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SINGLE-PHASE, TWO-SPEED, COMPRESSORS

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ABSTRACT

This paper presents a new procedure for the speed changing of the two-speed compressor driven by the single-phase Permanent Split Capacitor (PSC) motor.

The use of the two-speed motor for compressor is one of the effective ways for their capacity control. But the two speed compressors now in use are driven by three-phase motors. It is because a single-phase, two-speed motor has rather a small starting torque, thus making it difficult to change the number of poles from four to two, unless it is connected with a starting capacitor of comparative large value.

We have developed new procedure for the compressor driven by the two speed motor with no starting capacitor. This motor has main and auxiliary windings for 2-pole running as well as for 4-pole running. The speed changing from 4-pole to 2-pole running is made by the following procedure.

If the speed is to be changed during the 4-pole running, the 2-pole windings are energized without the 4-pole windings being de-energized. In other words, at this stage, both 2-pole and 4-pole windings are supplied with the power simultaneously.

After several tens of milliseconds, however, the 4-pole windings are de-energized, the 2-pole windings remaining energized alone.

The combined torque caused by the 2-pole and 4-pole winding is equivalent to the sum of their respective torques. Therefore, the speed changing from 4-pole to 2-pole running is possible even in a heavy load condition.

By using the above-mentioned procedure, a staring capacitor of any value can be dispensed with. According to our experiment, this type of motor shows a very effective capacity control for single phase household application of compressors.

FIG. 1 WIRING CONNECTION
INTRODUCTION

Two-speed, pole-change induction motors have been used widely in industries for many years. But they were until very recently seldom used for hermetic compressors, because of the high cost of the motor and the unsatisfactory performance as a compressor (discussed later). However, two-speed motors have recently come to be used as one of the effective ways for the capacity control of compressors to increase the value of SEER.

Although various winding arrangements for the two-speed operation of single-phase motors have been presented, three-phase motors are still preferred to such motors on the market. It is partly because any of such single-phase motors fails to achieve 100% winding utilization for both 2-pole and 4-pole running, while three-phase motors afford this quality, thus reducing the size and the cost of the compressors.

Furthermore, single-phase, two-speed motors have another disadvantage when used for compressors.

In general, single phase motors cause a smaller starting torque than three-phase motors. And single-phase, two-speed motors cause an even lower starting torque than single-phase, single-speed motors. So the starting conditions of such single-phase, two-speed compressors are severely limited. To raise the limit of the starting performance, a starting capacitor is required.

Accordingly such single-phase, two-speed compressors must take the form of the Capacitor Start and Capacitor Run (CSR).

In spite of the use of a starting capacitor, the speed changing from 4-pole to 2-pole running is still difficult because of the long switching time of relays. The power is removed for 10 ms or more by switching. And meanwhile the motor speed falls and the compressor is likely to stall, unless a starting capacitor of large value is attached. Therefore, the refrigeration and air-conditioning systems, driven by the single-phase, two-speed compressor, but not equipped with such capacitor of large value, must be stopped for several minutes for equalizing to change the speed from 4-pole to 2-pole running to increase their capacity. For the refrigeration and air-conditioning systems, such stoppage of the compressor is a great disadvantage.

This paper discusses how to change the speed from 4-pole to 2-pole running for the single-phase, two-speed compressor using the Permanent Split Capacitor (PSC) motor, and that without stopping the operation of the systems.

THE MOTOR

The wiring connection that we use in our procedure is shown by Fig. 1. The motor has main and auxiliary windings for 2-pole as well as 4-pole running respectively. In the case of Fig. 1, a common running capacitor is connected with both poles. It is not economical to connect separate running capacitors with each pole, though it would achieve high efficiency at each speeds.
Fig. 3 shows the timing diagram for the typical single-phase, two-speed motor. The 4-pole stalling torque is smaller than the 2-pole stalling torque. On the contrary, the 4-pole starting torque is larger than the 2-pole starting torque. The torque ratio must be adapted to the requirement of the compressor. But the torque ratio is limited within a certain range by the size of the slot and the number of the turns of the windings. Even if a large core is used, an insufficient torque may occur in some cases on account of such wiring limitation.

The 2-pole and the 4-pole windings are independent from each other, so that both winding may be supplied with the power simultaneously. The combined torque caused by the 2-pole and the 4-pole windings, energized simultaneously, is shown by the dotted line in Fig. 2. This torque is equivalent to the sum of the respective torques of both poles at a given speeds.

By using this type of motor, the speed changing is made by the following procedure.

1. The motor is to be started with the 4-pole running, even in the case where the 2-pole running is required. After several minutes, the speed may be changed to 2-pole running.

2. When the speed changing from 4-pole to 2-pole running is required, the 2-pole windings are energized without the 4-pole windings being de-energized. At this stage, the 2-pole and the 4-pole windings are supplied with the power simultaneously. After several tens of milliseconds, the 4-pole windings are de-energized, the 2-pole windings remaining energized alone. Fig. 3 shows the timing diagram of our procedure.

Fig. 4 shows the torque-speed characteristics for the PSC two-speed motor. The effect of our procedure is explained by Fig. 4. If the load has the torque-speed characteristics shown by the dashed line A, the speed of 4-pole running will be such as indicated by A1, and, if the switching time of relays could be disregarded, would immediately after the speed changing, theoretically raise to the point as indicated by A2. The torque A2 is larger than the load torque at the speed, with the result that the motor is accelerated to the speed A3. On the other hand, in the case where the load has the torque-speed characteristics shown by the dashed line B, the speed of 4-pole running will be such as indicated by B1, and immediately after the speed changing would theoretically fall until it reaches the 2-pole line. The torque caused by the 2-pole windings at its speed is smaller than the load, with the logical consequence that the motor will be stalled.

If we use the procedure described above the speed of the motor will be changed as follows. In case the load has the torque-speed characteristics shown by the dashed line B as explained above, the speed of the 4-pole running will be such as indicated by B1. When the 2-pole windings are energized during the 4-pole running, the combined torque caused at that speed raises to B2. Then the speed of the motor is accelerated to the speed B3. And the torque at the speed at the time when the 4-pole windings are de-energized is B4. Then the speed of the motor is accelerated to the speed B5, that is, the speed of 2-pole running. By using this procedure, the speed of the motor changes from 4-pole to 2-pole running even in the heavy-load condition, as indicated by line B.
This procedure is easily realized by using such timer relays, as may determines the running time of the 2-pole and 4-pole windings energized simultaneously. And we can call the motor using this procedure a PSC motor for no starting capacitor is connected to the windings. Table 1 shows the typical two-speed motor specifications compared with the single-speed motor of the same ratings.

Table 1
The specifications of the two-speed motor and the single-speed motor of the same rating.

<table>
<thead>
<tr>
<th></th>
<th>Single-speed</th>
<th>Two-speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Core OD.</td>
<td>105 mm</td>
<td>125 mm</td>
</tr>
<tr>
<td>Stack height</td>
<td>75 mm</td>
<td>85 mm</td>
</tr>
<tr>
<td>Mode</td>
<td>2-pole</td>
<td>2-pole</td>
</tr>
<tr>
<td>Efficiency</td>
<td>85%</td>
<td>83%</td>
</tr>
<tr>
<td>Running Capacitor</td>
<td>45μF</td>
<td>70μF</td>
</tr>
</tbody>
</table>

Such speed changing tests were run on the actual compressor. We used a rotary compressor of the rolling piston type for household air-conditioning. The speed changing characteristics from 4-pole to 2-pole running are indicated by the 4-pole running torque.

Fig. 5 shows the speed changing characteristics as the function of the running time of the 2-pole and the 4-pole windings energized simultaneously. The hatched area is the region where the motor can be accelerated to the 2-pole speed. The point at which the running time is zero indicates that the 2-pole and the 4-pole windings are not energized simultaneously. Actually a no-voltage time, generally 10 ms or more, occurs on account of the switching time of relays before the 2-pole windings are energized.

An appropriate running time of at least 60 ms is required for the 2-pole and the 4-pole windings energized simultaneously to change the speed at a sufficiently high torque. Too long a running time, however, would lead to the temperature rise of the winding and finally to the motor burn-out.
For comparison, the speed changing characteristics of the CSR motor are shown by Fig. 6, as a function of the value of the starting capacitor which is connected with the auxiliary windings of the 2-pole in parallel with the running capacitor at the moment of the speed changing. We know from Fig. 5 and 6 that a 100 ms running time of our PSC motor results in a which would be caused by 25μF starting capacitor of the CSR motor.

These results are expressed by the running conditions of the compressor, that is, the suction pressure and the discharge pressure where the suction temperature is constant, as in Fig. 7. The area under each of the three curved lines is the region where the compressor can be accelerated to the 2-pole speed by the conventional procedure (4P + 2P), our procedure (4P + 4P + 2P + 2P) and CSR procedure respectively. For example, the point where the suction pressure is 6 kg/cm²G and the discharge pressure is 19 kg/cm²G falls on the stalling region by the conventional procedure.

It is found that the result attained by our procedure are about the same as those by the CSR procedure with 25μF starting capacitor.

If the speed changing is required in a heavier load condition than the dashed line in Fig. 7, a starting capacitor may be used with our procedure. When the 2-pole windings energized, a starting capacitor of a small value may be connected with the 2-pole auxiliary windings. The accelerating area will be widened. Anyway, the required value of the starting capacitor is smaller than in the case of the CSR procedure.

CONCLUSION

A single-phase, two-speed compressor has found its new use by the procedure that the 2-pole and the 4-pole windings are supplied with the power simultaneously at the moment of the speed changing. At the time of the speed changing, its 2-pole windings obtain the torque from its 4-pole windings instead of a starting capacitor. It remarkably saves energy in the single phase household refrigeration and air-conditioning.

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