1978

Two Speed Hermetic Motors for Air Conditioning

R. V. Zigler

Zigler, R. V., "Two Speed Hermetic Motors for Air Conditioning" (1978). *International Compressor Engineering Conference.* Paper 290.
https://docs.lib.purdue.edu/icec/290

TWO SPEED HERMETIC MOTORS FOR AIR CONDITIONING

Robert V. Zigler, Engineer-Advanced System Development
Hermetic Motor Department
General Electric Company
Holland, Michigan

INTRODUCTION

Two speed, pole changing induction motors have been common for many years in some applications. Air conditioning systems have not used any significant quantity of two speed compressor drive motors. We in the Hermetic Motor Department of the General Electric Company furnished motor samples for evaluation as early as 1955, but no production until last year. The reasons two speed motors have not been used is because of the higher first cost, the difficulty in achieving high motor efficiency and the increased control complexity. However, the present and future expected cost of electricity has presented an opportunity to pay for the increased first cost with an improved air conditioning system consuming less total energy for the season.

In this paper, I shall attempt to show why a well designed single speed motor will always be more efficient than a two speed motor of the same size, the effects of the motor efficiency on the SEER of the two speed system, and the opportunities for integrated system design work to take maximum advantage of the basic motor characteristics.

THE MOTOR

Typical motor speed torque curves for a single phase, two speed, pole changing motor are shown by Figure 1. Above 1800 rpm (synchronous 4 pole, 60 Hz speed), switch over to the 4 pole mode causes the high braking torque shown and correspondingly high winding currents. Design for switching under load from one speed to the other should consider the potential increased stress condition on the electrical and mechanical systems. Other considerations in the design and application of the motor, compressor and auxiliary devices which will not be discussed in this paper but are nevertheless, very important in the operation and life of the system, are electrical switching transients, starting, control logic, overloads (thermal protection), and rotating inertia requirements. This paper will concentrate on the punching, windings and the steady state load - efficiency relationship.

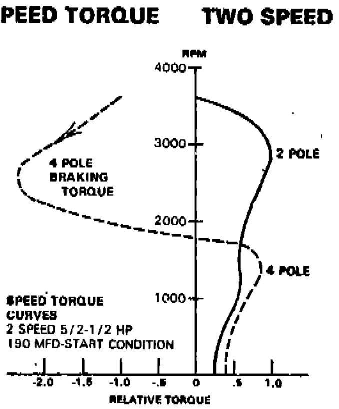


Figure 1

MOTOR PUNCHING CONSIDERATIONS

One of the main reasons that pole changing multi-speed induction motors are larger and/or less efficient than single speed motors is the difference in the punching requirements of the different number of poles. Figure 2 shows a comparison of two and four pole stator punchings for forty frame diameter motors. The relative amount of magnetic flux in the various sections is different necessitating the dimensional differences shown in the teeth and stator yoke. The rotor conductor and air gap flux density requirements also dictate the different rotor diameter. Therefore, any punching will favor one speed at the expense of the other or be a compromise. Since the available output for any specific number of poles is a function of the flux in the iron, and good efficiency requires low iron saturation, the best punching design will depend upon the relative maximum load requirements of the different speeds. This effect on the motor output requirements is shown by Figure 5 and will be discussed in more detail later. High four pole outputs mean large rotors and large stator yokes, increasing the size and cost of the motors.

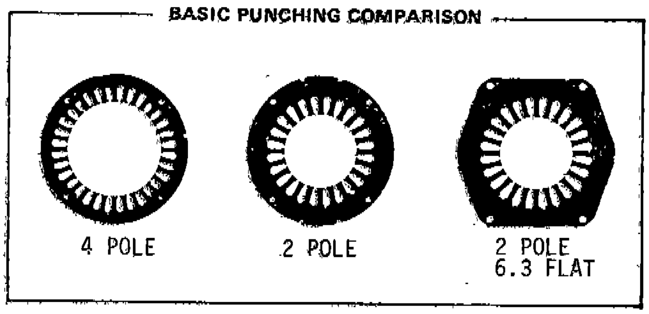
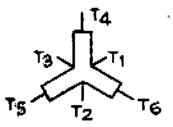


Figure 2

MOTOR WINDING CONSIDERATIONS

Three phase motor windings can be reconnected to create twice the number of wound poles (viz. a two pole motor can be reconnected as a four pole motor) by reversing half the poles. This allows for a limited number of connections, wye or deta and series or parallel connected poles. This in turn results in 100% winding utilization at both speeds but a limited number of useful "torque ratios." By "torque ratio" I mean the ratio of four pole break-down torque/two pole break-down torque. Figure 3 shows two three phase windings which are useful in positive displacement air conditioning compressor applications. The coil spans can be adjusted to gain only limited control of the "torque ratio." Two separate windings, one for each speed could be used to gain any desired torque ratio within the punching limitation; but, this is not usually economic in the use of space and material.

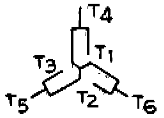
THREE-PHASE, TWO-SPEED, ONE-WINDING
CONSTANT TORQUE



SPEED	L1	L2	L3	OPEN	TOGETHER
1 LOW	T1	T2	T3	ALL OTHERS	
2 HIGH	T6	T4	T5		T1,T2,T3

Figure 3A

THREE-PHASE, TWO-SPEED, ONE-WINDING
VARIABLE TORQUE



SPEED	L1	L2	L3	OPEN	TOGETHER
1 LOW	T1	T2	T3	ALL OTHERS	
2 HIGH	T6	T4	T5		T1,T2,T3

Figure 3B

Single phase motors will be considered for the remainder of the paper since they have most of the three phase motor limitations plus some of their own. As in three phase, separate windings can be used for the two speeds with an increase of about one frame size. Because of the angular placement of coils in the single or two phase machine, 100% utilization of the winding is not practical for both speeds. The winding arrangement that we are generally using is shown by Figure 4. The major portion of the main winding is used for both speeds while two separate auxiliary windings are required for the capacitor run applications. Reasonable efficiency can be obtained with both speeds in single speed diameter motors as long as the four pole torque requirements are low which allows the use of a two pole standard punching. As the four pole requirements are increased, the quantity of conductor material increases along with the rotor and tooth requirements, forcing an increase in the motor diameter.

TWO SPEED WINDING DESIGN FOR
INDEPENDENT TORQUES

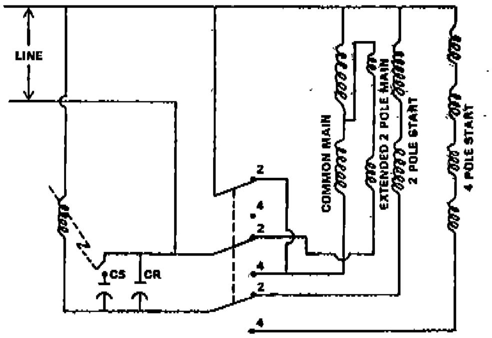


Figure 4

MOTOR PERFORMANCE

Figure 5 shows typical efficiency plots of three different two speed motors designed with different four pole torque capabilities. This motor is about 20% longer than a single speed two pole motor of the same rating in this same punching. It should be understood that many variations of relative efficiency and torque capabilities are possible. However, this plot is quite typical as to what one can expect. The end points on the efficiency curves show the MRT (maximum running torque) on the horizontal axis. The four pole flux carrying capability of the core allows for good efficiency of about 80% by option 1, where the MRT is about 315 oz.ft. or 61% of the two pole MRT. As the four pole MRT is designed for higher levels (option 2 and 3), the efficiency goes down because the flux density in the air gap and teeth becomes excessive. Since the problem is primarily one of punching design and motor size limitations, only small gains in four pole efficiency can be made by a sacrifice in the two pole winding. Here then is the dilema that exists. Two speed systems are expected to run 70% to 90% of the time on the low speed but four pole output and efficiency is a lot more expensive than two pole output and efficiency. The answer to this must be accomplished in a total system optimization approach to the application. Now, let us turn our attention to what one of these two speed motors can do in an air conditioning system.

2 SPEED MOTOR COMPARISONS

6.3 FLAT 6 INCH STACK TYPICAL 5 TON LOAD

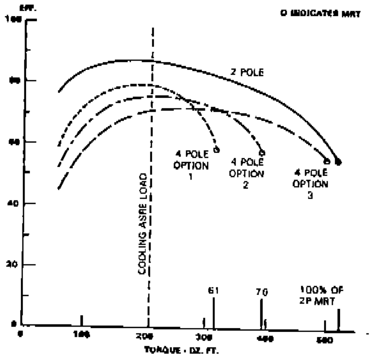


Figure 5

SEASONAL ENERGY EFFICIENCY RATIO

One of the important considerations to the optimization problem is the relative effects of efficiency on the SEER. I have attempted a rather crude calculation of this quantity and compared a two speed to a single speed system. I have made many assumptions in my analysis. They may not be the best but I think they are reasonable and one can easily change them if they wish.

ASSUMPTIONS

1. Single phase air conditioning.
2. Two speed motor design shown by Figure 5, option 2.
3. Total cooling requirements 60 million Btu's per year using a 65,000 Btu/hr air conditioner.
4. Operating time 85% on low speed and 15% on high speed.
5. One point in motor efficiency changes EER 1.6% on high speed and 1.4% on low speed.
6. Two speed calculations include the effect of thermodynamic rebalance due to changes in compressor speed and do not include multispeed fans or ambient effects on loading.
7. Assumed reference starting points.

Speed	Motor Efficiency	System EER
Two pole	85.9	6.93
Four pole	76	9.01

SYSTEM PERFORMANCE CALCULATIONS

Letting the four pole or half speed condition produce 1/2 of the two pole Btu's/hr and combining with the assumed percent "on time", results in the operating hours and output shown in Table I. It is important to note that the 85% "on time" of the four pole operation produces only 74% of the seasonal Btu requirements.

Calorimeter tests have shown that on some compressors the EER responds to motor efficiency at about 1.6% for each point change in motor efficiency. On low speed operation with the same fan power inputs this is reduced by about .2% to 1.4%. The actual effects of the thermodynamic rebalance in the system at low speed could further reduce the importance of the four pole motor efficiency on EER. In the absence of any good system test or simulation data, the 1.6% and the 1.4% were taken as adequate for the purposes of this paper as was the fixed load conditions in setting motor efficiencies and Btu/hr output. The increase in four pole EER over the two pole EER is a function of the design compromises in the basic two pole system. A highly efficient two pole air conditioner will not show the same relative improvement when switched to 1/2 speed.

The combination of assumptions 5, 6 and 7 result in two equations for calculating the EER.

$$\text{Two pole EER} = 6.93\left[1 + .016\,(\text{Eff.} - 85.9)\right]$$

$$\text{Four pole EER} = 9.01\left[1 + .014\,(\text{Eff.} - 76)\right]$$

The new EER's can now be combined with the energy outputs to find the new seasonal power inputs with the equation

$$\text{KWH/year} = \frac{\text{Btu/year}}{\text{EER}}$$

This is shown in Table I. It is important to note that the 85% "on time" for the four pole operation consumes only 69% of the annual power input. In fact, if the compressor operated only 70% of the time at low speed, more total energy would be consumed during the season operating at high speed than operating at low speed. For the single speed and two speed cases being studied, summing up the power over the season, we find a SEER of 6.96 for single speed and 8.37 for two speed (a 20% improvement over the single speed).

TABLE I

COOLING LOAD PERFORMANCE

	Single Speed	Two Speed (4P Option 2)	
Stack Mode	5" 2 Pole	6" 4 Pole	2 Pole
Hrs/Yr (% Total)	923	1364 (85%)	241 (15%)
Output (% Tot.) 10^6 BTU/Yr	60	44.3(74%)	15.7(26%)
Motor Eff.	86.2	75.7	86.9
EER	6.96	8.97	7.04
Input-KWH/Yr (% Total)	8,620	4,940(69%)	2,230(31%)
Total Input-KWH/Yr	8,620	7,170	
Total SEER - $\frac{\text{BTU}}{\text{W-H}}$	6.96	8.37 (+20%)	

OPERATING COSTS

At six cents/KWH cost of electricity, the operating costs for the season presented by Table II shows $517 to operate the single speed system and $430 to operate the two speed system, a savings of $87 or 17% for the two speed hermetic motor and compressor.

There are many other considerations that can improve the two speed system considerably. These effects can be as important as the rather simple calculations that I performed. For instance, cycling losses brought about by the "on off" cycling used to control indoor temperature has been estimated by many to be between 10 and 15% of the single speed system output. By operating for longer periods between off cycles, a two speed system should be able to cut these losses in half, a 5 to 7.5% reduction in input. Table II takes the more conservative value of 5%. Two speed, pole changing, fan motors can be applied to further reduce the inputs for much of the low speed operating period of the compressor. A very rough estimate of this effect might be another 5% reduction in input. The total savings, as shown at the bottom of Table II, is now $139/year or a 27% reduction in energy consumed.

Limiting the four pole by always switching into two pole operation at high loads will allow the use of lowest torque, highest efficiency four pole designs. For instance, the use of an 80% efficient four pole motor will decrease the energy consumed by another 3%. Other changes in compressors, controls, etc., may make additional improvements in the two speed system performance.

TABLE II

ESTIMATED IMPACT OF
TWO SPEED HERMETIC MOTORS
ON OPERATING COSTS

	SINGLE SPEED	TWO SPEED
COOLING		
INPUT (KWH/YEAR)	8,620	7,170
COST/YEAR (6¢/KWH)	$ 517	$ 430
SAVINGS		$87 (17%)
ADDITIONAL SAVINGS		
REDUCED CYCLING		$26 (5%)
TWO SPEED FANS		$26 (5%)
TOTAL SAVINGS		$ 139 (27%)

SUMMARY

The available two speed motor efficiency is dependent upon the relative torque requirements for the two speeds and the size and cost limitation placed on the motor. Reasonable designs offer potential energy savings of 17 to 27% versus single speed motors on cooling applications. The calculated savings is heavily dependent on the assumptions made concerning the system operation. The "true" potential can be reached only by designing with simultaneous consideration of all system components over the total season.

NOMENCLATURE

EER = Energy efficiency ratio $\frac{\text{Btu/hour}}{\text{Watts}}$

KWH = Kilowatt hours

MRT = Maximum running torque (3000 rpm for two pole, 1500 rpm for four pole motors at 60 Hz)

SEER = Seasonal energy efficiency ratio