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Characterisation of the dielectric properties of the propellants MON & MMH

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ABSTRACT

Future (commercial) satellites will require accurate propellant gauging systems, in order to meet the end-of-life reorbiting requirement and the need for replacement planning. A capacitive Gauging Sensor Unit is currently being developed for the Meteosat Second Generation spacecraft. Its measurement principle is based on the difference of the dielectric properties of the propellant liquid and vapour. To optimise the sensor accuracy, the dielectric properties of propellants need to be accurately known as a function of the temperature (and pressure). Therefore the dielectric properties of MON (Mixed Oxides of Nitrides) and MMH (Mono Methyl Hydrazine) were to be measured. The test setup and the test results are described in detail.

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CHARACTERISATION OF THE DIELECTRIC PROPERTIES OF THE PROPELLANTS MON & MMH

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Abstract

Future (commercial) satellites will require accurate propellant gauging systems, in order to meet the end-of-life re-orbiting requirement and the need for replacement planning. A capacitive Gauging Sensor Unit is currently being developed for the Meteosat Second Generation spacecraft. Its measurement principle is based on the difference of the dielectric properties of the propellant liquid and vapour. To optimise the sensor accuracy, the dielectric properties of propellants need to be accurately known as a function of the temperature (and pressure). Therefore the dielectric properties of MON (Mixed Oxides of Nitrides) and MMH (Mono Methyl Hydrazine) were to be measured. The test setup and the test results are described in detail.

INTRODUCTION

Future (commercial) satellites must incorporate accurate propellant gauging systems to meet the end-of-life de-orbiting requirement and the need for replacement planning. Earlier discussions (Hufenbach et al. 1997) led to the conclusion that gauging system requirements depend on: Type of Mission (commercial/scientific), Orbit Type (LEO, MEO, HEO, GEO, interplanetary), Overall Delta Velocity Requirement, Propellant Mass Fraction, Mission Profile, Stand Alone/Constellation Spacecraft, Spacecraft Design (operational lifetime & complexity), and Costs of Spacecraft, of Launch (absolute cost, spacecraft mass margin) and of Operation. The degree of accuracy for the propellant mass determination usually is the major driver for the design and implementation of gauging systems. The required accuracy level follows from the weights of the above issues. Other requirements, taken into account for spacecraft design & development, are: Mass Budget (mass of the gauging system and of necessary spacecraft modifications/adaptations), Power Budget, Lifetime of the Gauging System, Aging (of electronics, propellant properties), Amount of the Data (to be transferred on the TTC channels), Costs (recurring/non-recurring, for integration/calibration, for spacecraft interfaces adaptation, operation cost) and Availability of Technology.

For Meteosat Second Generation (MSG) spacecraft series, Eumetsat requires the determination of remaining propellant mass in the tanks (during the last three mission years) to an accuracy of ≈ 4 kg, meaning three months of satellite lifetime. This is an accuracy of ≈ 1.25 kg per oxidizer tank, ≈ 0.75 kg per fuel tank. The Gauging Sensor Unit (GSU), developed for MSG spacecraft, measures the capacitance of the medium between two electrodes to determine the propellant level. The measurement principle is depicted in Figure 1, for a configuration with two electrodes coated with an electrically insulating layer. The GSU (Figure 2) consists of a 125 mm long Platinum profile, the first electrode, embedded in a solid glass tube. The glass tube is within a Titanium frame, the second electrode, providing mechanical protection for the glass tube. The open construction of the Titanium housing allows

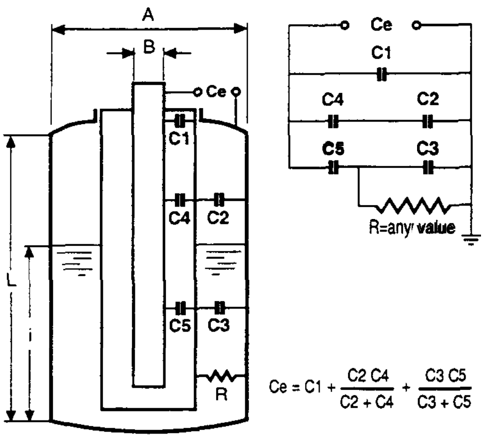

FIGURE 1. Coated Capacitance Probe (Schematic).

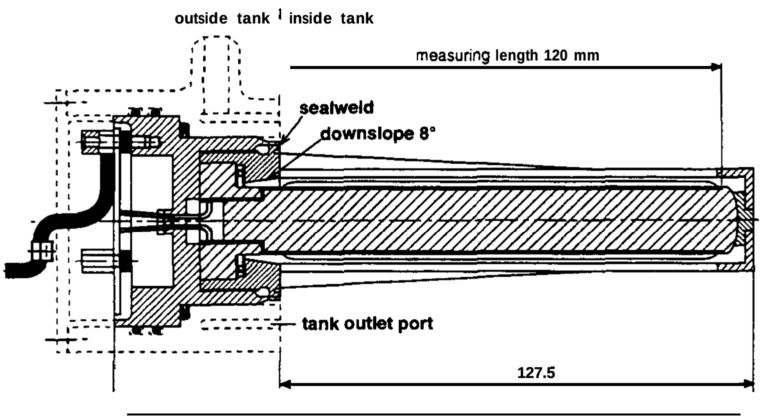

FIGURE 2. Propellant GSU for MSG.

the liquid to enter the space between the two electrodes. The liquid level determines the dielectric permittivity of the medium between the electrodes, hence the capacitance (Deli1 et al. 1997 and Hufenbach et al. 1997). The whole assembly is inserted via a propellant port in the propellant tank of a spin-stabilised spacecraft. The sealing of the sensor consists of a pre-tension type PTFE jacket with an Inconel spring first seal and a Kalrez second seal, placed radially on the glass container. Two PTFE O-ring seals are present as backup. Electronics are mounted on the bottom of the instrument, outside the tank. Wires coming from the Platinum electrode are melted inside a glass feedthrough. The whole assembly mass is 376 grammes, excluding harness. It can withstand a peak load of 200g. It is 200 mm long and has a maximum diameter of 58 mm. The sensor is capable to withstand the environment inside the propellant tank: it can handle temperatures between 273 and 343 K, pressures up to 2.3 MPa. The electronics unit needs 0.3 W peak power, 0.15 W average.

The platinum profile on the glass tube is divided into segments (Hufenbach et al. 1997). Three of them are used for active gauging. The lower one is used for reference purposes only, as it is always emerged in the liquid during the operational mission. When the propellant level reaches the lowest segment, the de-orbit manoeuvre has to start. The different segments are used in an active guarding technique. This means that whenever a certain segment is not wetted, its potential is equal to the wetted (liquid measuring) segment potential. This technique, combined with a smart set of electronics, eliminates secondary effects: field bending and variable parasitic capacities. Over each segment the level has to be measured with an accuracy better than one millimeter. To attain this, just measuring the capacitance is not sufficient as this varies between 30 and 33 pF only. Therefore the loading time of the capacitor segment is measured and converted to a frequency for easier processing. The loading times of each of the four segments are measured in individual sessions of one minute. The measurement of the lowest segment will be used to determine the parasitic capacitance behaviour of the sensor. Due to on ground calibration and knowing that the lowest part is fully emerged in the liquid, the offset signal is eliminated from the level measurement. The liquid level can be determined from the comparison of this reference signal with the signal coming from segments partly emerged in the liquid. The total amount of propellant left in the tank can be determined from this level. The frequency signals will be sent to the ground where the processing is done.

Several errors are to be corrected for. Due to the reference segment at the bottom of the sensor most errors can be eliminated. A disturbing effect is field bending, occurring when two adjacent capacitors have different potentials. Analysis of this effect is hardly possible and accuracy and reliability figures can only be achieved by means of tests. Active guarding proved to reduce the field bending effect to an acceptable level (Mastenbroek et al. 1997) during tests with a GSU Bread Board Model, using MON-1, expected to be non-conductive. Figures 3 and 4 depict measured frequency versus level curves for the segments, resp. the measured GSU resolution. It is clear that, though the test item is only a BBM, the test results for MON-1 are very promising.

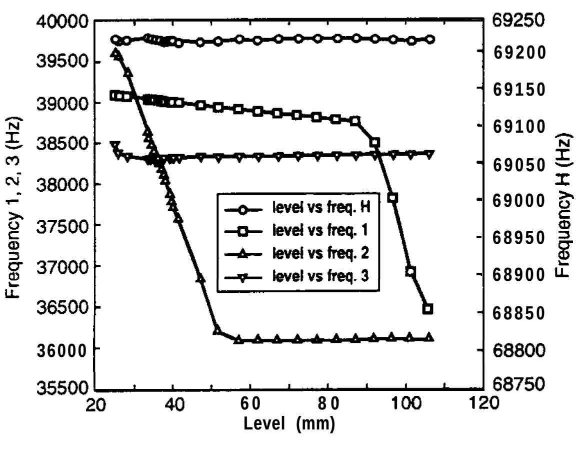

FIGURE 3. MON- 1 Test Data for Segmented GSU.

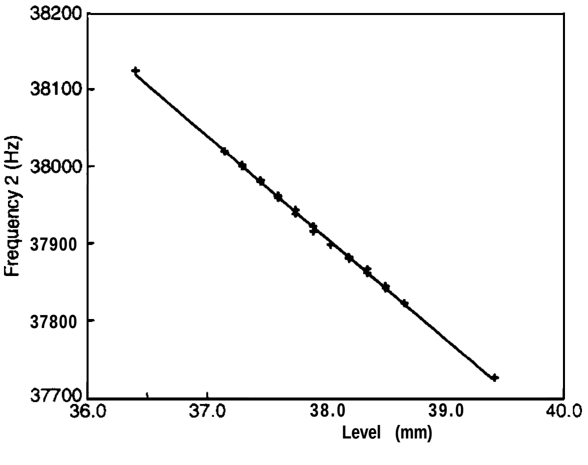

FIGURE 4. GSU Resolution Test Data.

To summarise the conclusions and recommendations (Mastenbroek et al. 1997), it can be said that: the span is within the same range for the three segments, the linearity and the reproducibility is very good, active guarding has led towards a very stable sensor, the required resolution (0.5 mm) is obtained even without any temperature calibration/compensation, a level variation of 0.1 nun can be detected reproducibly under constant temperature conditions, better stability can be obtained by dedicated optimised electronics (small PCB, short wires, efficient routing), optimal accuracy can be obtained by calibrating each individual segment, a proper “level protocol” will

Figure 10 depicts the, from the capacitance derived, dielectric permittivity as a function of the temperature. The figure shows an almost linear temperature dependence (there is some hysteresis below a temperature of 298 K). Also the capacitance slightly increases with time. This is probably due to the aforementioned penetration of MON-1 into the Teflon insulator. The permittivity ε_r as a function of the temperature can be approximated by the linear relation: ε_r = 2.833-0.0052 * (T-273), (T = Temperature in K). The error in the permittivity is the sum of inaccuracies of the test setup (2 %) and of the curve approximation (2 %). This gives a total error of 4 %.

The minimum resistance, measured during the tests of the two batches, turned out to be 3.8 MR. Conversion of the lowest measured value of 3.8 MΩ into a specific resistance, gives a minimum value of 14 MR m. The fluctuations, at lower temperatures, are not fully understood. As the tests with a empty and cleaned test cell after the MON-1 test show very high resistance (2 GΩ), it is concluded that the test setup can not cause such low resistance values during tests. Also it can be remarked that the test cell interior did not show visible traces of corrosion. Together with the fact that the decreases of the resistance during the MON-1 tests are reproducible and occur after passing the lowest temperature, it is concluded that the resistance decrease is caused by solving/dissolving of some MON-1.

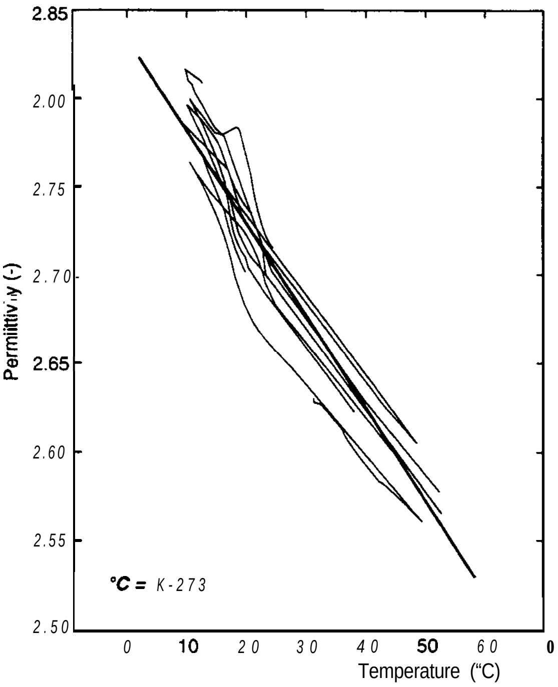

FIGURE 10. Temperature Dependent Permittivity of MON- 1.

RESULTS OF MMH TESTS

The MMH characterisation has been done by NLR at DASA-Lampoldshausen. Table 3 lists the tests performed.

TABLE 3. Test Performed to Characterise MMH.

Test	Name	Purpose and description
1	Pre Empty cell	To check the characteristics of the empty test cell and test setup. The temperature is cycled in the range 283 to 323 K. The capacitance is measured as a function of the temperature.
2	1st batch	To characterise MMH. The MMH tilled test cell is passivated for 10 hours. The temperature cycling between 283 and 323 K is done at a rate of 2 K per hour.
3	2nd batch	To characterise MMH for the second time. Test: same as test 2.
4	3rd batch	To characterise the MMH for a third time. Test: same as test 2.

The MMH characterisation has been done for three batches. The temperature cycling was from 283 to 323 K. The average pressure during the measurements was 1.2 ± 0.2 MPa (Helium pressurised). During the measurement of the first batch, the resistance and capacitance drifted. The second and third batch results do not show drift at all. An explanation for this is the fact that the test cell was passivated during the testing of the first batch. Therefore the data of the first batch will not be used in the evaluation. Figure 11 shows the from the capacitance derived permittivity as a function of the temperature. The temperature dependence is almost linear and can be approximated by: ε_r = 23.1 - 0.11 * (T - 273), (T in K). The error in the permittivity is the sum of the test setup inaccuracy (2 %) and the curve approximation of the curve (5 %), yielding a total error of 7 %.

The, from the measured test cell resistance derived, specific resistance of MMH, is depicted in figure 12. The figure shows that the specific resistance is about 400 Ω m at 293 K. The difference between batches 2 & 3 is ≈ 25 %, is probably due to small differences in water concentrations. The specific resistance can be approximated by: p = 8.2 * exp [1135.5/(T - 273)], (Ω m, T in K). During the measurements, the resistance of the test cell was about 100 Ω. The (capacitive) impedance turned out to be minimal 30 kΩ. As the resistance is much lower than the impedance, MMH can be considered to be an electrically conducting fluid, for frequencies up to 10 kHz.

Calibration results

Figure 7 shows the permittivity (derived from the capacitance) for water, in the temperature range 283 to 323 K. Values found in the literature are given also. The graph shows that the test setup measures the permittivity of water with an accuracy better than the required 2 %. The "waves" in the measured values are due to the temperature cycling. In bending points the temperature was kept constant for 2 hours, which leads to the more accurate values of these points. To verify the test setup for other permittivities, several liquids were used (Table 2). The literature values are compared with the measured ones.

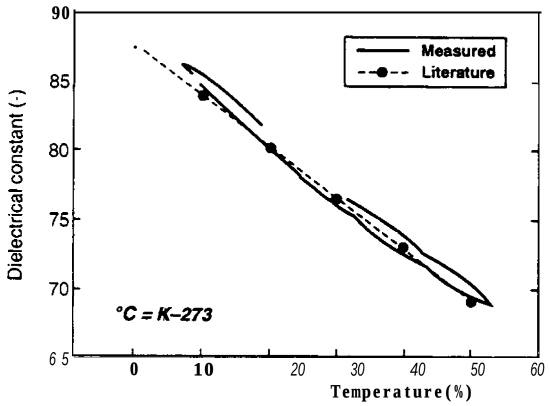

FIGURE 7. Calibration of Test Cell, Using Water.

TABLE 2. Measured and Literature Values of Permittivities of Liquids.

Fluid	E measured	E literature	relative error [%]
n-Octane	1.94	1.95	0.3
Ethylacetate	6.04	6.02	0.3
Methanol	33.44	32.63	2.5
Acetone	21.26	20.70	2.7

The measured permittivity is in good agreement (< 3 %) with the values from literature. It can be concluded that in this test setup the permittivity of a liquid can be measured (from 283 to 323 K) with accuracy better than 2 %.

Test results evaluation

The MON-1 characterisation has been performed for two batches. The temperature cycling was from 283 to 323 K. The average pressure during the measurements was 1 .18 ± 0.04 **MPa** (Helium pressurised). The figures 8 and 9 show the temperature cycle, the capacitance and resistance of the first and second batch. For the second batch some extra cycles have been done. These figures show that the capacitance is clearly temperature sensitive and that the resistance is high (> 3M Ω), but not clearly temperature sensitive.

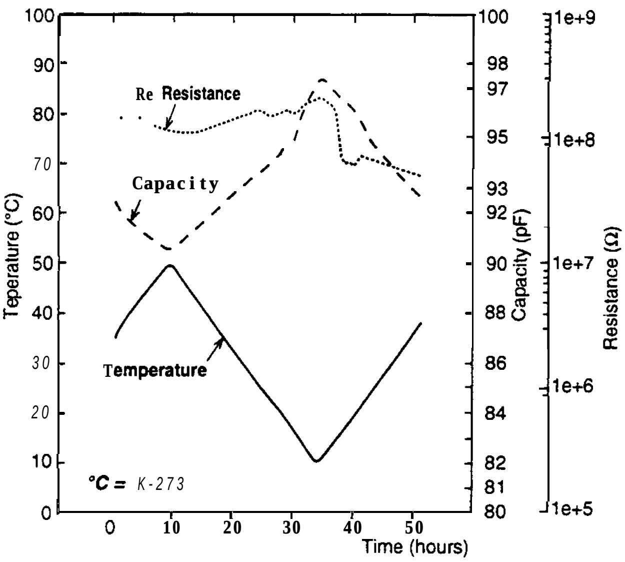

FIGURE 8. Capacitance & Resistance versus Temperature (1 st MON- 1 Batch).

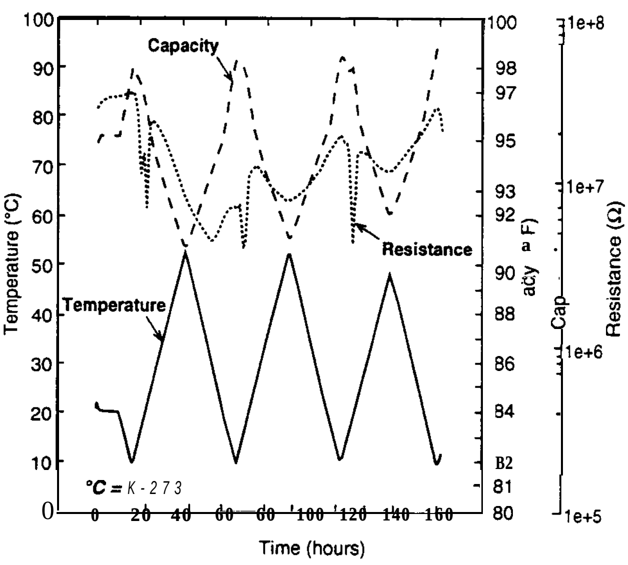

FIGURE 9. Capacitance & Resistance versus Temperature (2nd MON-1 Batch).

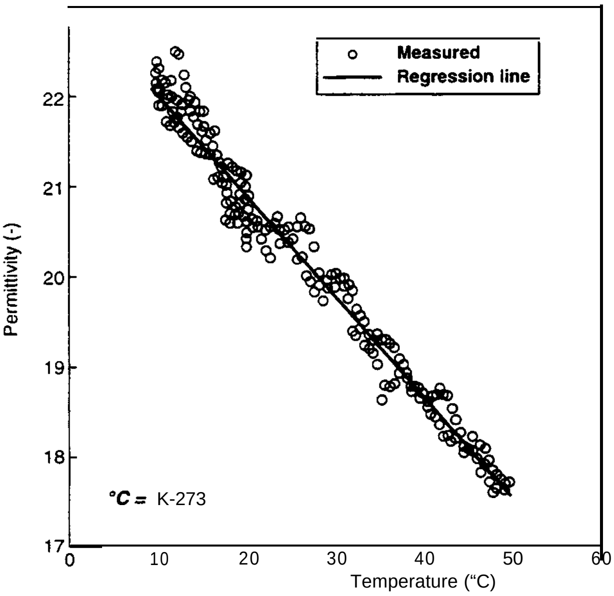

FIGURE 11. Temperature Dependence of Permittivity of MMH.

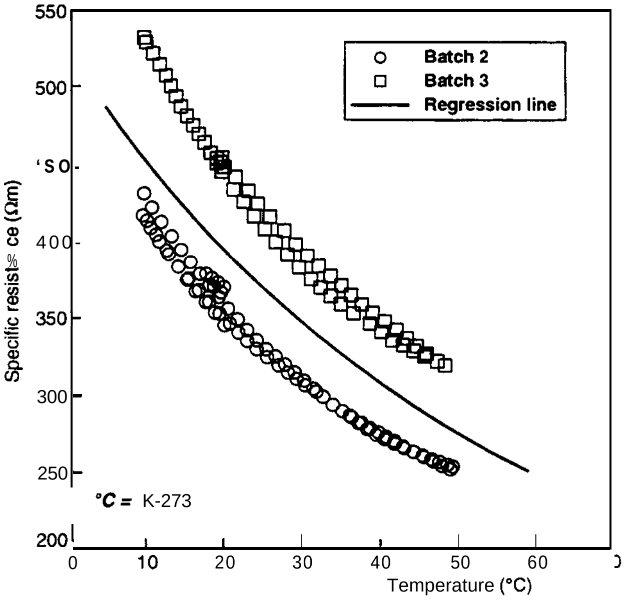

FIGURE 12. Temperature Dependence of Specific Resistance of MMH.

CONCLUDING REMARKS

A test setup to measure the dielectric properties (permittivity and electric conductivity) of propellants has been designed, manufactured and calibrated (using water, n-Octane, Ethylacetate, Methanol, Acetone). In this test setup the above dielectric properties have been experimentally determined for MON-1 and MMH, as a function of the temperature, under MSG propellant tank pressure conditions (Helium at ≈ 1.2 MPa). The data will be used to optimise Gauging Sensor Units developed to measure the level in propellant tanks of MSG spacecraft.

MON-1 confirmed to be a non-conductive liquid. MMH turned out to be a conducting liquid. As the electric conductivity is an error source for a propellant gauge with (a) non-coated electrode(s), it is obvious that electrodes covered with an electrically insulating coating are to be preferred for conducting propellants as MMH.

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