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Experimental Study of the Effects of the Cycle Characteristics on the Refrigerant-Induced Noise in System Air-Conditioner

Weui Bong Jeong[a,*], Hyung Suk Han[b], Jin Yong Mo[b], Jae Kwon Lee[b]

[a]*Department of Mechanical Engineering, Pusan National University, Jangjeon-dong, Kumjung-ku, Pusan 609-735, Korea*
[b]*Air-conditioning Technical Expert Group, System Appliance Division, Samsung Electronics, 416, Metan-3dong, Yeongtong-Gu, Suwon, Korea*

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Abstract

The main sources of the refrigerant-induced noise can be classified 2 types according to its characteristics. One is due to the cyclic characteristics such as quality, velocity of the refrigerant, pressure drop and mass flow rate. The other is due to the structural characteristics such as distributed path pipe layout, distributor and expansion device. In this paper, the effects of cycle characteristics on the noise of multi-type system air-conditioner are investigated experimentally. In the indoor unit of multi-type air-conditioner, the variation of noise is examined when the in-flowing and out-flowing refrigerant to the indoor unit are 2-phase state according to its cycle control. And several factors are recommended in order to reduce the refrigerant-induced noise of the air-conditioner.

Keywords: Refrigerant-induced noise; Quality; Mass flow rate; Electric Expansion Valve (EEV)

1. Introduction

Nowadays, the requirements of lower noise in air-conditioner have been increasing as the use of air-conditioner is growing up in our life. Reducing the noise from air-conditioner, especially at low refrigerating mode, has been one of the most important issues in the development of air-conditioner. Reducing air-flow rate can reduce the noise, but there are some restrictions. One restriction is that related to cycle problems and the other restriction is that related to the sound quality problems. The cycle problems, such as evaporator-freezing or water-dropping at high humidity condition, can occur at low temperature. These problems occur because temperature of evaporator decreases when air-flow rate is reduced. And sound quality problems, such as the compressor noise transferred by pipe, refrigerant-induced noise at evaporator and fan motor noise, becomes dominant at indoor side as decreasing the air-flow rate. Among these various noise problems, the refrigerant-induced noise is focused in this paper.

The refrigerant-induced noise usually depends on the state of the phase and flow pattern of the refrigerant. Hirakuni(2004) studied porous metals in front of expansion device in order to reduce the refrigerant-induced noise by changing the flow pattern from slug-flow to bubbly-flow. Hirakuni(1998) dealt with the refrigerant-induced noise of the refrigerator at the capillary tube in order to get more degree of sub-cooling. Umeda(1993) suggested the layout of inlet and outlet pipe in order to avoid slug-flow which produces the noise. Kannon(1997) dealt with the relationship between refrigerant-noise and flow pattern of slug-flow.

*Corresponding author. Tel.: +82 51 510 2337, Fax.: +82 51 517 3805
E-mail address: wbjeong@pusan.ac.kr

In this paper, the mechanism of refrigerant-induced noise is discussed. And refrigerant-induced noise is investigated experimentally according to the cyclic characteristics of system air-conditioner. Since the refrigerant-induced noise depends on its velocity at cooling mode, the variation of refrigerant-induced noise with different quality is also discussed at cooling mode. Since the phase of the refrigerant at condenser-outlet will be 2-phase as mass flow rate of the refrigerant, the variation of noise with mass flow rate is discussed at heating mode.

2. Mechanism of refrigerant-induced noise

Figure 1 shows the Molier diagram (p-h) of general refrigeration cycle. The refrigerant flowing out from the condenser is sub-cooled liquid, and its phase changes from liquid to 2-phase when passing through the expansion device. In addition, as shown in Fig. 1, the pressure drop of "ΔP" occurs and the vapor fraction in the refrigerant grows up while this refrigerant is passing through the pipe between expansion valve and evaporator. Because of these reasons, the refrigerant flowing into the evaporator becomes 2-phase state with high velocity. The energy loss occurs at these positions because of high velocity and pressure drop of the refrigerant. This energy loss of refrigerant cycle causes noise which propagates through the pipe. Refrigerant-noise is produced due to these cyclic characteristics of air-conditioner. And the velocities as well as the states of refrigerant at evaporator inlet are very important factor for reducing these kinds of noise. The quality is introduced to represent the velocity and the refrigerant state at the evaporator inlet. Quality represents the mass flux of the gas which decides the velocity of the refrigerant.

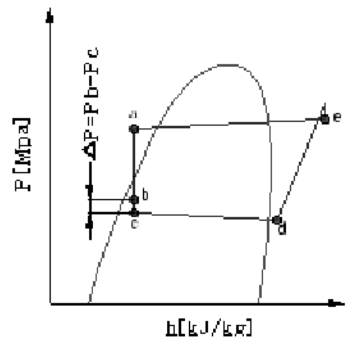
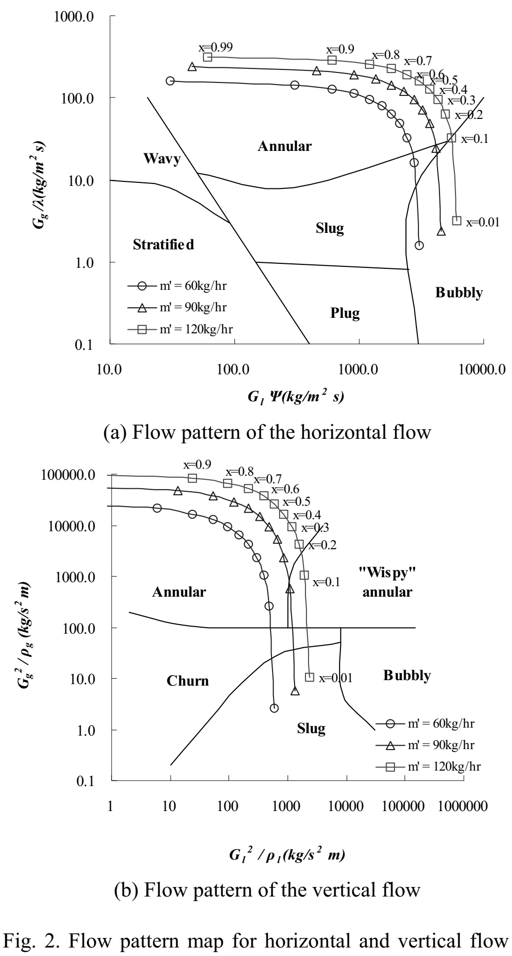


Fig. 1. Molier diagram (p-h diagram) for general air-conditioner.

The flow pattern of 2-phase flow is generally dependent on the mass flux of the gas and liquid. Baker(1954) suggested the flow pattern map related to mass flux for the horizontal flow and Hewitt and Roberts(1969) suggested for the vertical flow. In this paper, Baker map and Hewitt map will be used for expectation of flow pattern in a pipe. Figure 2 shows those maps for the variation of flow pattern with quality at the evaporator inlet where the pressure is 0.68 Mpa, inner diameter of pipe is 4.95mm, and mass flow rate is 60~120 kg/hr.

In Fig. 2, m' is mass flow rate of the refrigerant, x is quality, A is cross sectional area of the tube, G_g is mass flux of the gas, G_l is mass flux of the liquid, ρ_g, ρ_l, ρ_{water} are the density of the gas, liquid and water, μ_g, μ_l, μ_{water} are the viscosity of the gas, liquid and water, and σ_{water}, σ are the surface tension of the water and liquid. The relations between parameters are as follows;



(a) Flow pattern of the horizontal flow

(b) Flow pattern of the vertical flow

Fig. 2. Flow pattern map for horizontal and vertical flow at evaporator inlet.

$$G_g = \frac{m' x}{A}$$

$$G_l = \frac{m'(1-x)}{A}$$

$$\lambda = \left(\frac{\rho_g}{\rho_{air}} \frac{\rho_l}{\rho_{water}} \right)^{\frac{1}{2}}$$

$$\psi = \frac{\sigma_{water}}{\sigma} \left(\frac{\mu_l}{\mu_{water}} \frac{\rho_{water}^2}{\rho_l^2} \right)^{\frac{1}{3}}$$

When the refrigerant flow pattern is changed from bubbly to annular without slug-flow, the refrigerant-induced noise by slug-flow does not happen. Therefore, at the evaporator, the velocity change due to quality change will be the main reason of the refrigerant-induced noise. But when the refrigerant flow pattern is changed from bubbly to slug, the refrigerant-induced noise is produced even though the quality is low. Except this special case of the slug-flow, quality should be minimized at evaporator inlet in order to reduce the velocity of the refrigerant. And also in order to minimize quality at evaporator inlet, the sub-cooling degree at condenser outlet should be maximized. Han(2006) described the refrigerant-induced noise as quality for single-room air-conditioner and showed the relationship between quality and noise. The quality and sub-cooling degree is changed by cycle control in the multi-type air-conditioner. EEV(Electric Expansion valve) is usually used for this cycle control. The mass flow rate of the refrigerant varies according to the cycle load because of these devices. The variation of mass flow rate will cause the variation of cycle characteristics such as heat transfer capacity, quality and sub-cooling degree. Therefore, this variation of mass flow rate affects the refrigerant-induced noise.

3. Refrigerant-induced noise for system air-conditioner

Multi-type air conditioner which has single outdoor unit and multi indoor units is called system air-conditioner. The cyclic load of system air-conditioner is controlled by mass flow rate using electric expansion valve. For this kind of air-conditioner, the noise problem is more complicated than that of room air-conditioner because change of mass flow rate makes different cycle factors such as sub-cooling, super heating and quality. These cycle factors are very important to decide how much bubble in the refrigerant will exist in a pipe and how much refrigerant-induced noise will increase as its phase difference.

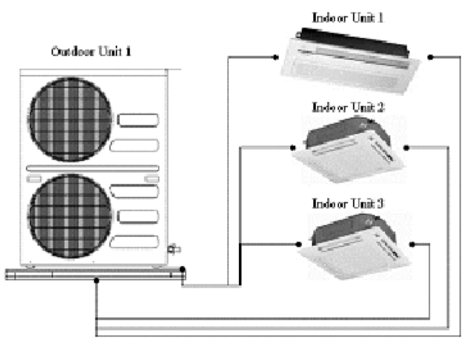


Fig. 3. Schematic diagram of multi-type air-conditioner (3 indoor unit and 1 outdoor unit).

In order to check the noise as well as cycle factors according to the mass flow rate, the test is performed with 5 HP system air-conditioner which has 3 indoor units as shown in Fig. 3. The refrigerant used in the test is R22. In order to check the sound pressure level, microphone is located 40cm apart from the side cabinet near by electric expansion valve where the refrigerant-induced noise is dominant. The noise source of indoor unit of air-conditioner is mainly due to fan and refrigerant. The noise from the compressor is not dominant since the length of the connecting pipe between indoor unit and outdoor unit is sufficiently long to damp down the vibration-transferred noise from the compressor. Since the fan usually produces a steady noise, in this paper, the deviation of noise of indoor unit is assumed to be caused by the change of refrigerant-induced noise when the cycle characteristics are changed.

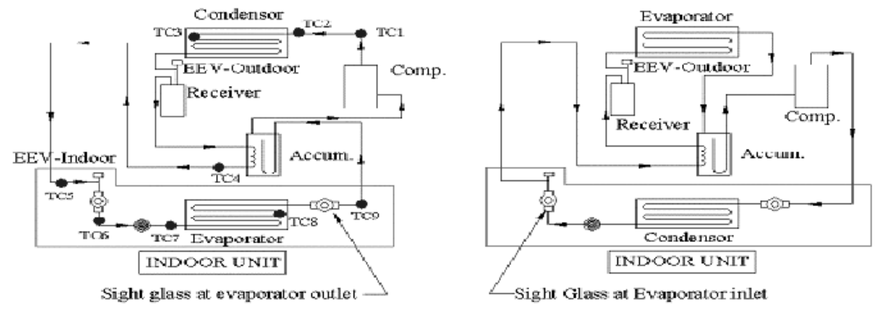
Thermo-couples are attached at each position of indoor and outdoor side in order to check the cycle temperature. And sight-glasses are established at electric expansion valve inlet and evaporator outlet in order to monitor the refrigerant state. Figure 4 shows the schematic diagram of test set-up. Table 1 shows the temperature condition of this test at the indoor and outdoor side.

3.1 Quality of evaporator inlet at cooling mode

In order to investigate the effects of quality level for the refrigerant-induced noise, the noise test is performed with different temperature of indoor and outdoor side at cooling mode as given in Table 1. The

Table 1. Temperature conditions for the test (ISO standard).

Value	Heating				Cooling					
	Heating Standard		Heating Overload		Cooling Standard		Cooling Low Temp.(ISO)		Cooling Overload(ISO)	
	Indoor	Outdoor	Indoor	Outdoor	Indoor	Outdoor	Indoor	Outdoor	Indoor	Outdoor
DB(℃)	20.0	7.0	27.0	24.0	27.0	35.0	21.0	21.0	32.0	43.0
RH(%)	58.4	86.7	25.1	55.3	46.0	24.4	52.8	52.8	45.5	24.4



(a) Cooling (b) Heating

Fig. 4. Schematic diagram of the test setup with multi-type air-conditioner (TC: Thermocouple).

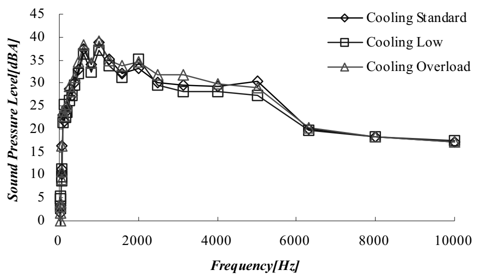
quality is 0.14 at cooling low temperature, 0.16 at cooling standard and 0.19 at cooling overload condition. Figure 5 represents the sound pressure level measured at these different temperature conditions for the indoor unit “2” for multi type air conditioner. In Fig. 5, it can be known that the noise increased at high frequency over 1000 Hz when the quality increases. And over-all sound pressure level also grows up according to the increasing of the quality. As referred to previous section, it can be verified that the variation of noise with quality is dependent on the velocity of refrigerant when the flow pattern of the refrigerant is not slug or churn flow. Because the mass flow rate of the indoor unit is at least 60 kg/hr and the quality at evaporator inlet is over 0.14 for the cooling mode, the flow pattern at the evaporator inlet should be annular as shown in Fig. 2.

3.2 Cycle characteristics at heating mode

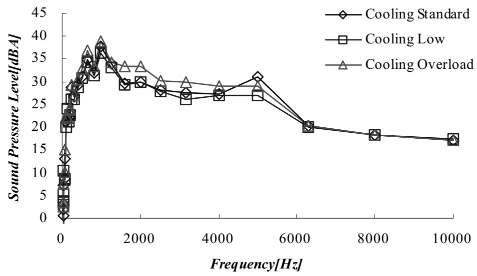
A digital scroll compressor manufactured by Corperland Co. is installed for 5 HP system air-conditioner and it controls the cycle with on-off control of PWM valve. The on-off control of PWM valve is shown in Fig. 6. When the PWM valve is on, the refrigerant in the compressed room bypasses to the low pressure line and discharge valve in the compressor will be closed, which makes the mass flow rate in a pipe decrease suddenly. And the refrigerant is compressed and discharge valve is opened when the PWM valve is off, which causes the increasing of mass flow rate. Because of this cycle variation, the control of open-step for EEV(Electric Expansion Valve) is very important in order to control mass flow rate approximately. Figure 7 shows the Molier(p-h) diagram of this cycle at heating mode, and Table 2 shows the temperature of the heat exchanger for the indoor unit while the PWM valve is on and off . At the heating mode, indoor unit becomes condenser and the refrigerant at condenser outlet becomes sub-cooled liquid. Monitoring its state with sight-glass and cycle temperature, it is observed that the state of refrigerant becomes 2-phase according to EEV open-step and control of PWM valve. It means that the sub-cooled temperature becomes 0 degree. Therefore, the point “A” in Fig. 7 moved to right and left direction according to EEV open step. And point “A” in Fig. 7 moved from “1” to “3” during on-off control of PWM valve. It is monitored that the refrigerant-induced noise grows up when EEV open-step is 300step and PWM valve becomes on, at which point “A” is moving through “1” in Fig. 7(b).

Table 2. Temperature of the heat exchanger for the indoor unit.

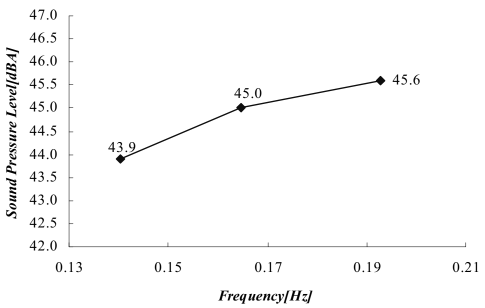
Operating Mode	Indoor Unit	PWM Control	EEV step		Temperature(℃) Heat exchange(indoor)		EEV-out of indoor side	Sub cooling
			Indoor	Outdoor	In TC9	Mid TC8	TC5	
Heating Overload	Unit 2	loading	444	200	64.0	45.0	42.6	2.4
		unloading	444	300	62.8	41.0	47.6	0.0



(a) 1/3 octave noise at loading condition



(b) 1/3 octave noise at unloading condition



(c) Over-all noise level at loading condition as different quality

Fig. 5. Sound pressure level of 4 way cassette at cooling mode as different temperature conditions.

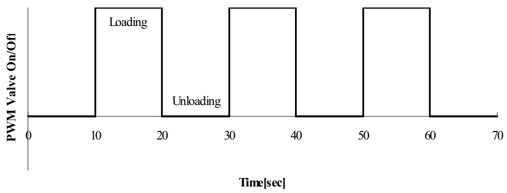
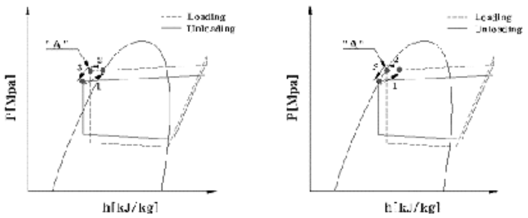


Fig. 6. PWM valve control logic(Loading : PWM valve = On, Unloading : PWM valve = Off).

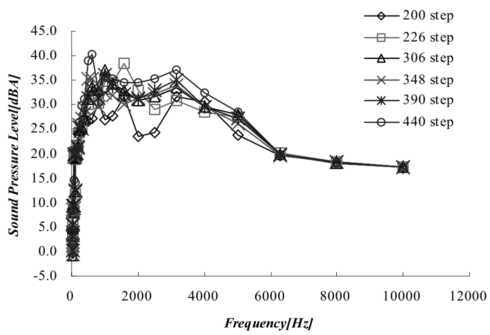


(a) EEV open step = 200step (b) EEV open step = 300step

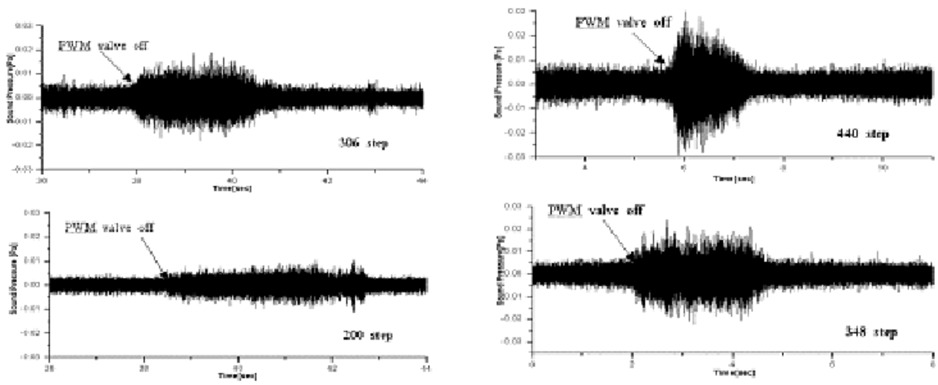
Fig. 7. Molier diagram of 5HP system air conditioner at heating mode.

3.3 Mass flow rate at heating mode

Figure 8 shows the refrigerant-induced noise as different EEV open-step and PWM valve control. When the EEV step is over 300 steps, the level of the sound pressure increases as shown in Fig. 8(a), and the difference of sound level is dominant at high frequency range from 1 kHz to 4 kHz, at which the human ear is very sensitive. Figure 8(b) shows the sound pressure variation as time while the PWM valve is on and off. It can be found that the sound pressure level increases suddenly when the PWM valve is off (loading condition). For different EEV open-step and PWM valve control, the refrigerant state is monitored by sight-glass. When the EEV open step is 300steps, the refrigerant state which goes out from the condenser is not sub-cooled liquid during the PWM valve is closed (loading condition). It can be



(a) Spectrum of the sound pressure



(b) Time signal of sound pressure

Fig. 8. Sound pressure as different EEV step and PWM valve control.

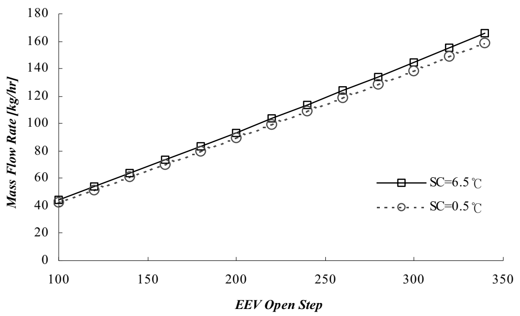
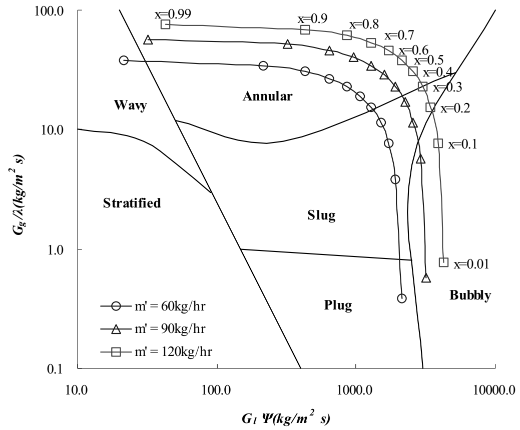


Fig. 9. Mass flow rate variation as EEV open-step.

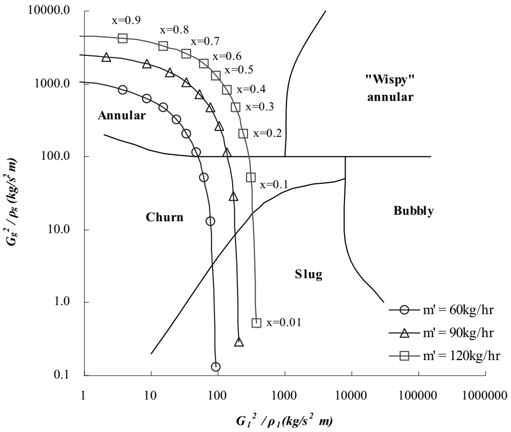
verified that its 2-phase liquid produces the refrigerant-induced noise. When EEV open step is 200steps, however, all of the refrigerant states at the condenser outlet are single phase (sub cooled liquid). In this case, the difference of the sound pressure level between PWM valve on and off is not so much.

These test results show that the mass flow rate of the refrigerant is excessive when the EEV open step is over 200step, which produces high refrigerant-induced noise at this time. The variation of the mass flow rate as EEV open-step was calculated by Jang and Kim(2005), which is given in Fig. 9. In Fig 9, the high pressure is 1.812MPa, low pressure is 0.68Mpa and sub cooling is 6.5 ℃ and 0.5 ℃. The variation of flow pattern with mass flow rate can be found with Baker map and Hewitt map as shown in Fig. 10, where the pressure is 1.812 MPa and inner diameter of the pipe is 8.12 mm. In Fig. 10, the refrigerant flow pattern will be churn or slug flow when the quality is lower than 0.3, and refrigerant-induced noise will increase at this time.

With these results, it can be verified that the mass flow rate should be controlled by EEV open step appropriately in order to get enough sub-cooling degree at condenser outlet. It means that the refrigerant in the heat exchanger cannot be transformed to the liquid completely if the mass flow rate is excessive compared to the heat exchanger capacity, and the noise from 2-phase slug-flow can increase when it flows out to the heat exchanger outlet.



(a) Horizontal flow



(b) Vertical flow

Fig. 10. Flow pattern map as different mass flow rate at condenser outlet.

4. Conclusions

The refrigerant-induced noise of the multi-type air conditioner was investigated experimentally and the following phenomena were observed.

(1) The refrigerant-induced noise increased when the quality at the evaporator inlet increased at cooling mode.

(2) The refrigerant-induced noise at indoor side varied according to its sub-cooling degree at heating mode, while the sub-cooling degree varied as the variation of mass flow rate.

(3) Mass flow rate increased suddenly and refrigerant-induced noise increased when PWM valve was on.

Therefore, in order to design multi-type air conditioner with lower noise, the following factors are recommended.

(1) Quality at the evaporator inlet should be minimized.

(2) Sub-cooling should be maximized at all of the operating conditions.

(3) Velocity at evaporator inlet should be minimized and the flow pattern must not be slug-flow.

(4) EEV open-step should be controlled approximately not to be 2-phase for the refrigerant at condenser outlet.

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