TB-2010-002

How Do I Properly Size a Motor?
AC and DC Motor Selection and Sizing

This paper explains the basic technology behind AC and DC motors and gives insight into considerations involved with properly sizing a motor by the system designer.

The driving principle within the electric motor design is the phenomena of attraction and repulsion between alike and opposing magnetic fields, respectively. Tesla's initial AC induction motor consisted of two basic parts: a stationary section with an AC current providing a varying magnetic field, and a rotational part attached to an output for the torque.

Output rpm and horsepower are determined respectively by the number of rotor poles and field coils, and the rotor diameter and coil size used in the stator assembly. Recent advancements in die casting tools made from heat-resistant nickel-base alloys enable copper to be cast into the rotor slots, increasing motor efficiency by reducing resistive losses in the motor core (Ashley, 2007).

Selecting an AC induction motor (ACIM) involves determining the efficiency rating, type of motor enclosure, and torque suitable for the application. The National Electrical Manufacturers' Association (NEMA) establishes efficiency ratings for AC/DC motors conducive with government standards. Traditional AC motors are 75% to 85% efficient and high efficiency motors are 85% to 95% efficient. Lower energy costs result from employment of high efficiency AC motors to high duty cycle applications.

Induction motors are currently the simplest and cheapest motors to build, making their use common in industry. AC motors can be accurately used for applications with gradual speed change. They also tend to be smaller and more reliable, and are regularly used in compressors and fans. The AC induction motor has lasted well over a century due to rugged construction and low production cost. Recent advances in microelectronics technology has allowed the AC motor to attempt catching up with the DC motor, in terms of precision. More specifically, use of fuzzy logic controllers in electronic circuits allows an AC motor to be operated with greater accuracy.

Current ACIM are classified as single-phase and three-phase. The induction motor design is commonly referred to as a "squirrel cage" design, referring to the construction of the rotor assembly. Common and reliable ACIM rotor assemblies are constructed with slotted laminations and copper bars and copper end pieces installed on each end of the lam stack. The bars are inserted into the laminations slots and held in place by the end pieces.

Brazing the copper bars to the end pieces contains the rotor assembly components. An outer cylinder of steel laminations wound with copper wire comprises the ACIM stator assembly. Transformer action between the stator and rotor assembly induces electrical currents inside the rotor creating magnetic poles. The resulting electromagnetic interaction between the stator and rotor translates to speed and torque (Persson, 2008).

A DC current motor does not have a varying magnetic field, but a stationary one. There are also many configurations possible for a DC motor, but a simple example of its principles is displayed in shunt-wound and series-wound motors. Both use a stationary field and a rotating armature winding. Their construction differs in that the field winding in the ideal DC series motor is in series with the armature, and for the ideal DC shunt motor, the field winding is in parallel with the armature.

In the shunt motor, the voltage drop across the shunt field and armature is the same and current is dependent on element impedance. This motor type is known for stable speed and torque when under a load.

For a series DC motor, the current in all the elements is the same. This motor must always have a load for regulating the speed, but is ideal for a high initial torque and good torque under a load.

The recent trend in industry has been to move away from DC brush motors to brushless DC motors for low to moderate temperature environments. In these more moderate environments the brushless motor is generally superior due to the lack of the requirement to maintain the brushes. However in extreme high temperature environments the brushless controllers have generally proven to be of lower reliability if installed without cooling. In the brushless motor, the permanent magnets rotate instead of the electromagnets.

Different electrical motor enclosures are available and suited to various operating climates. MilMotion offers four types of enclosures for their ACIM's:

TENV (Totally Enclosed Non-Ventilated): a totally enclosed non-ventilated motor without fan cooling. This type of motor can be used in material handling applications where another source of ventilation for motor cooling is available. This enclosure type does not expose the inside of the motor body to the environment.

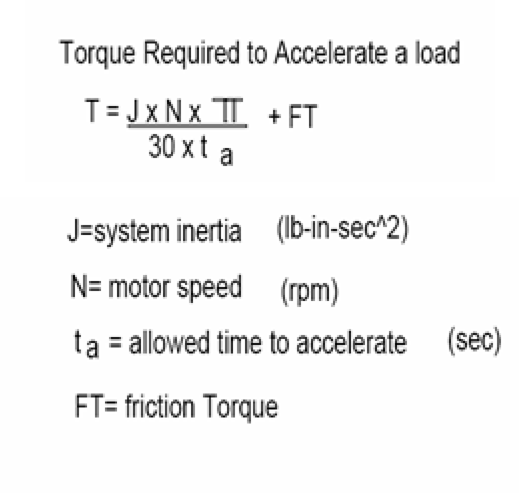
TEAO (Totally Enclosed Air Over): a totally enclosed motor with air holes drilled in the housing and depends on an external cooling apparatus usually a fan. The enclosure of this fan is not completely sealed. Fan applications will implement this type of motor enclosure.

VEP (Ventilated Explosion Proof): applied in environments where combustible elements such as gasoline, oil, ammonia, coal, or combustible dust are present.

VEPAO (Ventilated Explosion Proof Air Over): applied in fans intended for use in environments where combustible elements such as gasoline, oil, ammonia, coal, or combustible dust are present.

TriNertia's motor enclosures are more suitable to industrial and commercial applications and are defined by their on line catalog.

When developing a working motor design, a few basic requirements need consideration in order to create a successfully starting motor, aside from output horsepower and construction details. These requirements are the voltage applied to the terminals, speed-torque characteristics, and the inrush current. The applied voltage directly relates to the output torque of the motor, output torque from these elements is the key to a successful motor. In order to successfully accelerate an inertial load the motor must develop and maintain torque in excess of that required by the inertial load. Torque can be calculated by:



Torque Required to Accelerate a load

$$T = \frac{J \times N \times \pi}{30 \times t_a} + FT$$

J=system inertia (lb-in-sec^2)

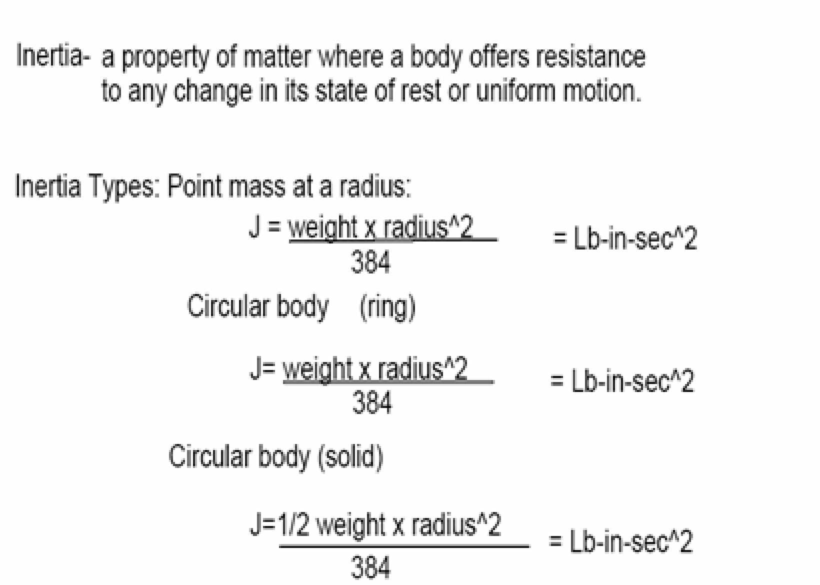
N= motor speed (rpm)

t_a = allowed time to accelerate (sec)

FT= friction Torque

Torque developed by ACIM varies by the square of the terminal voltage. Decreased voltage at the motor terminals may be caused by high starting current or a reduced voltage starter. Voltage drop during motor start-up increases the acceleration time due to reduced voltage at the motor terminals (Coyle, 2005). Long acceleration times at start-up lead to motor heating. NEMA Standard MG-1 is the most common applied standard for motors and generators. This standard requires motors to start a full load with a minimum of 90% rated voltage. Thus, calculating load inertia and determining acceleration time is important for application success.

Determining inertial load requires understanding the type of load applied to the motor. The following calculations are applied to calculate inertia type:



Inertia- a property of matter where a body offers resistance to any change in its state of rest or uniform motion.

Inertia Types: Point mass at a radius:

$$J = \frac{\text{weight x radius}^2}{384} = \text{Lb-in-sec}^2$$

Circular body (ring)

$$J = \frac{\text{weight x radius}^2}{384} = \text{Lb-in-sec}^2$$

Circular body (solid)

$$J = \frac{1/2 \text{ weight x radius}^2}{384} = \text{Lb-in-sec}^2$$

Inertia is important to determine in order to calculate the torque. Point mass inertia can be thought of as a weight suspended from a string at a certain radius. Circular body inertia can be represented as a cylinder with a particular outside diameter and inside diameter, and circular body inertia as a solid bar equally balanced around its center of gravity. The constant $384\frac{in}{\sec^2}$ represents acceleration due to gravity.

Once the motor torque is determined, the brake horsepower can be found:

$$\text{Brake Horsepower} = \frac{\text{Torque (in-Lb) x RPM}}{63{,}025}$$

In conjunction with calculating the required motor torque operating rpm's must be determined. The MilMotion and TriNertia motor data bases can be referenced on line through your web browser in order to find the corresponding performance curve for the ACIM considered for the particular application.

The AC induction motor has dominated many applications in several industries for decades. The brushless ACIM is an asynchronous machine because it does not follow electrical frequency exactly; there is slip between the rotor and stator fields. This slip is inherent to all ACIM's, usually up to 3%. The ACIM survives today because of simple design and low cost construction. Mechanical transmissions provide the ability to change speed and direction but modern applications require precision control.

Introduction of variable frequency drives improves functionality and efficiency of the ACIM system. Benefits of variable frequency drives are expanding applications for the ACIM into areas such as robotics where precision control is required (Hosein, 2007). Understanding how to apply AC induction motors by deriving the inertia and torque and brake horsepower is paramount to application success.

References

Ashley, S. (2007). Rotor in Motor, **Scientific American**, Nov. 2007, Vol. 297, Issue 5, p26-28, 2p.

Coyle, T. (2005).TORQUE IS KEY, **Engineered Systems,** Oct. 2005, Vol. 22, Issue 10, p60-64, 5p.

Hosein, M. (2007). Using AC Motors in Robotics, **International Journal of Advanced Robotic Systems,** Sep. 2007, Vol. 4, Issue 3, p365-370, 6p, 2 charts, 2 diagrams, 4 graphs.

Persson, E. (2008).Drive Decisions, **Appliance Design,** Apr 2008, Vol. 56, Issue 4, p40-45, 5p.

Rajvanshi, A. (2007). Nikola Tesla—The Creator of the Electric Age, Resonance: **Journal of Science Education** Journal; Mar 2007, Vol. 12, Issue 3, p4-12, 9p.

Trebilcock, B. (2007). Motors basics, **Modern Materials Handling;** Mar 2007, Vol. 62, Issue 3, p28-31, 4p.