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Appliance and Compressor Manufacturer's Joint Effort to Reduce Noise

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ABSTRACT

Appliance manufacturers establish standards to meet customer's requirements. Whirlpool of India (WOIL) surveyed its market and converted the customer's need for a quiet appliance into an acceptable sound level when tested in their reverberation room. Tecumseh Products India Limited (TPIL), a major compressor supplier to WOIL, was made a partner in meeting this standard. The standard specifies a maximum overall sound power level of 46 dBA for the refrigerator when tested in the WOIL reverberation room.

The compressor manufacturer reviewed their compressors for sound, vibrations and pressure pulsations. It was found that near 400 Hz, which is the 8^{th} harmonic of the running frequency of 50 Hz, both sound and discharge pulsations were high. This resulted in a overall sound power level of 50.6 dBA. The sound reduction was made at Tecumseh Research facilities in India and also at Tecumseh Research Labs in the USA. Joint work at these three places resulted in better time management for designing, verifying and validating the changes required to reduce the sound power levels to 45.0 dBA on the appliance.

The final customers of this new model refrigerator, with reduced sound, will reap the benefits of WOIL-TPIL team work.

INTRODUCTION

Refrigerator sound testing at WOIL is done in a reverberation room as shown in Figure-1. Sound levels are reported in 1/3 octave levels. Correction factors at each of the frequencies are applied, according to ISO 3741:1988(E) annex C, to obtain 'A' scale sound readings.

The acceptance standard of WOIL and the sound levels of the existing compressor are shown in Figure-5. Since the overall noise is above the acceptable limits, a project for improvement was accomplished.

The noise test lab at TPIL is a semi-anechoic room. The sound lab at Tecumseh Ann Arbor is an anechoic room. A correlation between the test results was established for the three labs in order to make the design work acceptable for the final test at WOIL.

Initial sound tests identified peaks near 400 Hz in the both the discharge pulsation and the suction path. Muffling system review was made from measurements as given by Anatomy of Sound [1], Rajinder Singh and Werner Soedel [3] and James Hamilton [8].

In an earlier study [7] we had reviewed the representation of hermetic compressor muffling system by transfer matrix formulation of Munjal [3] and by Finite Element Method of Craggs [2]. In this study the muffling system was represented by a 1D model using a Four Pole Acoustic Method (FPAM) derived from the work of Victor L. Streeter [4] and Prakash J. Thawani [5]. A simple one-dimensional acoustic element is found sufficient for studying acoustic properties of a pipe system where the transfer dimensions are small compared to the wave length. Also the plane wave theory assumed in the 1D model restricts the accurate predictions up to 6000 Hz only in hermetic mufflers where the Mach number is below 0.1. As our frequencies of interest were around 400 Hz, which falls in the lower band, a 1D model was found sufficient.

ANALYSIS

The reverberation room at WOIL is shown in Figure-1. The location of microphone boom is as per ISO:4758-1968 entitled "Methods of Measurement of Noise Emitted by Machines". The microphone should be a minimum of $\lambda/4$ from the wall, where λ is the wave length of the sound at the lowest frequency of interest.

Thus η should be $\geq \lambda\ max \div 4$
At 63 Hz $\lambda = 350 \div 63 = 5.5$ m
$\lambda \div 4 = 1.4$ m

For the microphone to be sufficiently away from the source to be in the reverberant field and not in the near field of the source, a minimum distance of $2/3\ v^{1/3}$ is recommended, where v is the volume of the room.

Or $Y \geq 2/3\ v^{1/3}$. However, rotation of boom should be accounted for.

V = Reverberation chamber volume = 204.55 cu.m.
s = reverberation chamber surface area = 221.6 sq.m.
α = coefficient of absorption = 0.04257 for WOIL room
T = Reverberation time = 0.161 (V/A) = 3.5 sec.
$A = S * \alpha$
Lw = Lp - 10 log (4/A) for a reverberation room where only diffused sound, i.e. constant everywhere in the room.
Lw = Sound Power Level and Lp = Sound Pressure Level

The muffling system on the suction and discharge side requires a procedure for analyzing behavior of sound waves in pipe networks. In the four-pole analysis a transfer matrix method is used [3] & [4]. Acoustic pressure p and mass velocity v are the state variables and for the r^{th} element, the element transfer matrix is :

$$\begin{pmatrix} p_r \\ v_r \end{pmatrix} = \begin{pmatrix} T11 & T12 \\ T21 & T22 \end{pmatrix}_{r^{th}\ \text{element}} \begin{pmatrix} p_{r-1} \\ v_{r-1} \end{pmatrix}$$

and transmission loss $T_L = 20 \log_{10} (| p_{r-1} | \div | p_r |)$ dB

The transfer matrix technique is ideal for dealing with chainlike structures. Our modeling using FPAM (four pole acoustic method) requires the length and diameter of equivalent pipe sections of the muffling system.

Figure-2a shows the line diagram of the existing suction muffler FPAM model; suction gas inlet is at IN and it goes out to cylinder head at p∅. The network is approximated by pipes with each end of the pipe terminating at a node. Figure-2b shows the line diagram for the modified suction muffler.

Figure-3 shows the existing discharge muffler model. In this model, inlet to the cylinder head is at IN and the flow follows parallel paths to nodes M5 and M7 which are also connected by a crossover tube 14. In the modified version pipe 4 is blocked making the gas follow a series path through pipe 4.

The effect of the modified discharge muffler is seen in the discharge pressure pulsations shown in Figure-4. At 400 Hz the reduction is more than 20 dB and at 4000 Hz the reduction is more than 10 dB. This resulted in a reduction of transmitted vibrations to the system through the anti moisture tube.

During the final test of modified compressors in refrigerators at WOIL's reverberation room, the overall sound power was below 45 dB and therefore acceptable. The effect of modifications to the suction and discharge mufflers is shown in Figure-5.

CONCLUSION

The joint effort by the teams from WOIL, TPIL and Tecumseh Labs has reduced the sound of finished refrigerators to bring it below the customer's acceptable levels. Teamwork helped in cutting down the design time and establishing a correlation between the three test labs. The modifications made to this compressor can also be adopted in other compressors of the same series.

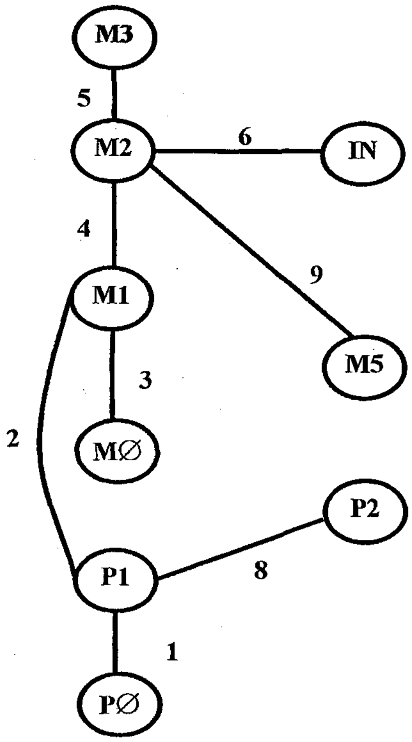

FIGURE-2a
EXISTING SUCTION MUFFLER MODEL

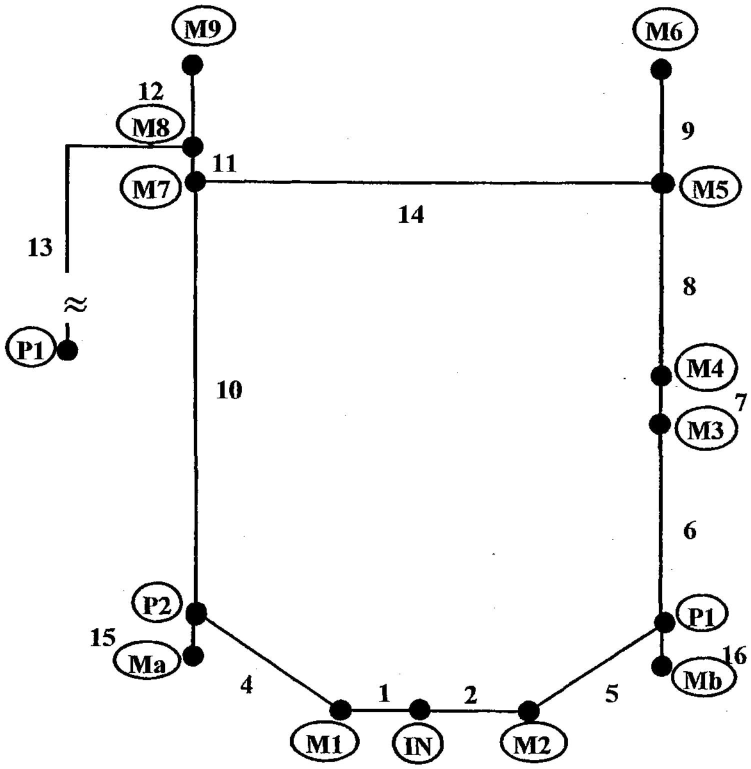

FIGURE-3
DISCHARGE MUFFLER MODEL

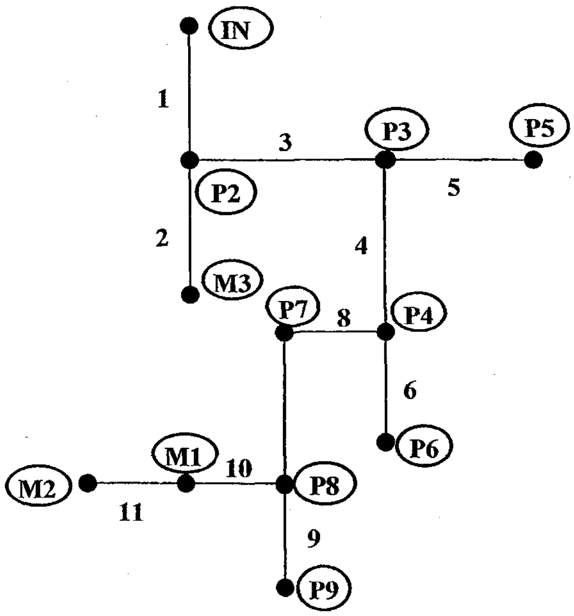

FIGURE-2b
MODIFIED SUCTION MUFFLER MODEL

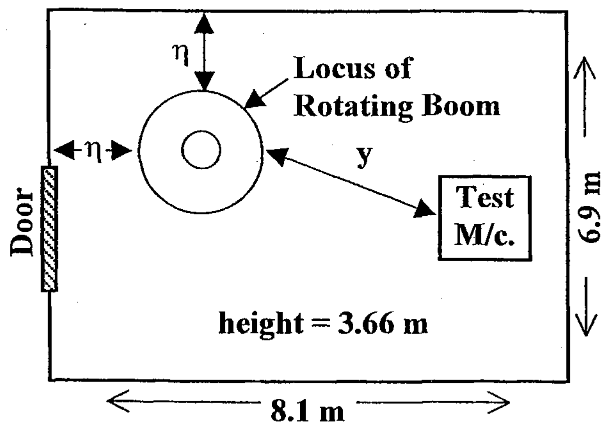

FIGURE-1
REVERBERATION ROOM AT WOIL

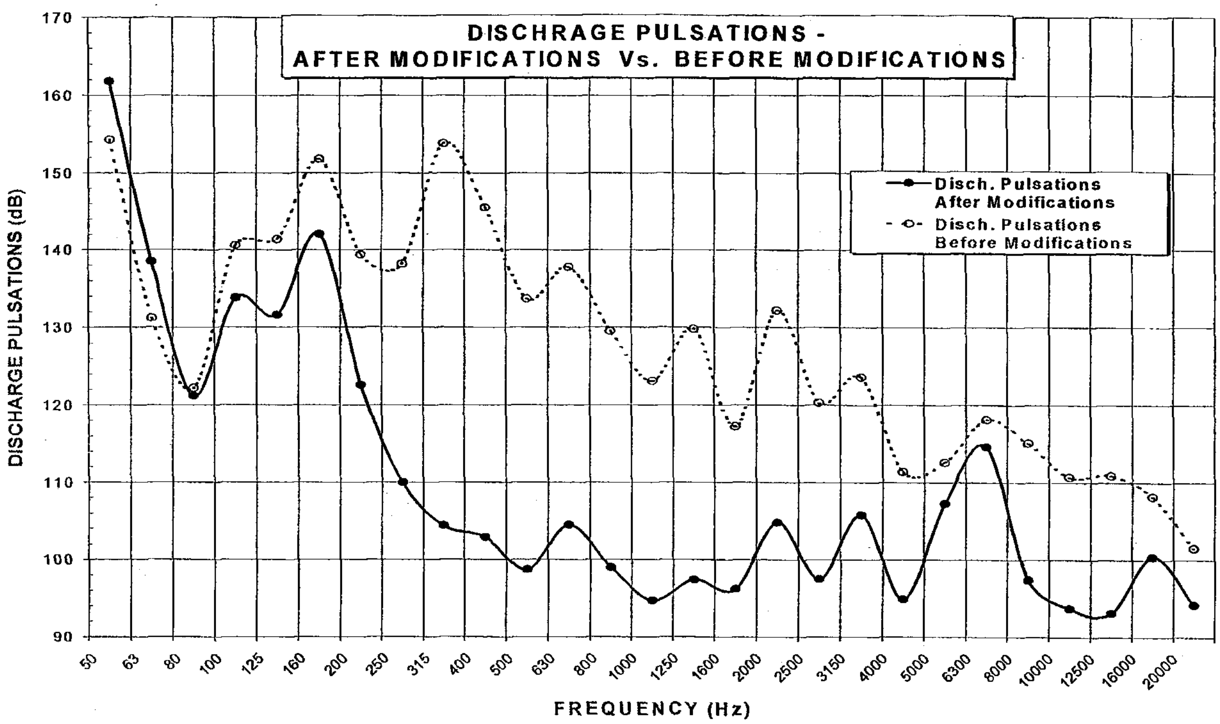

FIGURE-4

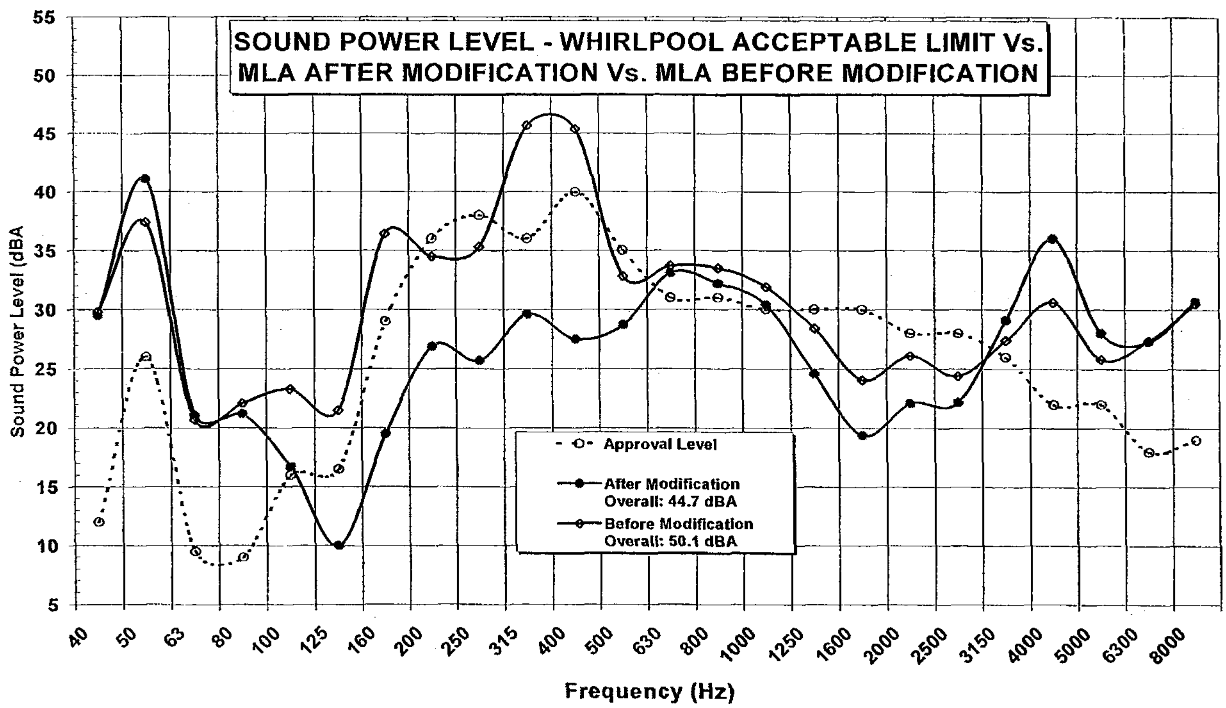

FIGURE-5

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