Sensitivity and Stability of A Level Measuring Device

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Abstract
Experimental research proves the correctness of choice of method and device for controlling the level of bulk material in silos (bunkers) providing high sensitivity and stability when changes of temperature and supply voltage occur.

Key words: **Level of bulk material.**

Introduction

Module [1] is used for controlling the level of bulk material in silos and stock level in bunkers. *It consists of a primary converter "level - capacity" and a secondary converter "capacity - frequency" which includes a crystal oscillator.* The general scheme (circuit) of the module used for experimental research is shown in Fig.1.

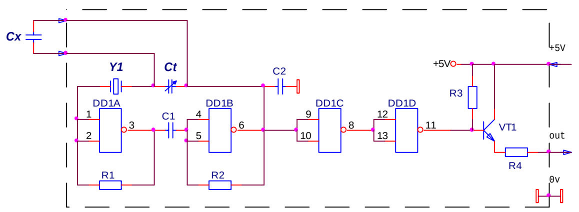

Fig.1. Module for experiments

The primary converter "level - capacity" is represented by the Cx capacitor, connected in series with the crystal resonator. It uses the possibility for slight variations of frequency of the crystal oscillator under the influence of the change of capacity of the capacitor connected in series with the crystal resonator. The trimmer Ct capacitor is connected in parallel with the Cx capacitor.

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Experimental Research

The experiments carried out are as follows:

1. Determining the sensitivity and the linearity of the circuit of the converter.

2. Determining the stability of the circuit of the converter during changes of supply voltage and temperature.

Three crystal resonators are used with the following frequencies of the series resonance:

Fs_1 = 1,000.0 kHz; Fs_2 = 3,200.0 kHz;
Fs_3 = 5,000.0 kHz.

1. Results from the experiments on the sensitivity and linearity of the converter

The experiments are carried out at different values of the Cx capacitor - from 0.5 to 20 pF; the Ct capacitor is not connected but exists as a parasite mounted capacity.

The results for each of the three crystal resonators are shown graphically in Fig.2, Fig.3 and Fig.4 respectively.

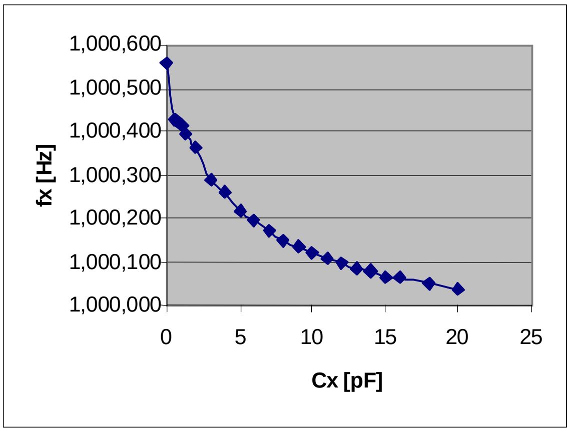

Fig.2. Dependency $f_X = \varphi(C_X)$ for fs_1 = 1,000.0 kHz

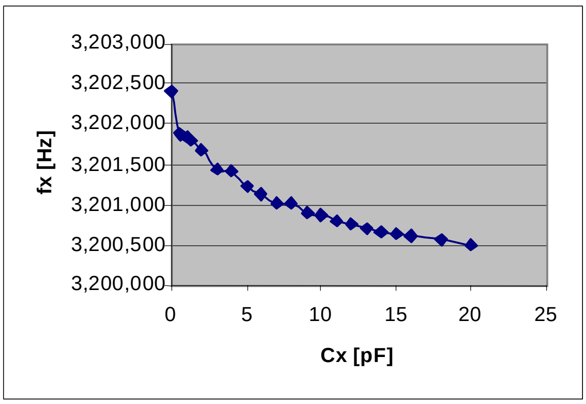

Fig.3. Dependency $f_X = \varphi(C_X)$ for fs_2 = 3,200.0 kHz

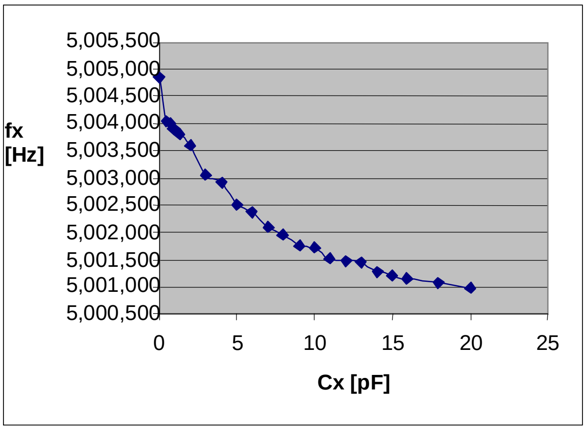

Fig.4. Dependency $f_X = \varphi(C_X)$ for fs_3 = 5,000.0 kHz

<u>*Conclusions:*</u>

1. The dependency *fx = φ(Cx)* is non-linear.

2. The non-linearity of the characteristic *causes great difficulty in using the capacity converter for uninterrupted control of the level of liquids or bulk material.*
Its use is recommended mainly for control of minimum and maximum levels.

3.The experiment on the dependency of the fx frequency value of the Cx capacitor shows that *the sensitivity of the capacity converter decreases with the increase of the measured Cx capacitor values*.

4. *The exceptionally high sensitivity of the circuit allows its use for controlling even slight changes of capacity (under 1 pF).*

2. Results from the experiment on the stability of the converter circuit.

Circuit stability is tested in two cases - with an available measured capacitor *Cx* = 4 pF and when there is no such capacitor (only the mounted capacitor remains).

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2.1. Circuit stability when the supply voltage changes – fx = φ (Uo)

The experiment is carried out when the supply voltage changes from 5.25 V to 4.75 V as well as in lower voltage, which allows the circuit to be efficient.

2.1.1.With a lack of Cx capacitor - the instability of the crystal resonator with frequency of the series resonance:

- 1,000.0 kHz is *3 Hz*,
  i.e. ±*1.53*x10^{-6} *% / V* with *(Uo = 5.25 ÷ 3.3 V);*
- 3,200.0 kHz is *1 Hz*,
  i.e. ±*0.18*x10^{-6} *% / V* with (*Uo = 5.25 ÷ 3.6 V*);
- 5,000.0 kHz is *38 Hz*,
  i.e. ±*8.94*x10^{-6} *% / V* with (*Uo = 5.25 ÷ 4.4 V*).

2.1.2. With an available capacitor Cx = 4 pF - the instability of the crystal resonator with frequency of the series resonance:

- 1,000.0 kHz is *1 Hz*,
  i.e. ±*0.51*x10^{-6} *% /.V* with *(Uo = 5.25 ÷3.3 V);*
- 3,200.0 kHz is *1 Hz*,
  i.e. ±*0,23*x10^{-6} *% / V* with *(Uo = 5.25 ÷3.9 V);*
- 5,000.0 kHz is *26Hz*,
  i.e. ±*4,95*x10^{-6} *% / V* with *(Uo = 5.25 ÷4.2 V*).

<u>*Conclusions:*</u>

1. *The most stable in terms of the change in supply voltage is the crystal resonator with frequency of the series resonance 3200.0 kHz*. It also has very little dependency on the value of the capacitor connected in series with the crystal resonator.

2. The instability of the oscillator frequency in this case doesn't exceed ±*1 Hz (*±*0.23*x10^{-6} *% / V*), with a change of the supply voltage within 3.9 ÷ 5.25 V. This instability is equivalent to the admissible error in measuring the oscillator frequency *(*±*1 Hz*). It allows the supply voltage to be connected to the measuring module with wires of considerable length.
3. The connection of the *Cx* capacitor influences the stability of the frequency to a different extent (degree) and in a different direction for each crystal resonator.

2.2. Temperature stability of the circuit

The circuit stability is tested for each of the three crystal resonators with changes in temperature within 20 °C - 60 °C. The data are for the same two cases - with a lack of measured *Cx* capacitor and with an available measured capacitor *Cx = 4 pF.*

The results from the measuring tests when there is no measured *Cx* capacitor are shown in Table 1.

TABLE I

t,°C / ***f***, *kHz*	20°	30°	40°	50°	60°
1,000	1,000. 543	1,000. 558	1,000. 573	1,000. 586	1,000. 608
3,200	3,202. 741	3,202. 718	3,202. 705	3,202. 700	3,202. 696
5,000	5,004. 680	5,004. 526	5,004. 423	5,004. 318	5,004. 382

The graphic presentation of the results is shown in Fig.5

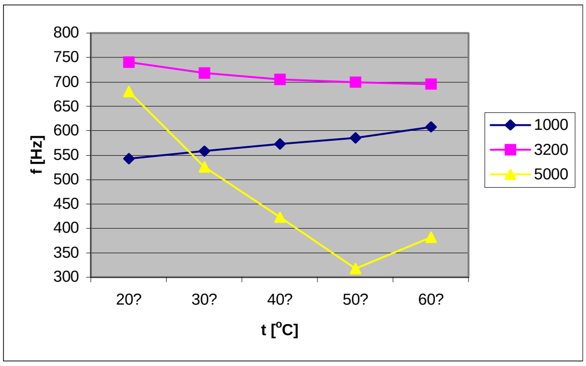

Fig.5. Dependency $f_X = \varphi\ (t)$ without *Cx* capacitor

The results from measuring with an available measures Cx capacitor are given in Table 2.

TABLE II

t,°C *f*, kHz	20°	30°	40°	50°	60°
1,000	1,000.272	1,000.285	1,000.398	1,000.320	1,000.347
3,200	3,201.576	3,201.569	3,201.567	3,201.565	3,201.580
5,000	5,003.017	5,002.994	5,002.953	5,002.895	5,002.836

The graphic presentation is in Fig.6

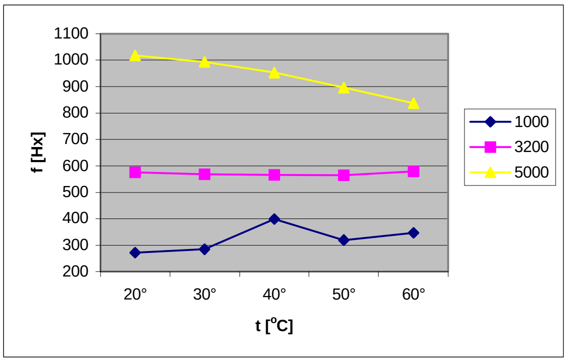

Fig.6. Dependency $f_X = \varphi\ (t)$f with capacitor $Cx\ = 4\ pF$

The respective frequency changes of the three crystal resonators are as follows:

- For 1,000.0 kHz it increases by *65 Hz* (*without Cx*) and by 75 Hz (with Cx = 4 pF);
- For 3,200.0 kHz it changes by *55 Hz* (*without Cx*) and by 15 Hz (with Cx = 4 pF);
- For 5,000.0 kHz it decreases by *298 Hz* (*with Cx*) and by 181 Hz (with Cx = 4 pF).

The respective temperature coefficients for the three crystal resonators are as follows:

- For 1,000.0 kHz
  - TCF = $+1.62\text{x}10^{-6}$/°C (without Cx);
  - TCF = $+1.88\text{x}10^{-6}$/°C (with Cx=4pF);
- For 3,200.0 kHz
  - TCF = $-0.43\text{x}10^{-6}$/°C (without Cx);
  - TCF = $\pm 0.06\text{x}10^{-6}$/°C (with Cx = 4 pF);
- For 5,000.0 kHz
  - TCF = $-1.49\text{x}10^{-6}$/°C (without Cx);
  - TCF = $-0.91\text{x}10^{-6}$ / °C (with Cx = 4 pF).

Conclusions:

1. The most stable in terms of temperature changes is the crystal resonator with frequency of the series resonance *fs* = 3,200.0 kHz. The temperature coefficient *TCF* for it doesn't exceed $\pm 0.25\text{x}10^{-6}$/°C.
2. *TCF decreases when the Cx capacitor is connected in series to the crystal resonator.*
3. The selection of values for *Cx* and its temperature coefficient may decrease *TCF* additionally.
4. The low values of *TCF allow measuring very small capacities in a wide temperature span.*

GENERAL CONCLUSION

1. The suggested circuit solution allows the registration of very small changes in capacity (under 1 pF).

2. The dependency $fx = \varphi(Cx)$ is non-linear. The use of this module is recommended mainly for the control of minimum and maximum levels.

3. The circuit sensitivity is maximum at a minimum change of the measured capacity (under 1 pF).

4. The stability of frequency of the crystal oscillator at a wide range of changes in the supply voltage is very high - it doesn't exceed ±1 Hz ($\pm 0.23\text{x}10^{-6}$ %/V).

5. On the whole, the temperature stability is very high. The experimental results show that the most stable in terms of the temperature change is the crystal resonator with frequency of the series resonance *fs* = 3,200.0 kHz (the temperature coefficient *TCF* is smaller than $0.5\text{x}10^{-6}$/°C). *TCF* is additionally decreased with the parallel connection to *Cx* of a *Ct* capacitor with a selected value and temperature coefficient.

The results obtained from the tests show the correctness of choice for a method and device for controlling the level of bulk material in silos providing high sensitivity and stability when temperature conditions and supply voltage change.

Given the temperature instability and the one caused by the change of supply voltage a well-grounded choice can be made of an optimum construction and size of the primary converter "level - capacity" which will be used for controlling the level of bulk material in silos and stock in bunkers.*l*

REFERENCE

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