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EXPERIMENTS WITH THE ACTIVE VIBRATION CONTROL OF A CANTILEVER BEAM

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Abstract. *The paper deals with a laboratory test rig for demonstration of the efficiency of active vibration control of a cantilever beam. The configuration of the actuator and sensor pair is non-collocated. Vibration of the beam is sensed at its free end while the actuator acts near to the clamped beam end perpendicularly to the beam axis. The beam is mounted in an aluminium frame in the vertical position. The vibration of the beam is excited by an electrodynamic exciter. The source of vibration is a moving mass of the exciter. Vibrations are transferred through the rig frame to the clamped beam. The frequency of the first vibration mode of the cantilever beam is equal to 17 Hz. The exciter vibrates at the same frequency as the first mode frequency therefore it can be observed significant vibration of the beam's end. These vibrations can be reduced by the active vibration control system. The vibration of the cantilever beam's free end is measured by the laser sensor for deflection, system dSPACE works as a controller. The controller output voltage is amplified and then supplies the linear stack piezoactuator.*

1 INTRODUCTION

Vibration damping can be achieved by several manners. Damping systems can be divided into two general categories – active and passive vibration control. Passive damping uses components as rubber dampers, springs, additional masses and their combinations to suppress vibrations of mechanical structures. Majority of problems can be solved using these elements and it can be observed on many buildings, bridges, machines and other structures [1].

The active vibration control systems, which consist of actuators, sensors and control algorithms is getting more popular. In some applications the active vibration control is more effective. These systems can be seen on modern buildings, especially skyscrapers in the tectonic active areas, where buildings have to be protected against an earthquake excitation. Buildings should be elastic to protect against earthquakes, but on the other hand, buildings must be resistant to wind excitation, which is a long-period harmonic force and the building structure must be also rigid. The active control is used in these complicated situations very often.

This paper will introduce a laboratory model of the cantilever beam, its excitation and active vibration control with a non-collocated configuration. The use of the stack piezoactuator is one of the most interesting things on this rig.

2 LABORATORY MODEL

2.1 Frame and beam

The laboratory model consists of an aluminium frame. The cantilever beam is made of steel and its dimension is of 500 x 40 x 5 mm. The stack piezoactuator is fastened as near as possible to the clamped end of the cantilever beam. The displacement of the free end of the cantilever beam is measured by the triangulation laser sensor [2].

The configuration of the system is non-collocated, because the actuator's force acts and the displacement is measured in different points of the structure [3].

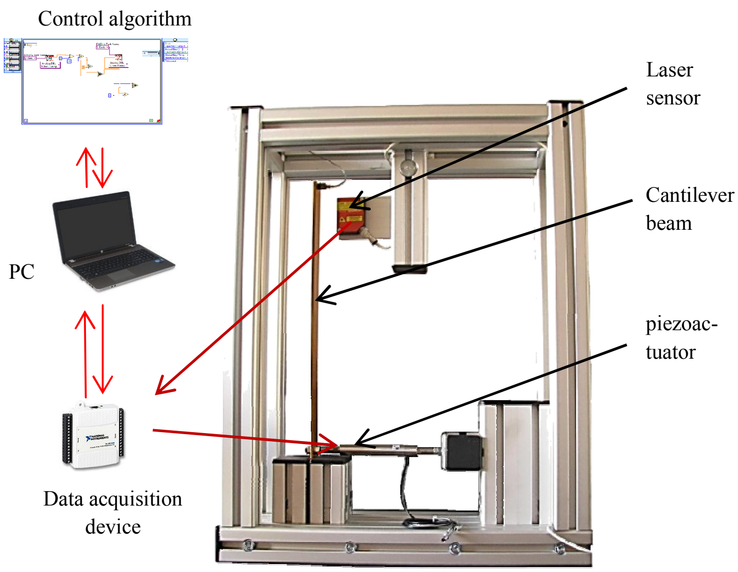

Figure 1: Laboratory model of cantilever beam.

The next equation describes vibration behaviour of the beam [4]:

$$\cos\lambda\cosh\lambda + 1 = 0 \tag{1}$$

λ_n are roots of this equation and these are as follows:

$$\lambda_1 = 0{,}5968\pi$$
$$\lambda_1 = 1{,}4942\pi \qquad (2)$$
$$\lambda_n = \left(n - \frac{1}{2}\right)\pi; \quad n = 3,4,\dots,\infty$$

Then, natural frequencies are:

$$f_n = \frac{\lambda_n^2}{2\pi l^2}\sqrt{\frac{EJ}{\rho S}} \qquad (3)$$

where the Young modulus for steel is as follows:

$$E = 2{,}1 \cdot 10^{11}\ \mathrm{Pa} \qquad (4)$$

Moment of rectangular cross section area:

$$J = \frac{b \cdot h^3}{12} \qquad (5)$$

Density of steel is considered to be equal to

$$\rho = 7850\ \mathrm{kg \cdot m^{-3}} \qquad (6)$$

and S is a cross section area of the beam.

The first seven solutions of equation (3) are as follows: $f_1 = 16{,}84\ \mathrm{Hz}$, $f_2 = 105{,}57\ \mathrm{Hz}$, $f_3 = 295{,}53\ \mathrm{Hz}$, $f_4 = 579{,}23\ \mathrm{Hz}$, $f_5 = 957{,}50\ \mathrm{Hz}$, $f_6 = 1430{,}35\ \mathrm{Hz}$, $f_7 = 1997{,}75\ \mathrm{Hz}$

These results were experimentally verified by measuring the frequency response function:

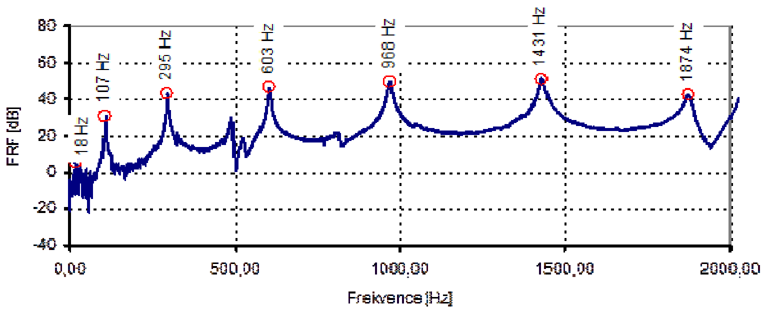

Figure 2: Frequency response function of the cantilever beam.

2.2 Sensor

The laser sensor Micro-Epsilon ILD 1300-20 uses the triangulation principle. The measurement range is of 20 mm. The sensor has a standard current output, which is then transformed into 1÷5 V range by an output circuit. The internal sampling rate of this sensor is of 500 Hz.

Figure 3: Laser sensor Micro-Epsilon ILD 1300-20.

2.3 Piezoactuator

The Piezoactuator Physical Instrumente of the P-845.60 type has the travel range of 90 µm and is able to produce 3000 N in push direction and 700 N in pull direction.

Figure 4: Piezoactuator Physical Instrumente PI P-845.60.

The piezoactuator is controled by variable voltage of the 0÷10 V range. This voltage is then amplified to -20÷120 V in the amplifier and this voltage powers the piezoactuator.

Figure 5: Amplifier E-500.00.

3 CONTROL LOOP

3.1 Data acquisition device

The multifunction card of the NI USB 6008 type includes 8 analogue and 12 digital inputs. The sampling rate is of 10 $kS \cdot s^{-1}$, but the sampling frequency of the analog output is only of

150 S·s^{-1}. The natural frequency of the first vibration mode is equal to 17 Hz, so this device enables to suppress this mode of vibration. The data acquisition device is connected to the PC via an USB port.

Figure 6: Data acquisition device NI USB 6008.

3.2 Control algorithm

The cantilever beam is stabilized by proportional feedback control. The control algorithm is programmed in the LabView environment:

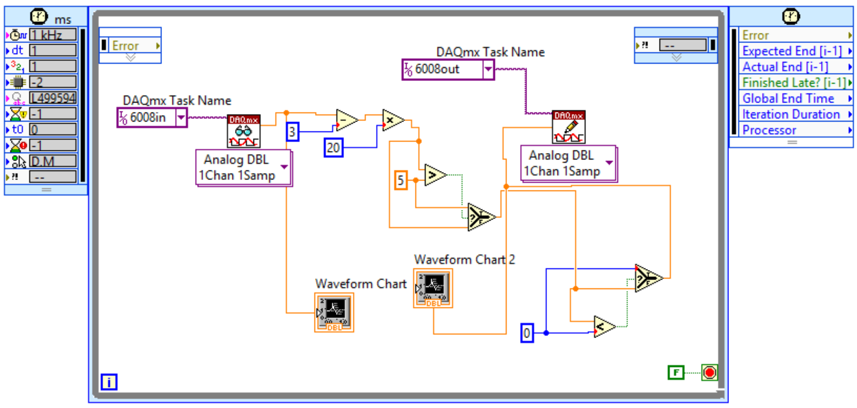

Figure 7: Control algorithm for active vibration control.

System dSPACE programmed in Simulink can be used alternatively.

4 RESULTS

The efficiency of the control algorithm is evaluated on the physical model. Time captures of the beam's decaying vibration without and with the active vibration control is shown in the next two figures. The active vibration control stabilises the beam eight times faster than without the active vibration control.

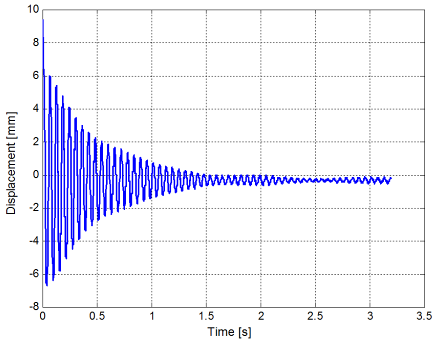

Figure 8: Natural decaying of the cantilever beam.

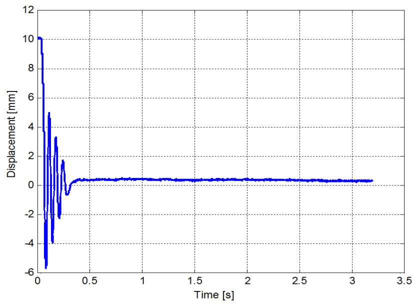

Figure 9: Decaying with the active control

5 MODEL WITH EXCITATION

This test rig can be modified by adding an electrodynamics' exciter. This enables to demonstrate the resonant frequency and the efficiency of the active vibration control.

Figure 10: Model equipped with electrodynamic exciter

6 CONCLUSIONS

- The test rig consists of the frame, beam, piezoactuator and laser sensor.
- The laboratory test rig was designed to visualize the efficiency of the active vibration control.
- The use of the piezoactuator is unusual, but very effective.
- The control algorithm is based on the proportional feedback
- The test rig can be equipped with the exciter.

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REFERENCES

[1] GERB, Schwingungsisolierungen GmbH & Co KG., *Vibration Isolation Systems*,10. ed. Germany, 2007.

[2] Šuránek, P. *Active Vibration Control*: Diploma Thesis. Ostrava: VŠB – Technical University Ostrava, University study programmes, Department of Control Systems and Instrumentation, 2012, 49 p. Thesis head: Tůma, J.

[3] Preumont, A. & Seto K., *Active control of structures*. New York: WILEY, 2008, 296 p. ISBN 978-0-470-03393-7.

[4] Juliš, K. & Brepta, R., *Mechanika II.díl –Dynamika (Mechanics vol. II – Dynamics)* 1. vyd. Praha: SNTL, 1987. 687 s.