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Design and Control of a Compact Ultra-Precision Machine for High Dynamic Performance

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Introduction

The 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. The research will be yield design and development of a mechatronic system leading to high-dynamic motional control of desktop-size machine tool, as required for free-form manufacturing. The research products will be implemented in the desktop-size machine tool – µ4 made by Cranfield Precision Engineering Institute and Loxham Precision Ltd.

Aims and objectives

The aim of the project is to perform design and optimization of ultra-precision technologies, which allows free-form surfaces manufacturing using µ4 by achieving high-dynamic motional control.

The work will include system identification and validation before and after the mechatronic implementation of improvements to the µ4 machine.

The high-dynamic motional control will be demonstrated by: sub-micrometer accuracy and high jerk (>500m/s^3) capabilities.

The contribution to knowledge and the novelty of this research comes from combining the apparently antagonistic requirements of small size machine and free-form surfaces manufacture into one solution based on experimental and simulation work.

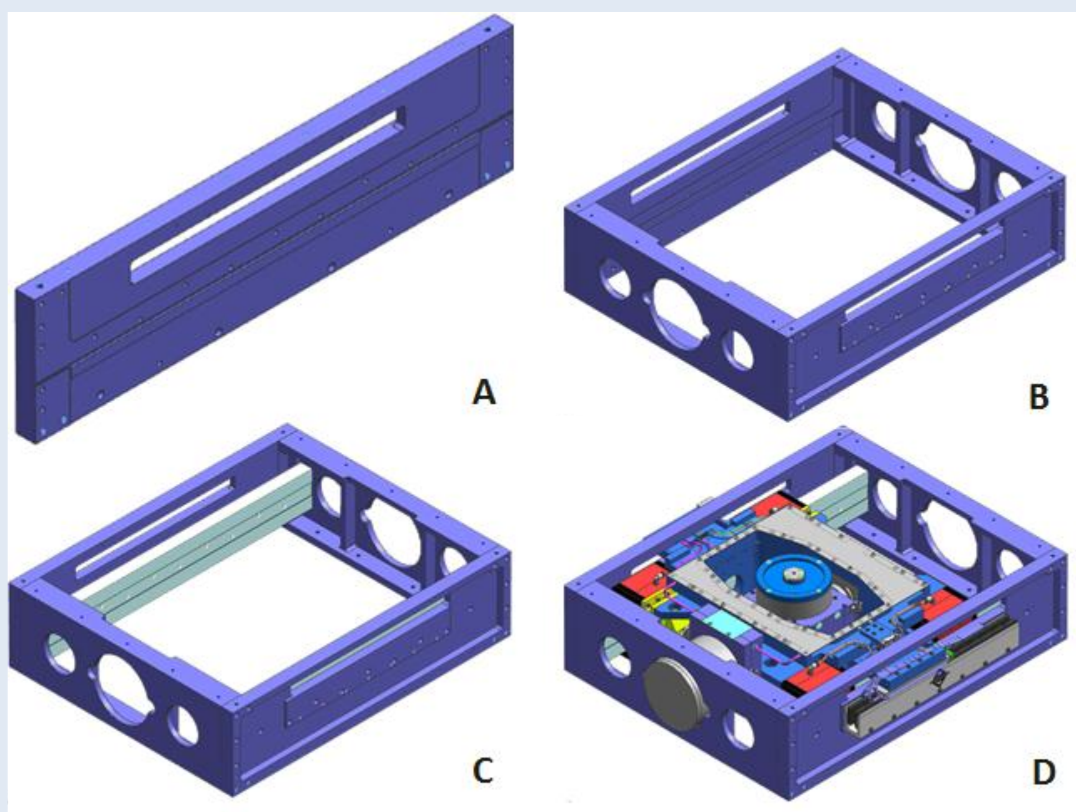
System identification methodology

The 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.

The 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 and frequency response functions measured using hammer excitation. In the free-free suspended boundary condition, rigid body modes and flexible modes are sufficiently separated enabling identification of the rigid body modes for debugging the measurement setup.

The 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

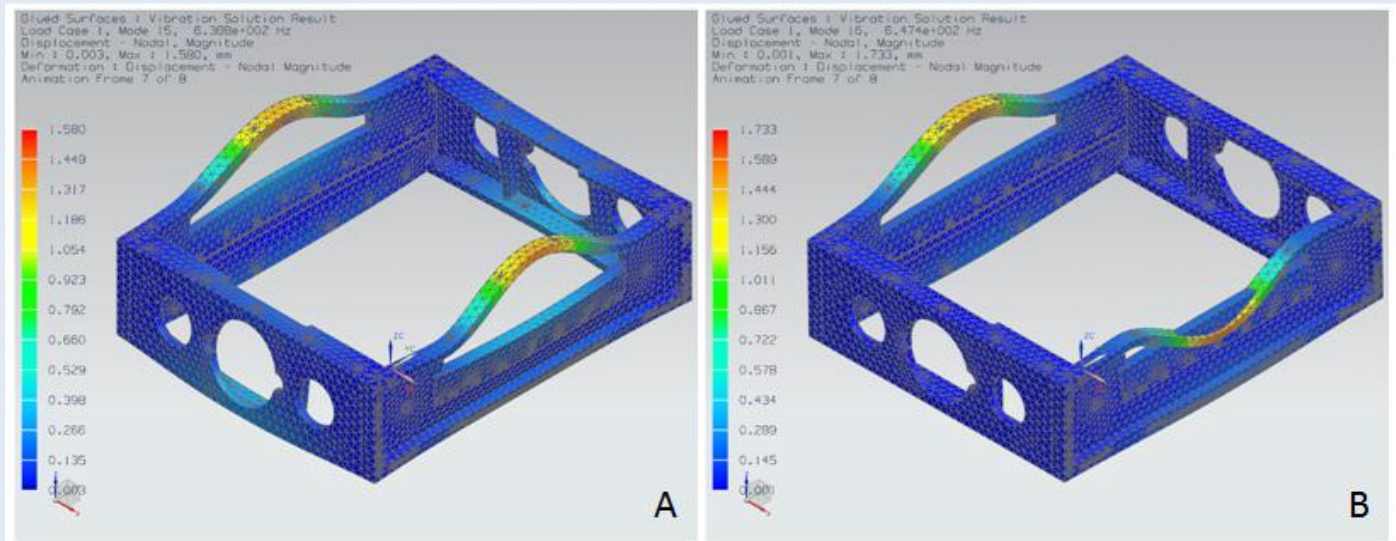


Bottom-up system identification

Free-free boundary condition

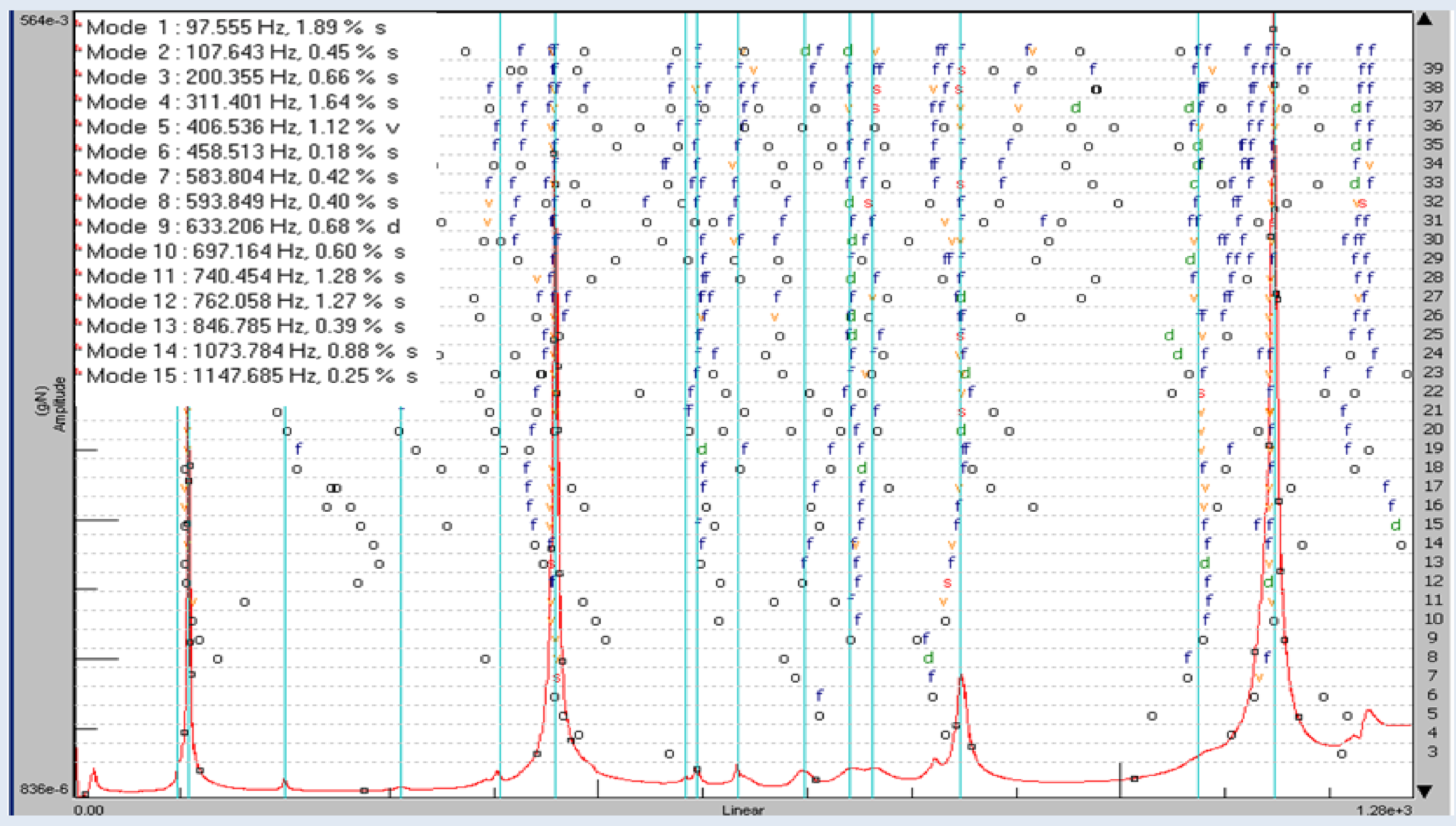
FEM and modal measurements

The components and assemblies were suspended on a vibration-isolated table and a bubble wrap ‘mattress’ for a free-free boundary condition. An impact hammer was used for the excitation and three axis accelerometers were used in various locations for measuring the response. The accelerometers locations were chosen based on the mode shape results from the FEM.



Two mode shapes at 639Hz (A) and 647Hz (B) of frame only assembly

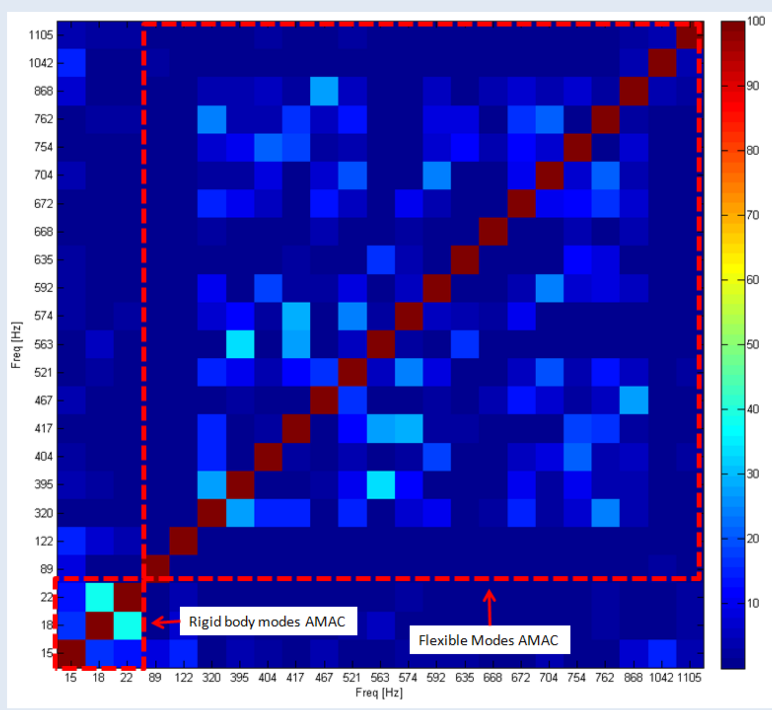
The measurement product is the accellerance Frequency Response Function(FRF) which is then post-processed by parameter estimation techniques (curve fitting) to identify the modal parameters: frequency, damping and mode shape. The user selects the model order and the bandwidth of the fitting. Hence, the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



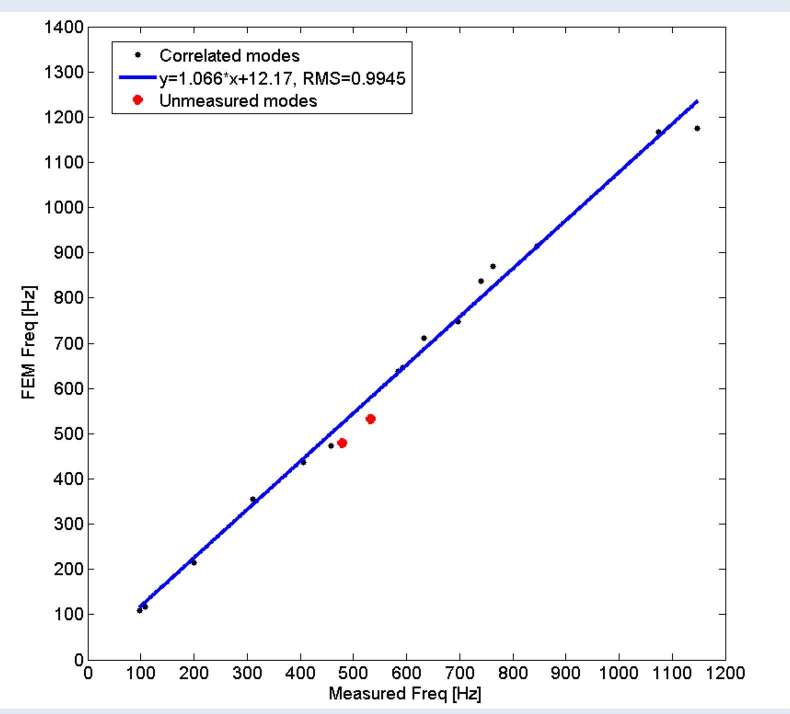
Stabilization diagram of frame only assembly measurements

The Auto MAC tool can be used to assess whether sufficient measurement points have been used by calculating the correlation between measured modes.

The 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.



AMAC of frame with rails measurements



FEM and measurements correlation

Conclusions

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

The 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.

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