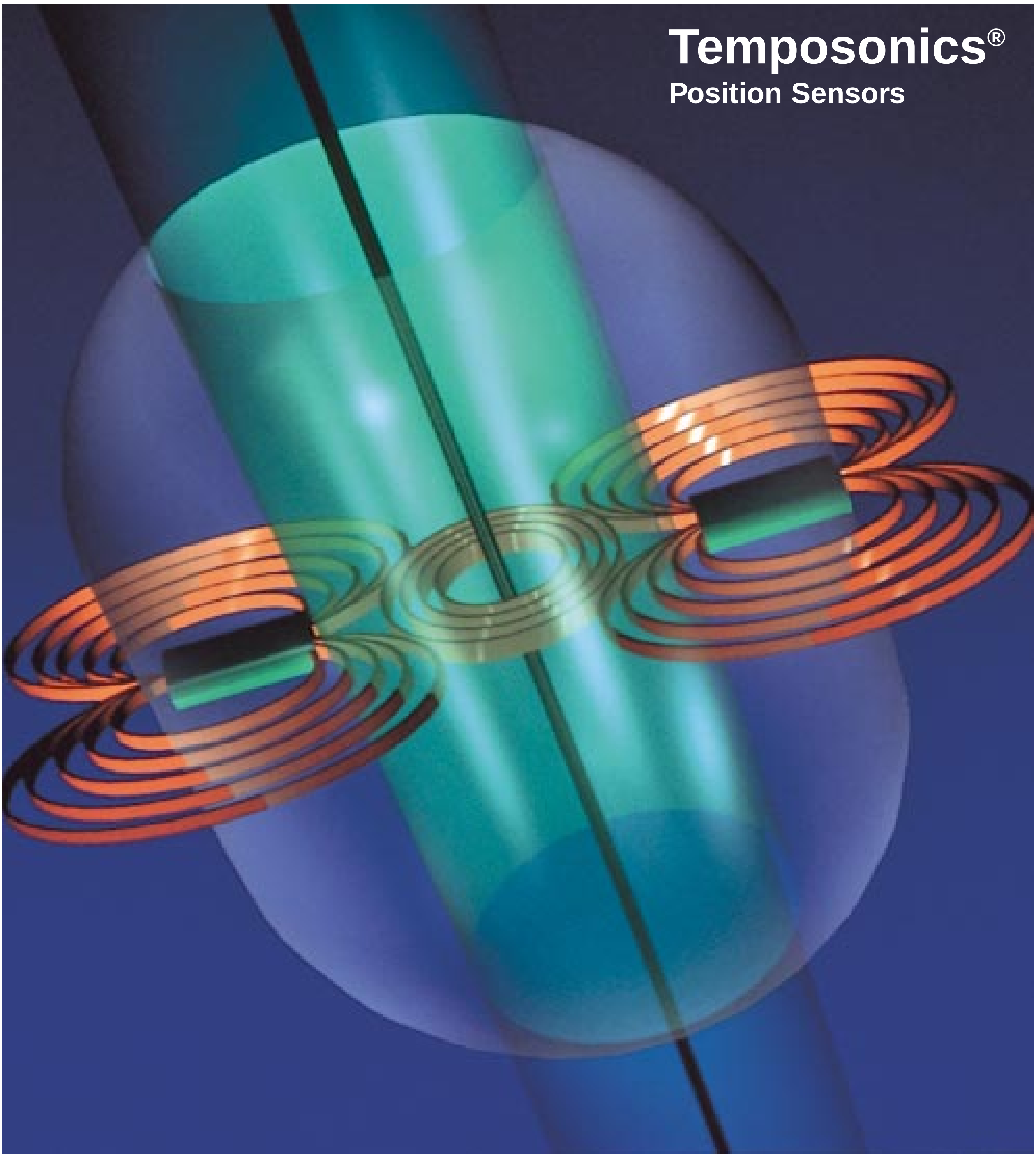
Magnetostriction

Basic Physical Elements



Industrial Measurement Technology

makes particularly high demands on the sensor robustness and measurement accuracy. The increasingly wide use of the magnetostrictive principle in exacting and intelligent applications raises questions for the basic physical elements of magnetostriction.

Temposonics®

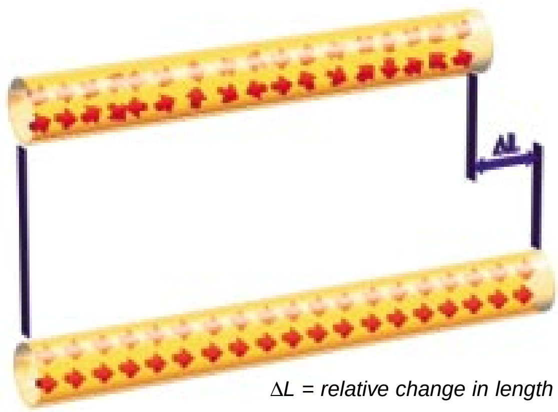
Contactless absolute linear displacement sensor working on the magnetostrictive principle

Historically, the basic principle of all magnetostrictive length measurement systems dates back into the past century. The study of electromagnetism revealed physical phenomena which are partly used by the measurement method presented in this description and implemented in a high-accuracy position sensor for use in industrial applications.

Theory
Magnetostriction is a phenomenon only found in ferromagnetic materials such as iron, nickel, cobalt and their alloys. The magnetostrictive principle is based on certain magnetomechanical properties of these materials. Ferromagnetic materials placed in a magnetic field undergo microscopic distortion of the molecular structure which causes a change of their dimensions. This physical phenomenon is due to the existence of high numbers of tiny little elementary magnets forming the ferromagnetic material. These particles show a tendency towards parallel arrangement within a limited field (Weiß area), even without being influenced by an external magnetic field. Within a Weiß area, all elementary magnets are oriented in one direction.

Due to random distribution of Weiß areas, the outer appearance of a ferromagnetic body at first glance does not indicate any magnetic properties. However, when influenced by an external magnetic field, these areas turn over in the direction of this magnetic field as a whole and get oriented in parallel to each other. The magnetic fields thus produced can be a hundred to thousand times as strong as the outer magnetic field.

When bringing e.g. a bar of ferromagnetic material into a magnetic field oriented in parallel to the longitudinal direction of the bar, there will be mechanical length change of the bar. The relative length increase, which can be produced by the magnetostrictive effect **(Joule effect)**, is actually very low: approx. 10^{-6} ***(Fig. 1)***.



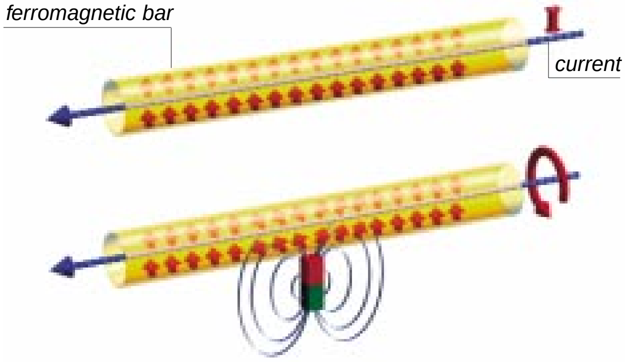
(Fig. 1) *The magnetostrictive effect (ΔL) is due to the orientation of Weiß areas by the influence of an external parallel magnet.*

The magnetostrictive effect, as an interaction of magnetic and mechanical parameters of ferromagnetic materials, can be optimized by suitable selection and handling of special metal alloys and controlled precisely by organizing the influencing outer magnetic fields.
Another magnetostrictive effect used by the industrial product based on this measurement principle is called **Wiedemann effect**, which describes the mechanical distortion of a long, thin ferromagnetic bar in a longitudinal external magnetic field. With electric current flow in the bar, a concentric magnetic field is produced.

In MTS sensors, the longitudinal magnetic field is created partially in the bar-shaped sensing element by a position magnet. With a current flow, the sensing element undergoes partial distortion ***(Fig. 2).***

Additionally, the MTS measuring method uses a magnetoelastic effect **(Villary effect)**. This effect relates to the change of the longitudinal magnetic properties, e.g. the permeability of a ferromagnetic bar, which can be caused by the distortion in longitudinal direction.

By means of the induction principle, such a permeability change in a magnetic field can be transformed into an electrical signal and made available for electronic signal conditioning.



(Fig. 2) *Due to the interaction of two magnetic fields, the Wiedemann effect causes mechanical distortion of a ferromagnetic bar in which an electric current flow is present.*

Translation into practice
To use the basic physical phenomena described above for implementation of a reliable measurement system, the schematic sensor construction shown in ***Fig. 3*** was selected. An MTS sensor comprising five main components was built:

- sensing element (waveguide)
- sensor electronics
- position-determining permanent magnet
- strain pulse converter system
- damping at the waveguide end

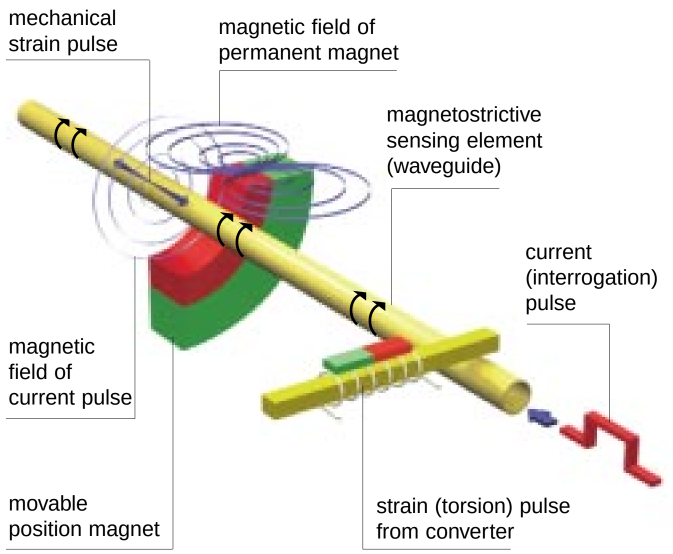
Heart of the system is the ferromagnetic sensing element. It is usually called waveguide, because it serves as a conductor of the torsional ultrasonic wave to the pulse converter. For measurement, the position is marked by a mobile permanent magnet around the waveguide. This position magnet, which is rigidly connected to the object of position measurement, produces the longitudinal magnetic field in the waveguide.
An important feature of this system is complete contactlessness of the position-determining magnet and the sensing element (waveguide): contactless measurement ensures wear-free operation throughout the long sensor lifetime.

For the actual measurement, a short current pulse is sent through the waveguide by the sensor electronics. As it travels through the waveguide, it carries along a second magnetic field in radial direction around the waveguide ***(Fig. 3)***.

In the position magnet area, the magnetostrictive waveguide is distorted elastically (Wiedemann effect). Due to the time curve of the current pulse, this is a highly dynamic process which produces a torsion wave in the effective field of the permanent magnet.

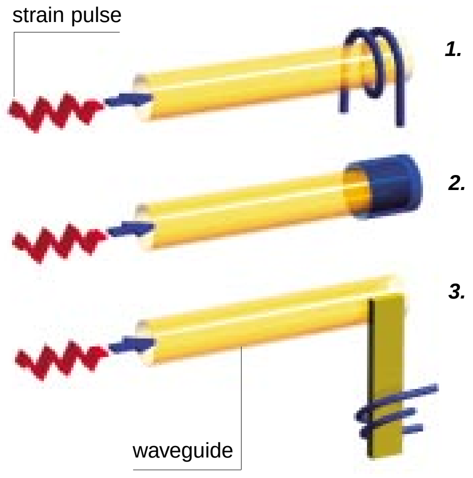
This impact sound-wave travels along the waveguide and down to its lower end, where it is completely absorbed, i.e. any interference effects on signal measurement are safely precluded. Detection of the torsion wave is in a special pulse converting system at the upper end of the waveguide: a magnetostrictive metal strip connected with the waveguide, an inductive detector coil and another, fixed permanent magnet. In the torsion pulse converter, the ultrasonic wave causes a permeability change of the metal strip according to the Villary principle. The resulting time change of the permanent magnetic field induces an electric current signal in the sensing coil, which is processed by the sensor electronics.
The torsional ultrasonic wave travels through the waveguide at constant ultrasonic speed. The position is determined accurately by travel time measurement, whereby the magnet position is a function of time between current pulse start and arrival of the electric reply signal: the ultrasonic wave detected in the torsion converter.

Although this displacement measurement principle may seem complicated, knowing its features helps to understand the well-known advantages of MTS sensors: for instance, utmost physical accuracy of run-time measurement and long-term stability of magnetostrictive metals. And due to the special sensor design based on our MTS engineers' know-how, the sensor principle operation is unaffected by external influences, e.g. machine vibrations. All these features are combined into precise MTS position sensors which offer high measurement reproducibility and reliability.



(Fig. 3) *Set-up principle of magnetostrictive measurement with a Temposonics sensor comprising the following components: electronics, waveguide, position-determining permanent magnet and strain pulse converter*

The implementation of the magnetostrictive measurement principle in a length measurement system suitable for use in rough industrial environments makes high demands on the manufacturer's competence. MTS engineers are experts of quick process data measurement and processing with in-depth knowledge of the basic physical elements, reinforced by decades of experience with magnetostrictive metals and materials technology in general. For instance, comparative studies were made by MTS to investigate the transformation of the torsional ultrasonic wave into an electronically measurable signal at various types of strain pulse converter systems as shown in ***Fig. 4***.



(Fig. 4) *Comparison of strain pulse converter systems*

1. *Direct detection of the strain pulse on the waveguide by an axial coil*
2. *Mechanical strain pulse detection by a piezoresistive sensing element*
3. *Strain pulse detection and conversion via a vertical tape embedded in a coil*

The study revealed that the sensor element shown in ***Fig. 4, type 3*** is required to make the most efficient use of the physical core technology and to obtain the optimum, safest magnetostrictive effect: only the strain portion of the mechanical wave is detected, whilst longitudinal vibrations are without effect on the measurement. Using torsion waves and a receiver system responding only to torsion pulses offers the advantage of high immunity to vibration, because torsion waves cannot readily be produced by external mechanical interference.

Uncompromised, reliable and reproducible operation of the complex physical measurement principle is ensured by our engineers' special know-how in mechanical construction and electronic signal processing technology reflected by all MTS sensors and developments. Extending our knowledge continuously and keeping it on the latest technical standards is our major commitment.

Temposonics position sensors are equipped with direct outputs, i.e. operation is without additional external indicators. In addition to all marketable analog outputs and digital point-to-point parallel (BCD, Binary, Gray) and serial (SSI) interfaces, position sensors are available for direct connection to the Fieldbus standards CANopen, CANbasic, DeviceNet, Profibus-DP and InterBus-S. Customized outputs are also possible.

Temposonics position sensors offer all advantages of the magnetostrictive sensor principle: contactless, i.e. wear-free measurement, utmost reproducibility and high longterm stability. Due to linear operation of absolute length measurement, the need for time-consuming zero setting by reference marks in case of trouble is omitted. Severe test procedures ensure top quality of each individual Temposonics sensor, e.g. re-calibration is not necessary throughout the sensor lifetime.

Certifications:

Reg. No. 30095-01

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