Mechanical Systems and Signal Processing 117 (2019) 689–708

Contents lists available at ScienceDirect

Mechanical Systems and Signal Processing

journal homepage: www.elsevier.com/locate/ymssp

Local tuning and power requirements of a multi-input multi-output decentralised velocity feedback with inertial actuators

Stefano Camperi *, Maryam Ghandchi Tehrani, Stephen J. Elliott

Institute of Sound and Vibration Research, Highfield, Southampton SO171BJ, UK

ARTICLE INFO

Article history:
Received 15 May 2018
Received in revised form 27 July 2018
Accepted 1 August 2018
Available online 22 August 2018

Keywords:
Local tuning
Decentralised
Power
Inertial actuator
Velocity feedback

ABSTRACT

This paper discusses the tuning of multiple decentralised velocity feedback units for broadband vibration control on a plate using inertial actuators. An analysis of the performance is presented in terms of maximising the mechanical power absorbed and of the control effort, defined by the electrical power in the control units, and the results are validated numerically. Two inertial actuators are mounted on an experimental plate, and driven with control currents proportional to the measured local velocities of the plate, collocated with the actuators. Tuning is compared by using either the measurement of kinetic energy of the plate, or the mechanical power absorbed by the control units from the plate. It is found that the mechanical power absorbed can be used as a local cost function to tune the control units, as an alternative to the kinetic energy, not only when reactive actuators are used, but also when inertial actuators are in use. In this way, the tuning process is greatly simplified, since the mechanical power absorbed can be measured directly from the feedback velocity signal and a knowledge of the actuators dynamics, without further information on the plate dynamics. The optimal gain for each unit is found to be reasonably independent of the gain implemented on the other unit. This implies that the system is robust against failure of a unit, since the other would still be optimally tuned. However, this tuning process depends on many factors, such as the type, position and number of control units implemented, and a comparison between different active control solutions, with respect to the optimal feedback gains only is not practical. For this reason, the measure of the electrical power, required by the control system, is suggested as a direct estimation of the control effort. To give an example of the proposed approach, the performance of the two control units is compared with the case in which only one unit at the time is active. The two-channel architecture is found not only to outperform the single-channel one in terms of vibration reduction, but also in terms of consumed electrical power. When the two channels are active, more than 8 dB broadband reduction is measured, and the consumed electrical power is found to be similar to the one consumed when only one unit is operating, which is optimally tuned.

1. Introduction

This paper presents the local tuning of a decentralised feedback control system, for vibration control of a plate, in terms of the mechanical power absorbed by the control units, and the electrical power supplied. Experimental results, which are

* Corresponding author.
E-mail address: s.camperi@soton.ac.uk (S. Camperi).

https://doi.org/10.1016/j.ymssp.2018.08.002
0888-3270/

validated by numerical simulations, demonstrate the local tuning of the velocity feedback units through power absorption maximisation for a two-channel control system. Moreover, the results obtained are contrasted with the minimisation of the global vibration level; and the electrical power, required by the two units, is investigated as a measure of the control effort of the control system.

In active structural control, the design of the controller is a crucial part, as it defines how the actuators are driven, according to the information from the sensors. This is often posed in terms of optimising certain control objectives with respect to specific constraints. In the case of vibration control of lightweight plates with low internal damping, the control objective is usually expressed as the minimisation of the global vibration level, and is quantified by its kinetic energy, for example. The constraint, on the other hand, is the minimisation of the implementation costs, as well as the computational requirements.

In fully centralised architectures, the information from the sensors converges to a single controller. The kinetic energy can be easily estimated, and very effective control laws can be implemented to target specific modes [1], or to design an internal model control [2]. However, this solution can be expensive because of cabling and implementation, since many sensors are required to be connected to the central controller. In addition, the complexity of the control law, as well as the data processing at each time sample, is computationally demanding. Finally, the control system is not robust to the failure of each sensor, and the mismatch between the controller model and the actual plant may lead to an increase in the level of vibration.

For the aforementioned reasons, several papers [3–5] have focused on moving towards decentralised architectures, in which part of the control action is carried out by sub-controllers, which operates locally. An example of this approach is the high-authority/low-authority control (HAC/LAC) system, in which the low-authority controller adds active damping through a simple local velocity feedback, and the high-authority controller accounts for the global behaviour of the structure [6].

In the extreme case, a fully decentralised control system can be thought, in which independent control units, consisting of a collocated sensor and actuator, act independently on the plate [5,7–10]. This is a rather appealing architecture, since it enables the design of a robust control system based upon self-contained modular units, where the complexity of the control design does not scale with the number of units implemented.

There are some concerns, though, on the performance of a fully decentralised architecture. In this regard, Baumann et al. [3] have shown that in some cases a fully decentralised velocity feedback control system can provide a global reduction of the kinetic energy comparable with the one obtained from a fully centralised control system. This result suggested that vibration reduction can be obtained by introducing active damping with local velocity feedback units, which are robust and can be implemented in a decentralised arrangement.

The challenge in this solution is the tuning of the control units, in order to determine the feedback gains. Although the minimisation of the kinetic energy guarantees a global reduction of vibration, a large number of sensors is required to obtain an accurate estimation of the kinetic energy. This poses a limit in terms of costs for the control system, as well as in terms of the design of a decentralised control system. On the other hand, the minimisation of the local velocity of the plate at the control position can converge to a pinning condition [9], in which the local velocity of the plate tends to zero, but the global vibration is not minimised.

In order to perform the tuning of the control unit locally, Zilletti et al. [9] considered the local mechanical power absorbed by the control unit from the structure with ideal force actuators, and showed that it almost corresponds to the minimisation of the kinetic energy [9,11].

Previous studies [9,11] have investigated the reduction of kinetic energy and the mechanical power absorbed with respect to the velocity feedback gains, when two control units with reactive actuators are implemented. Although this control system is unconditionally stable, the reactive actuators require an external support to react off, which may be impractical for real applications.

In this work, inertial actuators are considered, and their dynamic behaviour is taken into account to assess the conditional stability of the control system. This is due to the phase shift of the control force generated by an inertial actuator below its first natural frequency. In the literature, several methods have been suggested to improve the stability of a direct velocity feedback with inertial actuators. Examples of these studies include inerter elements [12] and compensator filters [13] to lower the natural frequency of the inertial actuator. Other studies focused on making the control system perfectly collocated by introducing a pair of poles and zeros in the open-loop transfer function by adding a feed-through term to the feedback loop [14] or an additional filter [15]. However, in this study it is shown that, if a suitable inertial actuator is used, with high internal damping and a low natural frequency, the global level of vibration of a plate can be minimised with a simple direct velocity feedback.

In this paper, the tuning of a decentralised velocity feedback control system with two control units is extended to the case in which inertial actuators are used. The dynamic behaviour of each inertial actuator is described in terms of their electrical and mechanical impedances, with respect to the base velocity at the control position on the plate, and to the control current. This enables us to estimate the mechanical and electrical power absorbed by each unit, directly from the velocity signal and a model of the inertial actuators only.

Moreover, the analysis of the kinetic energy with respect to the feedback gains is suitable for the tuning of the control units, but having some drawbacks. First, it does not contain information about the control effort, since it does not directly relate to the feedback gains. Second, this approach is not suitable for the implementation of additional control units, and it does not allow comparison between different types of actuators, or control positions.

The novelty of this work is to measure the reduction of kinetic energy of the plate with respect to the electrical power consumed by the control system, rather than to the feedback gains. The advantage of this approach is that different solutions