Advantages of a Magnetically Driven Gear Pump

By Steven E. Owen, P.E.

Introduction

Before considering a magnetically driven pump for use in a fluid system, it is best to know something about the technology behind the product. The purpose of this article is to provide insight into the design attributes of magnetically driven gear pumps, and to enable the reader to utilize these attributes to successfully apply this technology as an answer to different OEM challenges.

This article will focus on magnetically driven positive displacement pumps, and more specifically, magnetically driven gear pumps. In this respect, magnetically driven is synonymous with seal-less pump and we will use the term 'magnetically driven' or 'mag-drive' here. Mag-drive gear pumps can be of various types and sizes. Due to the flow ranges generally associated with metering applications (<10GPM), the pump size tends to be small.

Advantages

The main advantages of the magnetically driven gear pump are lack of dynamic seals, smooth flow, self priming, a direct relationship between pump rotational speed and flow and small size. Due to the lack of dynamic seals, they are very reliable. Magnetically driven gear pumps can be manufactured to close tolerances to achieve repeatable performance. As previously mentioned, mag-drive pumps are compact, allowing them to fit into a variety of different equipment used for many different applications. Mag-drive pumps can be driven by a variety of different means including AC motors, DC brush motors, DC brushless and stepper motors.

Sealing

One of the main advantages of a magnetically driven pump is that there is no dynamic shaft seal required, eliminating the failure mode of shaft seal failure. Mag-drive pumps rely on static o-ring or gasket seals. The nature of the static seal is well proven and requires no further explanation here. As seen in the example pump view below, the static seal completes the pressure boundary between the magnet cup and pump body. The sealed off area provides a space for the driven magnet to rotate and room for the fluid to flow out of the cavity and into the discharge side of the pump. The mag-drive gear pump can also use o-rings to seal between the other pump components, such as between the cavity plate and pump body or as shown in this design, gaskets can be used. The o-ring can be a radial or face seal, depending on how the magnet cup interfaces with the pump body.

Basic Operation

The gear pump provides flow by first sealing off a gear mesh. As the gears rotate and the gear teeth open up, they create an expanding volume and a low pressure area. The low pressure area induces the pumped fluid to enter the pump inlet where it is trapped between the gear teeth and cavity wall. The rotation of the gears moves the fluid around the cavity wall into the outlet area and passages, where a high pressure area is created as the gear teeth displace the pumped fluid.

The profiles of the gears can be generated using standard involute geometry, but they differ from the appearance of power transmission gears. The gear teeth are generally fewer in number and the teeth have sharper tips. This allows the pumped fluid volume to be maximized. The gear flanks act against each other to transmit torque and as a seal to prevent leakage of fluid from high pressure to low pressure. Stress at the roots is minimized by addition of appropriately sized radii. Noise and vibration is affected by gear tooth backlash, which can controlled by manipulation of tooth thickness, pressure angle and center distance. Unlike power transmission gears, minimizing backlash is not always best for noise reduction.

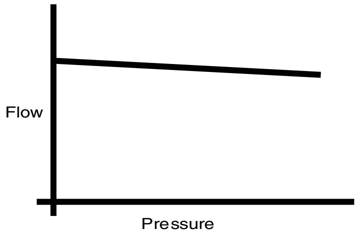
In a gear pump, volumetric efficiency is determined by comparing the theoretically displaced volume to the actual pumped volume. The difference between these two volumes is the amount of slip in the pump and this fluid is lost back to the inlet through the internal leak paths. Consequently, the efficiency changes with fluid properties such as viscosity. Fluids with higher viscosity reduce the amount of slip in the pump and increase volumetric efficiency. The internal leak paths occur in three areas: 1) between mating gear flanks; 2) the gear tips against the adjacent cavity wall; and 3) the gear faces against the body and bearing plate. While some slip is desired for lubrication purposes, due to the typical efficiency requirements, the gear width and OD as well as the cavity plate features are tightly controlled during the manufacturing process. As is the case with the adjacent flat metal components, these surfaces are usually lapped or ground. These leak paths are necessary for the pump to operate and they need to be understood in order to optimize gear pump performance.

Cavity Style and Suction Shoe Pumps

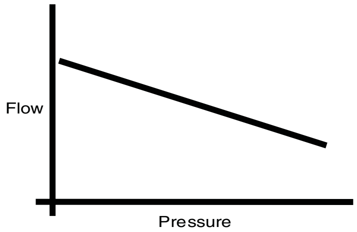

Cavity Style Gear Pumps


Suction Style Gear Pumps

The Micropump gear pump is available in two different basic pumping element configurations: cavity style and suction shoe style. The cavity style pump example has been used in the previous discussion. The suction shoe pump, instead of having a rigid cavity plate, has a floating suction shoe. Due to the discharge pressure acting on the outside of the shoe, it is forced against the rotating gear tips creating a more effective seal at higher pressures. The end result is a stiffer pump curve (less slip) at higher differential pressures, as compared to the cavity style pump, as indicated in the constant speed curves below. Because of these differences, these two configurations of pump wear differently. Cavity style pumps generally last longer and their end of life is more predictable. Suction shoe pumps of similar size and pressure generally do not last as long and end of life is less predictable.



Suction Shoe Pump

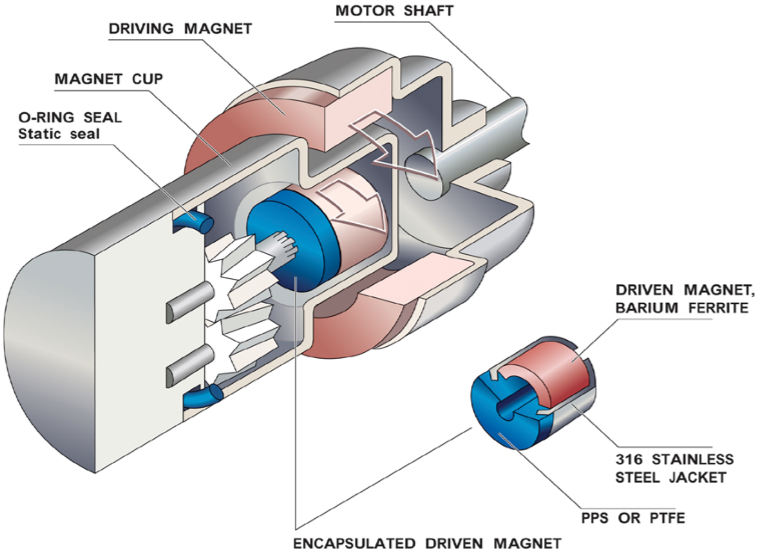


Cavity Style Pump

Magnet Coupling Drive

The standard Micropump magnetic coupling drive consists of two cylindrical magnets. A drive magnet (hub assembly) attaches to the motor shaft. A driven or inner magnet is sealed within the pump head by the pump body, o-ring and magnet cup. The inner magnet is a wetted component and is encapsulated by molding or a metal shell. The driving magnet turns the driven magnet without physical contact. The inner magnet is directly connected to the driving gear. The connection to the driving gear shaft is fixed, by way of a keyed connection on a cavity style gear pump. For a suction shoe pump, the drive magnet has a floating fit to the molded drive gear by way of a spline or hex connection to carry the torque. This is necessary since in a suction shoe pump, the driving gear is not integral with a shaft.

The magnet coupling itself includes a driving (outer) and driven (inner) magnet. The field lines between the two magnets complete the electromagnetic circuit. The strength of a magnet is measured in terms of flux density, which is a measure of magnetic flux lines through a given area. The number of poles is optimized to provide the maximum amount of torsional magnetic strength in the least amount of space.



The magnet assemblies can be made in various ways; including 1) by attaching pre-magnetized bars in the magnets, or 2) inducing a magnetic field in a magnet ring by applying current through an adjacent coil. The first method is done primarily with rare-earth magnet materials such as Samarium Cobalt (SmCo) and Neodymium-Iron-Boron (NdFeB), whereas the second method is employed generally with ceramic-ferrite rings. The flux lines of a rare earth magnetic coupling are closer together as compared to a ceramic-ferrite coupling of the same size, and therefore the flux density is greater.

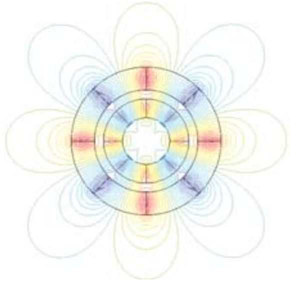
With the evolution of bonded NdFeB, it is possible to produce molded rings of rare earth materials. Special consideration is given to design of the magnetizing coil and higher voltages are needed in order to make it possible to saturate NdFeB magnet rings and gain the maximum amount of torque.

Under overload conditions, the torque required to drive the pump may exceed the torque capacity of the magnetic coupling, causing the pump to "decouple." This feature is inherent in mag-drive pumps. Decoupling does not indicate product failure, and will only occur when the magnet coupling torque limit has been exceeded. Decoupling also acts as a safety feature, preventing inadvertent pump/motor overloads. Re-coupling is usually done by simply stopping and re-starting the drive.

The magnet coupling adds a torsional spring to the mass-elastic model of the pump-drive system. The torsional spring effect is much more flexible than a conventional rigid shaft coupling. It is possible, though rare, that a resonant torsional vibration in the pump-motor system can cause the pump-motor to decouple spontaneously. A stronger, rare earth magnetic coupling can be the answer to this type of decoupling phenomena that may occur with lower flux density Ceramic-Ferrite couplings.

Magnet Coupling Drive - continued

From a design standpoint, the strength of the magnet coupling is determined by the following parameters:

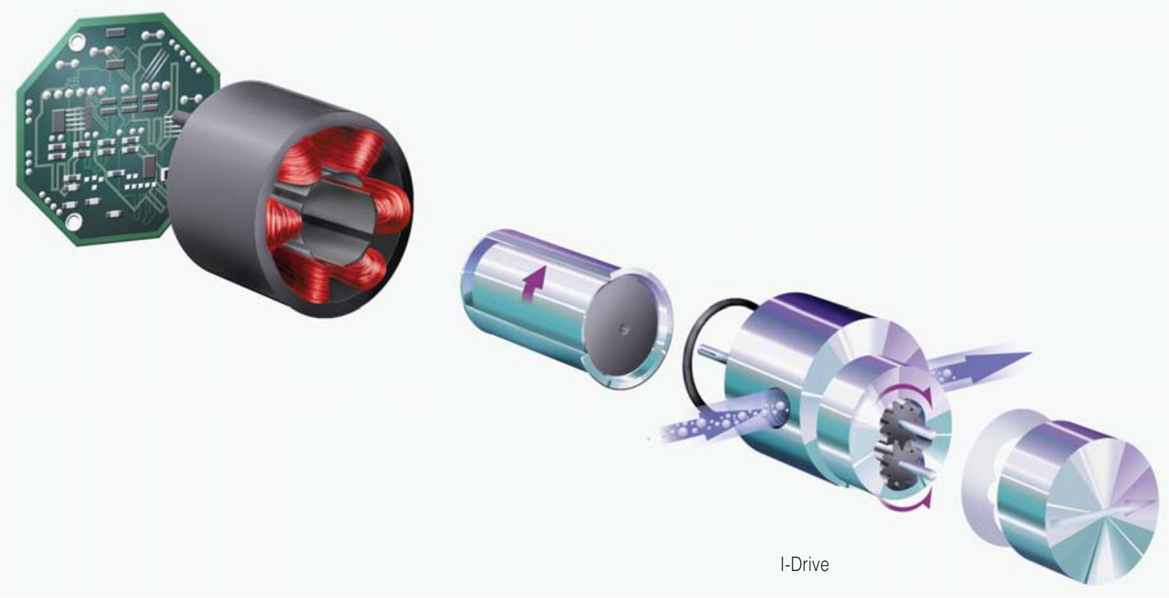

Magnetic Coupling Field Lines for radially magnetized 8-pole magnet coupling

1. the strength of the magnet materials
2. the radial air gap between the driving and driven magnets
3. the length of the magnets
4. the number of poles
5. the degree of saturation

These parameters are balanced to achieve a coupling that is within a certain size envelope and cost. Operationally, the magnetic coupling strength degrades with increasing temperature. For example, a mag-drive pump operating at 170˚C will have ~50% the strength it had at room temperature. A point can be reached where the atomic structure of the magnetic material will spontaneously change and lose it's magnetic properties, called the Curie temperature. The Curie temperature is different for each magnetic material and can fall in the range of 300-400˚C, which is outside the normal operating fluid temperature range of mag-drive pumps.

An Alternative to Magnet Couplings

The magnet coupling described in the previous section is possible because of the attraction of magnetic fields originated by permanent magnet poles. Just as easily, the magnet circuit can be completed with a current carrying stator to generate the magnetic field. It is possible, therefore, instead of a magnet hub assembly to have a stator winding provide the magnetic field. The I-Drive Series™ drive has been designed to integrate the pump and motor using this method. By eliminating the need for the hub assembly and adapter the size envelope is reduced further and decoupling is eliminated. The drive doesn't have any moving parts with the benefit that reliability is improved.


I-Drive

With the drive and pump integrated in a single, compact unit, the I-Drive™ achieves accurate and reliable operation. The rotating electromagnetic field, which is induced in the fixed and stationary stator by a controller, couples with and turns the permanent magnet sealed inside the pump. The speed of the pump is monitored and maintained with feedback from the controller. External control signals (0-5 VDC, 4-20 mA and manual) can be used to control the speed of the pump. The close coupling of the pump and motor allows sealing between the pump and drive against ingress of water and dust to protect the internal pump and drive components.

Summary

The design features of a mag-drive pump give it the characteristics of a robust pump solution that can fit many applications. Magnetically coupled gear pumps have a small size envelope, are reliable and provide smooth pulse-free flow. The tightly controlled tolerances of the gear set allow the pump to achieve precise and repeatable flow. The compact design of the pump and drive is ideally suited for OEM applications. Typical of these are inkjet printing, fuel cells and hemodialysis machines. They can be driven by a variety of means, including an integrated drive that accepts different inputs.

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