The Workhorse of Industry: The Induction Motor

Dan Jones

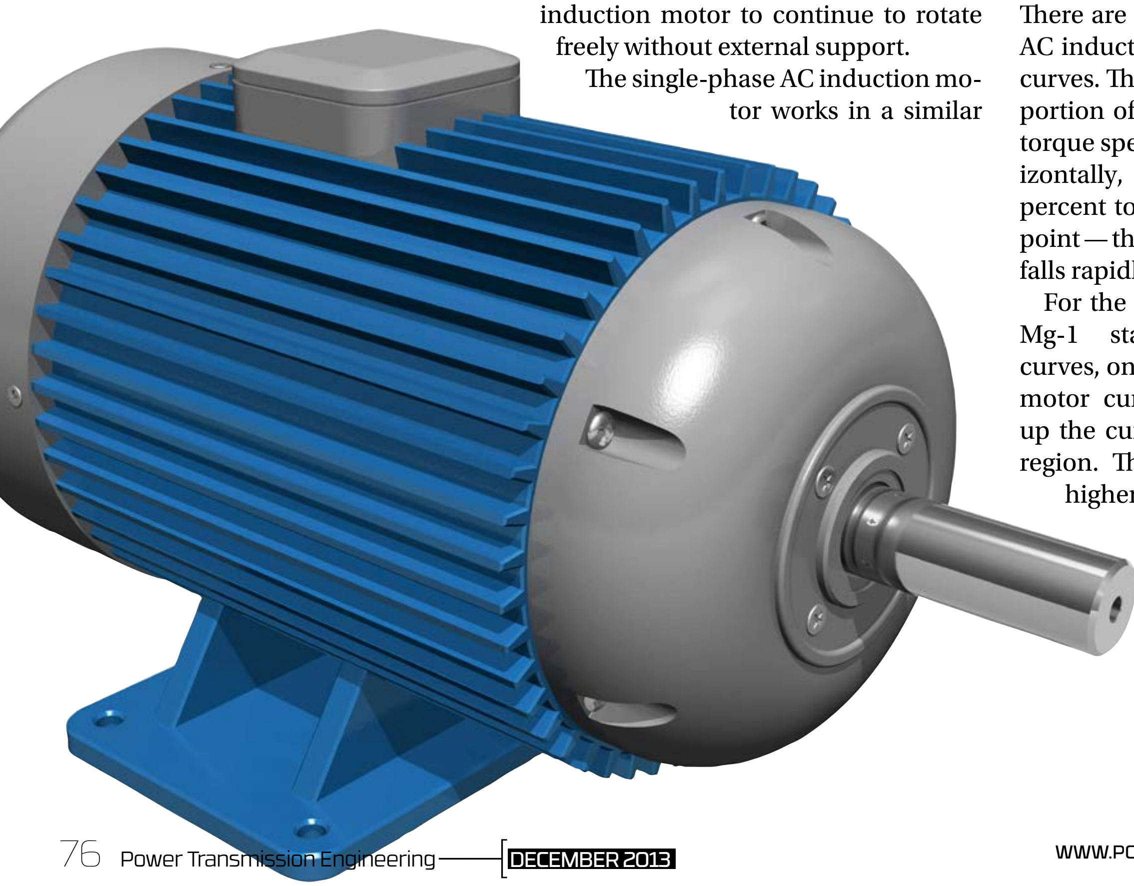
History

As with many new inventions, the first practical single-phase induction motors appear to have been invented in 1885 by Galileo Ferraris, an Italian. Two year later, Nicola Tesla, a Serbian-born naturalized citizen of the United States., created the 2-phase induction motor; Tesla was granted U.S. patents in 1887. George Westinghouse employed Tesla for one year to develop the induction motor for his company. The first wound-field, 2-phase AC induction motor product family was announced by Westinghouse in 1892. In 1888, Mikhail Dovilo Dobrovolsky created a 3-phase induction with a squirrel cage motor. GE began developing 3-phase AC induction motors beginning in 1891 under Charles Steinmetz's leadership. Induction motors continued to evolve in form and use. The 3-phase induction motor is used in the larger horsepower application above 1 hp while the single-phase AC motors were used in the smaller, below 1 hp applications.

Construction

The AC induction motor consists of two major assemblies — rotor and stator. AC power in the form of 60 Hz sinusoidal signals are fed into the 3-phase stator windings. This rotating magnetic field induces a rotor field in the rotor's shorted (closed circuit) squirrel cage windings. The established rotor field runs at a frequency and rotor shaft speed that is not in synchronism with the rotating stator frequency. This condition, defined as slip, results in the rotor shaft speed to be tens of rpm below the induction motor's synchronous speed (frequency) developed by the stator. The slip value varies between one percent and five percent on most AC induction motors. The 3-phase stator signals establish a series of rotating magnetic vector fields that allow the induction motor to continue to rotate freely without external support.

The single-phase AC induction motor works in a similar manner except it possesses a second winding — or auxiliary winding — that allows one to use a capacitor to establish a near 90 electric degrees between the stator winding and auxiliary winding. This action supports continuous rotor and shaft rotation. The housing, end caps and bearings complete the AC motor construction that supports the motor's rotation (Fig. 1).



Performance

The mechanical output is represented by the motor's torque vs. speed curves, based first on 60 Hz input voltage and current inputs, and later on a range of input frequencies. The motor's shaft speed is a function of the number of magnetic poles within the motor. It runs at a no-load speed of almost 3,600 rpm for a 2-pole and 1,800 rpm for a 4-pole. Remember the impact of slip. The AC induction motor's torque vs. speed curve is highly non-linear. There are three different regions on an AC induction motor's torque vs. speed curves. They are the near-vertical-rated portion of the curve (Fig. 2). Once the torque speed curve begins to bend horizontally, one reaches the maximum percent torque point — the breakdown point — the AC induction motors speed falls rapidly to stall or zero speed.

For the design A, B, C and D NEMA Mg-1 standard-rated torque-speed curves, only the design D AC induction motor curves can re-start and move up the curve back to the rated torque region. The price for the Design D's higher starting torque performance is much lower power efficiency. The other three design curves require extra help to return to the rated torque region.

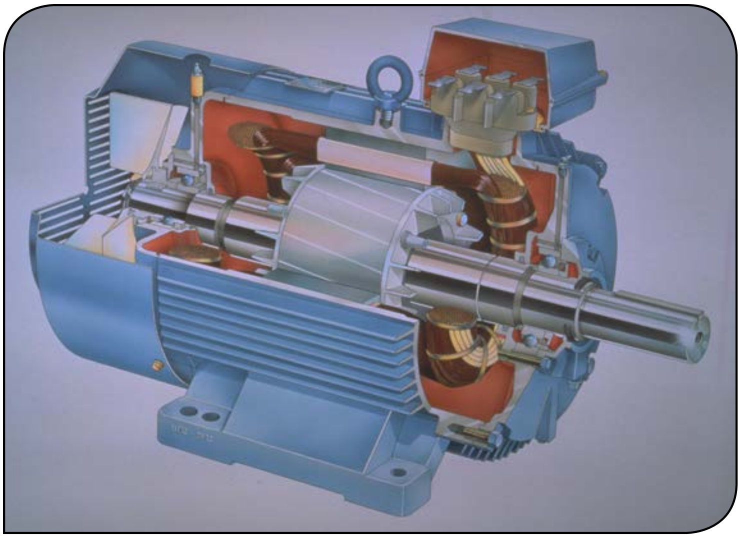


Figure 1

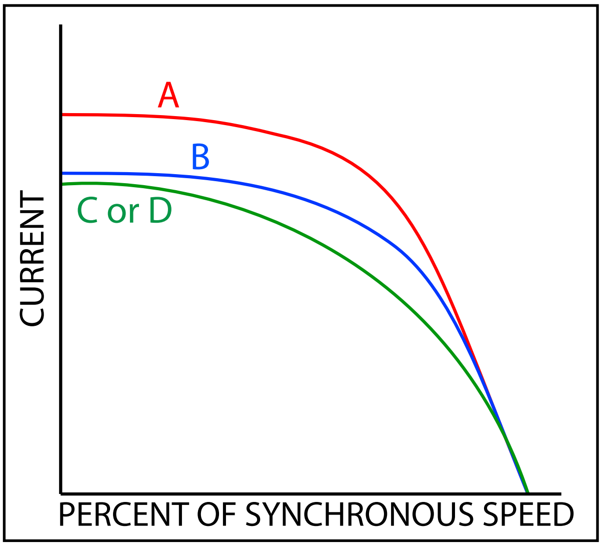


Figure 2

Current is non-linear; the most current for all four design torque-speed curves is drawn at stall (Fig. 3); the Design B curve is the most popular one today. The AC induction motor was originally designed for applications that have a near-constant load. One just plugs the AC induction motor's power cord directly into the 60 Hz wall outlet for constant speed applications. The motor can self-regulate its speed within ± 20 percent of rated load.

Enter the Variable-Speed Drive

The AC induction motor has a flaw when operating in its normal-rated torque region. At very light application loads, it draws nearly the same current at rated load. Power efficiencies could drop to 35 percent from its rated efficiency of 90 percent to 95 percent, depending on an AC motor's hp output.

The emergence of the 3-phase adjustable or variable speed drive (VSD) in the late 1980's provided the AC motor with a much wider speed operation. The variable speed drive is a solid- state power conversion unit that controls the frequency, voltage and current into a 3-phase induction motor. Typical VSDs can seamlessly vary volts and frequency to eliminate the difficulty in high current and low starting torque in AC induction motors. Field weakening, pulse width modulation (PWM), and current control provides other drive strategies available to be more controllable and to maintain high power efficiency over a variable load.

The AC induction motor is the most popular motor for use in a wide range of speed-based applications. Simple in design and rugged in construction, lower in cost and in maintenance — the AC induction motor continues to dominate industrial and powered home applications. **PTE**

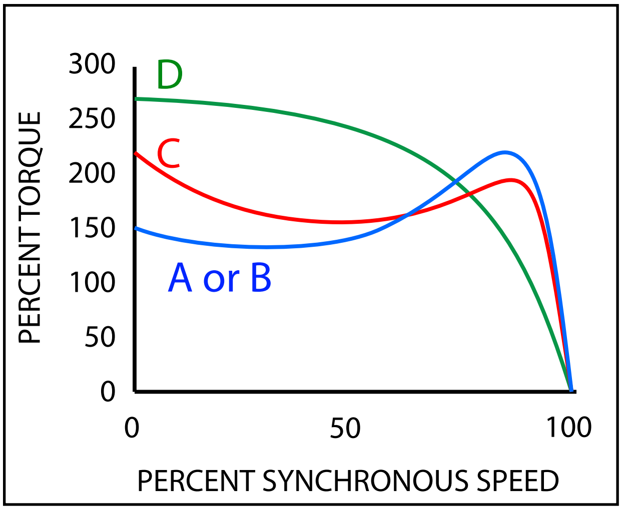


Figure 3

Dan Jones received his BSEE degree from Hofstra University in 1965 and MS in Mathematics at Adelphi in 1969. He has over 50 years' experience in the design of all types of electric motors and generators from 10 W to 500 kW and has held engineering design, management and marketing management positions at a number of companies. He is recognized as an international authority on electric motors and motion control. He has written 250+ technical articles/papers and held seminars in 10 countries. He is a past member of the board of directors of SMMA and EMERF. He currently is a member of the board of directors of the Motion Control Association (MCA). He is a life member of IEEE and a member of ASME. This article was adapted from his seminar on motor types, which is being presented at Motion Control 2013 (October 15–17 in Los Angeles) and at the Motor, Drives and Automation Systems 2014 Show (January 29–30 in Orlando).