Celera MOTION
A Novanta Company

Direct Drive Motors, Frameless Resolvers, Ring Encoders

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INTRODUCTION

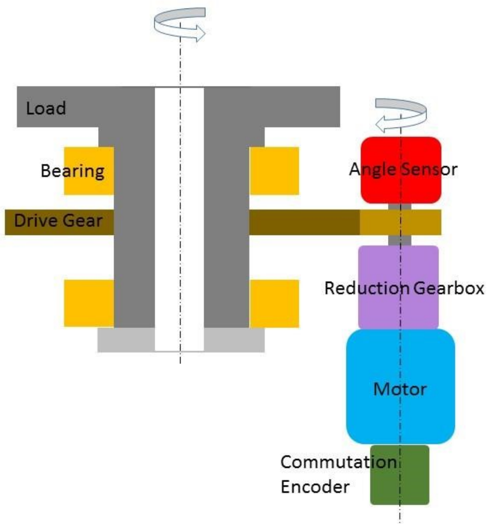
Direct drive motors have been around for many years but it is only very recently, with the demand for higher performance, that they have seen more widespread use. This article compares and contrasts the use of direct drives to more traditional motor arrangements and discusses the available position feedback options.

TERMINOLOGY

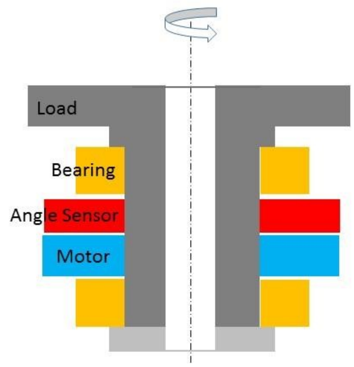
'Direct Drive' can be applied to any motor which directly drives a load or rotor without transmission elements such as gears, pulleys or chains. More usually, the term refers to brushless, permanent-magnet, synchronous motors which transmit their torque directly to their load or rotor. Often, they have a short axial height compared to their diameter and a large through bore. 'Torque motor' is also a term that is sometimes used to describe direct drive motors which produce a constant torque when stationary or moving over short angular ranges.

HOW DO DIRECT DRIVE MOTORS WORK?

Direct drive motors work in much the same way as most brushless DC motors. Magnets are attached to the motor's rotor and windings are arranged on the motor's stator. As the windings are energized, they produce electromagnetic fields which either attract or repel the rotor's magnets. Appropriate switching or commutation of power to the windings produces a controlled motion. There are linear and rotary direct drive motors but rotary versions are by far the most frequently used.



Traditional Motor Drive Arrangement



Direct Drive Arrangement

Direct drive motors with diameters of >1m are possible, able to produce torque of >10,000Nm. Many direct drive motors are 'frameless' which means that they are supplied without a housing, bearings or feedback sensor. This allows machine builders and system integrators to streamline their housing, shaft and bearing design to optimize overall size, shape, weight and dynamic performance.

The two main reasons for a design engineer to choose a direct drive are dynamic performance and shape factor. Rather than dealing with a coupling, gearbox, belts or chains, a direct drive motor attaches directly to the load so there is no hysteresis, backlash or 'lost motion' in any direction of movement. The design advantage that comes from motors which are fairly flat with a large hole in the middle – allowing slip-rings, pipes and cables to pass through - should not be underestimated.

The advantages of the direct drive approach include:

- **Excellent dynamic performance** and accurate control of position and/or speed
- **No backlash or wear**
- **High reliability** due to low part count & elimination of gears, pulleys, seals, bearings etc.
- **Compact** - with low axial height and large bore feasible
- **Low torque ripple** or 'cogging'
- **Energy efficiency** from eradication of losses in intermediate mechanical elements
- **Low acoustic noise** or self-induced vibration
- **No/low maintenance**

- **Low cooling requirements** due to advantageous thermal geometry
- **Relatively large airgaps –** easy installation and resistance to shock.

The main disadvantage is often more perceived than actual - direct drive motors are often thought to be more expensive than traditional motors. While this may often be true in a simple 1:1 comparison, a more holistic view (taking in to account the eradication of intermediate gears, couplings, maintenance as well as reduction in overall mechanical simplification) shows that direct drive arrangements are, perhaps surprisingly, the optimal cost and performance solution in many applications.

Classic examples of direct drive applications are found in gimbals such as antenna systems (e.g. vehicle mounted satellite communications), surveillance & CCTV cameras, scanners, telescopes, electro-optics, rate tables, and radar systems. There are also applications in CNC machine tools, packaging equipment, robotics and even high end record turntables.

If the bore of the direct drive is fairly small (<2″) there is a wide choice of position feedback sensors based on optical, magnetic, capacitive and inductive technologies. For larger bores the primary options are frameless resolvers, ring encoders and inductive encoders.

FRAMELESS RESOLVERS

A resolver whose axial height is small compared to its diameter, can be referred to as either a frameless resolver, a slab resolver or a pancake resolver. Strictly speaking 'frameless' simply means that the resolver housing has been eliminated but many engineers will use the term frameless when referring to a resolver with low height and big diameter.

Figure. 1 – Frameless resolver with low axial height and large diameter

Most resolvers are brushless rather than brushed, but are all based on transformer principles. In other words, they are inductive angle sensors. As the position of a resolver's rotor varies relative to its stator, the electromagnetic coupling between the rotor and stator varies. This can be seen as the resolver's output signals vary sinusoidally relative to the excitation or input signal.

Some resolvers are termed 'single speed', 'two speed', 'four speed' etc. This refers to the number of times that the resolver's output uniquely varies over 1 revolution. A single speed resolver's output is unique over 1 rev; a two speed resolver's output is unique over any 180 degrees within 1 rev; a four speed resolver's output is unique over any 90 degrees within 1 rev and so on.

Resolvers have an excellent track record in safety related applications – notably in civil aerospace. They are extremely rugged and reliable but tend to be bulky, heavy and difficult to customize.

RING ENCODERS

Ring encoders are also known as large hollow bore encoders or large through shaft encoders. As with frameless resolvers – all such terms refer to an encoder whose axial height is small compared to its diameter. Ring encoders are typically optical or magnetic.

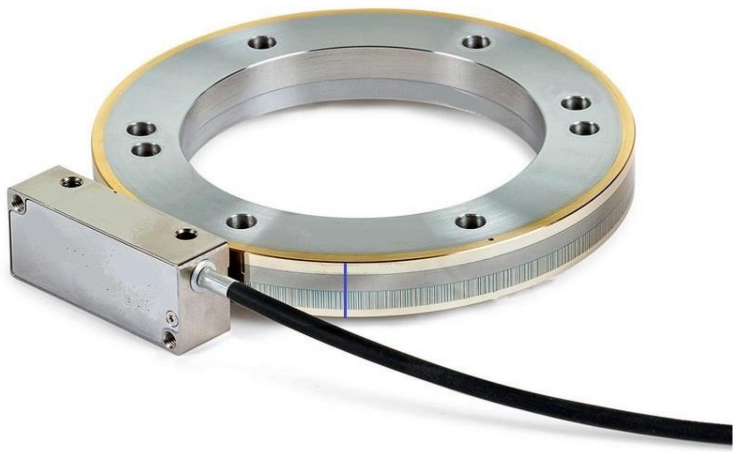


Figure. 2 – Ring encoder with low axial height and large diameter

The optical encoder employs the scanning of a fine grating or "scale" illuminated by an LED light source. The scale, rotary or linear, is made of transparent and opaque "lines" that are arranged in a 50-50 duty cycle. The number of transparent regions on the disc corresponds to the scale pitch which defines the resolution of the encoder. The sensor generates a voltage in proportion to the incident light intensity. As the sensor moves relative to the scale the voltage varies sinusoidally. Optical encoders deliver high levels of precision but are relatively fragile and susceptible to contaminants.

A magnetic encoder employs a multi-pole magnet track. The sensor, Hall-effect or magnetoresistive, measures the change in magnet flux as the magnetic poles move relative to sensor. Sine and cosine signals can be generated as in the optical encoder. Magnetic encoders are rugged, compact and can be very cost-effective. They are, however, susceptible to magnetic fields. It is difficult to produce a fine pitch magnetic track limiting resolution. Repeatability is compromised by hysteresis and accuracy changes over operating temperature range. The magnetic track is relatively brittle and can be susceptible to shock.

INDUCTIVE ENCODERS

Inductive encoders (Incoders) use the same fundamental physics as resolvers but offer the same digital electrical outputs as an optical encoder. This means they offer the same robustness and reliability as a resolver but with an easy to use, electrical interface.

Figure. 3 – Large bore, low height inductive encoder

Unlike a resolver, all the electronics required for operation are inside the Incoder's stator. This means that the electrical interface is typically a low voltage DC supply which produces a digital data output representing absolute angle or change in angle.

Unlike a ring encoder, the Incoder's measurement is not just made at one point but rather across the full planar faces of rotor and stator. This means that Incoders are much less susceptible to inaccuracies from non-concentric rotation, thus making their installation relatively easy.

Incoders are particularly well suited to applications such as gimbals and turntables where low axial height is required as well as a large through bore.

Incoders are available in absolute and incremental formats with high resolution digital outputs (up to 4million counts per rev) such as SSI, SPI, BiSS-C and AquadB pulses. Some devices are also available as replacements for potentiometers with 0-5V and 0-10V outputs.