Temposonics®

Magnetostrictive, Absolute, Non-contact
Linear-Position Sensors

Magnetostriction, How it Works

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550947 Revision A

Technical Paper

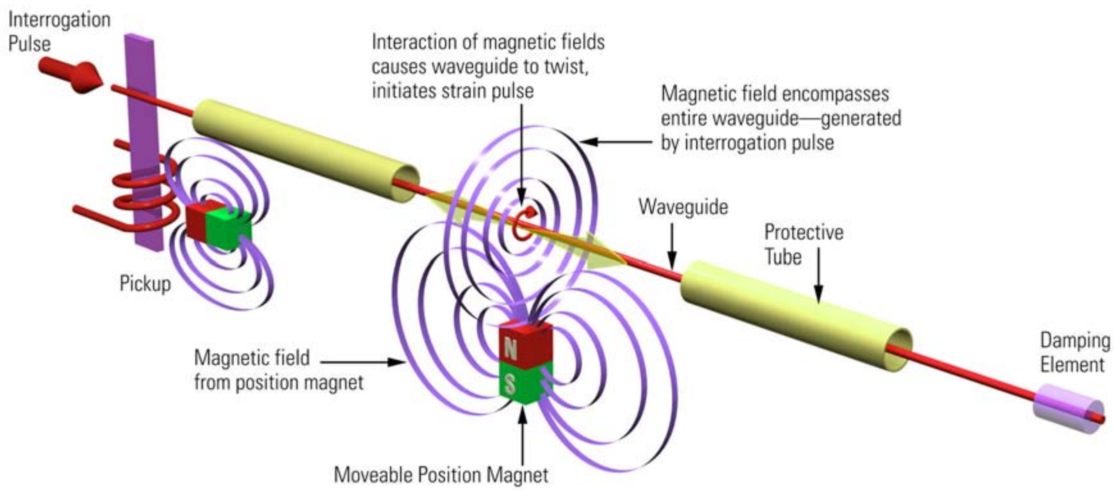

Figure 1. Magnetostrictive Principle

Introduction

Sensors based upon magnetostriction technology have been used in a wide variety of industrial applications for over 25 years since their invention at a company called Temposonics in the 1970's. The sensor's unique properties enable sensors to be built with measuring lengths from 1 cm to over 10 meters, with an accuracy on the order of microns. Over 1 million are in use today in industrial applications ranging from saw mills, injection molding and casting to petrochemical and pharmaceutical level control to off-road construction and agricultural machine control (see *Figure 1*).

Figure 2. The range of magnetostrictive sensors has grown considerably since their invention in the 1970's.

Recently, the cost of this type of sensor has been reduced through automation, which has allowed its deployment in higher volume, lower cost commercial and light industrial applications such as medical instruments, tools, and recreational equipment. The new product based upon this reduction, called the C-Series sensor, is modular in nature.

Figure 3. C-Series magnetostrictive core sensor.

The C-Series common core is a plastic housed sensor (see *Figure 3*) offered in short strokes up to 250 mm. Other modular housings (see *Figure 4* on page 2), and accessories (in *Figure 5* on page 2), allow the customer to pick and choose the final assembly that matches their application's needs.

Figure 4. Due to the new C-Series' modular nature, standard and customized application features such as the environmental housing can be added as options.

Figure 5. The new C-Series' sensor also offers accessories such as a stainless steel float to allow the position sensor' to be used as a liquid-level sensor.

What is magnetostriction?

Magnetostriction is a property of ferromagnetic materials such as iron, nickel, and cobalt to change size and/or shape when placed in a magnetic field.

This physical response of a ferromagnetic material is due to the presence of magnetic movements, essentially a collection of tiny permanent magnets, or domains (see *Figure 6*). Each domain consists of many atoms. When a material is not magnetized, the domains are randomly arranged. When the material is magnetized, the domains are oriented with their axes approximately parallel to one another and the change in size or shape is made. Interaction of an external magnetic field with the domains also causes the magnetostrictive effect. The order of the domains, and thus the magnitude of the effect, can be influenced by alloy selection, thermal annealing, cold working, and magnetic field strength.

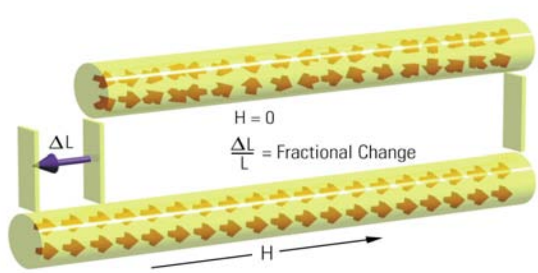

Figure 6. Magnetic domains align in ferromagnetic materials when exposed to a magnetic field, causing a dimensional change.

Ferromagnetic materials used in magnetostrictive position sensors are transition metals such as iron, nickel, and cobalt. In these metals, the 3rd electron shell is not completely filled, which allows the formation of a magnetic moment. (i.e., the shells closer to the nucleus than the 3d shell are complete, and they do not contribute to the magnetic moment). As electron spins are rotated by a magnetic field, coupling between the electron spin and electron orbit causes electron energies to change. The crystal then strains so that electrons at the surface can relax to states of lower energy. When a material has positive magnetostriction, it enlarges when placed in a magnetic field; with negative magnetostriction, the material shrinks.

Applying a magnetic field causes stress that changes the physical properties of a magnetostrictive material. However, the reverse is also true: applying stress to a magnetostrictive material changes its magnetic properties (e.g., magnetic permeability). That is, a dimensional change in the material can lead to induced magnetic fields. Magnetostrictive sensors (see *Figure 7*) employ both properties to generate an ultrasonic strain wave from the location of an external marker magnet and detect its passage by a fixed reference point in a wave guide. By knowing the speed of sound in the material, marker magnet position can be determined using a time-of-flight measurement technique.

As illustrated in *Figure 7*, the first step in the time-of-flight measurement is to apply an orthogonal magnetic field to a

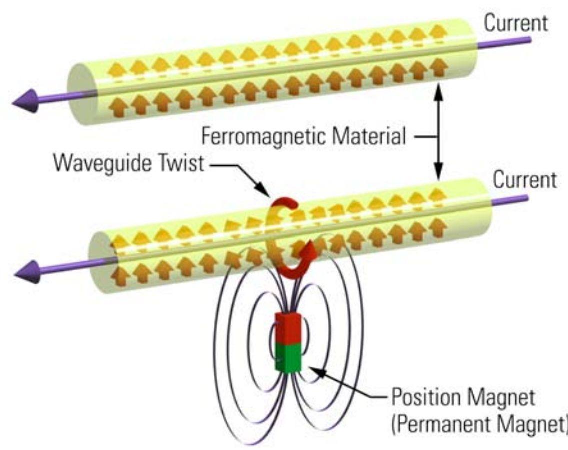

Figure 7. Magnetostictive sensors employ a time-of-flight measurement technique by launching a strain pulse from the moving magnet position that travels at the speed of sound in the Magnetostrictive wire until it is detected by a pickup.

magnetostrictive wire, and then pass a current through the wire. The Magnetostrictive effect causes a twisting at the location of the orthogonal magnetic field. The twisting is caused by interaction of the orthogonal magnetic field, usually from a permanent marker magnet, with the magnetic field along the magnetostrictive wire, which is present due to the current in the wire.

Because the current is applied as a pulse, the mechanical twisting travels in the wire as an ultrasonic wave. The magnetostrictive wire is, therefore, called the waveguide. Each magnetostrictive strain wave travels at the speed of sound in the waveguide material, approximately at 3000 m/s. The position magnet is attached to whatever is being measured, perhaps a piston in a cylinder. The waveguide wire is enclosed within a protective cover and is attached to the stationary part of the machine, perhaps a cylinder body. The location of the position magnet is determined by starting a counter timer when the current pulse is launched. The current pulse causes a sonic wave to be generated at the location of the position magnet. The sonic wave travels along the waveguide until it is detected by the pickup.

A pickup makes use of the reverse magnetostrictive effect described earlier. A small piece of magnetostrictive material, called the tape, is welded to the waveguide near one end of the waveguide. This tape passes through a coil and is magnetized by a small permanent magnet called the bias magnet. When a sonic wave propagates down the waveguide and then down the tape, the stress induced by the wave causes a permeability change in the tape. This in turn causes a change in the tape magnetic flux density, and thus a voltage output pulse is produced from the coil.

At a defined output level of the coil output voltage, the counter timer is instructed to stop. The elapsed time indicated by the timer then represents the distance between the position magnet and the pickup. The frequency of the counter determines the resolution of the measurement; the higher the frequency, the finer the resolution.

Elapsed time information is conditioned into the desired output. Many outputs are available such as DC voltage, pulse width modulation, start-stop digital pulses, CANbus®, Profibus®, Serial Synchronous Interface (SSI), HART®, and various other smart sensor protocols, including custom units.

Today magnetostrictive sensors are used by many industries these sensors dominate approximately 10% of the entire long-linear sensors market. Traditionally, these sensors have been used in a vast range of manufacturing equipment including injection molding machines, wood processing equipment, hydraulic cylinders, hundreds of specialty manufacturing machines, process level control in pharmaceuticals and petrochemical plants, off and on-road machinery for construction and agriculture as well as many others.

Magnetostrictive linear position sensors are well regarded for ruggedness and accuracy. Pavement machines, off-road machinery and saw mill machinery provide some of the most demanding environments and the sensors perform reliably. Some applications, such as high end injection molding machines, require micron-level resolutions. Recent advances in magnetostrictive electronics, including counter timers that have 150 picosecond periods or better, allow this depth of performance.

New, novel automated manufacturing processes reduce unit cost on some new models into a whole new realm compatible with the cost demands of high volume products. This technology advancement, which offers high reliability and high performance, is suddenly very attractive for high-volume use in medical, recreational, professional tool and other extremely cost sensitive commercial or light industrial applications. Standard products are available and customized units are possible in higher volumes.

Benefits

The magnetostrictive sensor is an absolute positioning device. A magnetostrictive sensor's electronic circuit measures directly, without any conversion, the interval of the sound wave's travel from the location of the magnet to the tip of the sensor. Resolution is limited only by practical factors (and by the electronic circuit) rather than by the measuring principle. In fact, in the standard industrial application (linear displacement) the accuracy of the magnetostrictive sensors are on the order of 1 to 2 microns (10-6 mm).

- Measurement is non-contact
- Complete integration is possible
- No wear parts
- Well-proven, long term stability
- High accuracy
- High temperature stability

A Magnetostrictive history

First discovered by Matteucci and Joule (1847) and extensively studied by Villari (1865) and Wiedemann, the application of Magnetoelasticity in Magnetostriction started during World War II in some sonar applications.

But many years intervened before finding the first industrial application. The first magnetostrictive linear position sensor was invented by Jacob Tellerman in 1975. He was developing delay lines for use in computer memory devices when it occurred to him to use similar technology to produce a position sensor. Tellerman had the idea of generating an ultrasonic wave at a varying location along the waveguide by using a permanent magnet. See Figure 8. Then the time elapsed until the ultrasonic pulse reached one end of the waveguide would indicate the position of the magnet. A new industrial sensor was born: he co-founded a company called Temposonics, which was further developed after being acquired in 1987 by MTS Systems Corporation.

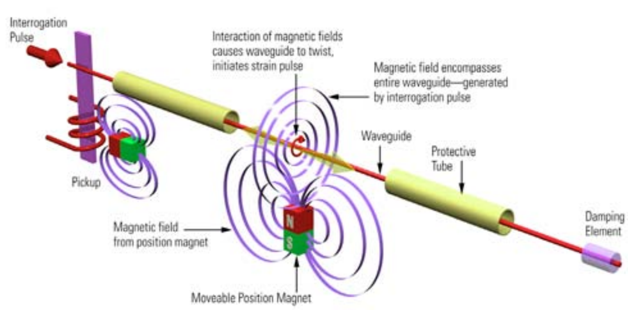

Figure 8. The Magnetostrictive Principle.

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