Noise Source Identification of Automotive Radiator by Using Sound Intensity Mapping Method

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Abstract. Automotive radiator played an essential role as a heat exchanger that exchange the circulated heated coolant inside the engine compartment to return into its ambient temperature. Radiator cooling fan that attached at the back of radiator, is a device that work to regulate the coolant temperature when the heated coolant is passed inside the radiator tubes. It produces external flow of air that passes through the fins and tubes of the radiator. However, this external flow contributes high noise level into the system. In consequence of this risk, a detailed experimental study on noise analysis to identify the location of maximum sound pressure level (SPL) generated by variations of cooling fan speed by using sound intensity mapping method is presented. Ethylene Glycol (EG)-water based was used as working fluid operate with engine temperature range from 80 to 90 ℃. The cooling fan speed of radiator cooling fan were varied from 750 to 1250 rpm and the water flowrates were 8.0, 11.0, and 14.0 l/min. The results indicate that the noise level is increasing with the fan speed. However, there is no significance difference of change in coolant flow rate and type of coolant fluids to the noise level. The location of maximum sound pressure level is identified and the higher SPL value most located on the blade trailing edge of the suction surface with highest SPL value of 81 db for 1250 rpm fan speed. The project delivers the reliable input for the engineering practice to reduce automotive radiator noise level.

1. Introduction

Noise is usually generated by the vibrating body which the vibrations is propagate through the medium to the listeners. It is also such a common part of everyday life [1]. When sound produced, energy have transferred from sound source to the surrounding air molecules takes place. The energy transfer is called Sound Power that have unit of sound power is W (Watt). The audible range of sound power is from $10^{-9}$ W to $1000 \times 10^{-9}$ W is the lowest level which can heard by people that are closed to the source and 1000 W can immediately create hearing damage. Lower level of sound power also can create hearing damage but in long period of time.

Kang concluded that sound have affected human in positive and negative way. In positive way, sound can be defined as pleasant and relaxing [2]. In other way, the unpleasant and unwanted sound is called noise which are occurred in high decibel (dB) frequency. Noise affected people in everyday life in different ways depending on the type of noise, noise level, frequency characteristics, time of day and variance over time.

Beranek and Ver discovered that when a source produces sound power (P) it will created a certain sound intensity (I) at distance away from the source [3]. The intensity is a measure for the amount of...
power through a certain area of the distance. Sound intensity is the rate of acoustic energy flow per unit area. It is also a current of acoustic energy through medium that have magnitude and direction. Sound intensity mapping is by integrated over enclosing surface of an object and its sound power. Sound intensity measurement is able to determine the sound directional and localize noise hot spot. Mapping software have provided a contour map of noise level that are provided intuitive documentation of noise problems.

According to Kim and Thompson, noise measuring devices are typically used a sensor such microphones to receive noise signals from source [4]. However, sensor not only detect noise from the source, but it is also detected any ambient background noise. Sound measurement for machine is running, it is important to make the background noise in lower level to ensure any influence on the result. Therefore, the anechoic chamber is needed to measure the source of noise.

Hanif and Rasid stated that sound intensity probe involves two closely pressure microphones where the both sound pressure and pressure gradients can be measure between the microphones. By sound intensity analyzer, it is necessary to convert these signals into sound intensity values [5]. Ginn and Haddad emphasized that Noise source identification (NSI) techniques are used to optimise the noise emission from a wide range of products including vehicles, household goods and wind turbines [6]. Noise source have two categories which are vibration-induced noise and flow-induced noise. First category has included noise from rotating machinery, noise due to structural resonance, impact noise, and others. Then second category included noise from rotating machinery, noise due to structural resonance, impact noise, and others. Then second category included fan noise, pump noise, jet noise, etc.

Other than that, NSI is sound field visualization techniques and find applications in non-destructive evaluation, underwater imaging and machine diagnosis. NSI techniques is useful in estimating the sources position and sound strength. Sani et al. [7] stated that other than conduct the experiment in an anechoic chamber room, this method can be applied on-site as long as the background noises are stationary. NSI is also to identify the major sources of noise radiation. The best reduction in noise can be achieved by reducing the noise that are radiated from the noisiest sources. The reduction noise is required not only the treatment of many different sources but also called for different approaches in each particular case depending upon the degree of the contribution of the various individual sources to the total noise.

Davy [8] presented that there will be energy flow in certain directions but not in others because sound intensity gives a measure of direction. Thus, sound intensity is vector quantity as it has both magnitude and direction whereas pressure is a scalar quantity as it has magnitude only. It is important to measure the intensity in normal direction which is at 90˚ to specified unit area through the sound energy flowing. Fahy [9] analyzed that it can be simply to measure the normal spatial averaged since Intensity, I is the power per area. This is according to intensity is over an area that encloses the source and then multiply it by the area follows the inverse square law for free field propagation to find the sound power intensity and pressure. Most of researchers revealed that contour plots give a more detailed picture of the sound field generated by a source which explained the intensity field intersecting the hood of crawler dozer [10-13]. Several sources and sinks can then be identified with accuracy. A grid is set up to define a surface.

Overall, this work aims to develop guidelines that can be used for noise analysis and advancement by process engineers to implement satisfactory operating flow ranges for their existing equipment. Data was collected and processed with commercially available software and transducers hence to emphasize the role of experimental activity in identifying possible sound power level problems, which could affect overall vehicle harmony.

2. Experimental setup and methodology
The experimental methodology is starting from fabrication of automotive radiator test rig, then followed by preparation of coolants and experimental setup acoustic devices in Advance Automotive Liquid Laboratory (A2LL). Next, it is followed by sensors calibration of intensity mapping prop. Noise measuring devices are used a sensor which is a pair of ½ inch microphone to receive noise signals from source. Then, the measurement intensity mapping can be conducted. The total sound power is computed and all of the experimental data is analyzed and evaluate according to the standard of experiment.
2.1. Automotive radiator test rig setup
The experimental facility consists of a car radiator (test section), coolant tank with heater, water pump with control valve, cooling fan with motor speed regulator, flow meter, temperature signals data acquisition system, and temperature sensor. A complete automotive radiator test rig to study the noise measurement analysis of automobile radiator is shown in figure 1 below.

![Automotive radiator test rig](image)

**Figure 1.** Automotive radiator test rig.

2.2. Test section (radiator system)
The test section is a conventional aluminium car radiator and its dimensions are 34.0×1.3×36.8 mm. It was consisted of 32 vertical aluminium tubes. The gap between the tubes is filled with thin perpendicular louvered fins as shown in the figure 2(a). Air was forced to flow through the fins of the radiator using a conventional forced draft fan with 5 blades in the range of 100 to 1250 rpm as shown in figure 2(b). The radiator cooling fan is made up of an electric motor with flange-mounted fan wheel. The cooling fan and its motor are mounted behind the radiator. Due to the air flow produced, the cooling fan withdraw heat from the coolant.

![Automotive radiator](image)
![Radiator cooling fan](image)

**Figure 2.** (a)Automotive radiator, (b)Radiator cooling fan.

2.3. Preparation of acoustic device and measurement
Sound intensity mapping measurement is to determine the sound power level of noise that produced by radiator cooling fans. A special acoustical facility which is an anechoic chamber room is required to measure the accuracy of sound. However, the advantage of using this method is it can be applied on-site rather than in an anechoic chamber as long as the background noises are stationary. Fortunately, by
using hand-held analyzer there’s only noise from the source are detected. Sound measurement for machine is running, it is important to make the background noise in lower level to ensure any influence on the result.

2.4. Hand-held analyzer
The Bruel & Kjaer Hand-held analyzer Type 2270 as shown in figure 3, is an instrument that allow the study of sound intensity and sound power measurements to be perform. The FFT analysis of sound and vibration and sound intensity mapping results can be execute using this measurement channels.

![Hand-held analyzer type 2270.](image)

**Figure 3.** Hand-held analyzer type 2270.

2.5. Sound intensity microphone pair
Figure 4 shows the Sound intensity microphone pair Type 4197 is equipped with 8.5 mm, 12 mm and 50 mm spacers and 8.5 mm spacer was used in this study.

![Microphone pair type 4197 and spacers.](image)

**Figure 4.** Microphone pair type 4197 and spacers.

The sensitivity of the transducer as well as the response of the electronic circuitry can vary slightly over time or could be affected by environmental conditions such as temperature and humidity. Therefore, before the experiment is conduct a calibration is important for an adjustment of hand-held analyzer to measure and display correct values. The calibration for microphone is followed calibration chart from Bruel & Kjaer type 4297 using Sound Calibrator Type 4231 as shown in figure 5.
Figure 5. Sound calibrator type 4231.

Figure 6 shows the microphone is calibrated until it reaches sound level around 94.0 dB. The calibration data provided included phase matching up to 1/3 octave centre frequency of 6.3 kHz, sensitivities at 250 Hz, actuator responses and individual free field frequency responses valid for the microphones mounted on a 1/4 preamplifier.

Figure 6. Calibration of hand-held analyzer Type 2270.

2.6. Experimental procedure of sound intensity mapping
The noise analysis of car radiator cooling fan in this study was set up properly in the Advance Auto Liquid Laboratory (A2LL) before the experiment is conduct. The devices and instruments used in this noise investigation are Brüel & Kjaer intensity probe, laptop, a pair of microphones, and hand held analyzer. First, before the experiment of noise source identification is conducted, a rectangular grid was directly set up by taking a photo of the measurement configuration first which is the car radiator by using the hand-held analyzer then 3x3 grid system is plotted to define its surface as shown in figure 7.
Figure 7. Rectangular grid of car radiator by Hand-held analyzer.

The microphones of sound measurement are placed 1 m away according to standard of noise measurement method as shown in figure 8.

Figure 8. Noise measurement technique during the experiment.

Figure 9 shows sound intensity technique were carried out from the front side of the radiator only. This is according preliminary studies, that location contribute high noise than other sides.
During the experiment, the radiator cooling fan as shown in figure 10 plays a key role in this study. It is necessary to know the speed of the cooling fan when the fan is in working condition. A tachometer is used to detect the cooling fan speed reading due to different coolant use will result in different fan speed hence influenced the noise and vibration results.

Finally, the data obtained already displayed on the screen of hand-held analyzer and is interpreted by using post processing software, PULSE LabShop Version 16.1.0. The noisier part of the radiator is determined by observing the colour of its contour mapping. The experiment is repeated for another cooling fan speeds and coolant flowrates.

3. Results and Discussion

Intensity mapping is the contour that explains a more detailed picture of sound field generated by a noise source hence giving a quick overview of the sources in the selected frequency range. The noise measurements are performed in an alternative energy laboratory with less than 20 to 30 dB background noise and already filtered by the hand-held analyser itself. The cooling fan speed is varied from 750 to 1250 rpm (critical condition) and coolant flowrates were 8.0, 11.0, and 14.0 l/min (critical condition). The comparison data between different fan speed also shown in this section.

Each contour mapping presented in this section corresponds to the pressure fluctuation on the suction surface of the rotor blade, which was induced by a different fluid flow through the test section. Figure 11 presents a contour plot of the sound pressure level produced when radiator system operates at constant flowrate 8.0 l/min. It can be seen at 750 rpm of cooling fan speed as shown figure 12(a), maximum sound pressure level located at point 2 with 66.29 dB in the red oval shape area. The lowest
SPL value located at point 1 with 55.97 dB. The SPL value produced ranges from 55 to 66 dB. Next, figure 2(b) shows contour mapping when the cooling fan speed increased to 1250 rpm which is the critical condition in typical operating rate. The maximum SPL value occurred at point 9 with 77.14 dB represented by green colour area and lowest value occurred at point 7 with 66.77 dB. The SPL value produced ranges from 66 to 77 dB.

Figure 11. Contour mapping at 8.0 l/min for (a)750 rpm, (b) 1250 rpm

Table 1 shows the details value of noise level at different location to determine where the highest sound signal radiated from the radiator surface.

| Location | Sound Pressure Level (dB) |
|----------|--------------------------|
|          | 750 rpm | 1250 rpm |
| 1        | 55.97   | 70.01    |
| 2        | 66.29   | 76.68    |
| 3        | 62.04   | 75.72    |
| 4        | 64.24   | 68.03    |
| 5        | 65.74   | 76.37    |
| 6        | 64.15   | 74.47    |
| 7        | 63.17   | 66.77    |
| 8        | 59.90   | 72.12    |
| 9        | 59.21   | 77.14    |

Based on data comparison presented in figure 12, 1250 rpm contribute higher SPL value than 750 rpm at all points of location due to pressure fluctuation at the suction surface of radiator is increasing with fan speed at this constant flowrate 8.0 l/min. This finding is in agreement with the previous studies of sound radiation investigated by Au and Wang [14] which they identified that the higher the speed will generates larger sound pressure.
Figure 12. Sound pressure level comparison at 8.0 l/min.

Figure 13 presents a contour plot of the sound pressure level produced when radiator system operates at constant flowrate 11.0 l/min. It can be seen at 750 rpm of cooling fan speed as shown figure 14(a), maximum sound pressure level located at point 1 with 73.6 dB represented by yellow area. The lowest SPL value located at point 2 with 56.25 dB. The SPL value produced ranges from 56 to 73 dB. Next, figure 14(b) shows contour mapping when the cooling fan speed increased to 1250 rpm which is the critical condition in typical operating rate. The maximum SPL value occurred at point 5 with 78.5 dB represented by green colour area and lowest value occurred at point 4 with 66.15 dB. The SPL value produced ranges from 66 to 78 dB.

Figure 13. Contour mapping at 11.0 l/min for (a) 750 rpm, (b) 1250 rpm

Table 2 shows the details value of noise level at different location to determine where the highest sound signal radiated from the radiator surface.
Table 2. Sound pressure level at 11.0 l/min.

| Location | 750 rpm | 1250 rpm |
|----------|---------|----------|
| 1        | 73.60   | 70.17    |
| 2        | 56.25   | 75.69    |
| 3        | 67.17   | 77.20    |
| 4        | 61.56   | 66.15    |
| 5        | 64.24   | 78.50    |
| 6        | 63.96   | 77.73    |
| 7        | 60.14   | 69.75    |
| 8        | 63.46   | 74.18    |
| 9        | 64.88   | 77.76    |

Based on data comparison presented in figure 14, 1250 rpm contribute higher SPL value than 750 rpm at most points of location due to pressure fluctuation at the suction surface of radiator is increasing with fan speed at this constant flowrate 11.0 l/min.

Figure 14. Sound pressure level comparison at 11.0 l/min.

Figure 15 presents a contour plot of the sound pressure level produced when radiator system operates at constant flowrate 14.0 l/min. It can be seen at 750 rpm of cooling fan speed as shown figure 16(a), maximum sound pressure level located at point 5 with 68.62 dB represented by light yellow area. The lowest SPL value located at point 7 with 60.65 dB. The SPL value produced ranges from 60 to 68 dB. Next, figure 16(b) shows contour mapping when the cooling fan speed increased to 1250 rpm which is the critical condition in typical operating rate. The maximum SPL value occurred at point 6 with 78.73 dB represented by green colour area and lowest value occurred at point 7 with 66.91 dB. The SPL value produced ranges from 66 to 78 dB.
Figure 15. Contour mapping at 14.0 l/min for (a) 750 rpm, (b) 1250 rpm

Table 3 shows the details value of noise level at different location to determine where the highest sound signal radiated from the radiator surface.

| Location | Sound Pressure Level (dB) |
|----------|---------------------------|
|          | 750 rpm | 1250 rpm |
| 1        | 63.55    | 70.50    |
| 2        | 61.43    | 69.56    |
| 3        | 60.92    | 77.08    |
| 4        | 61.18    | 73.23    |
| 5        | 68.62    | 70.00    |
| 6        | 66.56    | 78.73    |
| 7        | 60.65    | 66.91    |
| 8        | 61.12    | 71.45    |
| 9        | 64.67    | 76.00    |

Based on data comparison presented in figure 16, 1250 rpm contribute higher SPL value than 750 rpm at all points of location due to pressure fluctuation at the suction surface of radiator is increasing with fan speed at this constant flowrate 14.0 l/min. This finding is follow the expected trend which is supported by Kim et al. [15] where they studied Noise Source Identification (NSI) of small fan-BLDC motor system for refrigerators. Kim et al. analysed that the overall value of noise will increase as the speed of fan increases.
Figure 16. Sound pressure level comparison at 14.0 l/min.

Figure 17 presented data comparison between different flowrate varying from 8.0 to 14.0 l/min at constant speed of 750 rpm and 1250 rpm. Both figures indicate that there is no significant difference of change in coolant flowrate in radiator system to the noise level. Other sources of vibration are hydraulic imbalance, internal recirculation, suction, cavitation, vane passing forces and conditions resulting from pump installation in the system, which significantly affects the noise level due to the structural and air borne noise, and noise radiation behavior with respect to the excitation mechanism.

4. Conclusions

Based on measurement result, the location of maximum noise level is identified. It is also analysed that the change of radiator cooling fan speed increases the vibration induced into the system other than fluid flowrate. The results indicate that maximum sound pressure level located on the blade trailing edge of the suction surface. The noise level also is increasing with fan cooling speed where 1250 rpm contribute higher noise level than 750 rpm. The finding also indicates there is no significant difference of change
in coolant flowrate to the noise level. On the other hand, sound intensity mapping is an effective method to investigate the maximum noise level that are produced by the automotive radiator. The guidelines that can be used for noise analysis and advancement by process engineers to implement satisfactory operating flow ranges for their existing equipment can be developed through this project. In future, the advancement of vibration in automotive industry for better and safer radiator can be assisted by this study.

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