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Design and Evaluation of Noise Control Measures for a Pneumatic Nail Gun

Vignesh Jayakumar
Andrew Hubbard
George Schneider
Stephen Louie
2600 Clifton Ave
University of Cincinnati
Cincinnati, Ohio-45521
jayakuvh@mail.uc.edu

Edward Zechmann
National Institute for Occupational Safety and Health
cri6@cdc.gov

ABSTRACT

This paper describes the identification and noise reduction for major noise sources in a pneumatic nail gun. The objectives were to identify the major sources of noise, implement design changes to reduce the noise, and evaluate the effectiveness of the modifications. All sound power measurements were acquired in accordance with ISO 3744:2010. The sound output of the nail gun could be separated into two events: sound from the piston impact mechanism and sound from the exhaust event. For the piston impact event, the noise control effort concentrated on identifying the vibration transmission paths through the tool body. For the exhaust event, a custom muffler was designed. The impact and exhaust events were treated and analyzed separately. Wrapping foam around the nailer body and ducting the exhaust with a four foot-ten inch long hose, the impact event had a 6.2 dBA sound power reduction. In a separate measurement using the designed muffler and no wrap around the tool, the exhaust event had a 3.9 dBA sound power reduction.

1. INTRODUCTION

Pneumatic nail guns generate a high level of noise which can cause hearing loss. Workers must be adequately protected from pneumatic nail gun noise. Furthermore, hazardous noise exposures are regulated by OSHA to make sure that workers are adequately protected.[1-4] Pneumatic nail guns give rise to considerable air borne noise through the compressed air exhaust and structural noise through the piston strike. The focus of this work was to identify the noise sources and transmission paths of the noise in a pneumatic nail gun and to study feasible design changes to reduce those noise sources. The SENCO model Framepro 601 nail gun was used in these trials. The trials were divided into two parts: identification of the noise sources and the transmission paths for sound and the design solutions to reduce noise levels. The third octave band A-weighted sound pressure levels (SPL) of the proposed design changes were compared to the baseline measurements to compare the effectiveness of the design changes suggested.

The purpose of this study was to reduce the impact/structure borne and exhaust noises. We found sound power reductions of up to 6.2 dBA for the impact/structure borne noise with an integration time of 0.050 seconds and 6.1 dBA for the exhaust noise with an integration time of 0.046 seconds both integration times were normalized to 1.0 second. For the exhaust noise, a small custom exhaust muffler was designed. A design requirement of the muffler dimensions was the ability to fit between 16” spaced studs. The major source of impact noise was observed to be the nail driving through the wood. The secondary contributor to the impact noise was the structural noise radiating from the body as a result of the impact wave propagation. To mitigate this noise the transmission path was carefully studied and damping and sound absorbing material were applied to the exterior of the tool for comparison. To better understand the transmission path and identify the sound radiation pattern, an AC PRO Spherical, 48 microphone, 35 cm diameter, 192 kHz sampling rate acoustic camera was provided by Sage Technology. The acoustic camera had a resolution of approximately ±2 cm.

2. MECHANISM OF A NAIL GUN

The working mechanisms of the nail gun are shown below in Figures 1 and 2. On the left, the trigger is in its idle state which keeps the valve connecting the compressed air chamber and the piston stroke chamber separated. On the right, when the trigger is activated the valve closes the path of the compressed air to the top of the diaphragm and this opens the path for the compressed air into the piston stroke chamber. The piston is rapidly pushed downwards striking the nail and driving it into the wood. When the piston returns to its original position the compressed air in the stroke chamber is released through the exhaust port.

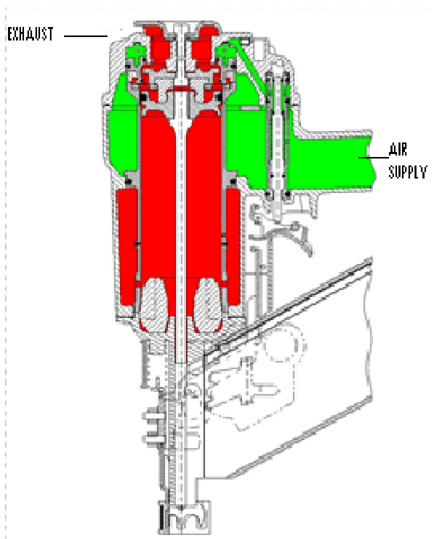


Figure 1 – Idle position

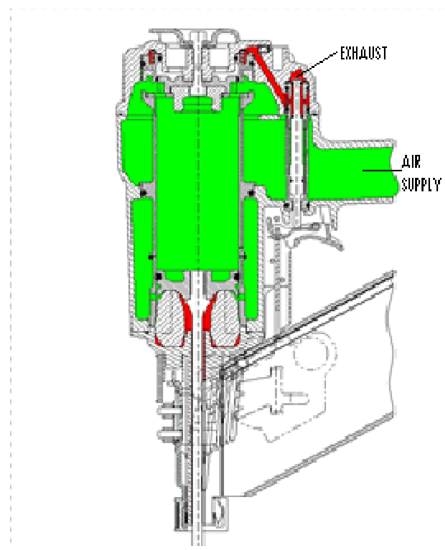


Figure 2 – Activated position

3. TEST SETUP

The nail gun noise levels were measured in a semi-anechoic chamber as per the ISO 3744:2010 standards.[5] Ten microphones placed on a 2.00-meter radius hypothetical measurement surface from the nail gun were used to make the sound power measurements. The test setup used for all the tests carried out in this study is shown below in Figure 3. Two-2"x4" wooden blocks were positioned horizontally on top of one another in a sand box. The nails were fired downward into the wooden blocks for the measurement procedure. The nails were fired from two different positions to reduce the effect of directivity and the effect of the tool operator body on the measurements. In position two the nailer is rotated 180 degrees and the tool operator has moved to the other side of the boards to fire the nails. Ten measurements were taken for each position.

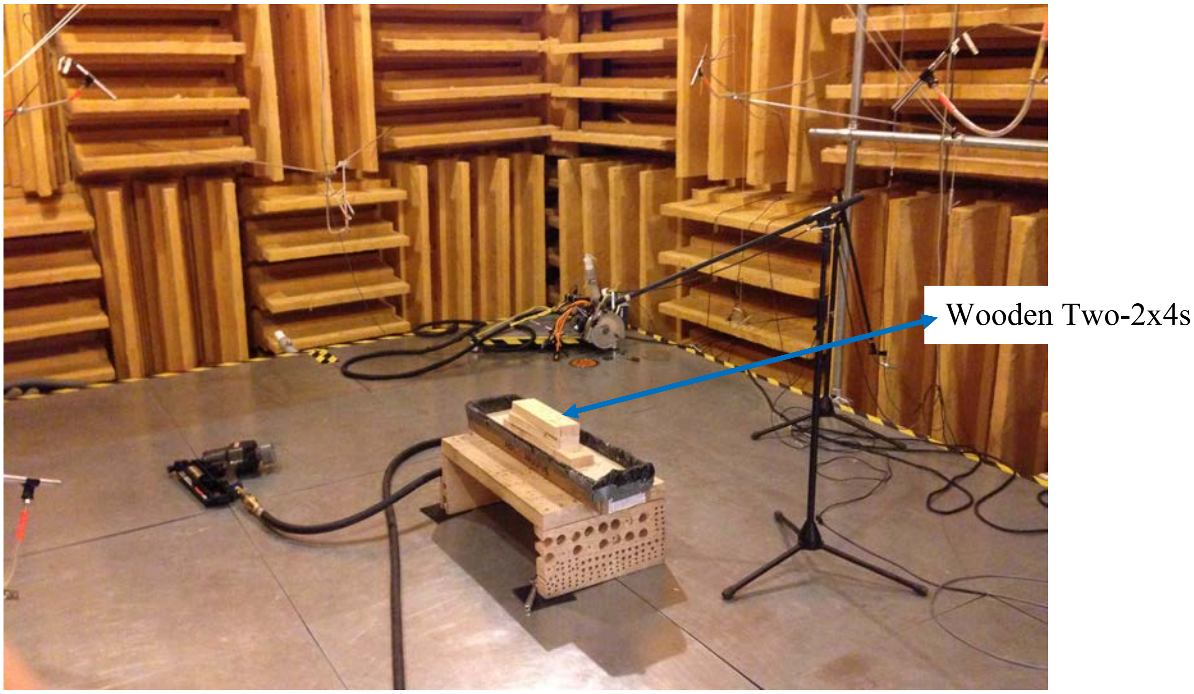


Figure 3 – Test setup. Wooden Two-2x4s are stacked in the sand box to receive the nails.

The measurements were processed using MATLAB to plot the A-weighted third octave band sound power. The data from the 10 microphones were spatially and temporally averaged for this procedure. The sampling rate was 100 kHz with a 1.0 second sampling window with the strike event pre-triggered to 300 milliseconds. The time domain data was manually used to demarcate the strike related noise and the exhaust related noise. The exhaust and strike related noise thus identified were processed and analyzed separately.

4. EXPERIMENT

For sound power analysis, the sound sources were demarcated and classified as two events namely: 1) strike related noise (structure borne) and 2) exhaust related noise (air borne). Figure 4 shows both the sound power analysis scheme and a few pictures from the acoustic camera analysis. The acoustic camera photos are shown on the top and labeled with letters (A through D. The strike noise is subdivided into three sub events (A) post-trigger pressure build up above diaphragm, (B) piston released, supply air flowing over the top of the piston forcing the piston downward, and (C) piston striking nail. The exhaust noise is (D) compressed air released through the exhaust port. These observations were made by similar previous work [6, 7]. The time window of the acoustic camera photos is 2.82 ms and each come from the colored areas of the time record respectively. The color bars of plots A-D represent different levels relative to the maximum sound pressure level within the analyzed time frame.

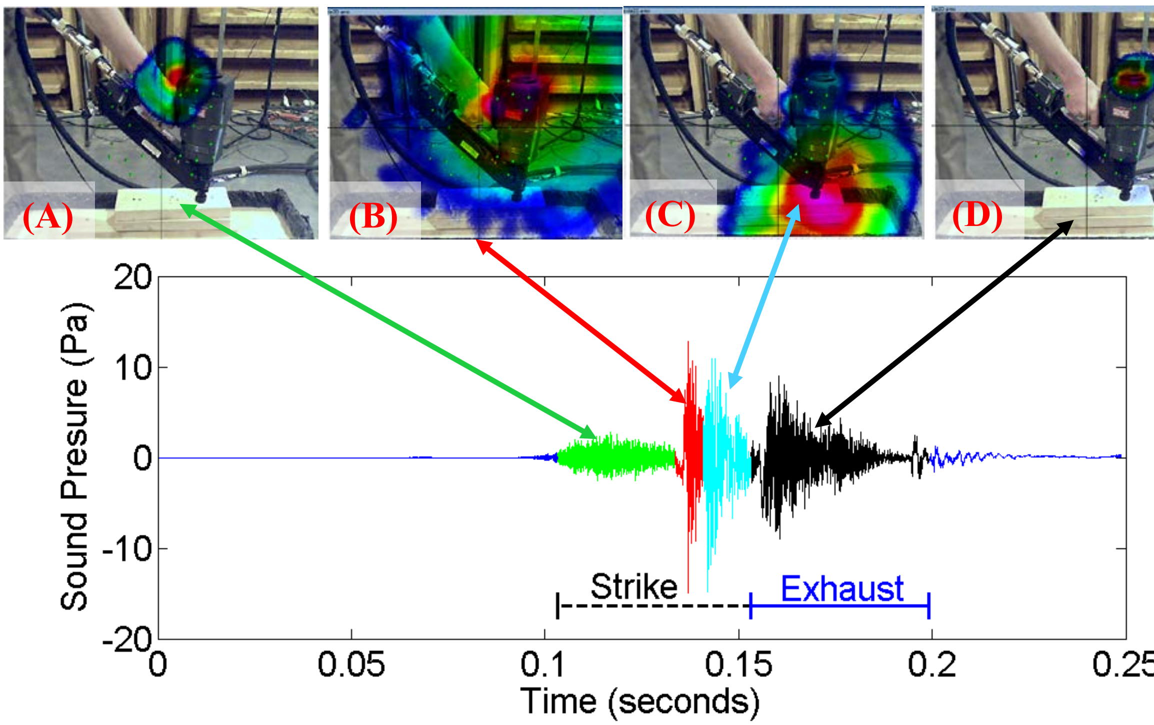


Figure 4 – Time history of the instantaneous pressure for a single fire of the nail gun. The strike event is within the dashed line on the left and exhaust event is within the solid-line on the right. The acoustic camera photos identify the noise sources during each cycle.

A. SOURCE IDENTIFICATION

The source identification was carried out by isolating the sound generated by the exhaust and by the body of the nail gun. The exhaust sound was isolated first with the help of an adapter and a 3/8 inch hose 4 ft. 10 inches long with an dissipative muffler used at the end. The idea was to try and take away as much of the exhaust noise as possible. A maximum of 6.1 dBA of noise reduction was observed with the foam wrapped around the tool and the exhaust piped out of the chamber (Figure 5 and Table 1).

Table 1: A-weighted sound power level comparison

Description of the trial configuration	L_W strike (dBA)	L_W exhaust (dBA)
Baseline	101.6	96.4
Baseline with exhaust noise attenuated by 4ft. 10 in. hose	99.7	90.3
Baseline with foam wrapped on body and exhaust noise attenuated	95.4	91.0
With design muffler	100.7	92.5

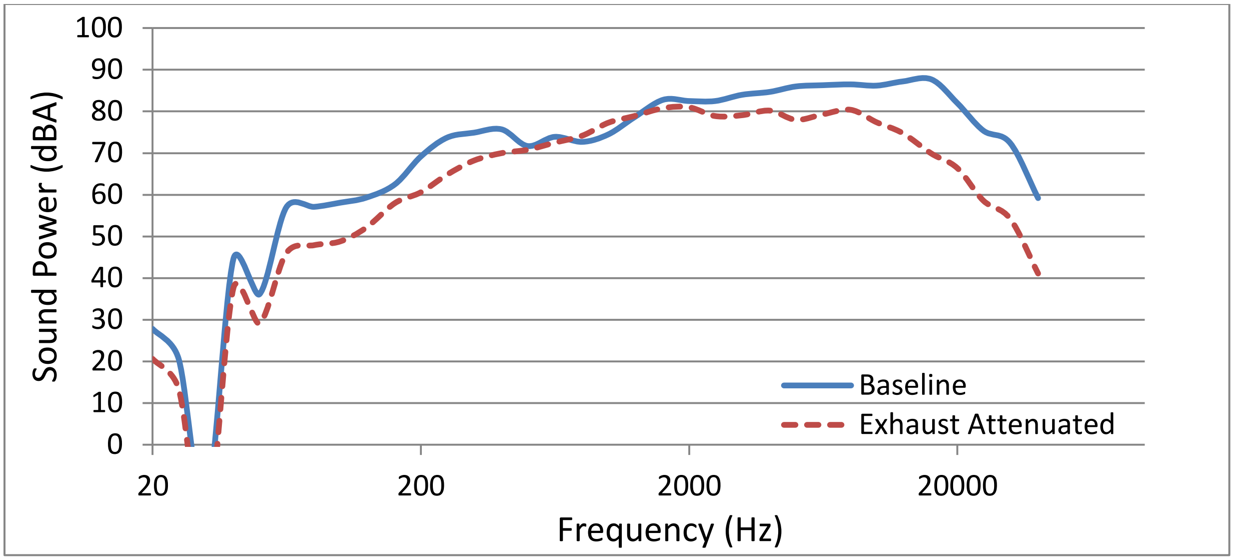


Figure 5 - A-weighted sound power one third octave –exhaust related noise

To identify the structural noise sources, the different parts of the nail gun were wrapped in foam material one by one and the measurements were taken in each of the cases for comparison. It was noticed that the area of the nail gun body corresponding to where the piston lodges itself back after the exhaust was the biggest contributor. Providing absorptive foam wrapping in this region helped reduce the noise levels by around 6.2 dBA. (Figure 6 and Table 1).

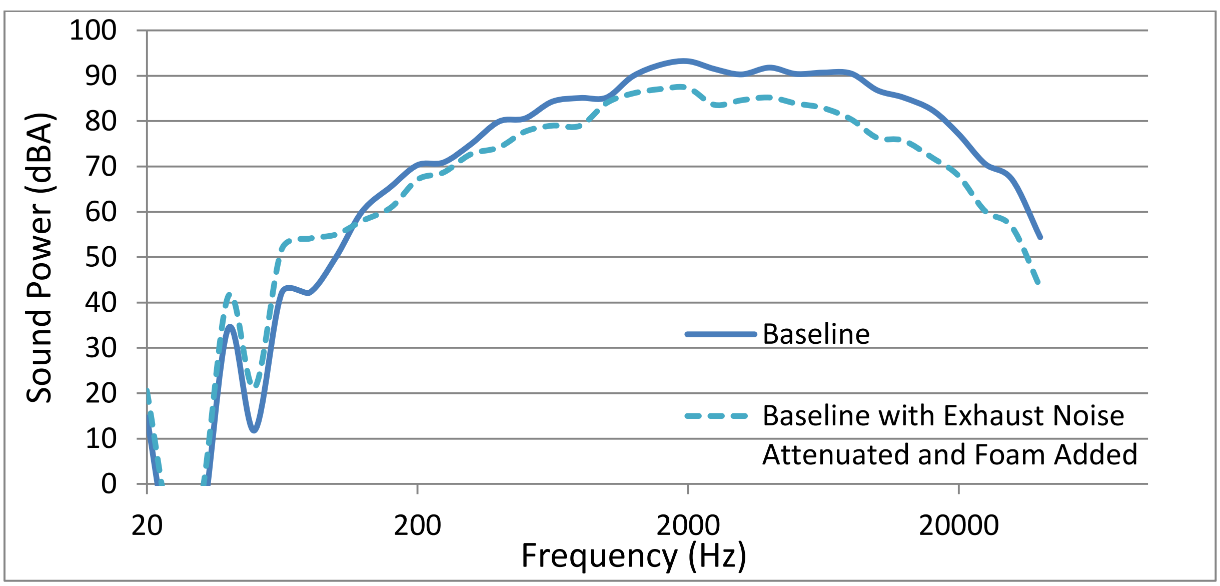


Figure 6 – A-weighted sound power one third octave – strike related noise

B. NOISE CONTROL MEASURES

1. MUFFLER DESIGN

A small volume muffler was designed and applied. The inlet pipe was modeled as a short pipe lumped system, the expansion chamber as a lumped volume and the tail pipe as a short pipe lumped mass. The four pole method was used for the design analysis[8, 9]. The transfer function defined in terms of the ratio of the output and input volume flow was used. An optimum muffler design from several possible combinations was obtained within the reasonable limits of design and usability constraints.

The four pole formulation of the muffler system shown in the figure below is;

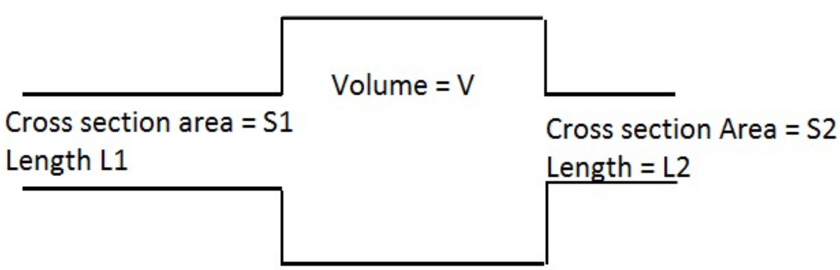
$$\begin{Bmatrix} Q_1 \\ P_1 \end{Bmatrix} = \begin{bmatrix} \cos(kL_1) & \dfrac{jS_1 \sin(kL_1)}{\rho c} \\ \dfrac{j\rho c \sin(kL_1)}{S_1} & \cos(kL_1) \end{bmatrix} \begin{bmatrix} 1 & \dfrac{j\omega V_2}{\rho c^2} \\ 0 & 1 \end{bmatrix} \begin{bmatrix} \cos(kL_2) & \dfrac{jS_1 \sin(kL_2)}{\rho c} \\ \dfrac{j\rho c \sin(kL_2)}{S_2} & \cos(kL_2) \end{bmatrix} \begin{Bmatrix} Q_2 \\ P_2 \end{Bmatrix} \tag{1}$$

$$= \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{Bmatrix} Q_2 \\ P_2 = 0 \end{Bmatrix}$$

where, L_1 and L_2 are effective lengths, k is the wave number and A, B, C, D are system four pole parameters. The transfer function is obtained as follows.

$$TF = 20\log\frac{Q_2}{Q_1} = 20\log\frac{1}{A} \tag{2}$$

The muffler dimensions are indicated in Figure 7 and the accompanying table below.



S1 (m^2)	0.001065
L1 (m)	0.01905
V (m^3)	0.000197
S2 (m^2)	0.000335
L2 (m)	0.0254

Figure 7 – Muffler schematic diagram and dimensions of muffler geometric parameters

2. RESULTS

Use of the muffler reduced the exhaust related noise by 3.9 dBA as compared to the maximum 6.1 dBA (the reduction when the exhaust is piped out of the room). This reduction was achieved with a very simple design, thus incurring minimal cost and without compromising on the ease of usability of the equipment. If usability and cost factors were to be neglected, it would be possible to have further reduction with bigger mufflers and use of absorptive material in the muffler. By increasing the size of the muffler chamber or of the tail pipe it would have been able to further lower the cut off frequency of the system and get reduction in exhaust noise in lower frequency range too. The exhaust related noise result with the custom designed muffler is highlighted in Figure 8 and Table 1.

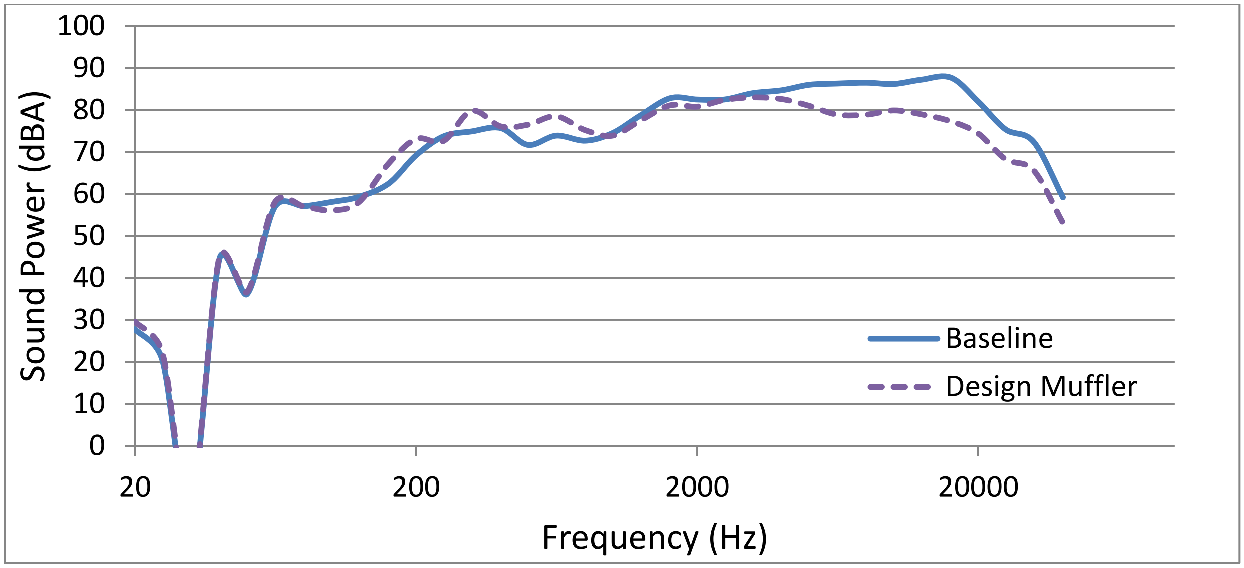


Figure 8 - A-weighted sound power one third octave –exhaust related noise

5. CONCLUSION

The noise performance of a nail gun was studied to develop sound reduction measures. The performance of the pneumatic gun and ability to fire nails repeatedly are quite finely balanced on the operating pressure, flow restrictions, and freeze up. Slight changes in these could lead to malfunctioning of the nail gun. Therefore, the impact generating mechanism itself was not a part of this study. Hence this study focused on attenuating the sound by design changes on the noise transmission path and design of an exhaust muffler. The flow impedance caused by the muffler and hose used in this study did not adversely affect safety or productivity. The type of setup used in the test and the type of wood and nails used to carry out this study are likely to affect the measured sound power levels.

It was shown that a noise reduction of up to 6 dBA can be achieved by the damping material and muffler. Further reduction of noise in this case could be achieved through design changes to address directly the sound sources. The use of softer material between the piston and its seat to create impedance mismatch, change in design of the body to make it stiffer so as to reduce noise transmission via structural vibrations etc. are possible solutions that can be addressed as future work towards reducing the strike related noise.[10] Structural noise can be further reduced by adding a viscoelastic damping treatment [11]. The overall cavity design of the exhaust pathway can also be studied with regards to the design of the chambers and the bleeder holes used in the equipment to bleed the exhaust out from it.

ACKNOWLEDGEMENTS

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