Technical Paper

The MagneGear™ — Efficient Rotary and Linear Magnetic Gearing Devices for Downhole Applications

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The Problem

Geared devices are a necessity in many types of downhole tools. The primary purpose of gearing is to provide either a speed change or a force change. Limitations in diameter on most downhole tools necessitate the use of a mechanical advantage in order to perform a particular operation. The use of reduction gearing has long been used as a simple way to gain that mechanical advantage.

Utilizing a planetary gearbox in a downhole environment presents many challenges. The operational temperature rating on a gearbox for downhole operation is the same as for other components, typically -40°C to 175°C. Typical differential pressure experienced downhole is 15,000 – 20,000 psi. High Pressure High Temperature (HPHT) conditions can approach 250°C and >30,000 psi.

Planetary gearboxes typically consist of a housing, an input shaft, output shaft, one or more ring gears, one or more spur gears, and one or more sets of planetary gears. A typical single stage planetary gearbox will have no less than six simultaneous gear meshes, three planetary gears each meshing with the ring gear on the outer diameter and the spur gear on the inner diameter. The gears require lubrication, and the input and output shafts must exit the gearbox housing. Those parameters require the use of dynamic seals to keep the lubricant inside the gearbox as well as keeping anything outside the gearbox from leaking into the gears. Most often some type of pressure compensation device is required within the gearbox. While sealing a low speed shaft with a differential pressure of 20,000 psi is challenging, sealing a high speed shaft at the same pressure can border on the impossible. High speed dynamic seals are the nemesis of every downhole tool designer.

The Solution

The advent of high energy rare earth magnetic materials coupled with recent innovations in magnetic design has led to the development of non-contacting magnetic gear systems. The result is a magnetic drive system, consisting of three concentric and non-contacting elements, whose operation can best be described as equivalent to a planetary gearbox. Any similarities between the subject magnetic gear system and a mechanical planetary gear, however, end with the description of like result. It should also be mentioned that the high energy rare earth magnetic materials that provide the force that propels the gear have been in use for a number of years in downhole operation. They are used routinely in downhole devices such as surface controlled subsurface safety valves, nuclear magnetic resonance formation logging tools, mud pulse telemetry tools, as well as many other applications.

Mechanical vs. Magnetic

The first dissimilarity between magnetic and mechanical is the non-contacting element. As mentioned earlier, mechanical planetary gearboxes have at least six mechanical interfaces. The magnetic gear system has none. There is no friction between gear members, therefore the second difference is that there is no lubrication required.

Further differentiation between magnetic gear systems and mechanical gearboxes is the ability to expose any or all of the components to drilling or production fluids. The concentric rings that form the magnetic gear system are full volume structurally sound solid bodies, packaged in an application suitable housing material such as Inconel. Therefore yet another benefit to the magnetic gear then becomes that it is not necessary to pressure compensate any part of the system.

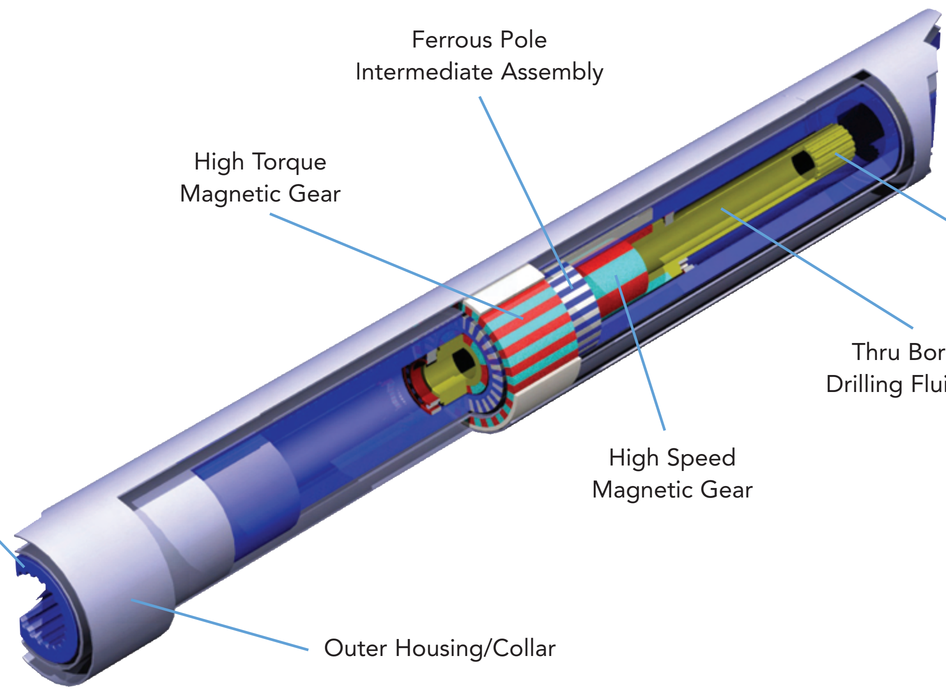
Another major difference between mechanical gearing and the concentric magnetic gearing described herein is that the magnetic gear utilizes the net of all magnetic poles to simultaneously transmit force, where any mechanical gear system is limited to point-to-point contact between only one input gear mesh and just one output gear mesh at any given point in time. The magnetic gear system described herein has an efficiency potential of 97% or greater. No mechanical gearbox can approach that efficiency due to inherent friction losses.

One additional benefit to magnetic over mechanical is operating temperature range. Mechanical planetary gearboxes are limited to an operating temperature compatible with whatever elastomer is used as part of the fluid and/or pressure seal. With no seals required, the temperature limit of magnetic gear systems is equal to the maximum operating temperature of the magnetic material selected. In this case, Samarium Cobalt has an operating temperature greater than 250°C. By default that makes a magnetic gear system capable of operation in even the most extreme HPHT environments.

Magnetic Gear System Configuration

Magnetic gear systems can be configured as either a rotary magnetic gear (RMG) or a linear magnetic gear (LMG). In both cases the design consists of three concentric elements:

Figure 1 | **MagneGear™ Rotary Magnetic Gear (RMG) For Wellbore Motor Application** *Patents Pending*



This MagneGear™ RMG is configured for use with a drilling motor such as a turbodrill, positive displacement motor (PDM) or air motor. The input shaft shown in yellow is the high speed shaft. You will notice a thru bore in the input shaft to allow drilling fluid flow. The output shaft to the bit is shown on the left side of the diagram.

An important attribute of a RMG device is the isolation of axial force. Axial forces, or thrust, exerted on one member are not directly transmitted to the other members of the RMG. For example, a high axial load from the bit end of a RMG used in a mud motor application would not transfer to the PDM or turbodrill used as the prime mover.

A design investigated for a 9-5/8" collar size, with a thru bore of 2-3/4" for mud flow, yielded >14,000 lb/ft torque through a single stage of magnetic gearing. Speed reduction was 6:1, with 1200 RPM input and 200 RPM output. The overall length of this 14,000 lb/ft device would be just less than 28 feet in length. That equates to approximately 500 lb/ft of torque per linear foot in a device of this diameter. Given the high torque per linear foot density it is clear there are other similar downhole applications for such non-contacting RMG devices that are suited for exposure to drilling fluids. Multi-stage rotary magnetic gear devices have also been modeled. The most radical gear reduction designed to-date for a downhole application involved a 4-stage, 1200:1 reduction ratio in a 4-3/4" package.

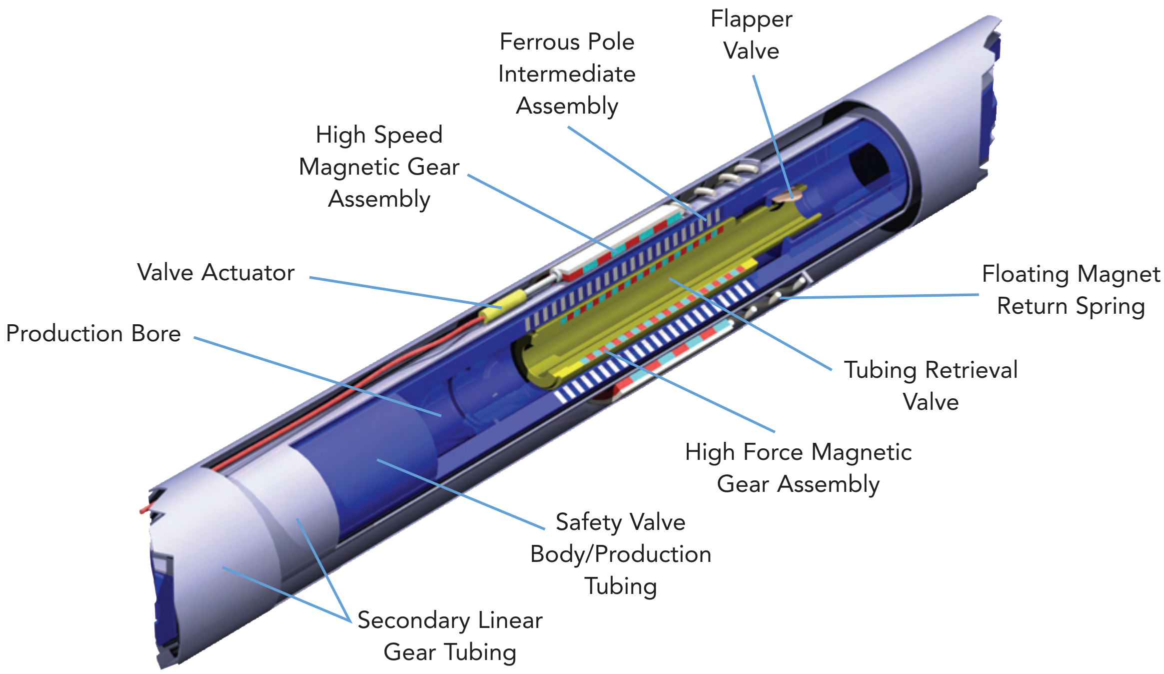
The smallest practical diameter for downhole application requiring moderate-to-high torque output appears to be 3-1/2" unless no mud flow is required through the ID of the RMG. With no flow required through the inside of the RMG device, for example if the RMG is needed to run inside a pressure housing on a tool, it can be practically applied in diameters of 2" or less.

an outer ring of magnets, an intermediate ring of ferrous pole pieces and an inner ring of magnets. In a RMG system the outer ring element has some even number of alternating polarity, radially oriented permanent magnets. The outer ring magnet poles are arranged so the magnetic lines of flux are concentrated inward. The inner ring element also has an even number of radially oriented permanent magnets, arranged with the magnetic flux lines concentrated outward. The inner magnets are wider (larger included angle) and fewer in number than the outer magnet set. An intermediate ring of ferrous pole pieces serves as the third concentric member, residing in the annular gap between the two magnet rings.

RMG and LMG Magnetics

The number of magnetic poles and soft magnetic pole pieces chosen for each element will differ for the application and total volume of the magnetic gear system. In a typical RMG application where speed reduction and force multiplication is desired, the input shaft from the prime mover will have a low number of magnets positioned in alternating fashion around the diameter of the ring. The low number of relatively wide magnets dictate that this is the high speed element of the magnetic gear. The magnetic flux from that ring, being concentrated toward the intermediate soft magnetic pole set, will then travel to and through the shortest path of least resistance, that being the ferrous pole pieces. The flux lines

Figure 2 | **MagneGear™ Linear Magnetic Gear (LMG) For Geared Downhole Valve Actuation** *Patents Pending*



This MagneGear™ is a LMG applied to a tubing retrievable surface controlled subsurface safety valve (SCSSV). Such a design gives the advantage of force multiplication on the tubing retrievable valve. For example, with a 6:1 ratio, which would be appropriate and smoothly operating in the diameters required for a safety valve as described, a 500 pound linear force applied to the input member by the surface controlled actuator would yield 3,000 pounds of linear force on the tubular valve actuator.

Other magnetically actuated valve operators exist in the industry, but they operate on a synchronous 1:1 ratio. These existing devices, if retrofit with the magnetic gear system as described, can benefit from the force multiplication as well. If the output force of an existing device is sufficient for application, force multiplication then allows a lighter and thus smaller prime mover. The force of the prime actuator, be it hydraulic or electric, can be reduced by 80% or more. There are a multitude of similar applications in the area of smart completions, such as sliding sleeves that can benefit from the force multiplying phenomenon of this device.

An alternative embodiment for either the RMG or LMG is to use the gear system to increase speed. For example, it is feasible that a high speed, low torque drill motor could be advantageous particularly in microhole drilling. In this instance an inverted RMG appears to have application.

then exit the opposite end of the soft iron pole pieces where they then interact with the magnetic lines of flux of the high force magnetic ring, having a greater number of pole pieces. As the high speed ring is rotated about the diameter of the intermediate ring of iron pole pieces the flux lines from the high speed ring of magnets is progressively stepping from one intermediate pole piece to the next, effectively propelling the field in a step fashion. That field is simultaneously interacting with the high force permanent magnet ring producing the desired rotation. The differing number of high speed magnets, low speed magnets and soft iron pole pieces yields the ratio with which the output turns relative to the input. It should also be noted that if the inner magnet member is connected to the prime mover, and the outer magnet ring is fixed to the drill collar or tool housing, the intermediate member would be affixed to the output shaft and will rotate the same direction as the input shaft. Conversely, if the inner member is again the input shaft, and the intermediate pole ring is fixed to prevent rotation, the outer magnet ring becomes the output and will rotate counter rotationally to the input.

The LMG system is of similar construction. The alternating magnetic poles in the linear design are arranged axially, as opposed to the radial poles for the rotary magnetic gear. The ratio of the speed reduction / force multiplication is again relative to the number of poles and pole spacing of the outer ring of magnets, intermediate soft magnetic pole pieces and inner magnet assembly.

For additional information please contact the nearest Dexter sales office.

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