THE ALIGNMENT JACKS OF THE LHC CRYOMAGNETS

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Abstract

The precise alignment of the 1232 dipoles, 474 Short Straight Sections (SSS) and some other components of the LHC collider, requires the use of 6800 jacks. The specific requirements and the need for a cost-effective solution for this large production, justified the development and industrialisation of a dedicated mechanical jack. The jack was developed, and is now being produced by Centre for Advanced Technology, India, in the framework of a collaboration between CERN and the Department of Atomic Energy in India [1].

Three jacks support each of the 32-ton heavy, 15-meter long cryo-dipole of LHC, and provide the required alignment features. Identical jacks support the lighter LHC Short Straight Sections.

Presently, the mass production of 6800 jacks is in progress with two Indian manufacturers, and 3545 jacks have already been delivered to CERN by April 2004.

Considering the successful performance of the jacks, it is now envisaged to extend their use, with some modifications, for even higher-demanding alignment of the low-beta quadrupoles of the LHC.

INTRODUCTION

The supporting of the LHC cryomagnets is achieved by a tripod configuration making use of three jacks, each having a controlled motion in the vertical as well as in one transversal direction in the horizontal plane, whereas the other transversal horizontal motion is free. A suitable layout and orientation of the three jacks yields the required degrees of control and freedom for the alignment (Figure 1).

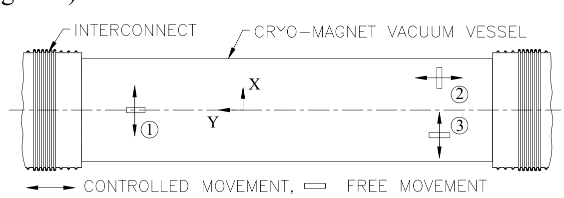

Figure 1: Top view of a cryo-dipole: alignment jacks at position 1,2 and 3.

The jack, (Figure 2), is composed of a mainframe body whose base plate is fixed to the tunnel floor by means of two bolts. The horizontal movement is obtained by controlled tilting of a vertical column, the so-called guide cylinder, by shifting a cylindrical feature on the column with two moving parallel planes of the so called push-pull ring. The push-pull ring is moved by an integral anti-backlash nut device. The vertical movement is obtained by changing the height of the column by moving a ram inside a cylinder. Considering the limited number of alignment operations in the LHC lifetime, an important choice, aimed at reducing the cost of the jacks, was to provide the vertical adjustment by using a removable auxiliary jack (not presented in this paper) inserted concentrically within the guide cylinder. The lifting and relieving of the cryomagnet weight is achieved by operating the auxiliary jack and the setting of the vertical position is achieved by manual adjustment of the ring nut.

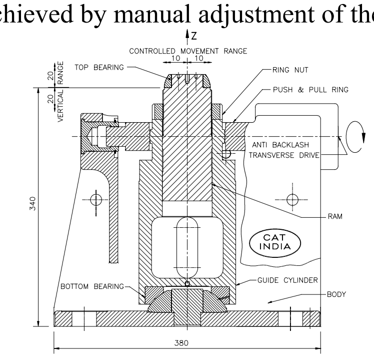

Figure 2: Cross section of the jack

JACK PARAMETERS

The main performance parameters for the jack are given in Table 1 :

Table 1

Parameter	Value
Maximum loads on jacks: - Fz - Fx	170 kN 80 kN
Adjustable range in X-Y directions	∅±10 mm
Adjustable range in Z direction	∂20 mm
Setting resolution (minimum incremental movement)	0.05 mm
Long term stability of position	Ω0.1 mm/year
Nominal operating torque	<60 N.m
Gap between magnet and floor	340 mm
Overall transversal limitation	380 X 200 mm
Bearing pressure on tunnel floor	< 20 MPa
Total integrated radiation dose	< 1 kGy

DESIGN

The design of the jacks evolved from a preliminary value analysis among three different concepts (the retained one versus a standard worm gear concept and an orthogonal slide system), towards the complete engineering of the retained concept, selection of the most appropriate and cost-effective industrial production processes and setting-up of an effective quality assurance

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plan. The tilting column type concept was retained due to its advantage of lower overall friction with the use of standard plain bearings. The sliding bearings were chosen to avoid indentation of rolling elements in view of very high loads and long dwell times.

Guidance from ASME standard on Jacks B30.1-1998 is taken in the design and testing. A unique type of jack, suitable for both the supporting systems of the cryo-dipoles and SSS, was designed with the aim of easing the logistics during tunnel integration, and reducing manufacturing costs consequent to the reduction of the number of components, and the associated QA and inspections during their assembly.

The manufacturing and testing of 36 prototype jacks allowed an extensive experimental validation of their performance at CERN, where they were used in the String 2 facility, and provided an improved understanding for design and manufacturing before launching the series production. Consequently, the design refinement led to the reduction of the number of parts (from 30 to 18), leading to a simplification of manufacturing and improvement of robustness, resulting in a cost-effective design solution.

Loads, Strength and Stiffness

Design forces acting on the jacks are calculated from the various combinations of the forces from misalignment of interconnects, magnet weight, force from the vacuum barrier (for 25 % of the SSS only) and the force of friction during movement. Thorough calculation of frictional forces is done to get the forces for operating the jacks and also to define the stiffness requirement of the jack structure for ensuring a high setting resolution in the presence of high loads.

Moreover to maintain the set position of a cryomagnet within 0.1 mm in both radial and vertical direction and within 0.3 mm in the longitudinal direction under the forces induced by a movement of 2 mm on the adjacent cryomagnets, led to a minimum design stiffness of the jacks In addition, under the 64 kN longitudinal force induced by the vacuum barrier, a maximum admissible deflection of 1 mm of the jack's head was imposed.

Configuration and Operation

The main challenges for the design were inherent to the development of a robust concept, minimising the number of components, the selection and development of appropriate surface treatments, the optimisation of the component geometries, chosen to suit the manufacturing processes thus resulting in an overall cost reduction of the jacks. The available space under the vacuum vessel is rather limited (see Figure 5). Tolerances on the sequence of components were defined carefully to guarantee the full range of movements, proper assembly of the jack, and the correct centering of the jack's head at installation.

All the way through the chain of interfaces between moving components of the transverse drive, elastically pre-loaded fits are used to eliminate the backlash . The components are designed for high stiffness to ensure narrow hysteresis between forward and reverse motion, necessary to ensure the initial fine positioning and its long term stability (Figure 3).

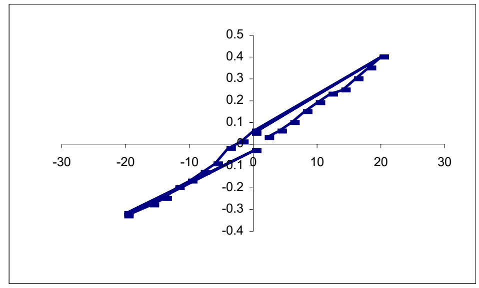

Figure 3: Jack's head deformation (Y-axis, in mm) under transversal load (X-axis, in kN).

The spherical bearing at the top is of an angular contact type. This is needed to take the large horizontal loads due to the vacuum barrier force on the longitudinal jack of the SSS.

Materials

The body is made from "Spheroidal Graphite" iron grade SG 400/15, casted by sand moulding. Guide cylinder and push-pull ring are made from through hardened steel 709M40-T as per "British Standard specification for wrought steels for mechanical and allied engineering purposes, BS: 970-1983" [2].

The mechanical properties of the materials used are as follows:

Material	Young's Modulus	Tensile strength MPa	Proof strength 0.2% MPa	Elongation %
SG 400/15$	1.7×10^5	400	250	15
709M40-T	2.0×10^5	850	665	13

$- Spheroidal Graphite iron grade as per IS 1865-1991

After determining the basic scheme of the components, the design and manufacturing optimisation of the structural components was made by stress and stiffness analysis using FEM softwares Cosmos/M and Nastran, (Figure 4). In conformity with ASME B30.1-1998 standard on Jacks, the computed stresses in the structural components of the jack do not exceed 50% of the yield strength of the material at the appropriate rated load for the components. However, in most of the components, the leading design criterion is stiffness of the structure rather than strength. The contact stresses at the highly loaded rubbing interfaces (between the push-pull and the guide cylinder) were determined and qualified analytically by comparing with the allowable contact stresses in AGMA standard for spur and helical gears for equivalent life cycles [3,4]. The interface between the jack's bottom and the concrete floor was analysed, using gap elements to define the minimum base plate thickness ensuring positional stability of the jack under mechanical loads. A bolted fixation of the jacks to ground is required to avoid slipping under the high external forces.

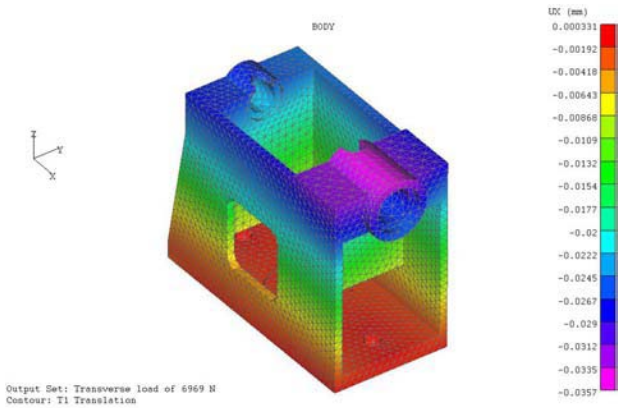

Figure 4: Deflection of jack body under transverse load.

Figure 5: Prototype jacks under String-2 at CERN.

Surface treatments, Lifetime and Environmental conditions

Surface treatments and lubricants are chosen to meet requirements of intermittent operation, long maintenance-free life, radiation tolerance, positional stability and low operating torque [5, 6]. The required operating lifetime of the jacks is 20 years, maintenance-free. During this period, the jacks shall be subjected to a total of 100 movements, in both vertical and transversal directions. Accordingly, specific engineering surface treatments have been applied to satisfy tribological and corrosion prevention requirements [7]. High Phosphorus (10 %) Electroless Nickel plating (SC2, Type-II, Class1, FeCr1/NiP10 15 as per ASTM B-733) having a thickness of 15 microns is chosen for parts running with close fit. Manganese phosphating with sealing has been selected for parts which are enclosed, and where low friction is required by retention of lubrication. MoS_2 based lubricants have been used for long term lubrication, which are relatively unaffected by aging and radiation. Bonded solid lubricants are chosen to avoid squeezing-out in rubbing contacts. Painting after zinc phosphating is selected for the outer body to enhance its adhesion and for better protection.

Testing

As per ASME B30.1-1998, the jacks have been subjected to mechanical load test at 110 % of the rated load by actuating them under this load, and static load test under 150 % of the rated load under static condition.

The jacks were successfully tested for specific positioning and operational performance requirements, under a gravity load of 32 tons for 100 movement cycles using a specifically designed test rig.

MANUFACTURING AND QUALITY ASSURANCE

The manufacturing requirements and quality assurance provisions are defined to meet the designed parameters. Materials are tested for chemical composition and mechanical properties. The castings are tested for mechanical properties using a test coupon cast at the end of the pouring. Electroless nickel plating is tested for adhesion using burnishing test of ASTM B 571 and for its thickness on all the components. Dimensional checking is done on all the features having functional fits; non functional dimensions are checked on 10 % of the components to control manufacturing drifts. Manufacturing processes were qualified before launching production. After their assembly all the jacks are operated without load throughout their full range. One jack out of one hundred undergoes complete mechanical testing.

CONCLUSIONS

The design for strength, stiffness, ease of manufacturing and assembly was completed successfully. All the required manufacturing processes viz. casting, forgings, plating, machining and assembling were developed and executed. Special test rigs for performance and load testing were developed and used for the qualification of the jacks. Consequently jacks meeting the requirements of the LHC alignment have been successfully developed and are being produced by two companies in India.

As of April 2004 more than 3500 jacks have been produced and shipped to CERN.

Considering the successful performance of these jacks it is planned to modify these jacks for even higher demanding alignment of the low-beta quadrupole triplets, where they will be motorised for online remote positioning.

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