Anti-Cog Technology

Introduction

Ironcore linear motors have traditionally suffered from a phenomenon known as cogging. This is seen as a periodically varying resistive force when the motor is pushed by hand and it is caused because the motor coil has preferred positions in relation to the magnet track and resists attempts to move it off of these preferred positions. Cogging limits the smoothness of motion systems using ironcore motors because the force generated by the motor must change with position in order to maintain a constant velocity. Ironless linear motors do not have these preferred positions and therefore can achieve very smooth motion.

Parker has developed anti-cog technology that virtually eliminates cogging and enables ironcore motors to be used in applications where only ironless motors would have been considered before. Since ironcore motors use half the magnets of equivalent ironless motors, this helps lower the price barriers traditionally seen with linear motor solutions.

Anti-cog technology eliminates cogging without skewing the magnets or laminations or otherwise compromising motor efficiency. It uses additional mechanical features inside the motor coil that create a cogging pattern equal and opposite the cogging pattern of the lamination assembly. These two cogging patterns combine and eliminate each other using destructive interference.

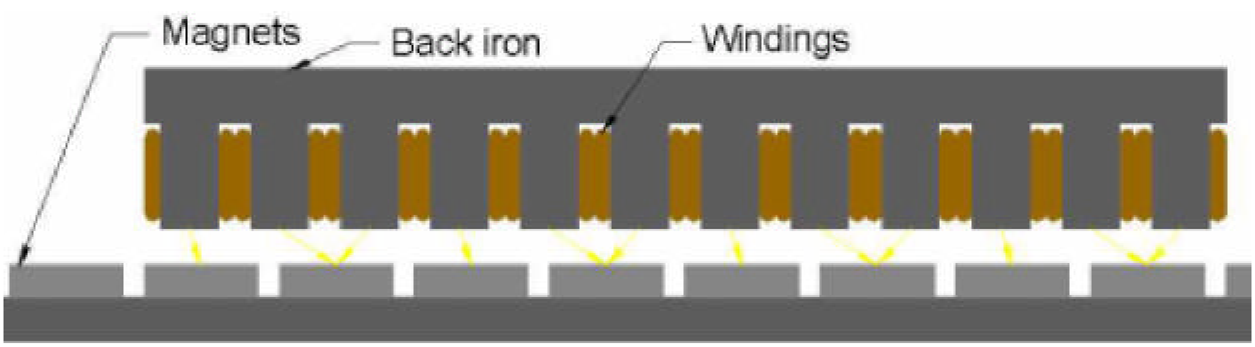

Figure 1. Typical Ironcore Motor Construction

Ironcore linear motors are simply rotary motors cut and unrolled; they contain the same parts but in slightly different relationships. The lamination cage becomes the comb-shaped back iron. The windings still reside inside slots in the lamination assembly. The shaft with magnets bonded to its circumference becomes a flat plate with magnets on the surface. Figure 1 shows a side view of a typical example of ironcore motor construction.

The yellow arrows in Figure 1 designate the magnetic force between the lamination teeth and the permanent magnet assembly for the given position. There is a horizontal component of the net force that is trying to move the lamination assembly to the right. As the coil moves relative to the magnets, this force will change. This is what causes cogging in an ironcore motor. There are some positions where this horizontal force will be very close to zero, some where it will be strong to the left, and some where it will be strong to the right.

The vertical component of the net magnetic force causes an attractive force between the coil and the magnet track which must be absorbed by the bearing structure. This is seen as bearing preload. There are some positions where the preload will be higher than others.

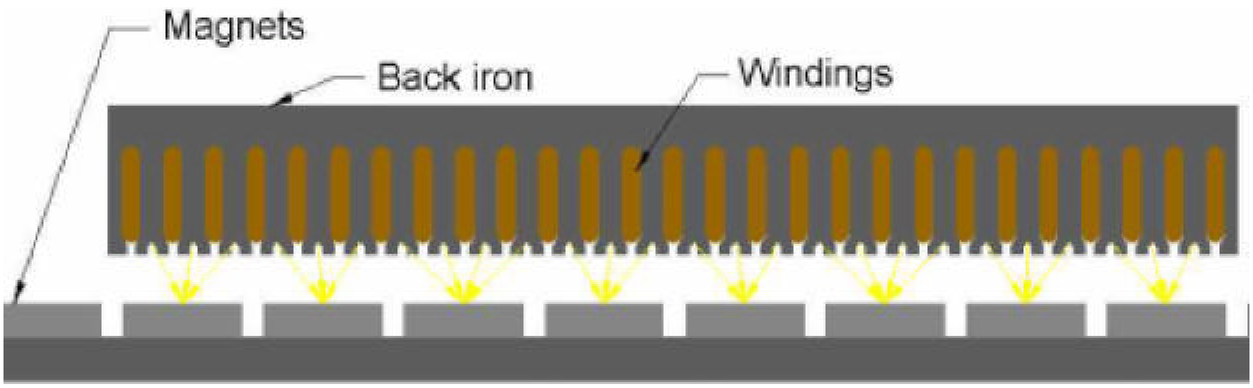

Figure 2. Ironcore Motor using a Fractional Winding

Parker ironcore motors are made using a fractional winding technique. An example of this is shown in Figure 2. With fractional windings, the teeth do not correspond equally to the magnets so the horizontal component of the net magnetic force from the inner teeth will be lower. Many of them will cancel each other out. However, the cogging forces from the leading and training edges remain.

The vertical component of the magnetic force also remains. However, it is much more constant which results in smaller variations in bearing preload.

Cogging Force

The cogging force can be measured by moving the motor at a constant velocity and recording the current output of the driving amplifier versus time. Knowing the velocity and the motor's force constant, force versus position can be plotted. Figure 3 shows a typical plot. This plot was created using a Parker Trilogy R1 0-1 motor moving at 2.5mm/s. Approximately 35N of the force is due to mechanical bearing friction. This motor has a magnet pitch of 30mm which leads to the periodic waveform shown. All anti-cog features normally included in this motor were removed to create this plot. The very slow velocity was chosen to accentuate the cogging force. Inertial damping can make the amplitude seem smaller at higher velocities and payloads.

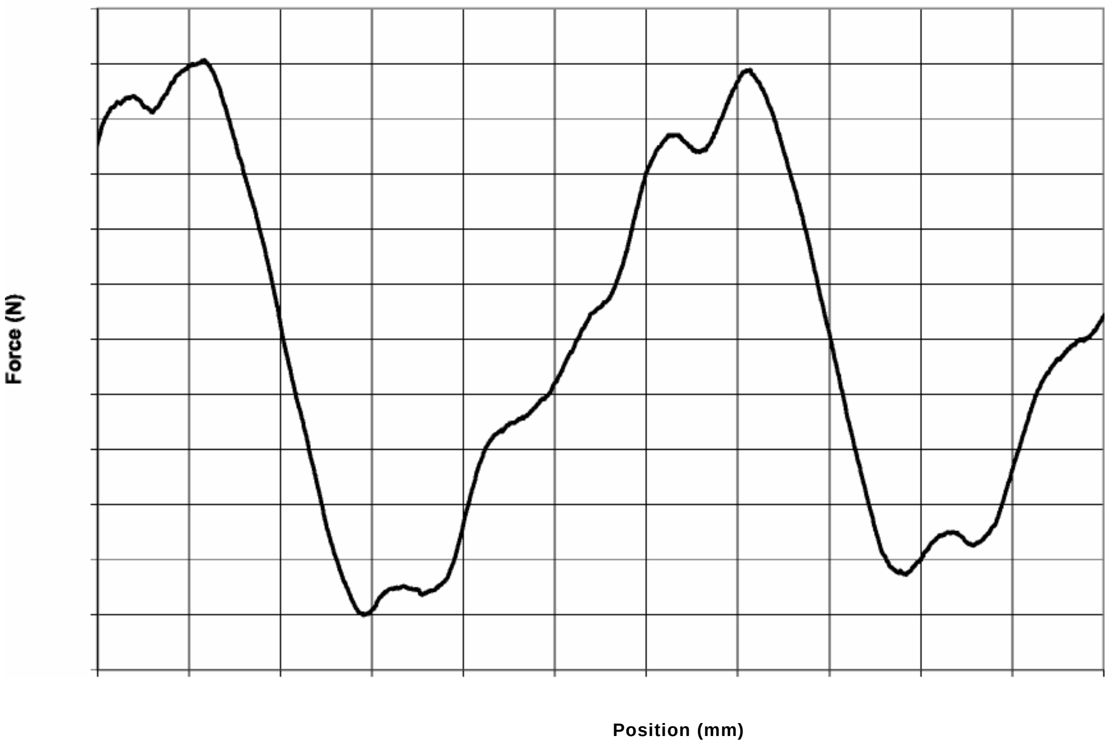

Figure 3. Plot of Typical Cogging Force vs. Position

Traditional Means of Reducing Cogging

Cogging is not unique to linear motors; rotary motors have the same problem and there are several methods traditionally used to minimize the effect that can also be employed in linear motors. These include skewing the magnets, shaping the magnets, and/or skewing the slots in the laminations. All of these reduce cogging by intentionally misaligning the laminations and magnets. This softens the transitions of the lamination teeth from one magnet to the next and reduces cogging, but it also reduces the motor's force output and efficiency because the windings and magnetic fields are no longer optimally aligned. Figure 4 shows examples of skewed and shaped magnets.

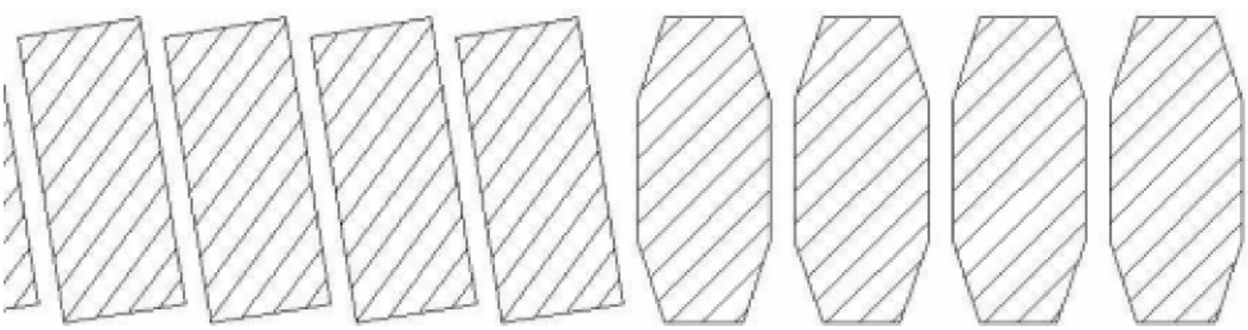

Figure 4. Skewed and Shaped Magnets

Anti-Cog Technology

Parker's anti-cog technology does not use skewed magnets or any other method that compromises motor efficiency to reduce motor cogging; it uses destructive interference. Additional features are added to the lamination assembly that produce an opposite and equal cogging pattern. These features are called anti-cog blocks. The cogging force an R1 0-1 with the addition of anti-cog blocks is shown in Figure 5.

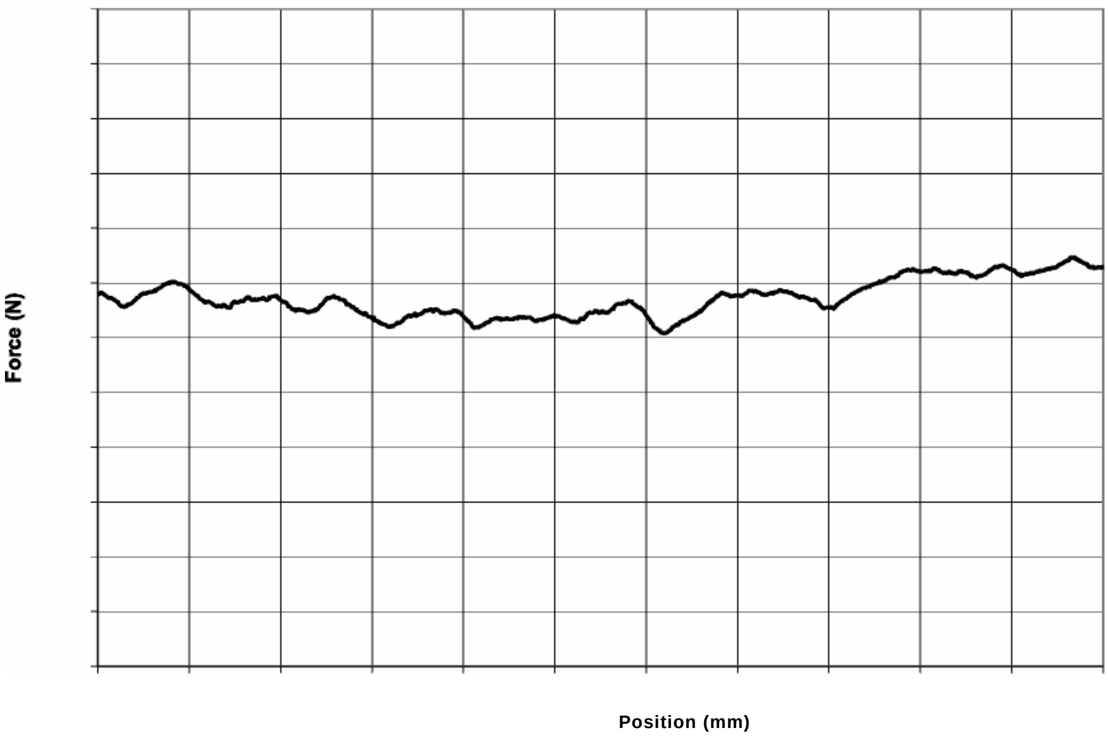

Figure 5. Example of Cogging Pattern with Anti-Cog Technology

Again, this plot was created moving at 2.5mm/s and about 35N of force was due to mechanical bearing friction. Notice the absence of the periodic waveform with the 30mm pitch. Most of the remaining force fluctuations are due to bearing seal stiction but even including these, the cogging force has been reduced more than 90%.

Figure 6 shows a top view of a typical lamination assembly and a typical anti-cog assembly in their most favored positions in the magnetic field. The large rectangle is the R1 0-1 lamination assembly. It is positioned so that the leading and training edges are centered on magnets. Since a fractional winding is used and the inner teeth cancel each other out, the interaction of the leading and training edges with the magnets determine the most favored position.

The anti-cog assembly is a parallelogram made using a proprietary powdered metal material and process. The most favored position for the parallelogram is bridging two magnets. The material, shape, and manufacturing process are all carefully controlled to ensure that the cogging force of the anti-cog assembly equals that of the lamination assembly.

Figure 6. Separate Lamination and Anti-Cog Assemblies

Two triangles can be created by cutting the anti-cog assembly parallelogram in half. If these triangles are placed at either end of the lamination assembly, as shown in Figure 7, they will be shifted 180 degrees in the magnetic cycle; that is, instead of being in their most favored position in the magnetic field, they will be in their least favored position. Now the combined lamination and anti-cog assembly are in balance and will remain in balance regardless of their position relative to the magnets.

This is how the anti-cog technology uses destructive interference to combine the cogging patterns of the lamination assembly and anti-cog assembly to remove the inherent cogging without sacrificing motor efficiency. The anti-cog parallelogram is cut into triangles and placed at either end of the lamination assembly to reduce the overall length. Because a fractional winding is used and the cogging forces from the inner teeth all cancel each other out, the same size and shape anti-cog blocks can be used regardless of the length of the lamination assembly; the anti-cog blocks only have to compensate for the cogging from the leading and trailing edge of the lamination assembly.

Figure 7. Combined Lamination and Anti-Cog Assembly

Summary

Ironcore linear motor coils have preferred positions relative to their magnets. This causes disruptive cogging forces and has traditionally limited their performance in applications requiring very good smoothness. Methods such as skewing the magnets or slots and shaping the magnets can reduce the cogging, but at a cost in motor efficiency.

Parker's anti-cog technology employs additional features inside the motor to cancel out the inherent cogging forces without sacrificing motor efficiency. The anti-cog blocks are made using a proprietary powered metal process and formed in the correct shape to create cogging forces that are equal and opposite to the motor's inherent cogging forces. When the two are combined inside the same housing, the forces cancel each other and can be reduced more than 90%. The use of a fractional winding simplifies the implementation of the anti-cog technology and results in a much more constant attractive force for more consistent bearing preload.

Anti-cog technology virtually eliminates cogging and enables ironcore motors to be used in applications where only ironless motors would have been considered before. Since ironcore motors use half the magnets of equivalent ironless motors, this helps lower the price barriers traditionally seen with linear motor solutions.