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Technology yields efficient motor designs

Computer simulation helps switched-reluctance motors exceed the efficiency of induction motors for hvac applications.

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In developing commercially viable switched-reluctance motors, engineers faced the challenge of improving their design to compete with the efficiency of conventional induction motors, which have been fine-tuned for many decades.

MOTORS & DRIVES

Searching for a switched-reluctance motor design that would offer major improvements in operating efficiency compared to conventional induction motors for hvac applications, engineers tried a computer simulation.

A script was developed that repetitively performs finite element-based electromagnetic analysis at every three degrees of rotation, in order to fully characterize the equivalent circuit parameters of proposed motor designs.

Being able to quickly model proposed designs without the time and expense of building a prototype made it possible to achieve system efficiencies of above 90% for 75-hp motors, and above 85% for 2.5-hp motors.

A NEW OLD DESIGN

Switched-reluctance motors are based on the principle that each pair of opposite stator poles is an electromagnet forming a phase of the motor. The phases are fired sequentially, causing the motor to rotate.

The earliest published record of this design goes back to 1838, but practical usage had to wait for an efficient method of achieving the precise timing required to fire the stator phases.

Because of recent advances in control technology and the rapid cost reduction of power electronics components, switched-reluctance motors are being developed for a wide range of applications as an alternative to conventional motors.

The application of switched-reluctance motors is being driven by a number of inherent advantages of this technology. The rotor is the only moving part of the motor and consists simply of laminated steel mounted on a shaft. Without rotor windings, aluminum or magnets to add to the cost, and magnet bonds or brushes to fail, switched-reluctance motors are significantly less expensive to manufacture and operate than permanent-magnet or induction motors.

As switched-reluctance motors move into mainstream applications, the issue of efficiency edges to the forefront.

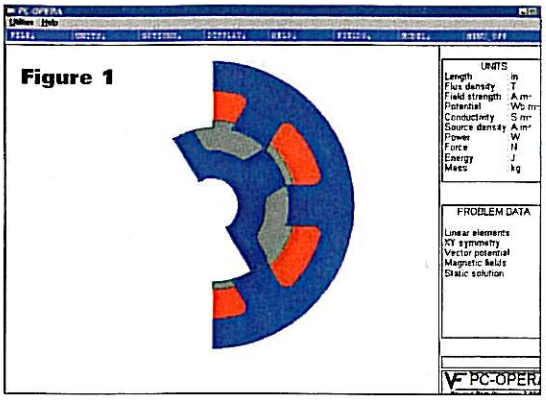
Induction motors have been widely used in commercial applications for many years. Over this period, engineers have tuned and tweaked their design to the point that today's induction motors are considered by many to be at or close to optimum efficiency.

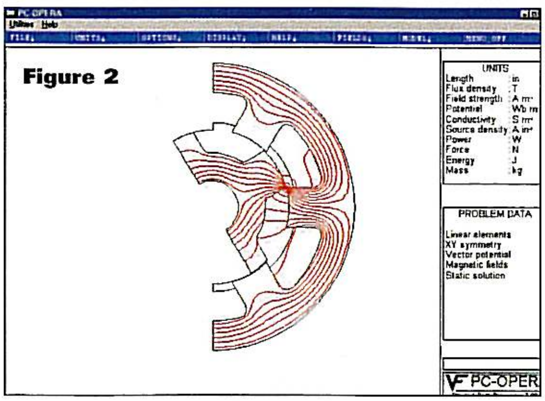
Despite this fact, the efficiency of an induction motor falls off fairly rapidly as loading either increases or decreases from the loading parameters for which it was originally designed.

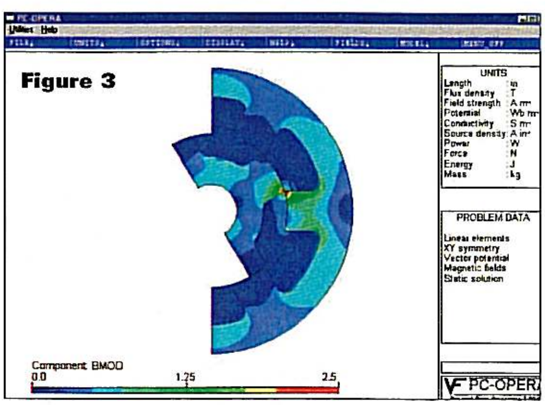
IMPROVING EFFICIENCY

The most important parameters needed to determine the performance of a switched-reluctance motor are the equivalent circuit parameters, which are usually expressed as the inductance at a certain current and rotor position.

Because switched-reluctance motors are just reaching widespread commercial use, this type of experience with their designs is limited. In order to effectively compete with existing induction motor designs, engineers needed to evaluate the performance of many hundreds of different alternative designs in







Figures 1-3. The finite element model, resulting flux contours, and flux density profile.

order to achieve an equivalent, or if possible, higher level of efficiency.

The traditional approach of building prototypes and testing their performance was clearly out of the question. This method would have raised design costs to the point that any effort to recover these costs would have raised the motor price well above existing induction technology.

The fact that it takes several weeks to build and test a single proposed motor design means that it would probably have taken close to a decade to optimize the design using this approach.

Another problem with the build-and-test approach is that it is quite difficult to accurately measure circuit parameters at each phase of an electrical motor.

As a result, A.O. Smith engineers considered the approach of using computer simulation to calculate magnetic fields in a proposed motor design. They evaluated a number of programs released in recent years that are capable of electromagnetic analysis of electrical machinery.

The engineers selected the 2-D software PC-OPERA from Vector Fields, Aurora, Ill., because they felt it had the most powerful scripting language, and they recognized the need to automate the analysis in order to rapidly evaluate a large number of proposed designs.

This package also offers outstanding technical depth and breadth, a graphical user interface that greatly reduces the time required to set up the analysis, and a robust solver that converges to a solution in even the most complex geometry.

Using this program for several years, A.O. Smith engineers have found that its results match experimental values very closely.

AUTOMATED ANALYSIS

To streamline the analysis of multiple motor designs, the engineers used PC-OPERA's scripting language to develop a generic switched-reluctance model. This model takes advantage of the inherent symmetry of an electrical motor by modeling one-half of a motor cross section in two dimensions.

The script prompts the user to enter the parameters, which can fully describe the geometry of the motor. The program then takes just a few minutes to automatically build a geometric model of the rotor. Then it creates a series of additional models, with the rotor successively rotated three degrees in each model over 90 degrees.

The entire process of defining the geometry and creating 30 models takes 1 hr. The script then creates a batch program to analyze each of these models, which is typically run overnight.

The finite model, as well as the resulting flux contours and flux density profile, are shown in Figures 1 through 3 (page 9). The script continues by interrogating the finite element solution to determine the flux linkage of each phase and the developed torque of the motor.

The resulting flux linkage profile at different current levels and rotor positions is shown in Figure 4, while the calculated torque profile as a function of current and rotor position is shown in Figure 5.

These values are then used along with the calculated winding resistance of the motor and the applied voltage to model the performance of the motor using:

$$v = ri + \frac{d\lambda}{dt}$$

Where v = applied voltage, r = resistance, i = phase current, and λ = flux linkage.

This can be accomplished by using any program that will perform numerical integration, such as MATLAB.

The switched-reluctance motor drive system performance characteristics are determined for a wide range of load factors. This analysis yields predicted current and torque profiles.

Experiments have shown an excellent correlation between experimental results and simulation using this method.

EFFICIENCY FOUND

Using these methods, engineers have been able to dramatically improve the performance of switched-reluctance motors in a remarkably short period of time.

The peak operating efficiency of the motors has been increased to a level above that of induction motors and the advantage is substantially greater at high and low operating loads because the new designs have a substantially

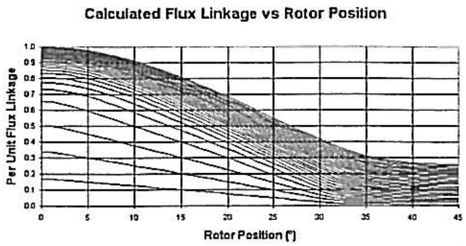


Figure 4. Flux linkage profile at different current levels and rotor positions.

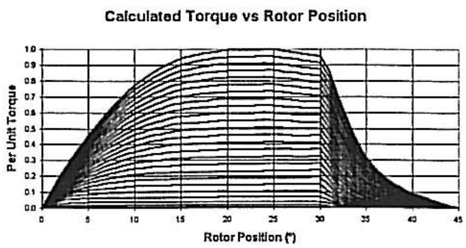


Figure 5. Calculated torque profile as a function of current and rotor positions.

flatter operating curve.

Engineers have also used finite element analysis to calculate the forces acting on the stator in order to minimize the noise of the motors. Stator forces are extremely difficult to determine experimentally, so the ability to determine these forces through analysis was critical in controlling noise levels.

This application clearly demonstrates the primary advantage of electromagnetic simulation — that it can be accomplished in far less time and expense than physical testing.

Once the initial model is developed, the time required to evaluate additional design iterations (a procedure in which repetition of a sequence of operations yields results successively closer to a desired result) is reduced to the point that A.O. Smith engineers are easily able to analyze 60 different designs in a month.

In addition, computer simulation provides considerably more information on the performance of the design. As opposed to the point measurements provided by physical experiments, users can obtain the value that they desire, at any point on the model, depicted in graphical presentations that are so easy to follow, they can considerably increase understanding of the design.

For further information, contact Vector Fields, 1700 N. Farnsworth Ave., Aurora, Ill. 60505; 630-851-1734; **www.vectorfields.com** *(website).*

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