Zero Cogging ThinGap Motor Allows CNC and Manual Vertical Positioning Along Curved Surfaces

The Mini-FlexTrack positioning system, made by Mobile Tool Management, is used in the manufacture of wings and fuselage for the Boeing 787 Dreamliner. The Mini Flex Track is a modular two-axis numerically-controlled positioning system that allows 2-axis CNC and manual positioning horizontally or vertically across a curved surface to tolerances of up to +/- 0.001”. The head can accommodate a variety of tools, including drill spindles, inspection probes, and die grinders.

Problem

Since the Mini-FlexTrack is used in many different orientations, gravity can work against it and make manually moving and positioning its head impossible because of the overall system weight. To make the system work, a method for counterbalancing the machine weight had to be designed. This in itself was a difficult problem because the weight varies with the orientation (vertical or horizontal) and size of the attached tool (5-40lbs.).

Possible solutions included air motors, pancake motors, and non-cogging, ironless core brushless motors. Each had its own set of issues, air motors couldn’t provide repeatable precision, pancake motors could not provide high shaft output power, and most compact non-cogging servomotors exhibit enough cogging torque that manual positioning is not possible.

Utilizing air motors coupled with a flex brake machine allowed an operator or computer program to vary input pressure until the Mini-FlexTrack’s head was neutrally buoyant and would not react to the force of gravity. The system allowed an operator to manually move the machine to the desired position/feature and use a probe to locate exact position. However, the air motor system could not achieve accurate motion profiles and system stability.

The engineers settled on servomotors for the system because they are very stable and capable of complex motion. However, most servomotors demonstrate cogging torque, even so-called brushless non-cogging motors have some cogging torque. For the system to work, a zero-cogging servomotor had to be found.

Cogging refers to shaft rotation that occurs in jerks or increments instead of smooth continuous motion. The non-uniform (“jerky”) rotation is caused by the tendency of the armature to seek specific discrete angular positions. The interaction of the armature coils entering and leaving magnetic fields, produced by the field coils or permanent magnets causes its speed to fluctuate, speeding up and slowing down as it moves through the magnetic fields during rotation. At low speeds, cogging is especially apparent and makes it difficult to impossible to achieve a precise manual position at low speeds.

Two types of servomotors were evaluated, including pancake and ironless core, non-cogging brushless motors. The pancake motor featured zero cogging, but it could not output enough power. Also, the size and weight made them unsuitable for this system.

Additionally, friction inherent in planetary gear heads had to be minimized. In order to drive a machine as small and light as the Mini-FlexTrack takes a small motor with relatively low torque coupled with a gearbox. This increases torque by 50 to 100 times over direct drive systems. This much torque, which is required to backdrive the system, is so high that the machine cannot be positioned manually. A gearbox with a low gear ratio, designed to minimize the back drive torque was found.

Solution

ThinGap was identified as a manufacturer of ironless core, no-cogging brushless motors that could provide a motor with zero cogging with the required shaft output and torque. After an evaluation of ThinGap's TG 2300ENC zero-cogging, ironless core brushless motor with encoder, it was selected for its combination of zero cogging, high peak torque of 574 oz-in, continuous power of 266 watts, small size, and weight of only 35.3 oz.

Because ThinGap's motor design does not feature slotted laminations cogging torque caused by slot interaction with magnets is nonexistent. Since the coils are constructed without iron, and all iron parts either rotate (i.e., brushless motor) or remain stationary (i.e., brush motor), cogging torque and hysterisis drag torque are virtually eliminated. This allows higher power, shaft output, and extremely precise positioning for such applications as the Mini-FlexTrack.

Additionally, a gearbox with low backdrive torque was selected to reduce planetary gear friction. Using a system of belts and pulleys to connect the motor with the gearbox provided additional torque to minimize torque and decrease backdrive torque. By way of explanation, the higher the gear ratio the higher the backdrive torque required for manual positioning. Hypothetically, if a gearbox achieves a 60:1 gear reduction the backdrive torque would be too high for manual positioning. However, by utilizing a 3:1 belt reduction combined with a 20:1 gearbox an output ratio of 60:1 with the backdrive torque of a 20:1 gearbox can be achieved.

Another factor crucial to ensure ease of use was the radius of the output pinion gear. A large radius pinion gear was used in the gearbox, making backdriving the system easier.

Results

According to Mobile Tool Management president, Mike Woogerd, "ThinGap's zero-cogging motor was essential for the precise positioning of our portable NC XY positioning system because cogging is especially apparent at low speeds making it very difficult if not impossible to manually position our machine. The TG2300ENC delivered better power-performance characteristics than most motors with the same dimensions and yet weighs less."