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Acoustic waves in piezoelectric plates in contact with gasoline

Iren KUZNETSOVA[1]; Anastasia KUZNETSOVA[1]; Boris ZAITSEV[2]; Andrey TEPLYKH[2]

[1] Kotelnikov Institute of Radio Engineering and Electronics of RAS, Russia

[2] Kotelnikov Institute of Radio Engineering and Electronics of RAS, Saratov Branch, Russia

ABSTRACT

We studied the properties of SH_0 wave in $LiNbO_3$ plate which was in contact with gasoline. The dependencies of phase velocity vs on parameter hf (h is a plate thickness, f is a wave frequency) were plotted. The influence of various types of gasoline on the wave properties has been studied. In the future it will be good to investigate influence of viscosity on the investigated parameters. The obtained results confirmed that it is possible to develop a gasoline identifier based on SH_0 wave in YX-$LiNbO_3$ plate. It has been found that the velocity of SH_0 wave in YX $LiNbO_3$ plate decreases with the increase of permittivity of gasoline or its octane number. In this case the frequency decreases with growing gasoline octane number.

Keywords: gasoline identifier, lithium niobate plate, octane number

1. INTRODUCTION

Recent motor gasolines present as a rule mixtures of components which are obtained by using various technological processes. Gasolines can contain more than 200 individual differently structured hydrocarbons depending on the hydrocarbon composition of raw material whose content and interaction define the gasoline properties. The quality of market gasoline components used in oil refinery plants is assessed with the use of standard laboratory methods at the values of physical and chemical properties normalized with appropriate documents [1]. Such a procedure requires cost equipment and complicated techniques. So the development of a sensor for the express analysis of gasoline acquired at gasoline station is quite important. Such a sensor should allow one to identify gasoline for its real octane number consistency with the gasoline octane number stated by a selling office. The available papers suggest usually to evaluate the gasoline quality by its viscosity [2]. In Ref. [3] they show a theoretical possibility of defining the viscosity and dielectric permittivity of liquid using a quartz torsion resonator. Recently it was suggested to use the self-excited oscillator the feedback of which contains the delay line based on the plate of Y – X lithium niobate with propagating acoustic wave with shear – horizontal polarization [4] for realization gasoline identifier. The liquid container with gasoline under study is placed on the path of acoustic wave. It has been shown that the frequency oscillation is unambiguously connected with permittivity of gasoline, which in one's turn is determined by its octane number [4]. In Ref. [5] it was suggested to realize the sensor for express analysis of gasoline octane number based on the lateral electric field excited resonator. In this paper we discussed the properties of SH0 acoustic waves in structure “piezoelectric plate-gasoline”.

2. THE MEASUREMENT OF THE DEPENDENCE OF THE RELATIVE PERMITTIVITY OF GASOLINE ON ITS OCTANE NUMBER

It is obvious that for the development of the sensor for express analysis of the octane number of gasoline one needs to know its parameter, which is unambiguously determined by its octane number. As it has been pointed this parameter is permittivity. The Table 1 contains the region of admissible values of permittivity for three values of octane number: 80, 92, 95 and their averaged values [6].

[1] kuziren@yandex.ru
[2] zai-boris@yandex.ru

Table 1 – Physical parameters of liquids

Octane number	80	92	95
The regions of admissible values of permittivity [6]	2 – 2.062	2.08 – 2.115	2.145 – 2.205
Averaged values of permittivity [6]	2.031	2.0975	2.175
Measured values of permittivity	2.084	2.148	2.2

The aforementioned grades of gasoline are standard for Russian market. We have measured the values of permittivity for these grades, which are also presented in the Table 1. Below the method of the measurement is described.

For measuring the permittivity the plane air capacitor with shear dimensions of 20×20 mm2 and with the gap of 1 mm was fabricated. The capacity of this capacitor in air was measured with the help of LCR meter 4285A (Agilent). Then capacitor was immersed into sample of gasoline under study and capacity was measured again. With the assumption that relative permittivity of the air is equal 1 the sought permittivity of gasoline was determined as ratio of capacity in gasoline and capacity in air. The obtained data for three grades of gasoline are also presented in Table 1. One can see that they are close to the values, which are taken from literature. Figure 1 shows the dependence of measured permittivity of the gasoline on its octane number. It is evident that permittivity of gasoline insignificantly increases with increase of the octane number.

3. THEORETICAL ANALYSIS

Let us consider the propagation of SH_0 wave in a “vacuum – YX $LiNbO_3$ plate – gasoline” structure. The geometry of the problem is presented in Fig.1. We consider a two dimensional problem where all field components are assumed to be constant in the x_2 direction. To analyze the wave propagation at a fixed temperature we have used the motion equation, Laplace’s equation, and constitutive equations for piezoelectric media [7]:

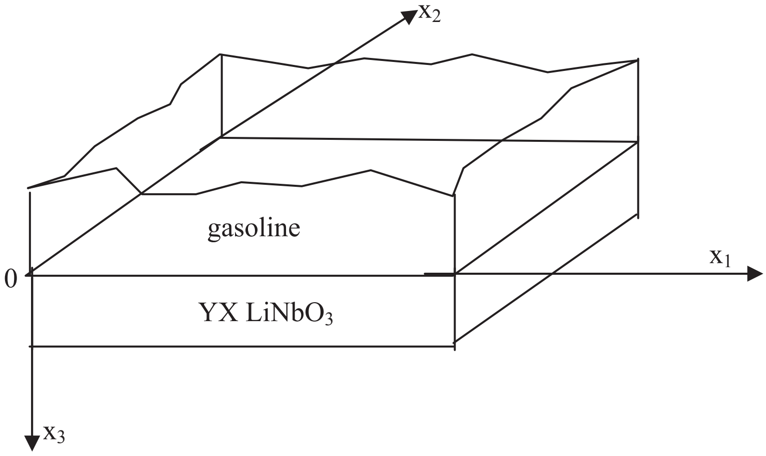

Figure 1- Geometry of the problem

$$\rho\, \partial^2 U_i \big/ \partial t^2 = \partial T_{ij} \big/ \partial x_j \tag{1}$$

$$\partial D_j \big/ \partial x_j = 0, \tag{2}$$

$$T_{ij} = C_{ijkl}\, \partial U_l \big/ \partial x_k + e_{kij}\, \partial \Phi \big/ \partial x_k, \tag{3}$$

$$D_j = -\varepsilon_{jk}\, \partial \Phi \big/ \partial x_k + e_{jlk}\, \partial U_l \big/ \partial x_k. \tag{4}$$

Here ρ is medium density, U_i are components of mechanical particles displacement, t is time, T_{ij} are components of mechanical stress tensor, x_j are coordinates, D_j are components of electrical displacement, C_{ijkl}, e_{ijk}, and ε_{jk} are elastic, piezoelectric and dielectric constants, respectively, and Φ is electrical potential.

We used the condition of quasistatic approximation:

$$E_i = -\partial\Phi/\partial x_i \quad (5)$$

where E_i are the components of electric field intensity.

For liquid we have to use the motion equation, Laplace's equation and constitutive equations in the following form [8]:

$$\rho^{lq}\,\partial^2 U_i^{lq}/\partial t^2 = \partial T_{ij}^{lq}/\partial x_j \quad (6)$$

$$T_{ij}^{lq} = C_{ijkl}^{lq}\,\partial U_l^{lq}/\partial x_k . \quad (7)$$

$$\partial D_i^{lq}/\partial x_i = 0 \quad (8)$$

$$D_i^{lq} = -\varepsilon^{lq}\,\partial\Phi^{lq}/\partial x_i \quad (9)$$

Here ε^{lq} is permittivity of a liquid.

The mechanical and electrical boundary conditions at the plane x_3=0 were written as [9]

$$U_3 = U_3^{lq}; T_{i3} = T_{i3}^{lq} \quad (10)$$

$$\Phi = \Phi^{lq}; D_3 = D_3^{lq}. \quad (11)$$

We used gasoline with C||=1.0092 Pa/s and ρ=800 kg/m3 for the study. Its permittivity changed in a range from 1.2 to 2.2. We considered the experimental case when parameter hf = 720 m/s (h is the plate thickness, f is the wave frequency). We used the material constants of lithium niobate from Ref. [10]. The SH_0 wave velocity for the YX $LiNbO_3$ plate without adjacent liquid was 4413.291085 m/s at hf = 720 m/s.

Fig.3 shows the fractional change in velocity of SH_0 wave in the YX $LiNbO_3$ plate to decrease with increasing permittivity of gasoline. The wave phase velocity changes from 4413.29 m/s up to 4400.14 m/s with the increase of εlq from 1.2 to 2.2 when both surface of plate are electrically open. Analysis has also showed that the presence of gasoline does not lead to noticeable attenuation of SH_0 wave (10^{-4} dB per wavelength).

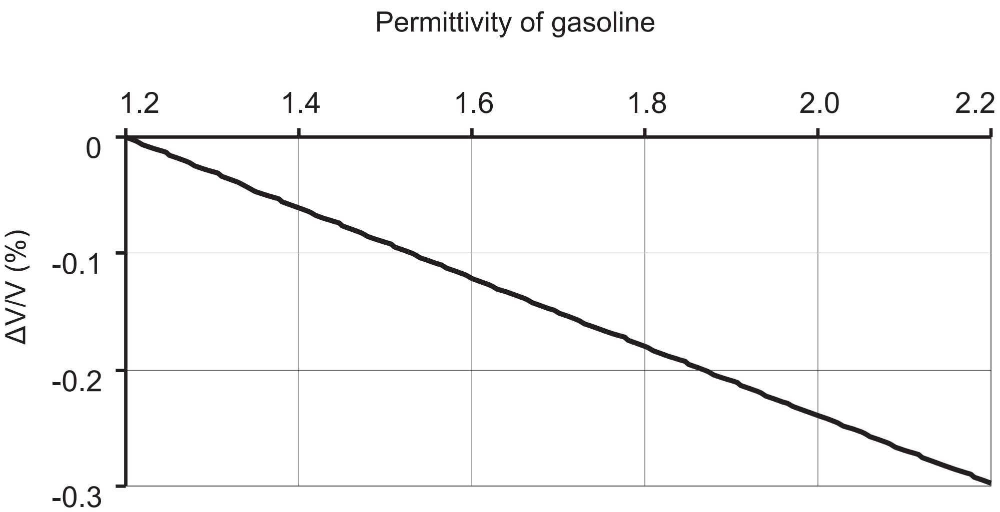

Figure 3 - Fractional change of SH_0 wave velocity in the "gasoline – YX$LiNbO_3$ plate-vacuum" structure versus permittivity of gasoline at hf = 720 m/s

4. CONCLUSION

We have theoretically studied the influence of various types of gasoline on the phase velocity of SH_0 wave in YX-$LiNbO_3$ plate. In the future it will be good to investigate influence of viscosity on the investigated parameters. The obtained results confirmed that it is possible to develop a gasoline identifier based on SH_0 wave in YX-$LiNbO_3$ plate. It has been found that the velocity of SH_0 wave in YX $LiNbO_3$ plate decreases with the increase of permittivity of gasoline or its octane number. In this case the frequency decreases with growing gasoline octane number.

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