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Bottom-up modal analysis of a small size machine tool

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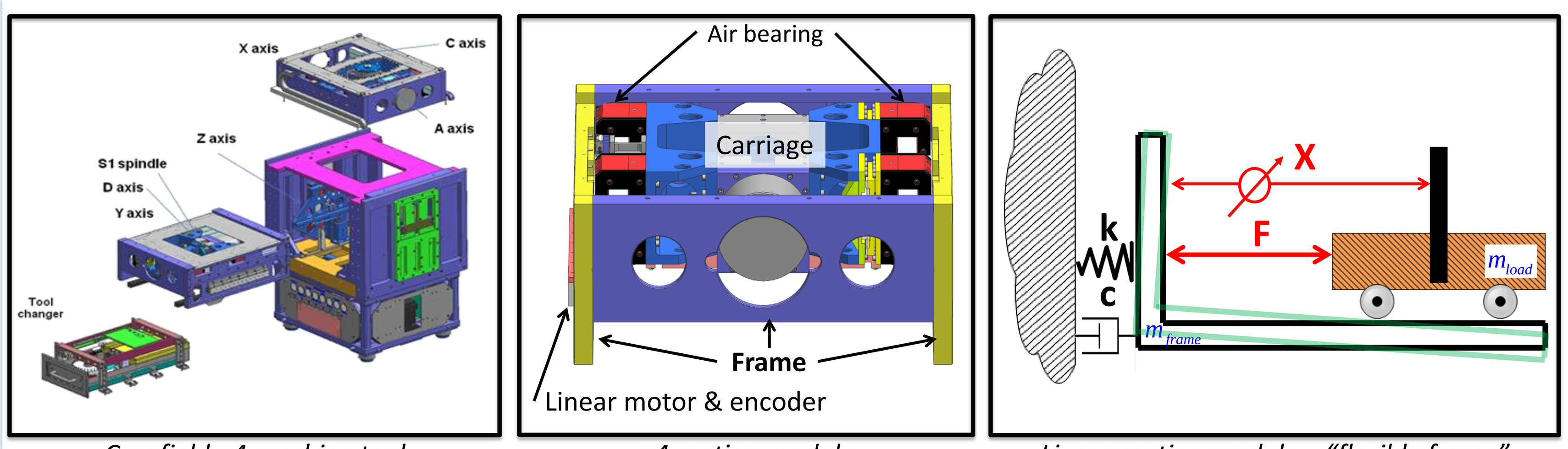
Introduction

This project work was started during December 2013, it is focused on technologies that allow manufacturing of free-form surfaces within the constraints of a desktop-size machine tool. It will be yield design and development of a mechatronic system leading to high-dynamic motional control of compact size machine tool, as required for free-form manufacturing. It products will be implemented in the compact size machine tool – µ4 made by Cranfield Precision Engineering Institute and Loxham Precision Ltd.

Performance of a mechatronic system, e.g., settling time, position error and bandwidth, is limited by the dynamic properties of the mechanical system. The desired motion – *X* of the load is generated by the servo force – *F*. The servo force acts on the frame and cause it to vibrate. The frame is neither infinitely heavy nor infinite stiff thus, the frame will exhibit resonances with flexible mode shape.



Cranfield µ4 machine tool — *µ4 motion module* — *Linear motion module – "flexible frame"*

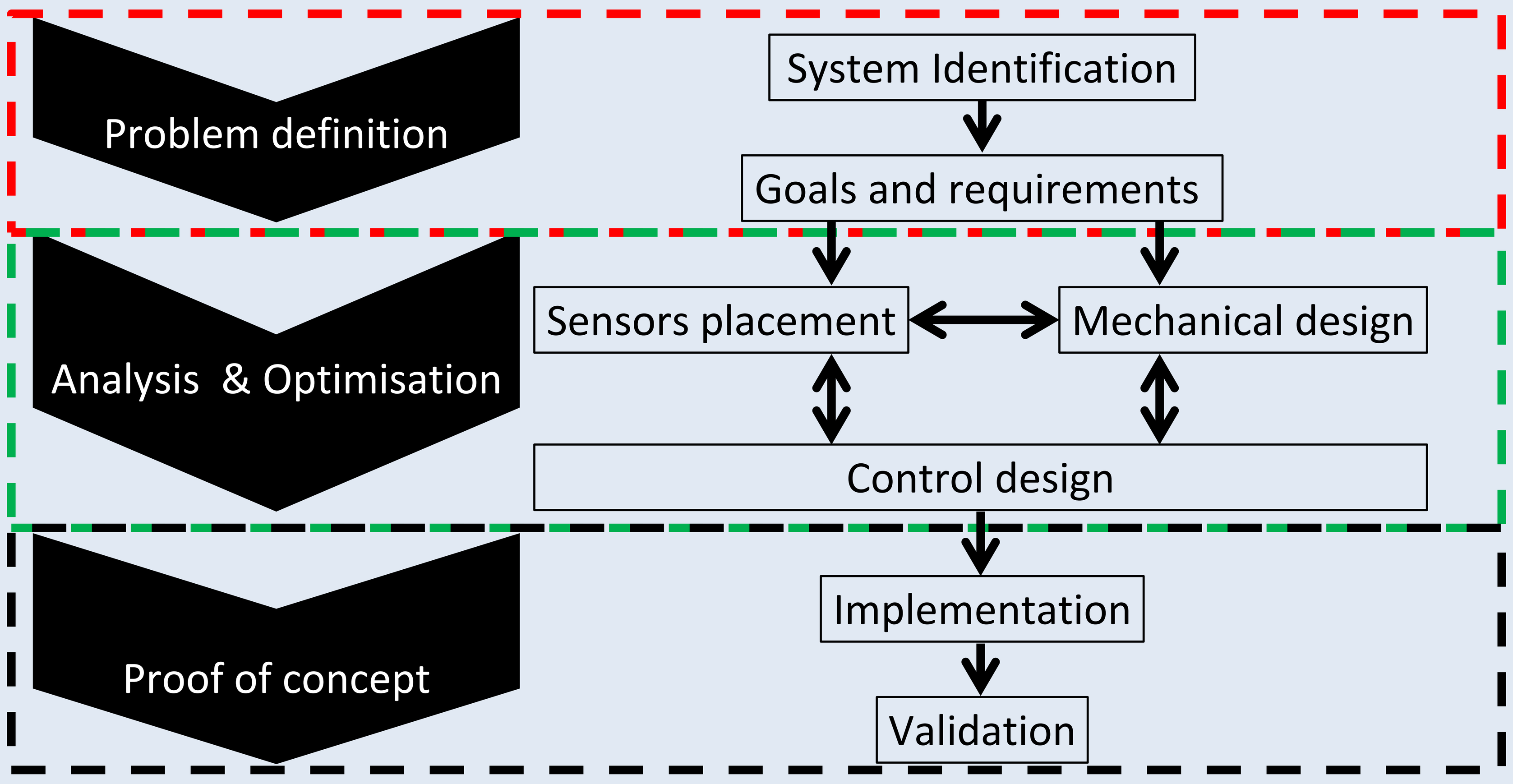
Aims and objectives

The research hypothesis is: Improving position control of a linear stage based on real time measurements from array of accelerometers.

The aim of the project is to perform design and optimization of the µ4 machine based on system identification and validation before and after the mechatronic implementation of the improvements to the machine.

The novelty of this research comes from combining the apparently antagonistic requirements of small size machine and high-dynamic motion control into one solution based on experimental and simulation work.

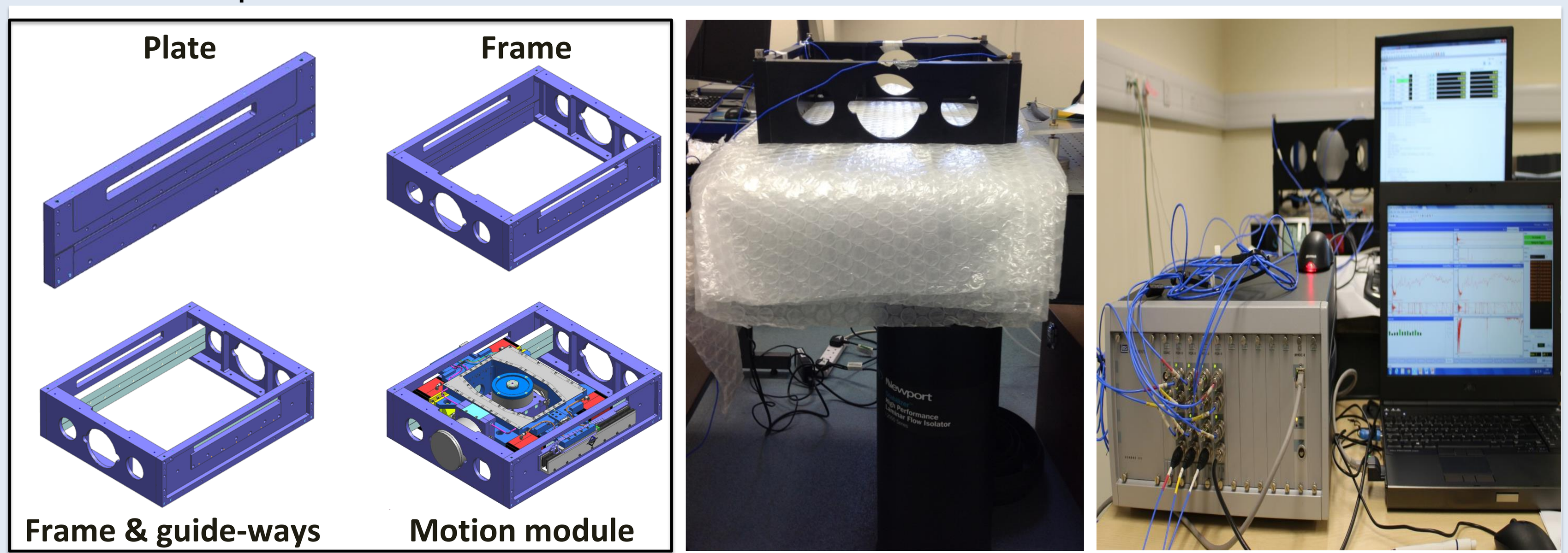
Research methodology



System identification

System identification methodology is a bottom-up process in which the lowest level components are tested and simulated first, then used to facilitate the testing of higher level components. Modal properties of the motion axes module were simulated using Finite Element Method (FEM), measured and analyzed using modal measurement equipment specified and procured for this research.

Each component and assembly was suspended in free-free conditions by suspending it on a vibration-isolated table and a bubble wrap 'mattress'. Thus, rigid body modes and flexible modes are sufficiently separated enabling identification of the rigid body modes for debugging the measurement setup. Three axis accelerometers were used in various locations for measuring the response. Their locations were chosen based on the mode shape results from the FEM.



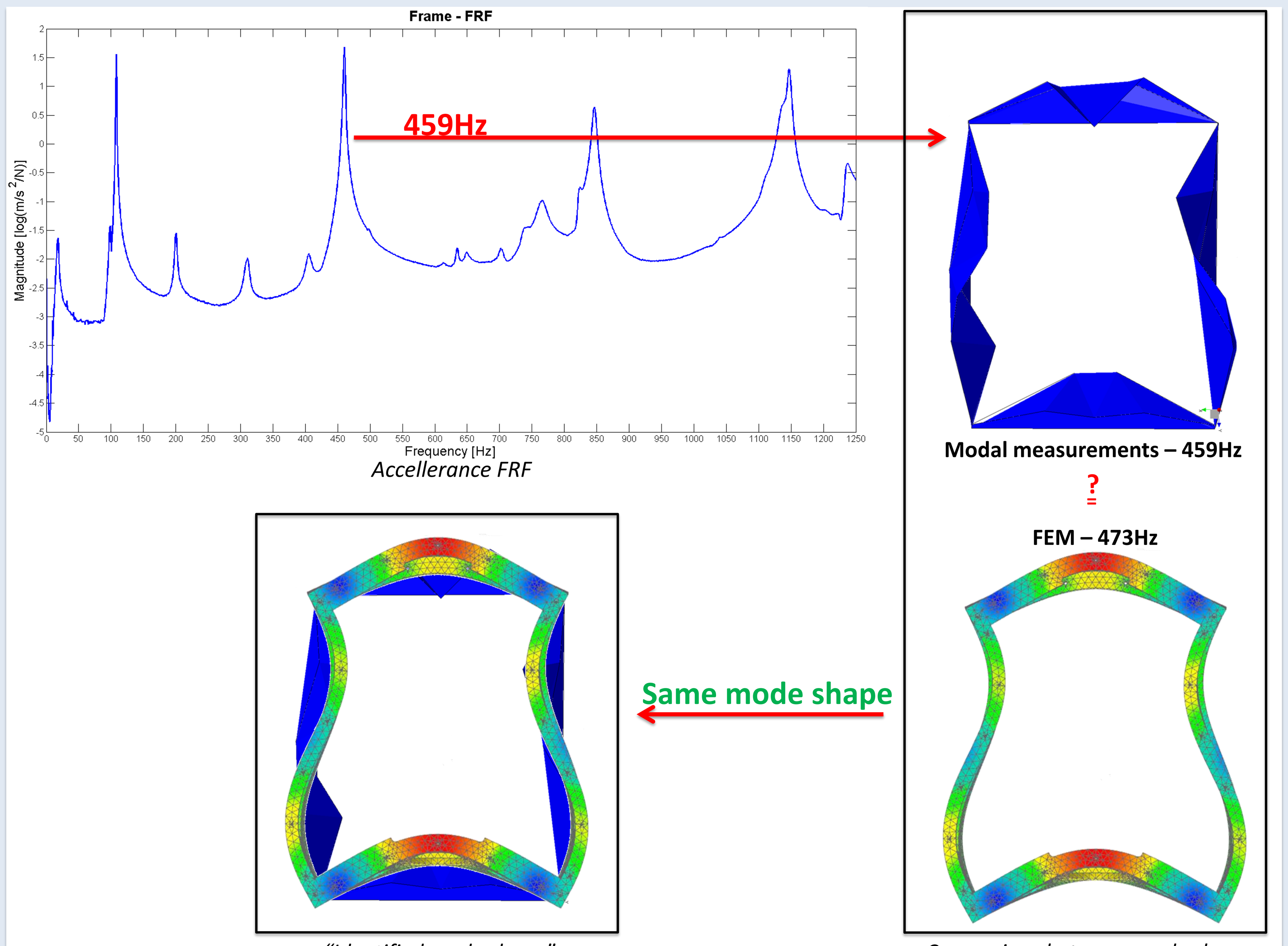
Bottom-up system identification — *Free-free boundary condition* — *Modal measurements*

FEM and modal measurements

Rigid and flexible body modes were synthesized using stabilization diagrams choosing the frequency and damping values. The results were validated by observing the animation of the modes and by comparing the properties to those from FEM.

Measurements product is the accellerance Frequency Response Function(FRF) which is then post-processed by parameter estimation techniques (curve fitting) to identify the modal parameters: frequency, damping and mode shape. The user selects the model order and the bandwidth of the fitting. Hence, the user selects only the real modes based on the quality of the fitting in the stabilization diagram.

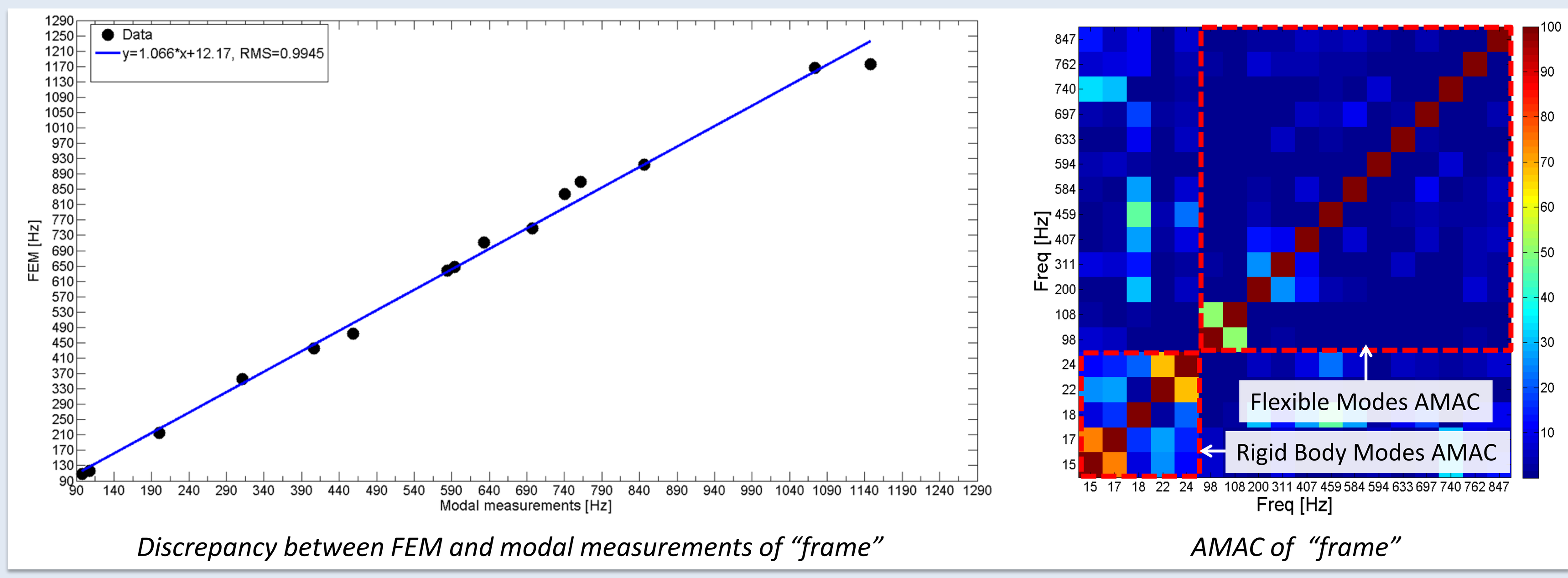
Estimated modal properties based on the measurements were compared and correlated. Each measured mode was identified by comparing the animation to the FEM animations. This process was made by focusing on the main characteristics of the mode shape.



"Identified mode shape" — *Comparison between mode shapes: modal measurements and FEM*

The identified measured and FEM modal properties were shown to have a good correlation with less than 15% discrepancy of the frequency values.

Auto Modal Assurance Criterion (AMAC) tool can be used to assess whether sufficient measurement points have been used by calculating the correlation between measured modes. Non-zero off-diagonal terms means some of the modes appear to exhibit a degree of correlation with others.



Discrepancy between FEM and modal measurements of "frame" — *AMAC of "frame"*

Conclusions

A bottom-up system identification methodology was adopted to investigate a novel small size machine – µ4.

System identification was based on FEM and measurements analysis and showed a good correlation.

Based on this methodology, the modal results will be used as an input to improve the mechanical design and help implement control technologies to achieve high dynamic motional control goals. The FEM-measurements correlation can now be used to simulate the performance of the improved motion axes module.

Future work

Future work will be focused on finding control techniques for the "flexible frame" phenomena and the optimal sensor placement. Different control techniques might be utilised and optimised, i.e., adaptive control, acceleration feedforward / feedback. Optimal sensor placement research will take into account number of sensors, their locations relative to the mode shapes and their specification.

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