The correlation between noise of outdoor unit and thermodynamic properties of cycle at transient condition of room air-conditioner

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Key Words : Outdoor unit, transient condition, noise reduction, thermodynamic properties

ABSTRACT

Recently, noise reduction of air-conditioner is one of the important design factors for high quality product. Especially, customer complaints arise due to noise problem of the outdoor unit. After the operation of air-conditioner start, noise level of outdoor unit is increased gradually and sometimes abnormal noise occurs until it reaches steady state condition. The aim of this paper is to investigate the relation between noise of outdoor unit and thermodynamic properties of cycle at transient condition of room air-conditioner. In order to find out the noise characteristics of outdoor unit, noise and vibration measurements are carried out. Also, the thermodynamic properties of compressor and heat exchanger are measured by using temperature and pressure sensors and experimental results are discussed. Finally, we find out the relation between noise and cycle properties at starting of room air-conditioner and the improvement method to reduce noise level is proposed.

1. INTRODUCTION

As living standards and quality of life have been enhanced, customer demand for high quality air-conditioner is increased. Noise and vibration control is one of the important design factors for high performance and customer satisfaction. Also, customer complaints due to noise problem of the outdoor unit are increased in recent years. The noise of outdoor unit is caused by many reasons such as excitation forces of fan and compressor, resonance of primary components, and so on. Among them, noise problem which is generated by the variation of refrigerant cycle is hard to find an improvement solution since it influences overall refrigerant system including compressor, pipes and thermodynamics characteristics such as temperature and pressure.

Many researches which are related to fluid induced noise and vibration have been studied. Goyder(1) investigated various fluid induced mechanisms that cause vibration and noise of heat exchangers. Han(2) experimentally investigated the characteristics of refrigerating cycle and improvement method to reduce the refrigerant induced noise. Han(3) also observed flow induced noise of air-conditioner due to two-phase-flow of refrigerant using flow pattern map. Celik(4) showed the flow induced noise which occurred at an evaporator of cooling unit by the measurement of temperature, pressure and noise. Bae(5) focused on the relation between refrigerant flow noise and shape of distribution pipe at low operating speed condition of air-conditioner.

In this paper, the relation between noise of outdoor unit and thermodynamic properties such as pressure and temperature is investigated. After the operation of air-conditioner start, noise level of outdoor unit is gradually increased depending on the operation speed and sometimes abnormal noise occurs until it reaches...
steady-state condition. In order to understand the abnormal noise phenomenon, noise and vibration measurements are carried out first. Also, thermodynamic properties of compressor and heat exchanger are measured by using temperature and pressure sensors and experimental results are discussed. At last, the relation between noise of outdoor unit and thermodynamic properties is investigated and the improvement method to reduce noise level is proposed.

2. EXPERIMENTAL APPARATUS

The experimental apparatus is prepared as shown in Fig. 1. Indoor unit and outdoor unit of air-conditioner are constructed at two anechoic rooms respectively and connected by pipes. In order to understand the occurrence of abnormal noise, the measurement is carried out using heating condition of 7°C indoor temperature and 20°C outdoor temperature. R410a which is widely used refrigerant for air-conditioner is applied as working fluid. Microphone is installed at 1m rear-side point from outdoor unit to measure noise level. Vibration is measured by using charge type accelerometers at suction tube and discharge tube of compressor, heat exchanger and electrical expansion valve of outdoor unit. The charge amplifier and FFT analyzer are used for signal processing. Piezo-electric type pressure sensors are mounted at suction tube and discharge tube of compressor to measure pressure variation at transient condition. Four thermocouples are located at primary positions of heating cycle to measure temperature variation. Table 1 shows the measurement positions and measured properties.

3. EXPERIMENTAL RESULTS

3.1 Noise and vibration measurement

Noise and vibration are measured during 1300 seconds of transient condition after operation starts. Frequency analysis for measured data is performed using FFT algorithm at the same time. Fig. 2(a) shows the variation of noise level at 1m rear-side point of outdoor unit. The operating speed of air-conditioner is increased through four steps and reaches setting speed, which is prescribed by control

![Fig. 1 Experimental set-up](image)

<table>
<thead>
<tr>
<th>Table 1 Measurement position and measured properties</th>
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<tr>
<td><strong>POSITION</strong></td>
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<tr>
<td>-------------------------------------</td>
</tr>
<tr>
<td>Compressor suction pipe</td>
</tr>
<tr>
<td>Compressor discharge pipe</td>
</tr>
<tr>
<td>Outdoor unit HEX</td>
</tr>
<tr>
<td>EEV</td>
</tr>
<tr>
<td>Indoor unit HEX</td>
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<td>1m from ODU</td>
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system, after 500 seconds have passed. Noise level is increased proportional to the operating speed however it is increased by 3 dB(A) continually until 1000 seconds while operating speed is not changed after 500 seconds. Noise level is 1 dB(A) reduced at 1300 seconds, compare to maximum noise level when refrigerant cycle is running at steady-state condition. Fig. 2(b) shows the comparison of frequency analysis results from 500 seconds to 1000 seconds. Many high-order harmonics of operating speed appear due to excitation force which is generated by motor and fan. Most of the noise peaks are increased throughout the overall frequency range. Hence, abnormal noise phenomenon is not considered as a resonance problem of component parts since specific peak of harmonics is not dominantly increased. Also, it is considered that increasing of the noise level is related to increasing of excitation force at transient condition.

In order to verify the relation between vibration and noise of outdoor unit, vibration measurement for primary location such as heat exchanger, electric expansion valve and compressor is performed. As a result of vibration measurement, vibration phenomena are similar to each other. Thus, vibration measurement result at heat exchanger is used as a representative of vibration of outdoor unit. Fig. 3(a) shows the variation of vibration level at heat exchanger of outdoor unit. As operating speed increases, vibration level of heat exchanger is also increased. Additionally, vibration level increases continually until it reaches 1000 seconds, which is similar to the variation of noise level. Fig. 3(b) shows the comparison of frequency analysis results from 500 seconds to 1000 seconds at heat exchanger of outdoor unit. Magnitudes of vibration peaks due to motor and fan arise simultaneously in all frequency range. Since the vibration measurement result is similar to the noise measurement result, it is considered that noise of outdoor unit is occurred by the vibration of air-conditioner structure.

3.2 Thermodynamic properties measurement

Usually, compressor is known as the major excitation source of outdoor unit. Also, the magnitude of excitation force is proportional to the variation of compression load. Therefore, variation of excitation force is investigated from compression load which is estimated by measurement results of pressure and temperature. Additionally, the relation between compression load and noise of outdoor unit is estimated.

Fig. 4(a) shows the variation of suction and discharge pressures during transient condition after starting operation. As operating speed of air-conditioner increases, the difference between suction pressure and discharge pressure is proportionally increased. However, discharge pressure of compressor is continually increased until 1000 seconds while the operating speed of air-conditioner remained constant after 500 second point. From 1000 seconds to 1300 seconds, discharge pressure is decreased and the ratio of suction and discharge pressure reaches at design value. Fig. 4(b) describes the temperature variation of refrigerant at suction and discharge tubes of compressor. Discharge temperature is increased by 35°C rapidly at 500 seconds, the starting juncture of setting speed, to 1000 seconds. The temperature of compressor reaches the steady-state condition at 1000 seconds, and it corresponds to 7°C indoor temperature and 20°C outdoor temperature. According to the measurement results, it is considered that high noise and vibration of outdoor unit are occurred by increased excitation force from compression load which is due to instability of heating cycle at transient condition.

4. IMPROVEMENTS

In order to improve the abnormal noise phenomenon of outdoor unit, it is essential to eliminate the instability of discharge pressure. The alternative operation logic is proposed as shown in Fig. 5. Fig. 5(a) shows the improvement plan for operating speed. The present operation logic of air-conditioner has four steps of varying speed and it reaches setting speed. On the other hand, the improved operation logic has three steps of increasing the operating speed and it reaches setting speed earlier than present operation logic. Fig. 5(b) indicates the improvement plan for opening angle of expansion valve. The maximum opening angle of improved method is 17% larger than present logic and opening angle is decreased gradually until it reaches steady-state condition.

Fig. 6(a) shows measured pressure level of suction and discharge pipes when improved operation logic is applied. Discharge pressure is increased slowly compare to the present operation logic and reaches the design value without abnormal overshoot phenomenon. Fig. 6(b) shows the measurement results of suction temperature and discharge temperature for improved operation logic. It takes
Fig. 2 Noise measurement results of outdoor unit

(a) Variation of Noise level

(b) FFT result of noise

Fig. 3 Vibration measurement results of heat exchanger

(a) Variation of vibration level

(b) FFT result of vibration

Fig. 4 Measurement results of thermodynamic properties before improvement

(a) Variation of pressure

(b) Variation of temperature
(a) Operating speed improvement

(b) Expansion valve opening improvement

Fig. 5 Improvement method of operating logic

(a) Variation of pressure

(b) Variation of temperature

Fig. 6 Measurement results of thermodynamic properties after improvement

Fig. 7 Comparison of noise level after improvement
1000 seconds to reach the steady-state condition where the test conditions are 7°C indoor temperature and 20°C outdoor temperature. Compare to the present operation logic, compression load increases depending on time and reaches the design value without any overshoot phenomenon. Fig. 7 shows the comparison of measured noise level between the present operation logic and the improved operation logic. When improved operation logic is applied, abnormal noise does not occur and the noise level of outdoor unit is reduced by 2 dB(A) at transient condition. It is expected that abnormal noise at transient condition is improved by control of operating logic.

5. CONCLUSIONS

In this paper, the relation between noise of outdoor unit and thermodynamic properties is investigated. When the operation of air-conditioner starts, noise level of outdoor unit is gradually increased and sometimes abnormal noise occurs until it reaches steady-state condition. Noise and vibration measurements are carried out to understand the abnormal noise phenomenon. According to the measurement result, abnormal noise is not originated by a resonance of component parts but caused by increasing of excitation force. Additionally, thermodynamic properties of compressor and heat exchanger are measured and experimental results are discussed. With this result, the relation between noise of outdoor unit and thermodynamic properties is obtained. It is considered that increased excitation force is proportional to compression load due to instability of heating cycle at transient condition. Finally, the improvement method to reduce noise level is proposed. When the improved operation logic is applied, abnormal noise phenomenon does not occur and noise level of outdoor unit is reduced by 2 dB(A). It is expected that abnormal noise at transient condition is improved by control of operating logic.

REFERENCES