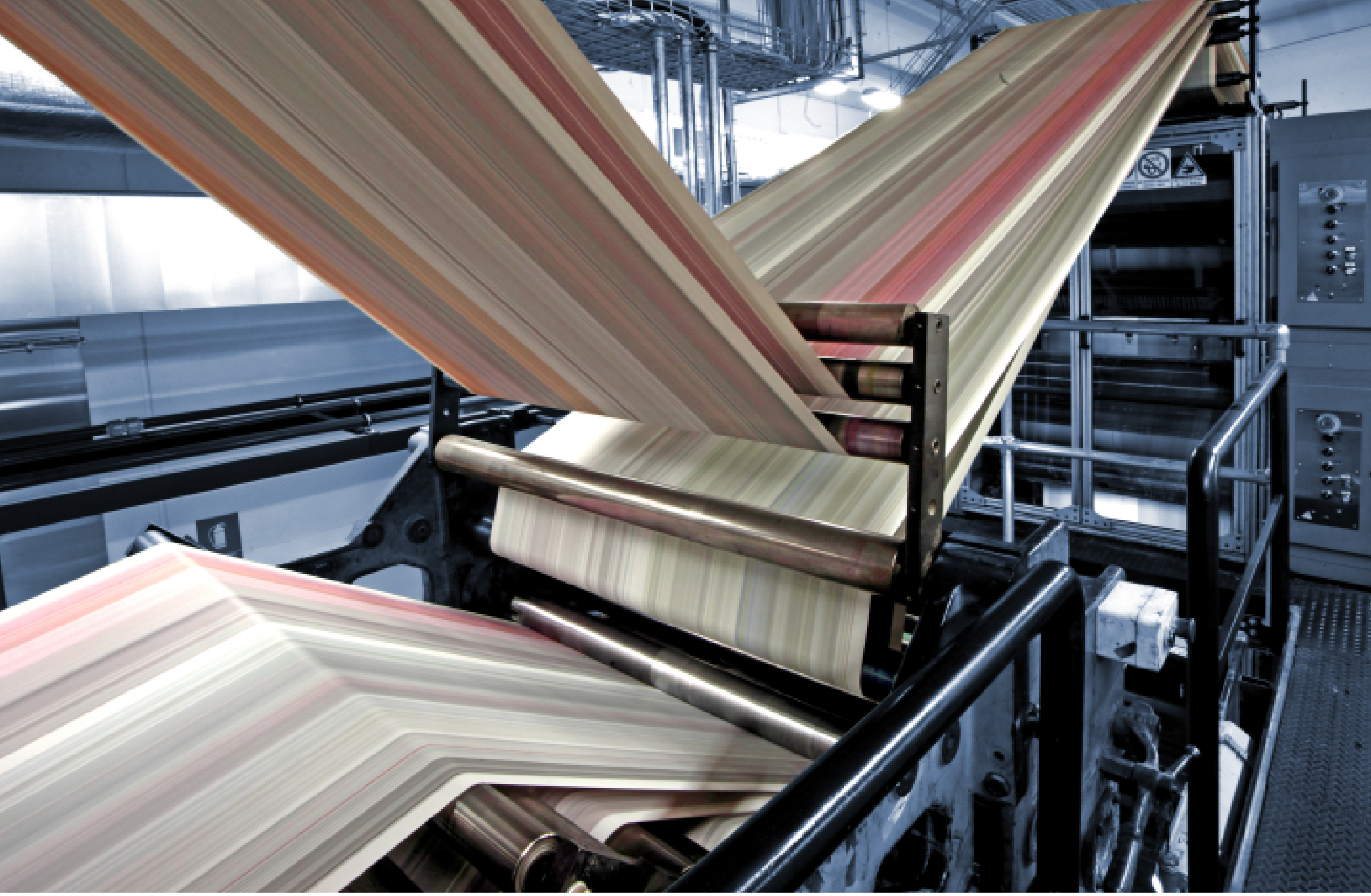


Improving Servo System Design to Optimize Coating and Laminating Quality

KOLLMORGEN®

Because Motion Matters™

White Paper

Tom England, Market Development Director

Coating and lamination applications demand extremely precise speed regulations in order to avoid velocity ripple that causes uneven coating and undesirable horizontal bars across the substrate. The key to achieving the most uniform coating is minimizing variations in velocity as well as in metering of the coating material.

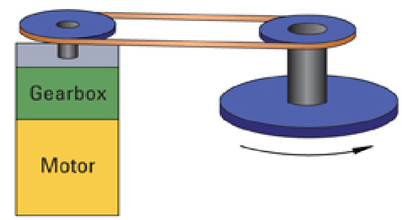
Mechanical transmissions such as gearboxes and timing belts can cause torque perturbations resulting in these imperfections in the coating. Moving to direct drive is one way to improve coating and laminating quality and uniformity. High-performance direct drive rotary (DDR) motors with reduced electromagnetic cogging combined with high-performance digital servo drives using versatile filters can isolate resonances and mechanical disturbances so as to provide high bandwidth control of the roll. Finally, using a precision feedback device is very important to minimize velocity ripple.

Coating and Lamination Loads

Coating and laminating applications are characterized by compliance caused by the elasticity of the web, which in turn produces variations in torque requirements. The coating or laminating process typically generates a fairly steady level of frictional force. The roll itself, and its bearings and shaft extensions, are usually large in comparison to the drive motor, which generally creates an inertia mismatch. However, through the use of direct drive rotary technology the load and motor inertia are coupled directly together and a “mismatch” is much easier to control. Typical load to DDR motor mismatches of 250+:1 are controlled well.

Web handling machines face the challenge of handling these loads while avoiding velocity ripple that can cause uneven coating and unsightly horizontal bars across the substrate. As an example, consider film coating, where depositing a dark film onto the substrate material at varying velocity would result in a series of dark and light "bars" across the material. As web speed and quality requirements have increased, the inevitable inaccuracies in the mechanical transmission and servo system have become the limiting factor on coating and laminating uniformity.

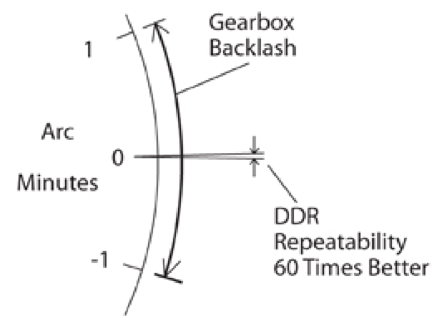
Effect of Mechanical Transmissions



Traditional servomotor and gearhead

Mechanical transmissions can have a negative impact on coating and laminating quality by causing tooth or belt chatter. Backlash is inevitable in any mechanical transmission system. Transmission components such as lead screws, gearboxes, and belts and pulleys all contribute error between the motor and the load. Even when a geared system is tuned very tightly, within a short period of time the gears will wear and backlash will begin to occur. Backlash causes the roller and cylinder to rapidly accelerate and decelerate as the gear teeth bounce back and forth against each other. The result is uneven coating of the substrate manifested by the appearance of alternating light and dark horizontal lines on the product.

Advent of Direct Drive Systems



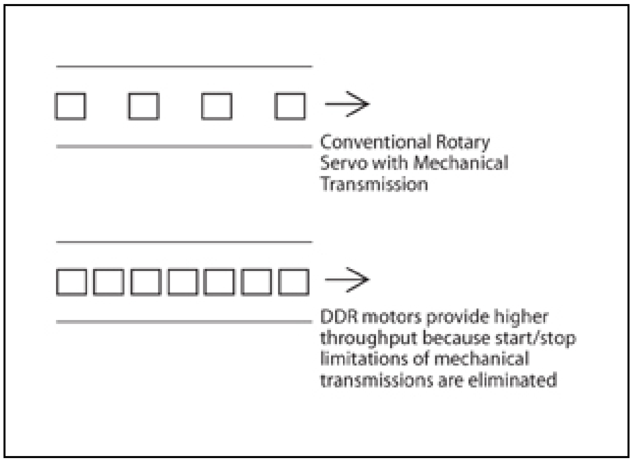
Improved repeatability of direct drive rotary system compared with mechanical transmissions.

In some cases these concerns can be adequately addressed by selecting high-quality mechanical transmission components. However, the added expense can become prohibitive and they will still wear eventually. The ultimate solution is a direct drive rotary system, which eliminates the transmission altogether. In direct drive systems, the motor directly drives the load. The accuracy of direct drive systems can be up to 60 times better than that of traditional systems and audible noise can fall by 20 dB. Other measures such as servo response (bandwidth), machine parts reduction, and reliability also can improve dramatically.

When the load is directly coupled, there is no limitation on the inertia mismatch between load and motor. The servo loop gains can now be increased significantly to provide the necessary servo stiffness to achieve excellent speed regulation to optimize product quality. Web speeds can be increased in many applications using direct drive technology because the accuracy of the mechanical transmission system is often the limiting factor.

When the transmission components such as gearboxes, belts, rack and pinion, and pulleys are eliminated, the servo system becomes free of such negative factors as compliance, backlash, and component wear. The accuracy increases, inertia-matching requirements relax, acceleration and deceleration improve, maintenance becomes unnecessary, and the product life increases by a significant degree.

Direct drive rotary motor size can be based on the peak torque required for achieving the desired acceleration time specifications. With direct drives, inertia mismatch of 250 to 1 is common and mismatch of 800 to 1 has been implemented. In many coating and laminating applications, the size of the motor is dictated by the inertial matching requirements. The result is that a much smaller and more energy-efficient DDR motor can be used in most applications.



DDR motors deliver increased throughput

The motor's primary contribution to velocity ripple is its electromagnetic cogging, which is usually at the pole or slot frequency or some multiple of it. The best way to overcome electromagnetic cogging is to begin with a low cogging motor that requires less correction. High-performance motors with less than 1% pk-pk cogging are a very good start, and nearly always superior compared with standard motor options due to better electromagnetic design, and simulation of the electromagnetic circuit.

Frameless Direct Drive Motors

Kollmorgen's KBM™ series frameless brushless motors

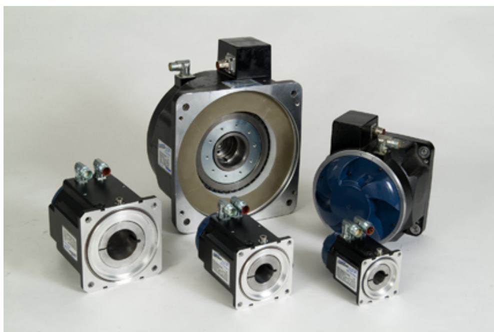
Direct drive rotary technology has developed in an evolutionary manner. The original frameless direct drive motors were designed into the machine architecture along with a feedback device and became a fully integrated part of the machine. This approach has the advantage of consuming the least amount of space. On the other hand, frameless motors are relatively expensive to fully integrate as they typically require substantial changes to the design of the underlying machine. Frameless motors are also more difficult to service because they are embedded into the machine. While the initial development cost burden is high, the benefits of higher performance, higher quality, and small space requirements justify this technology in some applications.

Full Frame Systems

Kollmorgen's Housed DDR motors

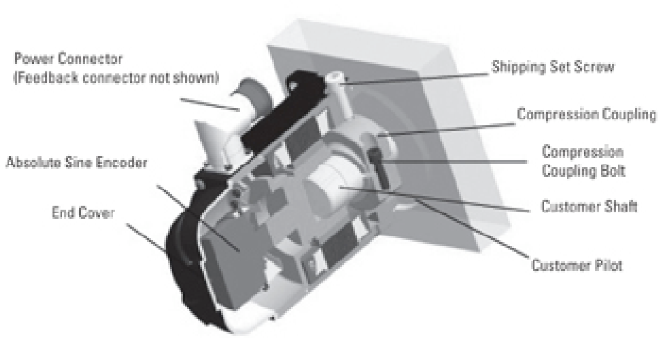
The next generation of direct drive rotary technology, sometimes referred to as full frame systems, integrates all of the components of a complete motor including the rotor, stator, bearings and feedback device within a housing. The machine shaft slips through the bore in the motor and attaches to the rotor. This approach substantially reduces development costs since the motor no longer needs to be integrated with the coating roll. The disadvantage of this approach is that the motor and machine bearings must be precisely aligned, which is a complex and time-consuming task. The bearings in the motor and the load are directly coupled in a linear fashion making it nearly impossible to align the system components properly without causing premature bearing failure due to uneven loading.

Kollmorgen Cartridge DDR® motors

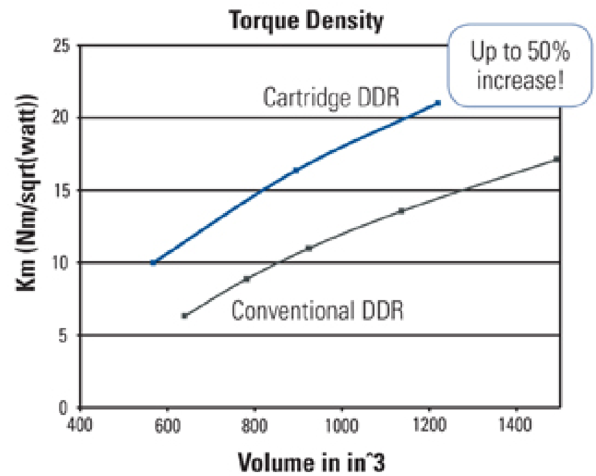


Kollmorgen Cartridge DDR® motors

The most recent approach to DDR systems is the Kollmorgen Cartridge DDR motor which is fully housed and ready for mounting to the machine. However it has no bearings in the motor, but instead uses the host machine to support the motor's rotor. This approach makes it easy to use direct drive technology on machinery that already has bearings, particularly in applications such as coating, laminating and printing where rollers already use heavy-duty, precision bearings. The motor has a hole in the middle which slips over the shaft extension of the roll and the motor housing bolts to the machine frame.



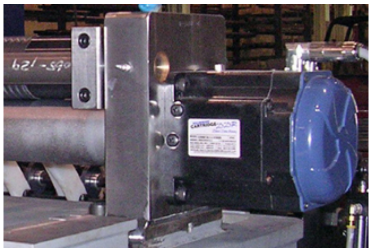
Installation typically takes less than five minutes. The motor slides over the shaft until a motor pilot engages a machine pilot. The housing is secured with bolts. The motor rotor is then secured to the machine roller shaft by means of a compression coupling tightened to a specified torque. The rotor is now rigidly connected to the machine shaft. The encoder alignment is pre-set so that no adjustments need to be made. Cables are connected and the motor is ready to run.



Proprietary electromagnetic design gives Kollmorgen Cartridge DDR® motors more torque per volume than conventional DDR technology.

A servo system equipped with a Kollmorgen Cartridge DDR servomotor is expected to work for ten years without any maintenance. Although the initial system cost might be higher compared to a conventional geared system, over a period of several years, eliminating the cost of repairs and periodic maintenance makes the overall cost of purchasing and operating a cartridge system lower. Even with the slightly higher initial cost, over a five-year period, ***Kollmorgen Cartridge DDR motors can reduce operating costs up to $10,000 per motion axis compared to conventional geared servo systems.***

Press-feed machine built with a conventional servomotor, gearhead, belt and pulleys.



Same machine with a Kollmorgen Cartridge DDR® motor installed.

Here, the shaft of the driven roll is extended into the Cartridge DDR motor and the motor applies torque directly to the driven roll.

Improving Feedback Device Performance

Since the feedback device is in the control loop, any error of the device itself is "corrected" by the drive in the servo loop, and ends up as a velocity ripple on the coating roll. As the servo loop gain is increased the error in the feedback device is amplified and transferred into the coating roll. So, starting with as precise a feedback device as possible is very important to minimize velocity ripple. There are several ways that accuracy can be improved. The most straightforward is to use a more accurate device. For example, most encoder manufacturers offer encoders in a variety of resolutions. Resolution is usually measured in lines per revolution. Encoders with higher line counts usually have greater accuracy. However, this is not always the case, so users must check the specifications of the encoder carefully. In some cases, highly resolved devices can still be relatively inaccurate.

Users can also change the type of feedback device. Sine encoders are the most accurate motor-mounted feedback devices commonly used in industrial servo systems. Sine encoders are typically accurate to +/-25 arc-sec, compared with a resolver at +/- 10 arc-min. High-line-count incremental encoders (above 10,000 lines-per-revolution) are also often highly accurate. Medium line-count encoders (2,000 to 10,000 lines-per-revolution) are fairly accurate, usually holding 3 arc-minutes or less. Resolvers are the least accurate sensors, typically holding from 5 to 20 arc minutes.

Effect of the Servo Drive

Kollmorgen's Ethernet-based AKD® servo drives deliver best-in-class performance with industry-leading flexibility, scalability and power range to meet the unique performance requirements of nearly any application.

The servo drive such as Kollmorgen's AKD® can add to and correct various velocity ripple components. It adds to the ripple by having uneven current loop gains in each of the phases, i.e. phase A might be 1% higher than phase B or C and this causes a torque error in the motor. Likewise, the amplitudes of each phase might be slightly different adding an error to the torque as well. The drive can correct these by having digital adjustments in the current loops to take out these offset errors.

One can also reduce the velocity ripple of the system by using harmonic correction in the current waveform. For example, when the characteristic of the cogging in the motor (frequency and amplitude) is known, this can be corrected by applying an anti-phase ripple in the 3 phase current from the drive. The same can be done with the feedback device to correct a repeatable error. Both the motor and feedback error frequencies are well known and repeatable so all we are left to do is adjust phase and amplitude.

With low inertia construction being inherent to the design of most permanent magnet servomotors, mismatches between the high inertial loads of the roll and the low loads of the motor need to be accounted for. Servo-motor control systems can be tuned to handle inertia mismatches that are inherent in coating and laminating applications. But the gain in the servo amplifiers needs to be optimized to maximize response while avoiding instability and oscillations.

The traditional approach to compensate for inertial mismatches and compliant loads is to use low-pass, band-pass and high-pass filters to eliminate the unwanted frequencies. The problem with this approach is that the multiple filters that are required to eliminate the resonances introduce calculation delays and phase shifts which have a tendency to throw the system out of control.

Recently, substantial improvements in performance have been achieved with the use of bi-quadratic filters that can emulate nearly any combination of simpler filters without introducing significant delays. The bi-quad filter tunes out problematic frequencies, making it possible to optimize servo system performance. For example, if the mechanical system has a 200 Hz resonance, the bi-quad filter can be configured to remove 200 Hz while providing high levels of gain and bandwidth.

Conclusion

Coating and laminating operators and equipment manufacturers are striving to increase machine speed while at the same time maintaining the highest possible levels of quality. Achieving this goal requires accurately maintaining constant web velocity in order to avoid banding and other problems. Improvements can be made by reducing the compliance of the mechanical transmission system, or eliminating it entirely through the use of Kollmorgen Cartridge DDR technology that connects the motor directly to the roll. The latest generations of servo drives, motors and feedback devices all provide advantages that can help minimize velocity ripple in order to deliver product that meets the requirements of the most demanding customer applications.
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ABOUT KOLLMORGEN

Kollmorgen is a leading provider of motion systems and components for machine builders around the globe, with over 70 years of motion control design and application expertise.

Through world-class knowledge in motion, industry-leading quality and deep expertise in linking and integrating standard and custom products, Kollmorgen delivers breakthrough solutions unmatched in performance, reliability and ease-of-use, giving machine builders an irrefutable marketplace advantage.

For more information visit www.kollmorgen.com, email support@kollmorgen.com or call 1-540-633-3545.

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