HIGH RESOLUTION STANDARD PROXIMITY SENSOR (HRSPS)
Publication and presentation of the final Specification and Test Results

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ABSTRACT

This paper presents the final results of the performances of the High resolution Standard Proximity Sensor developed under a GSTP contract for ESA /ESTEC.

The HRSPS is a general purpose displacement measuring system developed with the aim to replace the multitude of customised sensors used so far in scanning and pointing mechanisms. It will become the European standard nano-measuring system qualified for space mechanisms operating in closed loop control.

The HRSPS offers either two independent single or a differential output (s) offering a resolution of 1 nanometer.

Three different HRSPS covering three measuring ranges have been developed. This paper presents the test results and the final confirmation of the performances of the HRSPS.

The majority of sensor designs available industrially and in the launcher field are not readily suitable for high reliability space / satellite applications. The HRSPS manufactured can be supplied in either high reliability FM's for satellites and also FM's for microgravity / ISS applications requiring Mil 883B/C type of components.

The paper will present the first applications for microgravity and satellite applications.

Introduction

The High Resolution Standard Proximity Sensor herein after called "HRSPS" is a general purpose displacement measuring system developed with the aim of replacing, in the future, the multitude of customised sensors used so far in scanning and pointing space mechanisms or robotics applications. The HRSPS is an inductive sensor working on the eddy current principle. It can perform measurements in a single or differential sensor arrangement and can also be used as a proximity switch.

During the development emphasis was placed on a design that can easily be adapted to different measurement tasks and ranges thus being able to meet highest resolution requirements, to achieve a good overall accuracy or to provide a high measurement bandwidth.

Applications

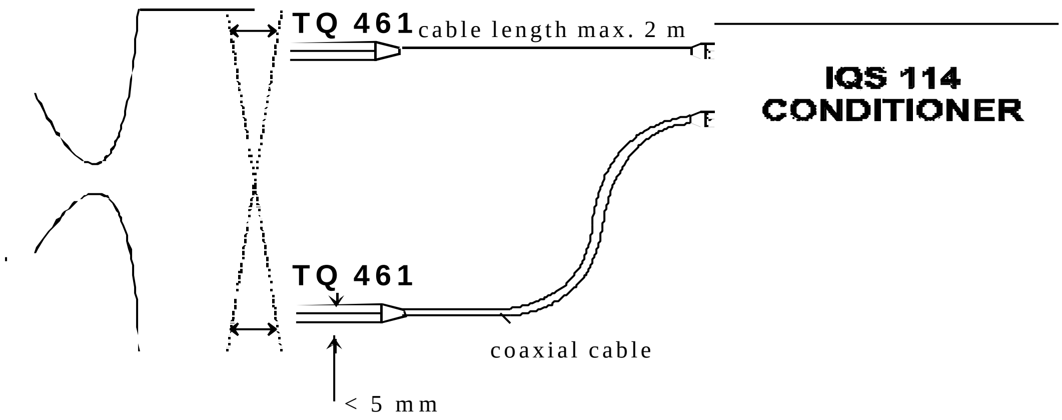
Mechanisms operated in closed loop control generally require sensors to provide a feedback on the position actually realised. Comparison with the desired position then allows the derivation of an immediate correction of any mispositioning leading to the superior performance of such mechanisms. The HRSPS offers displacement measurements in a single or differential arrangement.

The majority of sensor designs available industrially and in the launcher field are not readily suitable for high reliability space (satellite) applications. Typical ground or launcher approaches are very different in terms of material selection, electronics qualification and reliability status. The HRSPS has been developed from the beginning for space applications, taking into account the experience of Vibro-Meter in industrial and high-pressure cryogenic sensors design for launchers.

Technology

The choice of the Eddy current technology was considered as the best all-round performer and most suitable and adaptable to the installation requirements. The choice of this technology was also the result of a questionnaire sent to the industry world-wide.
An Eddy current measuring system operates in an RLC parallel network where the amplitude of the oscillation is proportional to the displacement to be measured. The passive sensor consists of a coil (L) and a cable (R, C) fed by a high frequency excitation generated by a nearby conditioner.
The electromagnetic field emitted at the front of the sensor induces Eddy currents in an adjacent conductive target resulting in an increase of losses, i.e. in a reduction of the amplitude across the coil. The value of the equivalent parallel resistance (Rp) will depend on the proximity and also on the target material.

FIGURE 1 : HIGH RESOLUTION STANDARD PROXIMITY SENSOR DMS 111



The task of the signal conditioner is to generate the high frequency oscillation and to convert the resulting signal into a linear output proportional to the relative distance of the target. The sensitivity of the system is dependent on the material, mounting constraints and the relative displacement of the target from the sensor.

The sensor coil (TQ 461) is a derivative of an existing range of proximity probes and has a measuring range of 1 mm. For greater measuring ranges up to 20 mm, different sensor coils will be derived from existing probes.

Technical description of the HRSPS

Two sensors type TQ 461 and two electronics conditioning channels located inside the IQS 114 conditioner are required for differential arrangement measurement (see **Figure 1**). The TQ 461 sensor includes a coil (position measurement element), a diode (temperature sensing element) and an integral cable of up to 2 meters. Each TQ 461 sensor is coupled to an oscillator located in the conditioner IQS 114.

As mentioned above, the amplitude of the voltage across the coil depends on the target position and on the HF current provided by the oscillator. Sensor temperature monitoring permits zero and sensitivity drift compensation independently for each measuring channel. The electronic conditioner IQS 114 also includes a diode for its own temperature monitoring, allowing independent compensation of the thermal effects on both channels.
Particular attention is given to minimise intrinsic drifts in both the sensors and the electronics in order to reach a good transient thermal behaviour. The rectifier and low-pass filter convert the AC signal of the oscillator to a DC voltage. A gain adjustment stage and " linearisation circuit " convert this signal to a voltage proportional to target position. The differential output amplifier gives the user a voltage proportional to the target position in a differential arrangement measurement. A voltage translator allows the modification of the output bias DC voltage. This translator has a zero volt default at the medium target position in a differential arrangement measurement. The electronic conditioner IQS 114 includes one direct output per channel, located after each "linearisation circuit", offering an independent output for single sensor application. Both single and differential outputs are permanently wired on the connector.

Transfer Functions and Measuring ranges with different sensor configurations

The initial requirement was for a maximum range of 20 mm. In order to achieve the low linearity error required for nano measurement in space mechanisms, the standard measuring ranges were set as below.

	Transfer / differential	Measuring range	
	V/mm.	Single	Differential
TQ 461	10	1 mm.	± 0.5 mm.
TQ 462	5	2 mm.	± 1 mm.
TQ 463	1.66	6 mm.	± 3 mm.

The standard measuring ranges above do not limit the capability of the Eddy current measuring systems. For instance, Vibro-Meter offers measuring systems with the following ranges wrt. the sensor heads offered for the HRSPS :

Tip diameter of 5 mm. like the TQ 461 typical measuring range of 2 mm., for 8.2 mm. like the TQ 462 typical measuring range of 4 mm. and for

18 mm. like the TQ 463, a typical measuring range of 12 mm. is possible.
The final HRSPS offered will be a compromise between the different parameters defining the final performance of the system.

Choice and Design Justification

Based on the results of the questionnaire used to write the specification, a review of existing sensor concepts and potentially suitable ones to be employed or developed / modified for the intended applications was identified. Possible solutions were assessed, and a trade-off was performed based on the criteria listed below. As a result of the trade-off, the preferred system concept was identified and the baseline definition for the sensor head and evaluation electronics was established.

CRITERIA:

- performance range
- short and long term repeatability (fidelity, reliance)
- calibration effort when changing the environment, effect of sensor cable length
- single or differential sensor head configuration
- independent thermal control
- miniaturisation potential of sensor heads and electronics
- design heritage
- adaptation need of the electronics when combined with different sensor heads
- number and configuration of sensor heads to cover the full range of displacement and rotation as identified in the specification
- qualification status of parts, materials and processes
- analogue output or digital output via a serial interface

Advantages over other Technologies

- True contactless technology
- Small sensor heads in an action free environment?
- Single and differential arrangement
- Sensor and target extreme temperature capabilities
- Sensor individual temperature compensation
- High vibration survivability
- High radiation survivability (Sensor 10^8 Rad)
- Operational in harsh environment
- Modular channel configuration

General Design Requirements

The sensor operating mode (single or differential), the various target materials and operating temperature ranges require a lot of adjustments inside the conditioner. Some specific components are different depending on the choice of sensor (oscillator).

The use of a hybrid technology has also been assessed but the gain of space and mass would have been minimal. The loss of modularity would have been very severe. The price of the hybrid technology was also one of the main factor condemning this technology.
The choice of the SMD technology allows to better managing the obsolescence of components which will become more and more a source of concern.
The choice of the SMD technology offers the advantage of manufacturing the FM's for high reliability satellites applications, but also for microgravity or for the International Space Station using the same basic electronics boards and conditioner casing.

Life and Reliability

The transducers and the conditioner are designed for a total life of 15 years.

The calculated reliabilities are as follow for an FM with two sensors and one conditioner:

Microgravity and for International Space Station using 883 B components - MTBF : over 270'000 hours

High Reliability Satellite -
MTBF : over 2'000'000 hours

Mechanical Design

The sensor casing is made out of a machinable ceramic which offer reduced thermal expansion. The sensors will be qualified with a mechanical interface represented as a screw (TQ 461 : M6 x 0.75, TQ 462 : M10 x 1 and TQ 463 M20 x 1.5) with axial cable output. This simple mounting has eased the large amount of testing on the existing Vibro-Meter in-house GSE. Different sensor casings will be available requiring a delta qualification.

Electrical Characteristics

The HRSPS output is 0 VDC to + 5 VDC in a single arrangement and ± 5 VDC in a differential arrangement for the full measuring range. Outputs (2+1) are always available on the output connector. The HRSPS offers the choice of working with ± 15 VDC or + 28 VDC power supply. There is room for the installation of a fuse in the power supply line on request.
For other electrical specifications, see the technical description attached.

Modular Construction

The standard HRSPS system, defined as Displacement Measuring System DMS 111, consists of an electronic conditioner IQS 114 connected to 2 sensor heads in either single or differential arrangement.
The electronic conditioner IQS 114 is made of 2 frames. One (1) Power Supply frame for either + 28 VDC or ± 15 VDC voltage and one (1) conditioner frame connected to two (2) sensor heads. If more than two (2) sensor heads are required, it is possible to add a second conditioner frame above the first one. In this case, the 4 sensor heads have to be the same as there is only one oscillator for both frames in order to reduce the intercoupling. This modular concept allows the adaptation of the configuration to any application and a reduction of the total mass of the system.

Environmental Requirements

The final qualified HRSPS will respond to ESA ECCS Standards as well as to most of the environmental requirements of various launchers that are flying today.

Conclusions

The choice of the Eddy current technology was considered as the best all round performer and most suitable and adaptable to the installation and the environment requirements.
During the development, emphasis was placed on a design that can easily be adapted to different measurement tasks and ranges thus being able to meet highest resolution requirements, to achieve a good overall accuracy and to provide a high measurement bandwidth.

The sensor TQ 461 measuring coil is a derivative of our existing range of proximity probes.
The work on the electronics conditioner IQS 114 has benefited from our 30 years experience in developing Eddy current systems for industrial and launchers applications.

- The possibility of simplifying the construction of the TQ 461. This simpler arrangement allows the temperature sensor and the target proximity to be on the same cable. As a result, a single coax cable for each TQ 461 will be necessary. This is an important improvement in terms of connection reliability and will allow the use of a standard connector and cable.

- The improved natural filtering eases a further digitalisation (sampling). The design of the antialiasing filter which may be in cascade with the HRSPS in case of digital processing will only have to consider the mechanical target frequencies.

ACHIEVEMENTS

The HRSPS (DMS 111) main capabilities are :

- resolution of 1 nm. for a measuring range of ± 0,5 mm with TQ 461, 1.4 nm. in single arrangement for 1 mm. range (100 Hz. Bandwidth at 1 kHz)
- resolution of 2 nm. for a measuring range of ± 1 mm with TQ 462, 2.8 nm. in single arrangement for 2 mm. range.
- resolution of 7 nm. for a measuring range of ± 3 mm with TQ 463, 10 nm. in single arrangement for 6 mm. range.

Thanks to the active temperature compensation in the sensors and electronics, the zero and sensitivity stability have been reduced to 50 ppm/°C within a dedicated temperature domain representative of that found in realistic applications.

The HRSPS is the only true contactless displacement measuring system operating within a temperature range from -140° to 125°C (sensor in different limited ranges). The sensor is made out of materials that comply with the ESA Standards and the selection of components in the conditioner has allowed the use of the SMD technology. The manufacturing of EM's and EQM's has been accomplished together with a major European manufacturer of space qualified electronics.
The radiation survivability has been established and the reliability and the ageing have been assessed.
The environmental requirements and especially the vibration (30 g rms. random) and shock specifications will allow the HRSPS to be used on any launcher that is on the market and operational today.

TECHNICAL DESCRIPTION of the achieved HRSPS

The HRSPS has received the Vibro-Meter definition of Displacement Measuring System DMS 111, consisting of one or two Eddy current displacement sensors TQ 461 and a conditioner IQS 114. The purpose of the DMS 111 is to measure displacement in either single mode (with one TQ 461) or in a differential mode (with two sensors TQ 461). The system provides high resolution, repeatablility and excellent accuracy. Two other sensors with wider measuring ranges are available TQ 462 (2 mm. or ± 1 mm.) and TQ 463 (6 mm. or ± 3 mm.) .

DMS 111

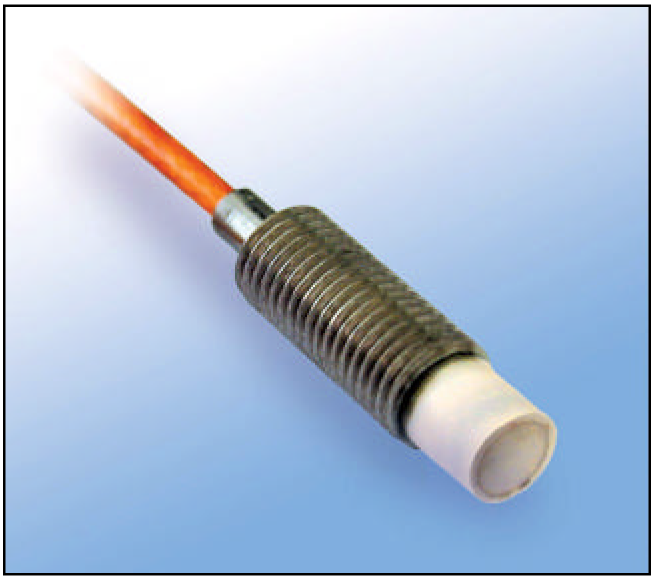
Measuring range with TQ 461	- Translation 1 mm in single sensor mode - Translation 1 mm i.e. ± 0.5 mm wrt. centre position in differential arrangement
Output transfer function / voltage	10 V/mm. Output voltage ± 5 VDC
Voltage translator adjustment capability	± 2.5 VDC
Linearity in the differential arrangement	Diff. ≤ 0.5 % FSD, single ≤ 1 % FSD
Long term stability	5×10^{-4} FSD/month (non cumulative),
Zero temperature stability	< 100 PPM/°C of FSD, design goal 50 PPM
Sensitivity temperature stability	< 100 PPM/°C of FSD, design goal 50 PPM
Frequency response	DC to 5 KHz
Phase lag	≤ 5° at 1 KHz
Equivalent RMS I/P noise in the band 100 Hz to 20 kHz in differential arrang.	≤ 1×10^{-7} FSD /√Hz (mechanical resolution 0.1 nm / √Hz)
Effective resolution in the differential arrangement	Less than 1 nm with a 100 Hz bandwidth at 1 kHz
Input voltage	± 15 VDC with a tolerance of -5% +25% or 28 ± 5 VDC with DC/DC converter
Power consumption	< 1.5 W with a power supply voltage of ± 15 VDC, < 2 W under +28 VDC.

TQ 461 Sensor

Temperature range	-55°C to +70°C (- 140°C to + 125°C)
Mass	≤ 30 gr with 2m. cable
Diameter	Tip ≤ 5 mm.
Length	Sensor 20 mm., integral cable max. 2 m.
Power dissipation	< 15 mW is expected in the sensor head i.e. 1 % of total DMS 134 power consumption.

IQS 114 Electronic conditioner

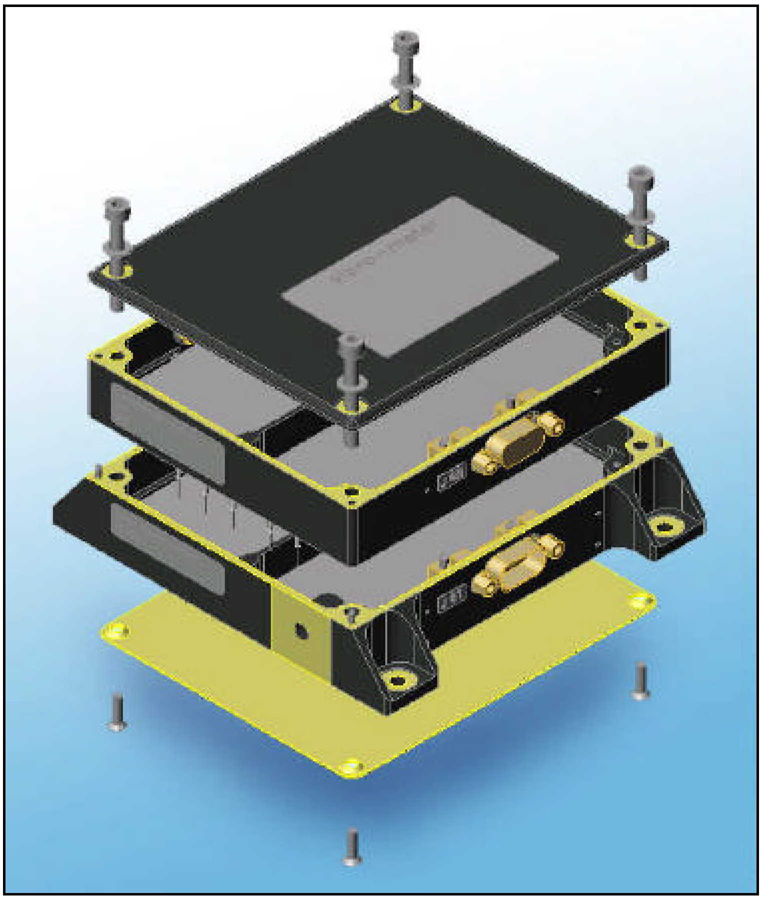
Temperature range	- 55°C to + 70°C
Mass	≤ 500 gr
Size (with one conditioner frame)	≤ 120 × 101 × 48 mm



TQ 461

TQ 462

TQ 463



HRSPS Electronics
IQS 114