Smart materials

15-415

THESIS ON DAMPENING OF STRUCTURES USING ACTIVE CONTROL

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ABSTRACT

In engineering practice, vibrations in structures are undesired. It is favourable to suppress these vibrations. The conventional way to do this, is to add mass to a structure. An alternative method to reduce vibrations is to use active control. In this thesis the dampening of a clamped aluminium beam is analysed. Two methods of dampening of clamped beams are investigated. Firstly, a beam of 13 millimetres thick is dampened without external actuation. This is called passive control. Secondly, a beam of 3 millimetres thick is dampened using active control. Active control is realized by using a position sensor and an actuating piezo element. The outcome of this thesis is that an actively controlled beam of 3 millimetres thick (mass 0.26 kg) results in the same settling time as a passively controlled beam of 13 millimetres thick (mass 1.12 kg). This constitutes a mass reduction of 77%.

1. INTRODUCTION

The rotor blades of windmills are less efficient when they are vibrating due to the forces of the wind. Helicopter rotor blades, ski's and wafer stages (high-precision-positioning in lithography machines) have to deal with the same type of problems. In engineering practice, many systems have to deal with similar undesirable vibrations.

Because of the problems described above, it is sometimes necessary to reduce these vibrations. There are different ways to achieve this. In this thesis, two ways of control are investigated, specifically damping solely by increasing mass, and damping using active control and piezo elements.

A piezo element deforms when a voltage is applied (*figure 1*). When a mechanical load is applied on a piezo element it deforms and generates a voltage as well. So a piezo element is able to work in two opposite ways (actuating or sensing).[1]

Thus, mass reduction is possible when making use of active control, while maintaining the same damping. The quantity of measure for damping is settling time, the time it takes to reduce an initial disturbance to within a certain margin.

Due to an initial disturbance, a system starts to vibrate in a superposition of its Eigen frequencies. All systems have an infinite number of Eigen frequencies. Every Eigen frequency has its own Eigen mode.[2] Because of the small amplitude of higher frequencies, only the first few should be considered.

When making use of active control, a desired condition, the reference input signal, is applied to a system. This is done by comparing the output signal (e.g. the position of a robot arm) with the reference input signal. Based on the difference between both signals a controller adjusts the loop gain to reach the desired condition.[3]

Lots of constructions are very complex by geometry, however there is one important thing that these constructions have in common: all geometries have Eigen frequencies and Eigen modes when they resonate. In this thesis the dampening of vibrations in an aluminium clamped beam is examined. Like all geometries a clamped beam can be modelled as a state space system. The mechanical behaviour of a beam resembles the behaviour of more complex systems, but it has fewer states, so it is easier to analyse.[4] In the active control setup the beam has got the following geometrical dimensions: 800 x 40 x 3 millimetres (length x height x thickness). The passively controlled beam has the same dimensions, except for the thickness which is 13 millimetres.

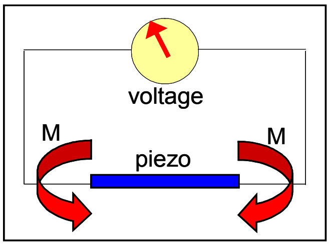

Figure 1: piezo element

Based on the simulation, the hypothesis can be stated in the following manner:

Hypothesis:

The actively controlled beam of 3 millimetres thick (*figure 2a*) has the same settling time (5.1 seconds) as the passively controlled beam of 13 millimetres thick (*figure 2b*).

The following piezo actuator is used: PZT P-151.05H 35 x 35 x 0.5 millimetres.[5]

The piezo actuator is positioned near the clamped end of the beam. The position sensor is placed 250 mm from the loose end of the beam (see Method).

In this study settling time is defined as the time it takes for an initial force disturbance of 24 Newton to be reduced to within 1 millimetre of the equilibrium position.

Mass is varied by the beam thickness.

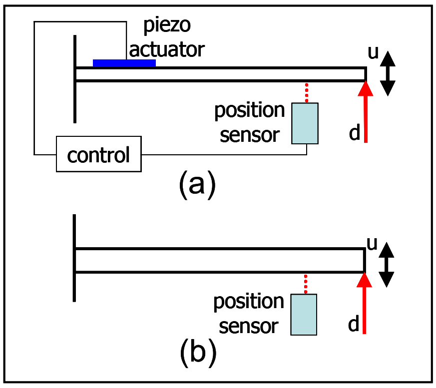

Figure 2: experimental setup with: active control (a), passive control (b)

2. METHOD

Using MATLAB, a state space model was developed. In this model, beam dynamics and piezoelectric effects are combined. Formula 1 shows the relation between beam dynamics and the voltage applied to the actuator piezo. Making use of the boundary conditions and the initial condition, an expression for the shape (U_i) of the i^{th} Eigen mode is derived (*formula 2*). The following parameters are used: E (Young's modulus of aluminium), I (moment of inertia of the beam), u (displacement), (maρdensity of aluminium), A (cross section of the beam), K (combined stiffness of the beam and the piezo actuator), x_1 and

$$EI\frac{\partial^4 u(x,t)}{\partial x^4}+\rho A\frac{\partial^2 u(x,t)}{\partial t^2}=K\frac{\partial}{\partial x}\left(\partial(x-x_1)-\partial(x-x_2)\right)V(t) \qquad (1)$$

$$u(0,t)=0 \qquad \left.\frac{\partial u(x,t)}{\partial x}\right|_{x=0}=0$$

$$\left.\frac{\partial^2 u(x,t)}{\partial x^2}\right|_{x=l}=0 \qquad \left.\frac{\partial^3 u(x,t)}{\partial x^3}\right|_{x=l}=0$$

$$U_i(x)=C_1\left(-\cos(\lambda_i x)+\cosh(\lambda_i x)-C_2\left(\sin(\lambda_i x)-\sinh(\lambda_i x)\right)\right) \qquad (2)$$

x_2 (the begin and end position of the piezo actuator), l (the length of the beam), λ_i (i^{th} Eigen value). C1 and C2 are constants. The variables x and t are, respectively, the distance from the clamped end of the beam and the time measured in seconds.

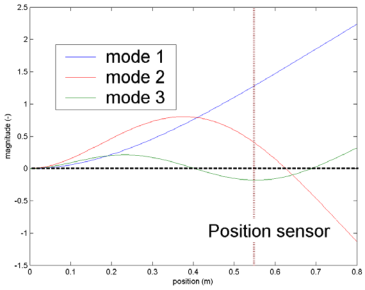

Figure 3: location of position sensor

To complete the simulation, system identification of the experimental setup was done by applying a white noise signal. The identification showed that only the first three Eigen modes are of importance. Therefore, the controller has been designed to suppress these three modes.

To control the first three Eigen modes, it is preferable to place the position sensor at such a location that the nodes of each of these Eigen modes are as distant as possible (*figure 3*). This way, the vibration of the beam can be measured in order to distinguish the first three modes from each other.

The two forms of control, passive and active, are implemented in an experimental setup, as shown in *figure 1*. Using a Lorenz actuator an initial force of 24 Newton is applied on the tip of the beam. DSPACE takes care of communication between the actuating piezo, the Lorenz actuator and the position sensor. In this setup, the controller and feedback loop from the simulation are used. The sampling frequency is set to 10 kHz. After the initial force, the deviation of the equilibrium position is measured.

3. RESULTS

The outcomes of the simulation and the experiments are presented in *figures 4, 5* and *6*. Simulation shows that an actively controlled beam of just 3 millimetres thick results in the same settling time (5.1 seconds) as a passively controlled beam of 13 millimetres thick does (*figure 4*). In the experiments, this hypothesis is investigated by testing an actively controlled beam of 3 millimetres thick (*figure 5*) and a passively controlled beam of 13 millimetres thick (*figure 6*).

4. DISCUSSION AND CONCLUSIONS

When 23% of the mass of the original beam (13 millimetres thick) is used, the original settling time (5.1 seconds) can be maintained. This is done by using active control.

However, this does not prove that a mass reduction of 77% is applicable for all geometries of clamped beams or for other geometries. On the other hand, reviewing the results, it is very likely that generally a large amount (over 50%) of mass reduction is possible when using active control.

For the examples stated earlier (see Introduction), rotor blades of wind mills, helicopter rotor blades, ski's and wafer stages, the outcome of this study gives useful insights. The examined beams have a geometry that resembles, among other things, the geometry of a rotor blade of a wind mill.

There are still some differences between this thesis on a clamped beam and other structures. The disturbance could be a varying influence instead of just being an initial force. Secondly, more complex geometries have to cope with more dominant Eigen modes, resulting in more complex controllers. Nevertheless, like all structures, they can be modelled as a state space model. This makes it possible to control vibrations using piezo elements and reduce mass.

The experiments are repeated 30 times and a correlation is determined to be at least 0.98, which means a high reliability of the experimental setup. During the experiments the effects of external noise (e.g. temperature, sound and humidity) were attempted to be kept to a minimum. By comparing the simulation results with the experimental results, it was determined that accuracy was high, measured errors were in the 0.1% range.

5. RECOMMENDATIONS

The scope of this study was on comparing passive and active control, to gain insight in the possibilities of mass reduction. Further research can be done. The following aspects might be interesting to examine:

- the effect of using collocated sensor and actuator piezo elements on the control performance;
- the effect of using more actuating piezo elements on the control performance;
- the possible mass reduction of other (more complex) geometries using active control;
- possibilities of mass reduction using active control in case of continuously varying disturbance (e.g. time varying force);
- comparing the damping performance of active control with composites and exotic materials like Glare®;
- testing the effect of piezo elements in applications in engineering practice (e.g. wind mill rotor blades).

6. REFERENCES

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[3] G.F. Franklin e.a., Feedback Control of Dynamic Systems, Prentice Hall, 2002

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[5] http://www.piceramic.de

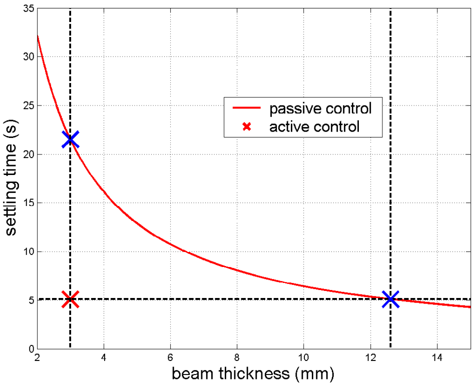

Figure 4: simulation results

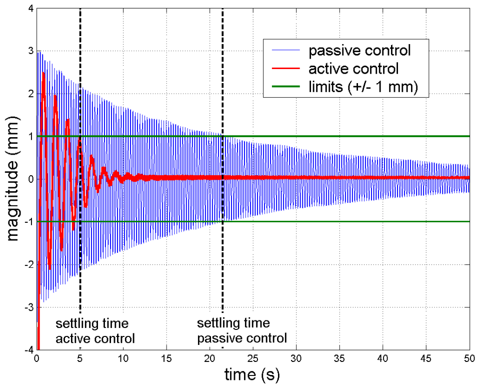

Figure 5: experimental results (thickness 3 mm)

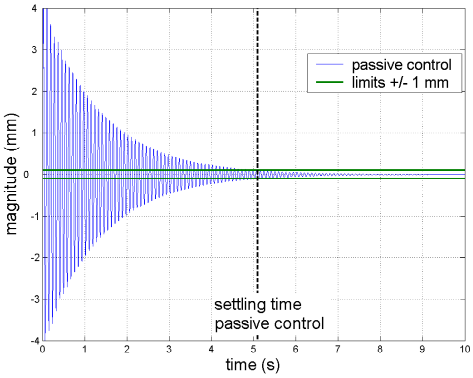

Figure 6: experimental results (thickness 13 mm)