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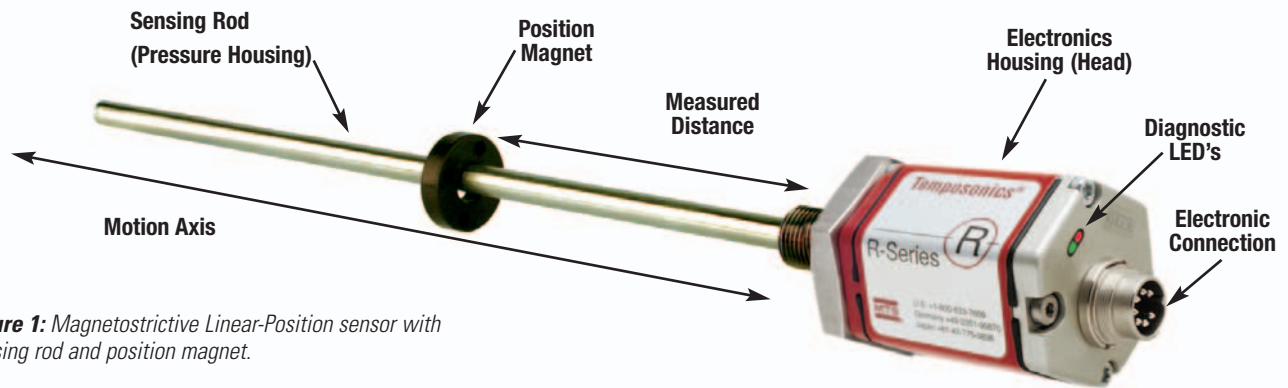
# Magnetostrictive Linear-Position Sensors

## Sizing and applying Magnetostrictive Linear-Position Sensors

Technical Paper

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**Figure 1:** Magnetostrictive Linear-Position sensor with sensing rod and position magnet.

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### Linear-position sensors

Many types of industrial processing equipment utilize sensors to provide the information needed to monitor and control the process. This enables the design parameters to be maintained in order to produce the end product at the desired level of quality and throughput. Typical sensors may measure temperature, pressure, flow, force, or position, for example. The type of measurement and the sensor technology will dictate the set of parameters which are important in specifying and sizing the appropriate sensor.

Linear-position sensors measure absolute distance along a motion axis. They are available in several technologies, each having its own advantages and disadvantages. This paper presents information on the application of magnetostrictive linear-position sensors, which are gaining popularity due to their accuracy and reliability. A comparison of magnetostrictive sensors to linear-position sensors of other technologies is also included.

### Theory of operation

A magnetostrictive position sensor measures the distance between a position magnet and the head end of the sensing rod. See Figure 1. The position magnet does not touch the sensing rod, and therefore there are no parts to wear out.

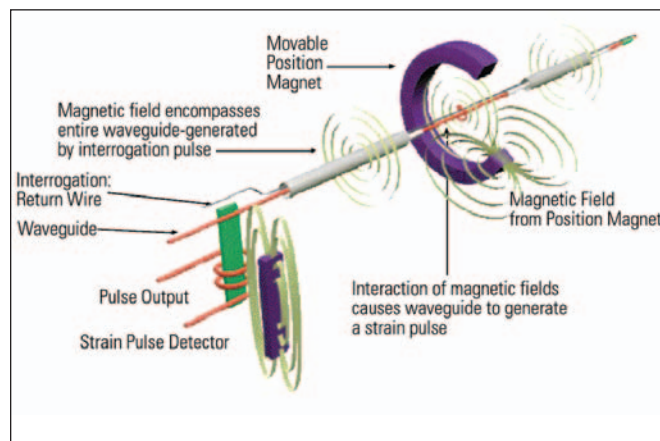
The sensing rod is mounted along the motion axis to be measured, and the position magnet is attached to the member that will be moving. The head includes an electronics module, which reports the position information to a controller (or other receiving device) in the appropriate analog or digital format.

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All specifications are subject to change. Please contact MTS for specifications that are critical to your needs.

Also incorporated in the electronics housing are the electrical connection interface - either an integral connector or cable - along with visual diagnostic LED's to ensure proper wiring, power and magnet positioning.

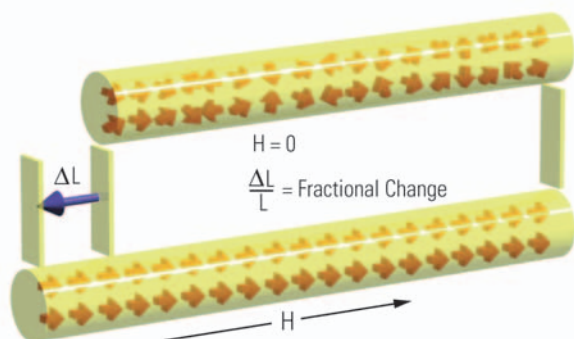
As shown in Figure 2, a magnetostrictive position sensor is comprised of five basic components: the position magnet, waveguide, pickup, damp, and electronics module. There is also usually a protective tube over the waveguide.



**Figure 2:** Basic components of a Magnetostrictive Linear-Position Sensor.

The position magnet is a permanent magnet, often made in the shape of a ring, which travels along the sensing rod. The waveguide is housed within the sensing rod, and is a small diameter tubing or wire made from a magnetostrictive material.

Magnetostriction is a property of certain materials, including iron, nickel, cobalt, and some of their alloys, in which application of a magnetic field causes strain which results in a change in the size or shape of the material. This is due to the alignment of the magnetic domains, within the material, with the applied magnetic field. As shown in Figure 3. Magnetic domains can be envisioned as many tiny permanent magnets which are randomly arranged before application of the magnetic field. When the magnetic field is applied, the poles of the magnetic domains align themselves along the gradient of the flux lines of this field.



**Figure 3:** Alignment of magnetic domains to the applied magnetic field  $H$ .

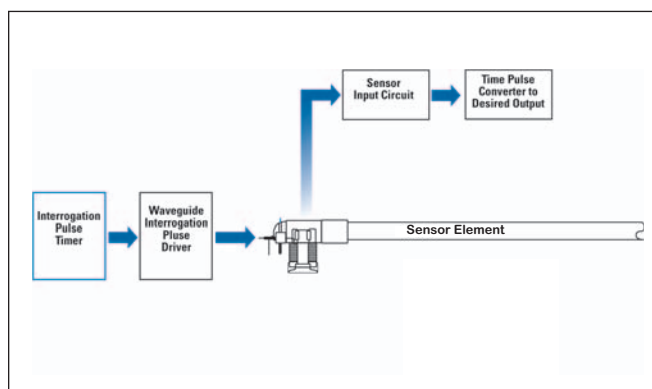
The waveguide is so-named because a sonic wave travels in it during operation of the sensor. The sonic wave is generated by interaction between the magnetic field from the position magnet and a second magnetic field generated in the waveguide by the application of a current pulse (called the interrogation pulse) through the waveguide from the electronics module. The vector sum of the magnetostrictive strain from the two magnetic fields results in the generation of a torsional strain wave in the waveguide at the location of the position magnet, as shown in Figure 2.

The strain wave travels in the waveguide, toward the head end, at about 2850 m/s. At the head, a pickup device senses the arrival of the strain wave (called the return pulse). Another strain wave also travels from the position magnet in the direction away from the head. This unused wave is eliminated by the damp in order to prevent interference from waves that would otherwise be reflected from the waveguide tip.

The electronics module applies the interrogation pulse to the waveguide and starts an electronic timer. After a time delay, which is proportional to the distance between the position magnet and the pickup, the electronics module receives the return pulse from the pickup and stops the timer. The magnitude of the time delay indicates the location of the position magnet. For example, at a measured distance of 1 meter with a waveguide velocity of 2850 m/s, the time delay would be:

$$1 \text{ meter} \div 2850 \text{ meters/second} = 0.35 \text{ milliseconds} \quad (\text{eq. 1})$$

The electronics module then uses the time measurement to produce the desired output. The output can be a logic level pulse-width, an analog voltage or current, or a standard digital interface. Figure 4 shows a block diagram of a typical electronics module, with an automotive style sensor element.



**Figure 4:** Typical electronics module block diagram (with sensor element).

The interrogation rate can be controlled from an external controller, or can be internally generated at a rate anywhere from one time per second to over 4000 times per second. This is the update rate, and is the frequency at which new position information becomes available at the sensor output. The maximum update rate depends on the waveguide length, i.e. a shorter waveguide allows a faster update rate to be used (per eq. 1).

## Installation considerations

An advantage of the magnetostrictive sensor, over other types of linear position sensors, is the ability to read the position magnet even when there is a barrier between the position magnet and the sensing rod. For example: the barrier can be the cylinder wall when the position magnet is part of a piston, or a transmission case when measuring gear position, etc. This is possible whenever the material directly between the position magnet and the rod can be a non-magnetic material. Common materials for this duty include plastics, ceramics, aluminum and non-ferrous metals, and many stainless steels.

Another advantage unique to magnetostrictive position sensors is the ability to measure multiple magnets while using one sensing rod. This allows making more than one measurement by only incorporating additional position magnets. Some sensor models accept up to 15 position magnets. In an injection molding machine, for example, the injector motion, mold closing, and ejector can be measured using only one sensing rod. Or, a slitting machine can measure the positions of all of the knives using only one sensing rod and adding a position magnet for each knife. Some Temposonics sensors are also capable of providing direct position and velocity outputs which is necessary for many high performance servo control systems.

## Performance specifications

Various models of magnetostrictive position sensors have their respective specifications, depending on the intended use and output style. Some of the specifications for a typical model are listed here for guidance:

CANbus industrial sensor:

Measured Variables: Position (up to 15), velocity (up to 5), set-points

Resolution of the sensing element is essentially infinite. Resolution with this output style is 0.002 mm

Repeatability is the difference between consecutive readings under the same conditions, and is 0.001%

Non-linearity is the maximum difference between a straight line and the actual output 0.01%

Hysteresis is the difference between upscale and downscale approaches to the same reading 0.004 mm

Update Time is the time period between consecutive readings 1 ms

Output style can be specified as various analog or digital types, this model communicates via an industry standard CANbus protocol (CANopen, DeviceNet, etc.)

## Comparison of Technologies

There are many things to consider when "designing-in" a linear position sensor. Proper attention must be paid to matching the sensor to the application requirements regarding power input, signal output, housing style, mounting configuration, sensing stroke, and ability of the sensing technology to make the measurement under the application conditions.

With all of these considerations and the number of options available, the task can seem a little daunting. However, here are some of the major product options to consider

Technology	Resolution <sup>a</sup>	Non-linearity <sup>b</sup>	FSR <sup>c</sup> available	Ruggedness
Magnetostriction	high	low	10 mm - 20 m	high
LVDT	high	medium	2 mm - 200 mm	high
Inductive	medium	medium	2 mm - 500 mm	high
Encoder	high	low	10 mm - 2 m	low
Ultrasonic	low	high	100 mm - 20 m	medium
Potentiometer <sup>d</sup>	medium	medium	10 mm - 500 mm	medium

<sup>a</sup> Higher resolution is better, and means smaller steps as the output changes.

<sup>b</sup> Lower non-linearity is better, and means the difference between a straight line and the output.

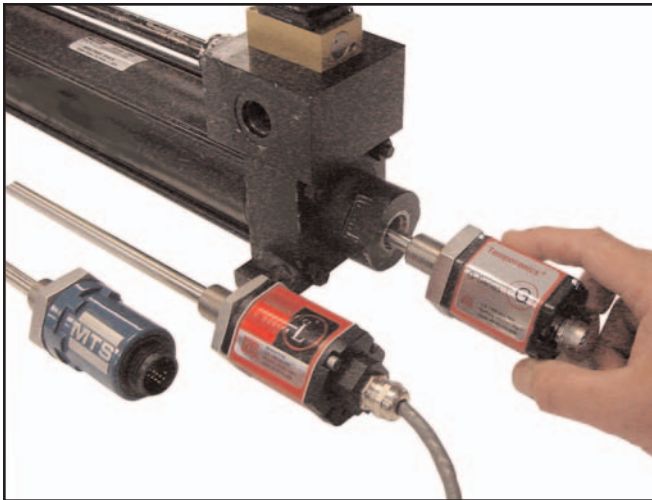
<sup>c</sup> FSR means Full Stroke

<sup>d</sup> The Potentiometer is a contact-type transducer, all others listed are non-contact

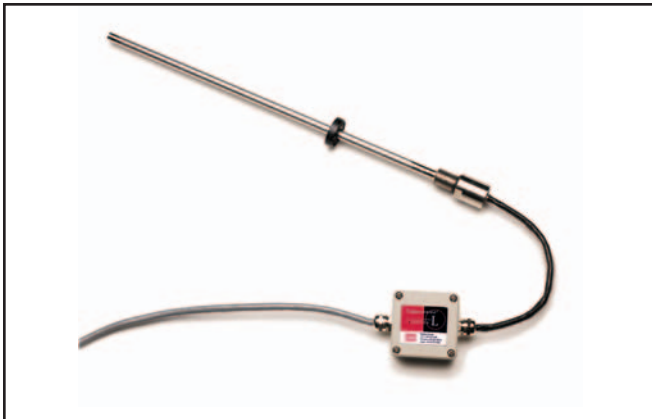
**Table 1:** Comparison of several popular types of linear position sensors.

## Selecting the appropriate type and size

**Housing Style:** Linear magnetostrictive position sensors are available in several housing configurations to enable mounting in a wide range of applications. Two hydraulic or pneumatic cylinder mount styles include the standard mounting of Figure 1, and the two-piece version of Figure 6. They both have rod and flange designs which are capable of withstanding and sealing the high cylinder pressures. The high pressure mounting thread can be specified in English or metric units. Installation of the hydraulic style sensor is accomplished by threading the unit into a cylinder that has been prepped with a hollow piston rod and an industry standard threaded port in the end cap. The appropriate torque may be applied to the hex flats adjacent to the pressure flange threads as shown in Figure 5.



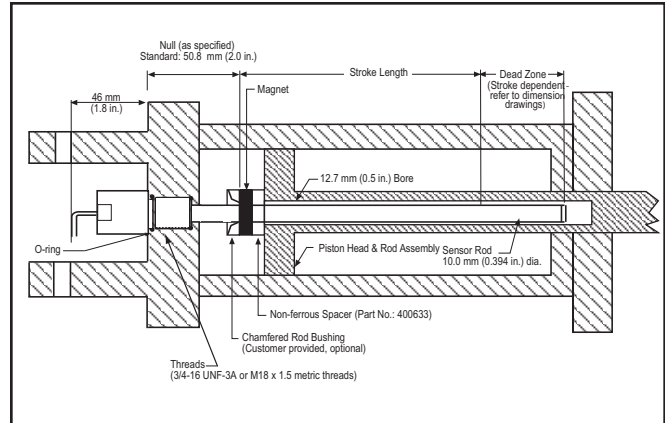
**Figure 5:** "Rod" style sensors can be installed into a wide variety of industry standard (NFPA) hydraulic or pneumatic cylinders.



**Figure 6:** Two-piece head for reduced headroom.

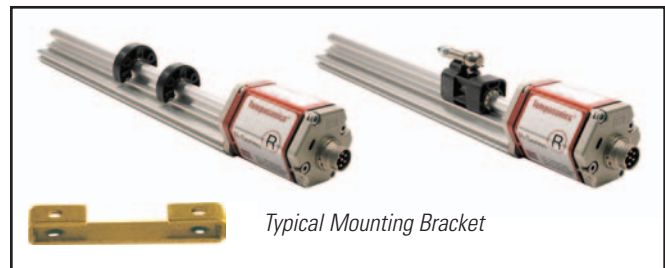
The configuration of Figure 6 is intended for installation into space-restricted clevis-type cylinders where the sensing element is separated from the electronics module by an interconnect cable, as shown in Figure 7.

Another popular way to mount a linear position sensor is by bolting its base to the machine frame, using a profile style housing. Examples of profile housings are shown in figure 8. Here, the



**Figure 7:** "Detached" style sensor used in a clevis mount cylinder with limited installation space. In this case, the electronics housing can be installed on the side or nearby the cylinder

sensing rod is enclosed within an aluminum extrusion. The extrusion provides the mounting base for the sensor as well as a means to locate mounting "feet" (brackets) or screws to secure the sensor in place. The position magnet can be a bar magnet ("floating magnet") passing along nearby the top of the extrusion (see Figure 8), or it may be captured inside of a shuttle ("sliding magnet") that rides along a rail which is part of the extrusion (see Figure 8). These magnet variations allow customers to use standard "off-the-shelf" mounting hardware such as ball-joints and extension rods or design their own to suit the application.

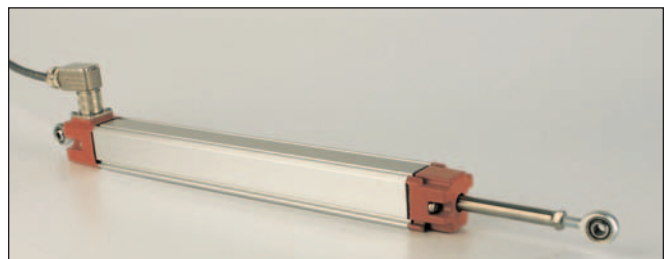


Floating Magnet

Sliding Magnet

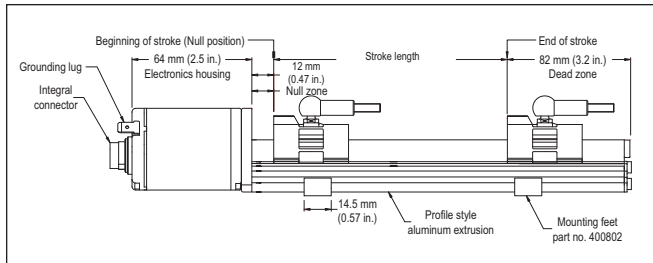
**Figure 8:** Profile style housings

A clevis mounting system is also available, as shown in Figure 9. This "rod and cylinder" style is similar to the profile housings of Figure 8, but the position magnet is moved via a metal rod, with a clevis on the rod end and also (optionally) on the opposite end of the housing. The sensor housing can be supported through the clevis mounts for use in articulated motion applications, or by mounting feet applied through the grooves in the aluminium extrusion.



**Figure 9:** "Rod and Cylinder" style with clevis (rod end) mounting

**Length:** When determining the proper size of a magnetostrictive position sensor to order for a particular application, it is important to consider the length and alignment criteria of the sensing rod and position magnet. See Figure 10. There is a minimum distance allowable between the head end of the sensor rod and the position magnet. This is to prevent interaction of the position magnet with the pickup, and is called the null. The specified length of the null depends on the mounting configuration of the sensor.



**Figure 10:** Sensor Electrical Stroke, Null, and Dead Zone

In Figure 10, it is 12 mm; so, the motion system and sensor mounting alignment must be designed so that the front face of the position magnet will be no closer to the mounting flange of the sensor than 12 mm. The front face of the position magnet is the face closest to the sensor electronics housing.

At the sensor rod tip (the end opposite the head), there is an unusable area in which the damp is housed. This is called the dead zone. Like the null, the system must be designed so that the front face of the position magnet will come no closer to the tip than the specified dead zone distance. In Figure 10, the dead zone is 82 mm.

For example, when ordering an MTS model with the dimensions shown in Figure 10. If the motion axis has a travel of 2 meters, then a sensor with a stroke length of 2 meters should be ordered. The total length of the rod, from the flange face (at the head) to the rod tip, will be:

$$2 \text{ meters} + 12 \text{ mm} + 82 \text{ mm} = 2.094 \text{ meter (eq. 2)}$$

### Electronic interface

**Electrical Power:** The standard power for industrial sensors is 24 volts DC, but some older systems use 15 Vdc. A special extended power option (9Vdc to 28.8Vdc) is available for non-standard power supplies and replacement of older products. Mobile applications usually utilize 12 or 24 Vdc from the battery; but often require special consideration because of a wide battery load range and the interface to the charging system. Make sure that you know the range of voltage provided by your power source. Automotive applications often power the sensor from a regulated 5 volts DC to avoid higher cost electronics in the sensor.

**Output Signal:** The signal from the transducer, and measured by the electronics module, is a time delay. This is shaped into a digital pulse when the sensor is specified with a start-stop interface. In operation, the user supplies a digital pulse to request a reading (starting a timer at the same time), and the sensor returns a stop pulse. The time between the two pulses indicates the

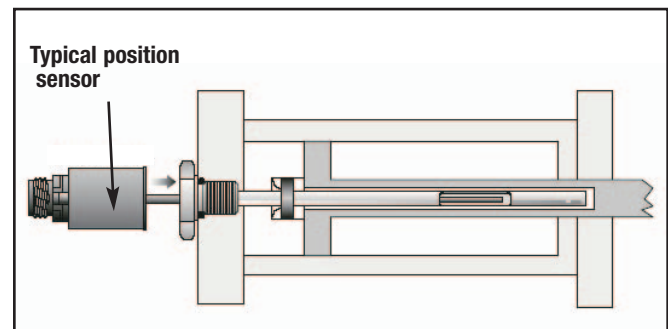
location of the position magnet. Similarly a pulse with modulated (PWM) output can be used to indicate the same time interval.

Analog current or analog voltage outputs are common interfaces. The signal can be 0 to 20 mA, 4 to 20 mA, or -10 to 10 volts. Temposonics analog sensors can be ordered with 100% or no field output adjustment.

Also available and more frequently applied today are absolute serial (SSI), and industrial network (CANbus, DeviceNet and Profibus) outputs directly from the same electronics housing.

### Application examples

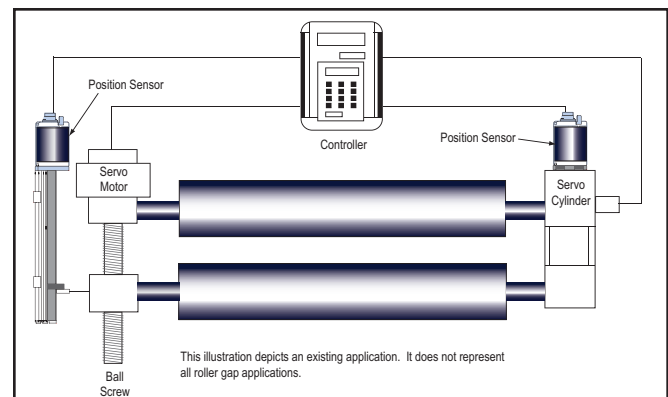
**Hydraulic or Pneumatic cylinder:** In Figure 11, a Temposonics sensor is mounted into a fluid power cylinder. The position magnet is attached to the piston, within the cylinder. The sensor flange is threaded into one end of the cylinder.



**Figure 11:** Flange, rod, and position magnet mounted in hydraulic cylinder with removable sensor head.

The sensing element (containing the waveguide) and the sensor head (containing the electronics module) can be withdrawn from the mounting flange, as shown, allowing easy replacement of the sensor without venting the hydraulic pressure inside the cylinder.

**Controlling of Gap Between Rollers:** Figure 12 is a pictorial of a sensing and control system for maintaining a specified roller gap. The Temposonics sensors are mounted along the roller adjustment axis, with the position magnets mounted at each end of the movable rollers. The controller accepts the sensor signals and sends the control signal to the servo motors.



**Figure 12:** Controlling the gap between rollers using linear position sensors and servo motors or servo cylinders.



There are a wide range of applications in many industries for magnetostrictive linear position sensors. Table 2 lists some industries and applications presently incorporating these sensors into their processes and products.

INDUSTRY	APPLICATION
Automotive	Production machinery, on-board suspension, transmission, and steering.
Chip & Wafer Handling	Precision measurement and no wearing parts enable this application.
Electric Actuators	Linear and rotary position can be measured using two position magnets.
Hydraulic/Pneumatic Cylinders	Sensor mounted within the rod and the magnet is fixed to the cylinder.
Food & Beverage	Milk tanks and can filling machines
Liquid Level	Process control, leakage detection, inventory control
Medical	Hospital bed positioning
Metalworking	Measurement & control in forges, presses, bending, and cutoff machines.
Mobile Equipment	Garbage trucks, agriculture, grading and paving.
Paper Converting	Used to control slitters and flexographic presses.
Plastics	Injection molding: injector, ejector and mold halves, also blowmolding.
Primary Metal	Walking beams and ladle control
Primary Wood	Sawmills, lathes, cutoff saws, positioning knees, and presses.
Secondary Wood	Saw positioning and tennoners
Testing Equipment	Materials, automotive, military/ aerospace, earthquake and wavemakers
Textiles	Used in carpet tufters

**Table 2:** Industries and applications using Magnetostrictive Linear Position Sensors.

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All Temposonics sensors are covered by US patent number 5,545,984. Additional patents are pending.

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