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ACTIVE CONTROL OF BEAMS UNDER A MOVING LOAD

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The passive and active control of the beam structures subjected to a travelling load is discussed in the paper. Passive vibration absorbers are insufficient for long lasting wave problems. The active control performed by actuators has also disadvantages. In the paper generalization of the problem of control performed by actuators to cover the case of the control performed by damping elements is presented. The results of numerical simulation prove efficiency of the approach.

Key words: active control, moving load, damping

1. Introduction

Lightweight structures have been intensively investigated in recent years. Optimal design with low weight criterion is insufficient in the case of dynamic behavior of the structure. There are some approaches to the decrease of vibration level.

- Passive vibration absorbers – the idea is performed by means of dynamic vibration absorbers as a set of additional masses flexibly attached to the main system. Both transverse and rotational types of absorbers can be applied. The out of phase vibration of dynamic absorbers results in elimination of vibration of the structure.
- Active control – the control forces are generated by electric actuators imposed on the tendons or on a stiff cantilever fixed to the end of the

beam (Frischgesell et al., 1998; Reckmann et al., 1998). Actuators can generate both transverse control force and bending moment. It allows for control of the predominant lowest vibration modes of the beam whereas the piezo-electric actuators are used to control higher ones. The possibility of unstable behavior in the case of improper design is a disadvantage of such a solution.

- Semi-active damping – the control of the damping of viscous dampers installed in the structure (Onoda and Minesugi, 1996). The span of the beam is supported by viscous dampers. They can be attached to a rigid foundation or hanged on a system of tendons. The damping properties are changed according to the position of the traveling load or other, more complex observation of the beam response. Such a control is always stable.

In the middle of the 1990s the research on the active control of king-post structure subjected to a moving inertial load was initiated. Within the framework of the Polish-German Research Project DFG-PAN coordinated by the first author of this paper and prof. Karl Popp from the Institute of Mechanics of the University of Hanover several publications were elaborated (Bogacz and Czolc, 1996; Bajer et al., 2000). The present research presents a generalization of the problem of control performed by actuators to cover the case of the control performed by damping elements.

Although the idea of passive vibration absorbers was well known in the machine industry and visible implementation could even be found in sport equipment as bows, skis or tennis rackets, the application to civil engineering structures is of minor importance. The reason was that the absorbers can not accumulate vibration for a longer time. That is why in the global count vibration absorbers (passive dampers) were not as promising as active dampers. The problems of actively controlled vibration were investigated by Frischgesell et al. (1994, 1999). The beam was subjected in the middle of the span to the force generated by actuators. Both the open loop and closed loop control were tested. However, the system of actuators seems to be poorly performed, since large forces are required in real cases.

More efficient displacement decrease of the moving vehicle or beam structure can be achieved by the use of semi-active or active dampers. From the practical point of view the arrangement in which we propose to change the damping parameters is much more efficient when using actuators. What is more, the dampers do not require power supply as high as in the case of actuators.

In this paper we consider the beam supported at two points by dampers (Fig.1). Their position should be selected depending on the parameters of the moving mass system. In the first step we choose the support positions to minimize the vertical displacement of the mass in the case when both dampers are acting during the time of mass-beam interaction. It allows us to determine the position of dampers acting in the structure. Later on we are looking for the range of activity of each damper. Generally the damping parameters can be modified as a continuous function of time, passed distance, vertical displacement or velocity of the mass, or dampers can be controlled by discrete functions depending on some of such arguments. In this paper we shall use the discrete control of the damping parameters. Further tests allow for determination of an optimal location of dampers.

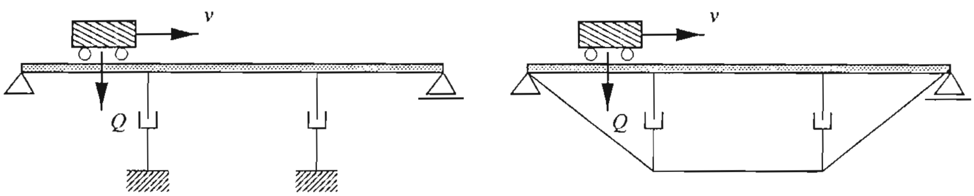

Fig. 1. Schemes of the damped beam: dampers supported by the foundation (left) or supported on tendons (right)

2. Mechanical model

We consider the Euler type of the beam. Let L be the length of the beam, x_1 and x_2 positions of damping supports with the coefficients c_1 and c_2, respectively, v stands for the velocity of the traveling mass m and EI represents the rigidity of the beam. The motion of the beam is described by the following equation

$$EI\frac{\partial^4 w(x,t)}{\partial x^4} + \rho A\frac{\partial^2 w(x,t)}{\partial t^2} = q(x,t) \tag{2.1}$$

where

$$q(x,t) = \delta(x-vt)m\Big(g - \frac{\partial^2 w(x,t)}{\partial t^2}\Big)\Big|_{x=vt} - c_1\frac{\partial w(x_1,t)}{\partial t} - c_2\frac{\partial w(x_2,t)}{\partial t} \tag{2.2}$$

δ – Dirac function

g – gravitational acceleration.

For the simply supported beam we investigate the structure with the following boundary and initial conditions

$$
\begin{aligned}
& w(0,t) = 0 && w(l,t) = 0 \\
& \frac{\partial^2 w(x,t)}{\partial x^2}\Big|_{x=0} = 0 && \frac{\partial^2 w(x,t)}{\partial x^2}\Big|_{x=L} = 0 \\
& w(x,0) = 0 && \frac{\partial w(x,0)}{\partial t}\Big|_{t=0} = 0
\end{aligned}
\tag{2.3}
$$

The problem is solved by the use of finite element method with the Newmark time integration scheme.

3. Results

A precise control of the vibration is a complex task. Several factors must be taken into account, first of all the velocity of the mass. Even in the case of fixed problem parameters our experiences show high sensitivity of the response to the activity of dampers. Generally, we react to a vertical displacement of the mass by switching on and off the dampers. Thus, we can reduce the range of displacement on the forthcoming segment. However, in the same time the shock type of disturbance introduces higher modes of vibration, with a significant amplitude. Successive control actions complicate the displacement diagram when the mass arrives to the end of the beam and makes further decisions difficult.

In our tests we assume the velocity of the moving mass equal to 0.3 of the critical velocity

$$\alpha = \frac{v\pi}{L}\sqrt{\frac{\rho A}{EI}}$$

In the first test we assumed a symmetric position of viscous dampers. The lengths of segments are: 64, 72, 64 cm. In such a case amplitudes of the mass are almost constant over the span (Fig.2). The dotted line shows displacements in the case when only the left or right damper is active. We must emphasize that the deflection of the beam under the moving mass without dampers is equal to 0.53. The plot of the deformed beam in time in the case of presence of both dampers is presented in Fig.3.

In the projection we can notice a strong influence of dampers for $c_{1/2} = 500$. To study the response of the system we apply damping in selected regions (Fig.4).

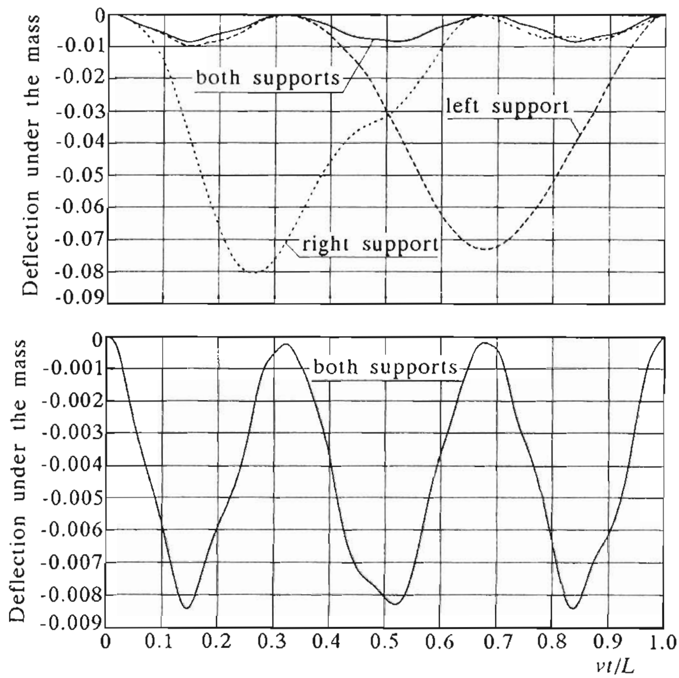

Fig. 2. Vertical displacement of the mass in the case of a single support and in the case of both supports active

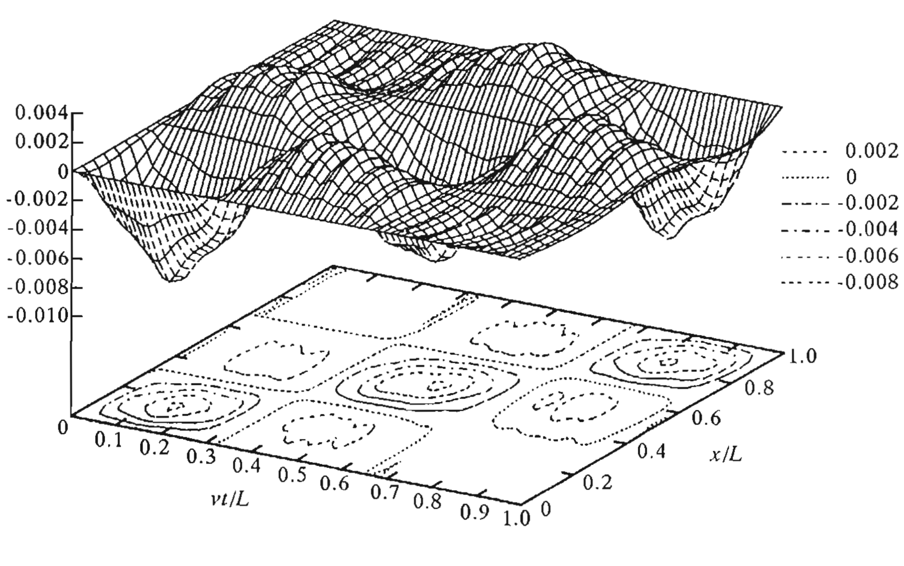

Fig. 3. Deformed beam in time (both dampers active)

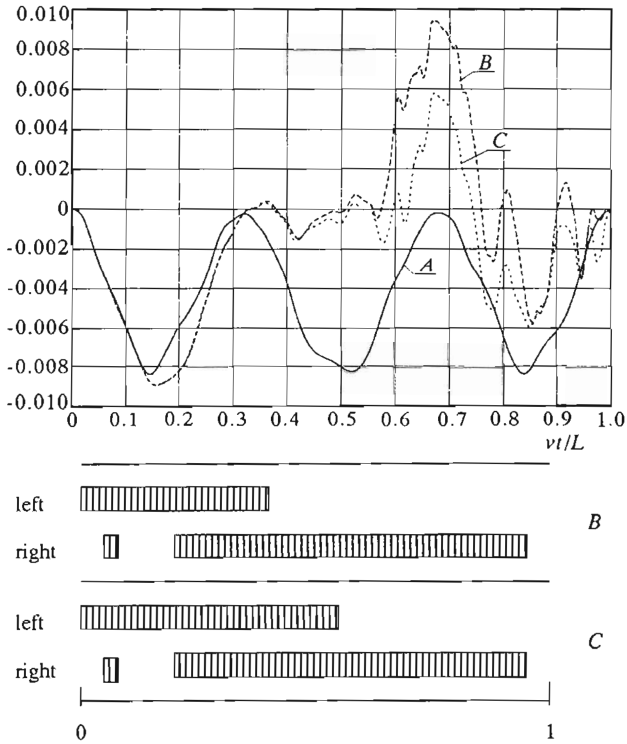

Fig. 4. Displacement of the mass in the case of uniform oscillations with both dampers and the control diagrams

A strong increase in the mass displacement is observed starting from the 1/3 of the beam length. The control scheme was chosen on the base of numerical experiences. The control performed by the jump switching results in relatively high displacement above the neutral axis line (case B). In practice we expect less strong switching and the diagram of the control will be a set of trapeziums. In such a case we can look for the results when the damping action is reduced in some zones. Line C shows the case when the gap in the control diagram has a form of steps. We notice a considerable decrease of the elevation of amplitude.

From the first test on active control of the system the following conclusion can be drawn. The first oscillation (of the three) is poorly damped. In the second test we place the dampers asymmetrically to obtain a lower first amplitude with both dampers active. Fig.5 shows the results for permanently damped systems ($L_1 = 56\,\mathrm{cm}$, $L_2 = 82\,\mathrm{cm}$, $L_3 = 62\,\mathrm{cm}$) and two selected schemes of the control (lines B and C).

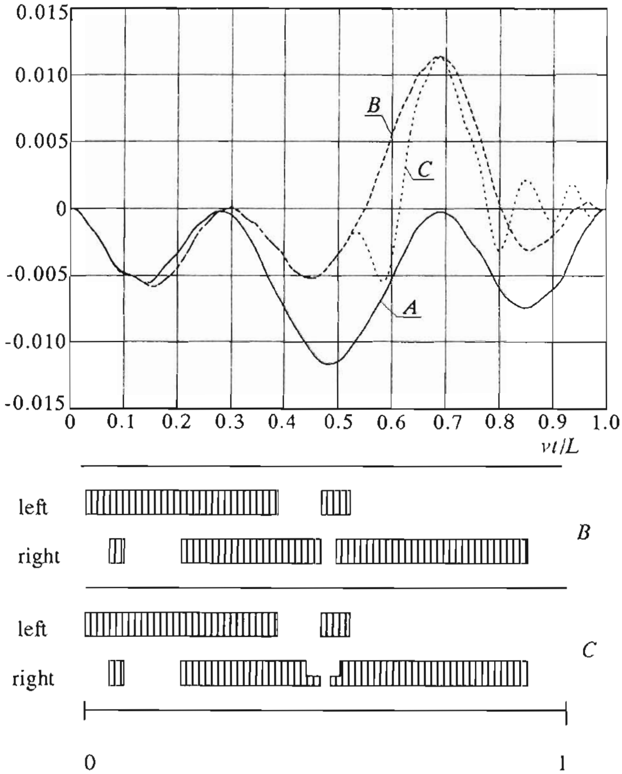

Fig. 5. Displacement of the mass in the case of reduced first oscillation and the control diagrams

The results of numerical analysis will be verified experimentally in the Institute of Mechanics, University of Hanover.

4. Conclusions

The results presented in the paper prove efficiency of the control of the beam vibration under the moving load. The damping absorbers can efficiently decrease the response of the considered single span beam. Further decrease of the vertical displacements can be achieved by slight pre-stressing of the beam. The system of tendons which supports the dampers can also be used.

A practical implementation force us to take into account not only the mass displacements but also the beam deflection. However, in such a case the answer to the question about the design function is difficult. One possible weighted form can depend on both the mass displacement w_m and the deflection at the chosen point of the beam or maximal beam deflection w_ξ: $F = \kappa_1 w_\xi + \kappa_2 w_m$. κ_1 and κ_2 are the weight coefficients with the sum equal to 1.

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Aktywne sterowanie konstrukcji belkowych poddanych ruchomym obciążeniom

Streszczenie

W pracy przedyskutowano zagadnienie pasywnego i aktywnego sterowania belki poddanej ruchomemu obciążeniu. Pasywne tłumiki drgań nie są skuteczne w przypadku długotrwałych obciążzeń generujących fale. Aktywne sterowanie siłownikami również nie jest doskonałe. W pracy przedstawiono koncepcję będącą uogólnieniem sterowania za pomocą siłowników na przypadek sterowania intensywnością tłumienia. Wyniki symulacji numerycznej wykazują skuteczność proponowanego podejścia.

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