An optoelectronic fuel level sensor

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Abstract. The block and schematic construction diagrams of a new optoelectronic fuel level sensor are considered. The operating principle of the sensor is based on registering the intensity value of the optical path reflected from the mirror, located on the reservoir bottom.

Introduction. Optical techniques are widely used to measure fluid flow parameters and less frequently used to measure the liquids level, the fuel level, in particular. The reason is that the impact on measurement accuracy is caused by the change of radiation source (RS) power, as well as total sensitivity and internal resistance of radiation detectors (RD) due to temperature [1, 2].

Materials and methods
To solve the assigned task, 1) the optical path, which converges at the calculated angle relatively the optical axis of the optoelectronic fuel level sensor (OEFLS), forms; the optical path proceeds a part of the track to the mirror through the medium with refraction coefficient \(n_0\), and the second part of the track – in the medium, the level of which is measured, with refraction coefficient \(n_1>n_0\), thus the optical path reflected by the mirror is registered; 2) the gain-phase method of signal transformation is used [4, 5].

A block diagram and design of the sensor. Paper [3] introduces a new technique to measure the fuel level by recording the intensity value of the optical path reflected from the mirror on the reservoir bottom or another level of the reservoir.

The optical path, converging by the calculated optic axial angle, is formed, one part of the optical path towards the mirror is going through the medium with refraction index \(n_0\), and the other part – through the medium with refraction index \(n_1>n_0\), its level being measured and the optical path being reflected from the mirror being registered. In order to implement the given algorithm of optical signals conversion, the block diagram (Figure 1) and construction design for the optoelectronic fuel level sensor (OEFLS) (Figure 2) have been developed.

Body 1 contains tightened holder 2 with four rolled in lenses 6. Light emitted diodes (LEDs) 3 are mounted in these lenses focus. Operating photodiode 5 is set up in the centre of holder 2, and lens 7 is rolled in closer than the focus distance. Compensating photodiodes 4 are mounted in close proximity to LEDs 3. The axes of LEDs 3 and photodiodes 4 are mutually perpendicular. Photodiodes 4 are supposed to compensate the change of LEDs 3 radiation power under the ambient temperature shift.
ORD – operating radiation detector; RS – radiation sources; CRD – compensating radiation detector; ST – scaling transducer; GU – generating unit; PSC – phase-shifting circuit; PI – phase indicator; Σ – adder; SC – scaling contour; OMT – optoelectronic measuring transducer; SR – specular reflector.

Figure 1. The block diagram of the optoelectronic fuel level sensor

Holder 2 is mounted in body 1 and tightened by first nut 9. PC-board 8 is tightened inside body 1 with the help of second nut 9. PC-board 8 contains integrated circuit 544УД1А, acting as a scaling transducer and a phase-shifting circuit. The sensor is connected to an intermediate transducer through the cable and plug 15. Plug 15 is inserted in sleeve 14, which, in turn, is sealed into body 1. Prior to mounting collar 14 with plug 15, the sensor’s body cavity is first treated under vacuum and then filled up with premium grade argon (National State Standard ГОСТ 10157-79). Glass 12 is mounted at the butt end of body 1 and is sealed against O-ring 11 to guarantee the structural integrity. O-ring 11 is tightened up with nut 13 to stay fixed in body 1. Nuts 10 are used to mount the sensor in a reservoir. Mirror 16 is a polished metal plate.

In order to ensure the sensor’s high reliability while in operation, structural and assembly parts are to be fastened by welding and soldering.

OEFLS operates as follows: luminous fluxes out of LEDs 3 go through lenses 6 and at an angle of α, they first go through air to the sensor optical axis, and then - through the liquid, which level is being measured. When the luminous flux reaches the interface of two media with different refraction indexes n0 and n1, they refract and then expand at an angle of β in the direction of mirror 16. Being reflected from the mirror, luminous fluxes make a return path and, having gone through lens 7, are focused upon the photosensitive surface of photodiode 5.

Transformation function. Luminous fluxes $F_{i0}$ of radiation sources $RS_1...RS_4$ are modulated by sine-curve voltage of low frequency generator unit $GU_{~}$, and then, by means of the optical system they are transferred into a measurement area onto specular reflector $SR$. Luminous fluxes cover one part of path $h_i$ in the air, and the other part $x_i$ - in the liquid, which level is being measured. Luminous fluxes, reflected from the mirror, reach the operating radiation detector (ORD), where they are converted into electric signal $U_f(x)$. Some parts of luminous fluxes of $RS_i$ reach compensating radiation detectors $CRD_1$, ..., $CRD_i$ directly, where they are converted into constant electric signals $U_{CRD_1}...U_{CRD_i}$, which are summarized in the join point. Signal $U_f(x)$ and combined compensating signal $U_C$ are scaled to levels $U_1(x)$ and $U_2$ at scaling transducers $ST_1$ and $ST_2$, respectively, and then signals are shifted at an angle of $\varphi_{12}$ relative to each other with the help of the phase-shifting circuit (PSC). Initially signal $U_2$ is shifted at an angle of 180 degrees relative to signal $U_1(x)$ (Figure 3). Signals $U_1(x)$ and $U_2$ reach adder inputs, where they are summarized geometrically. Signal $U_2(x)$ goes
from the adder output onto one of the inputs of phase indicator PI, the other input of which receives a reference signal: either $U_{\sim}$, or $U_{1}(X)$, or $U_{2}$.

1- body, 2 - holder, 3 - LEDs 3L107B, 4 - compensating photodiodes PD-19KK, 5 - operating photodiode PD20-32K, 6, 7 - lenses of a smaller and bigger diameter, 8 - printed-circuit board, 9 - inner nuts, 10 - mounting nuts, 11 - O-ring seal, 12 - safety glass, 13 - nut, 14 - collar, 15 - plug ST1-10-5-V, 16 - mirror.

Figure 2. The Construction Design for the Optoelectronic Fuel Level Sensor

The conversion function of OEFLS is written as:
\[ \varphi = \arctg \frac{\sin \varphi_{12}}{\cos \varphi_{12} + \frac{R_{ORD}(\Delta F)_1}{R_{ORD}(\Delta F)_1 + R_{ST1}}}, \] (1)

where \( R_{ORD}(X) \), \( R_{CRD} \) - conversion ratios of luminous flux for ORD and CRD; \( R_{ST1} \) and \( R_{ST2} \) - shrinkage ratios of ST1 and ST2, respectively; \( R_{PSC} \) - transfer ratio of PSC; \( S_{V1}, S_{V2} \) - voltage sensitivities of ORD and CRD, respectively.

Basic elements responsible for sensor temperature error \( t \) are RS, RD and measuring circuit:

\[ \Delta t = \sqrt{\left( \Delta t_p \right)^2 + \left( \Delta t_s \right)^2 + \left( \Delta t_{HC} \right)^2}, \] (2)

where \( \Delta \varphi_p, \Delta \varphi_s, \Delta \varphi_{HC} \) - temperature errors, caused by the change in the power of radiation source (RS), total sensitivity of radiation detectors (RD), and parameters of the measuring circuit (MC).

When measuring the ambient temperature, the radiation power of RS and the total sensitivity of RD change.

Then:

\[ \Delta \varphi_t = \sqrt{\left( \Delta \varphi_p \right)^2 + \left( \Delta \varphi_s \right)^2 + \left( \Delta \varphi_{HC} \right)^2}, \] (3)

where \( \Delta \varphi_p, \Delta \varphi_s \) - measurement errors conditioned by the change in radiation power of RS and total sensitivity of RD, respectively.

In order to reduce the temperature error, it is necessary that \( \Delta \varphi_p = \Delta \varphi_s \), that is, the changes of phase \( \varphi \) of sum signal \( U(x) \), caused by the change in the radiation power of RS and by the change in photosensitivity of RD, mutually compensated. This is possible in case of the following equality:

\[ \arctg \frac{\sin \varphi_{12}}{\cos \varphi_{12} + \frac{S_{V1}}{S_{V2}} f(\Delta F) R_{ORD}(X)} = \arctg \frac{\sin \varphi_{12}}{\cos \varphi_{12} + \frac{R_{IS}}{K_{2S}} \sum_i R_{IS} \sum_i R_{PSC} \sum_i R_{ORD}(X)}, \] (4)

where \( f(\Delta F) \) - some nonlinear function depending on the luminous flux of RS, where \( \Delta F \) is additional luminous flux of RS conditioned by the change in the radiation power of RS and total sensitivity of RD, respectively.

The stated equality is possible in case the radiation power of RS and the ratio of RD photosensitivities change will vary in opposite directions along with the ambient temperature change. For instance, when the ambient temperature rises, the RS power will increase, while the ratio of RD will decrease. It is possible to obtain a similar equality by changing the ratio of the number of ORD and CRD, as well as by changing the CRD position relatively RS (for example, bringing it closer to RS or, otherwise, moving away).

If the level indicator is built according to the scheme, shown in Figure 1, to obtain full temperature compensation, it is necessary to fulfill condition 5:

\[ \arctg \frac{\sin \varphi_{12}}{\cos \varphi_{12} + \frac{4}{\sum_i R_{IS} R_{PSC} R_{ORD}(X)}} = \arctg \frac{\sin \varphi_{12}}{\cos \varphi_{12} + \frac{4}{\sum_i R_{IS} R_{PSC} R_{ORD}(X)}}. \] (5)

The studies have demonstrated that in order to reduce the value of the error caused by ratios RST1, RST2, RPSC change, it is necessary to arrange parts ST2 and PSC3 out of the disturbing factors range;
to arrange ST1 in the OEFLS housing, as it serves as amplifier UP(X) of a small-signal, the transmission of which via the electrical cable is impossible without preamplification.

\[ U_k^H(\varphi) \]

index «H» refers to the signals corresponding to the opening of the measurement range, index «K» refers to the signals corresponding to the ending of the measurement range.

**Figure 3.** A vector diagram of OEFLS signals.

The study has defined that to reduce the temperature error caused by \( S_{V1}, S_{V2} \) nonproportional changes under the ambient temperature shift, it is necessary to use single-type radiation detectors with the same point of sensitivity deviation, which leads to partial compensation of the temperature error.

**4. Conclusion**

The reduction of temperature error of OEFLS can be achieved by:
- application of amplitude-phase transformation of signals;
- introduction of additional compensating channel;
- using ORD and CRD of a single type;
- changing of the quantitative ratio of RS in RD;
- changing of the ORD position relatively RS.

New OEFLS will have the temperature error which is no more than 1...2 %.

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