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Pressure Measurements on an Automobile Side Rear View Mirror

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Abstract

The vibration of automotive side rear view mirror is a concern for vehicles safety. Although the primary causes of mirror vibration are due to power train, road/tyre interaction and aerodynamic pressure fluctuations, not many studies have been undertaken on mirror vibration due to aerodynamic inputs. The primary objective of this paper is to study the aerodynamic pressures on mirror surface at various speeds to determine the effects of aerodynamic inputs on mirror vibration. The mean and fluctuating pressures were measured and analysed.

Introduction

A significant effort has been made by the automobile and component manufacturers to reduce aerodynamic drag, noise and vibration. However, relatively less attention has been drawn to the refinement of performance of automobile side rear view mirrors, especially mirror vibration. The primary function of a side rear view mirror is to provide the driver a clear vision of all objects to the rear and side of the vehicle. However, there are several problems associated with it such as image distortion due to aerodynamically induced and structural vibration, aerodynamically induced noise (due to cavities and gaps) and water and soil accommodation on mirror surface due to complex mirror shapes and airflow around it. An automotive mirror is a bluff body and causes significant periodic flow separation at the housing, which produces oscillating aerodynamic forces (due to hydrodynamic pressure fluctuations) on mirror surface. These pressure fluctuations not only cause the mirror surface to vibrate but also generate aerodynamic noise. Due to excessive vibration, the rear view mirror may not provide a clear image. Thus, vibrations of the wing mirrors can severely impair the driver's vision and safety of the vehicle and its occupants. The rear view mirrors are generally located close to the A- pillar region on the side window. An intense conical vortex forms on the side window close to A-pillar due to complex A-pillar geometry and the presence of side rear view mirror and flow separation from it makes the airflow even more complex. Although some studies ([3], [4], [5], [6, 7]) have been undertaken to investigate the structural input (engine, road/tyre interaction etc) as well as aerodynamic input to mirror vibration, very little or no study was undertaken to quantify the aerodynamic input to mirror vibration. Therefore, the primary objective of this work as a part of a larger study is to measure the aerodynamic pressures (mean and fluctuating) on mirror surface to understand the aerodynamic effects on mirror vibration.

Experimental Procedure and Equipment

In order to measure the mean and fluctuating pressures on mirror surface, a brand new production mirror was used. The glass of the mirror was replaced with a rigid aluminium plate (2.4 mm thickness) and the mirror case was slightly modified in order to hold the aluminium plate. There are 51 holes on the aluminium plate in a grid pattern. The diameter of the hole was 1 mm. The space between the two holes was 25 mm horizontally and 13 mm vertically. The mirror face was pressure tapped with rubber tubing. The rubber tubing was connected to four pressure sensor modules, each having 15 channels. All pressure sensor modules were connected to an interface box that provided power and multiplexes the inputs to the data acquisition system. The Dynamic Pressure Measuring System (DPMS) data acquisition software provided mean, rms, minimum and maximum pressure values of each pressure port on mirror. By entering dimensions of the tubing used, the data were linearised to correct for tubing response in order to obtain accurate dynamic pressure measurements. The instrumented mirror was attached with a quarter model of a current production Ford Falcon and placed in the working section of RMIT Industrial Wind Tunnel. The quarter model was used to reduce the blockage ratio and to have representative vehicle geometry and airflow pattern around the mirror. The mean and fluctuating pressures were measured at a range of speeds (60 to 120 km/h with an increment of 20 km/h) at zero yaw angle. The mirror was tested as standard configuration first and then modified configuration. The results for the modified condition are not included in this paper.

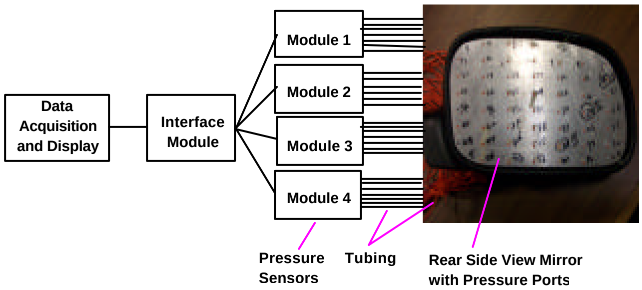

Figure 1: A Schematic of Pressure Measurement Set Up.

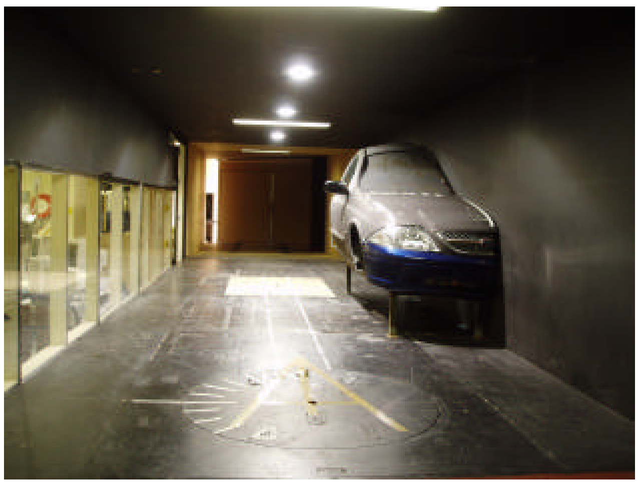

Figure 2: Experimental Set Up of the Mirror with a Ford Quarter Model in the Test Section of RMIT Wind Tunnel.

Figure 2 shows the experimental set up in the wind tunnel test section. In order to simulate real wind condition and A-pillar geometry, the mirror was attached to the quarter model current production car as shown in the figure. Experiments were performed in RMIT University Industrial Wind Tunnel which is a closed test section, closed return circuit wind-tunnel with a maximum speed of 145 km/h. The rectangular test section dimension is 3 m (wide) x 2 m (high) x 9 m (long). More details about the RMIT Industrial Wind Tunnel can be found in [1, 2]. The tunnel was calibrated before conducting the experiments and tunnel air speeds were measured via a modified NPL (National Physical Laboratory) ellipsoidal head Pitot-static tube (located at the entry of the test section) connected to a MKS Baratron Pressure sensor. The sampling frequency of each channel was 1250 Hz. It may be noted that the peak energy of fluctuating pressure on mirror surface is well below 500 Hz (for more details, refer to [5] and [6, 7]). The dynamic response of the tubing was calibrated in order to minimise the attenuation of frequency.

Results and Discussion

The mean and fluctuating pressures were converted to non-dimensional parameters such as mean pressure coefficient (Cp) and fluctuating pressure coefficient (Cp rms) by dividing the velocity head (q). The mean Cp and Fluctuating Cp rms were plotted in 3-D and also in contour. The origin of the plot is located at the top left hand corner position, eg., Position 1 (see Figure 3). The x-distance is horizontal and y-distance is vertically down as shown in Figure 3. The contour plots for 60, 80, 100 and 120 km/h for the mean and fluctuating pressure coefficients are shown in Figures 4 to 8, 10-11 and 13. The 3D plots of fluctuating pressure coefficients (Cp rms) for 100 and 120 km/h are shown in Figures 7 and 12.

The lowest surface mean pressure was found in the lower part of the mirror for all speeds except for the 80 km/h speed (see Figures 4, 6, 8 & 11). The maximum fluctuating pressure was also measured at the bottom part of the mirror surface at all speeds tested. The 3-D and contour plots clearly show that the fluctuating pressure is not uniformly distributed on the mirror surface rather concentrated at the lower central part of the mirror surface. It is believed to be due to the strong flow separation from the edge. Generally, the higher the magnitude of the fluctuating pressure, the greater possibility of generating intermittent force and aerodynamic noise. With the increase of speed, the affected area and magnitude of fluctuating pressures increase. The contour and 3-D plots for the mean pressure show a significant pressure drop (lowest mean pressure) at the lower right hand corner for all speeds except at 60 km/h. Further investigation is needed to clarify this phenomenon but this is thought to be due to the interaction of the A-pillar vortex. It may be noted that the airflow around the mirror housing is very complex and strongly influenced by the A-pillar vortex. It may be mentioned that when the mean pressure is low, the fluctuating pressure is high, however, the peak fluctuating pressure does not occur at lowest mean pressure. The peak fluctuating pressure shifts from the location of the lowest mean pressure.

A real mirror glass is generally mounted with the base using a primary pivot and two auxiliary supports to stabilize the mirror. The primary pivotal support is located approximately in the centre of the mirror glass. Therefore, intermittent fluctuating pressure acting on any part other than pivotal point causes mirror to vibrate. However, the vibration is neither purely horizontal nor vertical. The mirror glass vibration is generally diagonal (torsional) due to the asymmetric fluctuating pressure on the mirror surface as shown in Figures 5, 7, 9-10 and 12-13.

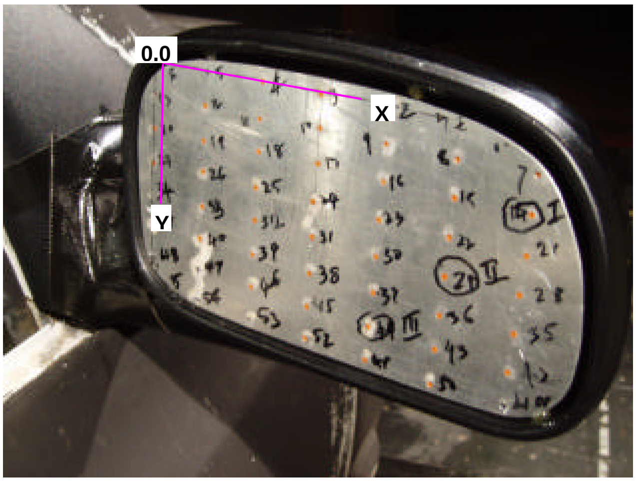

Figure 3: Schematic of Data Representation in Relation to Mirror Geometry and Coordinates.

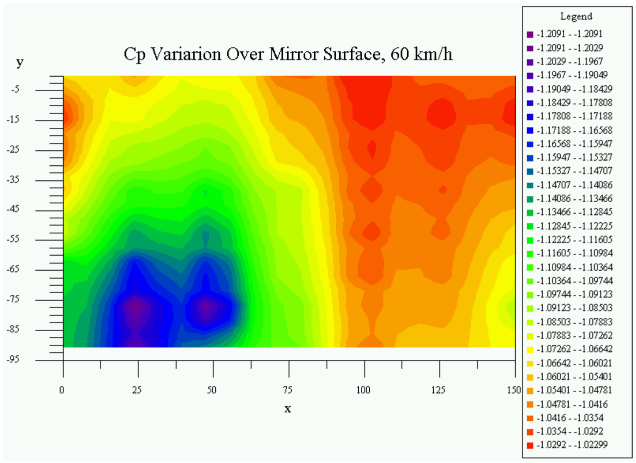

Figure 4: Contour Plot of Mean Cp, 60 km/h Speed.

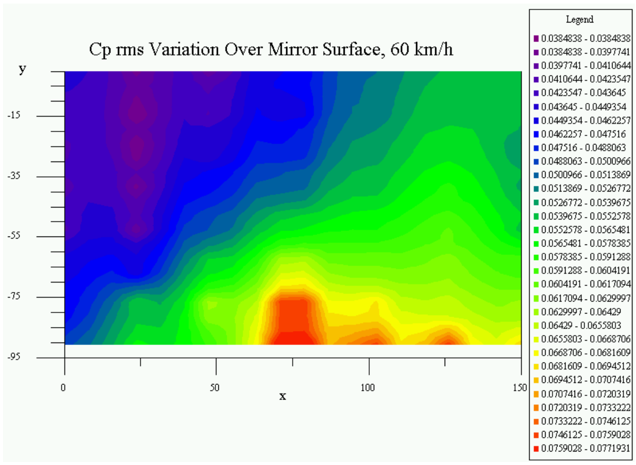

Figure 5: Contour Plot of Fluctuating Cp rms, 60 km/h Speed.

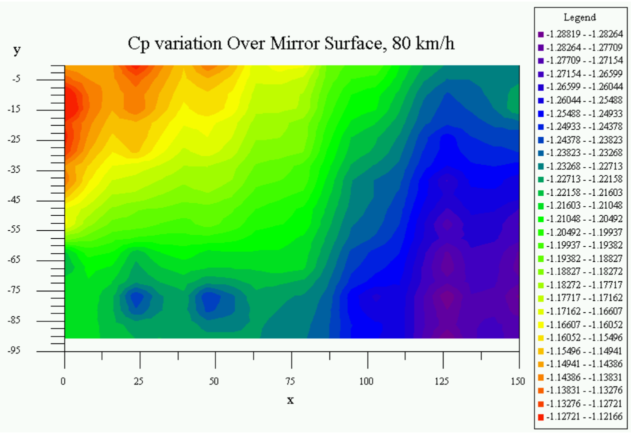

Figure 6: Contour Plot of Mean Cp, 80 km/h Speed.

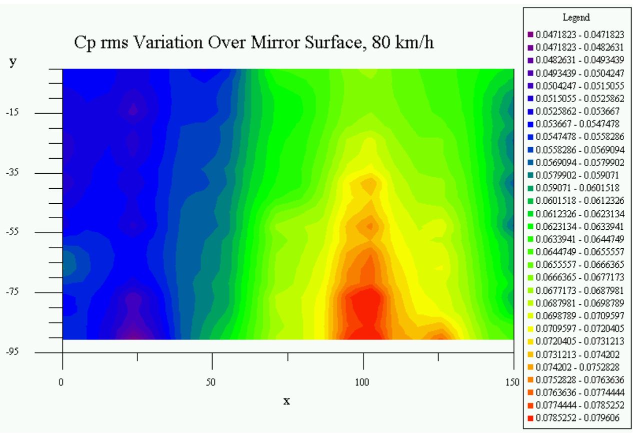

Figure 7: Contour Plot of Fluctuating Cp rms, 80 km/h Speed.

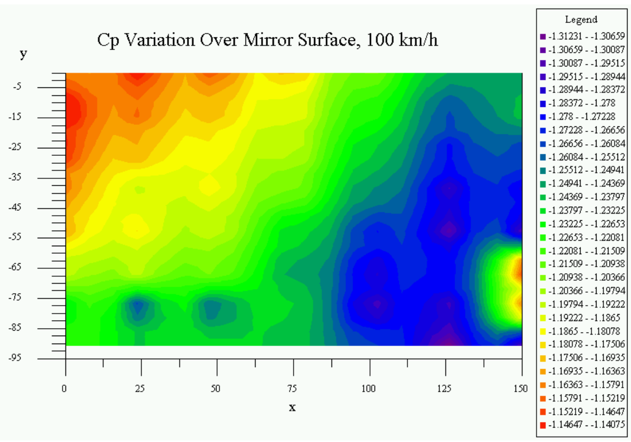

Figure 8: Contour Plot of Mean Cp, 100 km/h Speed.

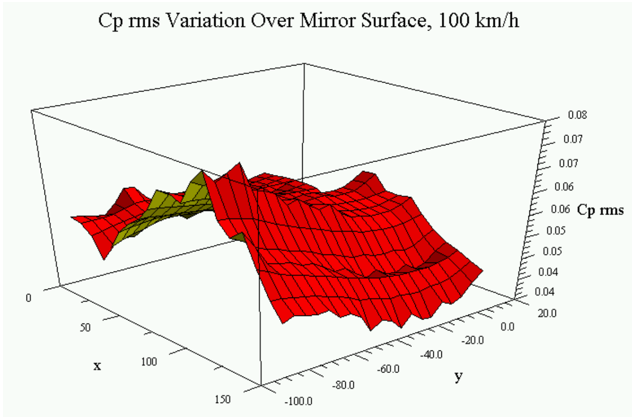

Figure 9: Fluctuating Pressure Cp rms Variation on Mirror Surface, 100 km/h Speed.

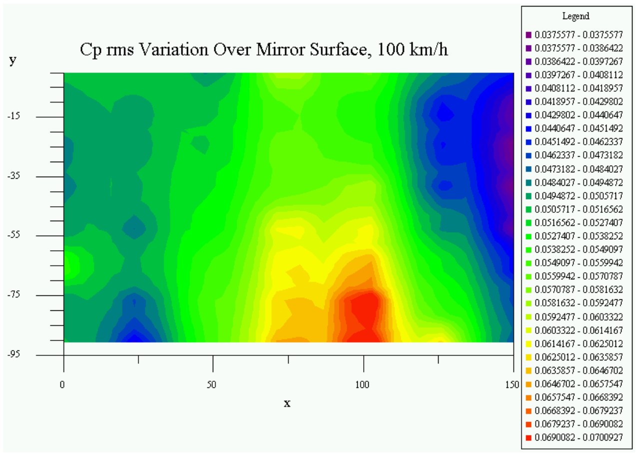

Figure 10: Contour Plot of Fluctuating Cp rms, 100 km/h Speed.

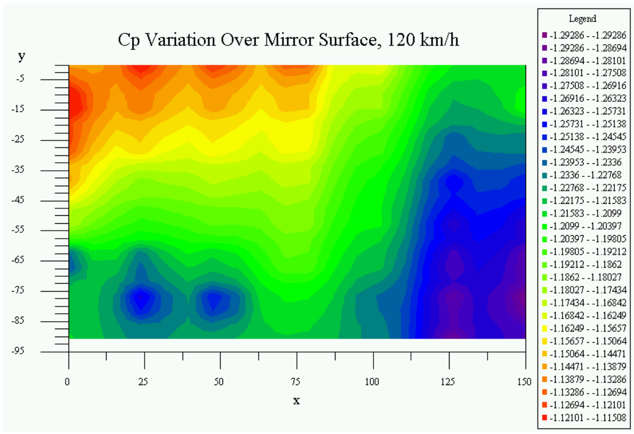

Figure 11: Contour Plot of Mean Cp, 120 km/h Speed.

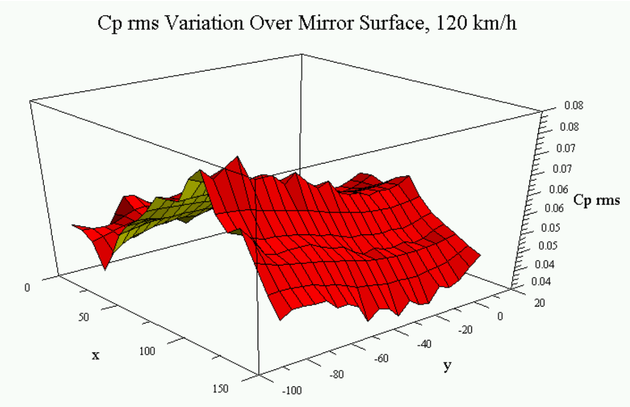

Figure 12: Fluctuating Pressure Cp rms Variation on Mirror Surface, 120 km/h Speed.

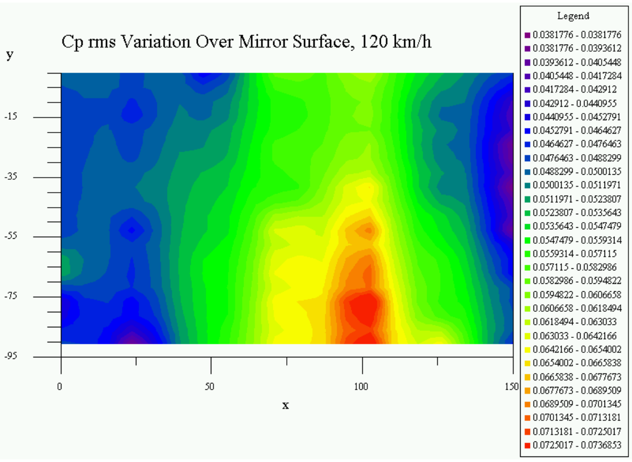

Figure 13: Contour Plot of Fluctuating Cp rms, 120 km/h Speed.

Spectral Analysis

Power Spectral Density (PSD) was used to document the energy characteristics of fluctuating pressure signals in the frequency domain. The fluctuating pressure data from the position on mirror surface where the maximum fluctuating pressure occurred was used for PSD analysis and plotted against frequency (see Figure 14). The spectra plot indicates that the fluctuating pressures on mirror glass are broad band type and most energy is located in low frequencies.

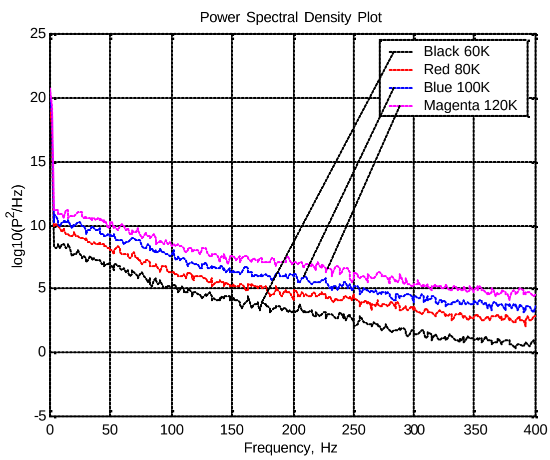

Figure 14: Fluctuating Pressure Spectra Variation with Speeds.

Concluding Remarks

The following conclusions have been made from the work presented here:

- Fluctuating and mean aerodynamic pressures are not uniformly distributed over an automobile mirror surface.
- The highest magnitude of fluctuating pressure can be found at the central bottom part close to the mirror edge.
- The lowest magnitude of mean pressure was noted at bottom right hand corner of the mirror surface
- The pressure fluctuation on mirror glass is broad band type and most energy is located in low frequencies (below 50 Hz)

Acknowledgments

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