DEVELOPMENT OF AN EXPERIMENTAL SYSTEM FOR STUDYING VIBRATION CONTROL OF A TRAVELLING CABLE WITH VARIABLE LENGTH

Sung-Wen Dung, Kefu Liu, and Henri Saliba
Dept. of Mechanical Engineering, Lakehead University, Thunder Bay, ON Canada P7B 5E1

Abstract
An experimental system has been developed for studying vibration control of travelling cables with variable length. This paper describes the system design and presents some preliminary testing results.

Introduction
Many mechanical systems use the mechanism of travelling media with a varying length such as hoist or elevator cables [1-2], satellite tethers [3], and robotic arms in a prismatic joint [4]. The model governing vibration of such systems is time-varying and control of time-varying systems poses many challenges. A Master thesis research is conducted at Lakehead University to study vibration control of travelling cables with variable length. An experimental system has been developed for the purpose of this study. The system allows to simulate the lateral dynamics of a travelling cable with variable length and to test control strategies for vibration suppression. This paper explains the design of the system and presents some preliminary testing results.

Design Requirements and Constraints
Several design requirements were set. First the cable can vary its length while maintaining its boundary conditions. Second, a closed-loop control system is needed for varying the travelling speed of the cable in a desired way. Third, lateral vibration of the cable is constrained in one plane to simplify the problem. Fourth, the cable tension can be adjusted. Fifth, an actuator is provided to implement a boundary force control. The design was subjected to several constraints. First, the budget for the apparatus is very limited. Second, the height of the apparatus is restricted by several factors: the room height, the length of stocks used for the frame and guide rails, length of sensor cables, etc. Third, the apparatus must be easy to be disassembled. The budget constraint greatly affected the final design, reflected in the selection of materials, instrumentation, and fabrication.

Travelling Cable Apparatus
Figure 1 shows the apparatus built in house. A steel band of width 12.7 mm and thickness 0.3 mm is used as the cable, because it is readily available. A rail system is provided to meet the requirement of varying the cable length while maintaining the lower end boundary condition. Two grounded steel bars with diameter of 95 mm and length of 2360 mm are used as guide rails. Two travelling blocks embedded with linear bearings are connected by two rigid aluminium bars. The lower end of the band is attached to an electromagnet (explained later). Then the electromagnet is connected to the upper bar of the travelling blocks by a thin aluminium plate. This thin plate plays a dual role: create an end spring at the lower end of the band and embed a strain gauge sensor for measuring the tension and lateral vibration of the band. The band runs through a band guide made from Teflon, providing the top fixed end boundary condition. Through four pulleys, the band forms a loop with its other end connected to the lower bar of the travelling blocks. A robber band is glued in the groove of each pulley to increase the friction. Tension of the band can be adjusted by a tensioner

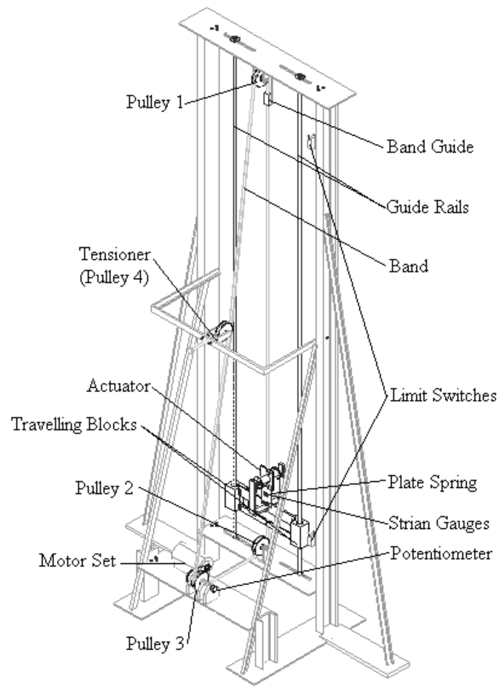

Figure 1: Travelling cable apparatus

consisting of an adjusting screw and a pulley. Pulley three is driven by a direct current (DC) motor (Dumore) through a pulley and belt set. The motor has a built-in gearbox with a transmission ratio of 13:1. The motor is rated to run 180 RPM at 1.5 amps with no load and 160 rpm at 6.2 to 7.2 amps with a load of 2.712 Nm. The pulley and belt set has a transmission ratio of 11:10. A potentiometer is attached to the shaft of pulley three. The frame that houses the moving system is made of two steel channels and two steel plates. The rail bars are subjected to some tension to ensure the straightness. The frame is supported by four steel angles. Two limit switches are installed to shut off the motor when the end mass reaches the highest position or the lowest position. The total travel distance of the actuator is about 1900 mm.

Actuator

A low cost actuator was developed in house. As shown in Fig. 2, it consists of an electromagnet and two permanent magnets. The electromagnet is connected between the lower end of the band and the plate spring. Each of the permanent magnets is glued on its holding seat that is attached to the upper connection bar of the travelling blocks. The poles of the two permanent magnets are arranged in such a way that, when an alternating current is applied to the electromagnet, a non-contact actuating force can be generated.

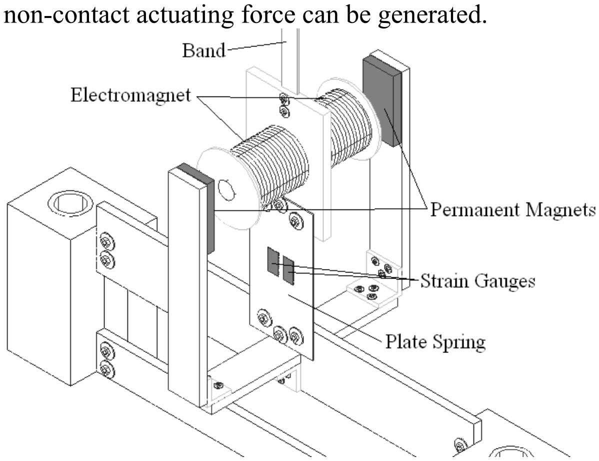

Figure 2. Actuator

Instrumentation and Control System

Three types of sensors are used: potentiometer, accelerometer, and strain gauge. The following circuits were built in house by a former Msc. graduate student: potentiometer signal amplifier, strain gauge signal amplifier, unregulated DC power supplier, and motor servo linear amplifier. An accelerometer (B & K 4393V) is used to measure lateral vibration of the band. The accelerometer signal is conditioned by a charge amplifier (B & K 2635). A Pentium III personal computer is used for control. The data acquisition board used is PCI-6024E and the interfacing software used is LabView (both from National Instruments).

Preliminary Testing Results

A preliminary test included: control of cable travelling and acquiring of acceleration signals of the band vibration. A LabView program was developed to implement the test. A proportional feedback control was used for control of the cable position. A desired motion was prescribed. The relation between the cable length and the potentiometer reading was determined. With this relation, the desired length change at each moment was converted into a setpoint. The motor control command proportional to the error between the setpoint and the potentiometer reading was sent to the servo linear amplifier through a digital to analog channel to regulate the current to the motor. The band was directly connected to the upper connecting plate of the travelling blocks. The accelerometer was placed at a position near the lower end of the band. As soon as the band was tapped, the motor control was activated. Fig. 3(a) shows the potentiometer readings for the upward (dashed) and downward (solid) travelling. The accelerometer readings while the band was travelling up and down are shown in Figs. 3(b) and 3(c), respectively. Clearly, a typical “unstable shortening” behaviour existed while the cable length was becoming shorter.

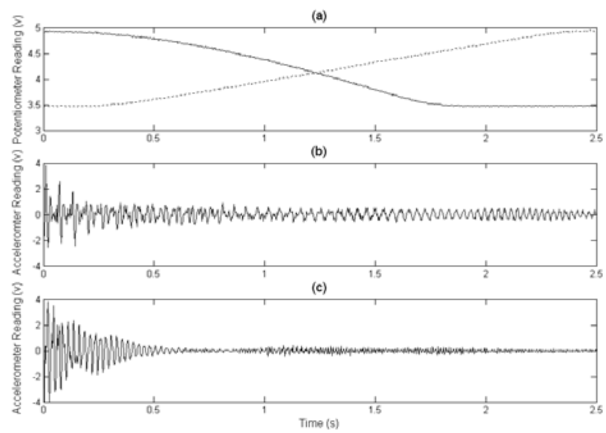

Figure 3. Preliminary Testing Results

Conclusion

An experimental system has been developed for studying control of lateral vibration of a travelling cable with variable length. A premilinary test has shown that the system meets the major design requirements.

References

1. R. M. Chi and H. T. Shu, Longitudinal vibration of a hoist rope coupled with the vertical vibration of an elevator car, *J. of S. and Vib.*, 148 (1991) 154-159.
2. W.D. Zhu and L. J. Teppo, Design and analysis of a scaled model of a high-rise, high-speed elevator, *J. of S. and Vib.*, 264 (2003) 707-731.
3. A. K. Misra and V.J. Modi, Deployment and retrieval of shuttle supported tethered satellites, *J. of Guidance*, 5 (1982), 278-285.
4. P. K. C. Wang and Jin-Duo Wei, Vibration in a moving Flexible robot arm, *J. of S. and Vib.*, 116 (1987) 149-166