APPLICATION AND RELIABILITY OF AC & DC DRIVES IN THE STEEL INDUSTRY

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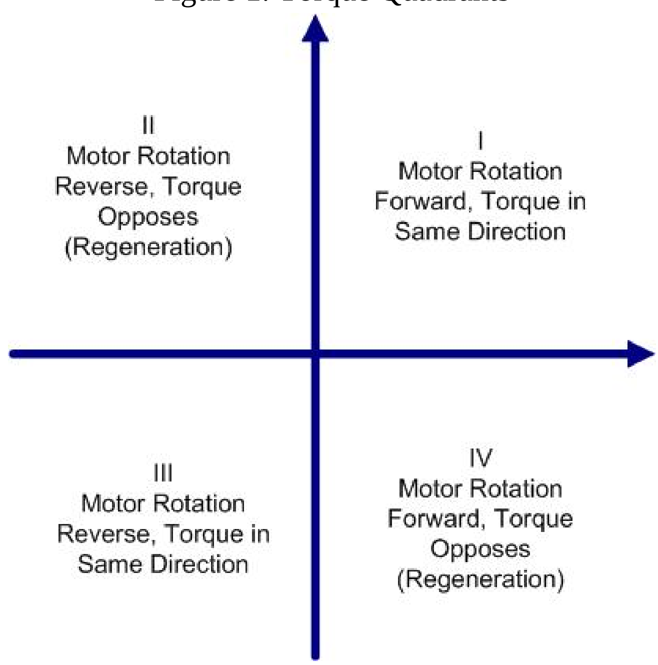
Abstract: Speed control of electric motor systems in the steel industry has a significant impact on throughput, quality control and energy improvements. In this paper, we will discuss the differences and similarities of AC and DC drives and how they are applied in the steel industry.

Introduction to DC Machines

Within the steel industry there are a great many applications that have traditionally used DC electric motors. The primary reasons include the ruggedness of the electric machine, the drive and the ability to provide large horsepower speed control. The ability of the DC machine to operate in each of the Four Torque Quadrants (Figure 1) has separated it from the ability of the AC electric motor until the late 1980's and 1990's.

Figure 1: Torque Quadrants



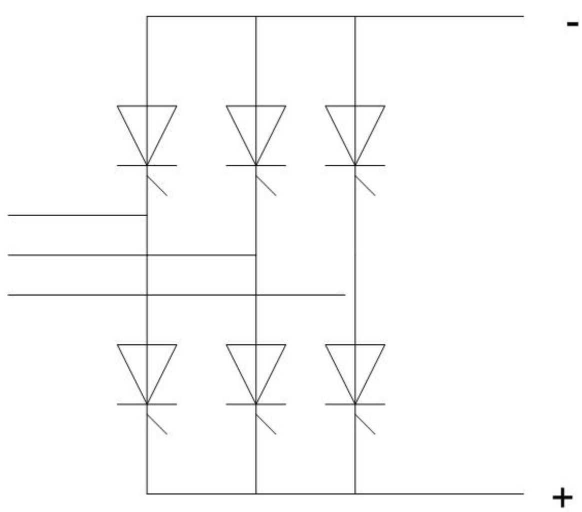
In the case of Figure 1, forward refers to clockwise rotation at the shaft end. For instance, in a winder, the take-up reel may use Quadrant 1 with the tension being maintained using Quadrant IV.

There are also three basic types of DC motors including:

1. Series Connected Motor:
    a. High starting torque of about to 500% of full load torque;
    b. Speed regulation is variable and a load must always be applied;
    c. Speed control is set by a series rheostat;
    d. High torque applications such as crushers, traction motors, etc.
2. Shunt Connected Motor:
    a. Provides ~250% starting torque;
    b. 5-10% speed regulation;
    c. Speed control up to 200% of speed with field weakening;
    d. Normally used for constant speed applications such as fans, pumps and compressors.
3. Compound Connected Motor:
    a. Starting torque of up to 450% of full load torque;
    b. Speed regulation can vary up to 25-30%
    c. Speed control up to 125% with field weakening.

The general components of a DC machine include the frame, armature windings, field windings, interpoles, commutator, brush rigging and brushes. The drives used for most larger DC machines are referred to as a ‘three phase full-wave rectifier.’

Figure 2: Three Phase Rectifier



Feedback devices to the drive include:

1. Armature (voltage) results in a speed regulation of 2-3% and directional information;
2. DC tachometer results in speed regulation of 1% and directional information; and,

3. Encoder (Digital Tach) results in speed regulation of at least 0.01% with directional information and position information with an accuracy related to the pulses produced by the encoder in multiples of 1024 per 360 degrees.

During operation of the DC machine, the full wave rectifier controls the voltage provided to the fields and armature by turning on and off the power electronics, or Silicone Controlled Rectifiers (SCR's). The switching allows the DC drive to control the DC voltage that also contains some level of AC voltage component equaling a line frequency and SCR frequency (# of SCR's times the line frequency). This value tends to be no more than 5-10% of the actual voltage or current value.

The lower the AC voltage, the lower the power factor of the system and the higher the fifth and seventh harmonic components in both voltage and current. As a result, filter systems, such as line reactors, are often applied to reduce the impact on the system. Another concern with DC machines is the amount of maintenance required due to the number of moving components in the motor and carbon dust contamination.

Introduction to AC Machines

The AC induction motor consists of a frame, stator windings, stator core, rotor core, rotor windings, a shaft and bearings. There are fewer friction parts and, as a result, a far reduced maintenance requirement than DC machines. However, speed control and shaft torque control can be more complex. The speed relationship has to do with the number of pole pairs of the machine, the frequency applied and the load on the shaft. As shown in Equation 1, the synchronous speed has a specific relationship:

Equation 1: Synchronous Speed N_s

$$N_s = \frac{120\ x\ f}{p}$$

Where *f* is the line frequency and p is the number of poles

The relationship between the synchronous speed and the actual rotor speed is referred to as slip, or N_{slip}. This is often presented as a percentage of the synchronous speed, or (Equation 2):

Equation 2: Percent Slip N_{slip}

$$N_{slip} = \frac{N_s - N_{shaft\ speed}}{N_s}\ x\ 100\%$$

In order to change speeds, the number of poles must change or the applied frequency. While there are some motors with multiple pole connections and/or windings, these are still fixed speeds, so the best method of operation is the Variable Frequency Drive. This type of drive varies the operating frequency and the voltage because a lower frequency and constant voltage would cause the rotor and windings to overload.

Open and Closed Loop – Vector drives provide similar responses to shunt and compound wound DC machines and can even provide a higher degree of accuracy and response in all four torque quadrants. The challenges have to do with the distance from the machine and filtering. The benefits have to do with a constant power factor across the entire speed range of the machine.

General Reliability Considerations for AC and DC Drives

Considerations of the differences between AC and DC drives, motors:

1. Cleanliness: Both the AC and DC motors are equally effected by the atmosphere that they operate in. However, the DC motor has the added issue of carbon dust developed by its own brushes during operation. This dust is the primary cause of grounds and shorts in the armature of the machine. Silicones will also have a significant effect on the life of the brushes in the DC machine, particularly if it is used to seal the motor.
2. Cooling: In most steel applications requiring constant torque or horsepower across the speed range, external cooling is needed by both AC and DC machines. However, the external blower on an AC machine moves air over the surface while the blower on a DC motor moves air directly onto the armature or commutator. This has the opportunity to introduce contaminants and also requires frequent changing of the filters.
3. Maintenance: The AC machine generally requires electrical testing, surface cleaning and bearing greasing. The DC machine requires the same plus brush and commutator inspections and cleaning, filter cleaning and blowing out of carbon dust from the armature windings.
4. General Reliability: The AC machine with fewer moving and friction parts should have a greater reliability, and does when applied correctly. The DC machine still tends to be perceived as a workhorse within the steel industry.

Considerations of the differences between AC and DC drives, VFD’s and DC Drives:

1. Ruggedness: DC drives tend to be thought of as more rugged than VFD’s. While this is normally considered perception, VFD’s do have a tendency to be more sensitive to misapplication and power quality issues.
2. Cooling: Older DC drives required some attention to cooling while modern DC drives and VFD’s both require much greater attention to ambient temperatures.

3. General Reliability: The general perception is that DC drives are more reliable than VFD's because they can 'ride through' power quality issues and some electrical faults. This can be balanced against the faster response times in AC induction machines when they are properly applied.

Both AC and DC drives require specialized training for programming (modern DC drives) and troubleshooting.

Conclusion

As the industry converts more towards AC systems over DC systems, there are some similarities and differences in the maintenance and reliability of both machines and drives. Modern open and closed loop vector drives provide many of the four-quadrant operating capabilities as DC drive systems. The primary difference in reliability and maintenance between the two systems actually resides in the machines themselves with AC machines requiring less attention and maintenance than DC machines.

About the Author

Howard W Penrose, Ph.D., CMRP is the President of SUCCESS by DESIGN Reliability Services. He has over a quarter Century in the rotating machinery industry and has been a pioneer in the development of successful industrial assessment and motor management programs since the early 1990's.

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