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Application of a Constrained Layer Damping Treatment to a Cast Aluminum V6 Engine Front Cover

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ABSTRACT

Constrained Layer Damping (CLD) treatments have long provided a means to effectively impart damping to a structure [1-3]. Traditionally, CLD treatments are constructed of a very thin polymer layer constrained by a thicker metal layer. Because the adhesion of a thin polymer layer is very sensitive to surface finish, surfaces that a CLD treatment can be effectively applied to have historically been limited to those that are very flat and smooth. New developments in material technology have provided thicker materials that are very effective and less expensive to apply when used as the damping layer in a CLD treatment. This paper documents the effectiveness of such a treatment on a cast aluminum front cover for a V6 engine. Physical construction of the treatment, material properties and design criteria will be discussed. Candidate applications, the assembly process, methods for secondary mechanical fastening will be presented. Noise and vibration data from both bench testing and engine dynamometer testing will also be presented.

INTRODUCTION

Constrained layer damping treatments with a thin damping polymer layer have long been used as a means to impart damping to a structure. The application of CLD treatments to cast engine covers has been difficult due to the rough surface finish of the covers. In order for a CLD treatment to work properly, the viscoelastic layer must be in contact with the surface. Factors such as casting tolerances, casting finish (as with a sand cast part) and heat/die checking all make applying a CLD treatment to a cast cover difficult. These factors can usually be overcome by machining the surface of the cover, but this additional step can make the treatment difficult to justify from a cost perspective.

In order to overcome these difficulties, a new, thicker damping material was developed that could be successfully applied to an engine cover without a costly machining process. This new damping material is a soft, thick polymer which can conform to surface irregularities inherent in a cast cover. The material can be die cut and applied to formed metal parts for application to multi-level surfaces and is very tolerant of typical underhood environmental conditions.

In the course of standard noise and vibration development on a new V6 engine intended for introduction in the model year 2004, it was found that the cast aluminum engine front cover was a significant contributor to the total engine noise level. It was also well documented that the acoustic response of the front cover component was primarily a resonant behavior. Program timing and architectural package constraints dictated that significant structural modifications to the casting were not practical noise reduction options. Therefore, constrained layer damping treatments were proposed, developed, and then optimized to provide a significant objective and subjective noise reduction from the untreated front cover component. A discussion of the application of a CLD treatment, utilizing this new damping material, to the front cover is presented.

DESIGN CRITERIA

Figure 1 shows a photograph of an untreated front cover. As can be seen in the Frequency Response Function (FRF) graph in Figure 2, there are several lightly damped panel modes in the center portion of the cover. These resonances contribute significantly to the noise radiated from the cover and make the cover the second highest noise source in the engine component sound power ranking as shown in Figure 3.

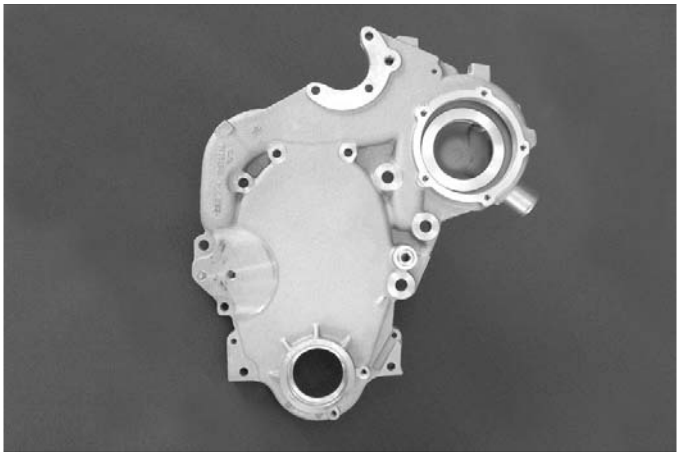

Figure 1: Photo of Front Cover

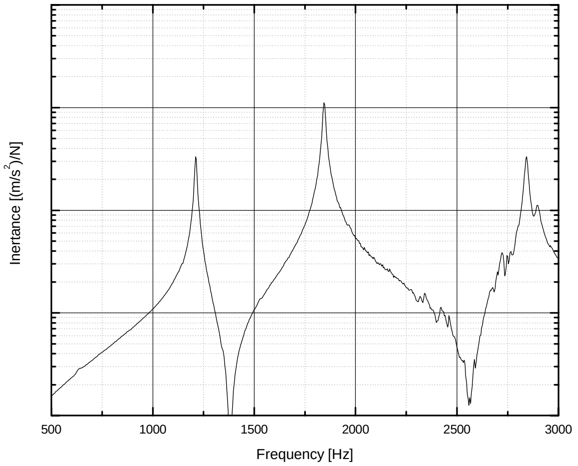

Figure 2: FRF on an Untreated Front Cover

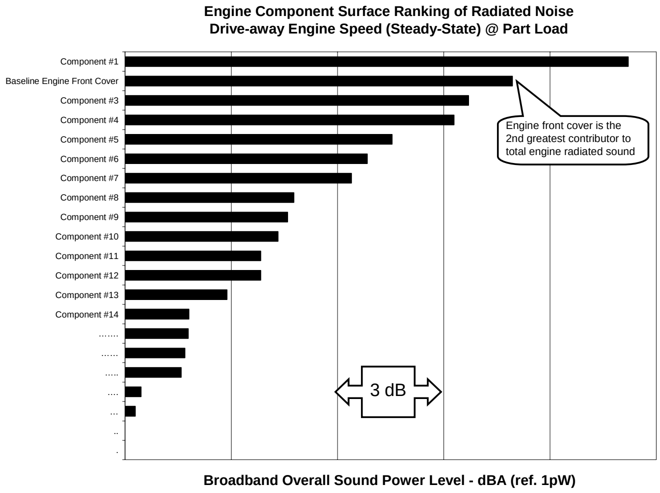

Figure 3: Component Sound Power Ranking

To achieve optimum performance, the damping treatment must cover as much of the noise radiating surface as possible. The primary requirements imposed on the design were:

- CLD treatment must reduce noise radiated from the front cover enough to provide an improvement in a subjective vehicle level evaluation
- Mechanical fastening must be used to ensure treatment never falls off
- Proper clearance must be maintained from nearby engine components (pulleys, FEAD belt, mount bracket)

Other challenges to applying a treatment to this cover included:

- Difficult to achieve a good bond to the rough sand-cast surface
- Step between machined tensioner pad and cast surface
- Cast surface height tolerance is very large
- Harsh environmental conditions (fluid exposure, temperature extremes, etc.)
- Low CLD part and installation cost

MATERIAL SELECTION

Historically, constrained layer damping treatments have used a very thin adhesive layer as the damping material. These thin layer CLD treatments have yielded exceptional results in many applications. However, due to the surface roughness of this cover, a traditional thin layer CLD was not feasible without a costly machining step. In order to make a CLD treatment practical on this cover, a low cost, thicker damping material was developed.

TREATMENT OPTIMIZATION

The CLD design was optimized for this front cover by using a simple bench fixture to test a number of design iterations.

Several variables were considered to achieve optimum performance in this design:

- Overall size and shape of the treatment (treatment coverage)
- Thickness of polymer and constraining layers
- Mechanical fastening method and placement

The front cover was clamped to a rigid plate using the production front cover bolting locations. FRF measurements were acquired at a number of points on the front cover to determine the impact and response location which best excited the modes of interest. A photograph of the test setup is shown in Figure 4.

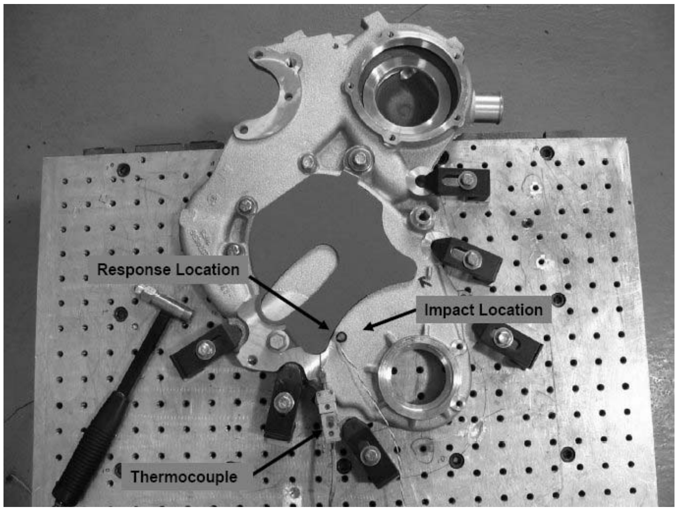

Figure 4: Bench Test Setup

After the measurement location was determined, an FRF was taken on the cover in the baseline (non-treated) condition (Figure 2). Because the damping performance of most viscoelastic materials is very sensitive to temperature, the cover and treatment were heated to approximately 200ºF for measurements taken during the optimization study. The cover and treatment were heated with an infrared heat lamp and temperature was monitored with a thermocouple inserted into the polymer layer.

Several design iterations were then evaluated to determine the optimum thickness of both the polymer and constraining layers. Figure 5 shows the FRF measurements from several of these design iterations. It was finally determined that the best, overall performance was achieved with a 2mm thick polymer layer, coupled with a 1.5mm steel constraining layer.

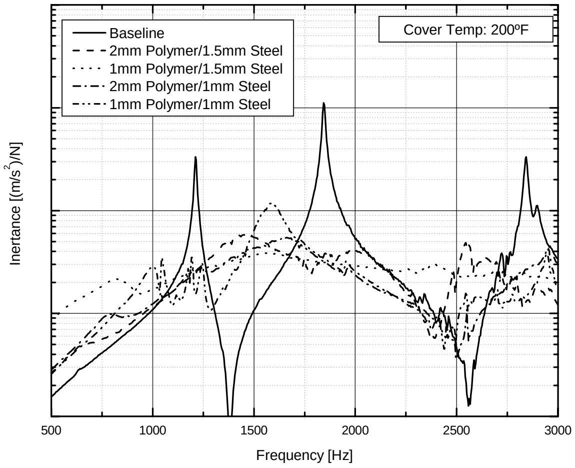

Figure 5: Thickness Optimization

Another design requirement was clearance for the FEAD belt, which runs across the front cover. In order to ensure that the belt would not come into contact with the treatment, it was necessary to remove a portion of the treatment in the belt path. Figure 6 shows the comparison of the treatment with and without the cutout for the belt. The response of the first mode is somewhat higher in both amplitude and frequency with the belt cutout. The second mode shifts higher in frequency with little change in amplitude.

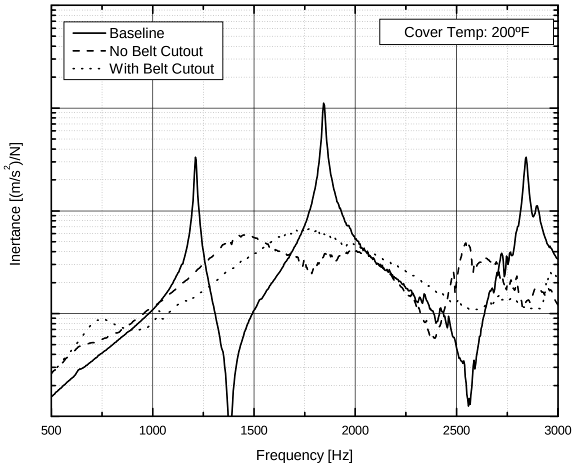

Figure 6: Belt Cutout Study

The final design variable examined was the method of secondary mechanical fastening. The two mechanical fastening options investigated were 1) staking or screwing the CLD to the cover through holes in the treatment, and 2) designing tabs into the treatment to take advantage of existing front cover fastening locations. Figure 7 shows the results of two of the configurations tested. All staking configurations showed significant degradation in damping performance. Damping performance with the two tab design was slightly better than the no fastening configuration.

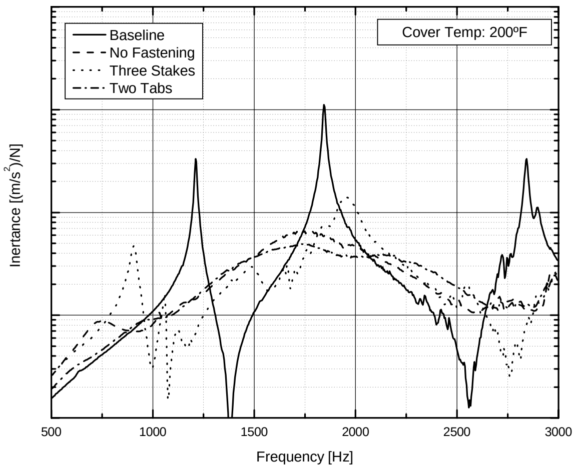

Figure 7: Mechanical Fastening

A comparison between untreated cover and a cover treated with the final design configuration is shown in Figure 8. Significant reduction in all three of the resonant peaks was achieved with the application of the CLD treatment.

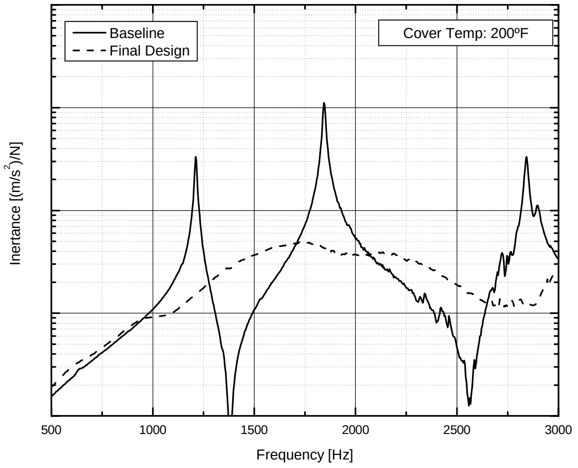

Figure 8: Final Design

NOISE DYNAMOMETER VALIDATION

The damping treatment was installed on an engine in a noise dynamometer test cell and sound power was measured on each engine component. Figure 9 shows the new component sound power ranking with the CLD installed on the front cover (see Figure 3 for comparison to baseline). The front cover now ranks as the seventh highest contributor with a reduction of almost 5 dBA.

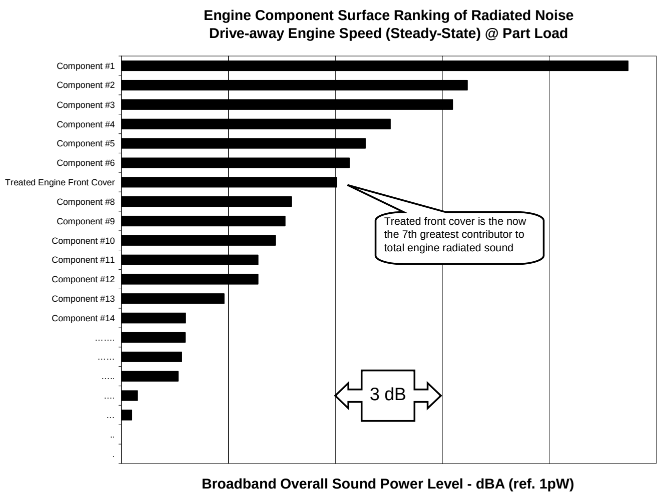

Figure 9: Component Sound Power Ranking

The sound power spectra for the treated and untreated front cover can be seen in Figure 10. A broadband (500 – 5 kHz) component level sound power reduction of nearly 8 dB was demonstrated, with the dominate resonance being attenuated by 23 dB using production intent hardware and processes.

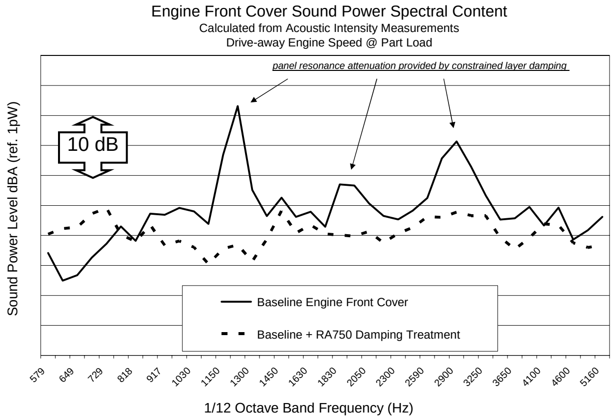

Figure 10: Sound Power Spectra

OTHER CONSIDERATIONS

ASSEMBLY PROCESS

The primary means of attaching the CLD treatment to the cover is through the use of a Pressure Sensitive Adhesive (PSA). At the time of assembly, a thin release liner is removed to expose the adhesive. The CLD is aligned on the cover and pressure is applied over the entire surface of the treatment. Generally, 40 PSI for 10 seconds is sufficient to bond the treatment to the cover at room temperature. To achieve a good bond, it is critical that the surface of the cover is dry and free from dirt, dust, oil and other debris. Varying levels of heat, pressure and time can be use to achieve an optimum bond depending on the application.

DESIGN FLEXIBILITY

A large degree of flexibility can be used when designing a treatment with this new damping polymer. The constraining layer can be made from many different materials (galvanized steel, stainless steel, aluminum, etc.) depending on the application and can also be formed in a stamping process and painted. The thickness of both the polymer layer and constraining layer can be varied to achieve optimum performance for a particular application.

ENVIRONMENTAL DURABILITY

The damping material has been exposed to a variety of underhood environmental conditions and fluids including:

- Gasoline/diesel fuel
- Engine oil/coolant
- Brake and P/S Oil
- Salt spray
- Environmental cycling (heat/cold/humidity)

Damping and adhesion tests after exposure to these conditions show that the damping material can maintain its functionality in an underhood environment.

TEMPERATURE SENSITIVITY

A contour map with a series of FRF measurements taken at various temperatures is shown in Figure 11. This graph demonstrates the sensitivity of viscoelastic damping materials to temperature. The design of CLD treatments made with the new polymer can be tuned to provide optimum performance at the right temperature. This particular treatment was designed to provide maximum damping at typical engine operating temperatures.

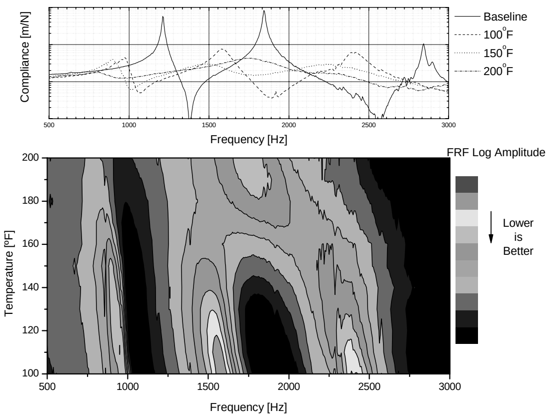

Figure 11: FRF Contour Map

CONCLUSION

The data collected on this engine cover has shown that the new damping material can function very well in a constrained layer damping treatment on a cast engine cover. Because of its thickness, it is particularly suited to cover surfaces that are rough and uneven. The design flexibility of the material makes it easy to optimize for a variety of covers and surface geometries. Bench testing on other types of cast components, such as valve covers and oil pans, have also shown very promising results.

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