A LIGTHWEIGTH 3-D SUPPORT STRUCTURE FOR PRECISE TRACKING SYSTEM

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ABSTRACT

The performance of a tracking system designed to achieve a spatial resolution down to 10-15 microns depends not only on the intrinsic resolution of the detector elements but also on the stability of the supporting structures. Since the structure can be significantly influenced by environmental and loading conditions, it is very important when designing such systems to take into account the effects of temperature, humidity, mechanical loads, and also the possibility of coupling between these variables.

The choice of the basic construction material is fundamental. Usually, carbon fibre reinforced plastics are the preferred choice in order to meet the stringent requirements of low mass and high stiffness.

In this paper we describe the design and manufacture of a lightweight 3-D structure made from carbon/epoxy which supports the silicon detectors, the front-end electronics, and the associated cooling pipes of the Inner Tracking System of the ALICE experiment. Results from simulations using transient analysis of the hygro-mechanical behaviour caused by cyclic humidity variations are also presented.

1. INTRODUCTION

The Large Hadron Collider (LHC) is a 27 km long particle accelerator now under construction at CERN. Along its ring, it will provide four intersection points where the circulating beams of protons or ions are brought to collide. In the collisions, large amount of elementary particles are produced which allow to study matter down to a scale of 10^{-19} metre.

Huge detectors (of the size of 20 m in both length and diameter) will be installed at the intersection points to measure the characteristics of the collisions. These detectors have a typical “onion-like” layout and cylindrical shape, with sub-detectors disposed symmetrically around the interaction point. Their inner part, the tracker, is designed to reconstruct trajectories by locating the particles, with a precision of few tens of microns. Such a precision is needed both to determine particle momenta up to few tens GeV/c with an error of the level of few percent and to disentangle the decay vertexes of short-lived particles from the primary interaction vertex.

In order not to spoil the intrinsic accuracy of the detecting elements, supporting mechanical structures have to be designed with very stringent specifications in terms of positioning accuracy, stiffness and stability over a period of more than 10 years. Moreover, for lower momenta, multiple scattering and energy-loss fluctuation in the material crossed by particles are the major source of degradation of the overall tracker precision. This translates into a demand for very low-mass supporting structures. In addition, these structures have to withstand rather harsh environment conditions like ionising radiation, temperature and humidity cycles, external vibrations, etc.,

In this paper, the solution to these problems adopted for the outer layers of the ALICE Inner Tracking System is reported. In section 2 the layout of the four outer layers of the ALICE Inner Tracking System is summarized, together with the geometrical requirements for the 3D structures used in these layers. Section 3 describes the stability studies of the 3D structure, while section 4 reports on the novel manufacturing process.

2. 3-D STRUCTURE DESIGN

ALICE (A Large Ion Collider Experiment) is one of the four experiments at LHC. Its overall layout is shown in figure 1. The central ALICE tracker is made of the Time Projection Chamber (TPC), the Transition Radiation Detector (TRD) and the Inner Tracking System (ITS). The ITS consists of six cylindrical layers of silicon detectors based on three different technologies; the choice was driven of the expected particle density per surface unit and on resolution requirement. From inwards, there are two layers of Silicon Pixel Detectors (SPD), two of Silicon Drift Detectors (SDD) and two of Silicon Strip Detectors (SSD).
In the following, only the four outermost layers are considered since the mechanical support of their detectors has been designed following the same approach, whereas, for the SPD, a different solution had to be studied because of space constraints.

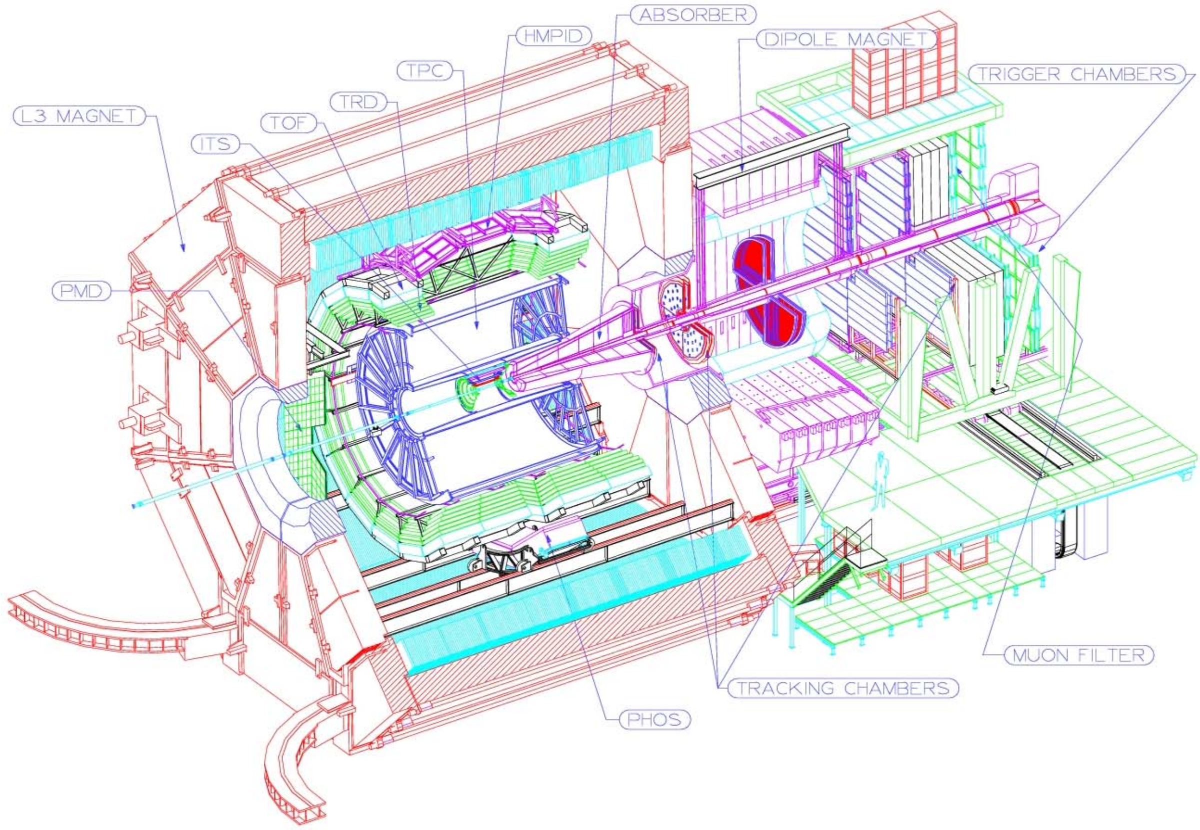

Fig. 1 ALICE experiment layout

Figure 2 shows a simplified cross section of the four outermost layers of ITS. Each triangle in the figure corresponds to a linear array of detector assemblies, referred to as a "ladder". The ladders are positioned in space in order to create four cylindrical, coaxial, tracking layers. Table 1 collects all geometric parameters of the ladders.
Each fully-equipped ladder represents a static gravitational load of 160g/m, resulting in a flexo-torsional stress. The load-bearing element of the ladders is provided by a monolithic three-dimensional triangular space frame, as shown in figure 3, which was found to provide a good compromise between the requirements of system stiffness, for accurate and stable detec-

tor positioning in space, and of minimum amount of material in the support structure, in order to minimize the multiple scattering of the particles on it. The requirements of lightweight and stiffness leads to choose the Carbon Fibre Reinforced Plastics (CFRP) as constituent material for the ladders [1, 2].

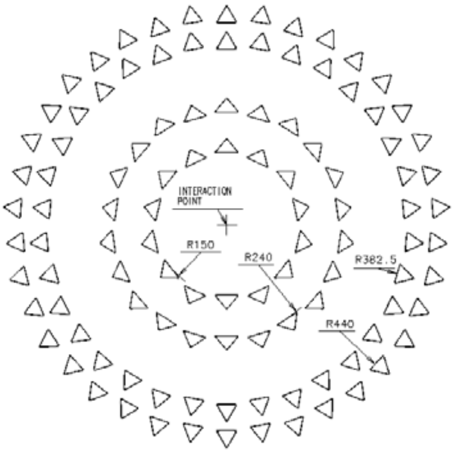

Fig.2 ALICE tracker. Radial ladder distribution.

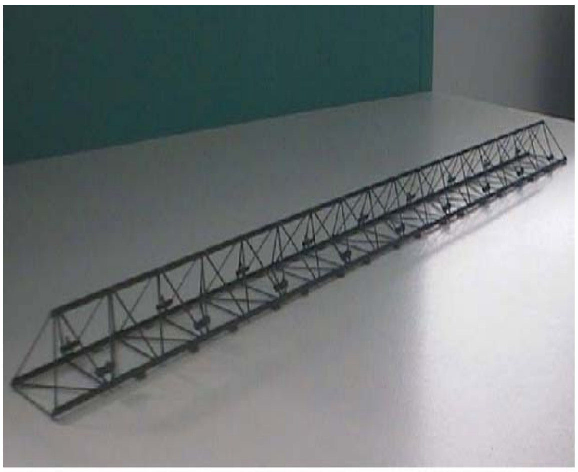

Fig. 3 ALICE tracker. CFRP space frame of a ladder of layer 3.

	# OF ELEMENTS	SIZE (mm x mm)	LENGTH (mm)
LAYER 3	14	50x35	520
LAYER 4	22	50x35	670
LAYER 5	34	42x36	950
LAYER 6	38	42x36	1070

Tab.1 Characteristics of the ladders geometry.

3. 3-D STRUCTURE STABILITY

The environmental effects on CFRP are known and well reported in literature. The behaviour of these materials immersed into radiation fields has been studied at CERN [3], demonstrating that CFRP based on either epoxy resin or cyanate ester matrix are sufficiently radiation tolerant for the ALICE case (≤ 200 Gy in ten years of operation for the considered layers).

The thermal expansion of the composite is very low, and represents an important advantage for the stability of the structures, even if they are stressed under thermal cycles.

The influence of humidity and humidity cycles on the stability must be investigated, also in combination with the environment temperature cycling. In this respect, the classic theories [4, 5], which assume perfect contact between the fibres and resin matrix, are not sufficient to describe the behaviour of the composite when the goal is a dimensional stability of the order of few microns. Experimental results [6] showed that the moisture diffusion along the interfaces between the fibres and the matrix has to be considered too. The influence of the diffusive interface is taken into account by introducing an empirical parameter $\tilde{D}$, related to D_m. A good correlation between experimental data and the interfacial model has been obtained and can be used to predict the dimensional stability of the composite structures [6]. The experimental data for $\tilde{D}$ give $\tilde{D}=0.3D_m$, for epoxy composites, and $\tilde{D}=0.5D_m$, for cyanate ester composites, where D_m is the moisture diffusion coefficient of the matrix.

Simulations of the behaviour of a single ladder structure of the ALICE ITS were made using the finite elements analysis software MSC-NASTRAN. In the simulations the ladder was constrained at both ends, like it will be in the real life. The moisture content and the relative deformation were estimated using a hygro-thermal analogy [7], assuming perfect contact and interfacial diffusion as a first approximation. Degradations at the fibre-matrix interface, due to differential swelling and dilatation, were not included. Figures 4 and 5 show the calculated displacements of the central point of a space frame of the layer 4, made from a cyanate ester resins composite, for a cyclical variation of the hygroscopic load based on the following expected variations of the environment in the experimental area: relative humidity oscillating between 35% and 75%, and temperature variations between 20 ^{0}C and 27 ^{0}C [8]. Figure 4 corresponds to an initial moisture contents of 30%, while figure 5 shows the behaviour of the space frame with an initial moisture contents of 50%

The results indicate that the dimensional variations are not negligible when compared to the expected detector performance. They also evidence a noticeable hysteresis effect as a function of moisture concentration oscillations, when the initial moisture contents was below the lower load limit (figure 4). In the worst case, at 27 ^{o}C, the central point of the ladder is predicted to oscillates by up to about 50 μm in the radial direction.

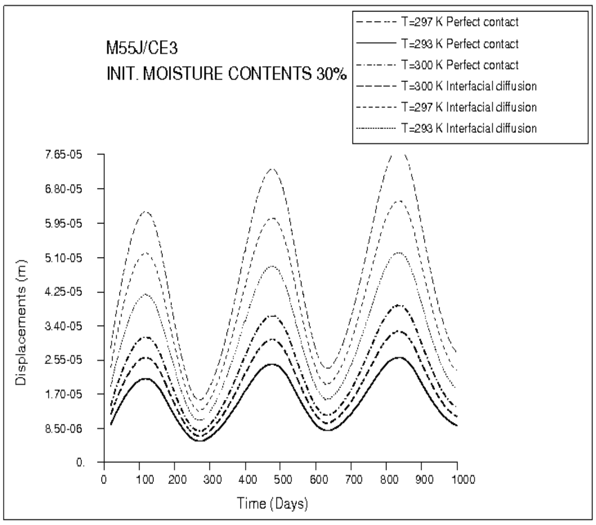

Fig.4 M55J/CE3 Cyanate ester resin – Initial moisture contents of 30%

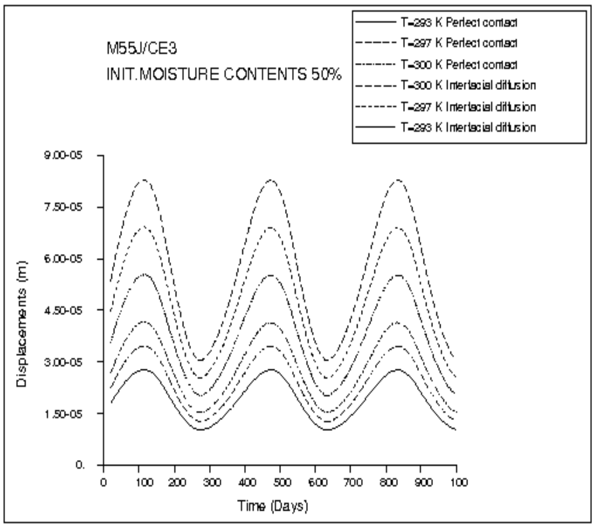

Fig.5 M55J/CE3 Cyanate ester resin – Initial moisture contents of 50%

Displacements behaviour of central point of a ladder of the layer 4, under humidity cycle for diffusive and non-diffusive interfaces at different temperatures.

In order to improve the mechanical performance of the ladder space-frame, all its surfaces have been protected by a plastic coating made of *Parylene C*, applied by means of an evaporative system. *Parylene C* exhibits low moisture absorption, up to two times less than cyanate ester resins, low permeability to water vapour pressure and good compatibility with carbon [9]. In addition, an active control of temperature and relative humidity will be foreseen to keep them more stable both during the normal operation and the maintenance of the tracker.

4. 3-D STRUCTURE MANUFACTURING

A novel fabrication method for the monolithic ladder space frames was specifically developed for this application [9], and consists of a "one-cycle" polymerisation process with defined curing parameters. The process was developed and tested in the laboratory of the *“Central Design Bureau of Machine Building, St.Petersburg (Ministry on Atomic Energy, RF)”.*
A key point of this technique is the use of precision metal moulds which define the complex shape of the space frame in a single curing process (Figure 6). The curing cycle is performed in a specially-built autoclave which allows to actively monitor and control the critical parameters during the operation (Figure 7).
After curing, the ladder space frames need hydro-abrasive cleaning to remove any remnants of anti-adhesive which could interfere with the mounting and gluing of the rest of the components that make up the assembled ladder structure: detector holders and cooling-pipe holders.
The geometrical parameters were checked after visual inspection of the space frames. The overall quality of the polymerisation process was tested for each sample by measuring the sagging of the frames under a given load, while the frame ends were supported by two cylinder (unconstrained ends). These stiffness measurements were performed at an optical bench by means of a laser interferometer providing the accuracy at the level of 0.1 μm.

Fig.6 Components of the mould used for manufacturing the space frames.

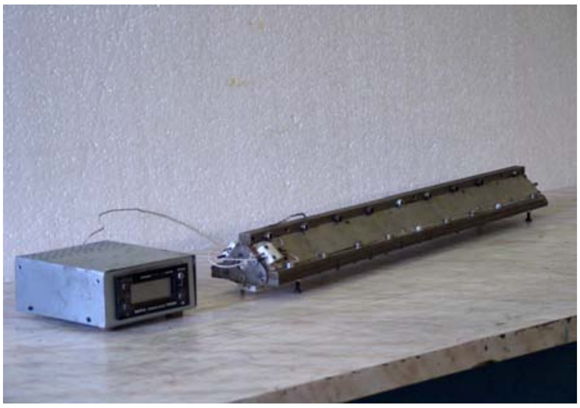

Fig.7 Assembled mould with process controller.

Two values of the centrally applied load were used, *120g,* and *240g.* The last one corresponds to the maximal operational load expected by the space frames equipped with the detectors, electronics, cables and cooling devices. Figures 8 to 11 collect all data from measurements.
All ladder series exhibit a remarkable uniformity in the sagging measurements: the data show a dispersion around a mean value not exceeding ±10 μm.
The mean values of the measured sagging very well agree with the predictions of the finite elements method simulations performed with the space frame stressed with a centred static load [11].

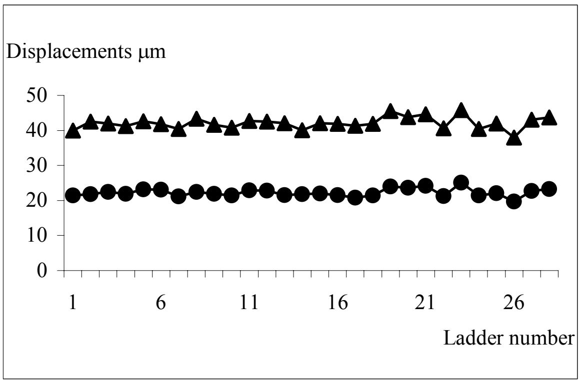

Fig.8 Displacements of central points of the ladders of layer 3 under two static load conditions of 120g and 240g. Simply supported ends distance 500mm.

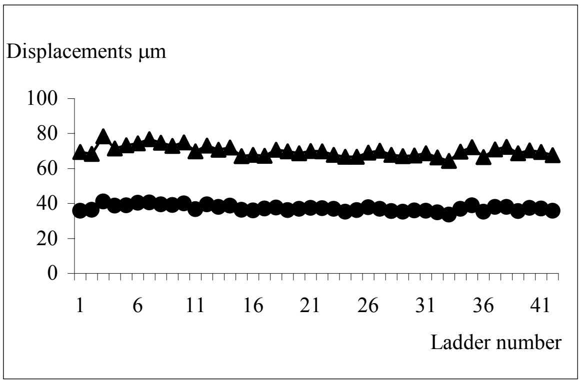

Fig.9 Displacements of the central points of the ladders of layer 4 under two static load conditions of 120g and 240g. Simply supported ends distance 650mm.

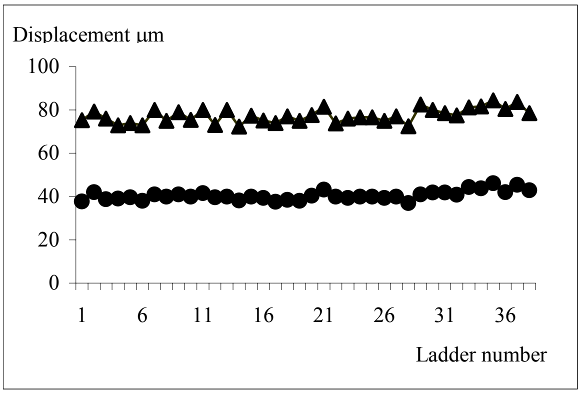

Fig.10 Displacements of the of central points of the ladders of layer 5 under two static load conditions of 120g and 240g. Simply supported ends distance 900mm.

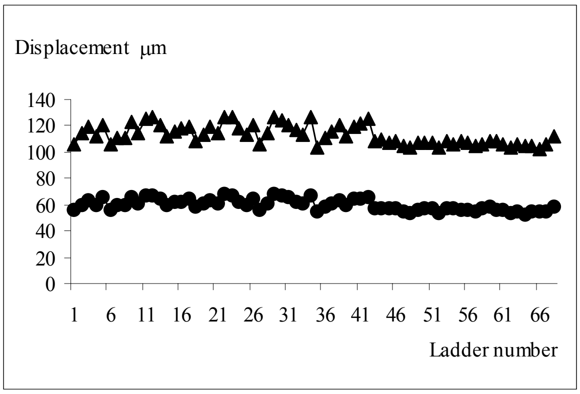

Fig.11 Displacements of the central points of the ladders of layer 6 under two static load conditions of 120g and 240g. Simply supported ends distance 1020mm.

5. CONCLUSIONS

The described ladder space frames have been demonstrated to comply with the mechanical constraints imposed by the ALICE experiment.

The construction process has been proved to be efficient, with a high yield of structures with consistent mechanical characteristics.

Simulations indicate that the structures can be expected to require careful local control of temperature and humidity in order to avoid non-negligible dimensional variations. Major problems of highly stable structures is more related to the dynamics of the system than to the static deflections due to mechanical loads: hygro-thermal cycles can strongly influence the dimensional stability, and variations from the equilibrium can be deleterious for the tracker operativity.

Surface treatments, such as *Parylene C* coating, are studied as a method of reducing the sensitivity of the structures to humidity and a better performance will be achieved.

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