Temperature Measurement Using Bridge Transducer ADC

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Abstract – **The topic of the paper is a temperature measurement on purpose for correction the result from a force sensor, built on strain gauges. A specialized bridge transducer AD7730, transforming the resistance of the PT100 into a voltage does the measurement. A proper methodology for temperature measurement treatment by linear and second order polynomial dependency has been proposed. An algorithm for measurement device calibration has been created. Practical experiments of error estimating have been done.**

Keywords – **PT100, Temperature measurement, Resistance transducer, Polynomial interpolation.**

I. Introduction

The topic of the paper is a problem of a temperature measurement on purpose for correction the result from a force sensor, built on strain gauges which measure the deformation of a specimen.

There exist a lot of methods for temperature measurement. Most of them measure the resistance of a temperature sensitive element. The measurement is done mostly with a DC current [1, 2].

A Resistive Temperature Device (RTD), like PT100, is suitable for measurement the temperature of the strain gauge environment. The PT100 is situated at the place where the gauge bridge is mounted. In our case, the signal from the gauge bridge is threaded by a specialized bridge transducer AD7730 (Analog Device). The AD7730 has got two measurement channels, using common reference voltage. The gauge bridge engages one of the channels and the second one is free. So, we decided to use the second channel for the temperature measurement.

Temperature measurement devices, using similar of the AD7730 transducers (AD7709, AD7719, AD7731 e.t.c.), are offered in [3]. Fig. 1 shows a fragment of a temperature measurement application for the AD7731 with a PT100. The arrangement is a four-lead RTD configuration. In the application shown, the external 400 μA current source provides the excitation current for the PT100 and it also generates the reference voltage for the AD7731 via resistor R1. Resistor R2 is required to set the common-mode voltage within the allowable range for the AD7731.

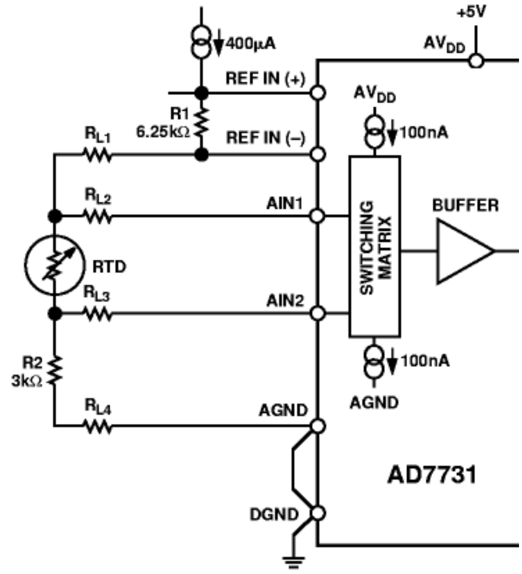

Fig. 1. Temperature measurement using PT100

In our case of the AD7730 using, a considerable changes in the measurement scheme are needed, according to the used transducer working mode:

– the AD7730 uses just one voltage reference for both channels. This requires the device for the temperature measurement to use the same voltage reference;

– the AD7730 could dynamically change, during the measurement, the polarity of the reference voltage, to reduce the value of polarization voltages. The device for the temperature measurement has to be consistent with this mode.

II. Temperature Measurement Scheme

The classical method for a temperature measurement by transforming the resistance of the PT100 into a voltage has been chosen. The external current source provided the excitation current for the PT100. The current is defined by:

$$I = \frac{V_{i\,max}}{R_{max} - R_0}, \qquad (1)$$

where R_{max} and R_0 are values of the PT100 resistance at maximal temperature and at 0^0C respectively. The V_{imax} is the input voltage range of the second channel of the AD7730. The resistor R shifts the input voltage in purpose to reduce the

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common-mode voltage and is calculated by:

$$R = \frac{V_R}{2I}. \tag{2}$$

The voltage of the PT100 is measured via the second channel of the AD7730. The current source is proportionally depended by the reference voltage, so its variations do not affect the result due to the ratiomertically method of the AD7730 measurement. Fig. 2 shows the flow char of the measurement device.

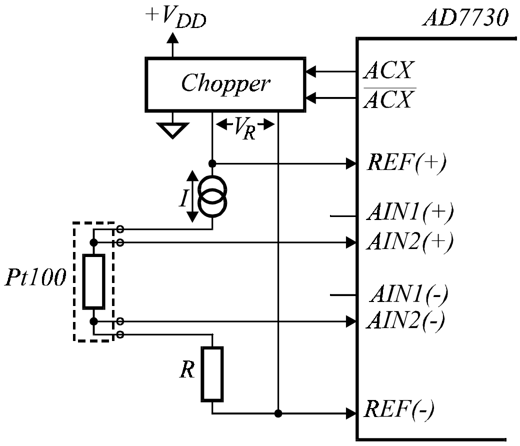

Fig. 2. Flow char of the temperature measurement device with the bridge transducer AD7730

In our case, the bridge transducer AD7730 is controlled by a 68HC11 microconroller unit [4]. The microcontroller threats the result from the gauge measurement as well as from the temperature measurement.

The combined circuit for the force and the temperature measurements is shown in Fig. 4. The external current source is realized by the amplifier TL081 and resistors R4, R5 and R6. Those resistors must have a low temperature coefficient to avoid errors in the reference current via the PT100 over temperature. The resistor R6 defined the value of the current, according the Eq. (1). In our case it is 250µA.

Variations in the reference voltage do not affect the circuit as the current via PT100 and the input voltage vary ratiometrically with the reference voltage.

Due to the four-lead connections, voltage drops across lead resistances do affect the input voltage.

II. Temperature Measure Treatment

The relationships between the temperature and the resistance for platinum thermometry is strongly defined [5].

The followed linear dependency is proposed for a short temperature range:

$$\Delta R = R_t - R_0 = R_0 \alpha t,\ \alpha = 0.00385\,^0C^{-1},\ R_0 = 100\Omega. \tag{3}$$

For a large temperature range (from 0^0C to 850^0C) should be used the relationship:

$$R_t = R_0(1+At+Bt^2); \tag{4}$$

$A = 3.9083\times10^{-3}$, $^0C^{-1}$; $B = -5.775\times10^{-7}$, $^0C^{-2}$.

We have decided to modeled the recurrent dependency by a second order polynomial relationship:

$$t = b.\Delta R + a.\Delta R^2, \tag{5}$$

Defining $\Delta R / t = R_0(A + Bt)$ from Eq. (4) and $t/\Delta R = b + a.\Delta R$ from Eq. (5), it can be written:

$$b + a.\Delta R = \frac{1}{R_0(A+Bt)}. \tag{6}$$

Replacing $\Delta R = 0$ at $t = 0$ in Eq. (6) the coefficient b is calculated:

$$b = \frac{1}{R_0 A}, \quad b = 2.5587,\ ^0C/\Omega. \tag{7}$$

Replacing Eq. (7) in Eq. (6) the coefficient a is defined as:

$$a = -\frac{Bt}{R_0 A(A+Bt)\Delta R}. \tag{8}$$

We suggest, the coefficient a to be calculated according the temperature range, e.g. at the maximal temperature t_{max}, corresponding to the value ΔR_{max}.

For example, for the temperature range from 0^0C to $+125^0$C $a = 0.001$, $^0C/\Omega^2$. The same coefficients are calculated using the table array $\{R_i, t_i\}$ of the relationship for the PT100 in the environment for the temperature range from -40^0C to $+125^0$C. The result is shown in Fig. 3. A small difference exists for the coefficient b.

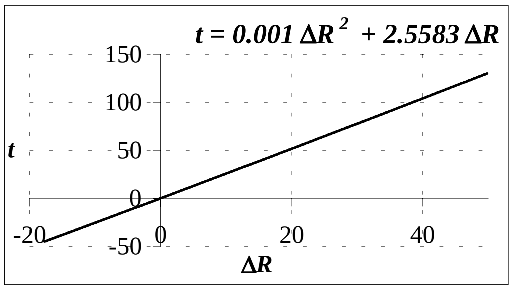

Fig. 3. The table relationship between the temperature and the PT100 resistance

III. Temperature Measurement Calibration

The temperature measurement calibration is similar to the AD7730 calibration for the force measurement purpose [6]. The process of the calibration consists of two stages. A resistance magazine, connected instead of the PT100 element simulates the temperature.

The first stage does the zero-scale calibration. The stage is performed at the temperature 0^0C. Followed procedures are sequentially performed:

– setting of the internal digital-to-analog converter (DAC);

– setting of the internal offset.

The first procedure aims to compensate in large steps the zero-scale shifting (each bit of the DAC has got the value of 2mV). A special algorithm, which applies the method of the successive approximation, is developed. It defined the new content of the selected DAC Register.

The second procedure compensates fine the zero-scale shifting. Hundred measurements are done, averaged and the result is subtracted from the content of the selected Offset Register.

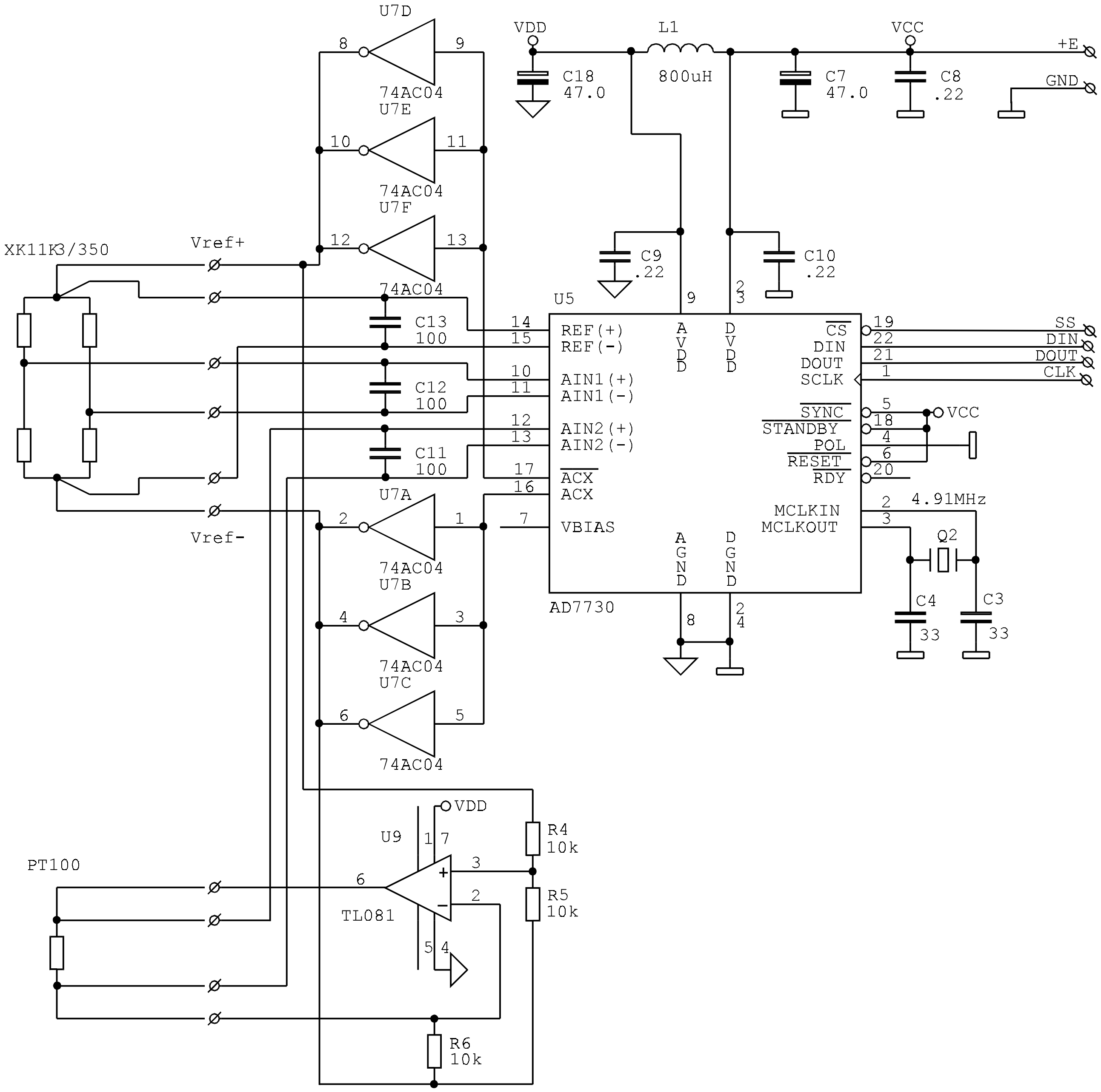

Fig. 4. Combined circuit for a the force and for the temperature measurements, using the bridge transducer AD7730

Determined during the first stage new contents of the selected DAC Registers and Offset Registers are stored into the internal EEPROM of the embedded microcontroller.

The second stage does the full-scale calibration. It determines the transfer factor k of the measurement. The factor k defined the relationship between the calculated number N by the measurement and the linear part of the measured temperature:

$$b.\Delta \mathrm{R} = kN, \tag{9}$$

Resistance of the PT100 is simulated at the maximal temperature, e.g. it is ΔR_{max}. New hundred measurements are done, averaged and the result N_{max} is substituted in (9). The factor k is calculated by:

$$k = \frac{b.\Delta R_{max}}{N_{max}}. \tag{10}$$

The AD7730 calculates N according the relation $N = GU$, where U is the input voltage, and G is the value of the internal gain coefficient. So, $kN = kGU$. A correction of the G is done in the way $G^* = kG$, and the new value N_S of the measured result is $N_S = kN = G^*U$.

The calculated value G^* is the new content of the selected Gain Register and it is also stored into the internal EEPROM of the microcontroller.

Stored in the EEPROM new values of the DAC Register, Offset Register and Gain Register are updated in the AD7730 each time a new measurement is performed.

According to the Eqs. (5), (9) and (11), the value of the real temperature is calculated by:

$$t = N_S + K_2 N_S^2, \qquad (11)$$

where $K_2 = \dfrac{a}{b^2}$ is a constant.

IV. EXPERIMENTS

Experiments have been done for the measurement errors estimating. The resistance of the PT100 has been emulated by specialized DC bridge P333 (Russia – 1991, class 0.5) used as a resistor magazine. The results are shown in Table 1.

TABLE 1
TEMPERATURE MEASUREMENT ERRORS

R	*t-tbl*	*t-clc*	*t-ms1*	*t-ms1*	Δ*t-ms1*	Δ*t-ms2*	Δ*t-clc*
84	-40.675	-40.683	-41.559	-40.746	-0.884	-0.071	-0.008
88	-30.564	-30.560	-31.161	-30.603	-0.597	-0.039	0.003
92	-20.411	-20.405	-20.787	-20.431	-0.377	-0.021	0.004
96	-10.225	-10.218	-10.395	-10.233	-0.17	-0.008	0.006
100	0	0	-0.015	-0.015	-0.015	-0.015	0
104	10.256	10.250	10.416	10.276	0.16	0.02	-0.005
108	20.538	20.533	20.801	20.567	0.263	0.029	-0.004
112	30.846	30.848	31.197	30.888	0.351	0.042	0.002
116	41.184	41.195	41.588	41.241	0.404	0.057	0.011
120	51.564	51.574	51.975	51.629	0.411	0.065	0.011
124	61.973	61.984	62.347	62.034	0.374	0.061	0.011
128	72.421	72.427	72.736	72.475	0.315	0.054	0.006
132	82.894	82.902	83.125	82.953	0.231	0.059	0.008
136	93.394	93.409	93.523	93.451	0.129	0.057	0.015
140	103.947	103.948	103.911	104.013	-0.036	0.066	0.001
144	114.526	114.518	114.301	114.571	-0.225	0.045	-0.007
148	125.131	125.121	124.706	125.161	-0.425	0.03	-0.009
R – Emulated resistance of the PT100;							
t-tbl – Corresponding temperature by the table [6];							
t-clc – Calculated temperature by Eq. (5);							
t-ms1 – Measured temperature, applying linear dependency;							
t-ms2 – Measured temperature, applying polynomial dependency;							
Δ*t-xxx* – Absolute temperature measurement errors.							

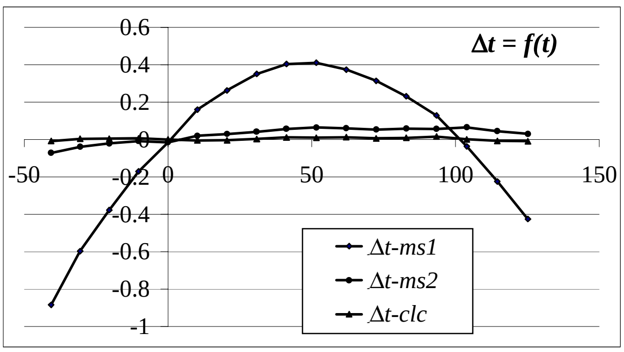

Fig.5. Allocation of the temperature measurement errors

The emulating resistance *R* of the DC bridge is fixed of each 4Ω for the range from 84Ω to 148Ω, that corresponds to the temperature range from -40^0C to $+125^0$C. The absolute error Δ*t* is calculated in comparison of the corresponding from the table value of the temperature *t* for the PT100. Allocations of the temperature measurement errors are graphically shown in Fig. 5.

V. CONCLUSIONS

The topic of the paper is a problem of a temperature measurement on purpose for correction the result from a force sensor, built on strain gauges which measure the deformation of a specimen.

A Resistive Temperature Device (PT100) has been chosen for temperature measurement of the strain gauge environment. In the presented case, a specialized bridge transducer AD7730 (Analog Device) threads the signal from the gauge bridge. This is the reason the same transducer to be applied for the temperature measurement.

The classical method for a temperature measurement by transforming the resistance of the PT100 into a voltage has been chosen. A proper scheme for the platinum element supplied has been built. It is adapted to the specific features and the modes of the bridge transducer AD7730.

A proper methodology for temperature measurement treatment by linear and second order polynomial dependency has been proposed. An algorithm for measurement device calibration has been created. Practical experiments of error estimating have been done.

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