1984

An Energy Saving Valve for Refrigeration Equipment Mounting Rotary Compressor

M. Morita
H. Nasu
M. Fujimoto

Follow this and additional works at: http://docs.lib.purdue.edu/icec

http://docs.lib.purdue.edu/icec/427

This document has been made available through Purdue e-Pubs, a service of the Purdue University Libraries. Please contact epubs@purdue.edu for additional information.
Complete proceedings may be acquired in print and on CD-ROM directly from the Ray W. Herrick Laboratories at https://engineering.purdue.edu/Herrick/Events/orderlit.html
AN ENERGY SAVING VALVE FOR REFRIGERATION EQUIPMENT
MOUNTING ROTARY COMPRESSOR

Mitsuru Morita
Hitoshi Nasu
Masatsugu Fujimoto
Research & Development Center
Matsushita Refrigeration Company
Higashi Osaka City, Japan

ABSTRACT

Today, rotary compressors have been used in a wide variety of refrigeration equipments from the standpoint of energy saving. In the case of household refrigerator, however, they have not been operated with their inherent improved efficiency.

This results from energy loss due to frequent on-off operation. This energy loss is high, particularly, in small-scale refrigeration equipment.

In refrigerators it was found that energy loss, being brought during inoperative state of the compressor, was serious. An attempt was made to analyze the causes of the loss in the state.

From the analysis it was found that the value of the loss in a refrigerator equipped with a rotary compressor was as much as about 2.4 times that with a reciprocating compressor.

Reduction of energy consumption in a refrigerator can be achieved by using a means of minimizing its energy loss due to on-off operation.

An energy saving valve capable of actuating in response to characteristic pressure change of the rotary compressor in on-off operation was developed to minimize that energy loss.

The implementation of this valve enabled household refrigerators to save by 22 percent their energy consumption.

INTRODUCTION

The calorimetric energy efficiency ratio of a small-sized rotary compressor for refrigerators is better by 15 percent than that of a reciprocating compressor with the same refrigerating capacity.

Nevertheless, the energy consumption of the rotary compressor mounted on a 10 cft. household refrigerator shows only 4 percent better than reciprocating compressor, and also lower than the efficiency of the compressor itself.

This paper describes the development of an energy saving valve and presents the results of quantitative measurements and analysis of refrigerant flow into the evaporator from the condenser (the high-pressure side of the rotary compressor) during inoperative state.

CHARACTERISTIC OF CONDENSER-TO-EVAPORATOR REFRIGERANT FLOW DURING INOPERATIVE STATE

1.1 Test Equipment and Test Conditions

Characteristic study of refrigerant flow was carried out using a 10 cft. refrigerator. The description of test equipment is shown in Fig. 1.

Test Conditions

<table>
<thead>
<tr>
<th>Condition</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>a) Ambient temperature</td>
<td>30°C</td>
</tr>
<tr>
<td>Provision compartment temperature</td>
<td>3°C</td>
</tr>
<tr>
<td>Freezing compartment temperature</td>
<td>-18°C</td>
</tr>
<tr>
<td>b) Ambient temperature</td>
<td>15°C</td>
</tr>
<tr>
<td>Provision compartment temperature</td>
<td>3°C</td>
</tr>
<tr>
<td>Freezing compartment temperature</td>
<td>-18°C</td>
</tr>
</tbody>
</table>

1.2 Test Method

Temperature measurements were made through the thermocouple solder-jointed at the point marked in Fig. 1.
1.3 Results of Analysis

The energy loss analysis was performed on the basis of the following equation:

\[ Q(t') = \int_0^{t'} g(t) \cdot h_c(t) \, dt + G(0) h_e(0) - G(t') h_e(t') \]

Where:
- \( Q(t') \) = energy loss during off-cycle (J)
- \( g(t) \) = amount of refrigerant entering into the evaporator during off-cycle (gr/min.)
- \( h_c(t) \) = enthalpy of refrigerant entering into the evaporator during off-cycle (J/gr)
- \( G(0), G(t') \) = amount of refrigerant in the evaporator just after turned on (0), and turned off (t'). (gr)
- \( h_e(0), h_e(t') \) = enthalpy of refrigerant in the evaporator just after turned on (0), and turned off (t'). (J/gr)
- \( t \) = time factor (min)
Pressure measurements were carried out using a pressure transducer, whose signal was amplified by an amplifier and then recorded on a pen recorder.

Refrigerant flow into the evaporator from the high-pressure side after the compressor turned off was checked visually through a glass tube.

After the compressor turned off each solenoid valve was closed at certain intervals. The refrigerant in the evaporator was collected into the condensation chamber, and the refrigerant weight was measured.

Fig. 2 shows the refrigerant distribution in both just before turning on and off.

In the Fig. 2 it can be recognized that weight percentage of refrigerant in the evaporator to the total refrigerant in the cycle has increased up to 86 percent from 24 percent during inoperative state.

1.3 Results of Analysis

The energy loss analysis was performed on the basis of the following equation:

\[ \theta(t') = \int_0^{t'} g(t) \cdot h_c(t) \, dt + G(O) \cdot h_e(O) - G(t') \cdot h_e(t') \]

where \( \theta(t') \) = energy loss during inoperative period \( t' \). (J)

\( g(t) \) = refrigerant flow. (g)

\( h_c(t) \) = enthalpy of refrigerant flow. (J/g)

\( G(O) \), \( G(t') \) = refrigerant quantity in the evaporator at the just turned-off movement. (g)

\( h_e(O) \), \( h_e(t') \) = enthalpy of refrigerant in the evaporator at the just moment \( t' \) and in the state. (J/g)

\( t \) = time elapsed after turn-off.
Figure 3 shows the characteristic of energy loss throughout time elapse during inoperative state of both reciprocative and rotary compressor mounted on a refrigerator. (measured values all at 30°C, ambient temperature)

The energy loss of load in the refrigerator is given in Table 1.

As found from these data, the energy loss per cycle of the rotary compressor when the inoperative time is 20 minutes is three times that of the reciprocating compressor.

Figures in the table 1 are on the basis in per hour that each value of refrigeration load in ambient temperature of both 15°C and 30°C are calculated in weighted average by proportion with 100 and 265. (The values shown in parenthesis in the table are indexes.)

The data shows that the energy loss increases the total refrigeration loads by 11 percent.

As a result, improved efficiency by 15 percent of the rotary compressor will be reduced apparently to 4 percent when it is mounted on a refrigerator.

### Table 1: Energy Loss of Load in the Refrigerator

<table>
<thead>
<tr>
<th>Item</th>
<th>Rotary (W)</th>
<th>Reciproc. (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Other Heat</td>
<td>4.9</td>
<td>4.9</td>
</tr>
<tr>
<td>Energy Loss</td>
<td>9.8</td>
<td>4.1</td>
</tr>
<tr>
<td>Heat that leaks into P.C.</td>
<td>19.9</td>
<td>19.9</td>
</tr>
<tr>
<td>Heat that leaks into F.C.</td>
<td>20.9</td>
<td>20.9</td>
</tr>
<tr>
<td>Total Cooling Load</td>
<td>55.5</td>
<td>49.8</td>
</tr>
</tbody>
</table>

The energy loss can be reduced by preventing refrigerant from entering into the evaporator during inoperative state.

In order to prevent it from doing so, applying solenoid valve in refrigeration cycle can be helpful. Using solenoid valve is, however, not a better solution from standpoint view of energy consumption as well as noise.

### 2. DEVELOPMENT OF AN ENERGY SAVING VALVE

#### 2.1 Configuration

A cross-sectional view and photograph of the recently developed energy saving valve are shown in Fig.4 and 5, respectively.

A low-pressure valve and a high-pressure valve operative in response to a pressure difference in the refrigeration cycle are housed in a single case. This is one of the characteristics of the valve.

High-pressure and low-pressure sides are separated by a bellows. The high-pressure valve is provided with a
bias-force adjustment spring so that the high-pressure valve can open when the pressure difference between both sides of the bellows exceeds a predetermined value $P_0$ and close when being lower than $P_0$.

2.2 Applications and Operation

The application of the valve to the refrigeration cycle of a refrigerator is shown in Fig. 6.

Figure 7 shows the internal-pressure change characteristic of the above energy saving cycle in the operating and not-operating states.

Valve operation is described below. $P_d$, $P_s$, and $P_e$ in Fig. 7 are the pressure at their respective measurement points shown in Fig. 6.
Operation

During running:

(1) Gas flow pressure in compressor operation makes the low-pressure valve to keep open.

(2) When \( P_0 - \Delta P = P_d - P_s \), the high-pressure valve keeps open because the pressure \( P_s \) is low.

Thus, a normal refrigeration cycle is carrying on and refrigeration operation is continued.

Just after turning-off:

(1) With gas flow stop, the low-pressure valve closes.

(2) The high-pressure gas in the compressor casing starts to return into the suction pipe.

(3) Rapid rise of pressure \( P_s \) causes \( P_0 > \Delta P = P_d - P_s \), and the high-pressure valve closes.

Thus, both inlet and outlet flow of the evaporator are closed; i.e., the high-pressure refrigerant is disabled from entering into the evaporator.

During inoperative state:

(1) The low-pressure valve is completely closed by back-pressure due to refrigerant returning from the suction pipe.

(2) The high-pressure valve remains in close by force of the adjusting spring.

Thus, the pressure condition in the refrigeration cycle is not changed from the operating pressure condition until the next operation takes place.

In restarting:

(1) With compressor operation, \( P_s \) rapidly drops and the low-pressure valve becomes open with gas flow pressure applied.

(2) \( P_0 < \Delta P \) causes the high-pressure valve to open immediately.

Thus, the time required to reach the steady state from the unsteady state is shorter than that of a conventional cycle. This means that the valve has ability to reduce also loss in every starting.

2.3 Application Effect

Table 2 gives a comparison of energy consumption between a rotary compressor cycle equipped with the valve and the conventional rotary and reciprocating compressor cycle.

The energy saving rate is lower by 25 percent than a reciprocating compressor system.

In addition, the valve requires no electrical control circuit and is little in valve on-off noise and excellent in cost-performance. It allows application to various refrigeration systems, not limited to refrigerators.

<table>
<thead>
<tr>
<th>REFRIGERATION CYCLE</th>
<th>ENERGY SAVING VALUE</th>
<th>SOLENOID VALVE</th>
<th>CONVENTIONAL</th>
<th>CONVENTIONAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>EER OF COMPRESSOR</td>
<td>ROTARY</td>
<td>ROTARY</td>
<td>ROTARY</td>
<td>RECIPROCATING</td>
</tr>
<tr>
<td>115</td>
<td>115</td>
<td>115</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>POWER CONSUMPTION OF REFRIGERATOR</td>
<td>78</td>
<td>80</td>
<td>100</td>
<td>104</td>
</tr>
<tr>
<td>75</td>
<td>77</td>
<td>96</td>
<td>100</td>
<td></td>
</tr>
</tbody>
</table>

Table 2 Comparison of energy consumption between a rotary compressor cycle equipped with the valve and the conventional rotary and reciprocating-compressor cycle.