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Development of an exhaust silencer for a counter balanced lift truck

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1. Introduction

This paper is on a project to design a silencer for an industrial truck (counter balanced lift truck). The existing silencer system on the vehicle failed to meet the client's requirements in terms of both performance and cost. The objective was to replace the existing silencer system with a cheaper and more effective solution. The new system should not adversely affect the back pressure or the sound quality compared to the existing system. The exterior shape of the silencer was specified by the client so as to not interfere with cooling of the vehicle.

In order to achieve this objective a test rig was constructed to assess various prototype designs. This rig used a centrifugal fan to blow air through a partition to the silencer being tested on the other side. To facilitate the adjustment of prototype designs a silencer that could be unbolted was constructed.

2. Methodology

Baseline sound pressure level measurements were taken on the vehicle to determine the sound power level of the vehicle with the existing silencer system. The measurements were taken in accordance with the standard:

> I.S. EN 12053 Safety of industrial trucks- Test methods for measuring noise emissions

The third octave frequency levels of the sound pressure level measurements were also noted.

The design of the silencer was based around the use of two expansion chambers. The prototype test model was constructed in such a way as to allow it to be unbolted and adjustments made to the interior. These adjustments included modifications to size and location of air inlet/connecting/outlet pipes, the adjusting the relative volume of chamber sizes and restricting/releasing airflow through the system.

The adjustable silencer was constructed using a cylindrical pipe section as the main body of silencer with a square steel endplates. The diameter of the cylinder fits within the area of the square. This allows threaded bolts to run through each corner of the endplate to the corner of the endplate on the other end so the silencer can be clamped between them and the join sealed. The two expansion chambers in the silencer were divided by a single circular partition that was tack welded in place with the edges sealed.

The adjustable prototype was then mounted on a test rig constructed and designed to test it. The rig featured an acoustic panel mounted in a one meter square aperture between two rooms. A pipe of the same diameter as the exhaust ran through the panel. A centrifugal fan fitted to one end of the pipe. It was used as a dynamic source, providing both a noise source and a gas flow. A flexible connection joined the fan to the pipe to isolate it from the rest of the test rig.

Figure 1 *The centrifugal fan mounted on the test rig**

*Originally the fan was mounted on a shelf attached to the panel in the aperture but this caused the panel to vibrate so the shelf was replaced with a separate support.

Figure 2 *A silencer fitted to outlet of the test rig.*

The adjustable prototype silencer was fitted to the end of the pipe on the other side of the panel to the fan. Sound pressure measurements were taken at a distance of 100mm form the air outlet point of the silencer, out of the direct airflow. Measurements were taken when there was no silencer fitted, with the existing vehicle silencer system fitted and when each prototype silencer variation was tested. The sound pressure measurements included third octave frequency measurements.

The final stage was to retest the vehicle and determine its sound power level with the prototype silencer fitted. These measurements are not included in this report but sound pressure measurements were taken in proximity to the exhaust while the vehicle was in the high idle operating condition and these are shown in the results section for indicative purposes.

3. Results

Frequency	No Silencer	Original Silencer	Prototype Silencer
Hz	dB	dB	dB
50	77.8	59.5	43
63	71.3	57	42.3
80	72.4	53.7	37.4
100	72.9	57.6	46.6
125	72.4	45.4	44.2
160	72.8	47.2	45.8
200	71	49.6	49.9
250	71	51.1	53.4
315	71.9	51.2	54.5
400	73.7	52.5	52.8
500	75.2	53.2	54.1
630	73.6	65.3	54.6
800	75.4	56.4	53.4
1 k	71.4	55.6	50.9
1.25 k	67.6	62.1	53.6
1.6 k	65.4	54.4	55.5
2 k	62.5	58	56.3
2.5 k	60.2	56	54.3
3.15 k	57.9	54.5	54
4 k	56.3	53.7	54.2
5 k	55.6	52.8	53.7

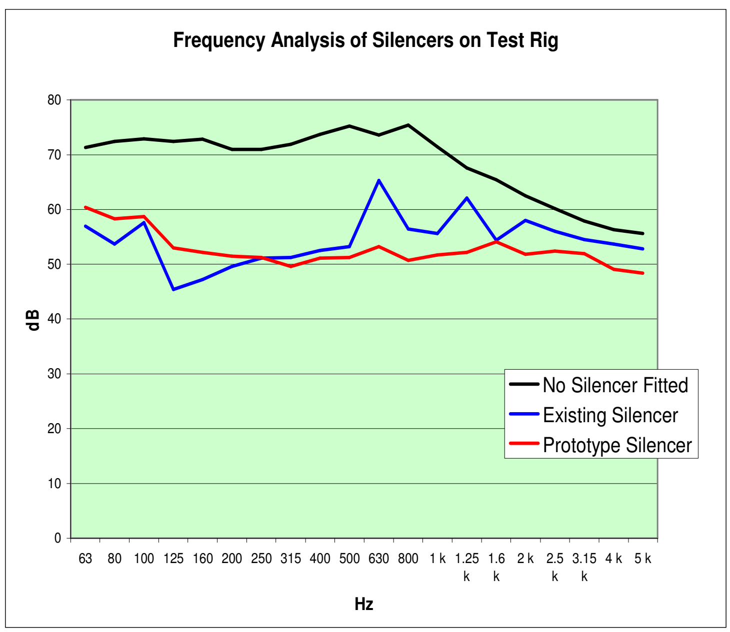

Figure 3 Frequency Analysis of Silencer on the Test Rig

Frequency	Oirginal Silencer	Prototype Silencer
Hz	dB(A)	dB(A)
63	30.8	28.6
80	31.2	33.7
100	38.5	38.3
125	29.3	36.4
160	33.8	38
200	38.7	38
250	42.5	39
315	44.6	42.6
400	47.7	41.6
500	50	41.9
630	63.4	42.9
800	55.6	47.3
1 k	55.6	52.2
1.25 k	62.7	55.6
1.6 k	55.4	47.8
2 k	59.2	48.9
2.5 k	57.3	51.3
3.15 k	55.7	45.7
4 k	54.7	41.7
5 k	53.3	40.9

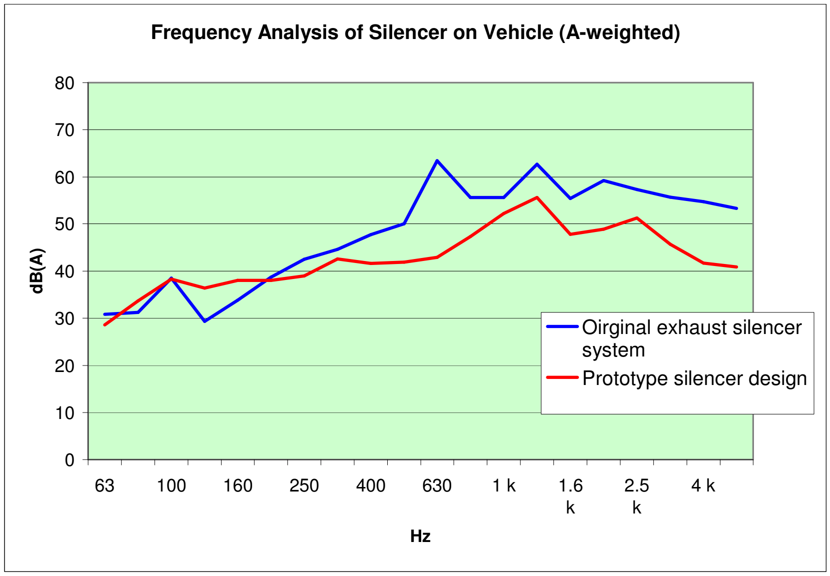

Figure 4 A-weighted Frequency Analysis of Silencer on the Vehicle

The new muffler not only met but exceeded the performance of the old mufflers in terms of

- Improved noise level at the operators ear
- Lower sound power level
- Improved cooling of the vehicle
- Improved sound quality
- Lower price.

4. Discussion

The ‘hands on’ nature of the testing proved key in developing the silencer. As the testing progressed it became apparent how even the slightest modification could dramatically change the performance of the silencer. This was particularly true for airflow, by either restricting or opening up the airflow through the silencer the acoustic performance of the unit was changed dramatically. In general the higher the air flow the better the performance at lower frequencies and the worse the performance at higher frequencies. The air flow rate varied, dependent on the silencer attached, from 0.015 m^3/sec to 0.02 m^3/sec. This means that the rig was less effective at predicting the performance on engines with higher exhaust gas flow rates.

Figure 5 below shows where a restriction was placed across the connecting pipe between the two expansion chambers. This proved very important in achieving the desired performance.

Figure 5 Connecting pipe between expansion chambers

Figure 6 shows the inlet pipe to the silencer which had the end blanked off but 10mm perforations were drilled into the side to allow the exhaust gas into the silencer. Even sealing individual perforations resulted in a measureable difference.

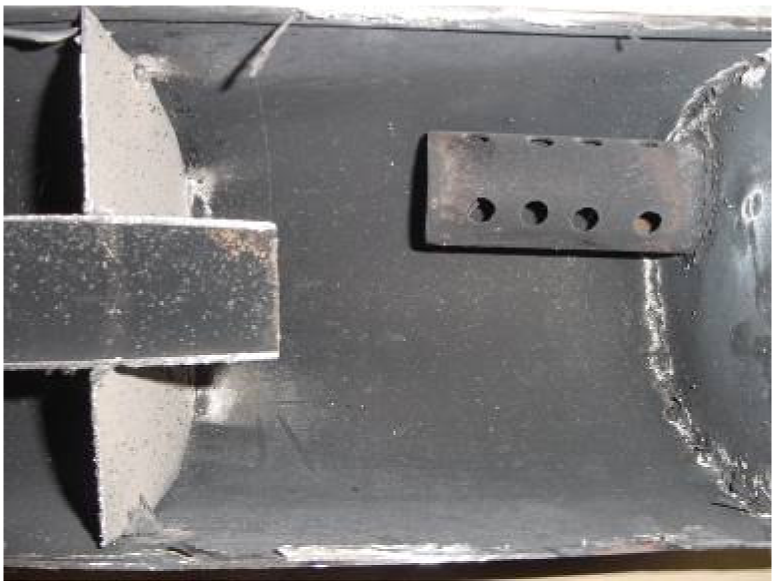

Figure 6 Inlet pipe to silencer.

The length of the expansion chamber was chosen based on a quarter wavelength of the target frequency. The target frequency was determined from sound pressure level measurements taken on the vehicle. The ratio of the area of the inside pipe to the area of the outside pipe was 25.

The final silencer prototype resulted in a vehicle that not only was quieter but also had an improved sound quality. This was subjectively determined from a blind folded comparison by the client's engineers/staff and is backed up by the frequency analysis which shows a marked reduction in the peaks measured on the original exhaust system.

5. Conclusion

This project began as a challenge to design a silencer for a vehicle. In order to achieve this, a test rig and an adjustable silencer prototype were also developed. During the development process it was found that small changes in design could have a significant effect on the silencer's performance. Therefore the ability to modify and re-test with relative ease was an enormous asset.

During the development process the project team perforce spent a lot of time with the silencer and the associated noise. This may have contributed indirectly to good sound quality as the more time spent exposed to the noise the more sensitive a person was to the changes in the noise due to any modification

This project was done without the use of any computer design package and as a result provided a level of insight into the acoustics that may not have been achieved otherwise