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SPECIFICATION OF THE STEEL CORE OF MAGNET MODEL I FOR THE INTERSECTING STORAGE RINGS

1. Introduction

The European Organization for Nuclear Research (CERN) in Geneva has started model studies for two high energy accelerator projects: a 300 GeV Proton Synchrotron and a set of intersecting storage rings (I.S.R.) for the present 28 GeV Proton Synchrotron. CERN is now in the process of inviting tenders for the supply of components of a first model of the I.S.R. magnet: this model may also provide useful information for the 300 GeV project.

This specification concerns only the manufacturing of the magnetic core of the model I: CERN has invited steelmaking firms to submit separate tenders for the supply of the required amount of steel to magnetic specifications, and will call separate tenders for the excitation windings, the poleface windings and the fixtures.

2. Description of the model

The magnet of the I.S.R. will consist of a number of unit magnets disposed along two intersecting curvilinear polygons with regularly distributed field free intervals. The average diameter of the two "rings" is about 300 m (Fig. I). There will be units of 2 different types, called F (focusing) and D (defocusing) respectively. The units of each type will be made in two lengths, of 3.4 and 5.9 m approximately: the steel cores of the long units will consist of two elements approximately equal to the cores of the corresponding short units. There will be in total about 80 short F units, 56 long F units, 64 short D units and 64 long D units. The proposed magnet model represents a full scale short F unit.

The complete magnet model is shown in Fig. 2. It consists of a steel core 2500 mm long, an excitation winding with its fixations, and a set of poleface-windings. It will rest on adjustable jacks.

A precisely defined distribution of magnetic field must be achieved in the air-gap between the magnet poles within a given range of excitation levels. This field distribution is mainly determined by the geometric configuration of the gap: therefore tight mechanical tolerances must be imposed on the magnet core and particularly on the pole profile.

In order to obtain useful constructional experience the model core shall be made by the same methods that would be adopted in the production of the magnet cores for the whole machine.

It is believed that the most economical method to achieve the required mechanical tolerances is to assemble the core by welding together precision punched laminations. In the construction of the CERN P.S. magnet, a lamination thickness of 1.5 mm has been found to provide a satisfactory balance between precision of die-punching, packing factor and cost of handling and assembling. It is proposed to use about the same thickness in the I.S.R. magnet, although, from the point of view of magnet operation alone, thicker plates could be used.

The cross section and the view of the core are shown in Fig. 3. The form of the pole profile drawn in Fig. 3 is only approximate, and is still being studied in relation with the expected particle orbits in the I.S.R. CERN must reserve the right to define the exact form of the pole profile until 120 days before the required delivery date.

In order that the experience of the model may be significant for the projects under consideration it is necessary that the core maker may be expected to be an acceptable tenderer for the manufacturing of the magnet cores in one of them at least. Therefore he should be able to cope at least with the delivery schedule of about 40 cores per month which would be required for the I.S.R. magnet.

3. Properties of the steel sheet

CERN's specifications for the supply of the steel sheet are attached for information. The mechanical properties of the proposed steel sheets will be specified in detail by the steelmakers. It can be anticipated, however, that the magnetic requirements will be met by very low carbon steels, suitably annealed and slowly cooled, which will be appreciably softer than normal mild steel.

The final mechanical specifications of the steel sheet must be the subject of an agreement between the steelmaker, the core-maker and CERN, previous to the signature of the contracts. No processing of the steel plates delivered to magnetic specifications can be permitted, except shearing and punching (and deburring).

4. Insulation of the laminations

The steel laminations shall be insulated with a continuous thin layer of heat resistent material preferably by surface treatment. In proposing the type of insulation the following considerations are relevant:

a) Previous to welding the tension bars, the interlaminar resistance of the core must be higher than $0.03\,\Omega/\text{cm}$.

b) The insulating layer must not be altered when tension bars are welded along the external edges of the stack of punched laminations to form the core. The tenderer shall supply convincing evidence to this effect.

c) Short circuits are not permitted elsewhere than at the external edges of the stack, in order to avoid conducting loops linked with the magnetic flux. Therefore the insulation must be continuous, well adherent, and mechanically strong. Previous to insulation, the plates must be clean and free from scale and must present no appreciable high spots.

d) In order to achieve a high packing factor, the thickness of insulations must be as small as is compatible with the above requirements.

The manufacturer of the core shall propose a method by which the absence of harmful short circuits can be demonstrated. (See also par. 9, e).

5. Punching of the laminations

A punched lamination is represented in Fig. 4. The precise procedure proposed by the manufacturer for punching, in order to obtain the desired tolerances, must be agreed to by CERN. From the experience of the CERN P.S., at least two, and preferably three successive press operations are necessary in order to cope with the differences in the degree of developability between the steel sheets from which the laminations are punched, which cause the gaps to close or to open by different amounts, after punching.

A possible procedure is outlined in Fig. 5, in which the following operations are indicated:

a) Opening of the plate.

b) Partial trimming of the exterior.

c) Formation of the pole profile and of the reference corners. It is essential that the pole profile and the reference corners be punched in the same operation, so that mechanical location may be obtained easily.

The profile die must also punch a witness mark, which identifies the position of the lamination with respect to the die.

Before assembling, each lamination must be freed from burs which could cause short circuits with neighbouring laminations, or hamper the stacking process. Of course, the deburring operation must be carried out in such a way as not to disturb the punched profile, and, if the laminations have been insulated before punching, the insulating layer should not be damaged.

6. Mechanical tolerances on the punched laminations

The permissible error in the gradient of the magnetic field along the median plane of the I.S.R. magnet, corresponds to an error of 2 μ/cm on the slope. Therefore the poleface must be cut to a precision better than $\pm$ 0.01 mm of the nominal dimensions. Distances, parallelism, rectangularity and summetry of the external reference surfaces, with respect to the pole-face, shall have a precision better than $\pm$ 0.025 mm. The absolute dimensions of the external reference surfaces shall be maintained with a precision better than $\pm$ 0.05 mm. (See Fig. 6).

7. Inspection of the punched laminations

Previous to production, a small number of sheets will be punched and inspected, to check that the required accuracy on the profile is achieved. The lamination will be placed under load on a reference plane and the minimum gap adjusted by forces on the external corners to have the nominal value. The projection of the profile of the lamination on the reference plane must not depart by more than $\pm$ 0.01 mm from the nominal profile. The manufacturer should propose a method for this measurement and have available adequate facilities.

This check will be repeated on two more laminations at the end of the production, to check the influence of die-wear.

For each finished lamination, the dimensions of the minimum gap must be tested with "go" and "no go" discs, which should have diameters 0.1 mm less and 0.1 mm more than the nominal minimum gap dimension, while the lamination is lying loaded on a flat surface. The unsatisfactory laminations shall be rejected.

8. The end plates

The stack of punched laminations to form the core shall be terminated by thicker end plates, which will prevent the end surfaces from bulging out and the pole tips from splitting open under the action of the magnetic forces.

The end plates must have the same pole profile as the normal plates but the precision required is not as high. Their thickness may be proposed by the manufacturer according to the rest of the structure, and it is expected to fall between 25 and 50 mm.

Shimming strips to compensate for end effects may have to be screwed to the end plates after assembling.

9. The assembly of the core

The punched laminations will be assembled to form the magnet core by means of steel strips welded along the external contour. The precise procedure by which the assembly will be performed must be proposed by the manufacturer and agreed by CERN. According to the principles established in the introduction this procedure must be adaptable to series production.

The following should be considered:

a) During stacking, the laminations should be confined on their exterior reference surfaces and against a profile gauge in the gap.

b) In order to achieve a high degree of mechanical symmetry in the core, the laminations should be placed in the stack so that each successive 30 laminations have their witness marks in alternate positions.

c) The welding operation should take place while the stack is kept under adequate pressure to insure that the welded core will behave as a solid block and will not be permanently deformed by bending or shearing stresses arising in handling, transportation and installation. A total pressure of the order of 100 tons is suggested.

d) Careful planning of the welding operation is required to avoid excessive distortions of the core by thermal gradients. Simultaneous welding at various locations may be necessary.

e) While the stack is under pressure, but previous to welding, an insulation test to be proposed by the manufacturer shall be performed. A possible method may be to measure the interlaminar insulation for every centimeter lenght of core. This test should be performed in the presence of a representative from CERN.

10. Mechanical tolerances concerned with the finished core

1. Space factor

The mass of the finished core shall be more than 96^{o}/o of the mass of a solid core with identical volume and constructed from material of the same average density as the steel of the laminations.

2. Gap height

The average value of the minimum gap in the core should be as near as possible the nominal value. The following testing criterion is proposed:

a) A cylindrical gauge, 5 cm long, having diameter 0.1 mm smaller than the nominal value of the minimum gap, must pass everywhere through the minimum gap,

b) no lamination in the finished core may have a minimum gap more than 0.1 mm larger than the nominal value.

3. Core length

The tolerance on the total length of the 2500 mm long core is ± 0.5 mm. The manufacturer may be permitted to adjust this length by machining the end surface of one of the end plates, but this adjustment should be as small as possible and in any case smaller than the thickness of one lamination.

4. Maximum permissible sagitta

If the straight core 2500 mm long is supported at both ends, the sagitta in the centre must be less than 0.05 mm. No permanent deformation can result from normal handling procedures in transportation and assembling.

11. Inspection of the core

The finished core will be weighed in order to determine the filling factor. It will then be placed on three adjustable jacks in front of a reference bench as shown in Fig. 7, and the following measurements will be taken:

a) Length of the core at the 4 corners and at the pole-tips.

b) Sagitta in the middle.

c) Deviation of the reference faces from planarity and parallelism. The maximum deviations of the vertical (resp. horizontal) reference faces from vertical (resp. horizontal) planes perpendicular to the middle plate in the core must be less than 0.4 mm.

d) Minimum gap. The height of the minimum gap all along the core will be checked by means of the cylindrical gauge described in 10. 2. a), which will be presented at intervals of 2.5 cm. The check corresponding to cirterion 10. 2. b) will be performed in correspondence of at least 100 laminations selected by the representative of CERN.

12. Access to information

In view of the purpose to be served by the model in providing experience for the design of the whole magnet, close cooperation between the manufacturer and CERN in the course of the construction is essential. Satisfactory facility should be given to representatives of CERN to inspect the components and the apparatus during the manufacturing, and to perform the specified tests.

13. Delivery of the core

The finished core shall be delivered to CERN not later than 7 months after signature of the contract. A shorter delivery time would be an advantage. The tenderer is requested to indicate the latest time by which the steel sheet should be made available to him in order for him to keep the proposed delivery time.

The tenderer is invited to indicate the means of transportation foreseen for the delivery of the core, and to specify separately the costs of packing, transportation and insurance.