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ALHORITHMS OF MULTIPLICATION ERROR OF MAGNETIC INDUCTION SENSORS' CORRECTION

S. G. Taranow,
Department of Measurement, Institute of Information and Electronics
Kiev Institute of Electrodynamics, 252680, Ukraine, Technical University of Zielona Gora, 65-246, Poland

Abstract: The accuracy of instruments for measurement a magnetic induction depends on a multiplication error of a sensor. It is considered the new algorithms of this error reducing by mean of a pilot signal with uninterrupted and periodic comparison and also with the negative feedback with respect to envelope of signals.
Keywords: magnetic induction, multiplication error, pilot signal, sensor of magnetic induction.

1 INTRODUCTION

The accuracy of permanent, alternating and pulse magnetic induction and also magnetic field strength measurement depends on, first of all, from an error of sensors for measurement of these quantities. Sensors based on Hall-effect, Gauss-effect, galvanomagetorecombination effect sometime have unacceptable multiplication errors. If technology cannot provide the positive result we have to use the special algorithms for this error minimization. The standard configuration of a close-loop feedback control system with the deep degenerative feedback it is possible to realize only for measurement a small magnetic induction or a magnetic field strength. This fact is connected with difficulties of compensating magnetic field creation in the area of a sensor location. Perfect results of this problem solution may be obtained by help of the method of non-retrieval adaptive systems, borrowed from the cybernetic engineering. The general idea is grounded on adding to a magnetic induction to be measured, a pilot signal: an additive small magnetic induction for auto-calibration. We compare a voltage drop across stable resistor in series with an inductor, that generate a pilot signal, with an envelope of an output signal. If a multiplication error equals to zero an output signal of a comparator is absent. Otherwise we use an error signal of a comparator after amplification for the gain of the forward branch change. We have no problem with selection of measuring and test signal in the case of measurement of permanent magnetic fields, because of a pilot signal has a sine configuration. If we measure AC or pulse magnetic induction, an angular frequency of a pilot signal must beyond an upper frequency band range of a parameter to be measured minimum in 5 times for reliable selection.

From the standpoint of mathematical description a close-loop feedback control system is described by non-linear differential equations with variable coefficients that are represented by break functions in the case of periodic comparison. For stability and quality analysis of these systems may be used proposed the generalized method of liniarization by the describing function, or the method of finite time intervals. The first method is grounded on three assumptions:

- Instead immediate signals we consider envelopes of these signals. This permits to reduce in 2 times the order of differential equations of a resonance and a quasi–resonance network by the usage the concept of a shorten transfer function and consider such essentially non-linear elements as an amplitude and a phase detectors as a linear units.
- We substitute a controlled element with variable parameters by cascade connected an adder and a non-linear, non-inertial element with a gain that may be approximated by a polynomial.
- We substitute an automatically controlled switch by a subtractor.

The second method is grounded on one evident assumption: inertia of the forward branch is in many times less than inertia of the backward branch. This permits to consider within a time interval under consideration a close-loop feedback control system as an open-loop control system. We determine a normal response to sine input signal by the complex number method taking into account that we have a steady state in the forward branch to the end of time interval. An output signal of a backward branch may be computed by the Duhamel integral method. Then we compute an output signal of a backward branch increment at the end of time interval and consider finite conditions of previous time interval as initial conditions for the next time interval, apply this increment to a control element. This action causes a transient in the forward and backward branch. The further order of computing is repeated. Second method provides very high accuracy of computing that comparable with the accuracy of linear

feedback control systems analysis. The method of finite time intervals is medium between analytical and nuberical – iteration methods, but requires in thousands times less quantities of samples. This method may be formalized and represented as the software.
The idea of signal's envelope usage we spread on linear systems if we use the method of periodical comparison a signal and its portion. The switching process cause appearance of envelope and the negative feedback we consider with respect to envelope.

2 MACHNIZM OF ACTING AND DESCTIPTION OF BLOCK-DIAGRAMS

The block diagram of an instrument for magnetic induction measurement with algorithm of a multiplication error correction and uninterrupted comparison of signals is shown in Fig. 1.The block-diagram consists of the forward branch and the backward branch. The forward branch includes an inductor L that generate a test induction B_c, a sensor S, an amplifier A with controlled gain, an amplitude detector AD and a low frequency filter LFF. The backward branch has a subtractor, an error amplifier EA, a phase detector PD+LFF. The backward branch and a controlled element are used for correction a multiplication error of an instrument I. A sensor's current flows in a sinusoidal pattern

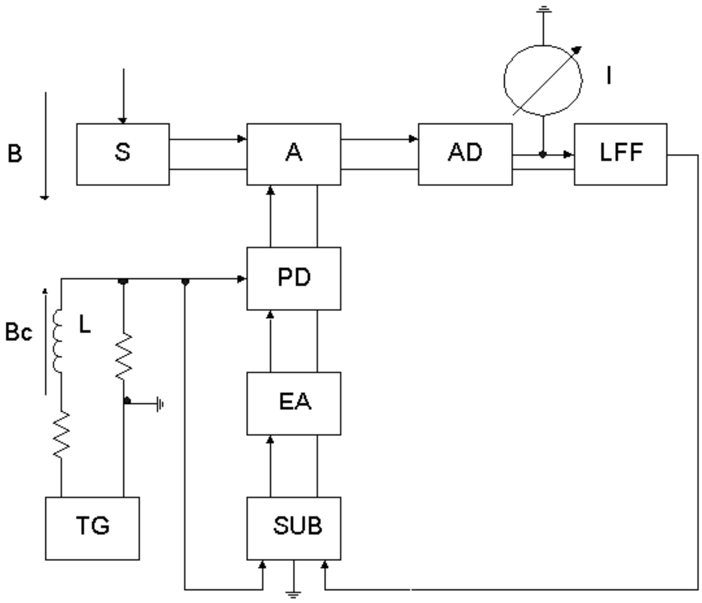

Figure 1

$$i = I_m \sin \omega t \tag{1}$$

A sensor is placed in a field of an inductor L, which is fed from a sine current generator TG. A magnetic induction equals to

$$B_C = cI_{Cm} \sin \Omega t = B_m \sin \Omega t \tag{2}$$

where $c = \frac{L}{wF}$ a constant of inductor, L-inductance, l, F length and cross-section of the air gap, w quantity of coils. An output voltage of a sensor equals to

$$v_3 = SI_m B \sin \omega t + SI_m cI_{Cm} \sin \omega t \sin \Omega t \tag{3}$$

where $I_{m.}$, I_{Cm} – amplitudes of currents across a sensor and an inductor
The direct component of an A+AD equals to

$$V_5 = SI_m B(k_2 + k_2^{'} V_C)k_3 \tag{4}$$

where k_2 and k_3 – amplification factors of A, AD, k_2' – factor of a control signal influence.

An AC component of LFF

$v_6 = SI_m I_{Cm} c(k_2 + k_2^{'} V_C) k_3 k_4 \sin \Omega t$, k_4 – amplification factor of LFF (5)

An output voltage component of a sensor, cause a test induction is equal to

$v_1 = rI_{Cm} \sin \Omega t$ (6)

An output voltage of subtractor is

$v_7 = \beta_1 I_{Cm} [r - SI_m c(k_2 + k_2^{'} V_C) k_3 k_4] \sin \Omega t$, β_1-factor of subtraction (7)

AE is tuned on Ω and its output voltage

$v_8 = \beta_1 \beta_2 (\Omega) I_{Cm} [r - SI_m c(k_2 + k_2^{'} V_C) k_3 k_4] \sin \Omega t$, β_2-EA factor (8)

An output controlling voltage of PD+LFF equals to

$V_C = \beta_1 \beta_2 (\Omega) \beta_3 I_{Cm} [r - SI_m c(k_2 + k_2^{'} V_C) k_3 k_4]$, β_3 – factor of PD+LFF (9)

Solution of (5) and (9) after simple mathematical manipulation is

$$V_{6m} = \frac{cI_{Cm} S(k_2 + k_2^{'} \beta_1 \beta_2 \beta_3 I_{Cm} r) k_3 k_4}{1 + cI_m S k_2^{'} k_3 k_4 \beta_1 \beta_2 \beta_3 \beta_4 I_{Cm}} I_m , \tag{10}$$

If $\beta_2 \to \infty$ we have

$V_{6m.} = rI_{Cm}$ (11)

The last formula shows that for great forward branch's gain an output voltage of the forward branch depends on only from a stable resistance r and an inductor's parameters. Same result we obtain if the forward branch gain equals to the normal.

In Fig. 2 is shown the block diagram of a teslameter with complete correction of a multiplication error with the pilot signal and periodical comparison.

The forward branch consists of an inductor L, in the field of which a sensor is placed, a high frequency ω AC current source G, a tuned amplifier A with controlled gain, an amplitude detector AD, a low frequency filter LFF and an instrument I. The backward branch contains an automatically controlled switch ACS, an envelope amplifier EA, an amplitude detector AD, a phase detector+low frequency filter AD+LFF. An inductor L is fed from a generator G_Ω an angular frequency of which is in 3 ranges lower than ω. The peculiarity of this block diagram is absence of error caused by a phase shift of the forward branch input with out voltage.

The mechanism of action is similar to considered above. The difference consists in fact that a comparator ACS in order transmits packages of voltages. An envelope of this voltage is modulated by meander if a multiplication error is not equal to zero. An envelope of a signal is used after conversion for control of the forward branch's gain for minimization a multiplication error. If the forward branch's gain is equal to normal, voltage v_1 across resistance r equals to output voltage v_6, and the output voltage of the backward branch also equals to zero. So we have

$SI_{m.} k_2 k_3 k_4 = r.$ (12)

Formula (11) is similar to (12).

Peculiarities of teslameters Fig 1 and Fig 2 with correction a multiplication error is possibility of their usage for measurement of large magnetic indications: if a measuring parameter is small we get over-modulation. Moreover, an output instrument is not comprised by the negative feedback.

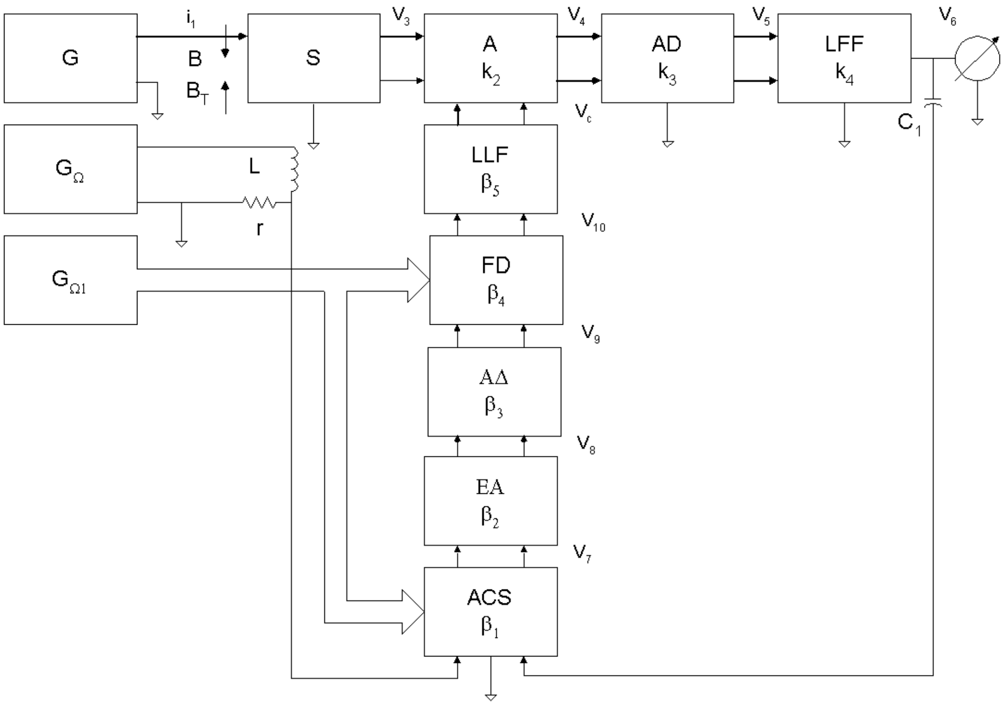

Figure 2

In Fig. 3 is shown the block diagram of teslameter with a test signal modulation an output instrument of which is comprised by the degenerative feedback. A sensor is fed by DC, and its output voltage through automatically controlled voltage divider with switch is applied to amplifier A. Second switch performs the operation of demodulation.
Output signal of sensor is

$$V = S(B - B_C) \qquad (13)$$

If ωL<<r, we get

$$I_C = \frac{V_{3m}}{2r}\left[\frac{1}{2} - \sum_{n=1}^{\infty}\frac{\sin(2n-1)\omega t}{2n-1}\right] \qquad (14)$$

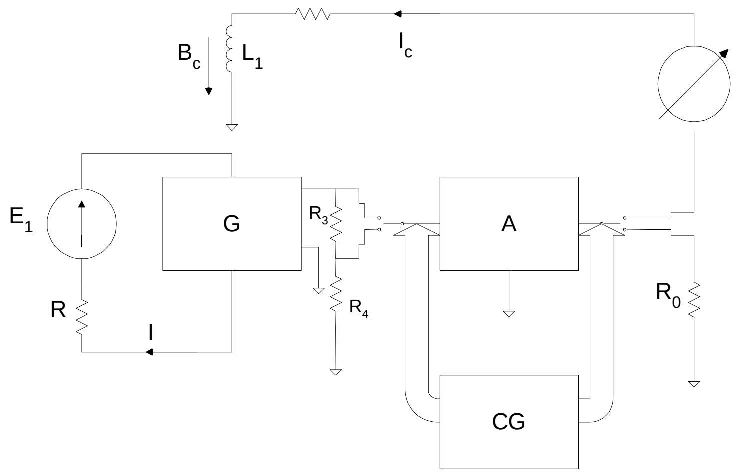

Figure 3

The function in the square brackets is the switching function that equals to zero in odds time intervals and one in evens time intervals. If we change – on + in the square brackets, we get switching function, which equals to zero in evens time intervals and one in odds time intervals. After simple mathematical manipulations we obtain

$$\alpha = \frac{1}{2rTC}\int_0^T V_{3m}[1-\frac{4}{\pi}\sum_{n=1}^{\infty}\frac{\sin(2n-1)\omega t}{2n-1}]dt = \frac{V_{3m}}{2rC} \tag{15}$$

where α - pointer deflection, C- instrument's constant,
that equals

$$\alpha = \frac{SkwF[r/2r(r+r_1)\}]B}{CL[Sk[r/2r(r+r_1)]} \tag{16}$$

The formula for relative multiplication error of a closed loop feedback control system we obtain by differentiation of logarithm of (16)

$$\frac{\Delta\alpha}{\alpha} = \frac{\Delta C}{C} + \frac{\Delta S/S + \Delta k/k}{1+\frac{SrkL}{(r+r_1)r_1 wF}} \tag{17}$$

where k- gain of the forward branch.
We suppose that r_3, r_4, r_0 are stable. Formula (17) shows, that an accuracy of the teslameter in the last case is determined by a class of instrument, if the negative feedback is quite deep.

3 SUMMARY

- The compensation method of a multiplication error correction may be used if measuring magnetic induction is less than 0.1 mT. Class of these instruments is 0.2-0.5.
- The method of modulation of magnetic induction may be recommended for measurement of magnetic induction greater than 1mT.
- Test methods with uninterrupted and periodic comparison of signals may be recommended for improvement accuracy of teslameters for measurement large magnetic inductions.

AUTHOR: Prof., Dr. Sc. S. Taranow, The Institute of Informatics and Electronics, Technical University of Zielona Gora, ul. Podgorna 50, 65-246, Poland tel. +4868 328-2329, fax +4868 324 4733. E-mail: S.Taranow@IIE.PZ.Zgora.P