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Study on layer short mechanism and discharge pattern in refrigerant compressor for refrigerants with disproportionation reaction like HFO-1123

Mitsuhiro Fukuta[a,*], Hideyuki Fujimoto[b], Masaaki Motozawa[a]

[a]Shizuoka university, 3-5-1 Johoku, Naka-ku, Hamamatsu, 432-8561, Japan
[b]Shizuoka university, Graduate school of Integrated Science and Technology, 3-5-1 Johoku, Naka-ku, Hamamatsu, 432-8561, Japan

Abstract

HFO-1123, one of the low GWP refrigerants, will be decomposed with receiving large amounts of energy under high temperature and pressure condition. Short-circuit between motor winding wires caused by an insulation breakdown, i.e. layer short, in refrigerant compressors could be a trigger of the disproportionation reaction of HFO-1123.

In this study, the layer short mechanism and the electric energy discharged by the layer short of winding wire in the refrigerant compressor were investigated. A compressor equipped with a short-circuit generation mechanism in a compressor shell was used to measure the electric energy by the layer short during the compressor operation. Experiments were carried out mainly with the short-circuit between both ends of a main-winding as the worst case. There were several short-circuit patterns and the maximum current was observed to be 700 - 900 A and the electric energy was about 160 J. When the short-circuit occurred between terminals of the main-winding and an auxiliary-winding, the motor stopped while the electricity was continuously supplied, and temperature of the winding wire increased approximately 2.5℃/s.

Keywords: HFO1123, Disproportionation reaction, Compressor, Motor, Layer short, Electric energy

1. Introduction

From the viewpoint of preventing the global warming, the Kigali amendment to the Montreal protocol entered into force to phase-down the production and consumption of HFCs, and the use of the low GWP refrigerant is eagerly desired. HFO refrigerants have the low GWP, and application of the HFOs has been investigated in recent years. HFO-1123 is one of the low GWP refrigerants whose GWP is less than one and a mixture of HFO-1123 is considered as an alternative of R410A and R32. Although the GWP of the HFO-based mixed refrigerant can be reduced by increasing the mixing ratio of HFO-1123, a disproportionation reaction of HFO-1123 may occur when HFO-1123 gets high ignition energy under pressurized condition in refrigerant compressors [1,2]. If the disproportionation reaction occurs in the refrigerant compressor, the temperature and pressure in the compressor will rise steeply, and the refrigerant compressor might be destroyed. Since short-circuit between motor winding wires caused by an insulation breakdown, i.e. layer short, in the refrigerant compressors could be a trigger of the disproportionation reaction of HFO-1123, layer short mechanism and an electric energy caused by the layer short should be clarified [3].

In this study, the layer short mechanism and the electric energy discharged by the layer short of winding wire in the refrigerant compressor were investigated. A compressor equipped with a short-circuit generation mechanism in a compressor shell was used to measure the electric energy by the layer short during the compressor operation. The short-circuit between any two lead wires of the motor could be produced in the compressor with the short-circuit mechanism. As the first step of the study, experiments were carried out mainly with the short-circuit between both ends of a main-winding as the worst case. Current, voltage and

* Corresponding author. Tel.: +81-53-478-1054; fax: +81-53-478-1054
E-mail address: fukuta.mitsuhiro@shizuoka.ac.jp

electric power when the short-circuit occurred were measured.

2. Experiment

Figure 1 shows a schematic diagram of the compressor for generating a layer short in the refrigerant compressor. A compression mechanism and a motor were assembled into a shell having a large space above the motor element. The short-circuit generation mechanism (Fig.1, right) was mounted at the upper space in the shell, and it could generate the short-circuit with two enamel wires in the motor winding by operating an external screw head during compressor operation. In addition, a glass window was installed on the shell, and the short-circuit generation could be observed from the outside.

Figure 2 shows a schematic diagram of the refrigeration cycle with the compressor shown in Fig.1.The refrigeration cycle was a gas cycle consisting of the compressor, a radiator, an expansion valve. The pressure condition was adjusted with the throttle valve and charge amount of refrigerant controlled using a small refrigerant cylinder connected to the cycle. The suction pressure and the discharge pressure were measured by Bourdon tube gauges. The temperature was measured by T-type thermocouple at suction and discharge pipe of the compressor, and before and after the throttle valve. Beside those, the temperature of stator windings inside the compressor were measured by the thermocouples at two points. The refrigerant used was R410A instead of HFO-1123 because of safety, and the oil used was PVE (VG68).

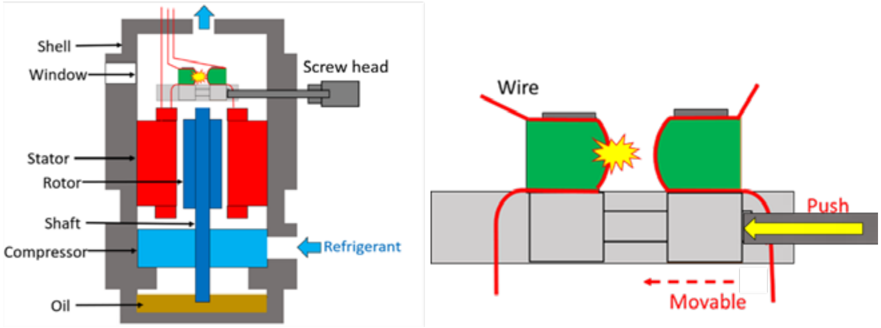

Fig. 1. Compressor for short-circuit experiment

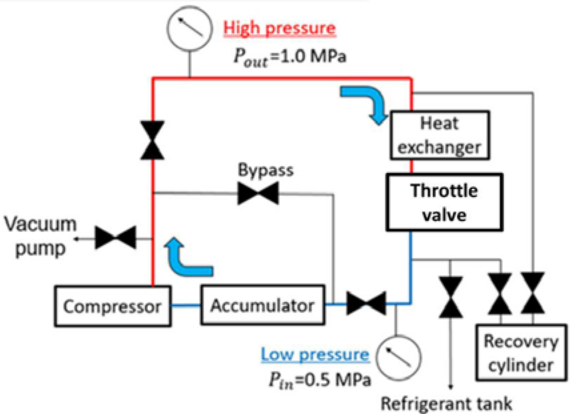

Fig. 2. Experimental gas cycle

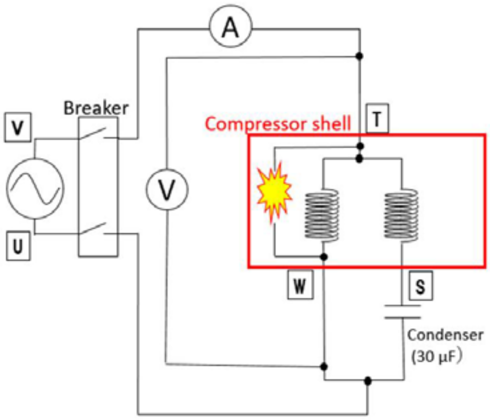

Fig. 3. Electric circuit (W-T short)

Figure 3 shows the motor driving circuit diagram. The motor was a 200 V single-phase permanent split type induction motor (rated output power is 750 W, outer diameter of motor stator is 112 mm, diameter of winding is 0.8 mm, resistance of winding is 35 Ω/km). A red square in Fig. 3 is the compressor shell and coils in the shell are the main-winding and the auxiliary-winding of the motor, respectively.

A breaker rated at 20 A was installed between the power source and the compressor. Over Load Protector (OLP) was not used at this time. Symbols W, T, and S represent the terminals of a glass terminal connected to the motor in the compressor. The short-circuit between W and T (W-T short) in the compressor shell is shown in Fig. 3. Enameled wires whose enamel coating was partially removed were inserted to lead wires of W and T, and these enameled wires were set at the layer short-circuit mechanism. When the short-circuit was produced, the voltage between the short-circuited terminals and the current flowing through the short-circuited enameled wire were measured using a high-voltage differential probe and a Rogowski coil, respectively. In addition to the W-T short, the short-circuit between W and S (W-S short) was conducted in this study.

After turning on the compressor, when the suction pressure and the discharge pressure reached 0.5 MPa (g) and 1.0 MPa (g), respectively, and became steady state, the short-circuit between two wires set at the short-circuit generation mechanism was yielded intentionally. The instantaneous electric power was calculated by the production of the current and the voltage. The electric energy due to the short-circuit was obtained by integrating the electric power with the time during which a large current was generated (short-circuit time). In addition, a high-speed camera was used to observe the sparks that occurred by the short-circuit generation.

3. Experimental result

3.1. Short-circuit at both ends of main-winding (W-T short)

The W-T short is shot-circuit between the both ends of the main-winding. Since it is equivalent to the short-circuit of the power source, this short-circuit is considered as the worst case discharging the maximum electric energy. When the W-T short occurred, a big spark rose, and the breaker was activated at that moment. Figure 4 shows the spark taken by the high-speed camera. The enamelled wire at the contact point after the short-circuit was fused as shown in Fig. 5 or welded. Figure 6 shows changes in current, voltage, and electric power against the time when the W-T short occurs. The zero point of the time on the horizontal axis is the time when the short-circuit occurred. Until the short- circuit occurred, the voltage waveform shows a sinusoidal one with an amplitude of 283 V. Although the current before the short-circuit is difficult to read from the figure because the full scale for the current is very large, it shows a sinusoidal wave with an amplitude of about 4 A. When the short-circuit occurred, the voltage between the W-T dropped to 0 V, and an instantaneous large current (maximum value of 784 A) flowed. The short-circuit time was 6 ms, and the electric energy due to the W-T short was 219 J.

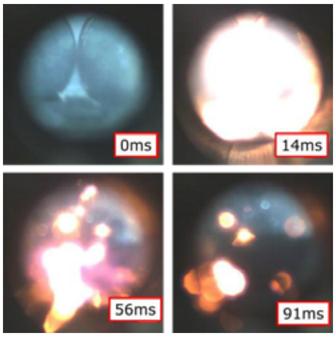

Fig. 4. Observation of the W-T short

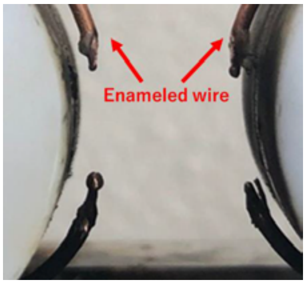

Fig. 5. Winding wire after the W-T short

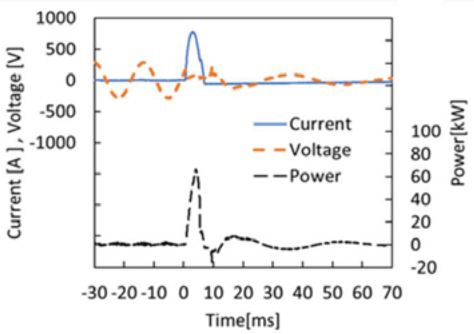

Fig. 6. Current, voltage, power (W-T short No.1)

Figure 7 shows another result when the W-T short generated under the same condition. As can be seen in Fig.7, once the voltage dropped to 0 V by the short-circuit, then increased and became 0 again. The instantaneous large current due to the short-circuit shows two peaks according to the voltage change. The short-circuit time was 6 ms in total for the two peaks. Electric energy generated was 168 J. In the case shown in Fig. 7, the two peaks were explained as that when the short-circuit occurred, only the contact part of the two enamel wires melted, the circuit temporarily recovered from the short-circuit to the normal state, and then the short-circuit occurred again.

In order to compare the results with the W-T short generated inside the compressor, W and T terminals were short-circuited at the outside of the compressor shell. No significant differences were observed in the current and voltage waveforms between them. Results for the W-T short generated both inside and outside of the compressor are summarized in Fig. 8 against phase angle θ of the voltage at the instant of the short-circuit generation.

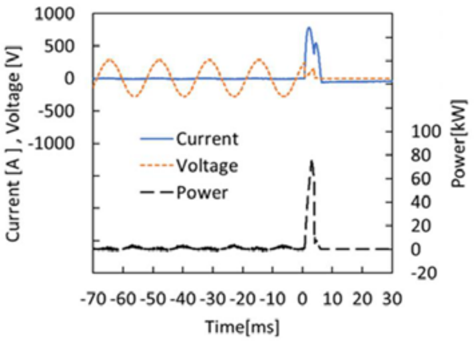

Fig. 7. Current, voltage, power (W-T short No.2)

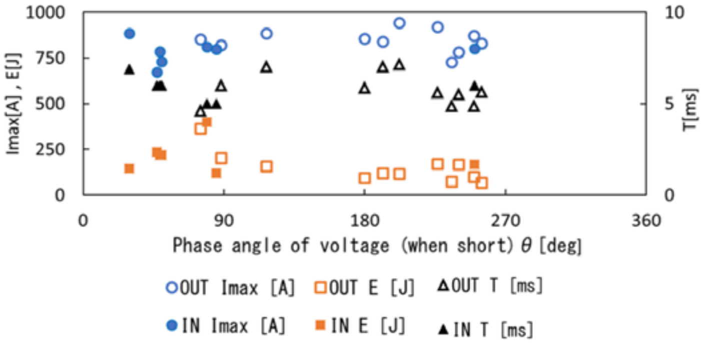

Fig. 8. Maximum current, short circuit time, and electric energy

The vertical axes of Fig. 8 represent the maximum current I_{max}, the electric energy E, and short-circuit time T. IN and OUT in Fig. 8 express the position where inside or outside of the compressor the short-circuit was generated. There was no significant influence of the voltage phase angle on the peak current, the electric energy, and short-circuit time. It can also be seen that the short-circuit often occurred at the range of phase angle 0-90°and 180 - 270°.The peak current was about 850 A, the electric energy was about 160 J, and the short-circuit time was about 7 ms. Since there was no difference between the short-circuit generated the inside and the outside of the compressor, the electric energy caused by the W-T short can be evaluated by the short-circuit between the W and T terminals outside the compressor. However, the layer short of the motor windings in the compressor accompanied by electric discharge should be examined in the compressor shell under the refrigerant atmosphere since the electric discharge is strongly affected by the refrigerant pressure [4], and an insulation of enamel deteriorates by high temperature [5].

3.2. Short-circuit between ends of the main-winding and auxiliary-winding (W-S short)

The W-S short is a short-circuit across the capacitor and makes the electric circuit of the motor into parallel two coils. When the W-S short occurred, the rotation of the motor stopped while the electricity was continuously supplied, and the motor temperature started to increase. Figure 9 shows the changes in the temperature of two positions of the upper coil end and the discharge pipe temperature when the W-S short occurred. When the motor temperature reached 150°C, the power was intentionally turned off to protect the motor. The temperature of Coil end (1) increased at 2.5°C/s after the short-circuit. If the temperature of the winding wire becomes so high that the enamel wire coating will deteriorate, the layer short may happen. This kind of risk is expected to be prevented by applying an over load protector in a power supply circuit.

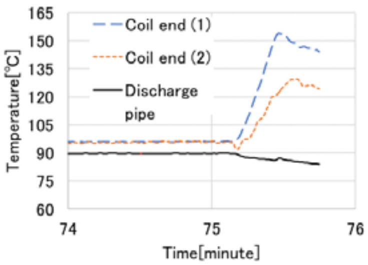

Fig. 9. Temperature change when the W-S short occurs

4. Future works

The following issues will be done to clarify the layer short mechanism and the discharge energy by the short-circuit in compressors.

1. Current and voltage measurement during the temperature rise by the W-S short
2. Investigation of the effect of over load protector
3. Short-circuit between both ends of auxiliary winding (T-S short)
4. Current, voltage and energy measurement in the case that the discharge occurs between wires with a certain minute gap.
5. Examination of degradation of enamelled wire due to short-circuit which occurs locally in the motor windings

5. Conclusion

Electric energy discharged by the short-circuit of winding wire in refrigerant compressors was investigated with a compressor equipped with a short-circuit generation mechanism in a compressor shell. The short-circuit between both ends of a main-winding (W-T short) was considered as the worst case. The maximum current was observed to be 700 - 900 A for about 7 ms, and the electric energy was about 160 J. When the short-circuit between both ends of a capacitor (W-S short), the motor stopped while the electricity was continuously supplied, and temperature of the winding wire increased approximately 2.5°C/s. Further study is needed to clarify the layer short mechanism in the refrigerant compressors.

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