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Research of Electrocapacitive Sensor for Detection of Leakages in Flow System Aboard Micro-satellite

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Abstract: The problem of reliability enhancement of power plants for micro-satellites is related to the need of assessing their technical state during continuous operation in space. The paper deals with an advanced method of calculating liquid consumption aboard a spacecraft. Electro-capacity meter in the oxidant and fuel pipelines as well as in on-board systems is proposed to be used as a primary transducer. The main advantage of this method is the small size of the sensor, lack of movable parts in it and ability to detect small liquid leaks. All these factors are very important for micro-satellite instrumental equipment. To verify the proposed method an experimental setup based on the measurement of fluid consumption in the capacitive measuring cell was made. With its help experimental dependence between the amount of fluid flow and the change in the rate of discharge of measuring capacitor in capacitive cell was obtained. The main goal of this article is to confirm the possibility of practical application of electro capacitive meter for measuring dielectric liquids consumption. Methods of increasing sensitivity of capacitance flow meter by using additional resistance and capacitance in the structure of primary transducer are considered as well.

Keywords: leakage control, fuel consumption, micro-satellites, dielectric fluid, capacitance flow meter

1. INTRODUCTION

Modern stage of space exploration creates a whole number of new problems in science and engineering which include such important problems as the design and development of improved propulsion engines for spacecraft. A typical liquid propulsion system consists of the combustion chamber, nozzle, fuel and oxidizer tanks and the means of delivering the fuel and oxidizer to the combustion chamber. Spacecraft should be equipped with propulsion system which will not only provide the estimated amount of propellant for a given trajectory but for orbital maneuvers as well. Fuel system used in a space craft (as well as cooling system) should provide delivery of liquid at high pressure under conditions of vacuum and zero-gravity as well as under other conditions connected with operation in space.

Thus, measuring consumption of liquids aboard micro-satellites is one of the important scientific and technical problems. It can be solved by using various methods of constructing measuring transducers. For example, flow meters with various turbines rotating in a liquid flow sensors estimating consumption according to pressure differential on the diaphragm or on a straight section of the pipeline, as well as flow meters, using inductive, ultrasound, laser, correlated and vortical methods are widely used.

However, despite the large number of known technical solutions, and many existing developments, research in this area continues due to the fact that the essential requirements for the accuracy, reliability, temporal stability of the basic characteristics, cost, dimensions, and ease of operation could not be realized in one or more optimal designs. Due to the shortcomings of known flow meters, their poor mass - overall performance, the high cost and low reliability in some cases they are not used at all.

Very attractive for ease of manufacture, simplicity and reliability of capacitive meters, which, except for a few (Kremlevskiy,1989), in practice, are not well known. The reason is that, despite the widespread of capacitive sensors (Puers, Robert, 1993), the physical processes occurring in the dielectric placed in an area between the electrodes are not yet completely understood. This is confirmed by numerous studies of the process of electrization of a moving fluid from the action of the external field (Touchard, 2001; Cotae, et al.,1999; Mefedova, Vlasov, 2003).

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2. THEORETICAL BACKGROUND

Research of the physical principle of measuring dielectric liquid velocity by capacitive sensor, which is essential for the constructing capacitance meter (Jackson, 2007; Gusev, Mulik, 1998), is quite important. Mechanism of such a meter is based on the change in capacitor charge when dielectric fluid moves through its plates.

If the capacitor is connected to the constant voltage source U_0 with internal resistance R_1, a capacitor charging current is expressed by the known formula:

$$i(t) = \frac{U_0}{R_1} e^{-\frac{t}{\tau}} \qquad (1)$$

where $\tau = R_1 \cdot S_1$. The charge Q, which accumulated on the plates of the capacitor will be as follows:

$$Q = C_1 \cdot U_0 \,. \qquad (2)$$

When power supply is disconnected the charge on a capacitor decreases gradually. Intensity of discharge depends on the temperature of the dielectric. Moreover, there is a self-discharge effect, which always occurs in real dielectric. For simplicity, let us consider the parameters of the interim self-discharge of the capacitor, the time constant τ_p. For the avoidance of doubt, it is necessary to use a range of time constants characterizing different physical processes of self-discharge. As a rule, its values are quite large and on a number of estimates makes units or tens of seconds.

Charged capacitor for some time retains its charge if dielectric is polarized and if voltage retains between transducer electrodes. If the dielectric starts to move between electrodes, part of the charge will be carried away, thus reducing the charge in the capacitor and reducing the stresses on the plates. The higher the velocity of dielectric liquid, the larger the reduction of the charge. Evaluating it, we can get an electric signal, with the help of which one can estimate liquid velocity.

Remaining volume of the dielectric fluid between the electrodes will keep some residual polarization, if its motion is laminar. Polarization in turbulent motion should quickly be disappearing. Defining the time interval during which the polarized volume of fluid goes forward for a certain distance, one can estimate the liquid flow as it moves through the pipeline with the known cross section.

Not appreciating the features of physical processes that are not fully explained even in the simplest of solid capacitors, consider only their consequences as important for the development of flow meters. A number of physical phenomena can be used, namely the change of:

- leakage current of a charged capacitor, depending on the speed of the dielectric fluid with respect to its electrodes;
- "apparent" capacitance and the alternating electric current flowing through the capacitor when dielectric flows by the plates;
- the voltage drop across the capacitor, resulting in charging it with direct current for a certain period of time;
- the curve of the charging current of the capacitor depending on the speed of movement of the dielectric liquid;
- the charge on the capacitor due to its additional self discharge as result of part of the charge being carried away by the dielectric fluid;
- the charge possessed by the capacitor, from the arrival of fluid, pre-polarized by flowing through another capacitor;
- time for which the electrostatic marks formed in the liquid appear at the capacitor that functions as a source of information signal.

An electrical signal carrying useful information is to some extent dependent on the nature of fluid motion in a chamber of the flow meter. If the motion is laminar, all these physical properties and phenomena can be used. When the motion is turbulent, where it is difficult to expect keeping polarization created in the liquid, the last two phenomena cannot be used. Values of the signals carrying information about the instantaneous momentary consumption for laminar and turbulent motions are calculated by different formulas.

Despite the apparent simplicity of the considered technical solution, its mathematical modeling is a rather difficult task with many unknown yet parameters even in cases when the motion of a dielectric liquid is laminar. This is due to the fact that from mathematic point of view problem is boiled down to the description of the electric circuit, which refers to parametric ones. Its mathematical model is a differential equation with variable coefficients. The nature of these coefficients depends on the flow rate and flow of design features that are yet to be established.