UDK 62 – 52: 621.317

N.I. Tverdostup

ACTIVE INDUCTIVE SENSOR USING A COMBINATION OPERATING CIRCUIT

Abstract. Investigated the input impedance combined linear-term operating circuit with an inductive sensor in the feedback loop of the amplifier. A scheme in which the realized multiplier effect of inductive sensors with partial compensation of its value, which allows to control the sensitivity of the sensor.

Keywords: operating scheme, combined feedback multiplier, impedance, inductance sensor sensitivity-productivity.

Topicality. The use of inductive sensors in the low-frequency resonance measurement and control devices, in some cases limited to small values of self-inductance, quality factor and low sensitivity to the controlled parameters. Therefore, actual is creating a device for increasing the inductance of the sensor to the desired value while increasing the sensitivity control.

Analysis Research. In [1, 2, 3] laid the foundations for the synthesis of the adjustable pre-impedance operational amplifier circuit solutions private inductor multipliers considered in [4, 5, 6]. Analysis of the results obtained in [7], proves the feasibility of using a combination of the operating circuit to generate multipliers inductance.

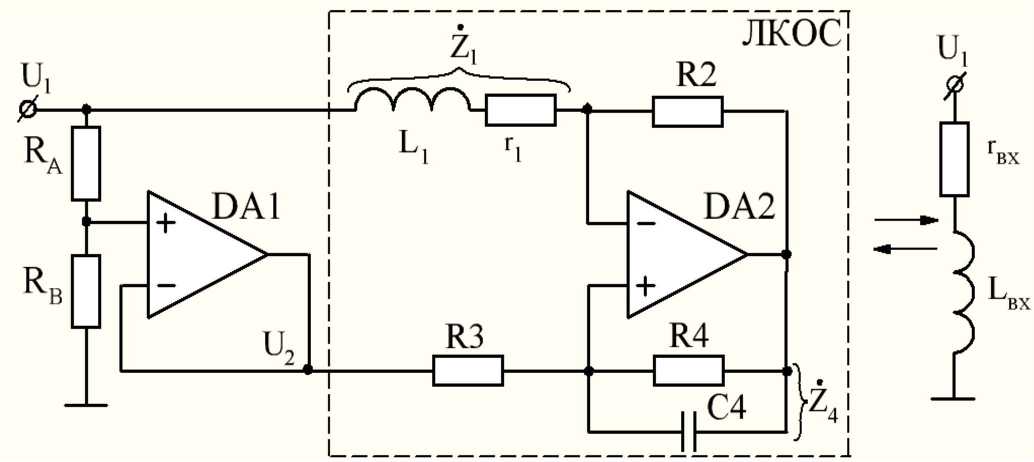
Statement of the problem. The aim is to develop a multiplier in-productivity parametric sensor with adjustable sensitivity on the basis of the combination of the operating circuit.

The main part. Linear combination operating scheme (LKOS) [7] has the property of scaling the impedance while maintaining the sign, which allows her to create the basis multipliers reactance. In [6] on the basis of high-quality LKOS multiplier was designed in-inductive impedance, which was accompanied by an increase in the inductance compensation of its active resistance, which leads to higher quality factor. To create a multiplier Inductive sensor with high sensitivity to the monitored parameters, note that the input impedance LKOS consists of positive and negative parts, which should be used as follows: the positive part for multiplying the inductance reactance and negative - to compensate for the specific part multiplied reactance, which should lead to an increased sensitivity of the inductive sensor.

In the linear combination of the operating circuit (Fig. 1) with an inductive impedance circuit in a negative feedback characteristic is the presence of combined feedback and that the outer excitation signals arrive in phase at both inputs of the operational amplifier. The findings to [7], the input impedance of this circuit is equal to

$$\dot{Z}_{вх} = (\dot{Z}_1 - R_2 R_3 / \dot{Z}_4 \text{¿} / (1 - n) , \qquad (1)$$

where $\dot{Z}_1 = r_1 + j\omega L_1$ – complex impedance inductor L_1 with active resistance r_1; R_2, R_3 - the active resistance of the circuit combined feedback amplifier DA2; $\dot{Z}_4 = R_4 / (1 + j\omega C_4 R_4)$ – complex impedance parallel connected resistance and capacitance R_4 C_4; $n = U_2 / U_1$, U_1 and U_2 – voltage excitation signals. Follower amplifier DA1 with resistive divider R_A, R_B is the source of excitation voltage U_2, the common-mode input voltage U_1.



a *b*

Figure 1 – Operating linear combination circuit (*a*) and equivalent of (*b*)

From (1) it follows that the ratio n excitation voltage has wasps mainly impact on the value $\dot{Z}_{вх}$, namely: when $n \to 1$ and $U_2 < U_1$ the input impedance $\dot{Z}_{вх}$ increases substantially. We can assume that the value of n determines the value the conversion factor of the inductive impedance $\dot{Z}_1$ the input impedance $\dot{Z}_{вх}$.

Ratio n excitation voltage can be represented by the ratio of the divider resistors

$$n = R_B / (R_A + R_B) , \qquad (2)$$

while the input impedance $\dot{Z}_{вх}$, expressed in terms of the parameters of the scheme will

$$
\begin{gathered}
R_A \\
1+R_B/\ \text{¿}\ (r_1+j\omega L_1-R_2R_3/\ R_4-j\omega C_4R_2R_3) \\
,\ \text{¿} \\
Z_{вх}=\text{¿}
\end{gathered}
\tag{3}
$$

It is also true that $Z_{вх}$, represented by the input parameters is

$$Z_{вх} = r_{\text{ВХ}} + j\omega L_{\text{ВХ}}, \tag{4}$$

where $r_{\text{ВХ}}$, $L_{\text{ВХ}}$ – input resistance and inductance. Then from (3) and (4) the expression of active and inductive components of the input impedance

$$r_{вх}=(1+R_B/\ R_A)(r_1-R_2R_3/\ R_4)\ , \tag{5}$$

$$L_{вх}=(1+R_B/\ R_A)(L_1-C_4R_2R_3)\ , \tag{6}$$

showing that in this scheme, the inductance L_1 with active resistance r_1 converted into the input inductance $L_{\text{ВХ}}$ and resistance $r_{\text{ВХ}}$ with multiplier equal to

$$m=(1+R_B/\ R_A)\ , \tag{7}$$

that is, when the condition $R_B >> R_A$, can take large values. From (5) it follows that the multiplication of active resistance r_1 accompanied his compensation negative active component of the input impedance equal LKOS

$$
\begin{gathered}
-\text{¿} \\
\text{¿} \\
\text{¿} \\
R_{\text{¿}}
\end{gathered}
\tag{8}
$$

At $|R_{(-)}|$ → r_1 input impedance $r_{\text{ВХ}}$ → 0, indicating the possibility of increasing the quality factor of the inductance. More details on improving the quality factor multiplied by the inductance is considered in [6].

From the expression (6) that the multiplication of the inductance L_1 sensor by a factor of m occurs simultaneously with the decrease of its initial value by $C_4R_2R_3$, which has the dimension of inductance. This quantity is called the compensating inductance $L_{\text{К}}$, it is the result of the transformation capacity C_4 in a negative inductance with a conversion ratio of R_2R_3. Equation (6) in the form

$$L_{вх}=m(L_1-L_к)\ . \tag{9}$$

Assume that under the influence of a controlled parameter inductance L_1 sensor changes by ΔL_1, then the input inductance becomes

$$L_{вх}+\Delta L_{вх}=m(L_1+\Delta L_1-L_к)\ . \tag{10}$$

From (9), (10) it follows that the absolute increment of the input inductance will

$$\Delta L_{вх}=m\Delta L_1 \;, \tag{11}$$

a relative increase

$$\Delta L_{вх}/\ L_{вх}=\Delta L_1/\ \left(L_1-L_к\right), \tag{12}$$

wherein when $L_к \rightarrow L_1\,\Delta L_{вх}/\ L_{вх} \rightarrow \infty$. We see that the absolute increment of the input inductance is determined by multiplying the coefficient *m*, and the relative increment - the value of the compensating inductance $L_к$. This shows that in this scheme can be scaled inductance sensor with control values of the sensitivity of the sensor to the monitored parameters.

Multiplier inductance on the circuit of Fig. 1 was built on operational amplifiers MCP604, as multiplied impedance sensor used with inductance L_1 = 21,06 mH and a resistance r_1 = 5,4 Om, investigations were carried out at a frequency of 1 kHz at $R_4 = \infty$.

The research results can be multiplied inductive impedance compensated its primary reactance is shown in Fig. 2 in the form of Expo experimental dependences (in logarithmic scale) input inductance $L_{вх}$ (in mH) from compensating inductance $L_к$ for different multiplication factor *m*. It is seen that the initial reactance without compensation inductance L_1 (with $L_к$ = 0), the input inductance $L_{вх}$ depending on the multiplication factor *m* is changed to two orders of magnitude reaches 2,12 H when *m* = 119,6. By increasing the compensating inductance $L_к$ input inductance is reduced from a maximum value to a value less than the initial L_1. The experiment confirms the possibility of controlling the magnitude of the input inductor within a wide range by means of the parameters *m* and $L_к$ according to the expression (9).

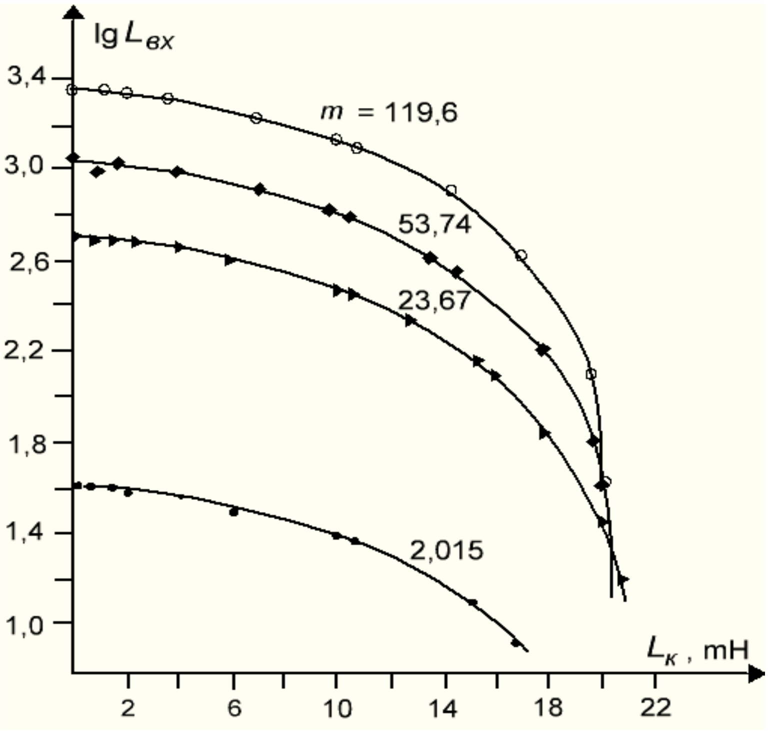


Figure 2 – Input $L_{вх}$ inductance $L_к$ as a function of compensating for different multiplication factors m

Increasing the absolute increment of the input inductance $L_{вх}$ coefficient multiplying m by (11) is confirmed by the experimental dependences in Fig. 3. Here, when changing the inductance of the sensor on the value of L_1 $\Delta L_1 = 0{,}71$ mH absolute increment of the input inductance $\Delta L_{вх}$ increases by two orders of magnitude when $m \geq 100$. In contrast to (11) the experimentally observed dependence of the parameter $L_к$ $\Delta L_{вх}$ in the form of bias, having a multiplicative character. This deviation reaches 20% and is explained by the fact that the source expression (1) was obtained for an ideal model of an operational amplifier.

Fig. 4 shows the relative increment (percentage) $\Delta L_{вх}/ L_{вх}$ input inductance of the compensating $L_к$.

It is seen that the value of $L_к$ significantly affect the relative increment, so when $L_к = 0$ $\Delta L_{вх}/ L_{вх} = 3.37\%$, and with increasing $L_к$ to 20.44 mH $\Delta L_{вх}/ L_{вх}$ increased to 270%. Here at $L_к > 0{,}5L_1$ observed influence on the multiplication factor m $\Delta L_{вх}/ L_{вх}$, expressed in deviations of up to 20% of the experimental data from the calculated by the expression (12).

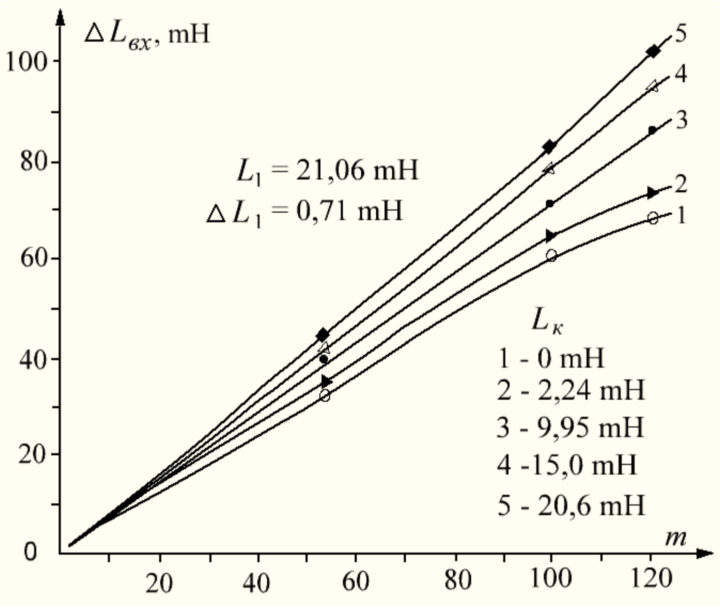


Figure 3 – Dependence incremental input inductance of $\Delta L_{вх}$
multiplication factor for different values of m
compensating inductance $L_к$

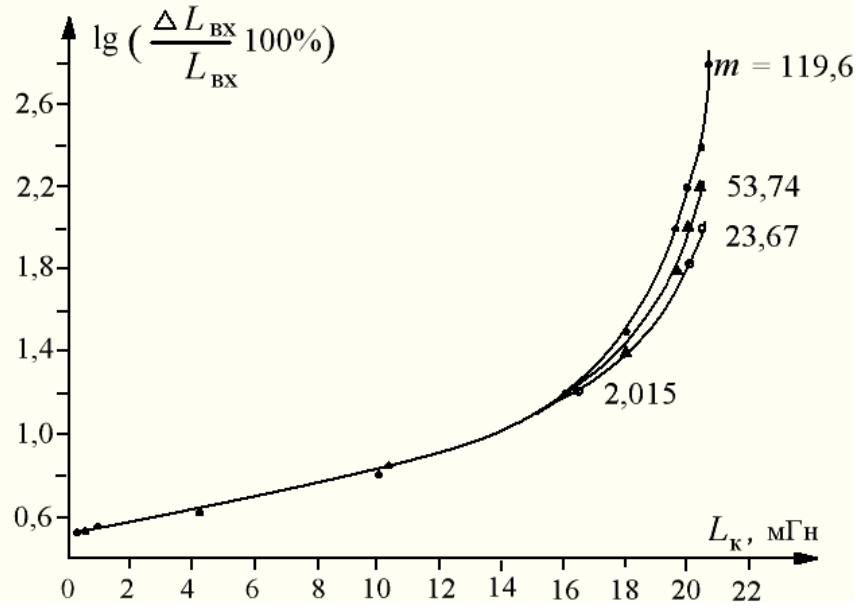


Figure 4 – Dependence of the relative increment $\Delta L_{вх}/ L_{вх}$
input inductance of the compensating $L_к$
for different values of the multiplication factor m

Conclusion. The study combined the operating circuits with passive inductive sensor in the feedback loop it possible to establish the following:

- application of the multiplier inductor allows a wide range (in the present experiment, two right) to change the self-inductance of the active sensor, which allows to use it in a low frequency range;
- multiplication reactance passive sensor increases the absolute increment of the inductance of the active sensor in proportion to the multiplication factor, which indicates an increase in the absolute sensitivity control;
- the presence of partial compensation circuit reactance can increase the inductance of the relative increment of the active sensor is almost two orders of magnitude;
- non-ideality of the used operational amplifiers leads to a deviation of up to 20% of the experimental data from the calculated.

REFERENCES

1. Филановский И.М., Персианов А.Ю., Рыбин В.К. Схемы с преобразователями сопротивления. – Л.: Энергия, 1973. – 192 с.

2. Марше Ж. Операционные усилители и их применение. Л.: Энергия, 1974. – 216 с.

3. Кустов О.В., Лундин В.З. Операционные усилители в линейных цепях. – М.: Связь, 1978. – 144 с.

4. А.с. 813696 СССР. Индуктивный двухполюсник/ А.Ф. Гришков, А.Н. Гуляев, И.Г. Дорух, А.В. Маргелов. Бюл. №10, 1981.

5. Войцеховская Е.В., Лищинская Л.Б., Лазарев А.А. Индуктивный негасенсор // Технология и конструирование в электронной аппаратуре. - №3, 2011. – С. 20 – 22.

6. Твердоступ Н.И. Высокодобротный умножитель индуктивности // Системні технології. Регіональний міжвузівський збірник наукових праць. – Випуск 1(72). – Дніпропетровськ, 2012. - С. 100 – 105.

7. Твердоступ Н.И. Обобщенная модель преобразователей импеданса // Вісник Дніпропетр. ун-ту. Фізика. Радіоелектроніка. – 2010. – Вип. 17, №2. – С. 103 - 108.