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TECHNICAL SPECIFICATION
FOR A PROTOTYPE BENDING MAGNET OF
THE 800 MeV BOOSTER - SYNCHROTRON

The European Organisation for Nuclear Research (CERN) in Meyrin (Geneva) is constructing an 800 MeV Booster Synchrotron to be used as injector for the 28 GeV Proton Synchrotron. Components of this Booster are the 33 bending magnets.

This specification deals with the manufacturing of one bending magnet prototype for the Booster Synchrotron.

Table of Contents

1. Introduction and scope of the tender

1.1. General description of the Booster Synchrotron magnet system

The Booster Synchrotron being a separated function machine, its magnet system will consist of a number of bending magnets and quadrupole lenses, separated by free intervals of different length. The magnets will be placed along a circle of 25 m radius. The Booster Synchrotron will consist of four vertically stacked rings. Each bending magnet unit and quadrupole lens unit will thus consist of 4 bending magnets and 4 quadrupoles, the steel yoke being common to each unit. There will be 32 bending magnets and 16 quadrupole triplets in the ring, each triplet consisting of two shorter F-lenses and a longer central D-lens. One additional bending magnet and one quadrupole lens triplet will be required as reference units.

Fig. 1 and 2 show an artist's view of the Booster magnet system and a schematic layout of the ring. Each bending magnet will consist of two approximately 800 mm long blocks of punched steel laminations held together by welded tension straps. The two blocks will be mounted at an angle with a wedge shaped clearance between them. The two blocks are fixed between a top and bottom plate and form a rigid unit (Fig. 3). The magnet is energized by the four excitation coils, which are series connected.

1.2. Nature and form of the invited tenders

The tenderer is invited to make an offer for the manufacturing, testing and delivery to CERN of one prototype bending magnet made in two blocks of precision stamped silicon steel laminations, end plates, tension straps, top and bottom clamping plates, main excitation and correcting windings, monitoring and security devices as well as for four special thin excitation coils, described in par. 8.10, all in accordance with this specification for non oriented silicon sheets with an V_{10} = 1.3 to 2.0 W/kg (referred to 0.5 mm thickness. B = 1T and f = 50 Hz) quality index but for sheets of preferably 1 mm thickness.

Prices for the stamping and stacking tools and for the coil moulds should be separately stated.

Tenderers are invited to give a separate price for one additional magnet block with magnetic steel end plates as shown in Fig. 11 b.

Tenderers are also invited to give tentative prices for 33 bending magnets in accordance with this specification taking into account that the steel sheets will have to be mixed as stated in par. 3.2.8.

It is clearly understood that the choice of the prototype magnet manufacturer does in no way engage CERN as to the choice of the manufacturer for the 33 magnet units. The final order will be subject to a new tender, incorporating all the experience and knowledge gained with the prototype magnet.

1.3. Scheme for Delivery

It is hoped to place the contract for the manufacturing of the prototype bending magnet within 1 month after the tender opening. CERN is very much interested in a short delivery such as 7-9 months from the day of placing the order. A tentative delivery scheme for the 33 bending magnets should also be indicated. It is hoped to place the final order for these magnets not later than 6 months after the reception of the prototype magnet, the 6 months being necessary for precision magnetic measurements.

CERN is, of course, prepared to discuss any question concerning delivery with the tenderer.

1.4. Access to information

CERN will place only one contract with the prototype magnet manufacturer, who will be responsible for placing the various sub-contracts. It is important that CERN be informed of the full technical content of these sub-contracts.

CERN also demands the right to have access to all technical information in the course of production. In addition, it is demanded that satisfactory facilities be given to representatives of CERN to examine and inspect the steel and copper delivery and any component and apparatus in the course of the prototype magnet manufacturing.

1.5. Guarantee

The prototype bending magnet will be excited to full magnetic field at CERN and extensive magnetic measurements will be performed. Should these tests and measurements show defects due to a faulty construction, damage during shipment or failure to meet the specified tolerances, CERN will be entitled to urgent replacement of the defective part free of charge. The magnet manufacturer shall guarantee the prototype magnet performance as stated in this specification for one year starting from the final acceptance test at CERN.

2. Description of magnet

2.1. Magnetic field

The prototype magnet and later the ring magnets will be excited with a pulsed current in accordance with Fig. 4. The nominal pulse repetition rate is 1 s^{-1}. The bending magnet may be operated at any current level from the nominal down to 10%. A very precise, uniform and vertical magnetic field must be achieved in the four air gaps within the whole useful range of excitation current levels and the field be reproducible as a function of the excitation current from pulse to pulse.

It is required that the magnetic field in the corresponding points of the various bending magnets belonging to one ring and at corresponding points of one magnet unit but belonging to different rings be the same within a few parts in 10 000. The field distribution being determined by the geometry of the gap and by the magnetic characteristics of the steel laminations, tight mechanical tolerances on the gap profile and length and adequate magnetic properties of the steel are imposed and must be observed. The positioning of the excitation coils having also an influence on the magnetic field uniformity, appropriate coil manufacturing tolerances must also be respected.

2.2. Structure of the magnet cores or blocks

The pulsed excitation current and magnetic field require that the cores of the prototype magnet and later of all magnets be laminated in order to avoid field distrotion due to eddy currents and to improve the uniformity of the magnetic characteristics by shuffling the laminations, this for the later 33 magnet units.

The experience obtained with several large accelerator magnets at CERN and in other laboratories has shown that the required tight tolerances of the gaps and of the laminations can in general be obtained by punching (stamping) them with a precision die.

As will be explained in par. 3.2. "Magnetic Properties of Steel Sheets" (see page 10) the magnetic field uniformity requirements for the four gaps of one bending magnet unit ask for high performance magnetic characteristics of the laminations such as:
low coercive force H_c [A/cm] and its variation ΔH_c, high relative permeability μ_r also for low magnetic fields around 0.1T (1000 G) and for a good uniformity of these parameters. It has been established that high percentage silicon steel laminations correspond best to our requirements.

From the point of view of handling and mixing, the highest sheet thickness still comfortably satisfying the requirements stated in this specification is preferred. It has also been established that silicon steel laminations of 1 mm thickness meet our requirements. Equal or better magnetic performances may be obtained when using 0.7 mm sheets.

The somewhat reduced filling factor when using 0.7 mm laminations is not relevant.

For the prototype magnet the Si-lamination properties and thickness will be determined in collaboration with the successful tenderer.

The laminations must be held together in such a way that the cores are not distorted due to stresses arising in assembling, handling, transporting and installation. The experience at CERN and in similar laboratories has again shown, that a satisfactory assembling is obtained by welding together a stack of precision stamped laminations between thick end plates by means of tension straps, placed along the external contour of the magnet. Such a construction is assumed throughout our design and specification.

3. Steel sheet

In order to obtain the required very uniform field distribution in the four gaps of the magnet, the steel sheet for the laminations and for the gap closing plates must satisfy certain specific magnetic requirements. These seem to be best fulfilled for high percentage non-oriented, silicon steel laminations.

An inquiry had therefore been sent to a number of magnet manufacturers and steelmakers asking to submit to CERN information on magnetic and mechanical properties of different Si-steel laminations, either in the form of measurements or by sending adequate ring samples. The magnetic and mechanical properties of the steel sheets as stated in this specification are the result of the investigations and measurements performed by CERN.

In order to ensure the required uniformity in magnetic properties it is important that all sheets for the prototype magnet be supplied by the same steelmaker. The same condition is required when later the 33 bending magnets will be ordered. It is understood that two different steel suppliers can be envisaged for the prototype magnet and later for the entire series.

3.1. Dimensions of the steel sheet and required quantities

Fig. 5 shows the dimensions and tolerances for a stamped sheet. The external dimensions of the finished laminations are 630 x 1560 mm^2.

The external dimensions of the non stamped steel sheet must be such as to allow sufficient margin for correct punching of the contour and for the removal of the wedge-shaped, reduced thickness regions at the edges. It is assumed that sheets not larger than 750 x 1620 mm^2 will satisfy the above requirements. The larger dimension should coincide with the rolling direction of the lamination.

The above figures assumed, the total amount of steel laminations for the prototype magnet amounts to 15 tons and to 500 tons for all 33 magnet units. These figures are not expected to change by more than 5%.

The steel sheets shall be oiled and packaged in order to be protected against surface deterioration and damage during transportation and storage.

If the prototype magnet is made of laminations belonging to more than one batch, the sheets from one and the same batch should be bundled together so that samples for magnetic measurements can be taken for every batch.

This condition will notably have to be fulfilled for a controlled mixing of the sheets envisaged for the manufacturing of the 33 bending magnets.

3.2. Magnetic Properties of the Steel Sheets

3.2.1. General

The Booster magnet iron parts will be operated at low to medium magnetic fields between 0.1T and 1.0T. The lamination cross section according to Fig. 5 indicates that the magnetic reluctances of the two outer gaps, the top and bottom one are different from the reluctance of the two inner gaps. This asymmetry, together with the variation of the magnetic characteristics of the steel sheets, introduces errors in the 4 gaps where a uniform field with deviations not larger than a few parts in 10 000 between corresponding points is required.

The main error sources are the following:

i) Due to the steel sheet coercive force H_c[A/cm] and the different magnetic flux path for the inner and outer gaps, their fields B at low field will be different.

ii) The coercive force variation ΔH_c cannot be compensated and must obey certain tolerances.

iii) During acceleration the field in the bending magnets rises from B_i[T] to the maximum transfer energy value B_{tr}[T]. Quite apart from i) above and due to the different reluctance for inner and outer gaps, the field B will be different in inner and outer gaps. This difference can in principle be reduced to zero for one particular field, e.g. at transfer B_{tr}[T], by means of a correction in the excitation, but it will persist at other fields. If, however, the relative permeability of the steel laminations μ_r is high throughout the range $B_i < B < B_{tr}$ an adjustment can be found yielding very uniform B-values in the four gaps during the whole acceleration process.

iv) High μ_r values are also important in order to obtain a highly uniform magnetic field distribution within the gaps.

v) A tolerance must also be imposed for the relative permeability spread $\Delta \mu_r$, since any permeability variation effects the field in the gap and as a consequence the required uniformity of the magnetic fields in the four gaps.

The steel sheets must therefore satisfy certain permeability (μ_r) and coercive force (H_c) requirements and tolerances must be imposed as to the spread of coercitivity (ΔH_c) and permeability ($\Delta \mu_r$).

3.2.2. Type of Steel

The requirement of high permeability at low and medium magnetic fields and for low coercive force suggests a very low carbon, high quality silicon steel with low content of impurities. The Si-sheets must not be oriented.

3.2.3. Coercive Force requirements

The coercive force value H_c[A/cm] hereafter specified is the value of the magnetising force, reducing the induction in the steel lamination to zero from the value B = 1.5 T (15kG). Besides this value, the coercive force after complete saturation (H_{max}>60 A/cm) shall also be given.

Based on adequate Si-steel sample measurements, the following coercive force H_c and coercive force spread H_c values are suggested for laminations of 1.3 W/kg quality and 1 mm thickness.

$$(H_c \pm \Delta H_c)_{1.3} = 0.35 \pm 0.03[A/cm]$$

In order to check the agreed upon H_c and ΔH_c-values for the prototype magnet laminations, sample measurements according to par. 3.2.6. will be performed.

3.2.4. Relative permeability

We define the relative permeability μ_r as the ratio of the magnetic induction B [G] to the applied excitation 1.257 H [A/cm] along the normal magnetisation curve. Fig. 6 shows the minimum μ_r = f (H) curve CERN requires for the bending magnet prototype. The curve refers to a 1.3 W/kg-quality silicon steel of 1 mm thickness. At B = 0.1T or 1kG, μ_r should be $\mu_r \geq 3300$, at B = 0.3T $\mu_r \geq 5500$, at B = 0.6T $\mu_r \geq 6500$, at B = 1.0T $\mu_r \geq 4500$ and at 1.2T $\mu_r \geq 2500$ (see Fig. 6).

The maximum deviation $\Delta\mu_r/\mu_r$ from this curve shall not be greater than $\pm$ 10%, to be verified according to par. 3.2.6.

3.2.5. Ageing

The supplied steel laminations should be stable in time, especially the relative permeability μ_r- and coercive force H_c-values. Since the operating temperature of the iron cores will not exceed 25°C, it should not be difficult to maintain stable magnetic steel properties for many years of operation.

As a practical criterion the following ageing test is proposed: the steel sheet samples are subjected to an ageing process at 100°C during 600 hours. The values of μ_r and H_c, measured on the aged samples should not differ from the initial ones by more than 10%. Ageing tests will be performed on samples submitted by the tenderer before starting the manufacturing as well as on steel samples during the construction of the prototype magnet and later on of all bending magnets.

3.2.6. Samples for Magnetic Measurements

The magnetic properties of the Si-steel for the prototype magnet will be checked by measurements on three kinds of samples:

i) Before the construction, the manufacturer shall supply at least three samples made of rings 114Ø/76Ø $\pm$ 0.1 mm, stamped out of Si-steel laminations of agreed quality and thickness and piled together in order to obtain an overall height of about 14 mm. These samples should come from different batches.

ii) Some 0.5 to 1% of the steel laminations required for the prototype magnet should be used for stamping out ring samples as under i) in order to check the magnetic characteristics of the sheets. To do this, each sheet will be subdivided into a number of rectangles and samples made.

iii) Average characteristics sample

In order to obtain samples representative of the average magnetic properties of the steel for the prototype magnet, some 15-30 sheets shall be selected and at least three samples made by always collecting the 15-30 stamped out rings belonging to the selected sheets.

The exact sampling procedure to be discussed with tenderers.

It is proposed that the results of measurements performed at CERN be submitted to the steelmaker. If no objection is made within 17 days upon receipt of the results, the steelmakers agreement will be assumed and the measured values considered as a base for acceptance or rejection.

In the case of an irresolvable dispute about the measured figures, a neutral institution will be asked to arbitrate.

3.2.7. Tolerances on magnetic characteristics measured on samples

The average characteristic sample shall have magnetic properties within the limits given in section 3.1. and 3.2.

CERN must reserve the right to reject a batch of steel for which an average property sample shows unsatisfactory magnetic characteristics.

3.2.8. Mixing of steel sheets

Applies only for final delivery of the 33 magnets.

Controlled mixing of steel sheets is necessary in order to ensure the required uniformity in the magnetic properties of the blocks without having to improve tolerances beyond the possibilities of commercial silicon steel production.

The procedure consists of arranging the steel delivery in equal piles and in taking the sheets for the core or block-manufacturing in such a way that each core contains approximately the same number of sheets from each of the piles. If done so, the magnetic, geometrical and mechanical properties of the cores will be more uniform and unforeseen or undesirable phenomena will probably occur in a similar way in all blocks. The exact number of piles will be discussed between CERN and the successful tenderer. As an indication the number of piles will be of the order of 100.

The mixing procedure requires adequate available space for storing the whole steel delivery in piles of reasonable size and accessibility.

The steel sheets should be picked up by complete layers, one sheet from each pile in turn, following always the same sequence.

3.3. Geometrical and Mechanical Properties of Steel Sheets

3.3.1. General

The final geometrical and mechanical specifications of the steel sheets will be the responsibility of the (prototype) magnet manufacturer and the steel manufacturer as stated in a contract between these two parties. The agreement of CERN will, however, be necessary for this contract to become effective.

In order to maintain constant magnetic characteristics, no mechanical processing of the steel sheets other than shearing, punching and deburring can be allowed once samples are taken for magnetic measurements.

It is in general required that the steel sheets be suited for adequate insulation, precision stamping and for assembling and welding into blocks.

The following proposals indicate the requirements considered necessary for obtaining satisfactory blocks.

3.3.2. Flatness and Internal Stresses

Flatness and freeness from internal stresses are necessary in order to avoid gap profile changes and local modifications of magnetic properties during stacking under pressure. It is, as an acceptance criterion for flatness, proposed to apply a pressure to the measured sheet of some 100 kg/m^2; all points of the sheet should then lie within δ + 2 mm, δ being the sheet thickness (see fig. 7).

The amplitude of any local wave should not exceed 0.5 to 1% of the wave length which is of the order of 200 to 300 mm. In order to demonstrate the absence of internal stresses, it is proposed to cut a sheet along its two main symmetry axes and bring the surface back to contact; the maximum appearing gap should be inferior to 0.3 mm.

3.3.3. Thickness

As a guiding line, every single sheet should have a thickness as uniform as possible. In order to obtain satisfactory stacking, one should reduce as much as possible systematic difference of thickness between different points of one sheet. As an acceptance criterion and basis for discussion with the tenderers it is proposed that the maximum thickness deviation$_+$ from an average value, measured on a 630 x 1560 mm sheet should be inferior to $\pm$ 1.5%. When measured along a width of 150 mm centered on the air gaps, the maximum thickness deviation from an average value along the part should be smaller than 1%. In order to measure the above spreads, some 16 samples in form of 80 mm ± 0,1 diameter discs will be taken from a number of sheets and weighed. The deviation of the sheet thickness from a specified rated value, given for all sheets is less important, and spreads of ± 3% are acceptable, provided every single sheet is in itself flat within the above limits.

3.3.4. Surface finish

The surface shall be clean, free of scale on both sides for good insulation adherence and shall not show any visible fault. A certain roughness seems desirable, but no high spots which could damage the insulation should be present.

3.3.5. Inspection of the steel supply

It will be the responsibility of the magnet manufacturer to perform the adequate geometrical and mechanical tests of the supplied steel while being delivered in agreement with the steelmaker and CERN. CERN shall receive the results of the measurements.

4. Laminations

4.1. Gap profile

A punched lamination with the external dimensions and tolerances of the gaps is shown in Fig. 5. The parallel gap profile shown on this figure may not be the final one, as it generally depends upon the magnetic properties of the steel sheets. The final profile of the four gaps will be given to the successful tenderer when signing the contract. It is, however, believed that the profile will closely correspond to that indicated in Fig. 5.

For the purpose of the present quotation the tenderer can assume that the gap profile will be straight and parallel.

4.2. Punching Procedure

The precise procedure for punching in order to obtain the required tolerances is the entire responsibility of the manufacturer but his proposals shall be described in the tender. From the experience of the CERN Proton Synchrotron and Intersecting Storage Ring models and magnets it seems that at least two, possibly three successive operations are necessary in order to deal with the differences of flatness and with the residual stresses in the sheets the profile has been stamped out of.

A possible procedure could comprise the following three operations:

i) opening of the plate in the four gaps

ii) partial trimming of the external surface

iii) stamping out of gaps and of all reference surfaces+.

It is essential that the four gaps and the reference surfaces be punched in one and the same operation so that their relative position from sheet to sheet is as uniform as possible.

It is suggested also to punch a witness mark to be changed every time the die has been modified, for instance sharpened. In order to provide a statistics complete record must be kept of the sharpening, changing and gauging of the dies and of the corresponding witness marks. The number of successive operations between successive sharpenings shall be recorded and one lamination kept for inspection after every 500 operations of the profile stamping die. These laminations shall bear serial numbers.

In order to reduce systematic variation of sheet thickness, alternate sheets may be reversed prior to punching. After punching each lamination must be freed from burr which could cause short circuits with adjacent laminations or disturb the stacking process. Deburring should by no means affect the punched profile.

In general, great care must be taken to avoid distortion or damage to the laminations in handling, transport and storage.

4.3. Dimensional tolerances of the laminations

The field uniformity in the four gaps of the prototype bending magnet requires tight tolerances for the profiles.

Since the profile die may introduce systematic geometrical errors, tighter tolerances are required for the die than for the gaps stamped out of individual laminations.

4.4. The profile die

The part of the die which cuts out the four gaps, as shown in Fig. 5, must be made with a precision better than ± 0.01 mm of the nominal dimensions.

Parallelism, rectangularity and symmetry of the external parts of the die, cutting the reference corners with respect to the four gaps shall have a precision better than ± 0.05 mm/meter. The vertical dimensions of the external reference planes shall be maintained with a precision of ± 0.15 mm. The tolerances refer to a temperature of 20°C.

The profile die tolerance shall be checked by adequate measurements, for example by means of a precision coordinate boring machine in the presence of a CERN-representative.

4.5. The die profile reproduction in the laminations

This will be checked as follows: the lamination will be placed on a surface plate under uniform load of 100 kg/m^2 and the dimensions of the four gaps and of the outer reference corners measured. The deviation should not exceed the tolerances given in Fig. 5.

4.6. Insulation of the laminations

The steel laminations shall be insulated with a continuous layer of heat resistant material, preferably by surface treatment.

In order to obtain a high packing factor, thin insulation layers are required.

Insulation procedure:

i) The insulation of the laminations can be done before or after punching. In the second case deburring is easier but it is essential that no permanent deformation and dimensional changes occur especially as far as the four gaps and the references planes are concerned.

ii) The maximum temperature during the insulation process shall not influence the magnetic characteristics of the steel laminations.

iii) With the exception of a few millimeters around the welding seams + when welding the tension straps, the insulation shall not be altered; no short circuits are permitted elsewhere than in the immediate surrounding of the welding seams.

iv) Before welding, the insulating resistance of the stack should be measured; it should be higher than $0.03\Omega/cm$, this at a lamination stack compression higher than $10\ kg/cm^2$.

Tenderers are required to give a description of the insulation process covering points i)-iv)

4.7. End profile laminations

As shown on Fig. 5 the end profiles of the four magnet gaps are obtained by the stacking of laminations with progressively enlarged, higher aperture gaps. It will therefore be necessary, once the stamping of all constant gap profile laminations for the prototype magnet is terminated, to make the end profile laminations either by using a die which can progressively stamp out larger gaps leaving other dimensions unchanged, or by first stamping out the normal gap and then by enlarging the four gaps by adequate machining of the laminations. If the latter solution is adopted it shall be proved that the magnetic characteristics of the end lamination do not change in an inadmissible way due to machining.

The required precision for the end laminations is inferior to that of the standard laminations, the gap height tolerance amounting to ± 0.1 mm. (see Fig. 5).

4.8. <u>Checking of the lamination geometry</u> (to be performed under a uniform load of 100 kg/m^2)

i) Inspection of the reference surface plate

The flatness error of the reference plane shall not exceed ± 0.005 mm over 1 m length. Adequate checking methods shall be proposed by the manufacturer.

ii) Flatness of the laminations

This will be checked by means of a dial indicator along different lines, as shown in Fig. 7.

iii) Length and parallelism control

For this control, end plates, calibers and internal micrometers placed on a reference plate as shown in Fig. 8 could be used.

iv) Gap control

A method for checking the gap parallelism is indicated in Fig. 9. The position of the gap axis with respect to the reference plane is then

$$\frac{2\ell_c + d_1 + d_2 + e}{2}$$

The gap width can be checked with a calibrated bar and a micrometer.

The gap height is controlled with "GO" (-0.015 mm tolerance) and "NO GO" (+0.015) tolerance gauges. Any lamination not satisfying this test shall immediately be rejected.

The parallelism and tolerances of the lamination outer reference lines shall also be checked by means of a calibrated bar.

5. End plates

As shown in Fig. 10, the two magnet blocks build up from punched laminations shall on both ends be fitted with 13 mm thick end plates, preventing the end surfaces from bulging and the gaps from splitting open under the action of magnetic forces.

CERN has not yet decided if the end plates shall be made from non-magnetic or of magnetic material. Further studies of the effect of magnetic end plates on the magnetic field distribution in the four gaps have to be carried out. The final choice will be made by CERN, before signing the contract for the prototype.

For the tender the two versions shall be considered as shown in Fig. 15. The two designs differ slightly, mainly in the total length and the length tolerance of the magnet blocks. If a price difference results from the difference of constructions, separate prices shall be given by the tenderer for the two versions.

The non-magnetic end plates shall be made from stainless steel. The tenderer shall for this case provide evidence about the non-magnetic behaviour of the end plates material: a relative permeability inferior to $\mu_r = 1.02$ is proposed as a criterion.

The magnetic end plates will be made from mild steel (low carbon steel) with the following magnetic characteristics:

i) The coercivity shall be lower than 1.5 A/cm. The variation of coercivity from plate to plate shall stay within an interval of $\pm$ 0.2 A/cm.

ii) When subject to a magnetising force of 300 A/cm the flux density must be larger than 2.0T.

The magnetic properties will be measured by CERN on machined ring samples of 76Ø/114Ø mm $\pm$ 0.1 mm and 14 mm height. For the prototype one sample shall be taken from each sheet being used for the fabrication of the end plates. For the later construction of all 33 magnet units one sample from every tenth sheet shall be taken for measurements.

6. Construction of the magnet core

The punched laminations and the end plates will be assembled to form the magnet blocks and cores by means of steel straps welded along the external contour. Tenderers are invited to give a detailed description of the proposed welding and assembling procedure and to consider notably the following points:

6.1. Stacking

This should be done in a rigid frame, confining the laminations against suitable reference surfaces. No stressing which could lead to systematic deformations of the laminations should be introduced. In choosing the stacking references it should be borne in mind that the tightest tolerances are imposed on the four gaps which thus form a privileged and preferred reference surface. The tenderer shall describe the stacking procedure he proposes.

6.2. Shimming of the stack

Due to inevitable thickness variation over the lamination surface, the stack could be shimmed by means of different width Si-sheets not thicker than 0.35 mm. The tenderers are invited to give details of the shimming procedure they intend to use.

6.3. Stack compression

At suitable intervals during stacking operation and at its end the stack should be compressed with a pressure of about 10 kg/cm^2. The length of the straight part of the gaps, the gap length including the end profiles, and the total length from end plate to end plate shall be measured. Before welding, the stack shall be left to settle under maximum pressure during several hours, after having several times applied and removed the pressure.

6.4. Welding under pressure

The welding operation shall take place while the stack is kept under pressure. The compression force to be applied will amount to 75-100 tons.

Simultaneous welding at several places will be necessary in order to avoid distortions due to thermal stressing. The tenderer is invited to specify in his offer the welding procedure, the size of the welding seams, electrode quality etc. and to propose methods of checking the quality of the welds.

If the tenderer thinks that the required mechanical tolerances cannot be obtained by the described and preferred welding technique, he may propose other procedures like gluing (and bolting). All these proposals will be carefully examined and discussed. The geometry and the positioning of the tension straps as proposed in Fig. 11 to 11b may be changed by the manufacturer.

7. Welded blocks

7.1. Block with straight end profile

Tenderers are also invited to give their price for one block as shown in Fig. 11b. The block made from laminations according to Fig. 5 has no specially shaped end profiles. The straight block has two 13 mm thick end plates of magnetic low carbon steel. The overall ± 0.1 mm length tolerance measured at the four gaps is obtained by adequately machining the end plates.

7.2. Machining of the blocks

In order to obtain the same length for all four gaps the blocks with magnetic end plates shall be machined along their two outer vertical surfaces. The length adjustment shall be done by machining the end plate of the straight part.

No machining of the variant with stainless steel end plates will be required because machining has in this case no effect on the magnetic properties of the block.

The top and bottom tension straps will have drilled holes in accordance with Fig. 11 in order to mount the top and bottom plates which keep the two blocks in the required position.

The drilling of an additional number of holes in the tension straps and plates may be required from the manufacturer.

7.3. Mechanical tolerances for the complete blocks

7.3.1. Gap profile

The average gap height obtained from at least 10 measurements along the block length and at three different points across the gap, i.e. the average value of these 30 measurements shall be within ± 0.02 mm from the nominal 70 mm gap height. In addition the gaps shall be checked with GO(-0.05 mm) and NO GO (+0.05 mm) gauges of appropriate length (≈5 cm).

7.3.2. Block length

For the variant with stainless steel end plates the required length tolerance of the laminated part is ± 0.2 mm, which must be obtained after stacking and welding (without machining of the end plates). It is realised that this represents a very tight tolerance which we are ready to discuss with the tenderer.

The length tolerance for the finished blocks with magnetic end plates is ± 0.1 mm measured along the four gaps after machining of the end plates.

7.3.3. Other dimensional tolerances

The tolerances on the relative position and dimensions of the machined parts, holes, etc. are given in Fig. 11.

7.3.4. Packing factor

The packing factor defined as the ratio of the mass of the finished block to the mass of a solid block of the same average steel density will depend on the lamination thickness choice. For a lamination thickness of 1 mm, a packing factor of ≈ 94% is expected. Tenderers are invited to specify minimum packing factors.

7.4. Inspection and checking of the block geometry

7.4.1. General

Before inspection the block shall be marked with a serial number and the measurements described in this chapter performed in the presence of a CERN representative.

7.4.2. Geometrical control of the finished block

The vertical reference surfaces of each block will be checked as shown in Fig. 12.

Fig. 13 shows the block height and parallelism checking with a reference plane, dial indicator or air gauge. A vertical or horizontal precision lathe can also be used for this verification.

The block thickness will be checked as proposed in Fig. 8.

The gap width of one block can be checked with a calibrated bar, a micrometer and several standard gauges, as shown in Fig. 14.

The straight part of the gap length ℓ_1 can be checked with a calliper-square or a gauge between two precision bars. For measuring the end profile part "e" two precision bars and a calliper-square can be used (see Fig. 14). The tolerances are $\pm$ 0.15 mm for ℓ_1, $\pm$ 0.05 mm for e, $\pm$ 0.2 mm for $\ell_2 = \ell_1 + e$.

7.4.3. The magnet block twist

The twist of one magnet block shall be checked as follows:
the block is placed on a rigorously plane surface plate. A vertical 1600 x 900 mm plate being precision machined at the height corresponding to the block reference planes along 900 mm, and being rigorously perpendicular with respect to the surface plate,is brought in contact with the block right and left hand side vertical reference planes. The clearance between the block

reference surface and the vertical caliber-plate shall everywhere be inferior to 0.2 mm.

A similar test shall then be performed with the calibrated plate in horizontal position parallel to the surface plate. The caliber plate is placed on the magnet block upper reference surfaces and the clearance measured. It should again be inferior to 0.2 mm. The measurements shall be repeated with the block now placed with the "upper" reference surfaces on the surface plate.

7.5. Finishing of the blocks

The surfaces of the four gap profiles of the reference corners and of the end plate parts - see Fig. 5 - shall be well protected against corrosion.

Each block shall be painted with at least one coat of suitable primer and two finishing coats of a high grade hard glossy enamel of a colour and quality to be selected in agreement with CERN.

7.6. Assembling of the two blocks into one magnet unit

The two blocks are assembled into a compact magnet unit in such a way that the angle between the inner machined stainless steel plates amounts to 2 x 2.8125°. In order to obtain the required precise angle when assembling the prototype magnet, the following method is proposed: the two blocks are turned horizontally with the four gaps in a vertical, downward position. Two precision machined steel gauges (Fig. 17) bearing on their top surface two very precise sliders (with a tolerance of $\approx 20\mu$) forming the required angle are placed at a distance corresponding to that between the top and bottom gap. The two blocks can then glide along the gauge sliders until they are brought into the correct position, given by the 5,625° wedge caliber and the cylindrical gauge as shown in Fig. 15 and 16. When the final relative position of the two blocks has been reached, the profile reinforced bottom plate is adjusted to the blocks so that the precisely machined surfaces touch the bottom reference surfaces of the two blocks. The bottom plate is then fixed by bolts screwed into the holes drilled in the bottom tension straps of the two blocks, as shown in Fig. 16. The simpler top plate is then fixed in the same way on the upper tension straps of the blocks. Fig. 18 and 19 show the upper and lower plate design. Before assembling the two iron blocks into one magnet unit, the inclination angle of the two precision machined steel gauges will have to be checked, for example as shown in Fig. 20. The two gauges, placed on a reference template, are checked with a dial-micrometer in at least two points by a [mm] apart. From the distance a and the difference in height readings δ [mm] the angle is found.

The above method is mainly proposed for the 33 bending magnets.

The tenderer can suggest other, less costly methods for the prototype magnet.

As the wedge shaped part between the two magnet blocks also contributes to the total magnetic length, a tolerance has to be imposed to the distance between the adjacent laminated parts of the two blocks. Measured at the closed orbit, the distance shall at all the four gaps amount to 50 ± 0.1 mm, as indicated in Fig. 3 and 15. Tenderers shall propose adequate methods for measuring this distance.

7.7. The gap closing plates or magnetic plugs

As shown in Fig. 3 and in detail in Fig. 21 the four magnet gaps will on their outward "open" side be closed by precision machined plates or plugs made of Si-steel laminations and serving a double purpose to limit a closing of the gap and to provide magnetic screening against stray fields, which would otherwise penetrate the gap. The closing plates are held by clamps shown in Fig. 22.

It is proposed to make these plugs of stamped or adequately machined Si-steel laminations glued with epoxy resin, the filling factor being less relevant than for the magnet blocks. An 80% filling factor, leaving 20% for the epoxy layer in order to have sufficient insulating distance once the glued together plug is being precision machined, can well be accepted. As to the required epoxy radiation resistance, see par. 8.4. 2.

7.8. Lifting tests

Lifting tests shall be performed with the two iron blocks and the assembled iron structure with the mounted top and bottom plates in order to make sure that the magnet can be handled safely.

The blocks and the assembled magnet will be lifted and displaced by means of a travelling crane. After several lifting and displacement tests no deformation or deterioration of the lifting pads or of any welded tension strap shall occur and the magnet main dimensional tolerances shall still meet the original specifications.

For this purpose gauges could, during the lifting test, be mounted on the magnet in order to observe any dimensional variation.

8. Excitation Coils

8.1. General description of the excitation coils

Before describing the bending magnet excitation and correcting winding, a general remark concerning this chapter, as far as the prototype magnet and the later order for the 33 magnet units are concerned, has to be made.

In what follows the full requirements to be satisfied and tests to be performed are specified referring to the windings of the 33 bending magnets. This is necessary in order to enable tenderers to quote prices for them as stated on page 7.

As to the prototype magnet coils, it would be of advantage to have them made with an insulation corresponding entirely or closely to that the tenderer would consider for the 33 bending magnets. By doing so, the insulation proposed by the tenderer could be checked when constructing the prototype magnet coils, and the prototype itself kept as a spare unit.

As far as the following paragraphs are concerned, par. 8.4.2. "Testing of radiation resistance" and 8.4.3. "Sample test on insulation" are not required for the prototype magnet winding. The tenderer may, however, also perform tests 8.4.2. and 8.4.3. should he wish to submit an early evidence about the properties of his insulation.

The "Prototype coil tests" described in 8.4.4. are, however, required before starting the construction of the prototype magnet coils.

As indicated in Fig. 3, the bending magnet prototype will have four main excitation windings, one per each gap. Every winding shall consist of two coils, an upper and a lower one, each consisting of two pancakes with three turns (Fig. 23 and 24). Within every main excitation winding, two auxiliary, two-turn correcting windings will be placed (Fig. 25). Since later two out of the 33 Booster bending magnet units will have to be equipped with special thinner main excitation coils, shown in Fig. 33 - two pairs of these coils shall also be manufactured in order to be inserted in the different prototype magnet gaps and adequate measurements made.

The four prototype magnet main excitation windings will be series connected and excited from a stabilized pulsed power supply with a current and voltage form in accordance with Fig. 4. The nominal peak current amounts to I_p = 2750 A, the rms current to I = 2000 A, the nominal peak voltage for all Booster magnets to U_p = 2500 V and the voltage drop for one (prototype) bending magnet unit to u_p<60 V.

For the main excitation coils a hollow copper conductor allowing demineralized water cooling will be used. All windings shall be insulated exclusively with glass-mica tapes and a thermosetting resin.

8.1.2. Magnetic forces on the coils

The excitation coils being located in the linearly decreasing magnetic field, they will be subject to pulsed mechanical forces, reaching a maximum value of ≈ 1 ton/meter for one coil (3 turns).

8.1.3. Effects of water cooling

The demineralized cooling water will have a resistivity larger than 2.10^5 Ωcm and an inlet temperature of about 12°C. At full load the water inlet side of the coils will be about 8°C below the ambient temperature, assumed to 20°C, the water outlet side of the coils about 12 to 14°C above the ambient temperature. The coils will first contract and then expand due to the average 10°C temperature rise in the coils. In the coils, stresses will be introduced due to the 20 to 22°C difference between inlet and outlet temperatures.

8.2. Samples and prototype coil

Samples for checking the brazing of the conductors and insulation samples shall be made ready within 4 months after signing the contract. A 3 turn prototype pancake shall be made within 6 months from signing the contract and tested in accordance with par. 8.4.4.

8.3. Construction of the main coils

8.3.1. Conductor material and dimensions

The conductors shall be made from electrolytic oxygen free copper, having at 20°C a conductivity superior to $57.10^6 \Omega^{-1} m^{-1}$.

The conductor has a rectangular cross-section with sides 28 ± 0.1 mm and 15 ± 0.1 mm with a cooling hole of 7 mm Ø $\pm^{0,2}_{0}$ mm. The corners shall be rounded off with a radius of 2 mm (Fig. 23).

The conductor cross section shall not be less than 370 mm^2. It would be strongly desirable to wind the individual three turn pancakes with a single conductor length, thus avoiding brazes at the interior of the coils. To do this, a minimum conductor length of 13.5 m would be required.

The resistance, measured at 20°C of one 3 turn-pancake shall be inferior to 0.65mΩ, the resistance of one excitation winding per gap inferior to 2.7mΩ and of the 4 series connected windings, that is of the entire bending magnet unit inferior to 11 mΩ

The internal and external surfaces of the conductor must be clean and free from cracks and burrs. An adequate procedure for conductor inspection and for the verification that the cooling water hole is not obstructed nor deformed is to be proposed.

The total copper weight per magnet unit is ~750 kg.

8.3.2. Winding

Each pancake shall be continuously wound on an adequate former assuring the proper distance in the straight parts and the appropriate bending radii for the curved parts.

8.3.3. Brazing of conductors

The brazed junctions must be made in the straight coil part. The brazing procedure must be entirely reliable and should not depend on the skill of a particular operator.

To achieve this, the following points should be observed:

i) Control of the brazing temperature as well as of the relative conductor position during the operation.

ii) Careful cleaning and machining of the joints, continuity of water holes.

iii) Use of a jig assuring the correct conductor position, constant pressure on the joint and allowing for the movements of the two conductor parts.

iv) The brazing material shall be added in the form of foils and should not contain zinc or any additional flux.

v) A reducing or at least neutral atmosphere shall be maintained around the joint and inside the hole during the time the conductors are heated.

No permission shall be given to start with the coil construction before evidence about the high quality of the brazes has been obtained. The following tests on samples and later on brazed joints shall be made:

a) After brazing and cleaning, the joints shall be machined to the nominal conductor dimensions. The joint shall then be stressed with at least 4 kg/mm^2. No cracks shall appear during this test, otherwise the joint will be rejected.

b) Hot water ($80^\circ C$) is passed through the conductor which is externally sprayed with cold water on the joints for 3 minutes. This cycle will be repeated 25 times.

c) A Helium leak detecting test shall be performed, and

d) The complete coil including connections shall be filled with water under 60 at and tested.

Any joint failing at any of these tests shall be remade. No repairs are permitted.

8.4. Insulation of the coils

8.4.1. General

The coils shall behave as rigid units in order to minimise the effect of mechanical forces and temperature stresses.

The insulation shall also be water-tight especially against condensed water, which could be found on the coils after longer shut-downs.

It is the experience of CERN that these requirements can only be met by using a suitable combination of glas-mica tape and thermosetting resin.

The only acceptable insulation processes shall be alternatively:

1. The interturn or conductor insulation is wound in the form of a tape of mica-paper bonded to a glass substrate, and finished with a suitable tape for mechanical protection. The ground insulation is then wound around the individual pancakes in a similar way and the whole pancake placed in an adequate mould, giving it the final dimensions. After drying the mould is evacuated and the coil impregnated under vacuum with a chosen thermosetting resin. The mould is then placed in an oven for the polymerisation of the resin.

2. The interturn and ground insulation consist of epoxy resin pre-impregnated mica paper-glass substrate tapes again with protective tapes. The coil is placed in a mould, evacuated at a temperature where the maximum fluidity of the resin is obtained and polymerized under vacuum.

3. A combination of methods 1 and 2.

Any insulation, even the conductor one, can only be applied after the coil had been completely wound, formed and bent into a pancake.

It is not permissible to polymerize the inter-turn insulation before winding the ground insulation. Such a method does not give sufficient guarantee that the two insulations will later not separate under the influence of stresses and radiation. The thickness of the main winding conductor insulation shall not be inferior to 0.8 mm and that of the ground insulation to 2 mm. After having been immersed in water and tested electrically as stated in par. 8.5., the coils shall be painted with a suitable water repellent paint.

8.4.2. Testing of radiation resistance

The excitation coils will operate in an irradiated zone due to beam losses occurring in the Booster Synchrotron. In order to determine the radiation resistance of thermosetting resins, CERN has investigated the behaviour of epoxy resins, cured with different hardners; the results are summarised in the report ISR-MAG/67-3, available on request.

The tenderer will have to submit 20 samples of the resin he intends to use. These samples shall be sent to CERN together with the tender. The sample dimensions shall be 90 x 20 mm^2 with 3 mm thickness.

The acceptance criterion for the insulation will be the flexural strength behaviour, measured on 5 selected samples. The average value of the flexural strength behaviour, measured on 5 selected samples. The average value of the flexural strength measured on these five samples having absorbed a dose of 5.10^9 rads shall not be inferior to 50% of the average value measured on 5 not irradiated samples.

8.4.3. Sample tests on insulation

The mechanical properties of the insulation will be tested in the following way:
Three bars of 2 meter length with a cross-section equal or close to the final conductor cross section will be adequately insulated as stated in par. 8.3.1. Hot water shall flow in the inner and cold water in the two outer ones, until a temperature difference of $30^{\circ}C$ is reached. The water flow shall then be inverted until the same difference is reached, a.s.o. The cycle shall be repeated 1000 times, and the thermal expansion recorded during the entire test. After this test the bars shall withstand at least 10 kV_{rms} at 50 Hz; the bars shall then be tested to breakdown.

8.4.4. Prototype coil tests

In order to check the satisfactory quality and process of insulating and impregnating the coils, a main excitation winding 3-turn prototype pancake shall be manufactured within 6 months of the contract signature. This prototype coil shall be tested as follows:

1. The insulation resistance of the completely insulated and impregnated pancake shall be measured at 2500 V, a wetted cloth wrapped around the pancake representing the ground.

The coil shall then be immersed in tap water at ambient temperature during 1 week and the insulation resistance again measured.

2. The coil shall then be subject to thermal cycles by adjusting the current such as to obtain a 40°C temperature difference between inlet and outlet water. The current shall then be reduced to zero and the pancake cooled down to tap water temperature, a.s.o. This cycle shall be repeated 1000 times.

3. After this test, the pancake shall again be immersed in tap water for at least 24 hours. The insulation resistance shall then be measured as stated under 1. It shall exceed 500 MΩ.

4. A 7 kV_{rms}, 50 Hz-20 minute test shall be performed.

8.5. Testing of the finished coils

8.5.1. Dimensional tolerances

The dimensions and tolerances as indicated in Fig. 23, 24 and 25 shall be checked by adequate methods, proposed by the tenderer. The overall length tolerance is ± 1 to 2 mm and ∓ 0.3 mm for the distance between the inner faces of the coils over the entire gap length. The same tolerance shall be kept in the case that the correcting winding is manufactured together with the main excitation winding.

The tolerances for the height of one pancake coil and for the excitation winding in one gap in accordance with Fig. 23 and 24 have to be observed, as the relative conductor location in the gap influences the magnetic field distribution.

8.5.2. Electrical tests

The electrical resistance of each coil shall be measured and recorded. The measured values shall be in agreement with par. 8.3.1.

Not before one week after the impregnation process, each 6-turn pancake shall be submitted to 10 thermal cycles with a temperature difference of $\Delta t = 30^{\circ}C$.

The waterflow in every 6 turn pancake shall be measured. It shall exceed 4.5 l/min at a pressure drop of $\Delta p = 2.0$ at.

The pancakes shall then be immersed in tap water at ambient temperature for 24 hours, only the electrical terminals being above the water surface and the following tests will be performed:

a) a 7 kV_{rms}, 50 Hz test during 20 minutes between conductor and ground (water).

b) a 20 kV, 1.2/50 impulse voltage test, the voltage being applied to one terminal, the other one being grounded. At least 10 pulses shall be applied. The manufacturer shall propose a suitable interturn fault detection method for this test.

After these tests the insulation resistance between conductor and water will be measured with 2.5 kV_{dc}. The resistance shall be higher than 500MΩ.

Any pancake failing any of these tests shall be replaced by a new one free of charge.

8.6. Correcting windings

As shown in Fig. 25 two 2-turn compensating or correcting windings are foreseen in every gap inside the main excitation windings. The conductor insulation thickness of this correcting winding amounts to 0.75 mm and the ground insulation to 1.7 mm. Tenderers may also propose a common ground insulation for the adjacent main winding coils and for the correcting winding. In this case in addition to tests 8.5.2. the insulation between both correcting windings and the main excitation coils shall be tested with 5 kV_{rms} at 50 Hz during 20 minutes, and a 500 MΩ insulation resistance measured at 2.5 kV_{dc}.

The insulation between the two correcting windings shall be tested with 1 kV_{rms}, 50 Hz during 20 minutes and an insulation resistance higher than 200MΩ measured. If separately wound and with separate ground insulation, the correcting windings shall be tested as follows:

a) After 24 hours water immersion a 5 kV_{rms}, 50 Hz-20 minute test between both conductors and ground (water) and

b) a 1 kV_{rms},50 Hz-20 minute test between the two correcting windings shall be performed and

c) an insulation resistance larger than 500 MΩ measured between both windings and their common ground insulation. The insulation resistance between the two correcting windings shall be greater than 200 MΩ.

8.7. Mounting of the coils

The relative position and the mounting of the coils is shown in Fig. 3. In principle the excitation coils, protected by vetronite (glass fibre reinforced epoxy resin) plates of adequate thickness and placed with a tight -0.2 mm tolerance in the gaps, should by themselves support the mechanical stresses. On the magnet open side the magnetic plugs, closing the gaps will help to support the outward forces on the coils.

As shown in Fig. 26 and 27 the coils are on the external yoke side held by a stainless steel band which is fixed to the magnet in the wedge shaped gap between the two blocks.

The 90^{o} bent coil ends are fixed to the two frontal end plates by aluminium or stainless steel holders with vetronite blocks as insulating inserts.

Figures 28 and 29 show the proposed layout of the electrical and hydraulic interconnections between the four main excitation windings. 45 x 45 mm^2 cross-section vertical copper bars are foreseen as electrical connections, insulated with the same insulation as the main windings.

The bars are fixed to the magnet yoke by vetronite plate insulated stainless steel or aluminium holders. In order to provide for adequate cooling water distribution, holes shall be drilled at the ends into the copper bars and the rubber hoses fixed via "Ermeto"-type connections.

Fig. 29 shows the detailed drawing of the proposed electrical and hydraulic connection between the bus bar and excitation coil.

Fig. 30 shows the electrical and cooling water schemes for the four main excitation windings. Windings 1 and 4 are series connected followed by the series connection of 2 and 3.

There will be one cooling circuit per every full excitation winding, i.e. per one magnet gap.

As a general rule it must be stated that no organic insulating material nor any radiation non resistant material shall be used for fixing the coil to the magnet.

8.8. Monitoring and protecting circuit and devices

Figures 30 and 32 show the scheme of the monitoring and protecting devices and of their connection to the protective relays.

It is suggested to monitor the excitation winding temperatures by four identical foil thermometers Th 1 to Th 4 (See Fig. 23). These are standard mercury or alcohol contact thermometers, placed into a small copper tube which is itself welded to a thin copper sheet placed between the upper and lower excitation coil in each gap and at the warm water exit side. The contacts of the four thermometers are series connected and are closed as long as the temperature does not exceed a certain adjustable value.

The water flow for two cooling circuits, that is for two excitation windings hydraulically in parallel is measured with an "Eletta"-type flowmeter. The average warm water temperature for the prototype magnet is monitored by thermometer Th5 placed in the main water duct.

The 0-15 at dial-pressure contact manometer M1 and the 0-10 at dial manometer M2 measure the water pressure at the magnet entrance and exit. The manometers have adjustable minimum and maximum contacts.

The contacts of all meters are series connected such that the contacts are closed under normal operating conditions. A list of manufacturers CERN prefers for the flowmeters, thermometer Th5 and for the manometer is attached to this specification.

Fig. 31 shows the location of the measuring and protecting instruments and their fixation to the magnet.

8.9. Tests on the completely mounted prototype magnet

The following tests shall be performed once the coils and all the monitoring and protecting equipment is mounted:

i) The main water outlet circuit shall be closed and all excitation coils filled with water under (compressed air) pressure of at least 40 at. This pressure shall be applied during at least 30 minutes. No leaks or pressure drop shall occur. During this test the manometers and flowmeters will be disconnected or adequately protected.

ii) A 7 kV-50 Hz voltage test shall be performed for 20 minutes between the main and correcting windings and between these two windings against the grounded magnet core.

iii) The insulating resistance between the above windings and against ground shall be measured at 2.5 kV_{dc} and values above 500 MΩ be found.

8.10. Special thin excitation coils

Two of the 32 Booster Synchrotron bending magnets along beam injection and ejection lines are foreseen to be equipped with special higher current density and thinner main excitation coils.

In order to check the performance and to compensate possible magnetic field differences in the gaps of these special magnets with respect to the 30 standard ones, 2 special coil pairs shall also be manufactured and delivered with the prototype bending magnet. These coils will later be inserted into two of the four gaps and adequate magnetic measurements performed.

The special thin coil design is shown on Fig. 33. Each excitation winding consists of two 6-turn coils. The conductor cross-section is 13 $\pm$ 0.1 x 11.0 $\pm$ 0.1 mm^2 with a 6.5 mm Ø cooling hole; the corners are reounded off with ρ = 1 mm. The conductor insulation thickness is 0.75 mm, the ground insulation 2 mm.

All four special coils shall at their inner part have the two correcting windings, as shown in Fig. 33.

There shall be one cooling circuit per one 6-turn coil. At a pressure drop of $\Delta p \geq 5.5$ at a water flow per coil of $Q \geq 5$ l/min shall be measured. The electrical resistance of one coil at 20°C shall be inferior to 4 mΩ.

The special coils shall be insulated in the same way and with the same insulation as the main excitation coils. The special coils shall be tested in accordance with par. 8.5.2. and 8.6.

The special coils shall be made in such a way as to be easily connected to the main electrical and cooling water distributing system, shown in Fig. 26.

Detailed information to be given by the tenderer concerning:

A. Magnet Core

1. Magnetic, mechanical and geometrical properties of the silicon steel laminations.
2. Punching procedure for the main laminations, punching or machining procedure for the end profile laminations.
3. Insulation of laminations.
4. Stacking and welding procedure, precision that can be obtained.
5. Assembling of blocks into complete magnet unit.

B. Excitation Coils

6. Detailed description of insulating materials, thermosetting resin, hardener, impregnation process.
7. Behaviour of proposed insulation under mechanical, thermal, dielectric stresses, radiation resistance.
8. Brazing technique.
9. Quality of conductor copper.

List of Drawings

List of CERN Standard Accessories

Reference	Type	Supplier
Water outlet thermometer 0 to 100°C	Standard CERN/MPS Antimagnetic No 245 R Sensor T 6734/T 6719 Contacts E 5417/Ni89	Haenni AG Jegenstorf - Bern Switzerland
Inlet manometer 0 to 25 at Outlet manometer 0 to 10 at	Standard CERN/MPS Antimagnetic No 1 R VICOS/803 same Contacts E 5417/N 189	same
Water flowmeter 10 to 20 l/min	"Eletta" VI - GO	Elektriska A.B. Stockholm Sweden
Rubber hoses	Bull cord, airduc 15	Angst und Pfister AG Stampfenbacherstr 144 Zurich, Switzerland
Water couplings main terminals	Mod. 5115 1" G. Si Mod. 5015 1" G. Si (brass)	C Walker GmbH Wuppertal - Vohwinkel Germany

i) Page 6, par. 1.3 add : CERN would expect a delivery of 9 months for the first magnet and of 18 months for all 33 magnets.

ii) Page 8, par. 2.2 read : distortion instead of ''distrotion''

iii) Page 11, par. 3.2.1 v) read : affects instead of ''effects''

iv) Page 12, par. 3.2.3 correct : spread ΔH_c instead of ''spread H_c''

put : $(H_c \pm \Delta H_c)_{1.3} \leq 0.35 \pm 0.03$ [A/cm]

'' par. 3.2.4 correct in Fig. 6 : $+\Delta\mu_r$ instead of $+\frac{\Delta\mu_r}{\mu_r}$

$-\Delta\mu_r$ instead of $-\frac{\Delta\mu_r}{\mu_r}$

v) Page 21, par. 4.8 iv) add : The gap parallelism checking as shown in Fig. 9 has to be adapted to Fig. 5 i.e. all measurements to be performed from the inner gap reference surface.

vi) Page 22, par. 5 last part correct : .. and of the same 13 mm height as the end plates.

vii) Page 34, par. 8.4.1 correct : glass instead of "glas"