TECHNICAL NOTES

Motor Technologies

Celera MOTION
Encoders | Motors | Mechatronics

Robot Joint Design Guidelines

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PURPOSE

The purpose of this technical note is to provide an example of how to properly integrate motor, encoder, and gear assemblies into a robotic joint design using precision zero backlash gearing, a brushless frameless direct drive motor kit, and two high resolution encoder kits.

BACKGROUND

As robotic and robotic assisted products proliferate the industrial, commercial, and medical markets, new design trends are emerging that capitalize on smaller and more compact assemblies with high precision and reliability.

To achieve this, one design solution is to develop an integrated robotic joint that contains a direct drive frameless torque motor kit, high resolution encoder kit, and precision zero backlash gear set in one common housing. This method of component integration results in a low weight and very low axial height, i.e. low profile, compared to that of prepackaged motors, gearboxes, and encoders assembled together.

INTEGRATED ROBOT JOINT

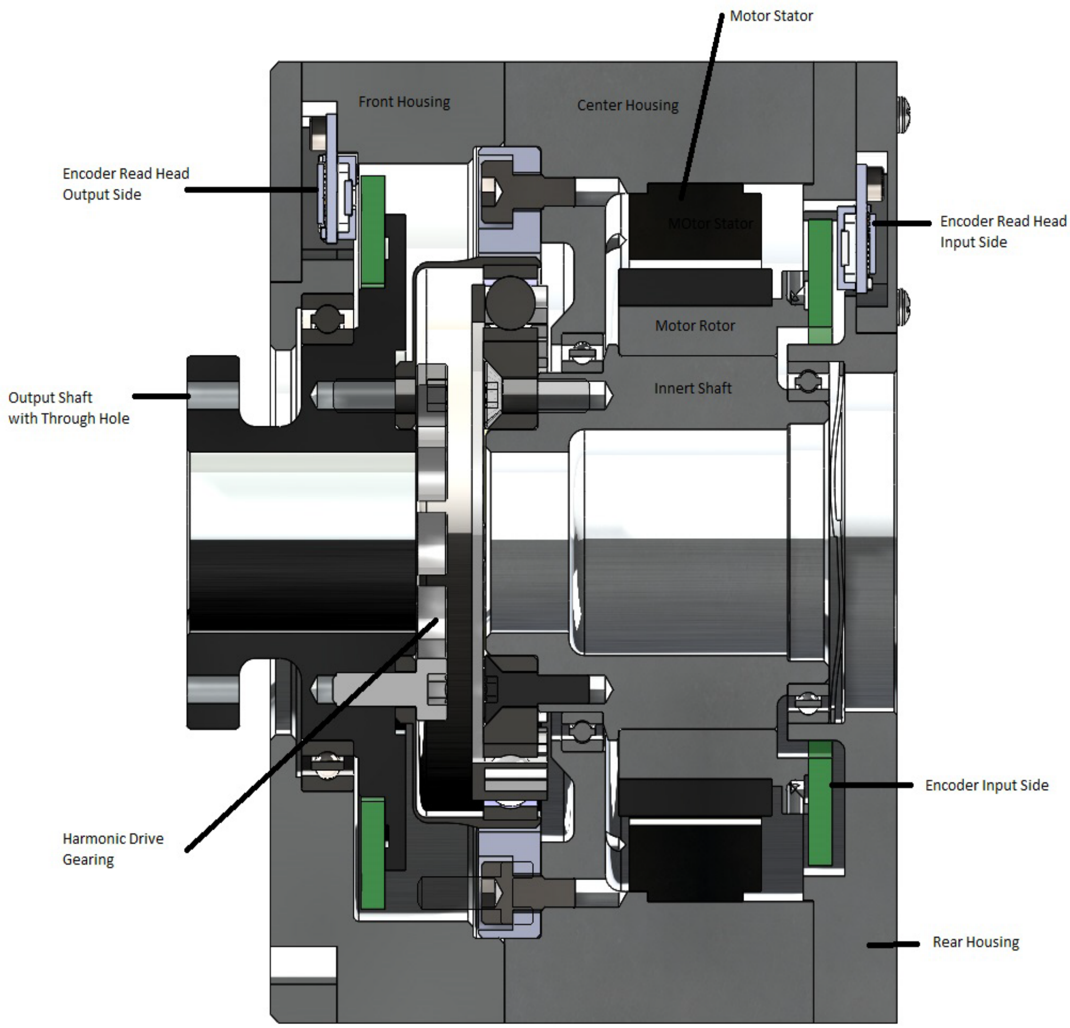
Figure 1 below depicts an integrated robot joint. This design has capitalized on components featuring low axial height, making the assembly very compact. The assembly also includes an encoder with high resolution and accuracy on the output, as well as a medium resolution encoder on the rear of the motor.

Figure 1: Integrated Robot Joint

The cross-section below reveals the major components in this integrated robot joint. It contains the following features:

- Precision low profile gearing with zero backlash.
- Frameless brushless motor kit.
- Medium resolution encoder kit on the motor side.
- High resolution encoder kit on the output side.
- Front, center, and rear housing components.
- A flanged output shaft for interfacing with nearby assemblies.
- Precision bearings for the input shaft, gearing, and output shaft.
- Axial through hole for simplified robot joint wiring.

Figure 2: Cross Sectional View of Integrated Joint



PRECISION GEARING

Robot joints have varying reflective loads and inertia based on position. Using a gear reduction increases output torque, mitigates the servo tuning implications of a large change in inertia with position, and allows for the use of smaller, more efficient motors.

One problem that arises from using traditional gear reductions is backlash. Although a higher gear ratio solves some torque and inertia quandaries, the resulting backlash will cause positioning errors and potential tuning issues. There are two commonly available types of gearing with zero backlash: harmonic drive and cycloidal drive. These two solutions both utilize a unique mechanical design that keeps sub-components in contact at all times. Recent improvements in design and packaging have produced very low profile gearing sets compared to previous offerings from the supply base.

Below is an example of a low profile harmonic drive component set. Cycloidal gear suppliers offer similar products.

Figure 3: Harmonic Drive Component Set

FRAMELESS BRUSHLESS MOTOR KIT

The assembly above uses a frameless brushless motor kit, also known as a torque motor kit. This kit consists of an electromagnetic stator and a permanent magnet rotor operating as a traditional, synchronous motor via a three phase servo motor controller.

A quickly emerging design trend is to use a motor kit intended for direct drive systems inside the integrated robot joint in order to drive a high ratio gear set. Direct drive motor kits have higher pole counts that improve torque output and large through holes to optimize mechanical packaging. These kits are shaped like a ring, and satisfy high torque requirements all while conforming to low profile constraints.

Robot joint output is generally slow. For example, 20 rpm would be a fast robot joint move. After a typical gear ratio of 150:1, the input speed, (motor rotating speed), is 3000 rpm. This is not considerably high for an electric motor as long as the proper impedance is selected to match the available voltage.

The figure below is an example of an Agility™ slotless, low profile, large through-hole, frameless motor kit.

Figure 4: Agility Motor Kit

Slotless motors eliminate cogging torque and make the fine motion of the robot predictable and smooth. They also have low magnetic core losses and large through holes. For more details on slotless motor kits, reference technical note TN-2001 at [www.celeramotion.com.](http://www.celeramotion.com)

Because proper choice and sizing of a frameless motor kit is critical to your entire robotic joint design, Celera Motion offers online tools and performance prediction software to allow for fast and accurate component selection that will help fulfill your design requirements.

ENCODERS FOR THE INPUT AND OUTPUT

Encoder: Input (Motor) Side of Joint

Most motor controllers benefit from medium resolution encoder feedback, i.e. 100,000 to 250,000 counts/revolution. If the motor controller is controlling torque only, then lower values are sufficient, however, velocity and position control greatly improve with higher resolution in this range.

The above integrated robot joint uses an optical encoder kit capable of more than 200,000 counts/revolution with installed accuracy of 20-50 arc-seconds. It is a low profile, diffraction based, interpolated encoder that uses a glass grating. Optical encoders typically have higher accuracy, measured in arc-seconds, compared to other lower performance encoder technologies like magnetic and capacitive encoders, measured in arc-minutes. While high accuracy on the input may not appear to be as critical, it can impact performance. For example, if the control system is differentiating position to create a velocity signal, inaccuracy in the position information will create a velocity ripple.

Below is an example of a Celera Motion Optira™ series configured as a medium resolution, low profile, optical encoder kit consisting of a read head and glass grating. This kit uses PurePrecision™ technology, and is capable of resolution of 250,000-500,000 counts per revolution with accuracy in the 20-50 arc-sec range. This is approximately 2 to 5 times more accurate than magnetic encoders or resolvers, while offering medium resolutions and allowing for higher motor speeds of the input shaft.

Figure 5: Optira Read Head and Glass Grating Scale

Encoder: Output Side of Joint

Motion controllers or robot controllers contain algorithms for trajectory control and coordination of multiple robot joints. These algorithms depend on high resolution feedback at each joint, i.e. resolutions greater than one million counts per revolution.

The output encoder is one of the most important components of the integrated robot joint. The performance and accuracy of the robot greatly depends on the absolute accuracy of each joint. In some cases, the robot controller may depend on the output encoder to compensate for stiffness and deflection of all the joints working together and changes in environmental conditions such as temperature.

The same Optira series encoder can also be configured as a high resolution, high accuracy, read head with the same grating. It uses Celera Motion PurePrecision™ optical technology. In rotary form, these encoders are capable of < 2 arc-sec of accuracy and resolutions well in to the millions of counts per revolution. Interpolation for a digital output is built into this small package and there is an option for 1 volt pp sine/cosine output for interpolation at in the host controller.

MECHANICAL HOUSING AND OUTPUT SHAFT COMPONENTS

The general form factor of a robot joint is driven by overall robot operational requirements. In the example above, the housing consists of three sections. There are two shafts: one internal for the motor and input encoder, and one external for the output and output encoder. All parts are precise in nature, following guidelines of the bearing, encoder, and motor suppliers.

Housing design must consider the following:

1. Relative precision of the housing must match the bearing, motor, and encoder requirements.
2. High resolution encoders require very tight axial and radial runout specifications. Any runout will reduce absolute accuracy. It is common to use ABEC 7 or better bearings.
3. Material selection should accomplish both mechanical accuracy and account for temperature fluctuations.
4. In the case of a robot joint, weight is important, so minimizing the number of parts advised.

CONCLUSION

In this technical note, the most compact, lowest profile robot joint is designed with a combination of low profile gearing, encoders, and a direct drive frameless motor kit. This combination contains the fewest number of components, and offers the highest torque output in the smallest size. While the final external packaging will vary by application, the internal components of the integrated assembly shown above are common, and the overall strategy can benefit all segments of the robotics market.

Each robot joint has a set of conditions that include voltage and current inputs, torque and speed requirements, and temperature limits on the inside and outside of the assembly. It is important to consider electrical, thermal and mechanical integration of all components, as well as manufacturability of the complete assembly.