ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-WEPMF079

EXPERIMENTAL MODAL ANALYSIS OF LIGHTWEIGHT STRUCTURES USED IN PARTICLE DETECTORS: OPTICAL NON-CONTACT METHOD

M. Guinchard†, M. Angeletti, F. Boyer, A. Catinaccio, C. Gargiulo, L. Lacny[1], E. Laudi, L. Scislo[1],
CERN, 1211 Geneva 23, Switzerland
[1]also at Cracow University of Technology, 31-155 Cracow, Poland

Abstract

CERN's specialized structures such as particle detectors are built to have high rigidity and low weight, which comes at a cost of their high fragility. Shock and vibration issues are a key element for their successful transport, handling operations around the CERN infrastructure, as well as for their operation underground.

The experimental modal analysis measurement technique is performed to validate the Finite Element Analysis in the case of complex structures (with cables and substructure coupling). In the case of lightweight structures, standard contact measurements based on accelerometers are not possible due to the high mass ratio between the accelerometers and the structure itself. In such a case, the vibration of the structure can be calculated based on the Doppler shift of the laser beam reflected off the vibrating surface.

This paper details the functioning and application of an advanced laser-scanning vibrometry system, which utilizes the fore-mentioned non-contact method. The results of the Experimental Modal Analysis of selected lightweight structure using this instrument is also presented and discussed.

MOTIVATION FOR THE STUDY

The continuous scientific strive at CERN is to investigate the nature of the universe and its minuscule building blocks of subatomic particles, requires an equally continuous improvement of detection technology and techniques. As the measurement precision increases, the detector systems and structures become more and more complex, meaning the quality of their design needs to improve as well.

This is especially true for lightweight detector structures such as ALICE Inner Tracking System (ITS) Stave Prototype [1]. The Stave has to cope with stringent requirement in term of resistance to dynamic excitation during transport and installation, as well as in terms of detector position stability once in operation. From the mechanical point of view this calls for a precise knowledge of the structural dynamic properties including natural frequencies and modal shapes.

Unfortunately, the delicate nature of these structures restricts the use of standard testing methods, which need to be replaced by alternative non-contact techniques. The goal of this study is to present the application and results of non-contact measuring technique based on Doppler effect and utilizing a laser scanning vibrometry system.

† Michael.Guinchard@cern.ch

DETECTOR TECHNOLOGY

The ITS Stave Prototype, represents a module of the New Inner Tracking System (ITS) of ALICE, that will be installed in the Experiment in 2020 and will track particles produced by the interaction of the LHC accelerated beams (Figure 1).

48 of these modules constitute the three Inner Layers of the ITS and are called Staves as they are placed as the stave of a barrel in cylindrical concentric layers around the particle beam line and centred on the interaction point. Each Stave has a sensitive area of about 1.5 cm x 27 cm constituted by 9 aligned silicon pixel chip sensors (1.5 cm x 3 cm x 50 μm). The sensors are glued on an ultra-light support, mass 1.7 gram, consisting in a high thermal conductive coldplate, with embedded kapton cooling pipes, reinforced by a structural carbon wound frame. Chips are connected by a flex printed circuit (FPC) that carries power and signal [2]. The mass directly supported by the structure, consisting in the 9 chips, the FPC and the glue, is 3 grams. An extension of the FPC, outside the support, at one side, connects the Stave to a patch panel that is served by the electrical and signal cables. A mechanical connector, at each end of the Stave, allows the fixation and alignment of the Stave and the connection to the cooling line.

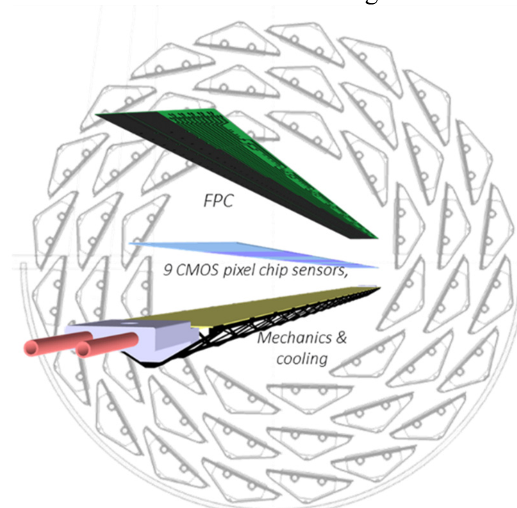

Figure 1: ALICE Inner Tracking System Stave layout.

EXPERIMENTAL MODAL ANALYSIS

Experimental modal analysis is a standard and well-known measurement used for determining the dynamic properties such as natural frequencies and modal shapes. Typically the method utilises either an electromagnetic shaker or a modal hammer for the excitation and a set of

ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-WEPMF079

precise piezoelectric accelerometers for the acquisition of the vibratory response of the structure.

This type of measurement is generally employed to medium and large-sized machine elements and structures, much larger in size and weight than the applied sensors. In the case of lightweight structures the application of standard accelerometers, with mass comparable to the mass of the analysed object would greatly impact the measurement and produce incorrect results.

Therefore, the modal analysis of lightweight structures requires alternative measuring method like laser-based non-contact motion measurement. In this paper a measuring process to determine the natural frequencies and modal shapes of the lightweight ALICE ITS Stave Prototype, using an advanced scanning vibrometry system, is presented.

EXPERIMENTAL SETUP

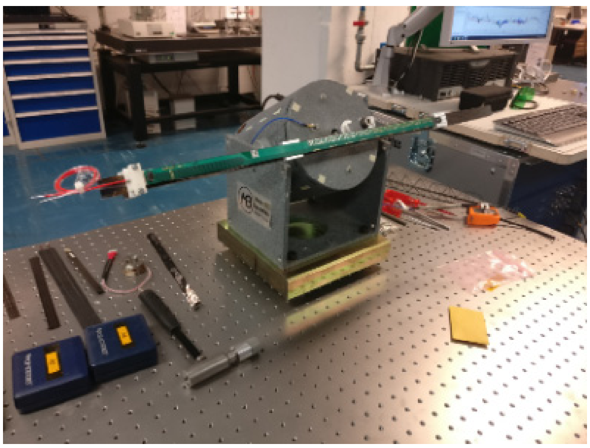

Figure 2: Measurement setup – ALICE Inner Tracker beam mounted on an electromagnetic shaker.

The measurement setup used for the experiment consisted of an ALICE Inner Tracker beam mounted using a specifically designed support on top of the electro-magnetic shaker (Figure 2). The vibratory tests of the beam were performed in a fixed-fixed boundary conditions – in a similar way the beams will be mounted in their final position in the detector.

Figure 3: Polytec PSV-500-3D Scanning Vibrometry System.

In order to perform the measurement a scanning vibrometry system consisting of three separate Laser Doppler Vibrometer heads was used (Figure 3). Each head was equipped with a set of two mirrors (vertical and horizontal) allowing for the position of the measuring laser to be moved over the surface of the analysed object.

The basic principle of the operation of the system is derived from the Doppler Effect. The velocity of the vibrating object in the measurement point is calculated based on the interference between the laser reflected from the vibrating structure and the reference laser inside the head. The value of displacement obtained in the similar way. The laser used in the presented vibrometry system is HeNe (λ=633nm).

Figure 4 shows the measurement setup view from the camera present in the top head of the PSV-500-3D system. The grid, consisting of scanning points, has been overlaid on the surface of Inner Tracker Stave, thus allowing the scanning system to perform an automated measurement over all the points.

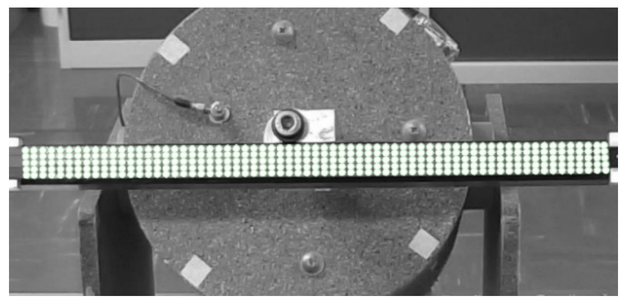

Figure 4: ALICE Inner Tracker beam – scanning grid.

In order to ensure that the analysis covers a wide array of frequencies, a repeated "burst chirp" excitation function (constant amplitude, variable frequency) was used for the shaker. In each test the frequency of "chirp" excitation was changing gradually from 20 Hz to 4 kHz over a time of 4.8 s with a 1.6 s pause between each cycle.

Finally, for each measurement point, the result was averaged over four separate tests such to reduce the noise level i.e. increase signal-noise ratio.

MAIN RESULTS

The measured 2nd bending mode of the Stave is shown in Figure 5. The freeze-frame of the modal shape is overlaid on top of the picture showing the measurement setup, as visible from the camera in the top head of the system.

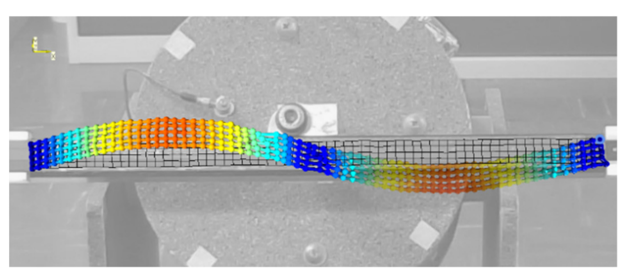

Figure 5: PSV-500-3D Camera View (2nd Bending Mode).

ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-WEPMF079

The graph consisting of longitudinal (red), lateral (green) and vertical (blue) frequency response functions up to 4 kHz is shown in Figure 6. Based on these Frequency Response Functions graphs and animated movement of the scanned grid for natural frequencies it was possible to recognize the modal shapes of the structure up to 4 kHz. Table 1 lists the natural frequencies up to 1 kHz and their corresponding modal shapes.

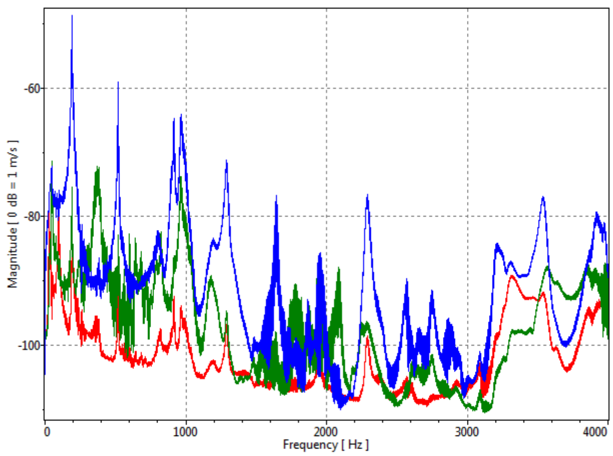

Figure 6: Frequency Response Functions.

Table 1: Natural Frequencies and Modal Shapes of the ALICE Tracker (< 1 kHz)

Freq. [Hz]	Modal Shape
29	Rigid Mode
98	Rigid Mode
192	1st Bending Mode
359	1st Lateral Mode
520	2nd Bending Mode
915	3rd Bending Mode
968	1st Torsional Mode

SUMMARY & FURTHER STEPS

As already explained in the motivation for this study, the determination of natural frequencies and modal shapes of lightweight structures requires the use of a non-contact method. Using the laser Doppler vibrometry scanning system it was possible to successfully perform the automated vibration measurement over the selected surface of the analysed lightweight structure, and to obtain the relevant information concerning its natural frequencies and modal shapes.

In order to improve the measuring technique of the lightweight structures with the scanning system, a modification of the excitation method has been suggested and considered. The proposed idea is to replace the electro-magnetic shaker with a loudspeaker, which would be controlled in similar fashion in order to excite specific frequencies of the tested object. The preliminary tests for the integration of such a loudspeaker in the measuring system have been performed recently.

CONCLUSIONS

The proposed non-contact vibratory measurements of the designed lightweight structures, under a simulated excitation, proved to be determinant for a correct measurement of the dynamical behaviour. This type of measurement opens up a possibility of additional adjustments or redesign of the structures, to ensure they are sufficiently rigid and resistant, before their final installation within the underground detector or system. This is especially crucial for structures of complex shape, for which neither the standard experimental modal analysis nor the numerical one are fully reliable.

The use of an advanced non-contact laser scanning system, brings out additional benefits in terms of measuring procedure respect to the classic mechanical approach. These include an extended bandwidth of excitation vibration detected by the system, an increase in the number of measured points and an improvement in terms of their spatial resolution as well as in the precision of the measurement itself. Finally, in the case of a 3D scanning vibrometry system, the possibility of measuring an object and extracting the vibrational response in three separate directions allows to easily recognize and classify the modal shapes.

REFERENCES

[1] B. Abelev *et al.*, "Technical Design Report for the Upgrade of the ALICE Inner Tracking System", *J. Phys. G Nucl. Part. Phys.*, vol. 41, no. 8, p. 87002, 2014.

[2] V.I.Zherebchevsky *et al.*, "Extra Lightweight Mechanical Support Structures with the Integrated Cooling System for a New Generation of Vertex Detectors", *Instruments and Experimental Techniques*, 57(3):356-360, May 2014.