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A Motor Designer Looks at Positive Temperature Coefficient Resistors

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POSITIVE TEMPERATURE COEFFICIENT RESISTORS

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INTRODUCTION

A positive temperature coefficient resistor (PTCR) is a device which switches from a relatively low resistance to a high resistance at some transition temperature. Figure 1 shows a typical curve of resistance as a function of temperature for a Barius Titanate PTCR. Note that at temperatures above 110C there is about a 10:1 change in resistance for every 20° change in temperature. The idea of using PTCR's in motors to control performance preceded the development of practical devices by many years. In fact, an early proposal was to use a common light bulb as the resistor. The light bulb does not give the dramatic change in resistance of Figure 1. Haddad (Patent 2,261,250 issued in 1941) suggested the use of the PTCR to switch out the start winding under running conditions (Figure 2). Martin on the other hand, (Patent 3,303,402* issued in 1967) teaches the use of at least one PTCR connected across run capacitors to increase starting torque while retaining good running performance (Figure 3). Various manufacturers are now offering PTCR's for these two applications. This paper does not attempt to evaluate the various PTCR offerings, but instead discusses the factors which are important in the successful application of PTCR's to attain a desired motor performance.

THE PTCR AS A START SWITCH

A resistance split phase motor relies on a difference in impedance between run and start windings to obtain a desired starting torque, and a relay to switch the start winding out after starting. The relay contacts introduce neglegible resistance into the start winding circuit. If the relay is replaced by a PTCR, the resistance in the start winding circuit is increased by four or more ohms by this PTCR, possibly much more at time of restart. The effect on starting torque may be derived from equation (1).

(1) $T = K a r_2 I_m I_a \sin\phi$

where a = ratio of start effective turns/main effective turns

r_2 = rotor resistance

I_m = main winding current

I_a = auxiliary or start winding current

ϕ = time phase angle between main and start winding currents.

This shows that starting torque is proportional to the product of the current in the two windings and the sine of the time angle between them. If the resistance of the start winding circuit is increased by the addition of the PTCR, the start winding current is decreased, and the torque is reduced as shown in Figure 4. It may be practical to compensate for the cold resistance of the PTCR by designing for a reduced start winding resistance. In some cases, the change in torque due to the additional resistance may be of no concern, and the relay and PTCR could be used interchangeably. In any case, the motor will not restart if an attempt is made before the PTCR has cooled below its transition temperature. This problem could be alleviated with a time delay relay, or if the overload can be relied on to delay restart for a sufficient time. The reset time of the PTCR is a function of its mass, the thermal conductivity of the mounting, the temperature of the surroundings, and the air flow over the PTCR.

Another thermal consideration is the time required for the PTCR to switch to a high resistance after the motor is energized. For the same resistance, one PTCR may have a large thermal mass, and another a small thermal mass. The first may not switch for many seconds, resulting in excessive start winding heating. The second may switch before the motor gets up to speed, resulting in insufficient torque and therefore motor stalling. The proper design would be between these extremes.

Thus it is evident that (a) PTCR's can be used to perform the switching function, but that (b) an incorrectly applied PTCR and overload can result in system malfunction. The motor must be carefully tested in the limiting conditions to insure that the system design is adequate.

The reliability of the PTCR in this application is potentially higher than that of a relay, since there are no moving parts, and the expected mode of failure would be open (stalled) rather than shorted. However, the question of the reliability of actual devices is outside the scope of this paper.

The power required to keep a PTCR switched off must be charged against the overall efficiency of the system. This will be in the five watt range, and will vary with the PTCR and with the way it is mounted. In the case of a refrigerator application, it is important to recognize that this heat is generated external to the refrigeration system, and therefore has a different effect than motor heat generated inside the refrigeration system.

*Assigned to Phillips Petroleum and subsequently reassigned to General Electric Company

THE PTCR ACROSS A RUN CAPACITOR

Putting a PTCR across a run capacitor may increase starting torque by a factor of 3 or more, while maintaining good running performance, as is shown in Figure 5. While permanent split capacitor motors are not known for their high starting torque, a very high percentage of air conditioners operate very satisfactorily without auxiliary starting devices. In most cases, air conditioning compressor manufacturers have learned to use the starting torque which is available when the motor is optimized for peak running performance. Therefore, a PTCR would offer little or no opportunity for air-conditioning motor redesign for higher efficiency. Its place in air conditioning seems to be as a "hard start" accessory, or to replace a start capacitor and relay. Here again, resistance, and switching time, both in heating and in cooling, are important, and vary from application to application. In addition, the voltage rating of the PTCR is very important, since a run capacitor generally operates at considerably more than line voltage, and the resistance of the PTCR is voltage sensitive. This usually requires that PTCR's must be packaged as resistors in series, with the probability that these PTCR's will not share the voltage equally unless tied together very closely in temperature. If the safe voltage is exceeded, the device no longer behaves as a positive temperature coefficient resistor, with potentially disastrous results. The end result of a failure would be expected to be an open circuit, which in this case would drop starting torque back to that with run capacitor only. From the motor designer's standpoint, the use of a PTCR as a hard start accessory has little or no effect on the design of the motor. Its use will be judged on its value as a start kit in competition with the conventional start capacitor and relay.

One interesting possibility for PTCR's is in refrigerator and freezer applications, where induction run motors are now used, and where starting torque requirements are high. A permanent split capacitor motor designed to produce sufficient starting torque would not be more efficient than the induction run motor, because of the high rotor resistance needed to develop the starting torque. A capacitor run motor, on the other hand, could be up to 8% more efficient than an induction run motor of the same size if a start capacitor or PTCR were added. The refrigerator is, on the average, the largest consumer of electrical energy in the home. Therefore the increased efficiency possible with the capacitor motor is attractive, especially where space prohibits the use of a larger induction run motor.

Figure 6 shows how a relay and run capacitor could be added to a conventional induction run motor in such a way that starting torque would remain unchanged, but the benefits of improved running performance could be obtained. In the circuit shown, a conventional current relay could be unreliable because the capacitor could be charged when the relay contact closes, and contact bounce could result in contact welding. However, a PTCR could be used in place of the relay, provided the resistance of the PTCR is properly compensated for. This gives the interesting curves of Figure 7. Note that breakdown torque is increased, running current is decreased, and efficiency is increased (by around 4%). Typical peak capacitor voltage on such a design is about 160 volts for 115 volt motors. If the motor is redesigned specifically for the resistance start, capacitor run application, the increase in breakdown torque can be designed back out with a further efficiency improvement, and the capacitor voltage can be changed. The optimum level of capacitor voltage depends on the cost of the capacitor and of the PTCR. As mentioned previously, the cost of PTCR's goes up with voltage because resistors must be packaged in series. This then presents a challenge to the capacitor manufacturers to produce a low voltage, low cost capacitor. As in the case of the induction run motor, the watts consumed in keeping the PTCR switched off during running must be included in system efficiency calculations, and depend on both PTCR and environment.

CONCLUSIONS

In a resistance split phase motor, the effect of replacing the relay by a PTCR can be and should be calculated before a PTCR is used.

In the case of the capacitor run motor, a PTCR can be used to increase the starting torque if this is desirable. It may have a much more attractive application in the use of capacitor run motors in refrigerators for high operating efficiency.

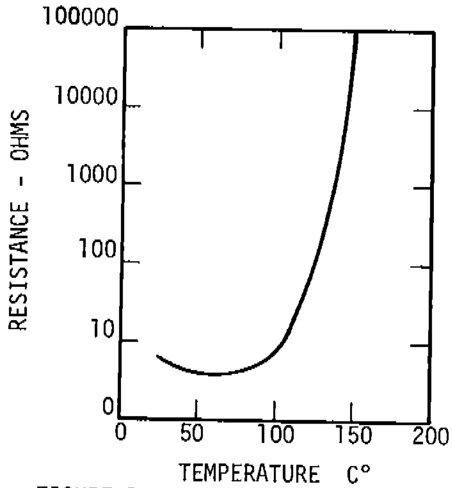

FIGURE 1. TYPICAL PTCR RESISTANCE-TEMPERATURE CHARACTERISTICS.

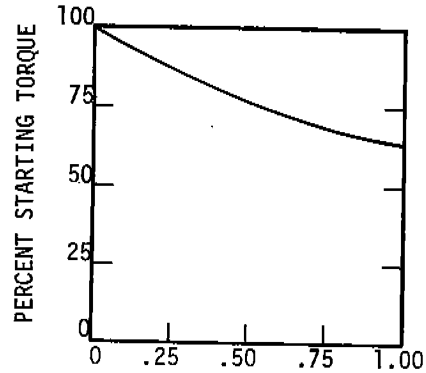

FIGURE 4. EFFECT OF PTCR ON STARTING TORQUE OF TYPICAL RESISTANCE-SPLIT PHASE MOTOR.

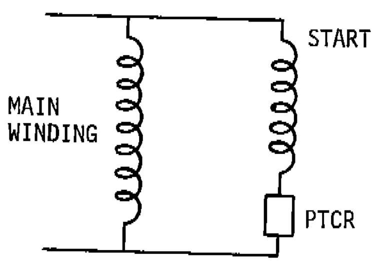

FIGURE 2. INDUCTION. RUN MOTOR WITH PTCR SWITCHING.

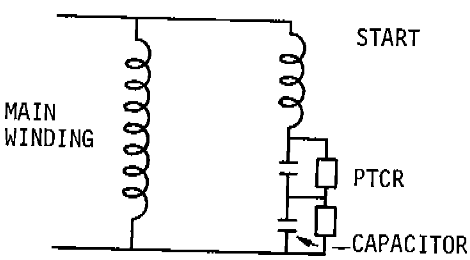

FIGURE 3. CAPACITOR-RUN MOTOR WITH PTCR STARTING.

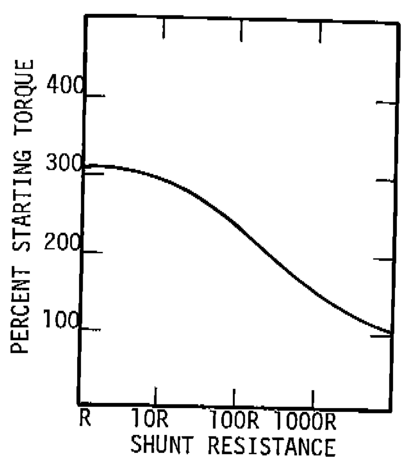

FIGURE 5. EFFECT OF PTCR ON STARTING TORQUE OF TYPICAL CAPACITOR MOTOR

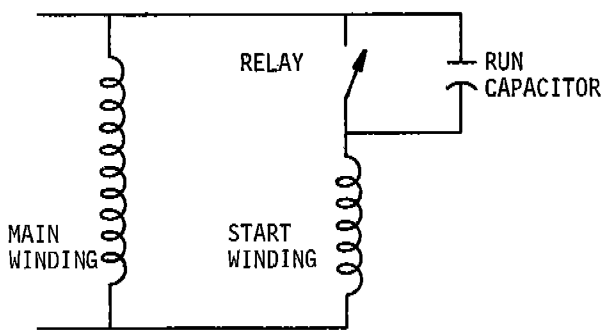

FIGURE 6. RESISTANCE START CAPACITOR RUN MOTOR

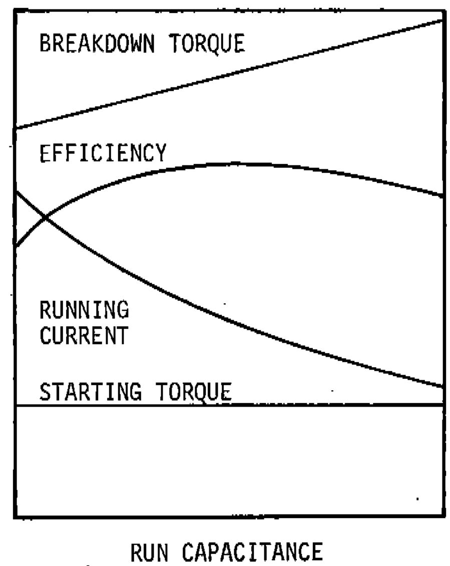

FIGURE 7. EFFECT OF RUN CAPACITANCE ON MOTOR PERFORMANCE FOR RESISTANCE START, CAPACITOR RUN MOTORS