Final design of the LHC Dipole for Pre-series and Series Contracts

M.Modena AT/MAS

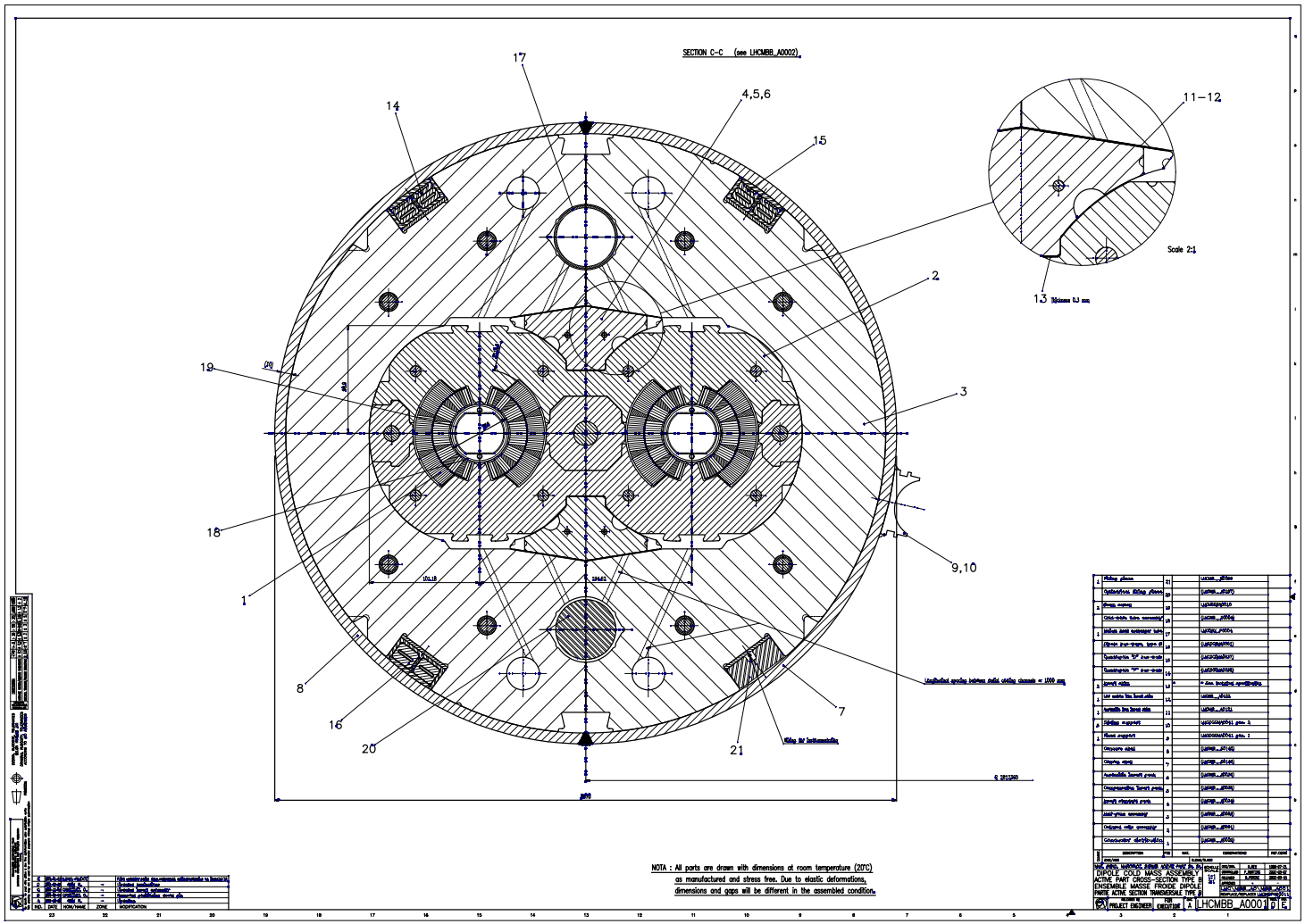
1. Series (and Pre-Series) Version:

   The Principal Components participating to the FQ achievement.

2. The Technical Specification:

   What we have asked on the FQ subject.

The Final LHC Dipole Section



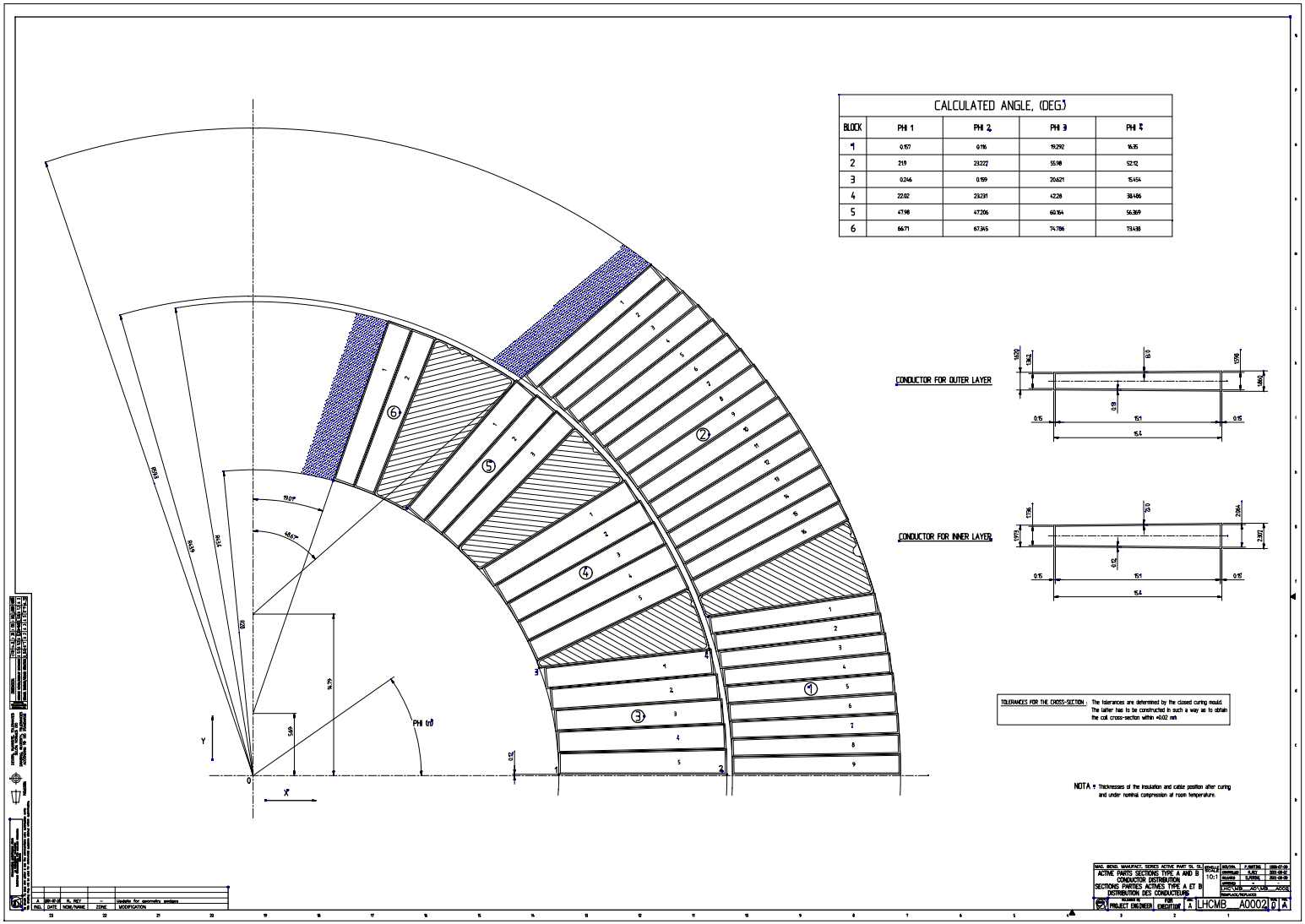
Workshop on FQ Steering of the Dipole Prod., 20-21 March 2003, M. Modena: “Final Design of Dipole for P.S. and S. Contracts

The Principal Components participating to the FQ achievement

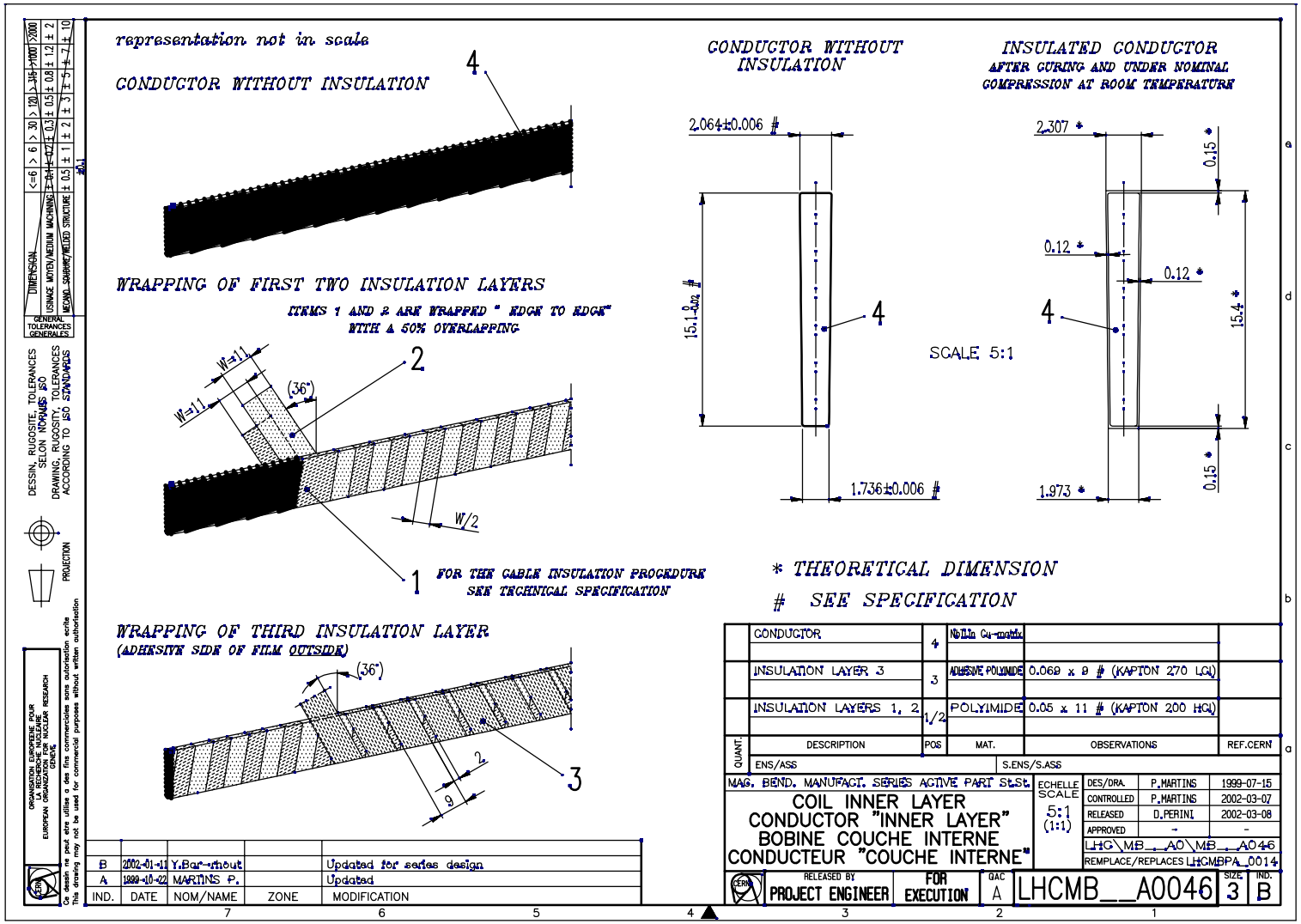
1. **Cables (2 types)**
2. **Copper Wedges (4 types)**
3. End Spacers & other (~ 30 types)
4. **Cable & Ground Insulation (3 types)**
5. Coil Inter-layers (2 types)
6. Coil protection. Sheets & Shim retainers (several types)
7. **Collars (6 types)**
8. Collaring Rods (3 types) + other small rods
9. Insert shim (1 type)
10. **Insert (2 types)**
11. Insert slide-sheet (2 types)
12. **Standard Laminations**
13. **Special Ends laminations**

(NOTE: In Bold are CERN Delivered Components)

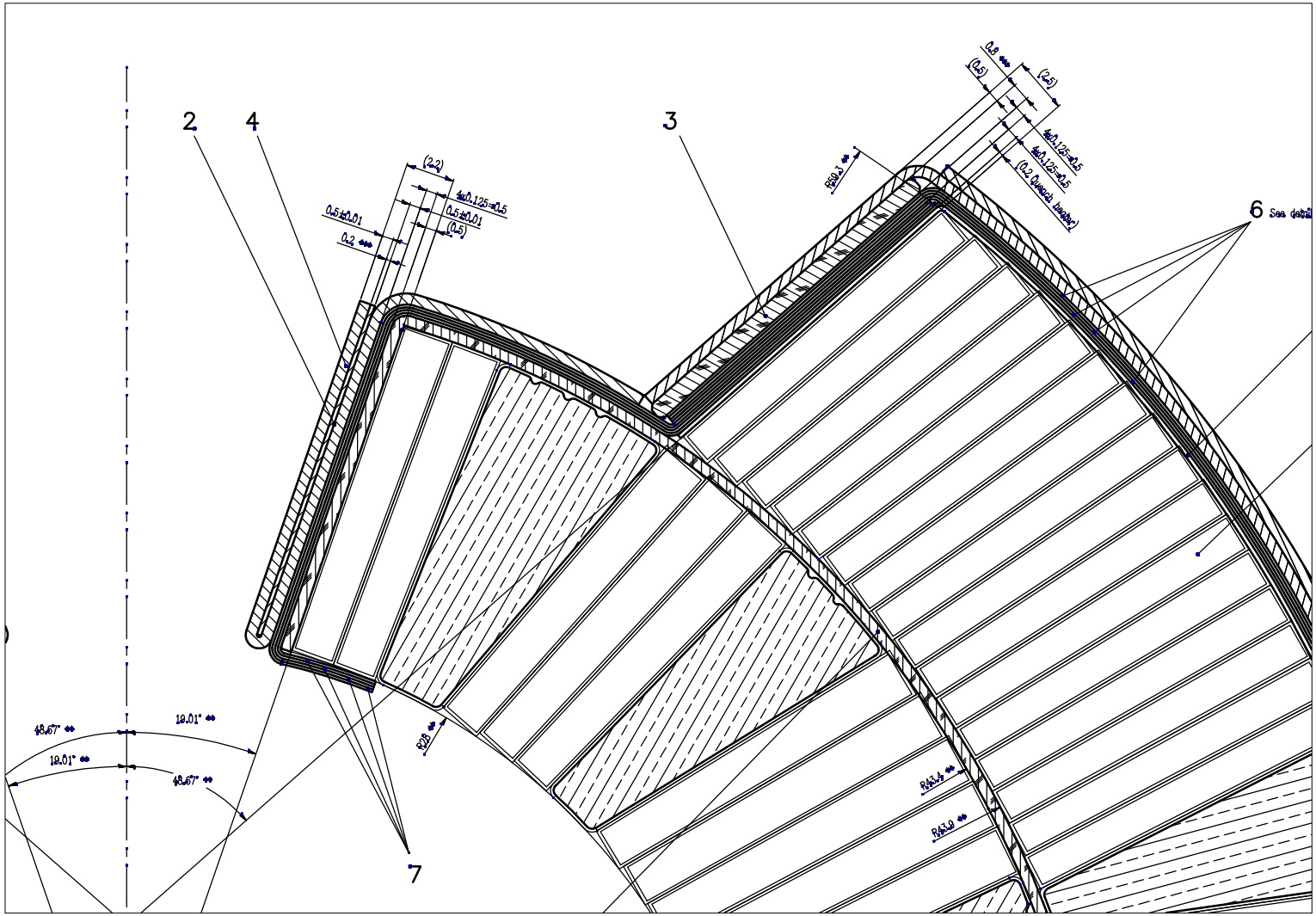
Cables & Copper Wedges



Cables Insulation

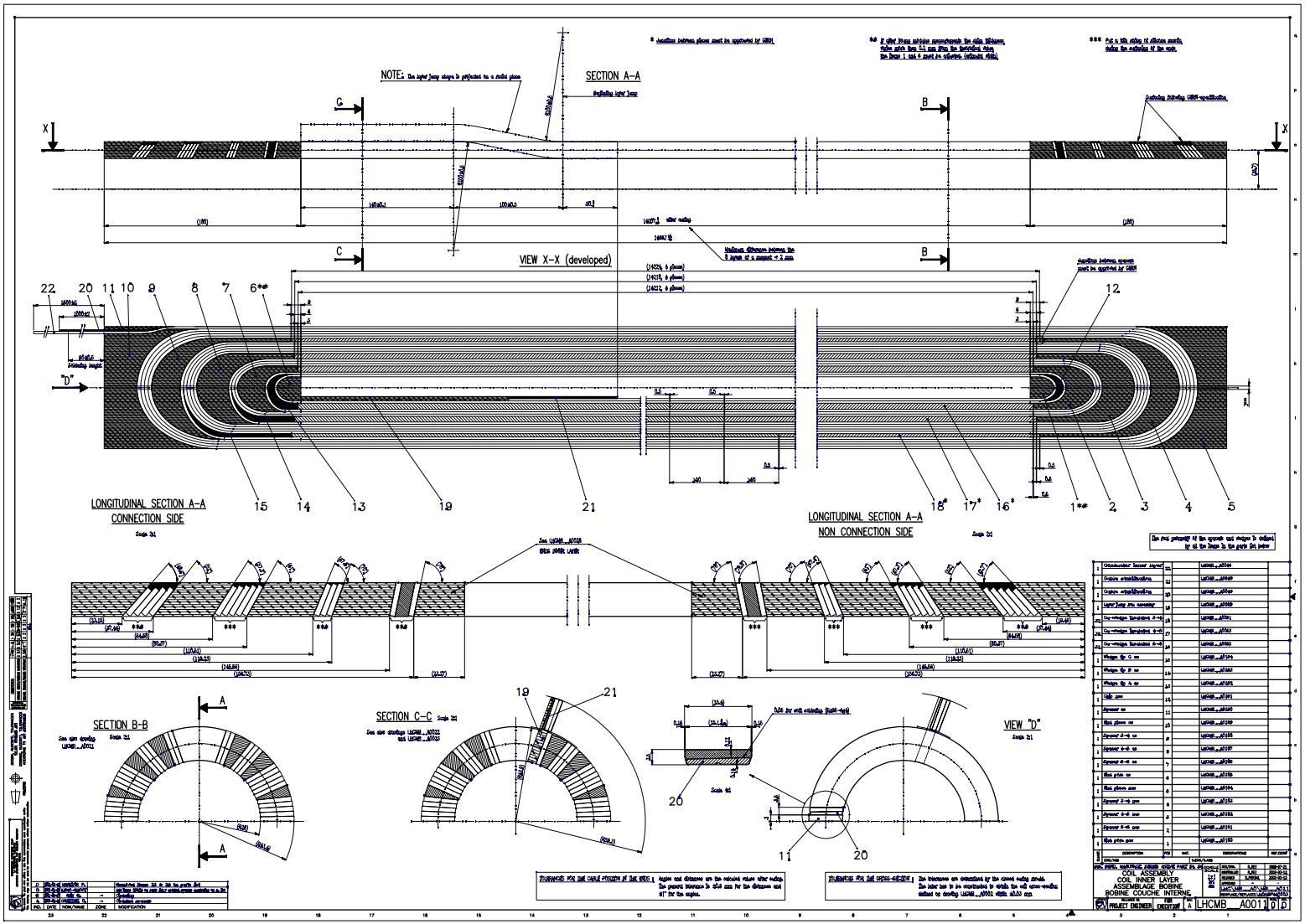


Ground Insulation, Prot. Sheets & Shim Ret.



Workshop on FQ Steering of the Dipole Prod., 20-21 March 2003, M. Modena: “Final Design of Dipole for P.S. and S. Contracts

Layers Manufacturing Parameters:

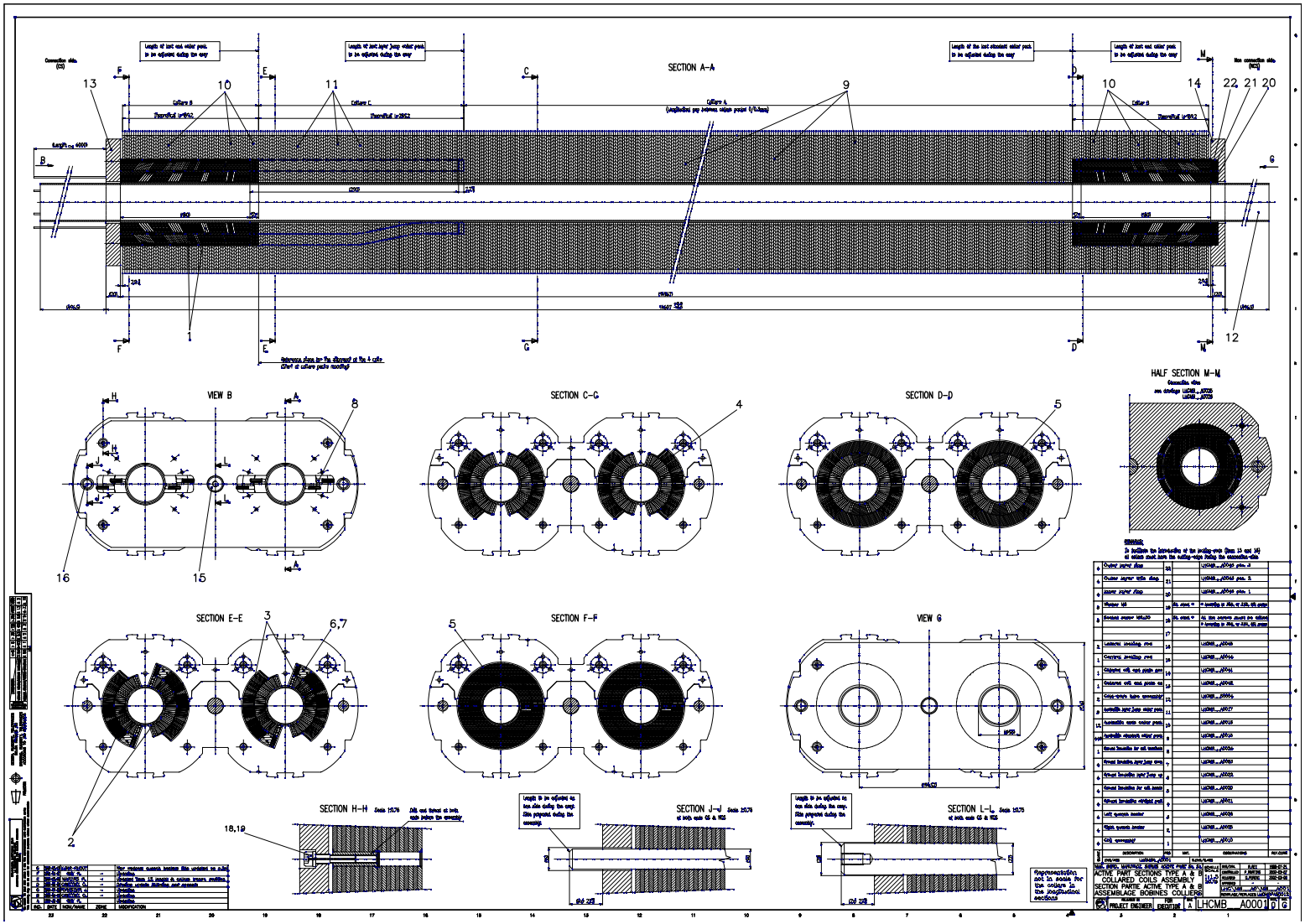


Workshop on FQ Steering of the Dipole Prod., 20-21 March 2003, M. Modena: "Final Design of Dipole for P.S. and S. Contracts

Layers Manufacturing Procedures

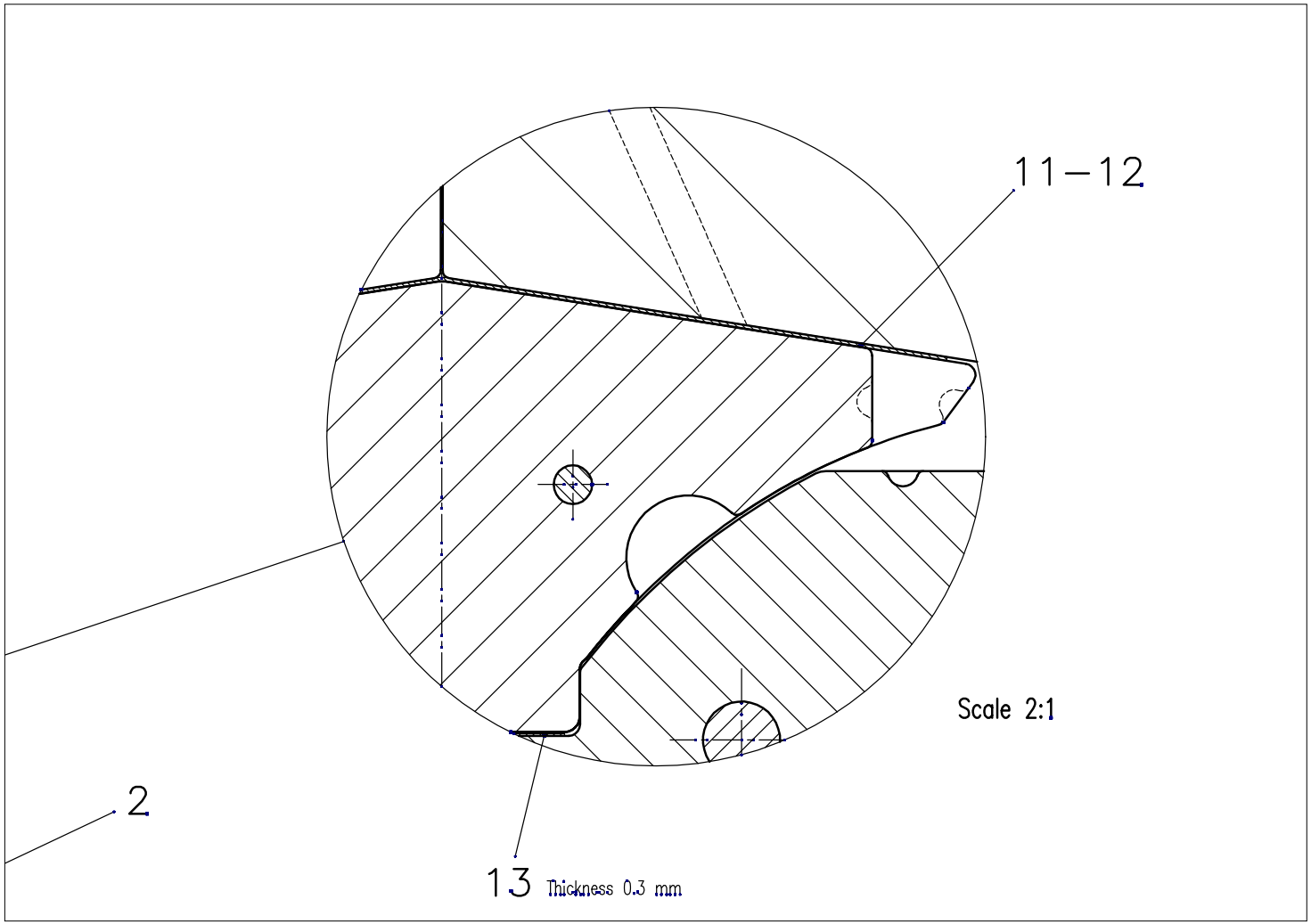
Workshop on FQ Steering of the Dipole Prod., 20-21 March 2003, M. Modena: “Final Design of Dipole for P.S. and S. Contracts

Collared Coils Components & Parameters



Workshop on FQ Steering of the Dipole Prod., 20-21 March 2003, M. Modena: “Final Design of Dipole for P.S. and S. Contracts

Insert, Insert shim & slide-sheet



Rods & other Permeability requirements (Annex B15 Final revision of the μ_r values)

LHC/MMS/MM/6379 21/02/2002

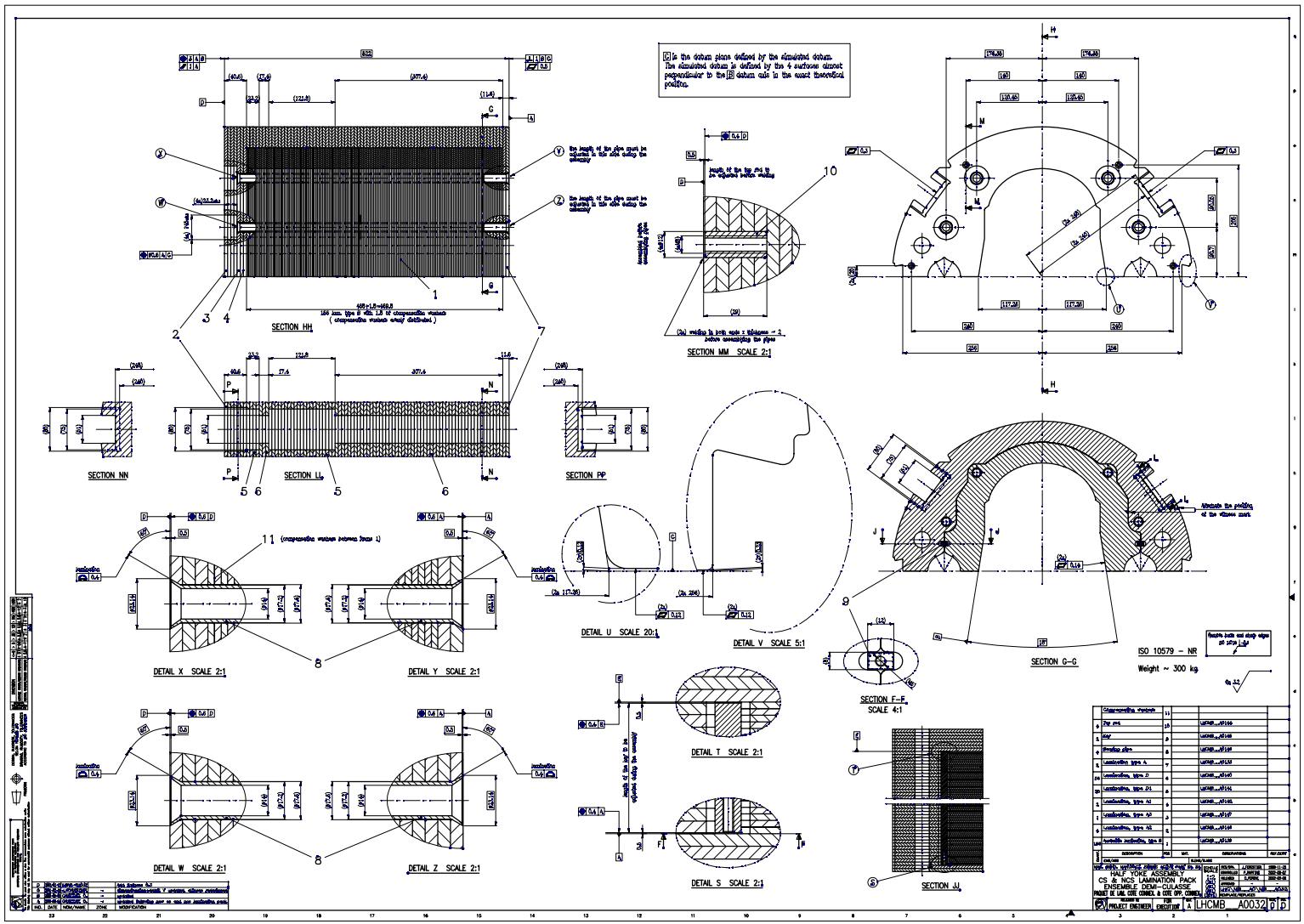
1. **ANNEX B15 "Magnetic characteristics and tolerances for the rods and shims under the responsibility of the Contractor":**
   The maximum admitted relative magnetic permeability for the Collaring and Collaring Pack Rods in Table B15.1 is released to these values (new values in Bold-Italic):

Table B15.1: Magnetic characteristics of components under responsibility of the Contractor

Items	Reference Drawing	"μ_r" value	Material	Note
Coil protection sheets & Shim retainers	LHCMB__A0020, 21, 22	≤ 1.005	Austenitic Steel as specified in this Annex	
Collaring rods	LHCMB__A0044, 45	***≤ 1.05***	316LN,316L	
Collar pack rods	LHCMB__A0101	***≤ 1.05***	316LN, 316L, 304L	
Tie rod yoke	LHCMB__A0132	Not spec.	304L	
Bearing pipes	LHCMB__A0135, 137, 143, 147	Not spec.	304L	
Tap rod	LHCMB__A0144	Not spec.	304L	
Insert pack rods	LHCMB__A0150, 153	Not spec.	304L, 316L, 316LN	
Iron insert slide-sheet	Tender drawing: LHCMBB_A0001, Pos. 13	Not spec.	Low carbon steel (soft iron)	*
Iron insert shim	Tender drawing: LHCMBB_A0001, Pos. 14	≤ 1.005	**	

* The permeability should be close to the one of the iron laminations (AnnexC8)
** Austenitic steel or non-ferrous metal (copper, brass, Cu/Be) could be proposed.

Iron & Special Lamination



Workshop on FQ Steering of the Dipole Prod., 20-21 March 2003, M. Modena: "Final Design of Dipole for P.S. and S. Contracts

7.2.4 Stacking factor

…..

In order to optimise the helium content (for thermodynamic and hydraulic reasons), the yoke laminations are provided with passages of appropriate sizes and the yoke packs are made according to a stacking procedure allowing enough free space for helium between adjacent laminations.

In addition, the magnetic length at cold shall be controlled with a precision of ± 15 mm. Therefore, the magnetic length at 1.9 K should be 14300 mm ± 15 mm. The yoke itself contributes at the injection field for about 17 % of the field strength. Therefore, the length of the magnetic lamination assembly of the yoke, which is theoretically 13554 mm according to drawing LHCMB__A0003, shall be adjusted on the basis of the warm magnetic measurements in order to fine-tune the integrated field, i.e. the magnetic length. Please refer to Annex B19.

The above-mentioned requirements imply a stacking factor of 98.5 % ± 0.25 % (98.25 % ≤ stacking factor ≤ 98.75 %).

The "stacking factor" denotes the ratio between the mass of the half-yoke as fabricated and the mass of a solid half-yoke with the same external dimensions and material.

…..

1.3.3 Acceptance Tests

…..

CERN will take full responsibility for the field quality of magnets that have followed the correct assembly procedure and have been made fully conforming to CERN conceptual drawings.

CERN may find it necessary to fine-tune the field quality during production. This will be achieved by small changes in pole shim thickness or geometry of the copper wedges of the coil layer. CERN will take full responsibility for defining these changes, for supplying the components under CERN's responsibility and for the subsequent field quality obtained. Such fine tuning operation should not affect the Contractor's tooling. At the present time, it is envisaged that only one such operation would be needed.

Annex B1 gives details of the field quality measurements, fine-tuning and target values of magnetic multipoles that CERN aims to achieve.

…..

4.2.10 Deviations from the Specification

CERN reserves the right to make minor modifications, e.g. fine tuning of component geometry and of assembly details, to this Technical Specification before the Contract is signed and also before the manufacturing drawings concerned have been finalised. These minor modifications will not entitle the Bidder to revise the tender price.

More substantial design modifications involving changes of materials and of assembly procedures may also be proposed by CERN and/or the Contractor following the results obtained on pre-series cold masses and other tests.

The positive or negative cost variations resulting from such possible modifications will be agreed by CERN and the Contractor.

Content:

- Scope of the Measurements
- Definition of Magnetic Measurements
  - Magnetic measurements at the Contractor’s premises
  - Influence of the deviatins from nominal geometry on field errors
- Tolerance on Main Field Module and direction
- Tolerance on Multipoles to detect assembly errors or faulty components
- Required filed quality and corrective actions (for information only)
  - Tolerance on multipoles required by beam dynamics
  - Corrective actions for odd normal multipoles
  - Corrective actions for even normal multipoles
  - Corrective actions for skew multipoles

ANNEX B9: "Geometric & Mechanical Meas. of layers, poles and c.c."

- …For series production, in principle only assembled poles will be measured. The measuring procedure will be agreed between the Contractor and CERN according to the results obtained for the pre-series coils. The final goal is to measure only the layer jump, the ends and only few points in the straight section….
- …For each layer and pole the difference between the *average* azimuthal size and the *minimum* and *maximum* size shall stay within ± 50 μm. The average values shall be consistent with the drawings of Annex A (tolerance ± 0.03 mm). The layers size is defined by the closed curing mould, the winding poles and mandrels and the sizing bars. The design of the tooling to reach the above mentioned tolerances is the responsibility of the Contractor. If during the series one or more pole (or layers if measured) are out of the tolerance range, extensive measurements shall be scheduled in order to collect enough data to localise and solve the problem. The measurements and the corrective actions will be at the Contractor's charge….

1. "μ_r **values Table"** (table already shown)

2. **Tolerances:**

- The thickness off all the shims (polymerisation shims, collaring shims, iron insert slide-sheet, iron insert shims, etc.) shall have the tolerance of ± 0.01 mm.

  (later derogated to ***± 0.02mm****)*

- The tolerances of the rods are indicated in the reference drawings.

Shim thickness calculation:

The design assumes that with the nominal collaring shims thickness (0.8 mm for the outer layer and 0.2 mm for the inner layer) the required field quality shall be achieved and the layer pre-stress should be in the centre of the admissible pre-stress ranges given above. For each layer, the Contractor shall calculate the thickness of the "theoretical collaring shims" necessary to obtain the nominal pre-stress values. If the calculated values do not differ from the nominal ones by more than ± 0.1 mm, the nominal shims shall be used. If not, the Contractor shall ask CERN for instruction on the choice of the shim thickness to be used. In addition the Contractor shall investigate the reason of the out-of-tolerance and take the necessary corrective actions in agreement with CERN.

ANNEX B18: "Warm Magnetic Measurements"

- System & Procedures provided by CERN.
- "… Two magnetic measurements shall be performed:

  - on the collared coils, before mounting in the yoke,

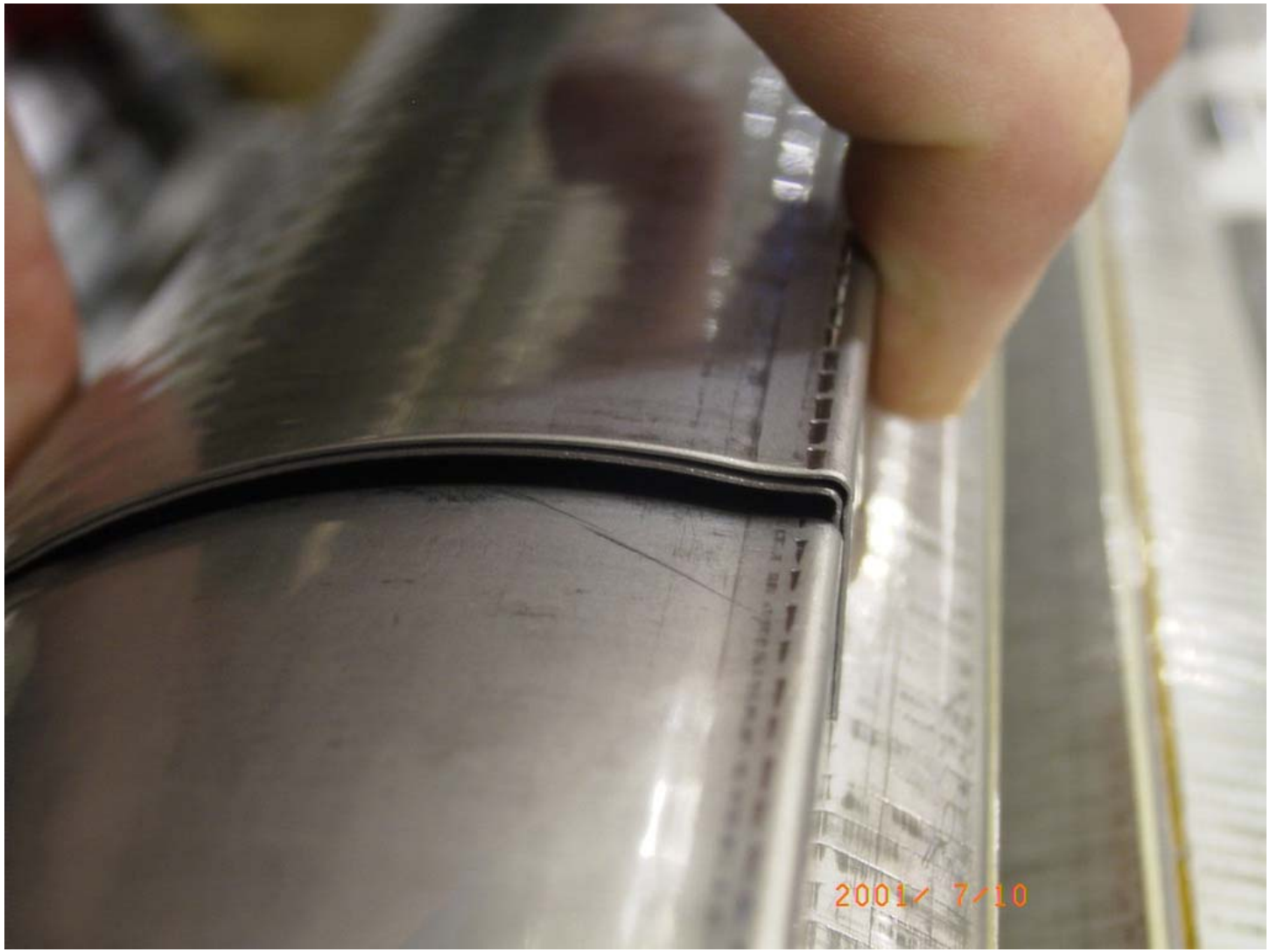
  - on the finished cold mass.

Out of tolerance components and incorrect assembly will be revealed by these measurements which will facilitate a rapid diagnosis of problems.

The first measurement permits to check the quality of the collared coils. This measurement will also give the magnetic length of the coils, which shall be used to control the magnetic length of the yoke as explained in Annex B19.

The second measurement shall be done on the cold mass after the positioning of the spool pieces. The acceptance criteria for these measurements are given in Annex B1…"

ANNEX B18: “Warm Magnetic Measurements”



Workshop on FQ Steering of the Dipole Prod., 20-21 March 2003, M. Modena: “Final Design of Dipole for P.S. and S. Contracts

1. Introduction

CERN requires that magnetic length of all the dipoles to be equal. This parameter will be derived from the warm magnetic measurements. Variation in the magnetic length shall be compensated when necessary by the procedure described below.

2. Adjustment of the non-magn. lamination packs in the non-connection side

The connection side and non-connection side non-magnetic laminations packs are assembled with a nominal length of 522 mm.

These packs shall be adjusted in order to compensate for possible differences of the magnetic length of the collared coils.

In any case, the minimum length of the extremity packs shall not be less than 472 mm in order to limit the magnetic field in the layer jump region.

The non-magnetic part of the extremities packs shall be equal on both sides for symmetry reasons.

One pack of the magnetic laminations shall be consequently adjusted in length (utilising, if necessary, special laminations provided by CERN with a reduced thickness of 1.5 mm) in order to maintain constant the total mechanical length of the half-yoke.

THE END