Some considerations on vibrations and noise of automotive HVAC system

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Some considerations on vibrations and noise of automotive HVAC system

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Abstract. The heating, ventilating and air conditioning system (HVAC) is one of the basic components of modern cars. At the same time, the system is a high energy consumer. The comfort of the passengers depends on its performance, and a malfunction influences the performance of the car. In the case of closed spaces (cars) factors such as humidity, air flow, noise and vibration influence the feeling of comfort. The purpose of this work is to analyse the vibrations and noise that occur when the air conditioning system works, because they are influencing the comfort of the passengers. Literature review is useful in designing more efficient system reducing noise and vibration in the passenger compartment.

1. Introduction

The year 1930 marks the beginning of the study of vapor compression with the help of a refrigerant. In 1939, the first cars were already equipped with the Wheather Eye air conditioning system, developed by Nash Motors. In 1964, Cadillac introduced automatic control of the ventilation and air conditioning system. Although the technology has evolved, the starting concept used by the manufacturers has been to improve the existing systems on the market [1]. This step is a major step towards a safe and comfortable journey. The optimum concentration of the driver during a trip is between 20 and 22 ° C. Studies show that increasing the temperature from 25 to 35°C reduces a person's concentration and reaction rate by about 20 percent [2].

If in the past the system took up a lot of space and did not offer many functions, now the manufacturers have managed to develop compact systems that provide control over temperature, air flow, recirculation function and various options for removing unpleasant odors. The air conditioning system has become a standard option for most manufacturers because it does not involve high costs.

Regardless of the manufacturer of the car, the components of the ventilation and air conditioning system are approximately the same. În figure 1 is presented a simple construction of HVAC system, where we can identify: A - magnetic clutch compressor; B - condenser (dissipates heat in the environment); C - dehumidifier; D - pressure sensor; E - maintenance hole (high pressure); F - expansion valve; G - evaporator (takes heat from the inside); H - maintenance hole (low pressure); I - passenger compartment fan.

An air conditioning system needs a refrigerant to work. The compressor is the one that converts by means of pressure into liquid state the refrigerant called freon (gas).

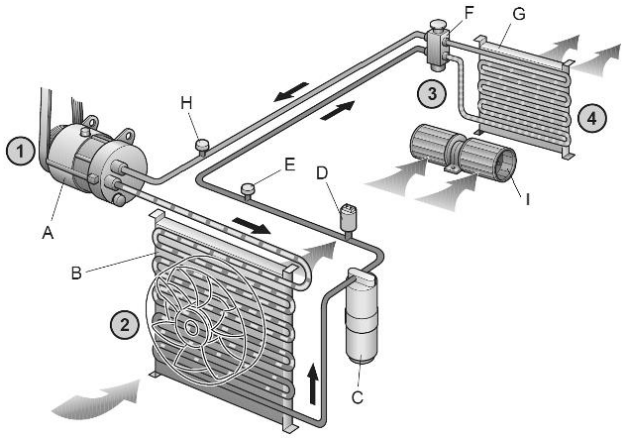

Figure 1. HVAC construction [2].

2. Compressor faults

The compressor (A), driven by a thermal or electric motor takes the refrigerant (freon) in gaseous form, compresses it and sends it to the condenser. Like any other system in the car's equipment, the HVAC (Heating, Ventilation and Air Conditioning) system can create various operating problems.

The air conditioner compressor is also one of the component parts of the air conditioner system that is causing problems (figure 2). Signs that indicate a malfunction are abnormal compressor noise, oil traces and sometimes failure to start the engine. The causes of the defects can be: manufacturing defects, low oil level or wear. Solving these problems involves replacing the part [3].

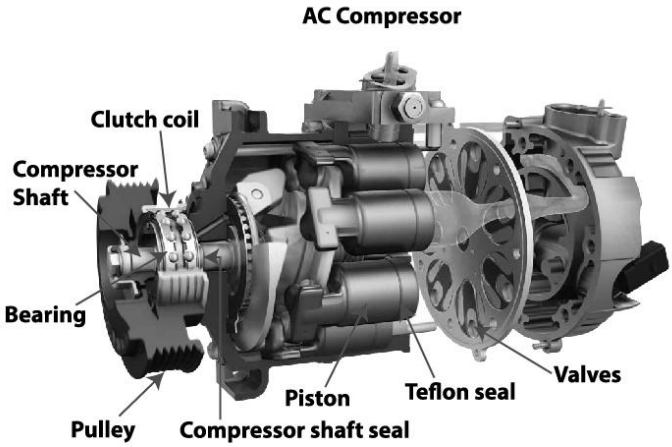

Figure 2. Section compressor [4].

3. Human technical comfort

The technical comfort is represented by all the parameters controlled with specific equipment, capable of influencing the human disposition and acting on his senses. These include: thermal, acoustic, visual and olfactory comfort.

Acoustic comfort is the ability of man to make the difference between sound and noise. Without proper analysis, acoustic comfort is a subjective parameter.

The definition of sound can be made from three perspectives:

- physical phenomenon - elemental vibration of elastic material probed in the form of a wave;
- external excitation of the auditory organ with direct influence on the reactions;
- information decoded by the human brain that can influence people's reactions.

Sounds negatively perceived by humans are called noise. Depending on the interpretation, the man makes the difference between sound and noise [5].

The air conditioning system must meet the needs of human comfort, both thermally and acoustically. On the other hand, the manufacturers of components for the air conditioning system must meet a series of quality characteristics for the production of parts and other requirements that come from the car manufacturer.

Behind the control panel of the climate system there are many components, which, only through proper functioning, provide us with a quality air in the passenger compartment, so comfort and safety during travel. With the advent of hybrid or electric cars, the requirements for ventilation and air conditioning systems are becoming more stringent.

Valeo company says that one of the highest number of complaints are registered for a high level of noise. The recommendations of the competent authorities are taken into account since the design phase. All companies need to know very well both the legal regulations and the end user requirements. In the production line, Valeo, uses a contactless vibrometer to monitor the vibration level. Collaborations between the producer and the academic environment provide classifications of HVAC systems from users [6].

Figure 3. Method of reducing noises în passenger compartment [6].

Figure 3 shows a method tested by Valeo for noise reduction inside the car. To solve a common problem among the user, the company tested soundproofing materials, capable of reducing noise that would be in the case of direct contact between different components.

4. Vibrations and noise of the HVAC System

Vibrations are usually referred to unwanted movements that produce relatively large mechanical noise or stresses. According to the “Explanatory Dictionary of the Romanian Language” (DEX-1998), the vibration is a “periodic movement of a body or of the particles of an environment, carried out around a position of balance”. The oscillation represents "the periodic variation in time of the values, of a size that characterizes a physical system, accompanied by a transformation of energy from one form to another". Mechanical oscillations are dynamic events characterized by the variation in time of a system state magnitude, usually in the vicinity of the value corresponding to a steady state.

Any body with mass and elasticity can vibrate. A vibrating system has both kinetic energy and potential energy. During vibrations, a potential energy transformation is made into kinetic energy and inverse. In a system without energy dissipation, the total mechanical energy is constant. At the position of maximum amplitude of the displacement, the instantaneous speed is zero and we can say that the system has only potential energy. In the static balance position, the deformation energy is zero, which means that the system has only kinetic energy. The maximum kinetic energy is equal to the maximum deformation energy. If we consider the two energies equal we can calculate the fundamental frequency of vibration. This is the principle of Rayleigh's method [7].

We must keep in mind that vibration is one of the first signs of a problem in a system or machine. The vibration level of a system can help us to identify its functioning state. Common causes that give rise to vibrations are the tolerance of the parts execution and the contact between the moving parts.

Most of the time the occurrence of vibrations leads us to the thought of reducing the life of a system, in our case air conditioning compressor [8].

Noise that occurs when the air conditioning system is operating contribute to the noise produced by road traffic. We all know that we are trying to reduce all types of pollution. The noise produced by the HVAC system during vibrations can be of several types: humming, hissing, clicking and air-rushes. The study of these noises is done to determine their causes. In the study by Satar et al. the noise type is studied [9]. We only considered the noise and vibration measurements from the air conditioning (AC) compressor.

Tachometer, accelerometer, microphone and sound camera were used for analysis. They were used both in idle state of the engine (850 rpm) and in running (850-1400 rpm). In both situations the speed of the blower was the same. The results show us that the humming noises type occurs both in resting state and in operation in the range 150–250 Hz and 300-350 Hz.

Noise from the AC system reduce the comfort level of the occupants and makes major problems for car manufacturers. The compressor, blower, screws and air pipes are just a few components that can produce vibrations and noises in operation. The blower is a carefully checked piece because it is behind the board, so close to the passenger compartment.

Mavuri et al. [10] identify the methodology for measuring the noise in the vehicle, the instrumentation to be used, the test parameters involved and the configuration procedures. Noise measurement is done in 4 conditions: neutral mode - HVAC off, neutral mode - HVAC in FFRC (Full Race-Full Cold-Re-Circulation) mode, driving mode - HVAC off and driving mode - HVAC FFRC. The identification of the sources of noise began subjectively.

After establishing the instrumentation, the content data was frequently taken for analysis and verification (figure 4).

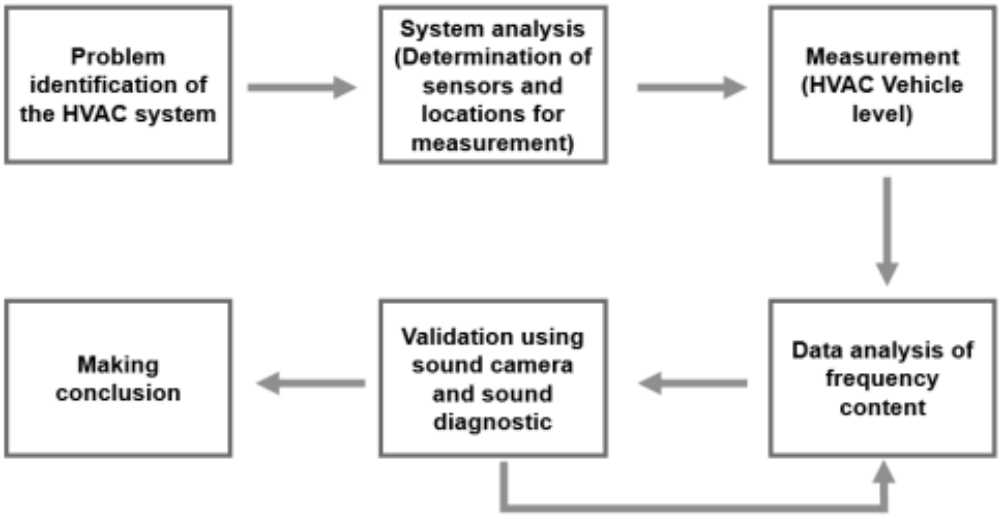

Figure 4. Methodology for analysis [9].

The process is a very important one for the manufacturers because this way they can establish the methods of reducing the noise in the car interior.

Figure 5 shows the flow diagram of the test and the test and measurement location of vibrations and noise produced by the HVAC system. The sensors used in the experiment were: tri-axial accelerometer (x-y-z directions) for vibration measurement; microphone for measuring noise and

tachometer for measuring speed tracking. Finally, the sound room was used to verify the collected data.

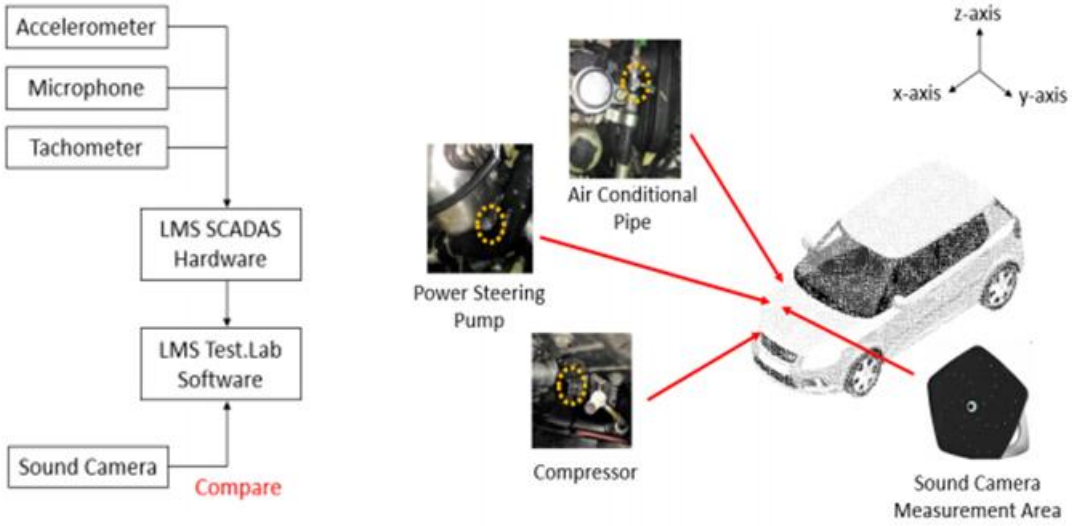

Figure 5. Test flow and locations for noise tests [9].

The microphone mounted in the compressor area helps to collect data. In the next step the data is useful in noise verification. With the help of the sound camera you can record the frequency range of the noise.

Using the frequency analysis, in figure 6 is presented the vibration response in the x-y-z direction for the compressor of the ventilation and air conditioning system in the idle state. The maximum recorded is in the range 300-350 Hz, and the vibration peak amplitude is about 8 ms^{-2}. The black, green and red lines represent x-y-z direction.

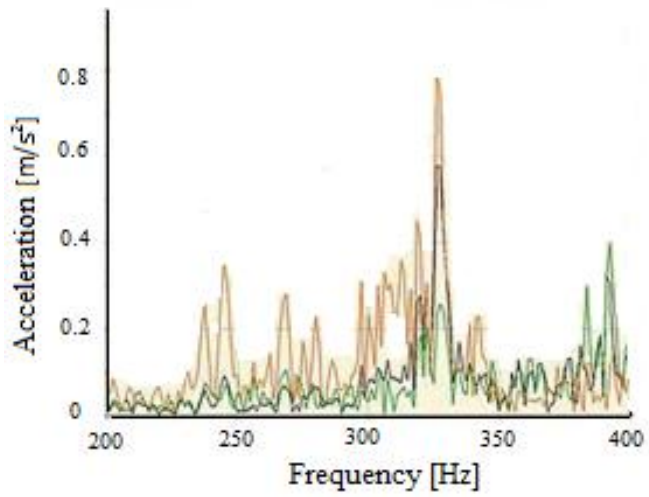

Figure 6. Frequency spectrum of vibration at HVAC compressor [9].

Figure 7 shows the noise produced by the compressor in the three x-y-z directions under operating conditions, but with the HVAC system switched off. In this case the frequency range reaches 400-500 Hz.

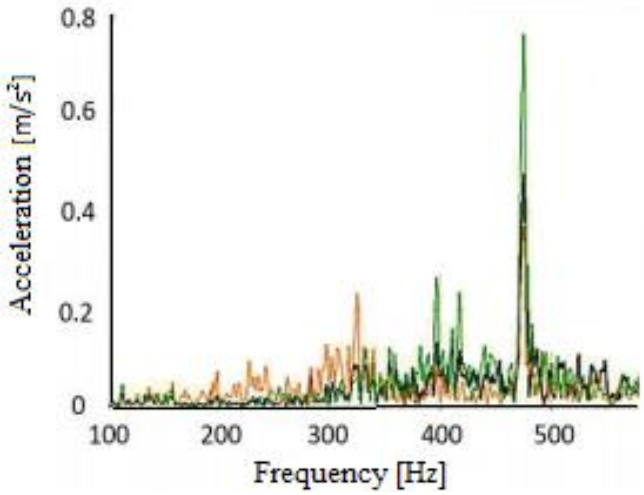

Figure 7. Frequency spectrum of vibration at compressor, tracking condition and AC OFF [9].

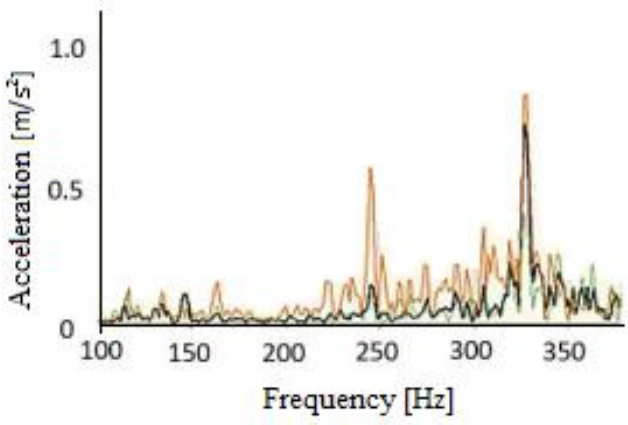

Figure 8. Frequency spectrum of vibration at compressor, tracking condition and AC ON [9].

Figure 8 shows the vibration responses for the compressor in working condition and the air conditioning system on. In this case, the vibration dominates along the x and y direction in the 300-350 Hz frequency range.

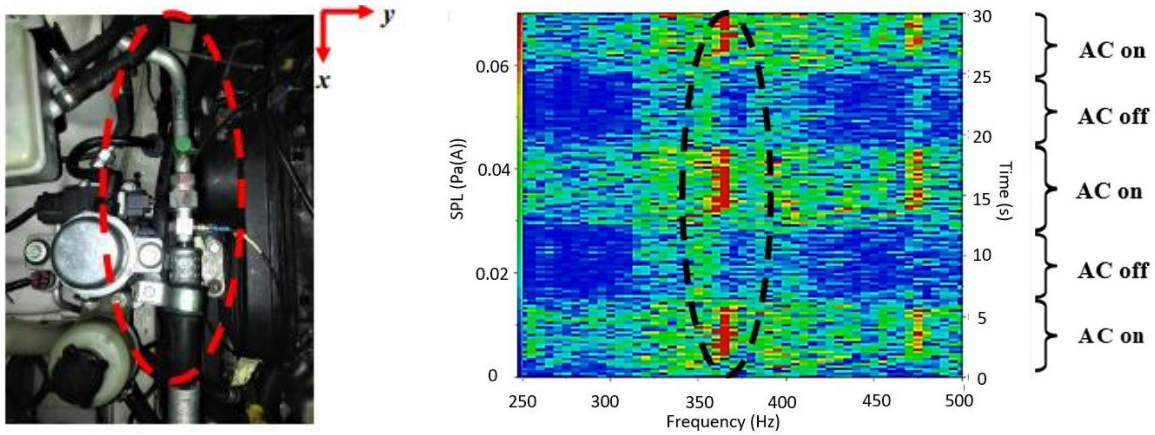

Figure 9. Sound pressure level (SPL) for compressor [9].

The spectrogram is a visual representation of the spectrum of frequencies of the audible signal that varies over time.

Figure 9 shows the sound pressure level (SPL) spectrogram acquired by the microphones placed on the compressor. There is a high intensity of red spots in the frequency range of 300-350 Hz when the HVAC system is switched on, indicating a high sound pressure level [9].

5. Conclusions

Indoor air quality along with safety and comfort during travel are elements that make the difference in choosing a car. All manufacturers make huge efforts to develop various systems capable of maximizing the level of technical comfort of the passengers. The air conditioning system in the current configurations is an energofag system because the air conditioning compressor together with the fans of the cooling system and the air distribution system consume quite a lot of engine power, which in the case of cars with low power engines represents a real disadvantage. In the event of a malfunction, the air conditioning compressor becomes a vibration generator. Creating a more efficient system will reduce the noise and vibration of the passenger compartment by increasing the passenger comfort level. A future work intends to study air distribution systems with several fans, studying the impact they have from an energy point of view, the noise and the degree of interior comfort. Proper functioning of the air conditioning system results in lower fuel consumption and ultimately lower levels of pollution.

6. References

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