Application of Carbon Fibre Composite Materials for the Collision Sections of Particle Accelerators

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Abstract

Components made of carbon fibre composite material (CFCM) with Epoxy or BMI matrix were designed for various applications such as vacuum tubes, vertex chambers or support structures. The outstanding properties of CFCM which in many aspects are superior to metal structures especially qualify CFCM components for use in the collision sections of particle accelerators. A total of some 50 m of CFCM beam-tubes and of around 20 different CFCM structures and support elements of various configurations were produced following the specific needs and requirements of high energy particle physics at CERN, DESY and several other research institutes.

I. INTRODUCTION

Carbon fibres are being used for manufacturing sports equipment (e.g. rackets) as well as sophisticated components for space and aircraft industry for many years. These applications of this fairly new material mainly make use of the outstanding mechanical properties of CFCM which are high specific stiffness E/ρ (E=Young's modulus, ρ=density), low mass and absence of corrosion. With Ultra High Modulus fibres of $E \approx 600$ GPa a modulus of up to 400 GPa may be achieved for a CFCM component.

Following a stimulus and specifications from CERN, Dornier extended the application of CFCM towards particle accelerators which benefit from additional properties of this material.

II. SPECIFIC ADVANTAGES OF CFCM

Several properties make CFCM components very attractive for the usage in particle accelerators especially in the experimental sections of high energy machines such as SPS, LEP or HERA.

First of all, CFCM material has a radiation length of around 30 cm, i.e. just about 20 % less than Beryllium. As described below, the manufacturing process for CFCM tubes is very precise, yielding a uniform composition of the tube structure and enabling the manufacture of very thin-walled tubes. Thus, the ratio thickness vs. radiation length for CFCM is comparable to that of Be tubes.

Secondly, the vacuum properties of CFCM-tubes with inner metal liners are excellent: For tubes with wound inner liners of Al foil, outgassing rates were measured in the order of 10^{-12} mbar l/s cm^2 (fig.1) which is as good as for metal tubes. The leak rates were below the

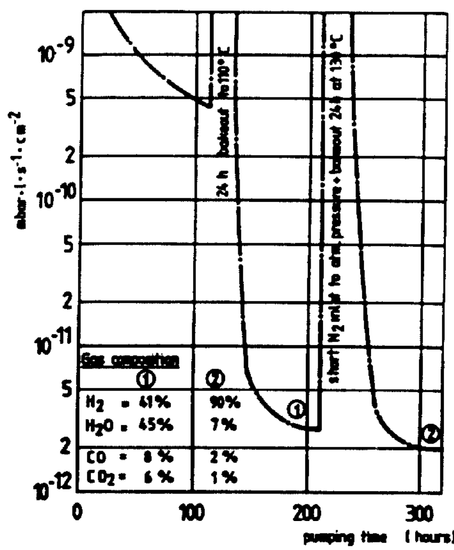

Fig. 1. Outgassing rates for a CFCM beam-tube with 0.01 mm liner of Al ribbon wound with 50% overlap [1].

detection limit of the instruments (10^{-10} mbar l/s) [1]. A further reduction of the outgassing rate caused by the resin between the edges of the Al-liner could be achieved by using a solid Al-tube the wall thickness of which was machined down to about 0.1 mm [2] before it was layered by wrapping and/or filament winding of CFCM. Apart from vacuum reasons, metallic inner liners are necessary in order to improve the electrical conductivity of CFCM and to provide a shielding of the detectors from beam-induced noise.

A third major advantage of CFCM is the versatility in mechanical design. Hardly any space between detector and outer surface of CFCM tubes gets lost since such tubes do not require an obstructing splice joint nor any overhanging flange. Thus, the detectors can be placed directly around the CFCM tubes enabling a large detection angle or, by the closer distance achieved, the observation of particles of extremely short lifetime. On the other hand, a sophisticated tube shape may be tailored to limited available space. Due to the high specific stiffness, distances of up to several meters may also be bridged without any mechanical support [3].

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Further items for the choice of CFCM are a high damage tolerance towards radiation - CERN reports experience of up to 10^8 rad [2] - and a temperature stability for thermal bakeout of 150 C for 200 hours [2]. New developments aim to increase the bakeout temperature to above 200 C.

Above all, CFCM components of comparable transparency usually are more cost effective and faster to manufacture than conventional components.

III. MANUFACTURING

The outstanding characteristics of carbon fibres enable the manufacturing of CFCM components with properties which can be adapted to the specific user requirements by choosing appropriate angles for the single fibre layers (fig. 2). However, these excellent

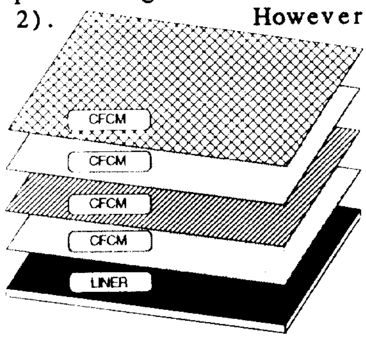

Fig. 2. Principle set-up of a CFCM structure with liner.

characteristics can only be utilized for components of high stiffnes or rigidity and of optimal transparency if suitable techniques for preparing, impregnating and laying of the filament windings are applied. In this process it is essential that a) the fibre characteristics be fully utilized by a careful laying technique and b) the required geometry of the component be built up from as many single layers as possible in order to achieve high homogeneity without increasing the wall thickness; this is achieved by an extreme 'spreading' of the fibre strands (fig. 3).

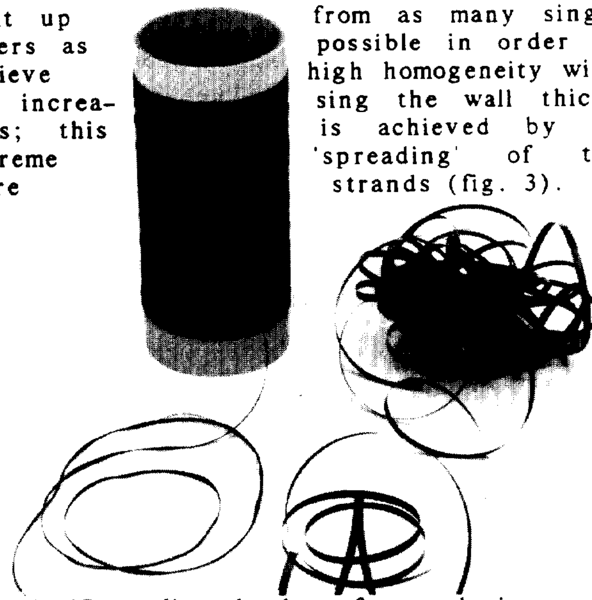

Fig. 3. 'Spread' technology for producing thin single layers; left/right: unspread/spread 6k fibre strands.

The fibre laying technology developed by Dornier takes care of all of these major criteria. In conjunction with a choice of the most appropriate matrix material - usually epoxy or BMI -, CFCM components are manufactured which match the requirements for application in the collision sections of particle accelerators. Specially developed liners or shielding layers provide the suitability for vacuum or electromagnetic shielding, if necessary.

The vacuum tubes applied in the experimental regions may be equipped with Aluminium end pieces with a somewhat higher wall thickness than the bulk CFCM tube. Thus, these tubes can be assembled into the beam pipes e.g. by temperature controlled automatic TIG-welding.

IV. APPLICATIONS

A large variety of CFCM components has been manufactured during the past years for several users in different European reasearch facilities. The range of applications comprised beam-tubes inside and outside collision sections, vertex chambers, support structures and support tubes for exact positioning of instruments.

Table 1
Some typical examples for CFCM components in experimental sections of particle accelerators.

COMPONENTS	IN OPERATION AT	TOTAL-L. / I.D. / WALL-TH. [mm]	SPECIAL FEATURES	FIG.
BEAM-TUBE	CERN / SPS / UA1	13000 / 156/50 / 0.7/1.0	TRANSITION SECTION ALSO LINERED	4
BEAM-TUBE	CERN / LEP / EXP.	1200 / 156 / 1.2/1.5	BUCKLING SAFETY FACTOR 3 ; STIFFNESS-RINGS	5
VERTEX-CH.	CERN / SPS / UA1	1900 / 173 / 1.0	FULL CFCM ,INCL END CAPS , WITH LINER	6
BEAM-TUBE	DESY / HERA	3800 / 184 / 2.0	BUCKLING SAFETY FACTOR 3 ; LONG	7
SUPPORT-STR.	CERN / LEP / ALEPH	270 / 156/220 / 0.2	LIGHT WEIGHT ; RIGID	8

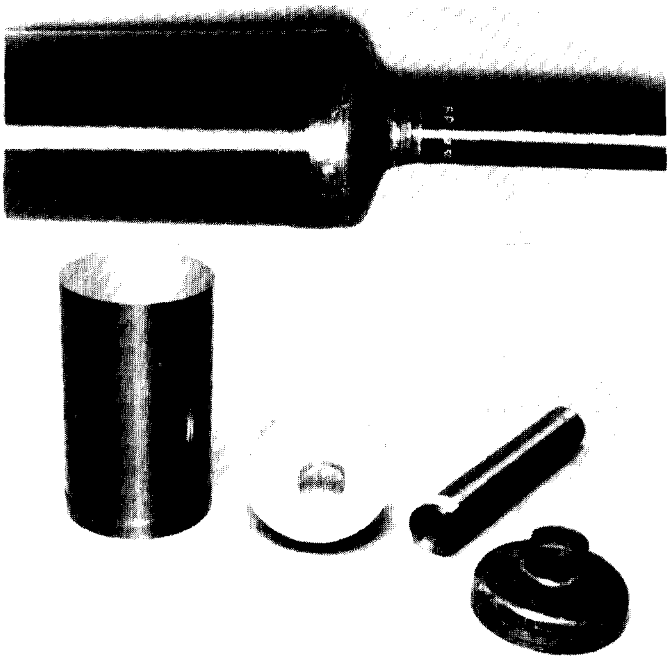

Fig. 4. Beam-tube for CERN/SPS with transition section; below: single components

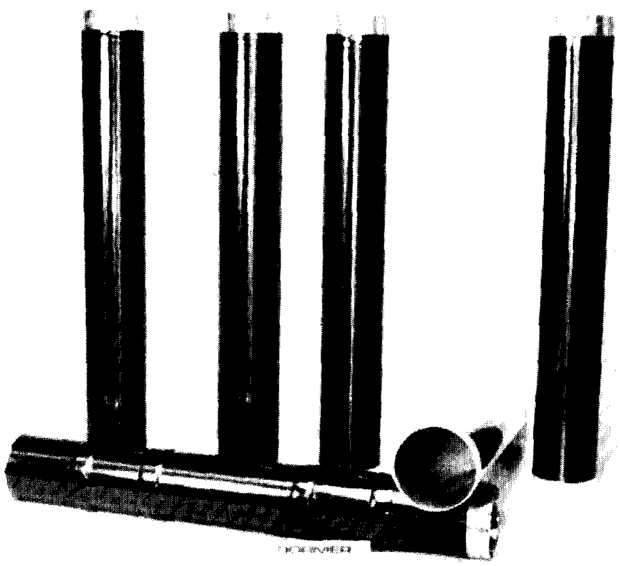

Fig. 5. Beam-tubes for CERN/LEP; at bottom: tube with integrated stiffness rings.

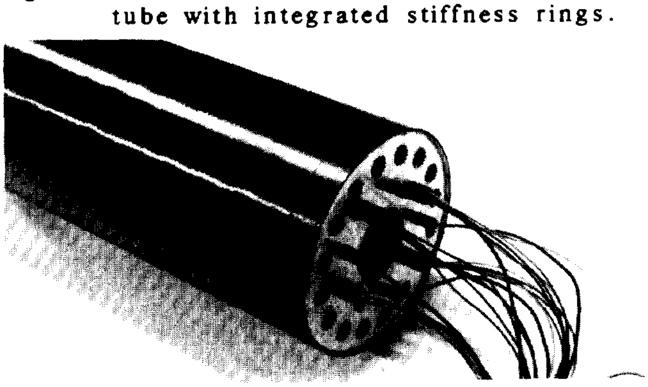

Fig. 6. Vertex chamber for CERN/SPS.

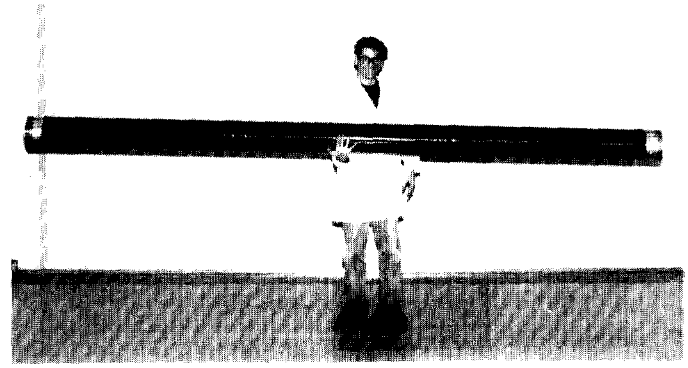

Fig. 7. Beam-tube for DESY/HERA; three parts welded together and fibre reinforced.

Fig. 8. Light weight support structure for an ALEPH detector at CERN/LEP.

V. ACKNOWLEDGEMENT

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VI. REFERENCES

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