Introduction

Direct drive motors have been around for many years but it seems that it is only very recently that equipment manufacturers and system integrators have grasped the advantages of this technique. This article compares and contrasts the use of direct drives to more traditional motor arrangements; highlights the relative advantages and discusses some difficulties and solutions.

Terminology

OK – let’s start with some terminology and definitions. Theoretically, the term ‘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.

![Diagram of Traditional Motor Drive Arrangement and Direct Drive Arrangement](image)

Direct drive motors usually have a large number of poles (>30 and sometimes >100) which allows them to produce high torque at no or low speed (usually <1000rpm). 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 torque-to-inertia ratio is also higher in direct drive motors than traditional motor arrangements and there is a low electrical time constant. This means that the torque is applied quickly when voltage is applied, achieving what control engineers refer to as good servo ‘stiffness’. More traditional motors are designed to generate maximum torque at higher speeds (typically >1000rpm) and are sized and specified on their power rating. Size and selection of direct drive motors is usually based on maximum or continuous torque rather than power.
Advantages and Disadvantages

The advantages of the direct drive approach are:

- **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
- **High torque to inertia ratio** and high torque to mass ratio
- **Low torque ripple** or ‘cogging’
- **High torque at low speeds**
- **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** and hence good resistance to shock and resilience in dirty environments.

The two main reasons for a design engineer to choose a direct drive are dynamic performance and shape factor. The design advantage that comes from motors which are fairly flat with a big hole in the middle – allowing slip-rings, pipes and cables to pass through - should not be underestimated.

The main disadvantage is often more perceived than actual:- direct drive motors are often thought to be more expensive than traditional motors. Whilst 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. Furthermore, the 1:1 cost premium is gradually reducing as more direct drives are produced and the availability of powerful neodymium-iron-boron (Nd-Fe-B) magnets increases. The advantageous cost/performance point is nicely illustrated by the increasing use of direct drives in cost sensitive applications such as washing machines, where the traditional motor, belt and pulley systems are increasingly being replaced by quieter, more reliable direct drive motors.

Classic examples of direct drive applications are found in a plethora of gimbals such as antenna systems (e.g. vehicle mounted satellite communications), surveillance & CCTV cameras, scanners, telescopes, electro-optics, rate tables, radar and weapons systems. There are also applications in CNC machine tools, packaging equipment, robotics and even high end record turntables.
Most motors exhibit positional torque ripple known as ‘cogging’. In high speed, traditional motors, this effect is usually unimportant, as the frequency is so high that it has negligible impact on performance. Direct drive units would suffer more from this phenomenon, unless the motor control system uses feedback to actively counter the effect. One of the factors that has perhaps slowed the uptake of direct drive motors is that precise electrical control is required. Only in recent years have sufficiently fast (update rates of >4kHz) and responsive controllers become widely available at realistic costs.

One of the major advantages of using direct drive motors is increased positional, speed and dynamic accuracy. 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. To achieve this, a direct drive motor needs a high resolution position feedback device to complete the servo loop. In some instances, the Hall-effect sensors typically used for commutation of power to the motor’s windings are sufficient but in many others they do not offer sufficient measurement performance to allow precise position or speed control.

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. As previously stated, one of the key factors for choosing a direct drive is form factor and a large through bore (>2”) in particular. Since most position sensors are based on a small input shaft or small through bore, this means that the choice of a suitable position sensor for direct drives has – until recently – been limited and hence problematic. The first option is optical ring encoders with a simple DC supply and absolute or incremental digital output. Unfortunately, they are unsuitable for dirty or wet environments because of obscuration of the optical sensor’s path; limited tolerance to extreme temperatures or shock and they require accurate installation to achieve good measurement performance. Capacitive encoders can face similar issues as well as the added complication of having to dissipate the buildup of static charge on the rotor. The second option is a magnetic ring encoder but their advantage over the Hall Effect sensors used for commutation can be modest and they lack high precision due to magnetic hysteresis. Since they are based on the sensing of DC magnetic fields they may also be susceptible to stray magnetic fields from the motor. The third option is the traditional choice – the brushless resolver. A resolver uses similar electromagnetic physics as the motor itself to sense the position of the rotor relative to the stator. Resolvers are generally unaffected by foreign matter and have an unparalleled reputation for reliability, ruggedness and safety.

Unsurprisingly, resolvers are the defacto standard choice in many high-reliability or safety related applications - most notably in aerospace and defence. Nevertheless, they can also be bulky, heavy and expensive – especially in large bore formats sometimes referred to as pancake or slab resolvers. The use of pancake or slab resolvers has perhaps fueled the view that direct drive systems are too expensive for some applications.
A Different Approach

A new type of sensor is increasingly being selected for direct drive position feedback: the inductive encoder or ‘incoder’. Incoders use the same electromagnetic or inductive physics as resolvers but instead of the bulky transformer windings, they use laminar, printed circuit board constructions and so are less costly, more compact and lighter. Rather than the complex AC supply and signal processing required by resolvers, incoders use simple electrical interfaces similar to those offered by optical encoders – DC power input and a digital electronic output. Incoders are available in absolute or incremental (A/B pulse) formats with resolutions of up to 22bits (roughly 4 million counts per rev); accuracies of \( <40 \text{arc-seconds} \) \( (<0.01^\circ) \) and very low temperature coefficients \( (<0.5 \text{ppm/K}) \). Until recently, incoders were considered too slow for highly dynamic applications but now offer fast update rates of up to 10kHz. Importantly, they also match the form factor of many direct drives – low axial height, relatively large diameter and bore. Furthermore, they are usually supplied in a frameless format without bearings, couplings or seals – so they can be mechanically fixed to the direct drive.

The combination of incoders with direct drives is increasingly the preferred arrangement for many design engineers and the combination is winning more supporters as it continues to demonstrate highly reliable, highly dynamic motion control for applications in the medical, aerospace, defence, industrial and petrochemical sectors.

An example of an incoder.
Further Information / Contact

For more information about Zettlex inductive position sensing technology, or to discuss your application with a position sensor expert, please contact Zettlex directly or speak with your nearest local representative.

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