ATTENUATION OF REAR VIEW MIRROR VIBRATION

Kaesler, J.P.* and Stanef, D.A.*

* Department of Mechanical Engineering, The University of Adelaide,
Adelaide SA 5005, Australia.
Industry Partner: Schefenacker Vision Systems Australia Pty Ltd, Lonsdale SA 5160, Australia

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ABSTRACT

Schefenacker Vision Systems Australia is the world's largest producer of automotive rear view mirrors. More than one third of their annual revenue is derived from the exportation of the large 'extendable' P131 model mirror designed for Ford F250 trucks in the United States. Customer feedback from truck owners has identified excessive vibration in the P131 mirrors as annoying, and in extreme cases, a safety hazard.

This project has been undertaken with the primary focus being the development of an active feedback control system that will reduce excessive vibration to levels that are deemed to be tolerable for people. The frequency range of interest is between 5-100 Hz.

Secondary objectives included quantifying human visual perception of vibration in a series of 'jury tests' to ascertain an average perception of vibration threshold (the point that divides tolerable and intolerable vibration). Tolerable vibration levels were established by exposing several individuals to controlled 'orbital' vibration of varying magnitude and frequency. The vibration threshold is to serve as the minimum level to which the vibration must be attenuated for the active control system to be considered successful. The vibration levels were measured in a mirror fitted to a test vehicle in order to provide understanding of the actual problem and formulation of a relationship to the human vibration perception data.

Initial results have demonstrated mirror vibration attenuation, although not at desired levels. Development of the control system is continuing.

1. BACKGROUND

1.1 Literature Review

Until recently, the problem of vibration in exterior rear-view mirror assemblies has not received significant attention. However, as vehicle specifications have evolved, vehicle suspensions have become stiffer and minimum driving speeds have moved upward. This has resulted in greater vibration affecting the rear-view mirror as well as increased driver awareness of vibration affecting his or her vision.

Many passive solutions to the problem of exterior mirror assembly vibration have been proposed [1,2,3]. These include the use of significantly stiffer polymer resins to support the glass and/or actuator assemblies in such mirrors, and anti-vibration members on the rear surface of the reflective element housing. To date, such anti-vibration members have constituted one or more spring-loaded contact members that are usually mounted on the axis of rotation of the reflective element or radially around its centre of rotation.

Despite the incorporation of such mechanisms to reduce the level of vibration in the mirrors, the problem still continued to exist to a degree. It was thus the purpose of this study to look at non-passive means to reduce the level of vibration. In particular, the use of active control was investigated.

Initial searches into the existence of any patents that used active control for mirror vibration returned zero. Research does exist however for other applications where attempts have been made to correct similar vibration problems with active means. One such example is the development of binoculars with ‘Image Stabilisation’ technology by the company Canon in Japan [4,5]. As many users would know, it is often hard to see a clear image of a target through a pair of binoculars due to the low frequency shaking of your own hands. Canon claims that their binoculars are capable of counteracting this hand shaking and can maintain a steady image when a stabilisation-activation button is pressed.

Several similarities exist between the problem of a Ford F250’s rear-view mirror vibration and image stabilisation in a pair of Canon binoculars. In both situations the core problem is to reduce, or in fact eliminate, the effect of vibrations on the performance of the product. Both problems also deal with the effect of vibration on images (i.e. what is *seen* is important). Moreover, given that the method used for stabilisation in the binoculars was successful, the application of the same general principles involved for the binocular problem to control of a vibrating mirror seemed worth investigating further.

1.2 Gap in Existing Research

The gap that this project attempted to fill was three-fold. First of all, a quantitative analysis of how a mirror’s vibrational characteristics affect human vision was completed. The data acquired from this analysis was a curve that shows the level of acceleration of the mirror at different frequencies that causes an image in the mirror to *just* become distorted. This is known as the ‘tolerable’ level of vibration. Secondly, tests were performed on the vehicle to generate data depicting the ‘actual’ level of displacement of the mirror at different frequencies whilst in use on the vehicle.

At some or all of these frequencies, the actual curve was higher than the tolerable curve – hence the vision distortion problem of the mirror. The final aim of this project was then to develop a control system that reduces this actual level down to or below the tolerable level. When this is achieved a driver of the vehicle will experience no vibration distortion in the rear-view mirror whilst driving.

2. THEORETICAL WORK

The system that is thought to possess the most appropriate characteristics for attenuating mirror vibration is an active feedback control system. In general a control system is a combination of individual components [6] aimed at generating a desired output. In order to monitor this desired output appropriately a closed loop or feedback control system can be configured. The figure below illustrates the system layout in a block diagram.

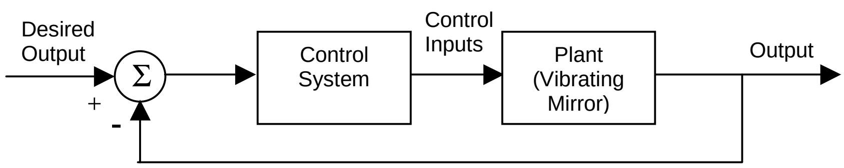


Figure 1 Feedback Control System Configuration

From Figure 1 it is apparent that the system output has a significant influence on the control input as a result of the feedback loop. This feedback system enables the controller to monitor the system output and to respond accordingly should the actual output not correspond to the desired output.

In the majority of scenarios, and such is the case in this project; feedback control is principally interested in disturbance attenuation. The physical disturbance in this instance is the vibration of the mirror surface caused by road surface and engine vibrations, and is similar in nature to random noise. This disturbance is recognised as the primary disturbance or primary excitation and is an undesirable characteristic of the system. By purposely introducing control inputs into the system the intention is to generate a desired response that in this project is to annul the mirror vibration and produce a perfectly still mirror surface.

3. EXPERIMENTAL STUDY

Research and experiments completed for this project can be divided into three key areas. As mentioned earlier, it was necessary to define a tolerable level of vibration for the mirror in quantitative terms, investigate the actual levels of vibration in the mirror when in use on the vehicle, and then ultimately devise a solution that brings the actual level below the tolerable level.

The tolerable level of vibration was determined by performing a human perception of vibration test. This 'jury test' involved shaking the mirror at predetermined frequencies and testing people's ability to recognise letters of the alphabet (as in a standard eye exam) by looking at the reflection of the letters in the vibrating mirror. The letters themselves were typed in large black bold font on a piece of paper and then reversed so that when viewed in the mirror they would appear in their correct orientation. At each frequency the subjects were presented with a mirror that was set vibrating in an orbital motion with amplitude of vibration large enough to completely distort the image of the string of letters. The frequency was then held constant while the amplitude was turned down to a level where the subject could correctly identify all letters in the string. The frequency range of the test was from 5 to 100Hz, with measurements being taken every 5Hz. The final level of vibration was recorded and then averaged for ten different subjects. Additionally, a factor of safety was introduced by lowering the tolerable level determined from the subjects by reducing it by a factor of ten after averaging. The curve that resulted is shown in Figure 2.

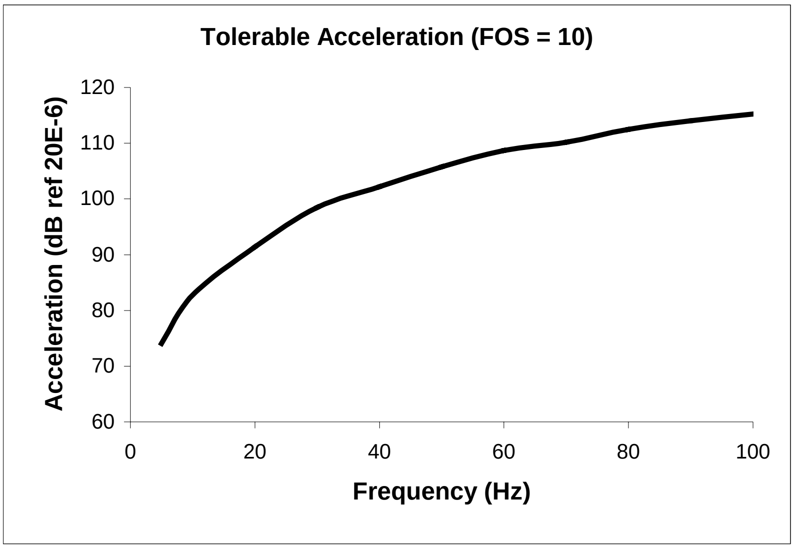


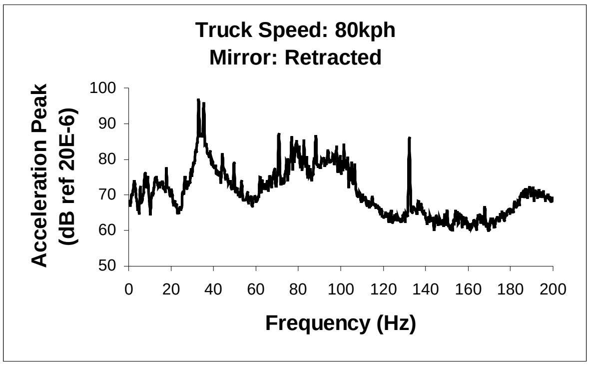
Figure 2 Tolerable Level of Mirror Vibration

Schefenacker Vision Systems own a F250 series truck that is regularly used as an engineering test vehicle. For the purposes of this project the F250 truck was borrowed and experiments performed on the road. Two accelerometers were placed on the rear-view mirror

Figure 3 P131 mirror with accelerometers attached

near the edges of the glass with double-sided tape (see Figure 3). First they were mounted horizontally across the middle, and then they were mounted vertically down the middle. Data was acquired with the truck travelling at 60, 80, and 100 kph, and with the mirror in the extended and retracted positions. Zonic Medallion FFT Analyser Hardware and Software was used on a Toshiba 420 CDT Laptop to acquire the frequency spectra.

A selection of the frequency spectra acquired from the truck whilst travelling at 80 kph is shown in Figure 4. In Figure 4(a) illustrated below, the mirror was in the retracted position, and the accelerometer mounted on the outer most point of the horizontal line that passes through the mirror's centre. In Figure 4(b), the mirror was in the extended position.



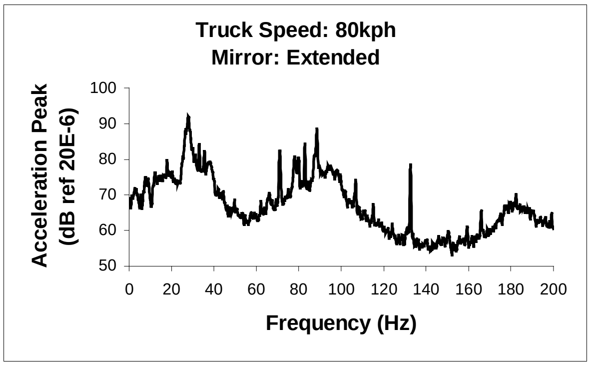


Figure 4 Vibration levels of mirror vibration acquired on test vehicle

4. ANALYSIS OF RESULTS

By superimposing the tolerable level curve onto any one of the actual level curves in Figure 4, the frequencies at which the vibration problem in the mirror is greatest could be determined. When this was done, it was found that the main problem frequencies are contained to the lower order frequencies, in particular from 5 to 40Hz. At frequencies above 40Hz, the tolerable level increases at a rate high enough such that the actual level of vibration never exceeds the tolerable level. From this, it is clear that the control system to be developed needs to target the lowest end of the frequency spectrum.

In the worst case, the actual level of vibration in the mirror was 6dB higher than the tolerable level. This occurred at 33Hz when the truck was driving at 80kph and the mirror was in the retracted position (see graph (a) in Figure 4). It is believed that this peak level of vibration in the mirror can be attributed to the engine speed of the vehicle. This is because when driving at 80kph, the engine running speed was 2000RPM, which, upon converting to cycles per second by dividing by 60, is 33.3Hz.

5. DISCUSSION

This project has sought to demonstrate the successful application of an active feedback control system in attenuating mirror vibration. From the outset, it has been the conviction of the authors that active feedback control is capable of attenuating adverse mirror vibration and in the past active control has successfully been used to attenuate vibration levels by up to 20dB [7].

Considerable effort has been devoted to understanding the critical issues of this project, namely visual perception of vibration and the vibration characteristics of the P131 mirror units. Our findings lend support to the previous research of Lynn [8] and in addition take his findings another step further by quantifying the visual perception threshold in human beings. The opportunity exists for this visual perception study to be replicated and conducted on a larger scale to firmly substantiate our findings.

Models of the system have been tested using Simulink®, and downloaded through Real Time Workshop® to a dSPACE® board run by ControlDesk®. As at the time of writing this paper, a full state feedback system incorporating an optimal controller and observer has produced positive results when applied to a mirror system, however attenuation is nowhere near desired levels, particularly over the critical frequency range of 5 to 40Hz. As results have demonstrated, it is in this frequency range that mirror vibration exceeds the visual perception threshold and is likely to cause irritation or render the mirror unsafe. It would appear that our physical plant is considerably more complex than initially thought and that controlling the mirror is not just simply a matter of restraining the two axes of rotation (pitch and yaw as in Figure 5).

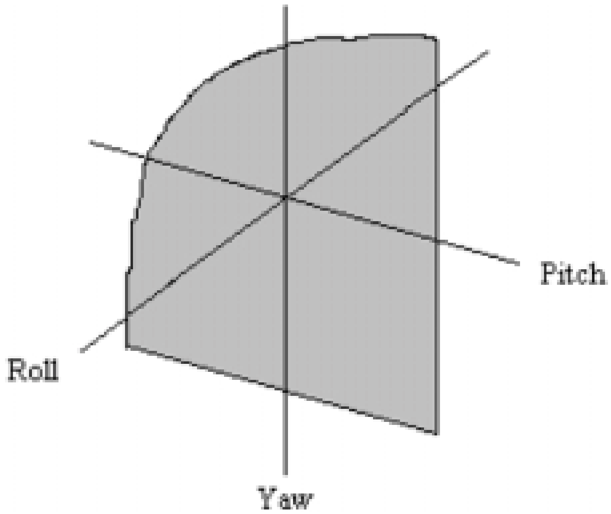


Figure 5 Axes of Mirror Vibration

It is quite plausible that the initial assumption of our two control inputs being completely independent of one another may not be entirely correct. Development of the active feedback control system is continuing.

Should this control system achieve its performance criteria it would appear that the concept is ready to be taken to the next phase of its design. This system possesses tremendous potential and is likely to have a significant impact on the automotive mirror market. Manufacturers of vehicles that currently use large automotive mirrors such as buses, trucks, some 4WD's and trains may seek to implement this control system in their future designs improving visibility and safety. However, considerable development of this system is required before it can be considered viable in a large-scale manufacturing environment. Sensors, actuators and manufacturing processes must all be re-evaluated to meet cost, spatial and weight criteria whilst at the same time not compromising control system performance. Special attention, and part of the scope of this project, is to be focussed on selecting and recommending sensors and actuators that will offer the necessary performance at low cost. At present the proof of concept model is fitted with technology that is not viable in a manufacturing scenario. Taking this system from a laboratory concept to reality is a project in itself, however the successful implementation of this active feedback control system will serve to significantly alter the current rear-view mirror market.

6. CONCLUSION

The primary objective of this project has been to utilise active feedback control to attenuate mirror vibration. Initial results obtained with the current control system have demonstrated promise, but attenuation is far from desired levels. Achieving these desired levels is critical to the success of the control system, particularly over the lower order frequencies (5 to 40Hz). It has been shown through the human visual perception of vibration trials that when vibration levels of the mirror in an actual driving scenario exceed tolerable vibration levels the driver is likely to find the mirror response irritating. Consequently the mirror fails to fulfil its designated purpose of providing the driver with useful information pertaining to objects behind them.

Development of the control system is continuing and it is hoped that in the coming weeks performance will meet expectations. Once the system has demonstrated its competency as a proof of concept model, recommendations will be made suggesting design alterations to be considered in order to make this system feasible as a manufactured product. Specifically, the recommended sensors and actuators will need to meet cost, spatial and weight criteria without compromising control system performance. It is hoped that this will lead into the next phase of this project and provide a starting point for those willing to undertake it.

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