An Application of TRIAC to Capacitor Motor for Hermetic Compressor

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AN APPLICATION OF TRIAC TO CAPACITOR MOTOR
FOR HERMETIC COMPRESSOR

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ABSTRACT

This paper refers to an application study of TRIAC to PSC motor for the hermetic compressor. It is well known that TRIAC delays phase angle of the current and has no losses if it is considered as ideal switch. Therefore it is possible to get a kind of variable capacitor by connecting TRIAC with capacitor in series and controlling the firing angle of it.

By using this variable capacitor for PSC motor, we could obtain the performance similar to CSR motor. Therefore we believe that this type motor should be developed as one of the single phase motor for the hermetic compressor with the progress of the electronics.

INTRODUCTION

Various kinds of single phase induction motors such as PSC, CSR, RSIR, PTC assist PSC and PTC assist CSR are used for hermetic compressors. We choice one of these according to the purpose for use.

In recent years, it is prosperous to try the application studies of semiconductors to the sphere of the motor control. An application study of TRIAC to a single phase induction motor is one of these.

As explained in this paper, it is possible to get a kind of variable capacitor by connecting TRIAC in series with capacitor of PSC motor and controlling the firing angle of it. We call this type motor TRIAC assist PSC motor in this paper.

This paper refers to the torque characteristic of TRIAC assist PSC motor and the starting performance on the actual hermetic compressor, based on the experimental results. And we try to compare it with the other existing motors. In addition, we view a possibility of TRIAC assist PSC motor for hermetic compressors.

TEST MOTOR AND CONTROL DEVICE OF TRIAC

2 poles, single phase induction motor shown in Fig. 1 was used for our experiment. Its voltage, frequency and output ratings are 100 V, 50/60 Hz and 100 W. It is a built-in motor for the rotary type hermetic compressor shown in Fig. 2. There are three types of the wirings of the starting device for this motor, as shown in Fig. 3. A shows CSR motor, B shows PTC assist CSR motor and C shows PTC assist PSC motor. The customer is able to choose a most suitable type of them for use.
Fig. 3 Wiring diagrams of the hermetic compressor motors for refrigerator

A: CSR motor
1: Main winding
2: Auxiliary winding
3: Relay
4: Starting capacitor
5: Discharging resistor
6: Running capacitor
7: PTC thermistor

B: PTC assist CSR motor

C: PTC assist PSC motor

Fig. 4 shows the wiring diagram of TRIAC assist PSC motor described in this paper. TRIAC is connected in series with capacitor of PSC motor.

Fig. 4 Wiring diagram of TRIAC assist PSC motor

Fig. 5 shows the control device of TRIAC made for our experiment. Fig. 6 shows its block diagram, and Fig. 7 shows its time charts. It is possible to set up the firing angle of TRIAC by 0.1 m.sec., using this control device. The detection circuit for the auxiliary winding voltage operates to turn TRIAC into no fire. For this operation, we make use of the property which the auxiliary winding voltage increases with revolution in PSC motor, as shown in Fig. 8. And the relation between the auxiliary winding voltage and the operating point of the detection circuit has a hysteresis characteristic as shown in Fig. 8.

Fig. 5 Control device of TRIAC

Fig. 6 Block diagram of the control device

TRIAC
Rectification
Alternation
Voltage comparator
Control logic
Drivers

Zero detector
Counters
Latch

Clock
Time set

215V +5V +5V ref.

A: To main winding
B: To running capacitor
C: To auxiliary winding
D: To common
TORQUE CHARACTERISTIC OF TRIAC ASSIST PSC MOTOR

We define the firing angle of TRIAC as shown in Fig. 9 in this paper, i.e., zero degree of the firing angle corresponds to zero degree of the source voltage. Fig. 10 shows the phase angle of the main winding and auxiliary winding currents for PSC motor used for our experiment, which the source voltage is base. Generally, the main winding current lags the source voltage, and the auxiliary winding current leads the source voltage. Therefore, in case that the firing angle of TRIAC is zero degree, the auxiliary winding current is chopped by angular lead for the source voltage.

Fig. 11 shows the measured waveforms of the source voltage ($E_1$) and the auxiliary winding current ($I_a$) corresponding to the firing angle of $0^\circ$, $47.5^\circ$, and $73.4^\circ$ at slip 1 (at starting) for TRIAC assist PSC motor. As seen from this figure, the phase angle of $I_a$ lags as the firing angle of TRIAC increases. That is to say, it shows the characteristic of a kind of variable inductance.
Fig. 11 Measured aux. winding current of TRIAC assist PSC motor (slip=1)

Starting torque of PSC motor is expressed as the following equation, as well known.

\[ T_s \propto I_m I_a \sin \alpha \]  \hspace{1cm} (1)

where

- \( I_m \): Main winding current
- \( I_a \): Auxiliary winding current
- \( \alpha \): Phase difference between \( I_m \) and \( I_a \)
- \( T_s \): Starting torque

Therefore it is possible to control \( T_s \) by controlling \( I_a \sin \alpha \), i.e., by controlling the firing angle of TRIAC for TRIAC assist PSC motor.

Fig. 12 shows the measured motor speed-torque curves for TRIAC assist PSC motor, corresponding to each firing angle shown in Fig. 11. They are measured from firing angle of 0 degree to 140 degrees. It is apparent that the speed-torque curve changes as the firing angle of TRIAC changes.

Fig. 12 Measured speed-torque curve for TRIAC assist PSC motor

The relation between the starting torque and the firing angle of TRIAC is shown in Fig. 13. These values of the starting torque were obtained from above measured speed-torque curves. As seen from this figure, the maximum point of the starting torque is given at the firing angle of nearly 50 degrees. Its value is about 3.3 times as much as the starting torque of PSC motor, which is shown as broken line in Fig. 13. And in this figure, the starting torque equals zero at the firing angle of nearly 115 degrees. It means \( \sin \alpha = 0 \) in the equation (1), i.e., the phase difference between the
main winding current and auxiliary winding current becomes zero degree at this firing angle. Increasing more than this firing angle, the auxiliary winding current lags the main winding current, i.e., \( \sin \alpha < 0 \); \( T_s < 0 \) in the equation (1). It means the motor rotates in reverse.

Fig. 14 shows the relation between the break-down torque and the firing angle of TRIAC. These values of the break-down torque were obtained from above measured speed-torque curves in the same manner as the starting torque. As seen from this figure, the maximum point of the break-down torque is given at the firing angle of nearly 55 degrees. Its value is about 1.4 times as much as the break-down torque of PSC motor, which is shown as broken line in Fig. 14.

Fig. 15 shows the relation between the starting and break-down torque and the firing angle of TRIAC. The values of the torques are expressed as ratio, which is 1 in case of PSC motor. The points of the maximum starting and break-down torque corresponding to the firing angle of TRIAC shift a few. And the starting torque is high ratio more than the break-down torque.

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**Fig. 14** Relation between measured break-down torque and firing angle for TRIAC assist PSC motor

**Fig. 15** Relation between the starting and break-down torque ratio (PSC=1) and firing angle for TRIAC assist PSC motor

**Fig. 16** Starting test data of TRIAC assist PSC motor on the actual hermetic compressor
Starting performance on the actual hermetic compressor

Fig. 16 shows the electrical performance data of TRIAC assist PSC motor from start to full speed on the actual hermetic compressor shown in Fig. 2. It shows that the firing angle of TRIAC is setted up at 50 degrees, which we can get the maximum value of the starting torque. From a practical point of view, we need set up the firing angle to take into consideration of the starting, break-down or transient accelerated torques cooperated with the loading torque in the system. TRIAC is turned into no fire at the point A shown in Fig. 16. At this point, the detection circuit for the auxiliary winding voltage of the control device shown in Fig. 5 operate, and the motor changes to the condition of PSC.

Comparison of TRIAC assist PSC motor with the existing other motors

We make the performance comparison of TRIAC assist PSC motor with the existing other motors using the experimental results obtained by changing the electric parts except for the running capacitor of the motor shown in Fig. 1.

Starting torque

Fig. 17 shows the starting torque of TRIAC assist PSC motor at the firing angle of 50 degrees, together with the existing other motors. As seen from this figure, TRIAC assist PSC motor at the firing angle of 50 degrees and CSR and PTC assist CSR motors having nearly 30 μF starting capacitor have a nearly equal value of the starting torque. And the starting torque of TRIAC assist PSC motor is nearly 1.3 times value as that of PTC assist PSC motor having 15 Ω PTC, and nearly 1.4 times value as that of PTC assist PSC motor having 33 Ω PTC.

Break-down torque

Fig. 18 shows the break-down torque of TRIAC assist PSC motor at the firing angle of 55 degrees, together with the existing other motors. As seen from this figure, TRIAC assist PSC motor at the firing angle of 55 degrees and CSR and PTC assist CSR motors having nearly 20 μF starting capacitor have nearly equal value of the break-down torque. And the break-down torque of TRIAC assist PSC motor is nearly 1.8 times value as that of PTC assist PSC motor having 15 Ω PTC, and nearly 1.5 times value as that of PTC assist PSC motor having 33 Ω PTC.
VIEW IN FUTURE OF TRIAC ASSIST PSC MOTOR FOR THE HERMETIC COMPRESSOR

Table 1 shows the cost comparison of the electric parts for various types of motors under nearly same value condition of the starting torque. As seen from this table, TRIAC assist PSC motor is not the best one of the minimum cost for performance.

<table>
<thead>
<tr>
<th>Motor Type</th>
<th>Parts</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Starting Capacitor</td>
<td>16</td>
<td>←</td>
<td>←</td>
<td>←</td>
<td>←</td>
</tr>
<tr>
<td>Running Capacitor</td>
<td>27</td>
<td>←</td>
<td>←</td>
<td>←</td>
<td>←</td>
</tr>
<tr>
<td>Relay</td>
<td>55</td>
<td>←</td>
<td>←</td>
<td>←</td>
<td>←</td>
</tr>
<tr>
<td>Discharging resistor</td>
<td>2</td>
<td>←</td>
<td>←</td>
<td>←</td>
<td>←</td>
</tr>
<tr>
<td>PTC</td>
<td>26</td>
<td>←</td>
<td>←</td>
<td>←</td>
<td>←</td>
</tr>
<tr>
<td>TRIAC &amp; Control device</td>
<td>125</td>
<td>←</td>
<td>←</td>
<td>←</td>
<td>←</td>
</tr>
<tr>
<td>Total cost</td>
<td>100</td>
<td>69</td>
<td>53</td>
<td>152</td>
<td>←</td>
</tr>
</tbody>
</table>

A: CSR, B: PTC assist CSR, C: PTC assist PSC, D: TRIAC assist PSC

As there is a possibility of cost down for the control device by the mass production or the integration, it is enough to say that TRIAC assist PSC motor has a possibility of a practical use in future.

CONCLUSION

It is possible to control the motor torque by connecting TRIAC in series with capacitor of PSC motor and controlling the firing angle of it. We obtained the following experimental results in 100 W motor for the hermetic compressor.

(1) The value of the maximum starting torque of TRIAC assist PSC motor is about 3.3 times as much as the starting torque of PSC motor, and about 1.3 times as much as the starting torque of PTC assist PSC motor having 15 Ω PTC, and about 1.4 times as much as the starting torque of PTC assist PSC motor having 33 Ω PTC. And it is corresponding to CSR or PTC assist CSR motor having nearly 30 μF starting capacitor.

(2) The value of the maximum break-down torque of TRIAC assist PSC motor is about 1.4 times as much as the break-down torque of PSC motor, and about 1.8 times as much as the break-down torque of PTC assist PSC motor having 15 Ω PTC, and about 1.5 times as much as the break-down torque of PTC assist PSC motor having 33 Ω PTC. And it is corresponding to CSR or PTC assist CSR motor having nearly 20 μF starting capacity.

(3) The maximum point of starting torque is given at the firing angle of nearly 50 degrees, and that of break-down torque is given at 55 degrees. They shift a little with each other.

TRIAC assist PSC motor has some superior characteristics comparing with the other existing motors. Although we cannot to say that it has a sufficient practical use with the present cost level, it should be developed as one of the single phase motor for the hermetic compressor with the progress of the electronics.

We reported as for the application of TRIAC to existing PSC motor in this paper. After this it is necessary for us to investigate to make the motor design most suitable for TRIAC assist PSC motor, and we shall continue to study.

REFERENCES


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