the holes and the hyperbolic surfaces H_1 and H_2.

The results of metrological expertise give grounds for making the following recommendations regarding the choice of metrological datum planes.

- Plane *K1* to be designed as a datum *D* for assessing the parallelism deviations of surfaces K_2, K_2, K_4 and datum E (the surface of contact with the lower part of yoke) and also for assessment of perpendicularity deviations of inner surfaces L_1, L_2, and end surfaces P_j (*j*=1…4).
- Datum *E* to be used for assessment of parallelism deviations of surfaces K_1' and *K2'* and also for assessment of perpendicularity deviations of surfaces L_1' and L_2'.
- Datum *B* to be used for assessment of perpendicularity deviations of end surfaces P_j (*j*=1…4) and for construction of yoke part plane of symmetry – datum plane *M*.

Datum plane *M* is constructed as a plane though the intersection line of datum plane *D* and datum plane *B* (line m) and perpendicular to the datum *D* (Fig. 5).

Cartesian coordinate *XYZ* related with the measured yoke part is the system with coordinate planes *X0Z* and *Y0Z*, which coinciding with the datum *D* and datum *M*, respectively. The centre 0 of the system can be considered as a point of intersection of mean line m with the plane P_1.

The coordinate system *X'Y'Z'* for assessing the form deviations of the hyperbolic surfaces H_1' and H_2' is constructed in an analogous way.

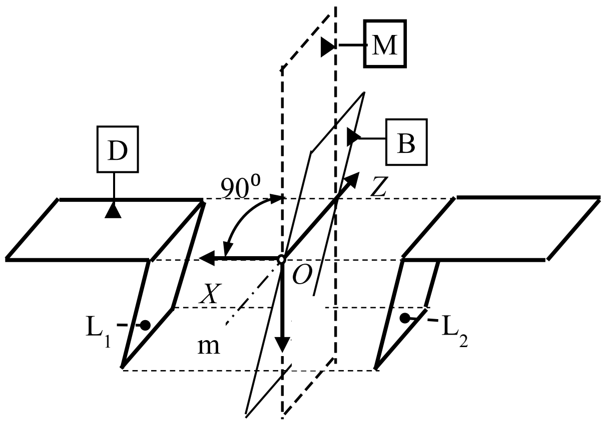


Fig. 5 Construction of datum M and XYZ coordinate system

3. Processing of Measurement Results and Evaluation of Geometric Parameters and Characteristics of the Yoke Part

The processing of the measurement results includes the determination of the numerical values of the deviation of the measured geometric elements (lines, surfaces, holes) from the prescribed dimensions, form, position and orientation.

3.1. Evaluation of dimensions, form, orientation and position deviations

of flat surfaces and holes.

Deviations of dimensions, form, orientation and position of flat surfaces and holes are determined using the specialized software of PCMA and according ISO 1101-2012 [4].

Linear dimensions are defined as the distances between geometric features (planes, lines, and points) associated to the extracted features.

The flatness deviation of surfaces K_i , K_i' (*i*=1…4) and P_j (*j*=1…4) is determined with respect to the mean plane associated to the extracted surface.

The symmetry deviation of holes O_1 and O_2 are determined as a distance from the centre of hole in the plane *P* to the datum plane *M*.

The perpendicularity deviation of surfaces is evaluated as follows:

- surfaces L_1 and L_2 to the datum *D*;
- surfaces L_1' and L_2' to the datum *E* ;
- surfaces P_j (*j*=1…4) to the datum *D* and datum *B*.

3.2. Evaluation of Form Deviation of the Hyperbolic Surfaces Profile

The theoretically exact profile of hyperbolic surfaces H_1 and H_2 in the coordinate system *XYZ* related with the measured part of yoke is described by equations:

$$Y = \frac{C}{X} \text{ - for H1 (C=1128,125)} \quad (1)$$

$$Y = -\frac{C}{X} \text{ - for H2.} \quad (2)$$

The local form deviation is determined as a distance from the point G_j of the extracted profile to the theoretically exact profile *HT*. To evaluate the profile form deviation of hyperbolic surfaces the coordinates of point G_j of extracted profile in the coordinate system related with the measuring system should be transformed into the coordinates in the system *XYZ* (Fig. 5), related with the yoke part.

The coordinate X_{Gj} in the system *XYZ* is given by the distance from point G_j to the datum plane *D*, and coordinate Y_{Gj} - by the distance from point G_j to the datum plane *M* (Fig. 6a).

The point $A_{Tj}(X_{Aj}, Y_{Aj})$ is constructed as an intersection point of the theoretically exact hyperbolic profile *HT* and a straight line through the measured point G_j and parallel to the coordinate axis *OX*.

The point $B_{Tj}(X_{Bj}, Y_{Bj})$ is constructed as an intersection point of the theoretically exact hyperbolic profile *HT* and a straight line through the measured point G_j and parallel to the coordinate axis *OY*.

The coordinates of these points are determined as follows:

$$X_{Aj} = \frac{C}{Y_{Gj}} \text{ (for surface } \mathbf{H_1}\text{) ;} \quad \mathbf{(3a)}$$

$$X_{Aj} = -\frac{C}{Y_{Gj}} \text{ (for surface } H_2\text{) ;} \quad (3b)$$

$$Y_{Aj} = Y_{Gj} \ ; \quad (4)$$

$$X_{Bj} = X_{Gj} \ ; \quad (5)$$

$$Y_{Bj} = \frac{C}{X_{Gj}} \ . \quad (6)$$

Chord A_{TJ} - B_{TJ} is constructed as line through the two points A_{Tj} and B_{Tj} and the line N_{ABj} perpendicularly to the chord A_{TJ} - B_{TJ} through the measured point G_j is constructed too.

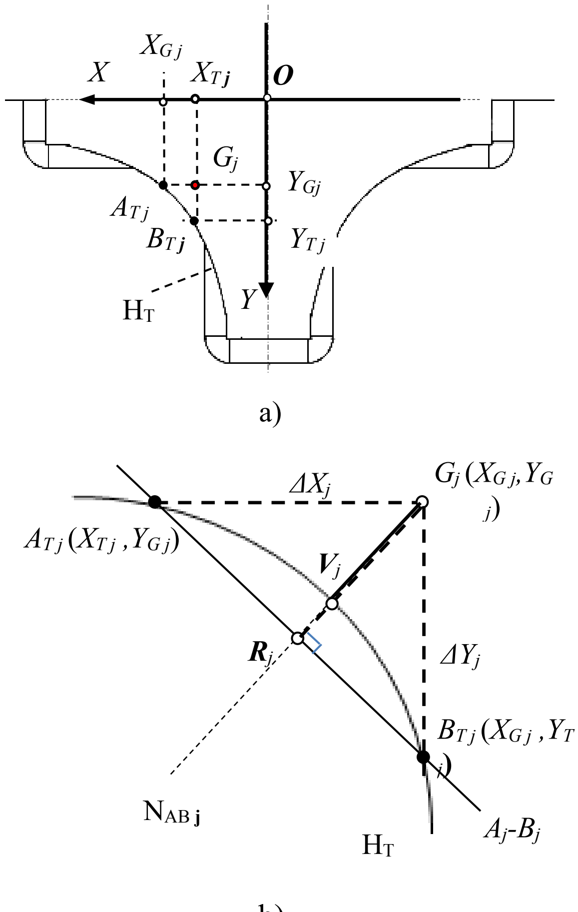


Fig. 6 Evaluation of hyperbolic profile form deviation

The local profile form deviation $\Delta_{\cap H}$ is defined as a distance from the point G_j of the extracted profile to the theoretically exact profile *HT*, measured along the normal N_j, (distance G_j-V_j).

In the first approximation the profile form deviation can be defined as a distance $\Delta_{\cap H}'$ from the point G_j of extracted profile to the chord A_j-B_j and calculated using the formula

$$\Delta_{\cap H}' = \frac{\sqrt{2}}{2}\left(X_{Gj} \cdot Y_{Gj} - C\right) \cong \Delta_{\cap H}. \quad (7)$$

4. Conclusions

The accuracy of the geometry of yoke of quadrupole lens, which is a part of magnetic structure of the Collider of NICA Accelerator complex, is one of the factors influencing the quality of the EM field within the yoke aperture. Special attention should be paid to the accuracy of the form, orientation and location of the yoke inner surfaces. An algorithm for evaluation of form deviation of profile of aperture hyperbolic surfaces is proposed.

To ensure an adequate assessment of the deviations of form and orientation of these surfaces the choice of appropriate datum features is essential. The new datum planes are recommended to be used for evaluation of form and orientation of yoke parts' surfaces as a result of the performed metrological expertise of yoke drawings.

The developed procedure for measurement by Portable Coordinate Measuring Arm allows adequate measurement and evaluation of form, orientation and location deviations of geometrical features of the yoke parts of lenses of the Collider of NICA Accelerator complex.

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