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Performance and Noise Measurement on the Fan Cooling System of Automotive

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Abstract: *Performance of fan cooling system occasionally should be measured in order to get appropriate flow capacity of the air. However during in operation fan also emit the sound to the ambient. The fan generates noise because of turbulence flow around the rotor dynamics system. Therefore the sound measurement is needed to quantify the annoying signal as the source of noise of the automotive. This paper presents a measurement result of the performance and noise generated by the fan cooling system used in a car. The results of the measurements are the capacity and sound pressure level of the fan cooling system. During operation condition, the fan has a sound pressure level with various magnitude, from 63 dB to 85 dB. The result of measurement so far agrees with the theoretically that the increasing RPM of the fan will increase the performance and noise of the cooling fan.*

Keywords: *Performance, noise, measurement, fan, automotive*

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I. Introduction

Motor vehicle propulsion systems require a form of engine that converts heat energy into kinetic energy. As an effect of energy conversion, the propulsion system generates heat so that engine maybe overheat. In order to maintain the temperature on the engine according to the requirement [1], an adequate cooling system is required. Another consequence of using a fan as a part of the adequate cooling system, it generates noise.

Fig. 1 shows the working principle of the cooling system in the form of lower temperature fluid stream passing through the cooling jacket. Engine releases heat to the fluid, which then flows into the radiator serves as a heat exchanger to the environment. In order for the heat exchange of the fluid to the environment occur properly mounted radiator cooling fan.

Furthermore, in order to get the performance of the cooling fan is factually required experimental measurements. Measurements made by BBTA3 refer to AMCA 210 and ISO 5801 Standard [8], [9]. In principle, the measurement can be performed on a variety of fan rotational speed. In this experiment, measurements were taken at the fan rotation at 1000 RPM, 2000 RPM and 3000 RPM driven by an AC motor. Paired throttle equipment to simulate the airflow in the downstream.

On the development of a testing facility in the BBTA3 build, a free inlet, ducted outlet, and ducted inlet, free outlet, fan performance test facility. The fan performance test facility shown in Fig. 2 is a part of testing facility belonging to National Laboratory for Aerodynamics Aero-elastics and Aero-acoustics Technology (BBTA3), Agency for the Assessment and Application of Technology (BPPT). BBTA3 has also an hemi-anechoic chamber test facility in order to support noise testing and in the near future will be equipped as anechoic wind tunnel facility.

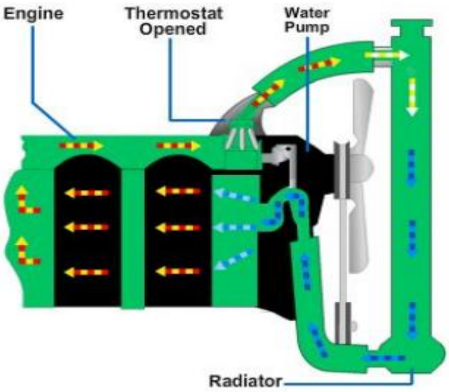

Fig. 1. Diagram of the engine cooling system [12].

II. Theory and Methodology

There are two kinds of measurement that were performed in this research, first is flow capacity measurement and the second is the noise measurement of the rotor dynamics system. The flow capacity measurement was conducted based on the measurement of the velocity of airflow, while the noise of the rotor dynamics system was measured in a hemi-anechoic chamber by following a measurement standard JIS-B8346 [10]. On the other hand, performance and noise are also predicted by numerical simulation [11], [13].

2.1. Measurement of flow capacity

Measurement of fan performance [6] essentially measures the amount of air that can be moved by the fan per unit time. This can be done by measuring dynamic pressure and static pressure in the measuring field can then be calculated airspeed V in m / s through ducting sectional area A m^2 if known air density ρ (kg / m^3) in the measuring field. If based on measurements in the field of measuring dynamic pressure P_v (N / m^2), the velocity V calculated by the formula;

$$V = \sqrt{\frac{2P_v}{\rho}} \quad (1)$$

With the acquisition of fluid flow velocity V in the field of measurement, the flow capacity Q (m^3 / s) in the field can be calculated based on the relationship:

$$Q = A \times V \quad (2)$$

Fig. 2. Ducting Inlet, Open Outlet Fan performance testing facility

Methodology on the measuring the performance of fan by using facilities owned by BBTA3, shown in Fig. 2. Based on the setup method, the data are recorded consist of dry bulb temperature, wet bulb temperature, barometric pressure, dynamic pressure, and static pressure.

Measuring instrument used is the PCE PFM 2 micromanometer, TA460 airflow, temperature sensors, and speed of rotation sensors. Each of the instrument is installed at each measurement plan and will be activated if the measurement start.

Methods of measuring first fan or fan RPM operated up to 1000. A throttle is used to simulate the flow in the downstream. The throttle is set to open from 10% to 100% with a gradual increase of 10%. Then these conditions do data retrieval. After completion of all the conditions of the throttle opening and then proceed to state 2000 and 3000 RPM.

2.2. Measurement of Noise

BBTA3 has the capability of examining the performance and noise of fans. The noise test was conducted in the hemi-anechoic chamber since this chamber has a low background noise (18 dB) with cut off frequency 100 Hz. This chamber is designed to make measurements in a free-field and is constructed such that all surfaces are lined with high sound absorbing materials. This ensures that the only sound being measured attributes to the noise source [7]. Therefore, in this room, it is possible to reduce the influence of the reflected sound because of the objects near the measurement object.

The noise characterization of this radiator cooling fan [3], [4] was performed in 5 different speeds, start from 1000 rpm to 3000 rpm with the increment of 500 rpm. The microphone located at a horizontal distance 1 meter in front of the fan from the intake side, with the height of measurement position, is 1 m from impeller axis to ground [2], as shown in Figure 5. Then the A-weighted sound pressure level has been collected using a B&K 4189 1/2" microphone. The sound pressure level is the most commonly used indicator of the acoustic wave strength. It correlates well with human perception of loudness. The reference sound pressure is set to the threshold of human hearing at about 1000 Hz for a young person. When the sound pressure is equal to the reference pressure the resultant level is 0 dB [13].

Fig. 3. Fan noise measurement in semi-anechoic chamber BBTA3.

Fig. 4. Measurement setup for background noise measurement

List of measurement equipment shown in Table 2.

Table 2. Measurement equipment.

No	Equipment	Type	Quantity
1	Microphone	B&K 4189 BNC	1
2	Data acquisition system	B&K PULSE LAN XI 3160-A-042	1
3	Tripod	B&K	1
4	Electric motor and support	-	1
5	Tachometer	CSI	1
6	Sound Calibrator	B&K Type 4231	1
7	Computer / Laptop	-	1

2.2.1. Test Configuration.

Radiator cooling fan noise measurement was taken place in the hemi-anechoic chamber of BBTA3 in order to obtain background noise as low as possible. According to the standard that was used, the background noise level should be 10 dB smaller or more from the reading-out value of the objective sound source. Sound pressure level/SPL data were collected at two measurement conditions, i.e.: measurement of rotating shaft without fan (this representing background noise level) and measurement of the shaft with a fan (this representing total sound pressure level).

2.2.2. Measuring background noise.

In this case, background noise is the noise that originates from the environment (in the absence of a fan). Measurement setup for background noise level can be seen in Figure 6. The result of background noise measurement are presented in the table below,

Table 3. Background noise level for each fan rotation speed

No	Shaft speed (RPM)	Background noise (dB-A)
1	1000	59.00
2	1500	63.14
3	2000	65.76
4	2500	70.21
5	3000	74.04

2.2.3. Measuring fan noise.

Measurement of noise theoretically based on the Lighthill aerodynamics analogy and extent by Ffowcs-Williams and Hawkings [5]. Noise emitted by radiator cooling fan itself (LA_{fan}) can be determined by the following equation :

$$LA_{fan}\,(dB.A) = 10 \times \log\left[10^{\left(\frac{LA\ total}{10}\right)} - 10^{\left(\frac{LA\ background\ noise}{10}\right)}\right] \quad (3)$$

Where: - LA_{total} : total sound pressure level

- $LA_{background}$: background sound pressure level

III. Result and Discussion

As explained in chapter 2 theory and methodology, in this chapter is presented the measurement results in tables and graphics plot.

3.1. Measurement flow Capacity

The results of the measurement quantities listed in Table 1 are calculated according to AMCA 210 and ISO 5801 in order to obtain the performance of the fan *Q*, *Pt*, and *Ps* as shown in Table 5 and Figure 7. The values given emphasis mark is the result of linear interpolation for RPM 1000, 2000 and 3000.

Table 4. Fan Performance Data Processing Results

1000 RPM			2000 RPM			3000 RPM		
Q (m^3/s)	Pt (Pa)	Ps (Pa)	Q (m^3/s)	Pt (Pa)	Ps (Pa)	Q (m^3/s)	Pt (Pa)	Ps (Pa)
0.60	23.03	14.96	1.12	90.19	61.65	1.62	203.88	144.17
0.57	28.12	20.95	0.99	107.41	85.08	1.42	240.56	194.41
0.52	39.64	33.54	0.87	152.23	135.08	1.23	344.04	310.26
0.48	**48.83**	**43.61**	**0.82**	**167.44**	**152.05**	**1.10**	**395.15**	**367.07**
0.41	63.32	59.49	0.57	236.29	228.92	0.80	515.50	500.82
0.22	87.54	59.49	0.23	358.48	357.29	0.38	811.06	807.84

The graph shows that the characteristics of the fan, static pressure is inversely proportional to the rate of airflow moved by a fan. The tendency of data due to the relatively linear measurements performed only at some points in the prediction of the fan so that the typical characteristics of the fan is not seen clearly. This causes the performance of the fan on the shut-off condition where the strip is not measured airflow is close to zero. Interpolation is done by creating a linear equation of the relationship *Pt* to *Q* and *Ps* to *Q*. From the obtained value *Pt* = 48.83Pa, *Ps* = 43.61Pa at *Q* = 0.48 m^3 / s at 1000 RPM.

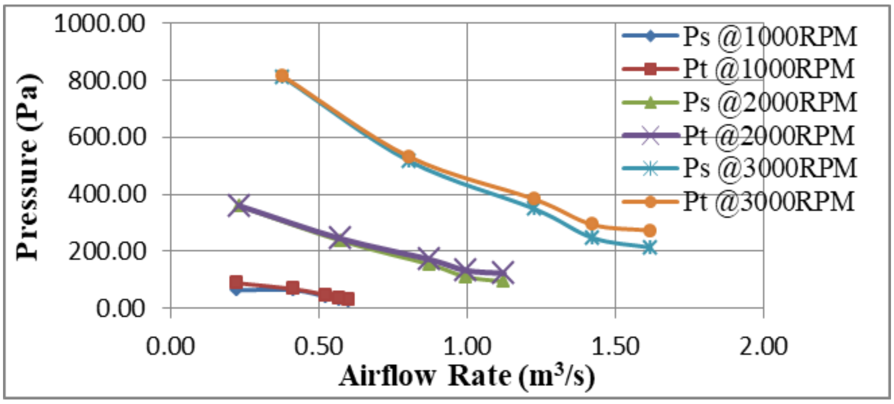

Fig. 5. Graph Static Pressure Total and pressure against Q.

3.2. *Measurement of noise fan*

For each rotational speed, noise level radiating by cooling fan itself can be determined by using equation (3), and the result is shown in Table 6. Then the acoustics spectrum for each speed of fan rotation is shown in figure 8.

Table 5. Noise level total and only fan.

No	Fan speed (RPM)	Total Noise level(dB-A)	Noise level fan(dB-A)
1	1000	65.00	63.74
2	1500	75.87	75.64
3	2000	83.58	83.51
4	2500	90.14	90.09
5	3000	94.76	94.73

Figure 8 shows the plot of noise level versus RPM.

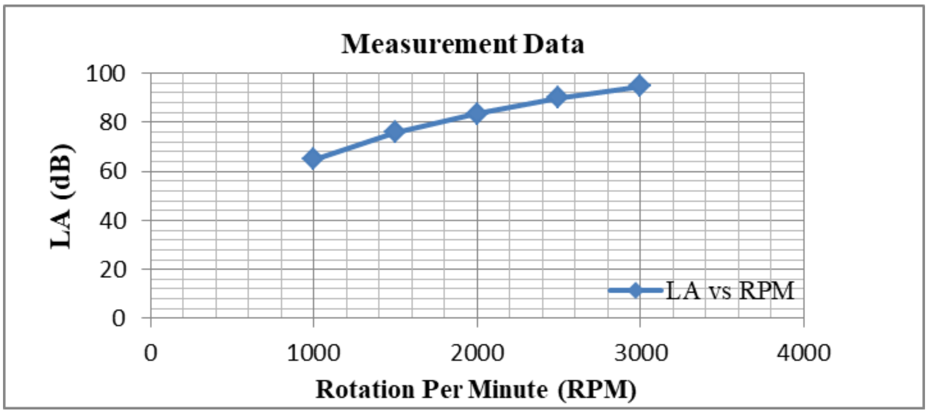

Fig.6. Fan noise measurement Result

IV. Conclusion

Two types of tools to measure the performance of the cooling fan with the method of Free inlet ducting outlet and Inlet Ducting Free outlets created and implemented in the BBTA3-BPPT. Measurement of quantities with instruments owned by BBTA3 is required to determine the performance of the cooling fan goes according to expectations.

The results of performance measurement at fan RPM 1000, 2000, 3000 and each is 0.48 m^3/s. 0.82 m^3/s, and 1.1 m^3/s. This indicates that higher performance with higher RPM in accordance with rules that make sense.

Fan Noise measurement is carried out with the correction of background noise generated by electric motors as the source of the mechanical noise. The results of measurements of noise fan noise result from the aerodynamic analogy formulated by Ffowcs-Williams and Hawkings (FW-H).

The Axial fan is very widely used in the Heating Ventilating Air Conditioning system. In this case axial fan use for the cooling system. The cooling fan requires an efficient fan with a noise level that can be tolerated. In this study the cooling fan diameter of 0.5 m with a blade number seven that meet the needs for flow capacity. The results of measurement noise levels that can be tolerated by the SPL range from 65 dB to 95 dB.

Acknowledgments

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