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ASPECTS OF SIGNAL CONDITION FROM DC BRIDGE CIRCUITS

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Abstract: Sensors based on the variation of the electric resistance are very common. There are many mechanisms that can modify the electric resistance of a material and also many signal conditions for resistive sensors. However, Wheatstone bridge measurement method is often used to measure unknown electrical resistance. This paper examined the application of signal condition for very small change of resistance. The tests were performed by a model with deformation unit which consists of two semiconductor strain gauges situated in two axes – X and Y. The outputs of bridges are connected into new special circuits which are distinguishable from operational and instrumental amplifier. The results according to the accuracy and uncertainty are played very positive quality for instrumentation amplifier. There is advantage to use only one amplifier and only one resistor as extern element for amplifying in the range from 1 to 10000 with minimum offset and temperature drift. The survey confirmed that high accuracy, stability and minimal uncertainty of bridge circuit measurement is corrected with instrumental amplifier and the circuit is very suitable as an intermediate stage between sensors and analogue inputs for microcontrollers.

Keywords: resistance sensor, Wheatstone bridge, signal condition, operational and instrumentation amplifier.

1 INTRODUCTION

The development of measurement system lead to the important aspect of the signal processing. In almost each situation of particular interest, it is necessary to define signal condition and amplification in order to obtain good quality of electric signal for further application. Various numerical methods of signal conditioning have been used to measure bridge circuits. Ramon Pallas – Areny and John G. Webster (2001) concludes that the Wheatstone bridge measurement is used to measure small resistances. According to S Tumanski (2006), nowadays, the bridge circuits are not as important as they used to be but there are commonly used as resistance (impedance) to voltage converters. The both Ramon Pallas – Areny and John G. Webster (2001) and S Tumanski (2006) have suggests that differential amplifiers suit for common resistive sensor bridges. Thus it will be of interest to certain distinguish the small resistance measurement with operational and instrumentation amplifiers. The aim of this paper is to define signal conditioning for circuits which consists with operational and instrumentation amplifiers. In addition, the circuit is assembled to improve the gain, linearization, and uncertainty of the measurement signal.

2 BRIDGE METHOD

In order to investigate the signal condition of bridge circuit, experimental model is included following main four parts.

First, the loading forces for strain gauge bridge circuits were executed via force – spring system. Second, the bridge circuit which consists of two semiconductor type strain gauges situated in two axes: X and Y. It is caused by affixing used to attach the strain gauge bridge circuit to the deformation unit. They have a very considerable and accurate change of the electrical resistance with applied mechanical strain. The main performances are shown below.

- Accuracy – 0.1%
- Thermal drift of zero value < +0.02%/^{0}C
- Thermal drift of the sensitivity < +0.03%/^{0}C

Third, the output signal depends on the applied mechanical strain but also on the supply current. Therefore, stabilized power supplier was provided by 7.6mA both constant and high precision current for bridge circuit. The electrical connection of strain gauge bridge circuit and its power supply circuit is shown in the Figure 1.

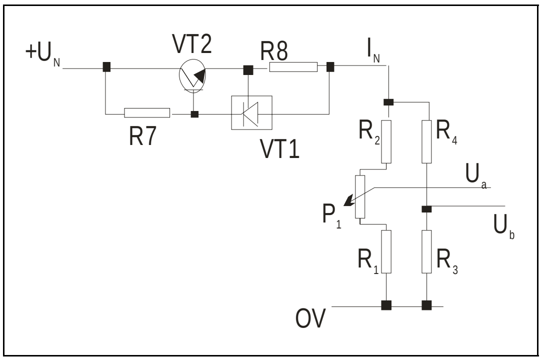

Fig. 1 *The connection of power supply for bridge circuit.*

Figure 1 shows the scheme of circuit. The special stabilized power supplier was designed with circuit TL431C. Adjustable precision shunt regulator TL431C has specified thermal stability over applicable automotive and commercial temperature ranges. In order to obtain constant and high precision current for bridge used the resistance $R8$ with value of 325Ω resistance for constant voltage 2,48V on the resistance.
The test bridge was used the standard connection of four resistors from R_1 to R_4 and the potentiometer P_1.The zero adjustment of the bridge or the difference of voltage is executed via the potentiometer P_1. The zero output has the formula:

$$U_{out} = 0 = I_{N,a}(R_1 - xP_1) - I_{N,b}(R_3) \qquad (1)$$

Where: $I_{N,a}$ and $I_{N,b}$ - are the part current, x - is part of the potentiometer P_1.

Fourth, three kind of evaluated electronic circuits are tested.

A) Circuit with difference connection of operational amplifier (op – amps).

The circuit is often described in literature and chosen as the first.

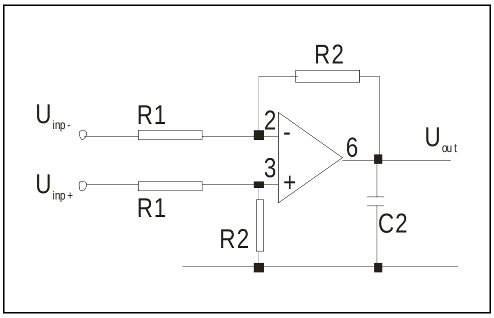

Fig. 2 *Scheme of differential amplifier*

Figure 2 shows a simple differential operational amplifier (DOA). The main problem of the circuit is known as very different input impedance for inverting and non-inverting input. The bridge arms are not loaded the equal impedance.The output of bridge is connected in two inputs supposed the amplifying according to value of resistors $R1$ and $R2$ in the both parts of circuit. The op-amp of OP1177 type was used in the evaluated electronic circuit.

The amplifying is defined as:

$$U_{out} = (U_{inp+} - U_{inp-})\frac{R_2}{R_1} \qquad (2)$$

In the circuit there are $100K\Omega$ resistances used to both the R2 and R1.

B) Circuit with non – inverting connection.

The goal of this connection (NIOA Non-Inverting Operational Amplifier) is to achieve very high input impedance for both inputs. The bridge arms are loaded the equal impedance. The theoretical formula of the circuit is:

$$U_{out} = \left[\left(U_a - U_b\right)\frac{R_2}{R_1} \pm U_{P1} \right] \frac{R_{22}R_{23}}{R_{11}R_{13}} \qquad (3)$$

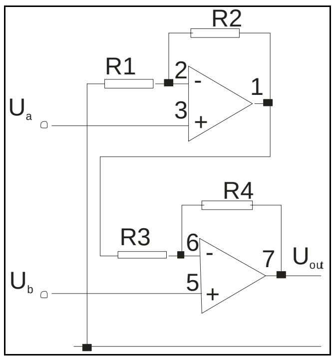

Fig. 3 *Tested connection scheme of operational amplifiers with non inverting inputs*

Figure 3 shows the tested scheme of op - amp circuit with non inverting input. The inputs are connected to the non-inverting inputs of two separated op-amps.

Their impedance is very high. That is advantage of this circuit. Next two op-amps were processing the signal condition.

The op – amps TL071CN and TL082CP types were used in circuit.

C) Circuit with instrumentation amplifier

The instrumentation amplifier is also the integrated circuit with differential amplifier which has stable and precise amplification factor and is immune to interferences.

The output signal is evaluated to the following mathematical model.

$$U_{out} = A(U_a - U_b) \tag{4}$$

For optimum performance, several items should be considered during construction. In our case a low cost, low power instrumentation amplifier AD620AN is used. The main specifications are shown below:

- Input Offset Voltage - 50 mV max,
- Input Offset Drift - 0.6 mV/8C max,
- Input Bias Current - 1.0 nA max,
- Common-Mode Rejection Ratio - 100 dB min (G = 10)

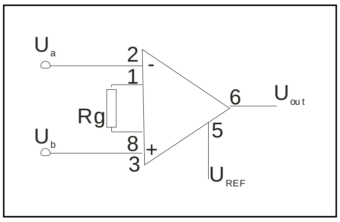

Fig. 4 *Scheme of instrumentation amplifier*

The scheme is shown on the figure 4. The differential voltage of tested bridge is connected into input pins 2 and 3 of the amplifier. The amplification factor is set by the resistance R_g according to the below formula. For example, amplifying about 500 is given resistor of 500 Ω value.

$$R_g = \frac{49400}{A-1} \tag{5}$$

3 TESTS OF OP-AMP CIRCUITS

Each of three electronic circuits of signal condition was separately connected to the strain gauge bridge circuit and tested. The circuit serves the bridge supplying of stabilized current and adjusts the output signal from diagonal of bridge. The measurement was repeated for true statistical calculation. The results as maximum, minimum, average, standard deviation and regression function are calculated for the measured sample.

A) Circuit with difference connection of operational amplifier.

The circuit with difference connection of standard op-amp showed on fig.2 was tested with testing bridge a its supply according to fig. 1. The output of bridge was set via P1at the voltage U_{inp-} and U_{inp+} in the table 1 for five measurement (M1 to M5). The value of R_2 was 22000Ω and R_1 8200Ω.

Table 1 *Measured data from DOA*

	M1	M2	M3	M4	M5
U_a=U_{inp-} (V)	1,155	-0,355	1,147	0,000	0,290
U_b=U_{inp+} (V)	1,158	0,000	0,000	1,160	0,000
U_{out} (V)	0,010	-0,359	-1,320	0,683	0,290
R_2/R_1 ()	2,683	2,683	2,683	2,683	2,683
A_U ()	3,333	-1,011	1,151	0,589	-1,000

As can be seen in Table 1, the theoretical (R_2/R_1) and measured (A_u) amplification are very different. Very variable value is for (A_u) and it is from 0.333 to 1,151. It caused the difference of input impedance for inverted and non-inverted input of op-amp. That circuit isn´t useable for the signal condition of small signals from DC bridges.

B) Circuit with non – inverting connection.

The scheme NIOA is showed on fig. 3. The goal is get to know the condition of its connection. The results of the NIOA test are in table 2.

Table 2 *Measured data from NIOA.*

	M1	M2	M3	M4	M5
U_a (V)	0,000	1,170	1,200	1,130	1,160
U_b (V)	0,000	1,160	1,160	1,160	1,160
U_1 (V)	0,000	4,730	4,840	4,560	4,710
U_7 (V)	0,000	-9,640	-10,060	-9,230	-9,660
A_I ()	0,000	4,043	4,033	4,035	4,060
A_{II} ()	0,000	2,700	2,734	2,715	2,721

Table 2 shows the result of NIOA circuit. The amplification factor for both amps A_I (for the first) and A_{II} (for the secondary amps) is almost stable and constant. The main problem is the output U_7 is very high and its finish change is small to inputs. That circuit isn´t useable for practical applications.

C) Circuit with instrumentation amplifier

The test of instrumentation amplifier (IA) was very positive. The results are in the table 3.

Table 3 *Measured data of IA*

	M1	M2	M3	M4	M5
ΔU=U_b-U_a (V)	-0,161	-0,027	-0,003	0,015	0,162
U_6 (V)	-8,220	-1,380	-0,120	0,742	8,350
G_{Rg} ()	50,95	50,95	50,95	50,95	50,95
A_0 ()	50,93	51,10	51,14	50,92	51,82

As can be seen from the expected (G_{Rg}) and calculated data (A_O) in Table 3, the amplification factor is almost stable and constant. It is almost certain that the measurement of strain gauge bridge circuit with instrumentation amplifier will result most linear characteristic. The expected relationship between input and output data is shown in the figure 6.

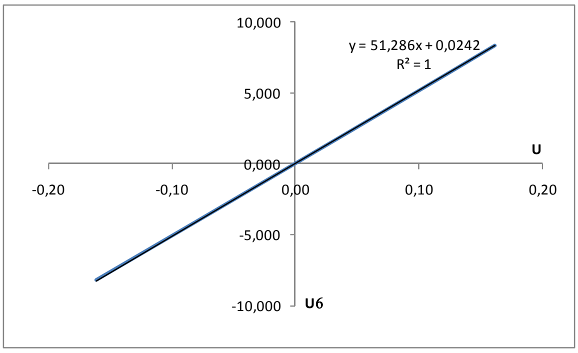

Fig.5 *Diagram of result from the circuit with instrumentation amplifier.*

As shown in Figure 6, the coefficient of determination is calculated 1 on the other hand; regression line perfectly fits the data. The new circuit according to the Figure 5 is suggested to eliminate all disadvantages of circuits from above circuits and possible to use certain application.

4 MEASUREMENT IN LAB MODEL

The positive results of testing of instrumentation amplifier were a generator preparing of measurement in Lab model. The LAB model has integrated two strain gages in X-Y axes. The one for X axis was connected with electronic circuit with current supplier of bridges and the instrumentation amplifier for signal condition and it was tested. The scheme of model and electronics is on fig.7.

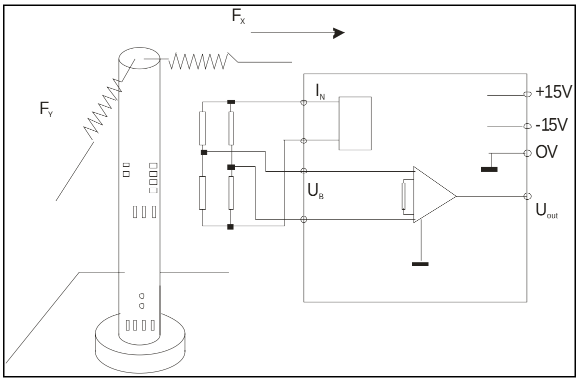

Fig.6 *Scheme of Lab model.*

The stick with strain gauges is loaded of the force F_X in range up 0 to 5N. The output of bridge U_B and output voltage U_{out} was measured. The date are in the table 4. As seen in figure 7, the characteristic of measured results is a little of non- linear. The coefficient of determination is calculated equals to 0.996.

Table 4 *Measured data of LAB model*

	F_X (N)	U_B (mV)	U_{out} (V)
M1	0,000	0,2	0,25
M2	0,550	0,266	0,327
M3	1,283	0,366	0,442
M4	3,115	0,7	0,766
M5	4,947	1,02	1,145

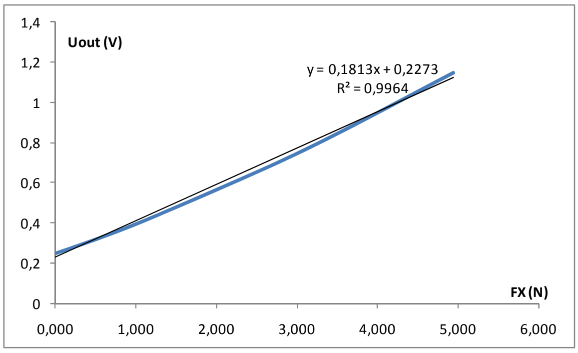

Fig. 7 *Graph of measured date of LAB model*

5 CONCLUSION

The paper describes the base development activity to solve the small signal condition of measuring bridges. The first result is solution of constant current supplying of bridge from range up units of μA to 10 mA. The other result is the application of the instrumentation amplifier and the confirmation of its availability for small signal of bridge.

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