Superstructures control with active tie rods

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Abstract

In this paper, we explore the possibility to increase the stability of particle collider superstructures with a network of active tie rods. Basically, they consist of carbon fibre tie rods, fixed at one end on the superstructure, and at the other end to stable points (e.g. detector frame) through active tendons. In the first part of the paper, the solution has been tested on a finite element model of one half of the future Compact Linear Collider (CLIC) final focus structure. With a reasonable design using four rods, it is shown numerically that the compliance is decreased by at least a factor 4, i.e. that the structure is 4 times more robust to technical noise at low frequency. It is also shown that the active rods offer two additional important advantages. The first one is that they can be used to damp significantly all the modes observable by the tendons. The second one is that they can be used to realign the superstructure components. The second part of the paper presents a successful experimental validation of this concept, applied to a scaled test bench. The bench has been designed to contain the same modal characteristics as the full scale superstructure. It is shown that the superstructure compliance can be decreased by a factor 30 in a large frequency range, and locally by nearly three orders of magnitude. The capability of the active tendons to damp and move the structure is also demonstrated experimentally, and found to comply well with theoretical predictions.

1 Introduction

Sometimes, in several large experimental facilities, precise equipments have to be mounted on very large structures. Unfortunately, these structures do not represent a very stable support, and can significantly affect the stability of the equipments, and thus, also affect the quality of the experiments. An emblematic example is the so-called final focus of future linear particle collider, where the electromagnets dedicated to focus the beams of particles are supported by large cantilevered structures, called the *superstructures* in this paper. A representative example of such structure exist at CERN (CMS experiment), and is shown in Figure 1. Recent measurements on this structure [1] have shown large vibrations

Figure 1 Superstructure of the CMS experiment at CERN.

of the free end of the superstructure (about 90 nm, i.e. nearly 3 orders of magnitude above the stability requirements), which are also poorly correlated with ground motion. This indicates that the structure is too sensitive to direct disturbing forces (ventilation fans, cooling, electronics, acoustic noise..). In order to address this issue, we propose to reinforce the structure with a network of carbon tie rods, as presented in the next section.

2 Superstructure stabilization strategy

The model of the CLIC final focus superstructure is shown in Fig.2. It consists of a large tube, cantilevered on the tunnel wall, inside which the electromagnet is supported. The compliance of the free end of this structure is shown in Fig.2. Using a finite element model of this structure, we have calculated that a network of 4 tie rods (shown in red in Fig.2), with a diameter of 4 cm, can reduce the compliance by a factor 4 in directions perpendicular to the tube main axis [2].

Now, let us further consider that an active tendon (constituted by a force sensor in series with a displacement actuator) is fixed at one end of each tie rod, and that we use decentralized loop in each tendon, with the following controller: $H=gs/(s+a)^2$, where s is the Laplace variable, a is a parameter and g is the gain.

It can be easily shown that the stiffness matrix K of the system becomes $K+k_cLL^T(s+a)^2/[(s+a)^2+gs])$, where k_c is the rod stiffness and L is a matrix projecting the rod forces in the structural degrees of freedom. At low frequency, the matrix is unchanged by the controller, i.e. it does not affect the robustness to the disturbing forces. At high frequency, the second term is proportional to S, which creates an active damping (also visible in Fig. 2). Obviously, the active tendons can also be used to realign the superstructures with a good authority.

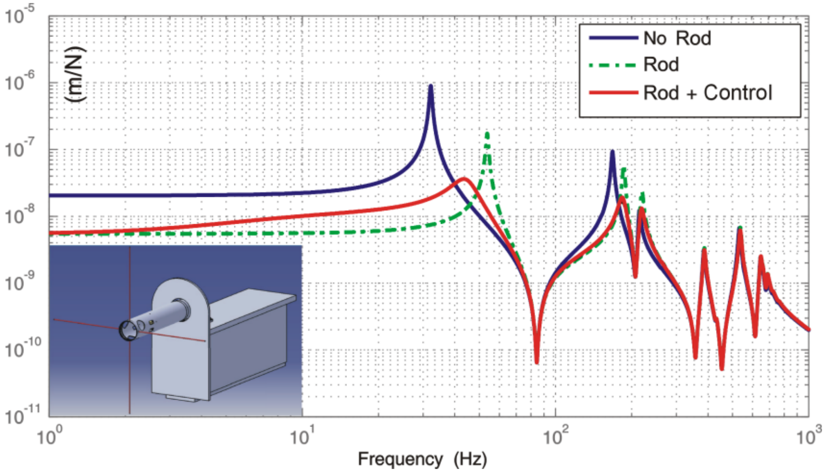

Figure 2: 3D view of the final focus superstructure and its compliance at the free end in the vertical direction.

3 Experimental validation

Figure 3(a) shows a picture of the experimental set-up and Fig. 3(b) shows a zoom on an active tendon. The detector has been represented by a rigid frame. The compliance has been measured in the vertical and lateral direction by exciting the structure with an instrumented impact hammer and measuring the displacements at the same locations. It is shown in Fig. 3(c) for the vertical direction. One sees that the compliance has been divided by a factor 30 at low frequency and, around 30 Hz, by more than two orders of magnitude. Theoretically, a higher reduction of the compliance could be obtained by an additional tension in the cables. However, an excessively high a value of the tension becomes risky for the force sensors.

Finally, the capability of the actuators to move the free end of the tube has been also successfully verified by injecting out of phase sinusoidal signals in the two vertical actuators (not shown in this paper because of space limitation).

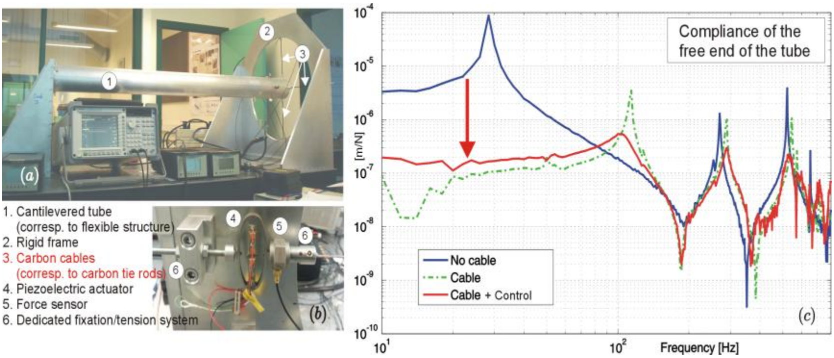

Figure 3. (a) Scaled flexible structure with active cables; (b) Active tendon; (c) Effect of the active cable on the compliance of the free end of the tube.

4 Conclusions

In this paper, it has been proposed to reinforce the superstructure with a network of active tie rods. Using a realistic design, it has been shown numerically that the compliance of the superstructure can be reduced by a factor 4, with only four tie rods. In addition to stiffening, it has been shown that the structural damping can be significantly increased with an active tendon connected at one end of each tie rod. A third property of the active rods network is that it can also be used to realign the superstructure. These results have been confirmed experimentally on a scaled test bench. It has been demonstrated that a network of four cables decreases the compliance of the test bench by a factor 30. The capability of the active tendons to increase the structural damping and to reposition the structure is also confirmed experimentally, and found to comply with the theoretical predictions.

References:

[1] Collette C., Janssens S. and Tshilumba D., Control strategies for the final focus of future linear particle collider, *Nuclear instruments and methods in physics research section A* , vol.684, 7-17 (2012).

[2] Collette C., Tshilumba D., Fueyo-Rosa L. and Romanescu I., Conceptual design and scaled experimental validation of an actively damped carbon tie rods support system for the stabilization of future particle collider superstructures, *Review of Scientific Instruments*, vol.84(2), 023302 (2013).