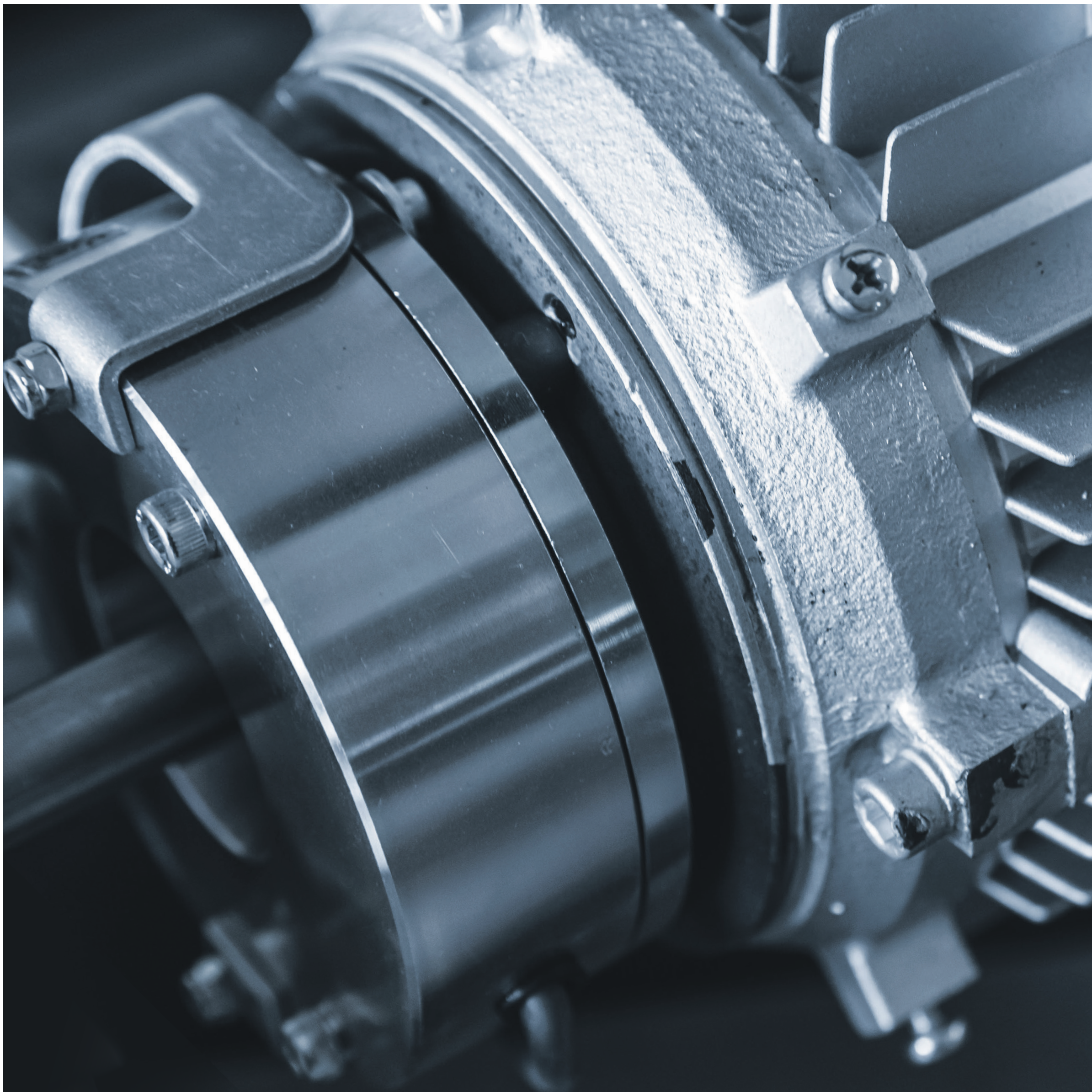
WHITE PAPER SERIES

Get your motor running

Part 2: An introduction to start torque



RIGHT FROM THE START

AuCom

MOTOR CONTROL SPECIALISTS

The starting function of motors is often misunderstood, impacting motor performance and compromising energy efficiency.

We're delivering a series of technical white papers to provide an introduction to the theory of starting motors, based on the work of electronics design expert Mark Empson, one of AuCom's founders in 1978.

There's more information on our website, or you can follow us on Twitter @softstarters. You can also talk to your local distributor of AuCom products. A directory is available at www.aucom.com.

Thanks for reading.

James Archer
Business Development
Contact me via j.archer@aucom.com

New Zealand
123 Wrights Road, PO Box 80208,
Christchurch 8440, New Zealand
T +64 3 338 8280 F +64 3 338 8104

China
203-1 JH Plaza, 2008 Huqingping Road,
Shanghai 201702, China
T +86 21 5877 5178 F +86 21 5877 6378

Germany
Borsigstraße 6, 48324 Sendenhorst, Germany
T +49 2526 93880 140 F +49 2526 93880 100

Middle East
10th Floor, Swiss Tower, Jumeirah Lakes Towers,
Dubai, UAE
T +971 4279 8349 F +971 4279 8399

North America
2528 Lovi Road, Building 2-2A,
Freedom, PA 15042, USA
T 855 928 2666 (855 9 AUCOM NA), +1 724 987 4952
F +1 724 510 3005
https://my.aucom.com

For more information and your local contact visit www.aucom.com

RIGHT FROM THE START

Start torque requirements of machines and motor loads

Machines and motor loads have widely differing start torque requirements. Some motor applications need only 10% rated torque to accelerate to full speed while other applications may require over 200% torque. The start torque requirement is usually not constant over the speed range from zero to full speed.

The start torque necessary to start a machine has two major components:

- Work or load torque
- Acceleration torque

The initial start torque requirement is the breakaway torque - the torque required to start the machine from a standstill.

Once the motor has begun to rotate the torque becomes the sum of the work torque and the acceleration torque.

The work torque is the torque required to overcome the mechanical work being done by the machine and includes friction losses and windage losses. The work torque is speed dependent and in applications such as fans and pumps, the work torque has a speed squared relationship.

The acceleration torque is the torque which accelerates the load or machine to full speed. It is the torque developed by the motor minus the work requirement of the motor load. To accelerate a high inertia load, a high acceleration torque is required.

Increased acceleration torque reduces the starting time. During start, the motor is under stress and is effectively overloaded. High inertia applications may need a long start time and/or high start current. For these applications the entire electrical system from mains supply to load must be considered. For example, fuses and other equipment, as well as the soft starter, should be selected for the long start time.

TYPICAL APPLICATION EXAMPLES

Punch press

A punch press application (where the motor is accelerating only a large flywheel) is an example of a machine requiring high acceleration torque and low work torque. The machine exhibits low friction and windage losses but has a high inertia. The torque requirements are initially the breakaway torque and then predominantly acceleration torque until full speed is reached.

Fan

In contrast a fan has a work torque which increases with the fan speed so sufficient torque must be available to accelerate the fan and also shift a volume of air dependent on the fan speed. Many applications such as fans and pumps exhibit a speed squared work characteristic.

Compressor

Refrigeration compressors generally start off load and work against a low pressure, but can reach full pressure within a limited number of revolutions unless a bypass valve is used during start. Sufficient torque must be available to either accelerate the compressor to full speed before a high pressure is reached, or accelerate the compressor against the maximum pressure achieved during start.

Flywheel

A flywheel is used as a mechanical energy reservoir in many machines, allowing a high intermittent or transient torque loading with a smaller motor operating with reduced maximum torque demand.

To start the motor and flywheel, the energy must be converted from the electrical energy by the motor, and be transferred to the flywheel by the coupling and drive system. The starting time is dependent on the amount of stored energy in the flywheel at full speed, and the rate of energy transfer from the electrical supply to the flywheel.

The potential energy of the flywheel at speed depends on the inertia and the speed of the flywheel. The rate of energy transfer from the motor depends on the torque developed by the motor.

The specification of the start torque requirements of a machine is an engineering problem and in some cases can become complex. In many cases motor selection and starting requirements are traditionally based on experience.

START TORQUE EQUATIONS

There are some equations that are useful in determining start torque requirements.

TORQUE OUTPUT OF THE MOTOR, T_M

$$T_m = 9600 \times \frac{kW}{N}$$

T_m = full load torque in Nm
kW = rated power in kW
N = rated full load speed of the motor in RPM

$$T_m = 5250 \times \frac{hp}{N}$$

T_m = full load torque in lb-ft
hp = rated power in horsepower
N = rated full load speed of the motor in RPM

$$T_m = 7040 \times \frac{kW}{N}$$

T_m = full load torque in lb-ft
kW = rated power in kW
N = rated full load speed of the motor in RPM

$$T_m = 63030 \times \frac{hp}{N}$$

T_m = full load torque in lb-in
hp = rated power in horsepower
N = rated full load speed of the motor in RPM

ACCELERATION TORQUE, T_A

$$T_a = \frac{M \times N}{9.5t}$$

M = moment of inertia seen by the motor including inertia of the motor in kgm^2
N = rated full load speed of the motor in RPM
t = time for acceleration from zero speed to rated full load speed

$$T_a = \frac{M \times N}{308t}$$

M = moment of inertia seen by the motor including inertia of the motor in $1b\text{-}ft^2$
N = rated full load speed of the motor in RPM
t = time for acceleration from zero speed to rated full load speed

If the load is operated at a different speed from the motor, a correction is applied to the load inertia.

$$M = M_{motor} + M_{load} \left(\frac{N_{load}}{N_{motor}} \right)^2$$

i.e. the effective moment of inertia seen by the motor is the actual load inertia multiplied by the speed ratio squared, in such a manner that if the load speed is higher than the motor, the effective inertia is increased.

The start torque of the motor must initially exceed the breakaway torque and must also exceed the work and minimum acceleration torque during starting.

REQUIRED START CURRENT

Once the start torque is known, the required start current can be calculated.

The LRT of the motor depends on the motor design - see the motor manufacturer's data.
The LRC is also a function of motor design, and typically ranges from 500% FLC to 800% FLC.

The ratio of LRT to required start torque is equal to the square of the ratio of LRC to the required start current.

$$\frac{T_{LR}}{T_{ST}} = \frac{(I_{LR})^2}{(I_{ST})^2}$$

T_{LR} = locked rotor torque

T_{ST} = start torque

I_{LR} = locked rotor current

I_{ST} = start current

Therefore required start current: $I_{ST} = I_{LR} \times \sqrt{\left(\frac{T_{ST}}{T_{LR}}\right)}$

Get your motor running white paper series

This paper is the second in a series of technical white papers published by AuCom as an introduction to the theory of starting motors.

Previous papers cover:

- Reduced voltage starting of three phase induction motors

Subsequent papers discuss the following topics:

- Methods of motor starting
- An overview of solid state soft starters
- Variable frequency control

To access these and other published motor control resources please visit our

IPD is the distributor of AuCom softstarters in Australia

Contact us on 1300 556 601 for more details or visit www.ipd.com.au