Specification for Dump Bumper, Injection Bumper, Chopper Dipole and Tune Kicker Magnets

M. Crescenti, A. Fowler, K. Metzmacher, L. Sermeus

Abstract

A synchrotron machine, capable to accelerate either light ions or protons, will be the basic instrument of the CNA (Centro Nazionale di Adroterapia), the medical center dedicated to the cancer therapy, that will be built in Italy in the near future. The machine complex consists of one proton-carbon-ion linac that will accelerate the particles till the energy of 7 MeV/u. An injection line will transport them to the synchrotron ring where the injected particles will be accelerated and extracted with an energy ranging from 60 to 250 MeV for protons and from 120 to 400 MeV/u for carbon ions. Fig. 1 shows a preliminary schematic picture of the CNA medical center.
ENGINEERING SPECIFICATION (SP)

Specification for Dump Bumper, Injection Bumper, Chopper Dipole and Tune Kicker magnets

Authors (TERA if non differently indicated)

M. Crescenti, A. Fowler¹, K. Metzmacher¹, L. Sermeus¹

¹ CERN - Geneve

Indirizzo per comunicazioni / Contact person

K. Metzmacher¹ (Klaus-dieter.metzmacher@cern.ch), CERN, 1211 Genève 23, CH

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Klaus Metzmacher

Klaus-dieter.metzmacher@cern.ch

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1 GENERAL

1.1 INTRODUCTION

A synchrotron machine, capable to accelerate either light ions or protons, will be the basic instrument of the CNA (Centro Nazionale di Adroterapia), the medical center dedicated to the cancer therapy, that will be built in Italy in the near future.

The machine complex consists of one proton-carbon-ion linac that will accelerate the particles till the energy of 7 MeV/u. An injection line will transport them to the synchrotron ring where the injected particles will be accelerated and extracted with an energy ranging from 60 to 250 MeV for protons and from 120 to 400 MeV/u for carbon ions. Fig. 1 shows a preliminary schematic picture of the CNA medical center.

![Fig. 1 – The CNA Medical Centre, exploded view.](image)

This contract is mainly for industrial engineering, design, construction, testing and shipment of the special Dump and Injection Bumper magnets, the Chopper Dipoles and Tune Kicker magnets. The magnetic computations have been accomplished by the CERN/AB/BT/KPS section. The engineering parameter lists and base line designs have been established [1], and are the fundamental basis of this specification.

Seller is not expected to carry out this part of the work.
This document defines the requirements of special magnets, normally referred to as bumpers, chopper and kickers. Any omissions in this document shall not relieve the seller of his obligation to furnish each magnet that is inherently complete such that it be treated as a stand alone turn-key entity.

The magnets must perform satisfactorily in accordance with this specification.

1.2 SCOPE OF WORK IN GENERAL

1.2.1 Work Included

The seller shall provide appropriate manpower for production related engineering, mechanical detail design and appropriate detail drawings of the special magnets governed by this specification. It is mandatory that all the design work has to be carried out by utilizing CAD. CNA project is using AUTODESK software package INVENTOR Series 6. All files provided by CNA will be in .DXF format. The compatibility of said files with respect to his own system is the sole responsibility of the seller. It is required that all the files, submitted by the seller, are in .DXF format on CD disks and be compatible with CNA's system.

The seller shall furnish all the necessary labor, materials, tools, fixtures and facilities for the fabrication, assembly, testing, quality assurance, fulfil specification, packaging and shipment of the special magnets. The system shall consist of, but not be limited to, the major items as specified in 1.8.1.

The seller shall prepare all the tool and fixture drawings, special to this contract, and submit a hard copy of "as built" drawings and CAD files to CNA for future references. All tools and fixtures fabricated by or supplied to the seller under this contract shall be considered as the exclusive properties of the CNA except otherwise stated in this document or in the contract. They shall be maintained in usable condition by the seller at all times while in his possession. At CNA's discretion, the storage duration can be as long as five years. The packaging and transportation related cost, at end of storage period, should be the responsibility of the CNA.

The seller shall prepare and submit three complete sets of documents to CNA at the conclusion of this contract, they shall include complete sets of "as built" assembly and detail drawings of all the components associated with this contract, both in hard copies and on disks in accordance with the first paragraph above. The drawings shall be so prepared that a third party can use them to produce same components in the future without any difficulty. In addition, the copies of relevant quality assurance reports, the operation and maintenance manuals shall also be part of deliverable if appropriate.

The seller shall prepare a complete Quality Assurance procedure specifically designed for this contract. A general manual published by some trade organization or government agency is not acceptable.

All the documents, including drawings, shall be prepared in the English language.

The tenderer shall nominate a senior specialist who will act as project leader and be responsible to CNA for all aspects of this contract throughout the contractual period. In particular he shall provide regularly an updated detailed time schedule covering material procurement and manufacturing and testing.
1.2.2 Work Not Included:
- Magnetic circuitry design
- Magnet engineering parameters
- Baseline magnet design
- Magnetic measurements
- Magnet supports.

1.3 APPROVAL

1.3.1 Equivalent materials may be substituted for those identified with a particular supplier, but no such substitution shall be made prior to receipt of written approval from CNA.

1.3.2 Before commencing construction the seller must submit to CNA for approval all the major tool and fixture and mould designs, but this approval process shall not relieve the seller from any of his responsibilities of performing satisfactory tasks governed by this specification.

1.3.3 A special approval in particular to the magnet assembly must be given by CNA after verification of the full compatibility of the subject magnets with the existing equipments and devices.

1.4 APPLICABLE DOCUMENTS

1.4.1 The drawings and specifications, supplied with this document, shall be considered as an integral part of this specification. These drawings and specifications depict in detail the baseline design of the special magnets.

1.4.2 Any conflicts, noted by the seller, among the requirements of any documents provided by CNA shall be referred to its designated representative for clarification before proceeding with any work.

1.5 DESIGN REVIEWS

1.5.1 Subsequent to contract award, seller is expected to complete and deliver to CNA a Preliminary Design Report (PDR, three copies) within one month or less in duration. This PDR shall describe engineering and design of those parts with which the seller wishes to deviate from CNA’s baseline design. The submitted documents shall be in sufficient details so that CNA can review and assess the merit of proposed changes. The tender is requested on the base of CNA’s baseline design; hence CNA reserves the right to reject any or all of the proposed deviations without the obligation of giving any justifications. Seller shall not have the right to vary his quoted price due to this rejection. A preliminary design review meeting will be scheduled two weeks after receipt of the PDR. After the satisfactory review, CNA will authorize the seller to proceed with the detail design and to purchase some of the long lead time items.

1.5.2 Subsequent to written approval of the PDR by CNA, the seller shall proceed expeditiously to complete all the necessary detail engineering, design and appropriate detail drawings of the components and associated tools and fixtures. CNA will review all or part of the documents at its discretion to assure that the quality of the detail designs is
commensurate with this specification. CNA will authorize, after satisfactory review, the seller to proceed with production of all or part of the components under this contract.

1.5.3 The preliminary review meeting shall take place at seller’s premise. The review and approval processes shall not relieve the seller from his full responsibility of producing the subject magnets to meet the requirements as given herein.

1.6 INSPECTIONS AND TESTS AT SELLER’S PLANT

1.6.1 Representatives of the CNA may visit the seller and his collaborator's facilities at any reasonable time to review the progress of this contract.

1.6.2 The seller shall give two weeks advance notice of the tests or inspections to be performed under the provisions of this specification. CNA may witness any or all of these procedures at its discretion.

1.7 ACCEPTANCE TESTS AT CNA SITE

1.7.1 The final acceptance tests shall take place in the CNA center, Pavia, Italy. CNA reserves the right to reject any magnet should there be defects discovered at that time.

1.8 QUANTITIES AND MILESTONES

1.8.1 Quantities (for spares see 3.1.4)

<table>
<thead>
<tr>
<th>Special Magnet type</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dump Bumper magnet 6-turns</td>
<td>1</td>
</tr>
<tr>
<td>Dump Bumper magnet 12-turns</td>
<td>1</td>
</tr>
<tr>
<td>Injection Bumper</td>
<td>2</td>
</tr>
<tr>
<td>Chopper Dipole</td>
<td>4</td>
</tr>
<tr>
<td>Tune Kicker Horizontal</td>
<td>1</td>
</tr>
<tr>
<td>Tune Kicker Vertical</td>
<td>1</td>
</tr>
</tbody>
</table>
1.8.2 Milestones

The following target dates and major milestones are CNA’s objectives in the design, construction, inspection and delivery of the special magnets; they shall be considered an integral part of this specification.

<table>
<thead>
<tr>
<th>Milestones / Time in months</th>
<th>Dump Bumpers</th>
<th>Injection Bumpers</th>
<th>Choppers</th>
<th>Tune Kickers</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Contract award date</td>
<td>T</td>
<td>T</td>
<td>T</td>
<td>T</td>
</tr>
<tr>
<td>2 Preliminary design report received by CNA</td>
<td>T+1</td>
<td>T+1</td>
<td>T+1</td>
<td>T+1</td>
</tr>
<tr>
<td>3 Preliminary design review Begin procurement of ferrites, if authorized. Proceed with tooling manufacturing if authorized</td>
<td>T+2</td>
<td>T+2</td>
<td>T+2</td>
<td>T+2</td>
</tr>
<tr>
<td>4 Detail design complete</td>
<td>T+4</td>
<td>T+4</td>
<td>T+4</td>
<td>T+4</td>
</tr>
<tr>
<td>5 Order mechanical housing, coils and small parts</td>
<td>T+4</td>
<td>T+4</td>
<td>T+4</td>
<td>T+4</td>
</tr>
<tr>
<td>6 Reception of mechanical housing, coils and small parts</td>
<td>T+9</td>
<td>T+9</td>
<td>T+9</td>
<td>T+9</td>
</tr>
<tr>
<td>7 Reception of ferrites</td>
<td>T+12</td>
<td>T+12</td>
<td>T+12</td>
<td>T+12</td>
</tr>
<tr>
<td>8 Start magnet assembly</td>
<td>T+12</td>
<td>T+12</td>
<td>T+12</td>
<td>T+12</td>
</tr>
<tr>
<td>9 Production completed, magnets ready to acceptance tests at the company premises</td>
<td>T+16</td>
<td>T+16</td>
<td>T+16</td>
<td>T+16</td>
</tr>
<tr>
<td>10 Start System tests</td>
<td>T+16</td>
<td>T+16</td>
<td>T+16</td>
<td>T+16</td>
</tr>
<tr>
<td>11 System tests complete. System ready for acceptance</td>
<td>T+18</td>
<td>T+18</td>
<td>T+18</td>
<td>T+18</td>
</tr>
<tr>
<td>12 Complete delivery of magnets</td>
<td>T+20</td>
<td>T+20</td>
<td>T+20</td>
<td>T+20</td>
</tr>
<tr>
<td>13 Installation at CNA</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14 Final running-in and acceptance test</td>
<td></td>
<td></td>
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</tbody>
</table>

1.8.3 Progress report

A monthly progress report shall be delivered to CNA on or before the 15th day of each month. CNA will use it to track the status of this contract.
## 1.9 Magnet Parameter List

Table 1: Combined Parameter table for special magnets, Bumpers, Kickers and Chopper.

<table>
<thead>
<tr>
<th>Component</th>
<th>Dump Bumper</th>
<th>Dump Bumper</th>
<th>Injection Bumper (2)</th>
<th>Tune Kicker Hor.</th>
<th>Tune Kicker Ver.</th>
<th>Chopper Dipole (4)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Name</strong></td>
<td>S3-010A-BDS</td>
<td>S8-016A-BDE</td>
<td>S3-012A-BDI / SD-010A-BDI</td>
<td>S4-020A-QKH</td>
<td>S4-022A-QKV</td>
<td>H3-001A / 005A / 009A / 013A-CHD</td>
</tr>
<tr>
<td><strong>Info</strong></td>
<td>2 different items powered in series, resonant power supply generator</td>
<td>2 items, powered in series, resonant power supply generator</td>
<td>PPN-type generator with thyatrons</td>
<td>4 items powered in series, current controlled power converter and programmable with a resonant HV branch</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Function</strong></td>
<td>Start beam dump</td>
<td>End beam dump</td>
<td>Injection bump</td>
<td>H beam mass</td>
<td>V beam mass</td>
<td>Extracted beam chopper</td>
</tr>
<tr>
<td><strong>Dispulsating</strong></td>
<td>Vertical</td>
<td>Vertical</td>
<td>Horizontal</td>
<td>Horizontal</td>
<td>Vertical</td>
<td>Vertical</td>
</tr>
<tr>
<td><strong>Effective magnetic length (m)</strong></td>
<td>0.1</td>
<td>0.1</td>
<td>0.3</td>
<td>0.3</td>
<td>0.3</td>
<td>0.3</td>
</tr>
<tr>
<td><strong>Fuller physical length (m)</strong></td>
<td>0.15</td>
<td>0.15</td>
<td>0.22</td>
<td>0.22</td>
<td>0.2</td>
<td>0.205</td>
</tr>
<tr>
<td><strong>Maximum integrated field BH [T m]</strong></td>
<td>0.0173</td>
<td>0.0346</td>
<td>0.0076</td>
<td>0.0095</td>
<td>0.0078</td>
<td>0.0149</td>
</tr>
<tr>
<td><strong>Maximum field B [T]</strong></td>
<td>0.0577</td>
<td>0.1153</td>
<td>0.0254</td>
<td>0.0282</td>
<td>0.0318</td>
<td>0.141</td>
</tr>
<tr>
<td><strong>Maximum beam rigidity [T m]</strong></td>
<td>6.3464</td>
<td>3.3646</td>
<td>0.363</td>
<td>6.364</td>
<td>6.364</td>
<td>6.364</td>
</tr>
<tr>
<td><strong>Deflection angle [rad]</strong></td>
<td>2.7</td>
<td>5.4</td>
<td>10</td>
<td>1.18</td>
<td>1.40</td>
<td>6.6</td>
</tr>
<tr>
<td><strong>Table</strong></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Effective magnetic length [m]</strong></td>
<td>0.3</td>
<td>0.3</td>
<td>0.3</td>
<td>0.3</td>
<td>0.3</td>
<td>0.3</td>
</tr>
<tr>
<td><strong>Total physical length [m]</strong></td>
<td>0.225</td>
<td>0.225</td>
<td>0.295</td>
<td>0.262</td>
<td>0.242</td>
<td>0.35</td>
</tr>
<tr>
<td><strong>Ferrite physical length [m]</strong></td>
<td>0.15</td>
<td>0.15</td>
<td>0.22</td>
<td>0.22</td>
<td>0.2</td>
<td>0.205</td>
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<td>10</td>
<td>1.18</td>
<td>1.40</td>
<td>6.6</td>
</tr>
<tr>
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<td>0.3</td>
<td>0.3</td>
<td>0.3</td>
<td>0.3</td>
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</tr>
<tr>
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<td>0.225</td>
<td>0.225</td>
<td>0.295</td>
<td>0.262</td>
<td>0.242</td>
<td>0.35</td>
</tr>
<tr>
<td><strong>Ferrite physical length [m]</strong></td>
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<td>0.15</td>
<td>0.22</td>
<td>0.22</td>
<td>0.2</td>
<td>0.205</td>
</tr>
<tr>
<td><strong>Maximum integrated field BH [T m]</strong></td>
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<td>0.0346</td>
<td>0.0076</td>
<td>0.0095</td>
<td>0.0078</td>
<td>0.0149</td>
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<tr>
<td><strong>Maximum field B [T]</strong></td>
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<td>0.1153</td>
<td>0.0254</td>
<td>0.0282</td>
<td>0.0318</td>
<td>0.141</td>
</tr>
<tr>
<td><strong>Maximum beam rigidity [T m]</strong></td>
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<td>3.3646</td>
<td>0.363</td>
<td>6.364</td>
<td>6.364</td>
<td>6.364</td>
</tr>
<tr>
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<td>5.4</td>
<td>10</td>
<td>1.18</td>
<td>1.40</td>
<td>6.6</td>
</tr>
<tr>
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<td>5.4</td>
<td>10</td>
<td>1.18</td>
<td>1.40</td>
<td>6.6</td>
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</table>

### Notes
- "h" is always given in the nominal B-field direction.
2 MAGNETS AND SUPPORTS

2.1 GENERAL

2.1.1 CNA provides the engineering parameter list (1.9) and specification drawings (4) of the special magnet assemblies. The specification drawings show the baseline design of the magnet and associated parts. Manufacturing dimensions and tolerances, except where specified by CNA, shall be the responsibility of the seller.

2.1.2 It is mandatory that all the parts are inspected and conform to specification and drawing before proceeding with assembly operation. Seller shall inform CNA of any non-conformity of the parts, and his intended method of repair. CNA reserves the right not to accept any repairs or to reject the proposed repair method if it deems not compatible with the functionality and/or reliability of the component. The time needed to rectify or remake the rejected parts shall not constitute a cause for schedule delay.

2.1.3 The electrical terminals and the coolant manifolds (where applicable) are part of the magnet assembly; safety cover(s) shall be provided for personnel protection against electrical hazards. The hoses and fittings shall be done in accordance with CNA standards which will be provided in the appendices of this specification. Manifolds, if needed, shall be made of stainless steel material and of welded construction.

2.1.4 Every magnet must be equipped with an appropriate grounding arrangement. CNA will supply the grounding cable.

2.1.5 The magnet base plates as shown on the specification drawings are part of the magnet support structure. CNA has specific requirements on these supports for reasons of initial alignment procedures and future maintenance of these magnets. Therefore, no deviation from the baseline design is allowed.

2.1.6 The top of the magnet assemblies must be provided with flat surfaces to enable the alignment in the horizontal plane with a spirit level.

2.2 YOKE ASSEMBLY

2.2.1 The magnetic yoke of the magnets is assembled from rectangular ferrite blocks to form a C-shape. It may be possible to directly machine the ferrite to form a C-type shape. For dump and injection bumpers magnets, once the ferrite, coil and insulation are in place the ensemble must be glued together with epoxy resin, using the housing as a mould.

2.2.2 The two ferrite types suggested are quite particular for a pulse excitation and have long standing excellent proven record. For the magnetic field calculations the properties of only these two types of ferrite material are considered. From past experience, both are acceptable in their magnetic and mechanical properties. They are of proven characteristics. The material is purchased finished to drawing from either company: CMD 5005 is from Ceramics Magnetics Inc. USA, (http://www.cmi-ferrite.com).
2.3 MAGNET CONSTRUCTION MATERIALS

2.3.1 Except for the ferrite material used, all other material (frame, support, screws, washers, nuts and bolts etc.) must be either insulating or non magnetic.

2.3.2 Antico™ (EN AW-6082 aluminium alloy) is to be used for the magnet frame.

2.3.3 Vetronite™ (IEC EPGC 201, NEMA G10, ISO EPGC 1) in sheet or tube form is the standard glass-fibre reinforced resin insulation.

2.4 RESIN SYSTEM, CLEANING, HANDLING, IMPREGNATION AND CURING (GENERALITIES)

2.4.1 For all coils, the tenderer must give full information about the insulating material used and the way he will proceed (number of layers, impregnation, procedure, curing temperature, etc.). The coils will be subjected to long term radiation exposure. The coil insulation system must not only be suitable concerning electrical and mechanical properties, but also be able to withstand minimum radiation doses of $10^7$ Gy without harmful effects. The flexural strength measured on irradiated samples after being exposed to the integrated dose of $10^7$ Gy must be not less than 50% of the value measured on non irradiated samples. The recommended glass-fibre tape is known to have excellent radiation resistance property. The tenderer is required to state in his tender specifically the type of the resin system, impregnation and curing procedures, which he will use for the coils. The radiation resistant capability of such system shall also be demonstrated with proper back-up test data or data from some creditable literature. Exterior surfaces of all the conductors (not only the water-cooled ones) shall be thoroughly degreased prior to the insulation procedure. Personnel wearing clean gloves, to avoid re-contamination, shall handle the cleaned copper surfaces and insulation material.

2.4.2 The coils must be vacuum-pressure impregnated in a single operation. CNA requires that the coil is cast in a suitable closed mould.

2.4.3 The thickness of un-reinforced resin on the surface of a finished coil must not exceed 0.5 mm. Sacrifice tape is allowed if seller deems necessary.

2.4.4 The insulation in the vicinity of the coil leads will need special attention. The seller is required to show, prior to production, that his design will provide adequate strength and also will avoid excessive resin build-up in that area. It is suggested to use Tedlar® tape, along the straight parts and the coil heads, as release agent.

2.4.5 The finished coils shall be free of voids, fissures, cracks, dry spots or other defects. Coils with internal defects shall be rejected, no repair is allowed. External defects may be repaired, contingent in each instance upon prior authorization from CNA, including approval of the procedure and material.
2.4.6 The coils must be fabricated in an area free of metallic particles, dirt, grease and welding or chemical fumes. Conductors, insulation materials and pre-insulated but not impregnated coils must be stored in clean and dry areas.

2.5 EXCITATION COILS FOR DUMP AND INJECTION BUMPERS

2.5.1 Material

The conductor shall be made from a single soft rectangular bar of Oxygen Free High Conductivity copper (OFHC). The conductivity of the material shall be at least ninety-nine percent (99%) of the International Annealed Copper Standard (IACS). Sharp edges must be rounded according to the magnet drawing. The copper surface must be free of voids, fissures, cracks, scratches, dry spots or other defects.

2.5.2 Coil forming

The copper bar may be bent using the final magnet parts (except for the ferrite blocks which are too brittle), on an external jig.

2.5.3 Coil Electrical Terminals

The electrical terminals shall be made of Oxygen Free Copper (OFC). They shall be hard brazed with a silver brazed solder (AWS-ASTM BCUP-5 or equivalent) to the coil bar after the coil forming. The contact resistance must be checked before going further and must not exceed 0.5 mΩ each. All excess solder material shall be removed by filing or grinding flush with the adjacent solder-free area.

2.5.4 Coil and Magnet Parts Cleaning

After forming, the coil must be cleaned according to 2.4.1. As the magnet frame and yoke will be used as a mould, all parts which will be in contact with the resin have also to be cleaned. Aluminium plates in contact with the resin shall be grit blasted.

2.5.5 Magnet Assembly and Impregnation

After cleaning, the magnet halves must be assembled and external joints must be made tight with silicone paste. Note that 2.4.4 does not apply here and no tape is required. Each magnet half must then be heated up to 75 – 80 °C. The resin must be vacuum out-gassed to below 1 mbar at a temperature of 75 - 80 °C until the mixture is free of air and low baking impurities. The magnet halves must then be placed in a vacuum oven and a vacuum of about 1 mbar must be established before filling with the resin. The curing cycle must then be made according to the resin type. The magnet cool down has to be done at 0.5°C/minute, to avoid cracks.

2.5.6 Coil electrical test (Dump Bumpers)

Ground insulation: A voltage of 5 kV d.c. must be applied between the conductor and the frame. The frame must be at ground potential. The leakage current must be recorded in the coil data sheet. A ground insulation resistance of one hundred MΩ or better is required.
Inter-turn insulation: To test the inter-turn hold off capability, the coil shall be treated as the secondary winding of a transformer. A voltage of 2 kV rms, 50 Hz shall be induced across the coil terminations for a period of one minute and the corresponding primary current recorded. Any indication of short circuit between turns shall result in the rejection of the coil.

2.5.7 Coil electrical test (Injection Bumpers)

Same as Dump Bumpers, but with 1 kV d.c., 500 V rms, 50 Hz.

2.6 EXCITATION COILS FOR CHOPPER DIPOLES

2.6.1 General description

The copper conductor to be used for the coils shall have a high electrical and thermal conductivity to keep the heat load of the coil below a limit. Inside the hollow conductor, water circulates with pressures up to 15 bar. Hence, the copper must be suitable for leak tight brazing. Due to the field quality requirements on these magnets and the limited available space for the coils, the mechanical tolerances on the conductor must be very tight.

2.6.2 Materials

The copper shall be free of cracks, scratches, porosity and voids. It shall not have any tendency for hydrogen embrittlement. Very good characteristics for brazing are required as well as a ductility which permits the winding of the conductor into magnet coils with tight bends. The copper shall be Cu-OF Oxygen Free (ISO). The composition shall be at minimum 99.95 % Cu (+ Ag). The oxygen content shall be below 10 ppm. The electrical resistivity shall be at maximum 1.7240 E-8 Ωm at 20 °C. The copper shall be annealed after cold work (dead soft fully annealed temper). The hollow conductors required have the following dimensions:

<table>
<thead>
<tr>
<th>Comments</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Cross section:</td>
<td>(15 ± 0.1) mm × (8 ± 0.1) mm</td>
</tr>
<tr>
<td>Hole diameter:</td>
<td>(4.5 ± 0.1) mm</td>
</tr>
<tr>
<td>Corner rounding-off:</td>
<td>1 mm.</td>
</tr>
<tr>
<td>Length:</td>
<td>9.1 m nominal / coil.</td>
</tr>
</tbody>
</table>

It is the responsibility of the seller to ensure the copper quality and correct dimensions by means of proper checks. Nevertheless, CNA stipulate that at least one chemical analysis and one hydrogen embrittlement test must be made in accordance with the procedure given in ISO 2626. Both tests have to be stated in
the certificate of conformity supplied with each billet. The seller shall further demonstrate that the annealed pancake rolls have the specified resistivity.

2.6.3 Brazing and bending

Connections brazed to the coil shall be hard brazed with a silver brazed solder (AWS-ASTM BCUP-5 or equivalent) without flux. All brazing shall be done carefully to prevent braze material from flowing into the water passage. Each joint shall be tested by pulling with tensions of $4 \times 10^5$ N/m$^2$, followed by a helium leak test. The contact resistance has to be checked before proceeding further and must not exceed 0.25 m$\Omega$ each. Both external electrical terminals shall be made of Oxygen Free High Conductivity (OFHC) copper. The electrical conducting surfaces of the external terminals shall be silver plated, the plating shall be continuous and of good adhesion; it shall not peel or crack when the joint pressure of 300 kg/cm$^2$ is exerted. Keystoning caused by bending the conductor shall be removed. The amount of copper removed shall not exceed the amount necessary to bring the conductor thickness at the centre of the bend to within tolerances of the straight conductor. Care shall be taken to remove all burrs, slivers, rough spots and sharp corners before application of the glass-fibre tape. Due to the large cross section of the conductor, application of the tape before bending is not permitted.

2.6.4 Application of the glass-fibre tapes

After cleaning, each conductor must be wrapped with glass-fibre tape of suitable dimension. Half-lapped wrapping is required between layers. The conductor insulation thickness is 1 mm. The use of 2 layers of 0.25 mm thick tape is recommended. The glass-fibre tape shall have a surface finish suitable for its bonding with the impregnating resin. After individual conductor tape winding, another 1 mm thick insulation has to be wrapped around each half coil. A final 1 mm thick insulation must then be wrapped around the whole coil. The coil will then be placed in a suitable mould for the vacuum-pressure impregnation process. The mould has to be designed such that, after curing, the coil may be inserted in the magnet without any adjustments. Sharp edges on the outside of the insulation resulting from sharp edges of the mould must be carefully rounded with a file. After mechanical and electrical checks, the coil must be painted with two layers of radiation hard anti-flash alkyde varnish. The maximum operating temperature of the coil can reach 63 °C, therefore, it is essential that the insulation system retains its mechanical and electrical properties beyond that temperature and it must withstand repeated thermal cycling without failure.

2.6.5 Electrical resistance

The electrical resistance of every coil shall be measured by using a bridge capable of measuring d.c. resistances to within 1 % in the 100 $\mu\Omega$ – 10 m$\Omega$ range. Test data shall be recorded on the coil data sheet. The values shall be corrected to 20 °C and shall be within ± 2 % of the mean value of all the coils.

2.6.6 Ground Insulation test

Insulation tests of the ground insulation of the coils shall be carried out at 10 kV d.c. The coils must be immersed in ambient temperature tap water with the terminals exposed above water level. The voltage shall be applied between...
one of the coil terminals and the water bath for 1 minute and the leakage current shall be recorded in the coil data sheet. A ground insulation resistance of one hundred MΩ or better is required. The test must be repeated on the assembled magnet (without water, magnet frame grounded) and no difference should appear.

2.6.7 Inter-turn Insulation test

The coil shall be treated as the secondary winding of a transformer. A voltage of 5 kV rms 50 Hz shall be induced between the coil terminals for a period of 1 minute and the corresponding primary current recorded. Any indication of short circuit between turns shall result in the rejection of the coil.

2.6.8 Leak test

All finished coils shall be tested for possible leakage by pressurizing the water passage with 20 bar (water) minimum for 1 hour. Any evidence of leakage from the coil or its connectors shall result in rejection of the coil.

2.6.9 Flow rate test

Water flow rates shall be measured in each individual cooling circuit and recorded by applying a differential pressure as stipulated in the parameter list between applicable coil inlet and outlet ports. The flow rates with respect to pressure drop shall not deviate from that stated in parameter list by more than 10%.

2.6.10 Thermal Switch

Thermal switches shall be provided for each water circuit to protect the coils from inadvertently overheating during the operation. They shall be located at the warm ends of each water circuit and shall be set to activate at a temperature of 60 ± 3 °C. The switches shall be capable of interfacing with the computer system so that any faults can be located and corrected without undue delay. The switch must be normally closed.

2.7 EXCITATION COILS FOR TUNE KICKERS

2.7.1 Copper Material

The single turn conductor of the horizontal tune kicker shall be made from a soft rectangular bar. The two-turn conductor of the vertical kicker shall be machined before bending from a copper sheet. Oxygen free high conductivity copper (OFHC) is required. The conductivity of the material shall be at least 99% of the International Annealed Copper Standard (IACS). Sharp edges must be rounded according to the coil drawing. The copper surfaces must be free of voids, fissures, cracks, scratches, dry spots of other defects.

2.7.2 The conductors shall be bent to their final dimensions with the help of a jig.
2.7.3 The electrical terminals shall be made of oxygen free copper (OFC). They shall be hard brazed with a silver brazed solder (AWS-ASTM BCUP-5 or equivalent) to the coil bar after coil forming. The contact resistance has to be checked before going further and must not exceed 0.5 mΩ each. All external excess solder material shall be removed by filing or grinding flush with the adjacent solder area.

2.7.4 Coil insulation

As the coils will have to withstand a bipolar voltage of 35 kV peak, the insulation requires the use of mica. CNA recommends the use of SAMICAPOR® (ISOLA) 0.15 mm thick tape or equivalent for this application. A minimum of 10 layers with 50 % overlap is required. Glass-fibre tape without mica is allowed to fill the remaining space. After wrapping, the coil will be placed in a suitable mould for the vacuum-pressure impregnation process. The mould has to be designed such that, after curing, the coil may be inserted in the magnet without any adjustments. Sharp edges on the outside of the insulation resulting from sharp edges of the mould must be carefully rounded with a file. After mechanical and electrical checks, the coil must be painted with two layers of radiation hard anti-flash alkyde varnish. This paint shall be oversprayed with high resistivity graphite coating (DAG 40® from Acheson Colloids is suggested). Care must be taken to respect a distance of at least 3 cm from the HV terminal. A layer of medium resistivity graphite coating (DAG 154 is suggested) must then be applied. The part of the coil not in the magnet aperture (left and right, round edges included) must then be oversprayed with silver paint (ELECTRODAG 1415 is suggested). The part of the coil in the magnet aperture must be painted with a conductive graphite coating (ELECTRODAG 109 is suggested) in order to obtain a resistance of about 500 Ω ± 50 Ω between the silver painted parts. This latter layer must then be protected by a transparent insulating varnish. Note that tests have to be made prior to the application of the conductive graphite coating to determine the layer thickness to obtain the desired resistance.

2.7.5 Coil electrical test

The coil must be tested prior to painting according to the following procedure:

1. The coil must be wrapped with aluminium foil on its whole surface except the connecting terminals. The foil must be grounded and a voltage of 20 kV rms 50 Hz must be applied via the HV terminal. Care must be taken to avoid sparking in air between the terminals and the foil. The test duration must be 5 min and no sign of breakdown should occur. Moisture level and temperature must be recorded on the test sheet.

2. The coil must then be tested using a Schering bridge to measure the dielectric loss angle (tg δ). Values must be recorded over an ascending and descending range between 2 kV and 20 kV rms, 50 Hz, with 2 kV steps.

Maximum acceptable values are:

- \( \text{tg } \delta @ 2 \text{ kV} = 15 \times 10^{-3} \)
- \( \Delta \text{tg } \delta / 2 \text{ kV step} = 3 \times 10^{-3} \)
A coil which does not comply with the second test might be acceptable. However, a long-term test as described in 1. of at least 10 days will be required followed by a new test 2. If no change in $\tan \delta$ is recorded, the coil might be accepted by CNA, assuming that the $\tan \delta$ values measured do not exceed twice the maximum specified values above. The coil should then not fail during the first two years of service at CNA.

2.8 MAGNET ASSEMBLY

2.8.1 The magnet assembly shall include frame, yoke, coils and their supports, manifolds, terminals, inter-connections, hardware and all the other necessary parts to make the magnet assembly a stand-alone turn-key entity.

2.8.2 Spacers shall be placed between ferrite surface and coil, to compensate for surface irregularities and to allow for thermal expansion, according to the specific drawing of each magnet type.

2.9 MAGNET SUPPORTS

2.9.1 The baseline design of the adjustable magnet support system is to be completed by CNA. The design will take into account the special alignment procedure requirements and future maintenance for these devices in the accelerator. They are not part of the present tender, except for the tune kicker as indicated on the particular drawings.

2.10 TRANSPORT AND PRECAUTIONS TO BE TAKEN

2.10.1 It is responsibility of the manufacturer to deliver all magnets well protected and without damage to a site to be indicated by CNA.

2.10.2 All cooling ducts must be dried out properly and closed off.

2.10.3 Parts sticking out of the magnet core, especially coil heads and magnet connections have to be protected by mechanically rigid covers.

2.10.4 The whole magnet shall be covered with protective plastic foil.

2.10.5 In order to avoid deformation and permanent damage, closed solid transport structures (containers) should be used. Several magnets may be transported in the same container.
3 APPENDICES

3.1 MANDATORY INFORMATION REQUIRED WITH THE TENDER

3.1.1 The information required with the tender specified herein is mandatory. Any omissions in part or in whole is considered "non responsive" and therefore the tender may be excluded from evaluation processes.

3.1.2 The tenderer is advised to include those non-mandated information, especially in the technical nature, which he deems advantageous to his acceptability as a winner during the evaluation process. All the documents must be in the English language.

3.1.3 CNA shall have the right to select one or multiple sellers for this contract. The selection will, in addition to the cost factor, be based on the technical capability and the ability of the seller, as judged by CNA, to complete the subject contract within the specified duration.

3.1.4 Individual and total cost to supply

- 1 off Dump Bumper magnet 6-turns + 1 spare coil
- 1 off Dump Bumper magnet 12-turns + 1 spare coil
- 2 off Injection Bumper magnets + 2 spare coils
- 4 off Chopper Dipole magnets + 2 spare coil assemblies
- 1 off Tune Kicker horizontal + 1 spare coil
- 1 off Tune Kicker vertical + 1 spare coil
- Cost of special moulds
- Cost associated with engineering, design, and QA shall be separately listed.

3.1.5 Project management and facilities

The tenderer has to propose a project organization, and a scheme of personnel project management. It must describe also the facilities that he intends to use and the QA program specifically intended for this project.

3.1.6 Schedule and Milestones

The tenderer shall propose a credible schedule in bar graph form in concert with CNA’s master and milestones indicated in 1.8.2.

Preliminary technical Milestones shall be proposed by tenderer for tracking project progress and used as a base for progress payment during the course of this contract.
3.1.7 Sub-Contractors

The name of sub-contractors and their intended tasks must be disclosed. Descriptions of their facilities and personnel who will be involved in this project must be also declared.

4 BASE LINE DESIGN DRAWINGS

4.1 GENERAL

Drawings (Hard copies and Autodesk Inventor 6 files) included in this section are the CNA’s baseline design of the special magnets; they must be used as a base for all the detail design work. CNA has assigned some dimensions and tolerances to more important details. Seller is expected to make up all the other necessary dimensions and tolerances for manufacturing purposes. Seller is also expected to make up all the other necessary detail drawings for manufacturing such magnet. Seller produced drawings shall have such quality that a third party will be able to produce the subject item without any difficulty. The drawings and specifications shall be prepared in English language and metric units. Autodesk Inventor 6 files shall be as per 1.2.1 of this specification.

4.2 DRAWINGS LIST

4.2.1 Dump Bumper 6-turns

Fig. 4.2.1.1 Dump Bumper 6-turns magnet assembly
Fig. 4.2.1.2 Dump Bumper 6-turns ferrite and coil assembly
Fig. 4.2.1.3 Dump Bumper 6-turns coil.
Fig. 4.2.1.4 Dump Bumper (6 turns) magnet assembly, CNA-DRDF_BDSMS3-02000

4.2.2 Dump Bumper 12-turns

Fig. 4.2.2.1 Dump Bumper 12-turns magnet assembly
Fig. 4.2.2.2 Dump Bumper 12-turns ferrite and coil assembly
Fig. 4.2.2.3 Dump Bumper 12-turns coil.
Fig. 4.2.2.4 Dump Bumper (12 turns) magnet assembly, CNA-DRDF_BDEMS8-02100

4.2.3 Injection Bumper

Fig. 4.2.3.1 Injection Bumper magnet assembly
Fig. 4.2.3.2 Injection Bumper ferrite and coil half assembly
Fig. 4.2.3.3 One of two Injection Bumper four turns coils
Fig. 4.2.3.4 Injection Bumpers magnet assembly, CNA-DRDF-BDIMSS-01900
4.2.4 Horizontal Tune Kicker

Fig. 4.2.4.1 Horizontal Tune Kicker with its support frame
Fig. 4.2.4.2 Horizontal Tune Kicker magnet assembly
Fig. 4.2.4.3 Horizontal Tune Kicker ferrite and coil assembly
Fig. 4.2.4.4 Horizontal Tune Kicker single turn coil
Fig. 4.2.4.5 Tune Kicker horizontal assembly, CNA-DRDF-QKHMS4-01700
Fig. 4.2.4.6 Tune Kicker horizontal magnet, CNA-DRDF-QKHMS4-01701
Fig. 4.2.4.7 Tune Kicker horizontal connection box, CNA-DRDF-QKHMS4-01702

4.2.5 Vertical Tune Kicker

Fig. 4.2.5.1 Vertical Tune Kicker with its support frame
Fig. 4.2.5.2 Vertical Tune Kicker magnet assembly
Fig. 4.2.5.3 Vertical Tune Kicker ferrite and coil assembly
Fig. 4.2.5.4 Vertical Tune Kicker two turns coil
Fig. 4.2.5.5 Tune Kicker vertical assembly, CNA-DRDF-QKVMS4-01800
Fig. 4.2.5.6 Tune Kicker vertical magnet, CNA-DRDF-QKVMS4-01801
Fig. 4.2.5.7 Tune Kicker vertical connection box, CNA-DRDF-QKVMS4-01802

4.2.6 Chopper

Fig. 4.2.6.1 Chopper dipole magnet assembly
Fig. 4.2.6.2 Chopper dipole ferrite and coil assembly
Fig. 4.2.6.3 Chopper dipole 2 × 8 turns saddle coils assembly
Fig. 4.2.6.4 Chopper dipole magnet assembly, CNA-DRDF-CHDMH3-02200
Fig. 4.2.6.5 Chopper dipole magnet assembly, CNA-DRDF-CHDMH3-02201
Fig. 4.2.6.6 Chopper dipole magnet assembly, CNA-DRDF-CHDMH3-02202
Fig. 4.2.1.1   Dump Bumper 6-turns magnet assembly
Fig. 4.2.1.2  Dump Bumper 6-turns ferrite and coil assembly
Fig. 4.2.1.3  Dump Bumper 6-turns coil.
Fig. 4.2.1.4  Dump Bumper (6 turns) magnet assembly CNA-DRDF-BDEMS8-02000
Fig. 4.2.2.1  Dump Bumper 12-turns magnet assembly.
Fig. 4.2.2.2 Dump Bumper 12-turns ferrite and coil assembly.
Fig. 4.2.2.3   Dump Bumper 12-turns coil.
Fig. 4.2.2.4  Dump Bumper (12 turns) magnet assembly CNA-DRDF-BDEMS8-02100
Fig. 4.2.3.1 Injection Bumper magnet assembly
Fig. 4.2.3.2 Injection Bumper ferrite and coil half assembly.
Fig. 4.2.3.3 One of two Injection Bumper four turns coils.
Fig. 4.2.3.4  Injection Bumpers magnet assembly, CNA-DRDF-BDIMSS-01900
Fig. 4.2.3.5 Injection Bumpers half magnet, CNA-DRDF-BDIMSS-01901
Fig. 4.2.4.1  Horizontal Tune Kicker with its support frame, (part of tender)
The electrical connection box to the left is not part of the tender.
Fig. 4.2.4.2  Horizontal Tune Kicker magnet assembly.
Fig. 4.2.4.3  Horizontal Tune Kicker ferrite and coil assembly.
Fig. 4.2.4.4  Horizontal Tune Kicker single turn coil
Fig. 4.2.4.5  Tune Kicker horizontal assembly, CNA-DRDF-QKHMS4-01700
Fig. 4.2.4.6  Tune Kicker horizontal magnet, CNA-DRDF-QKHMS4-01701
Fig. 4.2.4.7  Tune Kicker horizontal connection box, CNA-DRDF-QK HMS4-01702
Fig. 4.2.5.1  Vertical Tune Kicker with its support frame, (part of tender)

The electrical connection box mounted on top is not part of the tender.
Fig. 4.2.5.2  Vertical Tune Kicker magnet assembly
Fig. 4.2.5.3  Vertical Tune Kicker ferrite and coil assembly.
Fig. 4.2.5.4  Vertical Tune Kicker two turns coil.
Fig. 4.2.5.5  Tune Kicker vertical assembly, CNA-DRDF-QKVMS4-01800
Fig. 4.2.5.6 Tune Kicker vertical magnet, CNA-DRDF-QKVMS4-01801
Fig. 4.2.5.7  Tune Kicker vertical connection box, CNA-DRDF-QKVMS4-01802
Fig. 4.2.6.1  Chopper dipole magnet assembly
Fig. 4.2.6.2  Chopper dipole ferrite and coil assembly, (seen from connection side).
Fig. 4.2.6.3 Chopper dipole $2 \times 8$ turns saddle coils assembly, showing electrical and water connections.
Fig. 4.2.6.4  Chopper dipole magnet assembly, CNA-DRDF-CHDMH3-02200
Fig. 4.2.6.5 Chopper dipole magnet assembly, CNA-DRDF-CHDMH3-02201
Fig. 4.2.6.6  Chopper dipole magnet assembly, CNA-DRDF-CHDMH3-02202
5 REFERENCES