

Flow-Induced Whistle in the Joint of Thermal Expansion Valve and Suction Tube in Automotive Refrigerant System

Manfred Koberstein, Zhengyu Liu, Curtis Jones, and Suhas Venkatappa
Ford Motor Co.

ABSTRACT

In the thermal expansion valve (TXV) refrigerant system, transient high-pitched whistle around 6.18 kHz is often perceived following air-conditioning (A/C) compressor engagements when driving at higher vehicle speed or during vehicle acceleration, especially when system equipped with the high-efficiency compressor or variable displacement compressor. The objectives of this paper are to conduct the noise source identification, investigate the key factors affecting the whistle excitation, and understand the mechanism of the whistle generation. The mechanism is hypothesized that the whistle is generated from the flow/acoustic excitation of the turbulent flow past the shallow cavity, reinforced by the acoustic/structural coupling between the tube structural and the transverse acoustic modes, and then transmitted to evaporator. To verify the mechanism, the transverse acoustic mode frequency is calculated and it is coincided to the one from measurement. In the end, the recommendations for preventing the system from having whistle are also provided.

CITATION: Koberstein, M., Liu, Z., Jones, C., and Venkatappa, S., "Flow-Induced Whistle in the Joint of Thermal Expansion Valve and Suction Tube in Automotive Refrigerant System," *SAE Int. J. Passeng. Cars - Mech. Syst.* 8(3):2015, doi:10.4271/2015-01-2275.

INTRODUCTION

Vehicle interior quietness is one of the major quality attributes which affects the ownership satisfaction or even the purchasing decision of the critical customers. Nowadays, since significant progress has been achieved on the control of the major noise sources such as powertrain NVH, road NVH and windnoise, the traditionally secondary noise sources with relatively lower noise levels (such as flow-induced transient whistles, hiss and gurgles) from the refrigerant system become audible, and even annoying due to the reduced masking level in the higher frequency range (1000Hz and above) when climate control system operating at low blower speed.

Audible tones and whistles induced by the automotive refrigerant system are classified into four categories [1]: (1) A/C compressor induced tones (moan, whine); (2) Plate-fin type evaporator induced tones (transient - hoot or whistle) due to the formation of acoustic standing waves between plates or in the tank [2]; (3) Refrigerant flow-induced transient tones in the A/C lines such as high-pitched tone generated at the suction charge port, and (4) TXV related trumpeting noise following A/C engagement [2].

In this paper, the noise source identification and mechanism of the high-pitched whistle generated in the joint of TXV and suction pilot tube are investigated and studied. Recommendation for the suppression of the suction pilot tube whistle is also presented.

REFRIGERANT FLOW-INDUCED TRANSIENT WHISTLE IN SUCTION PILOT TUBE

Flow-Induced Transient Whistle

Figure 1 shows the configuration of the TXV connections with inflow suction tube and outflow liquid tube.

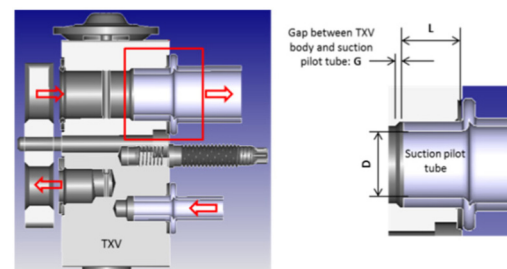


Figure 1. TXV connections with suction/liquid tubes

During the assembly process, the suction pilot tube can be damaged if it is not seated prior to the nut having the thread engagement. To avoid this failure mode, one of the solutions is to extend the length L of the pilot tube from 8 mm to 11mm. However, in one development vehicle with 11mm long suction pilot tube, a short (2 ~ 3 seconds) but pretty audible high-pitched whistle was perceived following A/C compressor engagements while driving at 2500 engine rpm and above or during vehicle acceleration. Figure 2 shows a measured driver's right ear sound FFT vs. Time spectrogram following A/C engagement at 3250 engine rpm, and the whistle frequency is measured around 6.18 kHz.

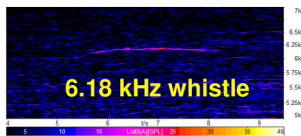


Figure 2. Transient whistle perceived in vehicle interior

Whistle Noise Source Identification

First, the vehicle level investigation was conducted in vehicle level. Along with the microphones at driver's ears, the uni-axial accelerometers were placed at the TXV inlet (liquid tube), and TXV outlet (suction tube) in the engine compartment. Figure 3 shows the noise & vibration spectrograms at 3250 engine rpm. It is clearly shown the 6.18 kHz whistling noise source is in the suction line because the whistle frequency correlation between the sound and suction line vibration is in excellent agreement. It was also noticed the transient whistle frequency 6.18 kHz is independent of vehicle speed.

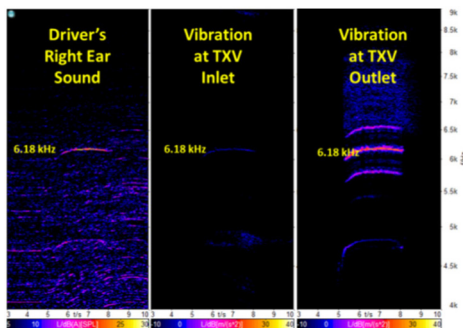


Figure 3. Interior sound and A/C line vibration spectrograms at 3250 engine rpm

In order to further conduct the whistle noise source identification and develop the optimal design, the Refrigerant Sub-system (RSS) level test method on flow-induced transient NVH (hiss, gurgle, and whistle) was used [3]. The RSS NVH test allows upfront TXV & evaporator NVH assessment including the cost-effective damping design and structural isolation design as well as RSS flow-induced NVH root cause study on various compressor systems with both R134a and 12334YF refrigerants. Also, the RSS NVH testing improves the design efficiency significantly.

The system was instrumented with two microphone at the specific positions, and the uni-axial accelerometers at the TXV inlet (liquid tube), and TXV outlet (suction tube). The experimental investigation was focused on three aspects: (1) Recreate the transient whistle on bench; (2) Identify the whistle noise source; and (3) Investigate the feasible design proposal.

Figure 4 shows the sound spectrogram comparison between vehicle level and RSS level when A/C engagement at 3000 engine rpm, and it is demonstrated the RSS test can readily induce the exact audible whistle perceived in vehicle interior.

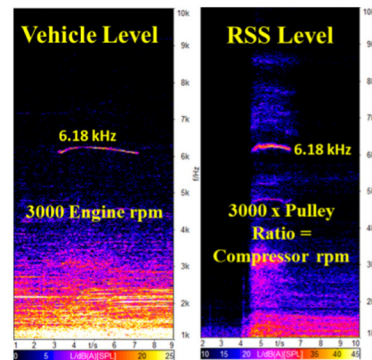


Figure 4. Whistle sound spectrograms at 3000 engine rpm: vehicle level vs. RSS level

Subjectively, the whistle is pretty audible and sounds radiating from the close proximity of TXV in the quiet chamber. Figure 5 confirms the whistle source is located at the joint of suction tube and TXV because the vibration level at 6.2 kHz in suction tube side is much higher than that in liquid tube (TXV inlet).

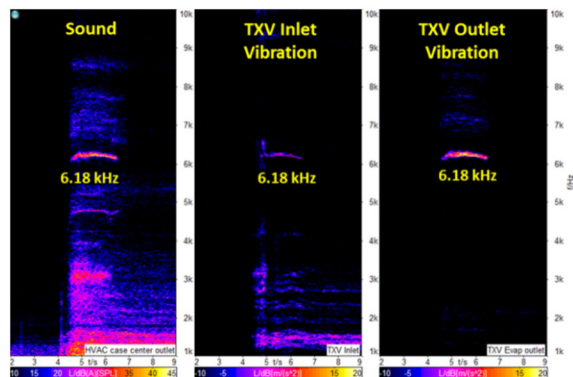


Figure 5. RSS level Sound and vibration spectrograms at 3000 engine rpm

Key Factors and Design Solutions

To fully understand the root cause and identify the design solution, a set of tests were conducted on the key factors: (1) Suction pilot tube length - 8.0mm, 9.0mm, 10.0mm, 11.0mm and 12.0mm; (2) Chamfered pilot tube ID 45° / 1.5mm (Figure 6a); (3) Chamfered pilot tube (Figure 6b); and (3) smoothed TXV suction port edge (Figure 6c).

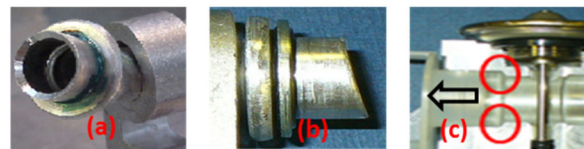


Figure 6. Test configurations: (a) Chamfered pilot tube ID 45° / 1.5mm; (b) chamfered pilot tube; and (c) rounded TXV suction port end

Figure 7 shows the effect of the suction pilot tube length on the introduction of the 6.18 kHz whistle. Both 8.0mm and 9.0mm pilot tube configurations do not exhibit the audible whistle, but objectively