Vibration	Overheating Phenomenon on Heat Pump Type Water Heater	Plant
Resonance		

Object Machine

CO_2 refrigerant heat pump type water heater, that is provided with a refrigerant circuit (injection circuit) whose purpose is to restrict the temperature rise of refrigerant gas discharged from a scroll compressor during heavy load operation and to enhance the operation capability. The injection circuit has a mechanism such that, when a motor-operated valve is open, refrigerant for cooling mixes with refrigerant gas that passes through the injection port during compression, thus performing cooling function (Fig.1).

Observed Phenomena

Under a specific operation condition during operation of the compressor with a motor-operated valve for injection circuit closed, a phenomenon occurred wherein the piping near the motor-operated valve at the end of the injection circuit was overheated to a temperature exceeding the compressor outlet temperature. Fig.2 shows as an example of the temporal transitions of compressor rotational speed, temperature and pressure of the discharged refrigerant gas, and temperature near the motor-operated valve, while the overheating phenomenon was observed. As it is seen from Fig.2, temperature near the motor-operated valve started to rise abruptly at the first elapsed time, and after the second elapsed time, increase or decrease in temperature near the motor-operated valve associated with the compressor rotational speed was observed.

Cause Estimation

The injection circuit for the water heater forms a closed pipe with one end closed when the motor-operated valve closes, thus it will be force-excited by refrigerant gas pulsations in the injection port. The overheating phenomenon near the closed end to occurs when an air column in the closed pipe is excited by a jet flow is known as a thermo-acoustic effect(1-3), which appears as a heating effect wherein temperature at the pressure loop(peak) part of the pipe under air column resonance rises(2). Increase or decrease in temperature near the motor-operated valve associated with changes in the compressor rotational speed after the second elapsed time in Fig.2 suggests that the overheating phenomenon occurred in response to the air column resonance due to refrigerant gas pulsations. Thus, it was estimated that the cause of this overheating phenomenon is the occurrence of a thermo-acoustic effect because of air column resonance of one end closed pipe. On the other hand, an abrupt temperature rise near the motor-operated valve at the first elapsed time was not a temperature change associated with the compressor rotational speed, so relationship with an air column resonance was not clear. However, as the refrigerant pressure and temperature in the injection circuit were stabilized, the refrigerant sound speed changed. Thus, a possibility is considered that the temperature rise occurred as the gas pulsation frequency and the resonance frequency agreed.

Analysis and Data Processing

In order to confirm the resonance frequency of the injection circuit, an acoustic analysis by finite element method was conducted for the piping shape from the injection port to the motor-operated valve, wherein the bend portions were regarded as straight pipe to facilitate analysis. As a medium, the acoustic analysis condition (CO_2) listed in Table 1 was used, while forced flow excitation at the position of the injection port was assumed. The result of analysis proved that an air column resonance occurs within the frequency range of 76 to 96Hz when the pressure near the motor-operated valve rises (Fig.3). Fig.4 shows the air column resonance mode at this time. The frequency range of this resonance mode was nearly identical with that of the compressor rotational speed where the overheating phenomenon occurred in Fig.2. Also, the pressure waveform upon occurrence of the overheating phenomenon has the dominant rotating primary component. Thus, it was concluded that agreement between this resonance mode and the gas pulsation frequency was the reason to cause overheating near the injection motor-operated valve.

Countermeasures and Results

As a method for countermeasures, the length of injection piping and the compressor operating conditions were reviewed so as to avoid coincidence of the resonance frequency of the injection circuit and refrigerant gas pulsation frequency. As a result, there has been no generation of overheating phenomenon near the injection motor-operated valve.

Lesson

Compressors for heat pump type water heaters are operated under a wide range of rotational speed by means of an inverter depending on various refrigeration temperatures and pressure conditions, together with switching of the circuit according to the operation mode. It is thus necessary to grasp the frequency range for generation of pipe resonance as well as the operation conditions, even in case of the presence of transient changes in the refrigeration circuit and refrigeration sound speed.

References

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Keyword

Heat pump water heater, variable speed compressor, injection circuit, air column resonance, thermo-acoustic effect, acoustic analysis, finite element method

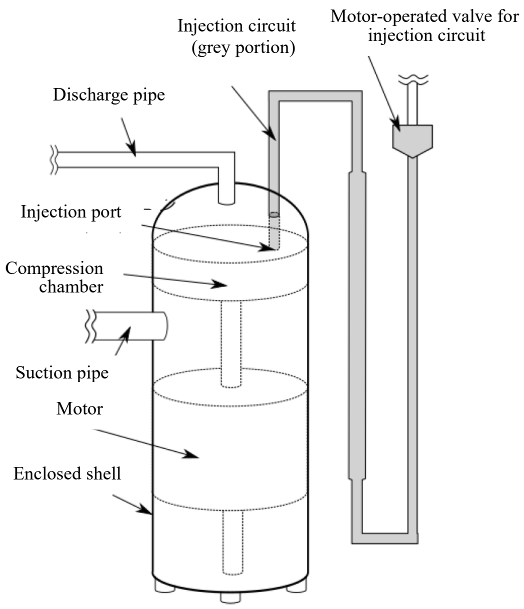

Fig.1 Schematic diagram of compressor and injection circuit

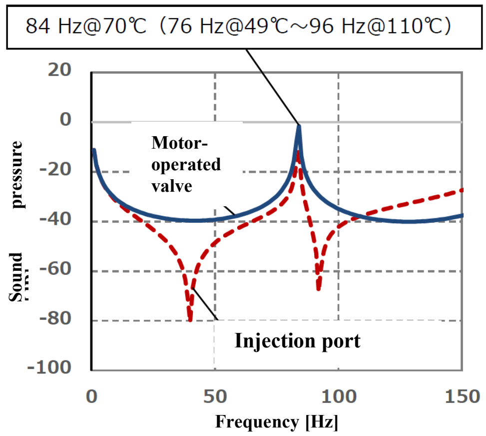

Fig.3 Result of acoustic analysis: sound pressure response frequency characteristics at positions of motor-operated valve and injection port

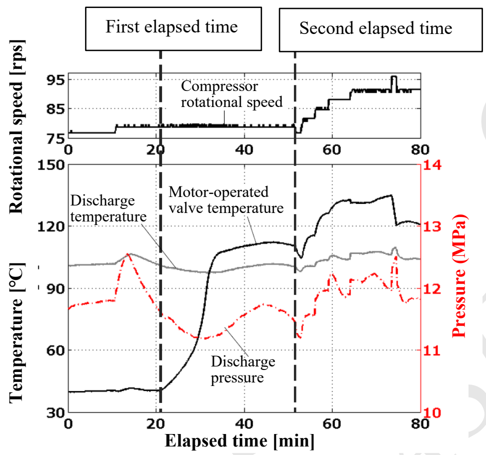

Fig.2 Temporal transitions of compressor rotational speed, temperature and pressure of discharged gas, and temperature near the motor-operated valve

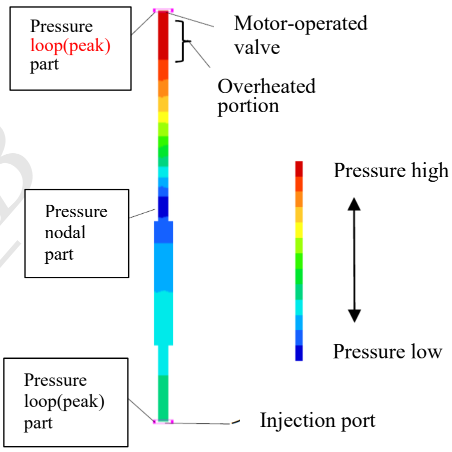

Fig.4 Result of acoustic analysis of injection circuit: resonance mode where pressure near the motor-operated valve rises

Table 1 Conditions for acoustic analysis of injection circuit inside

Item	Contents		
Type of refrigerant	CO_2		
Pressure	10MPa		
Temperature [℃]	49.0 *	70.0	110.0
Sound speed [m/s]	217.8	241.6	275.7
Density [kg/m^3]	401.6	247.8	177.0

* As the sound speed takes its minimum value for a pressure of 10MPa and a temperature of 49°C, the resonance frequency takes a lower limit under this temperature.