1. INTRODUCTION

1.1 STRUCTURE OF THE TDR BOOKLET

This Technical Design Report booklet, which is organised in four sections, covers the complete magnet project – yoke, coil, and ancillaries – and also comprises chapters presenting the magnet project in its relation to the CMS experiment, including the experimental area.

The first section, Chap. 1 to 6, contains introductory and general chapters, commencing with this chapter and followed by physics requirements in Chap. 2, general introduction to the project in Chap. 3, interface with the subdetectors in Chap. 4, parameter book in Chap. 5, and the magnetic analysis in Chap. 6.

The second section, Chap. 7 to 10, covers the yoke and the vacuum tank (which in CMS is a structural element closely related to the barrel yoke). The barrel yoke is described in Chap. 7, the endcap yokes in Chap. 8, the vacuum tank in Chap. 9, and the pre-industrialisation for the yoke in Chap. 10.

The third section, Chap. 11 to 24, describes the coil and ancillaries, the first part covering the coil proper from Chap. 11 to 19, the second part coil ancillaries, and the third part the pre-industrialisation plans for the conductor and winding process in Chap. 23 and 24.

The final section, Chap. 25 to 32, covers the experimental area, assembly and planning, quality assurance and safety. Project management and costing are also discussed, and all references are collected in chapter 32.

Perhaps less convenient for the reader, all coloured pictures have been regrouped at the end of the booklet to reduce printing costs. Each figure is not only referred to by its number, in the form of Fig. xx, but also by the page of the colour section on which it appears, in the form of p. C-xx.

1.2 STATUS OF THE MAGNET PROJECT

The design of the coil has evolved since the reference design, prepared by the Saclay team, was presented in the CMS Technical Proposal [1-1].

The two main features which have changed are:

- the choice of winding the full length coil on site, instead of winding it in four parts,
- the assembly of the composite conductor by electron beam welding, starting from an extruded insert.

The design was presented on 7 and 8 October 1996 to a Preliminary Design Review Committee, which regrouped a number of experts from outside the CMS magnet team, to review the state of advancement of the studies, and to give advice where appropriate.

The Committee recognised that [1-2]:

- the coil in a single module, as is currently proposed, has a simpler structure, and probably poses fewer compatibility and matching problems as compared to the previous four module reference design,
- the use of a reinforced conductor eliminating the necessity of a support cylinder also appears to be a good choice,

and it approved the idea to wind "on site", now that the coil is to be wound as a single item.

Nevertheless, the Committee addressed a list of questions on subjects needing further clarification such as:

- winding pack configuration (number of layers and turns),
- conductor geometry,
- insulation,

and requested to have a clear definition of the maximum operating field.

Following the PDR, the design team initiated an extensive review of the project in the light of the remarks and suggestions made by the Committee. Most of the technical choices have been confirmed. However, the mechanical structure of the winding has been improved, and, as the conductor *is* the mechanical structure, this implied also a change in the conductor geometry, leading to the "block" design. The new conductor geometry has the added advantage of being particularly well adapted to the use of electron beam welding, which has been retained as the base technique for fixing the reinforcement.

A brief summary of the present project situation, highlighting answers to points of concern raised by the Committee, is given below.

1.2.1 Coil

One important feature of the project is the high nominal field of 4 T. This parameter, which is central to the design, comes from physics requirements (Chap. 2), and the CMS Collaboration governing bodies have recently reconfirmed that to reach 4 T was a desirable goal to maximise the physics performance of CMS.

All safety factors and parameters are computed accordingly for 4 T, however, the limited radial space given to the coil has imposed, from the beginning, a 'leading edge' design in which some parameters are beyond what can be considered today as state of the art. In particular, the hoop strain reaches the high value of 0.15%. Although great care has been taken in the design to make sure that this strain does not induce large shear stresses in the insulation, possible effects, on the stability for example, may limit the operational field to a value slightly below 4 T. This fact has been fully recognised and accepted by the CMS Collaboration (Chap. 2).

Indeed, the basic design of the CMS coil has been oriented from the very beginning to maximise the chances of reaching 4 T (Chap. 11). The main innovative feature is to connect the conductor directly to the reinforcement, thus resisting the force where it is created. This allows suppression of the thick external cylinder and all mechanical analyses show that the induced shear stresses are very small. In fact, the shear stress distribution in the insulation is practically driven by the cool down differential contraction, and is essentially independent of the field (Chap. 14). Thus the CMS coil stability level at 4 T should be very similar to the level of stability of the ALEPH and DELPHI coils (Chap. 15).

It is considered vital that the pure aluminium, which will undergo cycles in the plastic range, be supported constantly by nearby elastic components. This is achieved in the "block" conductor design whereby two reinforcement sections are welded, by electron beam, on a conventional insert obtained by the co-extrusion process (Chap. 12 and 23). These two reinforcement sections act, at the same time, as hoop and axial elastic components for the winding structure.

Another important element for the final quality of the coil, apart from the conductor itself, is the quality of the winding and impregnation process. The choice of four layers as the optimum winding configuration has been confirmed. The present design, which calls for a monolithic four layer coil to be wound "on site" at CERN (Chap. 19 and 24), appears well adapted to a magnet of this size. It does not need any large mechanical structures (flanges, containment cylinder, etc.) as normally used in existing aluminium stabilised thin solenoids. In this way, mechanical coupling problems are avoided whilst minimising the shear stress in the insulation.

The finished coil is a 220-tonne monolithic object and clearly the associated risks must be analysed and minimised. These risks are well identified as they are mainly associated with electrical insulation and joints, and the pre-industrialisation programmes must fully take this fact into account. Nevertheless, other solutions, such as co-winding or the building of the coil in sections, have been or are still being looked at, to ascertain that the present choice is the correct one.

The selected insulation technique makes full use, as a starting point, of the developments carried out at RAL for the DELPHI and H1 coils (Chap. 13). Alternative insulation materials with improved mechanical properties (e.g. glass/polyimide composite as developed recently at KEK) are actively being considered, and the final choice will be a part of the pre-industrialisation programme for the winding.

Ancillaries such as cryogenics, power supply, process control, etc., are now well defined and detailed specification work can proceed.

In conclusion, the design of the coil has now reached a state of complete coherence, including manufacture, assembly and ancillaries, which allows well defined full pre-industrialisation programs to start as initial actions of the construction phase.

1.2.2 Yoke

The design of the barrel yoke, including assembly tools, is complete (Chap. 7). The recent market survey, and related visits to firms, has confirmed that this project is within the possibilities of industry, and the order could be placed towards the end of 1997.

The high magnetic field has a direct impact in terms of forces on the two endcap yokes and this call for 600 mm thick plates for the first and second disks. Assembly by electroslag welding was envisaged initially but has since been abandoned. The present design, which now uses a fully mechanical fixation, allows a precise trial assembly at the factory. Design is being finalised to allow a call for tenders before the end of 1997 (Chap. 8). The design of the supporting cart system for the endcap disks is also near completion.

Assembly and maintenance of CMS calls for a simple and reliable displacement system in both the surface hall and the underground area, to allow displacement of large and heavy sections of the magnet. High pressure air pads have been chosen for both the barrel and the two endcap yokes (Chap. 10), and this will greatly simplify logistics problems.

All the basic choices pertaining to the magnet have been made, allowing the completion of the experimental area design within timescale (Chap. 25), and allowing to proceed with the civil engineering call for tender.

[1-2] Report on the CMS Magnet Review held at CERN on October 7th-8th 1996, Preliminary Design Review Committee. Chairman, T. Taylor, CERN. Members: E. Baynham, Rutherford Appleton Laboratory, L. Bottura, CERN, H. Desportes, CEA-Saclay, M. Huguet, ITER, P. Komarek, Forchungzentrum, Karlsruhe, D. Leroy, CERN, W. Maurer, Forchungzentrum, Karlsruhe, R Parodi, INFN-Genova, H. Schneider-Muntau, National High Magnetic Field Laboratory, Tallahassee, H. ten Kate, CERN, B. Turk, CEA-Cadarache, A. Yamamoto, KEK.