Measurement system for the parameters of satellite propulsion

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Section 1 – Launchers propulsion technologies and simulations of rocket engines

Abstract: *Within the STRAuSS (Advanced Solar Thermal Propulsion System for Increasing of Satellite Operational Life) project to investigate the extension of a satellite operation period, a new valve type and a new type of nozzle were designed. Extending the period of operation of the satellite propulsion is an important factor for increasing its activity period and reducing the production and launch costs. To measure the force generated when releasing propellant gas from the satellite reservoir, a dynamic fine-scale force measurement system has been designed. This system also measures experiment parameters such as: simulated solar radiation size, 4 key temperature and nozzle pressure. The system controls the action of the propellant gas release valve and the activation of lamps that simulate solar radiation from outer space. The system is based on acquisition modules connected to a touch panel computer. Establishing the measurement system and its calibration was an essential step in performing the experiments within the STRAuSS project.*

Key Words: *thermal propulsion, satellite operational life, measurement system, force measurement*

1. INTRODUCTION

Satellites have been receiving careful attention over the last decade. It has been proven that the cold gas propulsion system is the most suitable and successful low thrust space propulsion for satellites maneuvers, due to its low complexity, efficient use of propellant which presents no contamination and thermal emission besides its low cost and power consumed. This type of propulsion system have begun to be used in small satellites for a wide range of earth orbit since 60's. The major benefits obtained from this system are low cost, mass and volume.

The cold gas propulsion system consists mainly of a propellant tank, solenoid valves, nozzles, tubing and fittings (Fig. 1c) [2]. Usually the following gases are used as propellants: Hydrogen, Helium, Nitrogen, Ammonia, Carbon dioxide. Ammonia and carbon dioxide are non-ecological and for this reason they are not used. The most suitable and commonly used is Nitrogen gas, which is preferred for its storage density, performance, and lack of contamination concerns. By operating a micro switch fitted with a nozzle, the measurements of the propulsion force obtained by releasing the gas from the propellant tank it is an essential problem which needs to be solved. The satellites lifespan is mainly limited by the initial quantity of propellant. To reduce the necessary propellant quantity, in the case of cold gas propulsion systems working with gaseous N_2, the periodical heating of gas using concentrated solar light was considered [3]. The focusing system is composed of a very thin and precise parabolic mirror (0.5 mm thickness) made of polymer composites (Fig1 b). Using focusing systems made of carbon fiber composites, will permit a longer serviceable life of the satellite for the same quantity of propellant.

The main scientific/technical objective of STRAuSS project is: “Research, design, manufacture and testing of an advanced/original LEO satellite [1] with combined solar - thermal / cold gas (N_2) propulsion system which has an operational life which is longer by 2.5 times than the life of present LEO satellites with cold gas propulsion systems”. In the case of Low-Earth Orbit (LEO) satellites the orbit is affected by the dynamic drag in the rarefied atmosphere. As a result, the satellite changes its attitude and speed, this leading to orbit decay and burning of satellite in atmosphere. For this reason, the propulsion system corrects periodically the attitude of satellite or accelerates it for reestablishing of orbit parameters [6]. The present paper shows how to measure the propulsion force obtained by releasing a gas from the satellite reservoir by operating a micro switch fitted with a nozzle. This force is increased by heating the gas cylinder by a concave mirror that concentrates the sun's radiation. The installation is shown in Fig. 1.

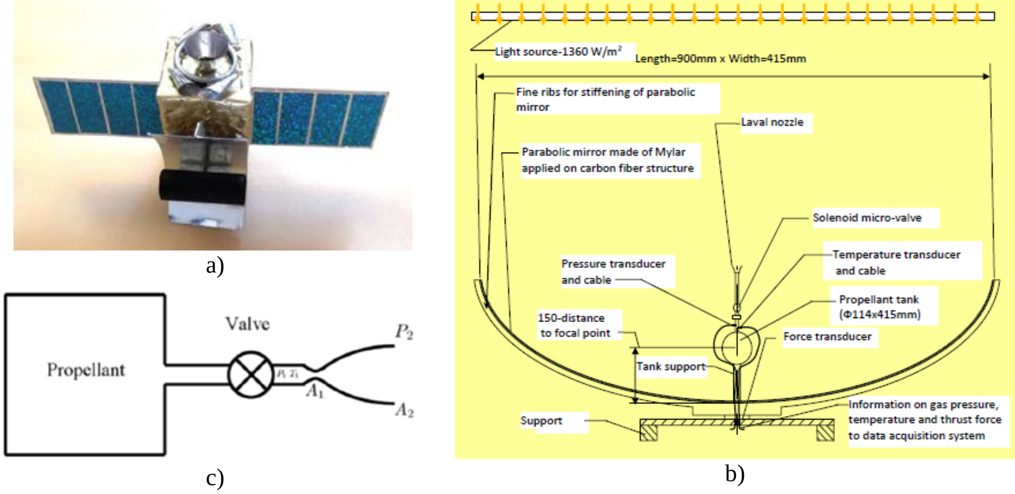

Fig. 1 – a) Satellite; b) Schematic diagram of propulsion system; c) Typical cold gas propulsion system

The system also measures the parameters related to the force, like temperature, gas pressure, the intensity of the radiation focused by the mirror.

2. MEASUREMENT OF PROPULSION FORCE

Analyzing the sketch of the installation, it can be seen that the force acting on the transducer is composed of the weight of the installation and the force generated by the expansion of the gas through the Laval nozzle.

$$F = G + Fe \tag{1}$$

The total mass of the installation comprising the gas tank, the mirror, the valve and the nozzle is about 20 kg. So the weight is equal to 20 daN.
In order to estimate the value of *Fe*, we simulated the exhaust gas through the Laval nozzle [7] during the valve action. The force in this case is given by the formula:

$$Fe = q \times Ve + (Pe - Pa) \times Ae \quad (2)$$

where:
q - propeller flow
Ve - velocity of the exhaust gas from the nozzle
Pe - pressure at the nozzle exit
Pa - ambient pressure
Ae - nozzle area at exit
For *q* = 0.02kg / s, *Pe* = 20bar, *Pa* = 1bar, *D* critic = 0.003mm, several simulations were made for different temperatures.
Fig. 2 shows the speed distribution in the field.

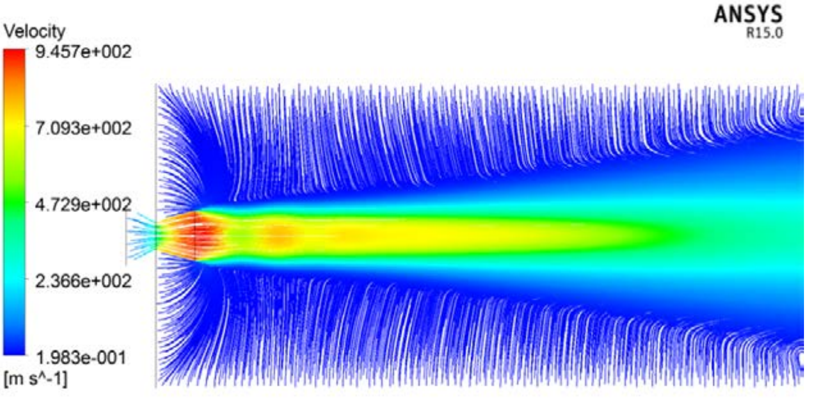

Fig. 2 – Speed distribution in the field [8]

For this case, a reactive force of 7.9385 N was obtained. For other cases, the Fe strength varied between 3.5 and 15 N. In conclusion, the force Fe is 10 times smaller than the force G of the installation. The force transducer must satisfy two antagonistic requirements. Its range of measurement must be large enough to measure the sum of the two forces, but it must be sufficient to accurately measure the force of the reactants. The difficulty in finding such a transducer has led to a change in the measurement solution.
To eliminate the influence of weight, the balance solution has been adopted. The drawing of the satellite propulsion force measurement is shown in Fig. 3.

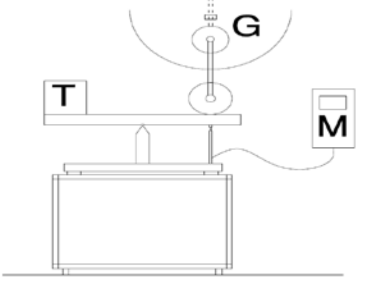

Fig. 3 – Measurement principle for propulsion force

In Fig. 3 the weight T cancels the influence of the weight of the satellite G propulsion system. The propulsion force is measured with an apparatus M having a measure extension provided with a rod fixed under the balance arm.

For the measurement of force, a device was used to measure the thrust force in [N] type SAUTER FH 50 EXT shown in Fig. 4, with the following technical features:

- display mode: Real Time Dynamics
- max load: 50 [N];
- resolution: 0.01 [N];
- precision: 0.5%;
- overload: 150%;
- test frequency: 2000 [Hz];
- PC interface: RS232;
- signal cable length 2.5 [m].

Fig. 4 – Digital dynamometer FH50 EXT

The force cell of the FH 50 dynamometer is mounted in an adjustable support under the active arm of the mechanical balance so that the adjustment point of the balance allows the scaling of the measured pushing force determined in a preferential area of the experiment.

To test the capability of the apparatus, an experiment was made with an available part, see fig. 5.

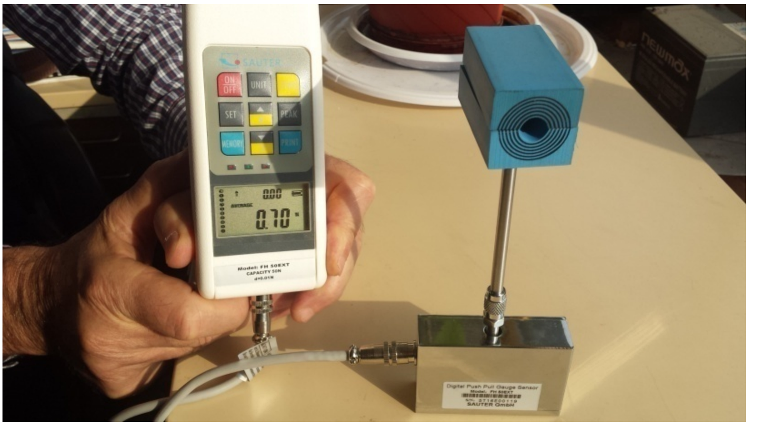

Fig. 5 – Example of force measurement with FH 50

The components from which the balance is comprised in the computer designed version are shown in Fig. 6.

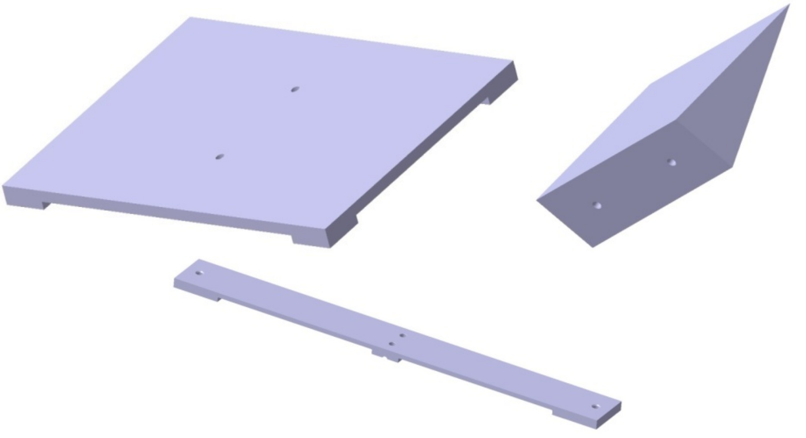

Fig. 6 – Balance components designed

Assembled balance is shown in Fig. 7.

Fig. 7 – Realized and assembled balance components

The fixing of the propulsion system on the balance is shown in Fig. 8.

Fig. 8 – Satellite propulsion fixed on balance [5]

The force measuring device allows both internal memory and display of measured values on a computer screen via manufacturer's software.
Communication with the computer is done through the serial port. Figure 9 shows the graph of measured values for the test.

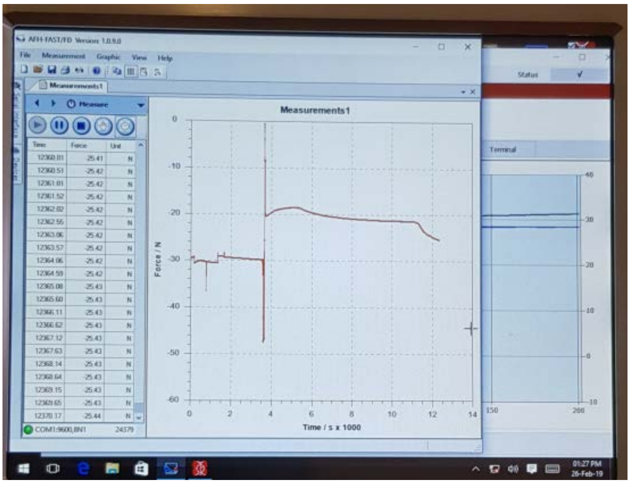

Fig. 9 – Graph example of force measured

3. RADIATION MEASUREMENT

The intensity of the radiation obtained by simulation with the help of some lamps is 1360 W / m2, which represents the intensity of the radiation at the limit of the atmosphere. The lighting system used by the STRAuSS test stand consists of 4 (four) lamps installed on the top of the skid (Fig. 8).
The power supply of the IR lamps will be made from the control box via a solid state switch for light intensity control.
Light intensity monitoring is done with a SPN1 sensor shown in Fig. 10

Fig. 10 – Digital pyranometer

The technical characteristics of the SPN1 equipment are:
- measuring range: 0 ÷ 2000 [W / m2];
- resolution: 0.6 W / m2;
- power supply: 12 VDC;
- operating temperature: -20 ÷ +70 ° C.

The PC interfacing connectivity variants are shown in Fig. 11. The pyranometer information is acquired from the analog output or via the RS485 serial interface connected directly to a computer's USB input through an adapter.

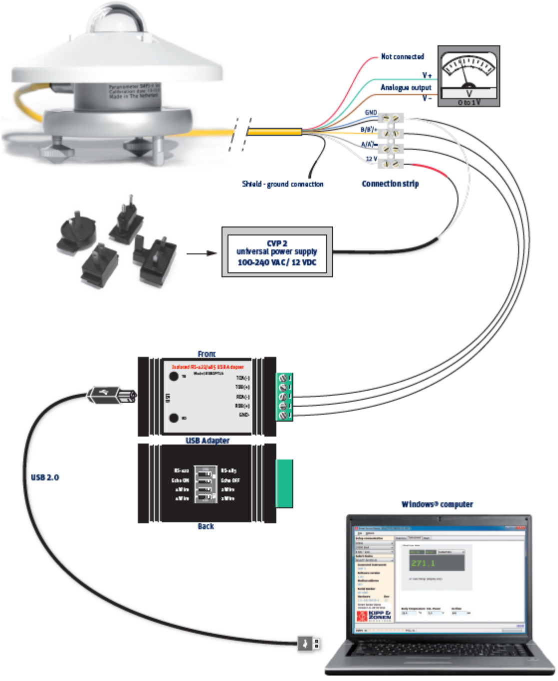

Fig. 11 – Connection and power supply of pyranometer [9]

4. TEMPERATURE AND PRESSURE MEASUREMENT

Temperature and pressure measurements are made using a NI cDAQ 9172 system from the National Instrument, connected to a Touch Panel Computer. The system is provided with T/C modules and with voltage measurement modules. Fig. 12 shows the system.

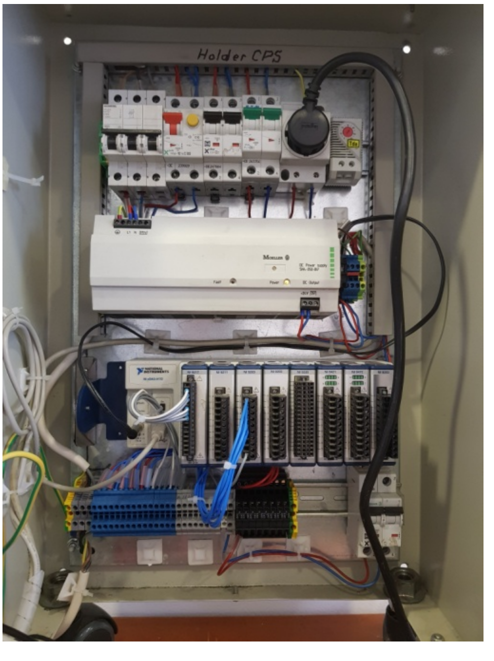

Fig. 12 – Measurement system for STRAuSS stand parameters

The image of control cabinet assembly is shown in Fig. 13.

Fig. 13 – Measurement system for STRAuSS stand parameters – overall image [4]

5. CONCLUSIONS

The paper presents a complete measurement system to acquire the operating parameters of the STRAuSS stand meant to verify the extension of the satellite resource by heating the propellant gas. An effective measurement of force has led to its accurate measurement. The accuracy of the force measurement and of the other parameters will lead to the validation of the design concept and its continuation through future research projects.

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[9] * * * Connection diagram SMP/SHP, KIPP & ZONEN.