MAGNETIC SENSORS

Some Cedrat Technologies Design & Innovations ...
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INTRODUCTION

CEDRAT TECHNOLOGIES

CEDRAT TECHNOLOGIES SA is a high tech SME of Cedrat group involving 70 peoples located in ‘Inovallée’, the French Valley of Innovation, close to Grenoble.

CEDRAT TECHNOLOGIES develops and manufactures high performance Electro-Mechanical Components & Systems, especially Actuators & Electronics, which can meet needs from SME to prestigious customers as CNES, EADS, ESA, LG, NASA... :

- **Piezo Actuators**: Piezoelectric actuators can be developed as customized products. They are also available as off-the-shelf products: see separate documentation ‘Piezo Actuators & Electronics’ from CEDRAT TECHNOLOGIES or www.cedrat.com.
- **New Magnetic Actuators**: Magnetic actuators are developed by CEDRAT TECHNOLOGIES as customized products: Several examples of such developments are presented in this document.
- **Magnetic Sensors**: Magnetic sensors are developed by CEDRAT TECHNOLOGIES as customized products: Several examples of such developments are presented in this document.

What CEDRAT TECHNOLOGIES proposes through this document?

This document presents several realisations of New Magnetic Sensors from CEDRAT TECHNOLOGIES and provides their technical performances. The presented technical characteristics reveal what the considered technology is able to achieve.

These sensors are not available as standard products, but as ‘technological bricks’. So, if interested in such a technology, CEDRAT TECHNOLOGIES can develop similar products upon customer specification.

Developments of new Magnetic Actuators

Upon request, CEDRAT TECHNOLOGIES performs step-by-step developments in partnership with its customers:

- **Analysis of customer specifications**: A preliminary analysis by CEDRAT TECHNOLOGIES is free of charge. From this analysis, CEDRAT TECHNOLOGIES emits a formal proposal, including commitments, work programs, prices and delivery time.

- **Design**: A pre dimensioning or a feasibility analysis in case of very specific need, is realized using available design tools, before to perform the detail design. CEDRAT TECHNOLOGIES can apply Design Standards (for example ESA ECSS). At each stage, the customer gets the results, which generally a Detailed Design Report.
CEDRAT TECHNOLOGIES accepts to perform such a Design work even if not in charge of the Prototyping, Testing and Manufacturing.

- **Prototyping & testing:** The prototyping & testing is performed according to specifications or following the defined work program. The test program can include a complete qualification. CEDRAT TECHNOLOGIES has already delivered several FLIGHT MODELS for space or aircraft applications. CEDRAT TECHNOLOGIES can apply Design Standards (for example ESA ECSS), a Quality Product Assurance Plan and a Configuration Management Plan. CEDRAT TECHNOLOGIES accepts to perform such a Prototyping & Testing works even if not in charge of the Manufacturing.

- **Industrialisation & Manufacturing:** CEDRAT TECHNOLOGIES can manufacture small or medium series of customized products. This can be performed applying a Quality Product Assurance Plan. In 2005, the number of manufactured actuators has reached 1000 units.
Cedrat Technologies Facilities

The R&D facilities used by CEDRAT to develop these technologies include advanced modeling CAD programs.

- **FLUX 2D/3D** is a standard Finite Element Method (FEM) software for the design of magnetic devices.
- **ATILA 3D** is a FEM software dedicated to the modeling of 2D/3D structures including active materials such as magnetostrictives and piezoelectrics.
- **ADINA** is a FEM software used for Computation of Flow Dynamics (CFD).
- **I-DEAS** is a CAD software used for the mechanical & thermal computation & design.
- **MATLAB-SIMULINK, SPICE, DXP** are software for the computation & design of driving & control electronics.

The R&D facilities include also workshop facilities and Test Equipment adapted to Electric Engineering and Electro-mechanics:

- 2D/3D metrology
- Clean assembly room
- Thermal-Vacuum chambers
- Vibration shakers
- PCs with LABVIEW
- Laboratory power supplies and amplifiers, including lock-in amplifier
- Impedance analyzer
- Spectrum analyzer
- Gaussmeters, permeameter
- Laser interferometers / vibrometers

Thermal-Vacuum Test Chamber.  
Force Measurement of the VC-1 moving coil.  
Electromechanical labs : Class 100 Clean assembly, Supplys & Vibrometers bench.
Magnetostrictive stress sensors

Principle

Any ferromagnetic material is able to be subject to magnetostriction. It means that there is a coupling between the mechanical and magnetic states of the material. Because of the “direct magnetostrictive effect”, the material displays a mechanical anisotropic deformation when it is put under a magnetic field. Conversely, the magnetic permeability of such a material changes as a function of the applied mechanical stress. This is called the “inverse magnetostrictive” effect.

Therefore, under appropriate magnetic conditions, a measurement of the material’s magnetic permeability gives an indication of its internal mechanical stress state.

Finally, the material’s permeability can be measured indirectly by using a coil placed next or around the material (Fig. 1)

Design issues

From electromagnetic analysis realised with our numeric tools like FLUX3D (Fig.2), to testing in laboratory, (Fig. 3 and 4), considering different design steps, we evaluated and adapted the various parameters of the sensor in order to get the best quality of measurement (frequency of measurement, level of magnetic polarisation versus the B(H) characteristic of the considered material, impact of eddy currents, temperature, electromagnetic compatibility of the magnetic circuit,….).

Figure 1: Principle of sensor using magnetostrictive effect.

(1) Ferromagnetic material,
(2) Magnetising coil to reach the operating point on the B(H) curve of the material,
(3) A measurement coil to get its impedance,
(4) The magnetic circuit.
We built a laboratory test bench to measure the magnetostrictive effect of various materials in order to evaluate if we can use them in such kind of sensor.

**Performances**

Typical performances are given in the following table. This table is not exhaustive as many other actuators can be rapidly designed by CEDRAT TECHNOLOGIES using its design tools, lab facilities and technological know-how.

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Unit</th>
<th>values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material</td>
<td></td>
<td>Magnetic steel</td>
</tr>
<tr>
<td>Diameter of the sample</td>
<td>mm</td>
<td>16</td>
</tr>
<tr>
<td>Active length of the sample</td>
<td>mm</td>
<td>300</td>
</tr>
<tr>
<td>Internal stresses</td>
<td>% Re</td>
<td>60</td>
</tr>
<tr>
<td>Relative variation of inductance</td>
<td>%</td>
<td>20</td>
</tr>
<tr>
<td>Precision</td>
<td>%</td>
<td>2.7</td>
</tr>
<tr>
<td>Power supply</td>
<td>W</td>
<td>2</td>
</tr>
</tbody>
</table>

**Applications**

Stress sensor used in applications such as monitoring stresses in bridge and nuclear power plant structure.

Stress sensor put into structures such as on the bridge cables so as to prevent any risks of rupture or relaxation. Torsion and flexion stress sensors...

**Keywords**

Force / Stress sensor, Magnetostriction, Magnetic sensor, Magnetic permeability, Non-destructive testing...
Magnetic Resonant Sensors

**Principle**

Magnetic resonant sensors (M.R.S.) are resonators whose resonant frequency can be driven, at distance, by a bias magnetic field. When excited at their resonant frequency, M.R.S. magnetic response can be detected and processed following the application (Fig. 1).

To allow this frequency control, the non linear properties of magnetic materials, as function of static or quasi-static field, are used. One interesting physical property is the variation of incremental dynamic permeability versus the bias magnetic field (Fig. 2 & 3).

This phenomenon is used in M.R.S. based on L.C. technology. These sensors are composed of a coil (L) with a capacitor (C) (Fig. 4 & 5). The coil core is made of saturable magnetic material. The value of self inductance changes with the bias magnetic field via the dynamic permeability, and induces a change of resonant frequency (Fig. 6).

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**Figure 1:** Detection principle.

**Figure 2:** $M(H)$ curve.

**Figure 3:** Dynamic permeability versus bias field.

**Figure 4:** L.C. M.R.S.

**Figure 5:** L.C. M.R.S.

**Figure 6:** $f(H_t)$ law of L.C. M.R.S.

**Figure 7:** Magnetostrictive M.R.S.

**Figure 8:** Magnetostrictive M.R.S.

**Figure 9:** $f(H_t)$ law of magnetostrictive M.R.S.
The magneto-elastic resonators, especially magnetostrictive ribbons (Fig. 7) also present a resonant frequency depending on the bias field. This is due to the Young modulus of the material which depends on the bias and which control the stiffness. This variation of stiffness associated to the modal mass (Fig. 8) determines the change of resonant frequency (Fig. 9).

Performances

Typical characteristics of MRS and their performances in possible applications are given in the following table (Fig.10). This table is not exhaustive as MRS can be customized for many applications. In particular larger detection range are possible with larger MRS.

<table>
<thead>
<tr>
<th>References</th>
<th>Unit</th>
<th>LC</th>
<th>Magnetostriective Ribbon</th>
</tr>
</thead>
<tbody>
<tr>
<td>Notes</td>
<td></td>
<td>LC</td>
<td>Magnetostriective Ribbon</td>
</tr>
<tr>
<td>Resonance principle</td>
<td></td>
<td>LC</td>
<td>Magnetostriective Ribbon</td>
</tr>
<tr>
<td>Sensor length</td>
<td>mm</td>
<td>30</td>
<td>[20 to 60]</td>
</tr>
<tr>
<td>Sensor width</td>
<td>mm</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>Sensor thickness</td>
<td>μm</td>
<td>2000</td>
<td>35</td>
</tr>
<tr>
<td>Frequency without magnetic field</td>
<td>kHz</td>
<td>[20 to 200]</td>
<td>[10 to 70]</td>
</tr>
<tr>
<td>Frequency variation</td>
<td>%</td>
<td>29</td>
<td>33</td>
</tr>
<tr>
<td>Detection distance</td>
<td>mm</td>
<td>200</td>
<td>200</td>
</tr>
<tr>
<td>Max field sensibility</td>
<td>Hz/μT</td>
<td>223</td>
<td>440</td>
</tr>
<tr>
<td>Excitation AC field magnitude</td>
<td>A/m</td>
<td>units</td>
<td>units</td>
</tr>
<tr>
<td>Max DC field magnitude</td>
<td>A/m</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Linear one axis consistency</td>
<td>mm</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Angular consistency</td>
<td>°</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Coding range capability</td>
<td>1.00E+06</td>
<td>1.00E+06</td>
<td></td>
</tr>
<tr>
<td>Simultaneous number of object identified</td>
<td>10</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>Number of detection axis</td>
<td></td>
<td>1 to 3</td>
<td>1 to 3</td>
</tr>
</tbody>
</table>

Applications

Magnetic resonant sensors are remote passive magnetic field sensors (contactless) with an integrated antenna for data transfer. They can be used for contactless magnetic field measurement.

Associated with a controlled magnetic source they are used as contactless angular position sensor or as contactless linear position sensor. A system association with computation means, MRS sensor can be used as ID tags for remote identification of objects. CEDRAT TECHNOLOGIES has a 10 years experience of this application.

Keywords

Contactless, remote, Magnetic sensor, Position sensor, Angular sensor, ID tags, Identification system.
Contactless Torque Sensors

Principle

The torque measurement usually comes from stain gauges bonded on a shaft. The main concern in this measurement is due to the fact that these gauges are also rotating and the integration of electronic on rotating parts is definitely a blocking point. New magnetic methods such as differential transformer, magnetostrictive or hall effect allow contactless torque measurement with stationary electronic. However their performances are limited: magnetic shaft required, limited speed, limited resolution...

Objective

A new generation of contactless sensor has been developed and patented to capture the torque in a stationary axle or rotating shaft. The measurement is done with stationary electronic components. This unique compact structure measures torque with low-cost standard eddy current sensor. This torque sensor concept has convinced automotive industry due to its good performances and other advantages. Since it is based on low number of parts, its price appears compatible with the market expectation for this application.

Structure

The architecture of the device is mainly composed of two targets, one or two position sensors, a proof body and a compact body (Fig. 1). In principle, the angular shift between two rotary targets along the shaft is converted into amplified axial shift between the targets. Only one sensor is required to measure the target motion. However two sensors perform a differential measurement in the stationary frame (Fig. 2) for temperature compensation.

Fig. 1: Contactless torque sensor mechanical design.  
Fig. 2: Contactless torque sensor principle
Performances

Typical performances are given in the following table. The preliminary specifications are defined with eddy current sensors mounted on the stationary frame. This table is not exhaustive as many other contactless torque sensors can be designed by CEDRAT TECHNOLOGIES.

In summary, Contactless Torque Sensor offers:
- Solid state design,
- Stationary axle or rotating shaft,
- High speed (Only limited by the electronic),
- High accuracy,
- Excellent resolution,
- Reliable measurement,
- Therally compensation,
- Ease of integration,
- Compatible with either ferromagnetic shaft or not.

The measuring device might be supplied in hollow shaft configuration for parallel integration (Fig. 4).

According to the shaft mechanical properties, CEDRAT TECHNOLOGIES designs customized sensor using its design tools, lab facilities and technological know how to achieve the required specifications. Alternatively the sensor can be supplied with its proper shaft for in series coupling (Fig. 5).

<table>
<thead>
<tr>
<th>References</th>
<th>Unit</th>
<th>CTS1</th>
<th>CTS10</th>
<th>CTS100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Notes</td>
<td>NA</td>
<td>NA</td>
<td>Preliminary data</td>
<td></td>
</tr>
<tr>
<td>Measurement range</td>
<td>N.m</td>
<td>&lt;0.1</td>
<td>6</td>
<td>&gt;100</td>
</tr>
<tr>
<td>Configuration</td>
<td>NA</td>
<td>stationary axle or rotating shaft</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Speed (depend on shaft)</td>
<td>Rpm</td>
<td>&gt;20000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resolution</td>
<td>%</td>
<td>0.1 Full scale</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Accuracy</td>
<td>N.m</td>
<td>0.15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Repeatability</td>
<td>%</td>
<td>0.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bandwidth</td>
<td>kHz</td>
<td>80</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operating temperature</td>
<td>°C</td>
<td>[-25 ; 125]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Output</td>
<td>V. DC</td>
<td>+/-10V</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Magnetic insulation</td>
<td>Oe</td>
<td>5000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dimensions</td>
<td>mm^3</td>
<td>40</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Applications

This new sensor finds an application for torque measurement in the automotive industry. However this measuring device allows a contactless measurement on the rotating machine output shaft in very large number of applications: Manufacturing machines, Machine tools, Electric motors ...

Keywords

Torque, contactless, sensor, transducer, steering, rotating machine, motor, transmission.
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