COMPENSATION FILTER FOR FEEDBACK CONTROL UNITS WITH PROOF-MASS ELECTRODYNAMIC ACTUATORS

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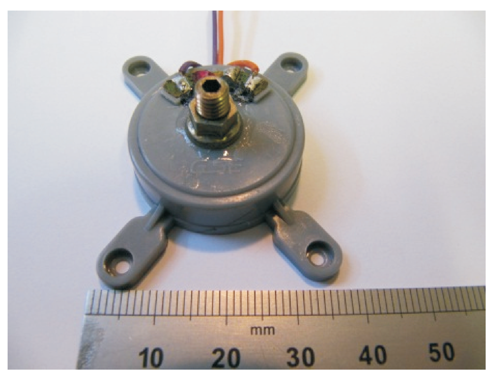
Abstract

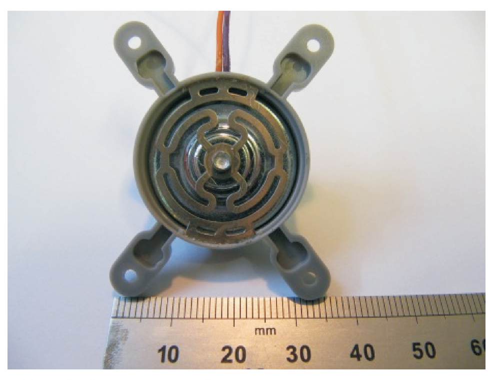
Vibration control of flexible structures is an important issue in many engineering applications. A simple and robust strategy is that of decentralised velocity feedback, which can reduce the response of a structure by means of active damping. An ideal velocity feedback loop with a dual and collocated sensor and actuator pair is unconditionally stable while with practical transducer pairs the resulting feedback loops are only conditionally stable.

In practice velocity feedback loops can be implemented on a structure by control units comprising a proof-mass electrodynamic actuator and closely located accelerometer-sensor pair with a time-integrator and fixed gain controller. Above the actuator fundamental resonance frequency the control force is in phase with the control signal. However the actuator resonance causes a 180° phase lag in the closed-loop control response which limits the maximum gain with which the sensor signal can be fed back into the actuator. The stability of the feedback loop depends on both the response of the control unit and that of the structure under control. For high feedback stability the actuator fundamental resonance should be highly damped and the natural frequency should be well below that of the structure under control. particularly the requirement for a low actuator natural frequency conflicts with requirements on the mechanical robustness of the control unit.

In this study a control unit with a commercially available, mechanically robust, small scale actuator is considered. The control unit is described in terms of the open- and closed-loop base impedance it presents to the structure under control, which allows deriving the frequency response function for an open-loop compensation filter for enhanced control stability and performance.

The actuator units



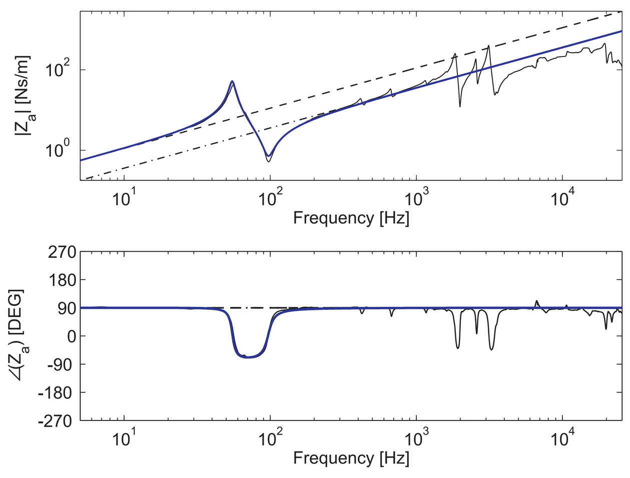


Spider spring
proof-mass suspension

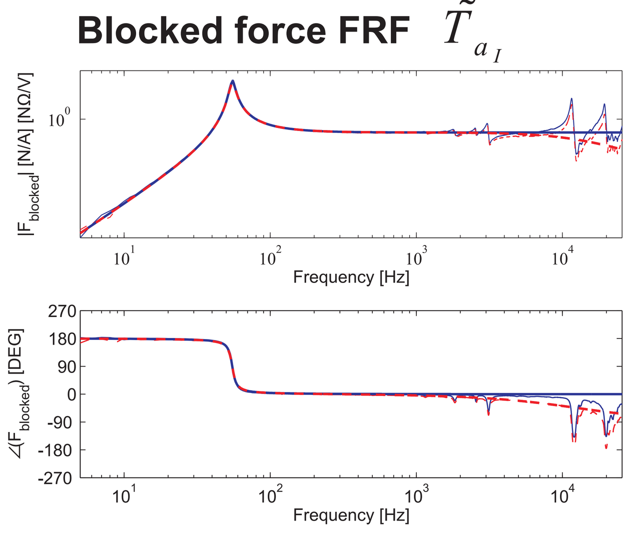
Trust HS-3100
Bass Vibration Headphone

Actuator base impedance

Open-loop base impedance $\tilde{Z}_{a_{passive}}$

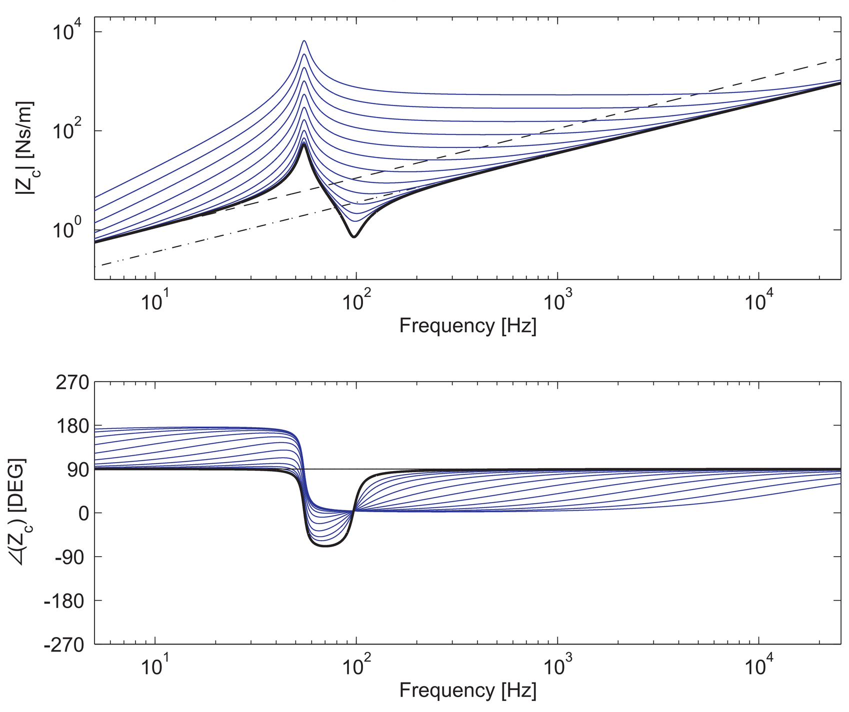


Blocked force FRF $\tilde{T}_{a_I}$



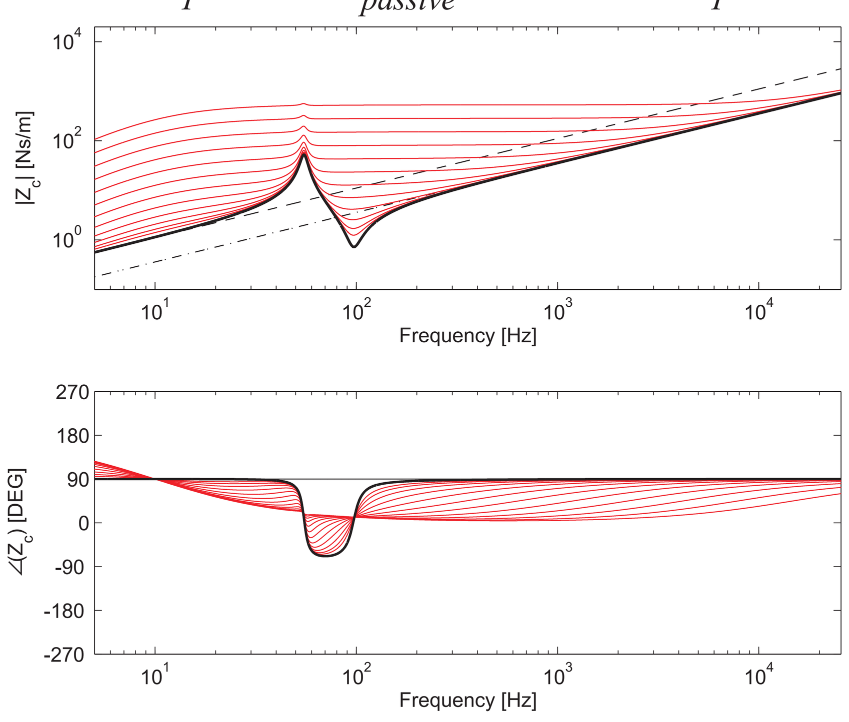
Base impedance without compensation

$$\tilde{Z}_{c_I} = \tilde{Z}_{a_{passive}} + g\tilde{T}_{a_I}$$



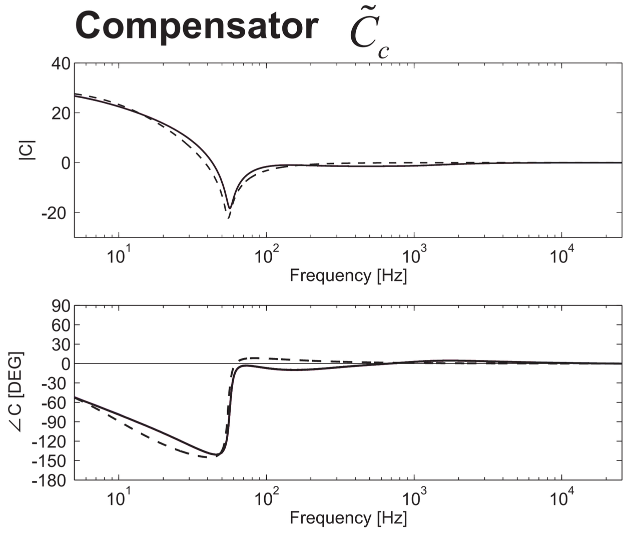
Base impedance with compensation

$$\tilde{Z}_{c_I} = \tilde{Z}_{a_{passive}} + g\tilde{C}_c\tilde{T}_{a_I}$$

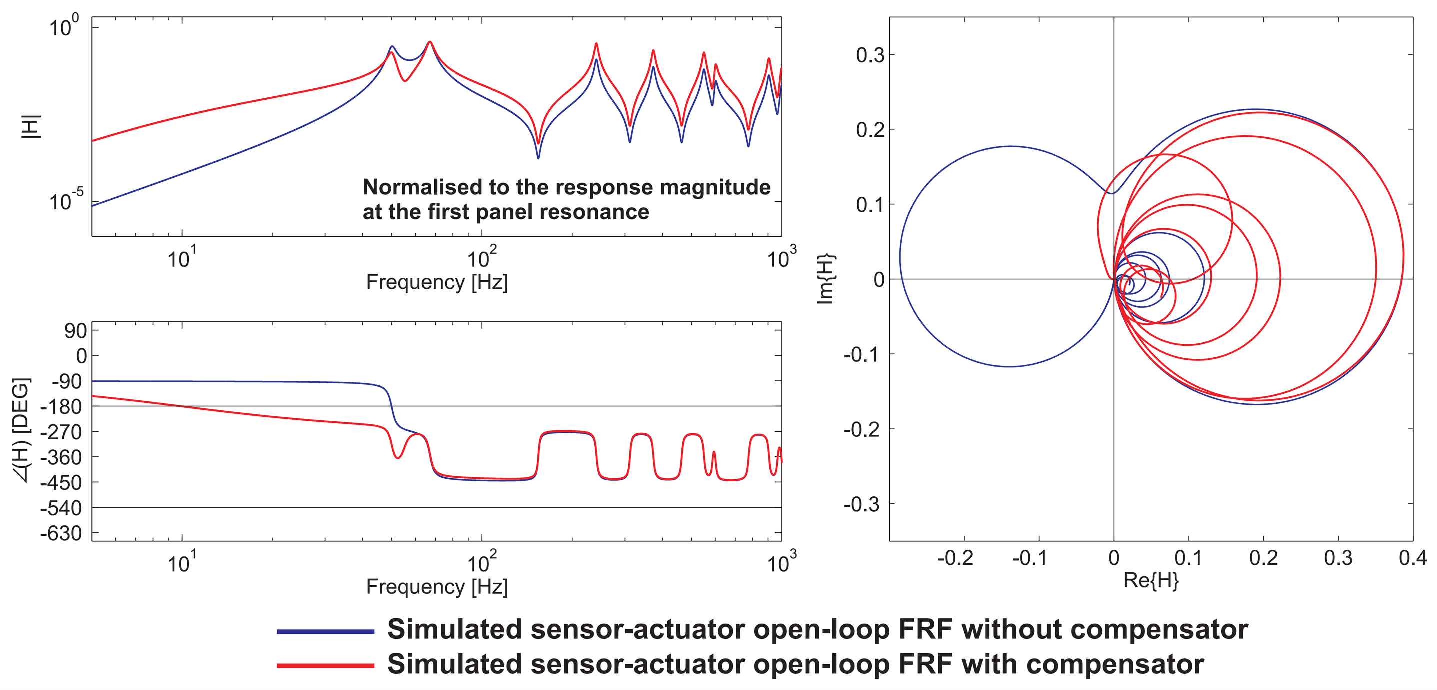


Open-loop compensator

Compensator $\tilde{C}_c$



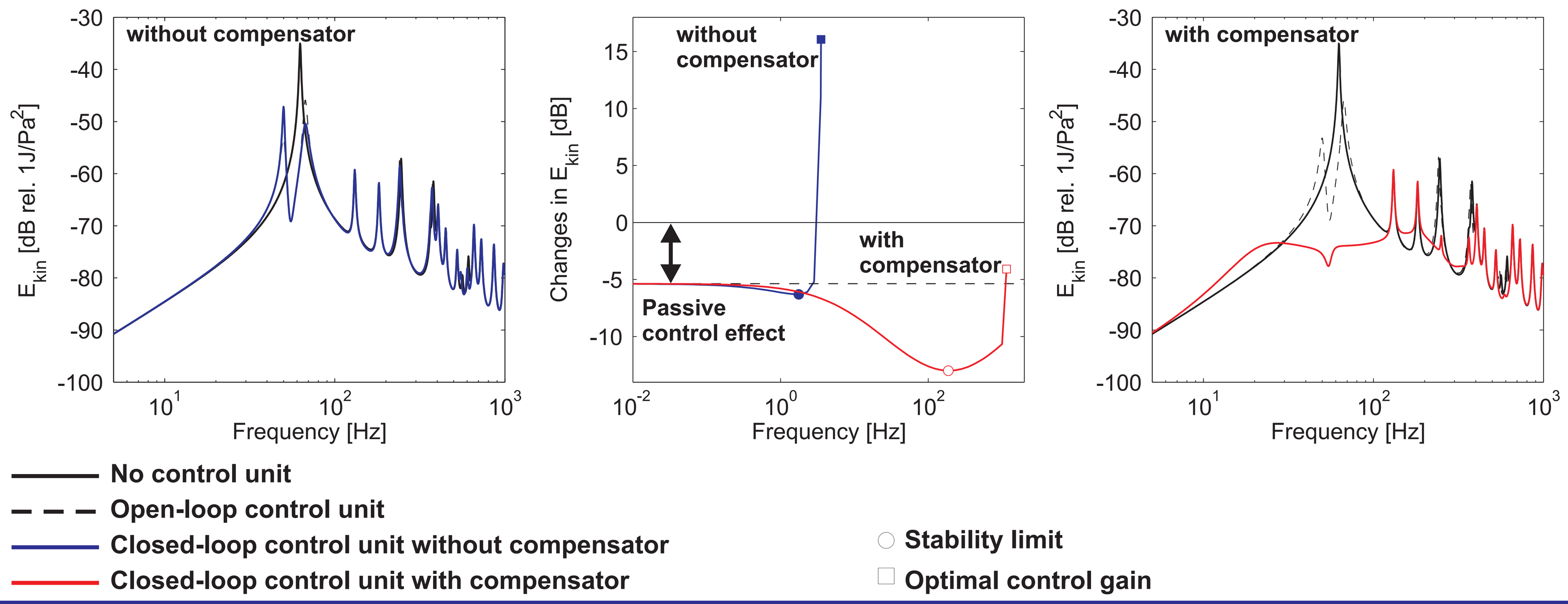
Sensor-actuator open-loop FRF (control unit mounted on a thin panel)



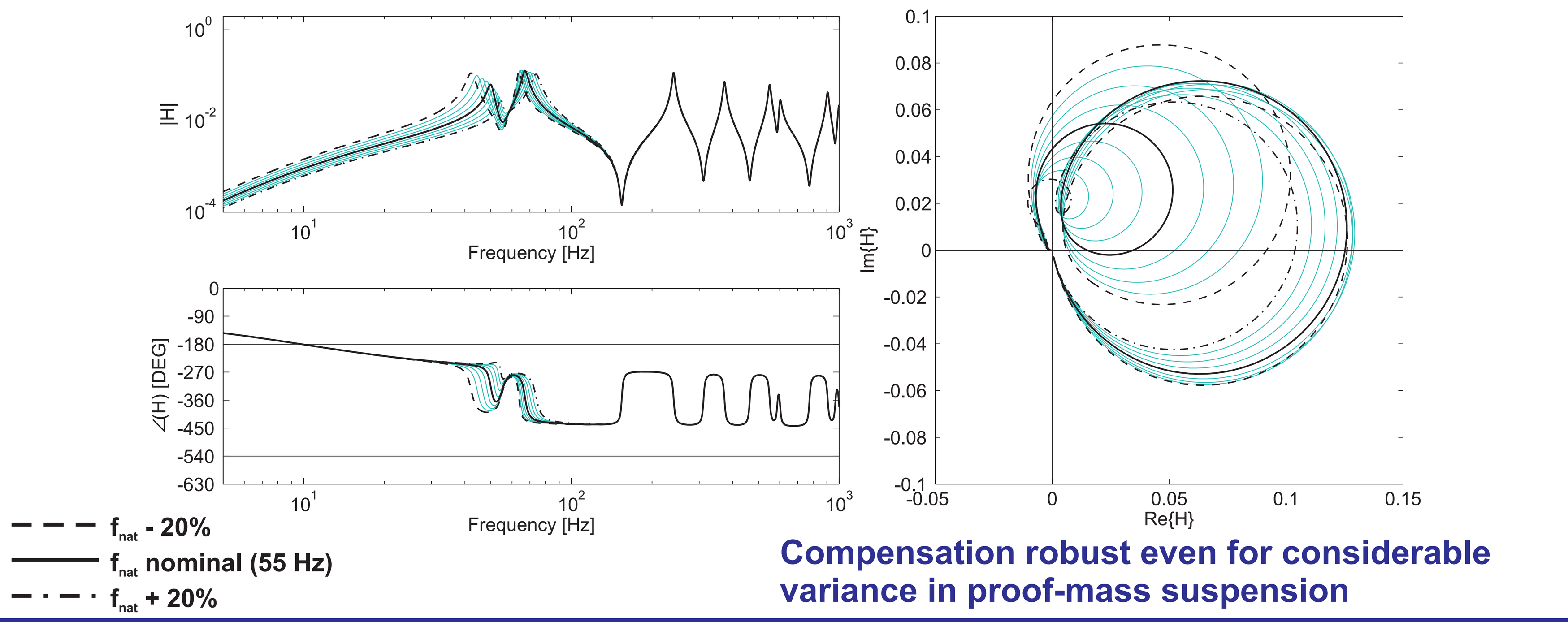
Green City Car
FP7-SST-2008-RTD: 233764

This research is conducted as part of the European FP7 "Green City Car" project

Control performance on a thin panel with and without compensator

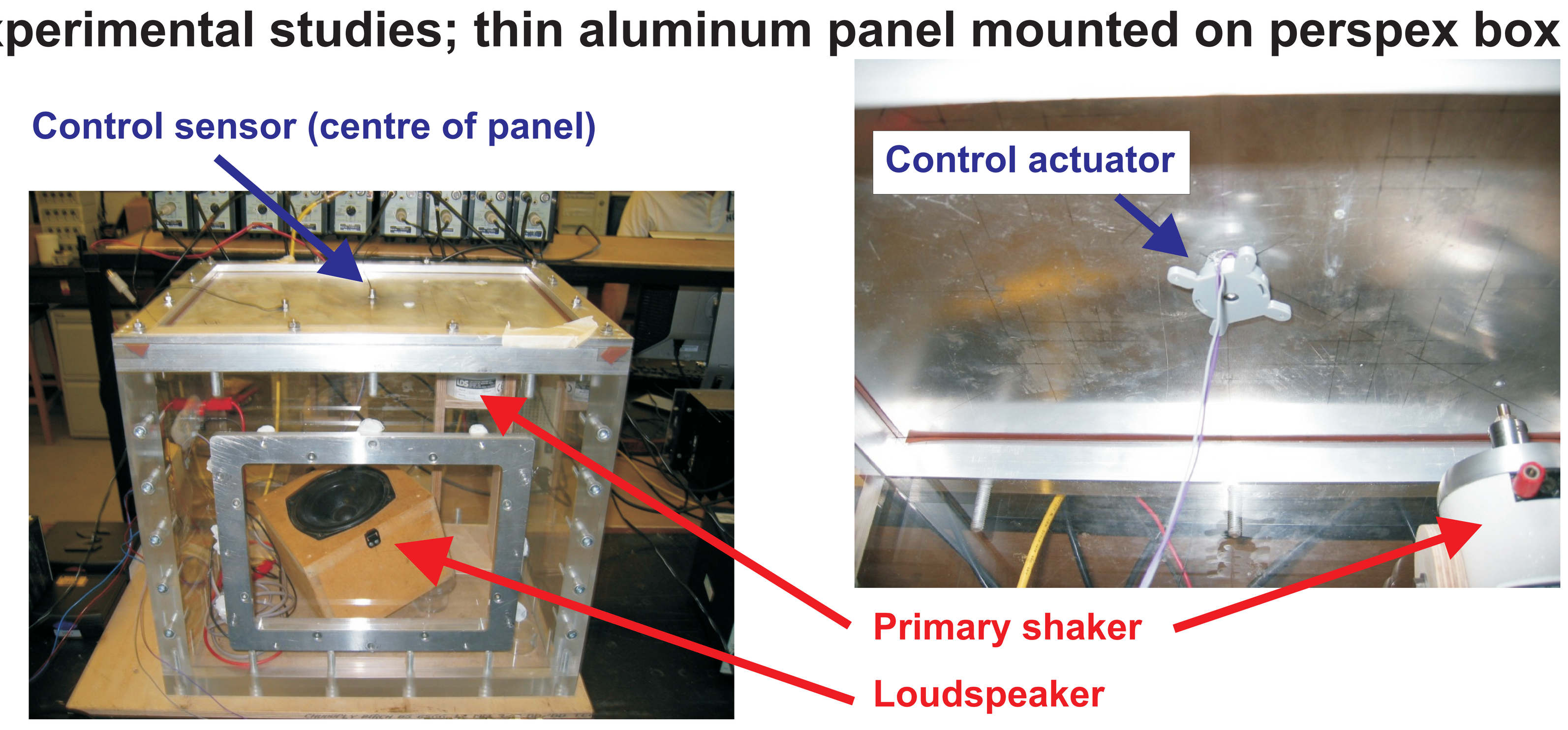


Robustness of compensation to variance in actuator natural frequency

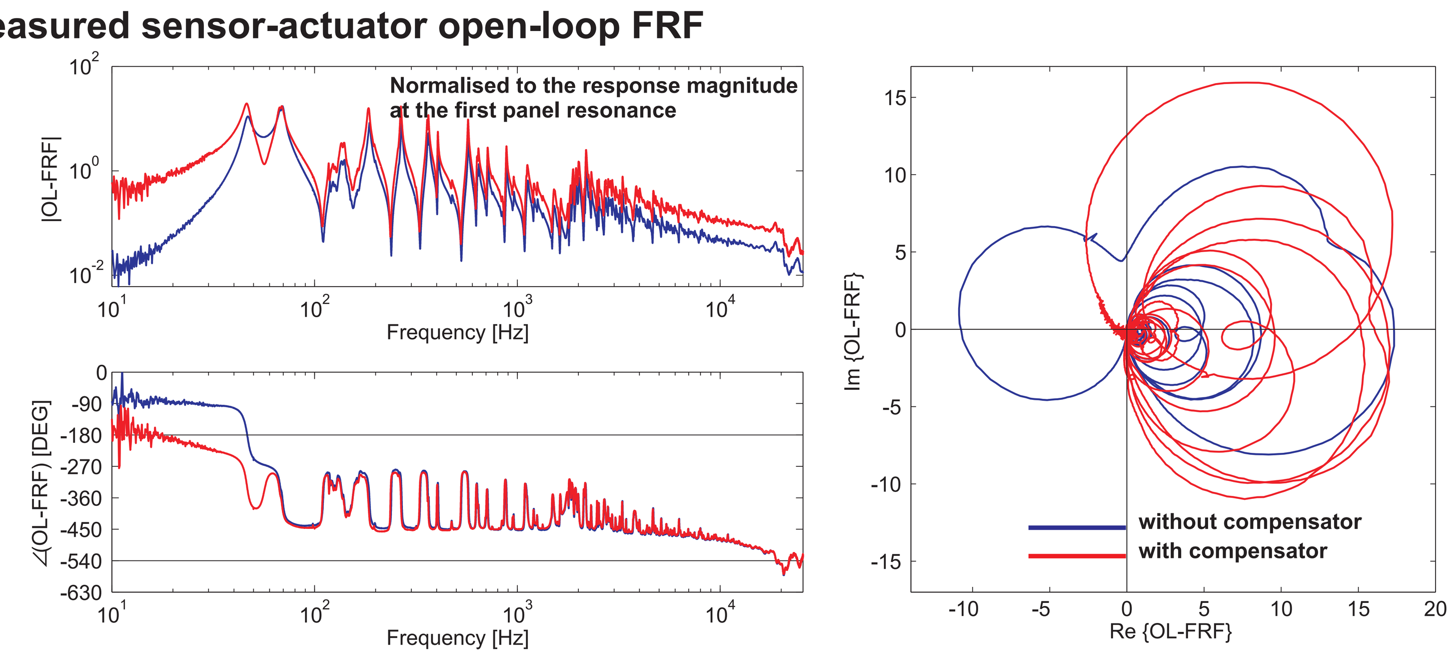


Compensation robust even for considerable variance in proof-mass suspension

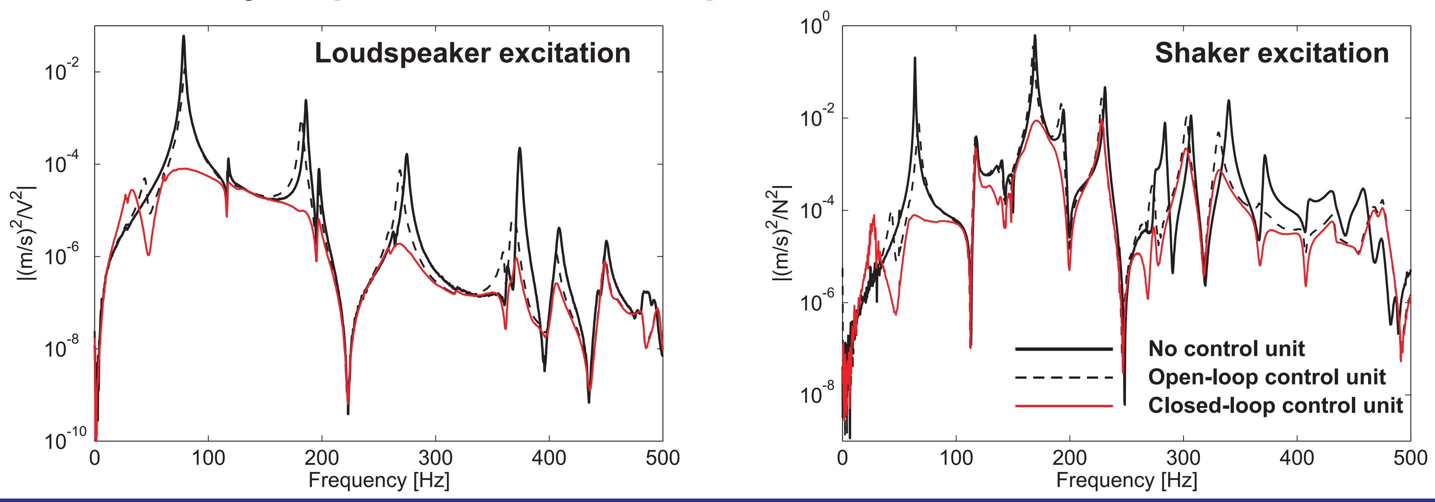
Experimental studies; thin aluminum panel mounted on perspex box



Measured sensor-actuator open-loop FRF



Measured velocity response at the control position



Conclusions

It has been demonstrated that a single degree of freedom electromechanical model can readily describe the feedback control unit in terms of its open- and closed-loop base impedance. The formulations presented allows for a straight-forward physical interpretation of both stability and control performance.

The actuator, taken from a vibration headset, satisfies three important criteria for practical feedback control applications (a) low weight, (b) mechanically robustness and (c) inexpensive commercial availability.

The closed-loop control unit without compensation, when mounted in the centre of a thin panel, shows only poor stability characteristics. This is because (a) the actuator has very little internal damping, and (b) because the actuators fundamental resonance frequency is close to the first resonance frequency of the panel.

It has been demonstrated that the control stability and performance can be significantly improved by implementing an appropriate compensation filter, directly derived from the base expressions for the control unit base impedance. The compensation filter fully compensates for the response peak in the actuator blocked force response and shifts the apparent resonance of the control unit down towards a new design frequency. The peak response at this design frequency can be effectively limited by implementing a high damping ratio.

The sensitivity/robustness of the compensation to manufacturing uncertainties were investigated by varying the actuator suspension stiffness (and damping ratio) while the compensation filter is fixed with respect to the nominal parameters. The results show that even for substantial variations in the actuator suspension parameters, the compensation filter provides significant improvement over the uncompensated case. One draw back of the presented compensator design is the enhancement of the feedback signal for frequencies below the compensator design frequency, a problem which may be overcome by implementing an additional high pass filter with a low cutoff frequency.