Influence of structural parameters on instrumental error of electromagnetic log sensor

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Abstract. Instrumental error of an electromagnetic log sensor at depths of more than one kilometer is studied. Operating principle of the electromagnetic sensor is shown and a mathematical model is developed. Analysis of sensor-registered speed dependence on external hydrostatic pressure is presented. It is demonstrated that an additional instrumental error occurs in the electromagnetic sensor due to the structure deformation during deep-sea submersion. It has been found that the value of relative error depends on design parameters and operational conditions of the sensor. It is shown that even when deep-sea vehicles travel at a low speed, the error caused by external hydrostatic pressure can make up a significant portion of the instrumental error and should be taken into account during operation. The design parameters of the sensor, affecting its instrumental error are determined. The influence of temperature on this error is studied. The ratio of design parameters at which the instrumental error does not exceed the permissible value is identified.

Introduction

The instrumental errors of an electromagnetic log sensor (hereinafter sensor) can be divided into methodological errors related to the method of measurements, and instrumental errors caused by environmental effects. Different types of these errors, the causes for their occurrence, and the methods of their control are rather fully described in [1–4].

When designing sensors for deep-sea vehicles operating under high hydrostatic pressure (HP) (up to 60 MPa), it is essential to provide for required rigidity and durability of their structural elements. Since the rigidity and durability are finite, the HP effect leads to certain deformations, the magnitude of which is proportional to pressure. The deformations cause relative motion of the structural elements due to the difference in their physical and mechanical characteristics (heterogeneity of the structure), which induces an additional instrumental error. Its magnitude depends on the structural parameters (SP) and the operation conditions of the sensor. This kind of the sensor error does not have a significant effect on the log measurements at small depths or during surface operations, so it was not taken into account previously. However, during deep water operations, e.g. submersions to 6 km, and with a certain ratio of SP of the sensor, the said error can reach several percent and needs to be taken into account [5].

This work deals with the analysis of the SP influence on the instrumental error caused by high HP.

1. Hydrostatic pressure influence on the sensor's error

While operating the sensor under the effect of external HP and temperature fluctuations, its structural elements experience deformations, so that their relative position changes. Due to the relative

displacement of the structural elements, electrodes in particular, the electromagnetic characteristics of the sensor change, thus leading to the sensor readings alteration. Relative displacements of the elements depend on the finite rigidity of the structure and cause additional instrumental error of the sensor. Relative error δV of the sensor, represented in Fig. 1, depends on HP and is written as follows [5]:

$$\delta V(P) = 1 - \left(\frac{R^2 + \left(l_1 \left(1 - \frac{P}{E_1} \right) + l_2 \left(1 - \frac{P}{E_2} \right) \right)^2}{R^2 + (l_1 + l_2)^2} \right)^{1,5}, \quad (1)$$

where P is hydrostatic pressure, Pa; E_1 is Young's modulus of the electrode material, Pa; and E_2 is Young's modulus of compound, Pa.

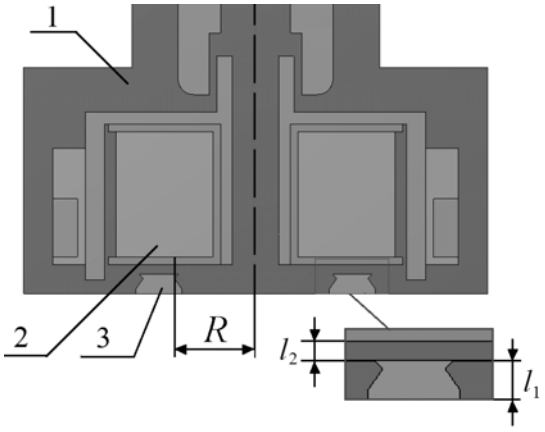

Fig. 1. Electromagnetic log sensor structure 1 – compound; 2 – coil; 3 – electrode; R – medial radius of the inductor; l_1 – electrode height ; l_2 – compound layer height under the electrode.

It follows from the expression (1) that the relative error of the sensor caused by the structure deformations depends on the HP value (P) and the sensor SP such as dimensions of its elements (R, l_1, l_2) and properties of the materials used (E_1, E_2).

Some values of the sensor relative error calculated according to the expression (1) for different values of the parameters R, l_1, l_2 are given in Table 1. Calculations were done with the HP value P = 60 MPa, which is equivalent to submersion depth of 6 km.

Table 1. Values of relative error of the sensor with varying structural parameters

R, mm	l_1, mm	L_2, mm	δV	R, mm	l_1, mm	l_2, mm	δV
2	2	2	0.247	10	2	2	0.0043
2	2	5	0.0397	10	2	5	0.0142
2	5	2	0.0172	10	5	2	0.0061
2	5	5	0.0296	10	5	5	0.0154
5	2	2	0.0121	15	2	2	0.0021
5	2	5	0.285	15	2	5	0.0077
5	5	2	0.0124	15	5	2	0.0033
5	5	5	0.0247	15	5	5	0.0095

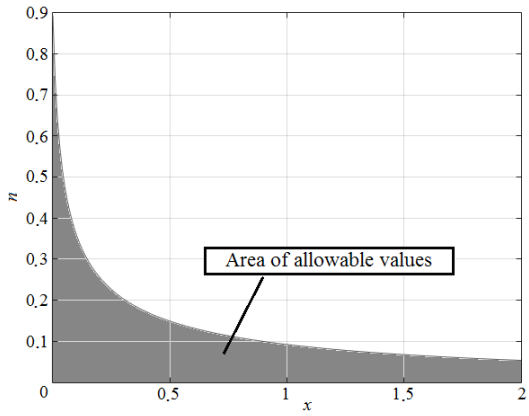

Fig. 3. Area of allowable values of structural parameters n and x at k=26; δV_0=0.02; X=7.5·10^{-4}; ψ=1.05.

If the parameter k is varying, the area of allowable values of the SP is limited by the surface (Fig. 4).

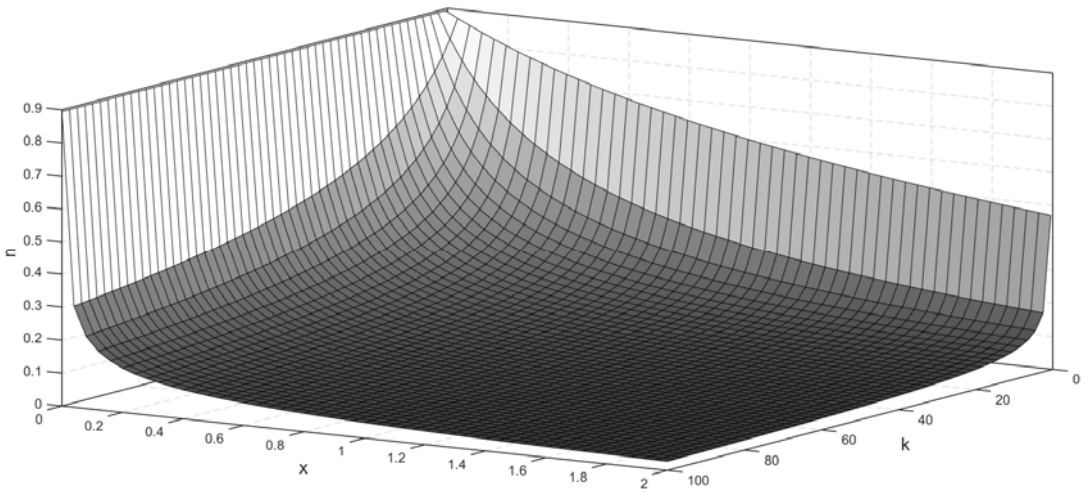

Fig. 4. Area of allowable values of structural parameters n, x and k at δV_0 = 0.02; X = 7.5·10^{-4}; ψ = 1.05.

The expression (13) makes it possible to choose the ratio of the sensor's SP at which the instrumental error of the sensor, which takes into account the structure deformation caused by HP, does not exceed the allowable value. Thus, using the expression (13), the error of the sensor, caused by the effect of HP, can be taken into account as early as at the design stage.

Conclusions

An additional instrumental error of the electromagnetic log sensor has been determined, which occurs under exposure to external hydrostatic pressure and depends on the finite rigidity of the structural elements. Analytical expressions have been derived, which make it possible to estimate the level of the sensor error under conditions of varying stress-strain state. It has been shown that with certain ratios of the structural parameters, the discussed error reaches a value of more than 3%. It has been found that temperature fluctuations within the acceptable range do not make a significant contribution in the error variations. An expression has been presented, which allows the ratio of structural parameters under given operating conditions to be chosen so as to ensure that the instrumental error does not exceed the allowable value. Knowing the dependence of the instrumental error of the sensor on the magnitude of the external hydrostatic pressure, it is possible to work out a correction to the sensor readings depending on the submersion depth.

REFERENCES

[1] Vinogradov, K.A., Koshkarev, V.N., Obyukhin, B.A., and Khrebstov, A.A., *Absolyutnye i otnositelnye lagi* (Absolute and Relative Logs), *Sudostroenie*, Leningrad, 1990.

[2] Saranchin, A.I., Polkovnikov, V.F., and Zav'yalov, V.V., *Elektromagnitnyi elektronnyi lag IEL-2M: Uchebnoe posobie* (Electromagnetic Electronic Log IEL-2M: Study Guide), Vladivostok, 2003.

[3] KorsunskiI, L.M., Electromag*nitnye gidrometricheskie pribory* (Electromagnetic Hydrometric Instruments), Moscow: Standart GIZ. 1964.

[4] Itenberg, S.I., Dvornikov, A.P. and Balashkov, I.V., Logs and dead reckoning // Ship navigation course. t.5, book 3. L.: UGSVMFF, 1964. – 542 p.

[5] Avanesov Yu.L., Evstifeev M.I., Voronov A.S. Estimating the instru-mental error of electromagnetic log sensor in ultradeep water// International Work-shop Navigation and Motion Control 2017: Proceedings – 2017. – pp. 62–67.

[6] CONCERN CSRI ELEKTROPRIBOR, JSC– LEM2-1M. Electromagnetic log [Electronic resource]. Access mode: http://www.elektropribor.spb.ru/katalog/navigatsionnye-pribory/lem2-1m-elektromagnitnyy-lag/

[7] Bell J.F. The Experimental Foundations of Solid Mechanics. Volume I. Mechanics of Solids, 1984. – 600 p.

[8] Rabotnov Y.N. Strength of materials Fizmatgiz, 1963. – 456 p.

[9] Molokov M.V., Nizin D.R., Nizina T.A., Startsev O.V. The results of experimental studies of polymer composite materials based on low viscosity epoxy binders // Ogarev-Online. – 2014. – Special issue. – p. 10.

[10] Voronov A.S., Methodology for designing a deep-sea induction log sensor // Materials of XX conference of young scientists with international participants. Scientific editor: O.A. Stepanov. General editor: V.G.. Peshehonov. 2018. – pp. 227 -229.

[11] Golod O.S., Gonchar A.I., Shlychek L.I. Prospects and concepts for the development of autonomous uninhabited vehicles / // Hydroacoustic Journal (Problems, methods and means of exploration of the oceans) – 2007. – №4. – p. 102.

[12] Sagalevich A.M. Subsea habitable vehicles of Institute of Oceanology of Russian Academy of Sciences// Materials of XIV international scientific and technical conference «Modern methods and means of ocean research (MSOI-2015)». Moscow, 2015. – t. 2. – pp. 14-30.