POSSIBILITIES FOR REGISTERING THE CHANGES OF CAPACITY OF A CAPACITY CONVERTER

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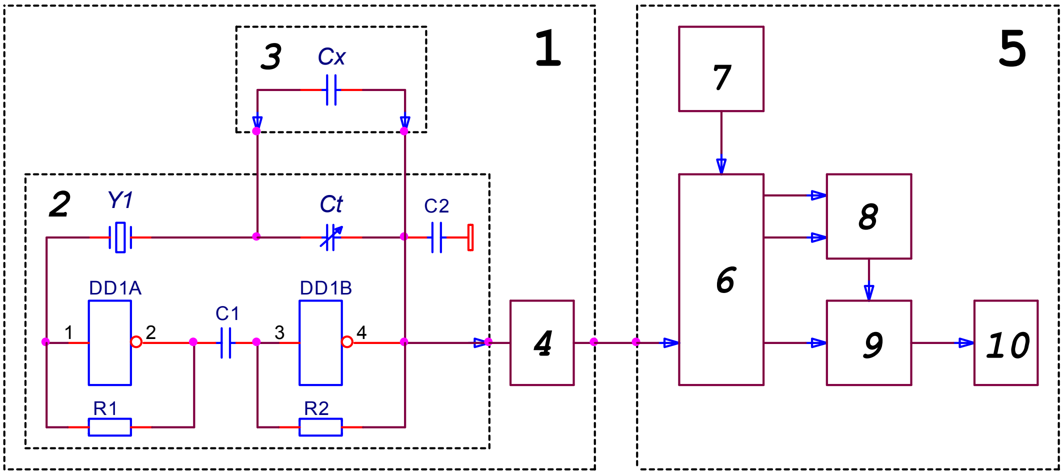
The possibility for registering even the very small changes of capacity of a capacity converter, connected in series with a crystal resonator within a crystal oscillator, is used in a primary capacity converter for measuring the level of bulk material, which provides extremely high sensitivity and stability of the experimental data.

1. INTRODUCTION

Device **[1]** is used for measuring the level of bulk material in silos and the stock level in bunkers. It consists of 2 parts: the converter *block* ***1*** and the measuring converter *block* ***5.*** The circuit of the whole device is shown in *Figure 1*.



Block 1:

3 - *primary "level –capacity" converter*, the structure of which is shown in **[1],** is replaced in the circuit by the *Cx* capacitor;
Parallel to the *Cx* capacitor is connected an additional setting *Ct* capacitor.

2 - *secondary "capacity–frequency" converter*,

4 - joining block**.**

Block 5:

7 - second crystal oscillator;

6 - controlling block;

8 - comparing the data block;

9 - memory block;

10 - indication block**.**

Fig.1. Device for measuring the level of bulk material

The device operation is as follows:

The change of level of the bulk material which is between the electrodes of the primary, 'level –capacity" converter ***3*** leads to a change in its Cx capacitor. This causes the change of frequency in the crystal oscillator ***2*** which is recorded by the comparing block **8** and after being saved by the memory block ***9*** it is recorded by the indication block ***10***. Blocks ***8*** and ***9*** are controlled by block ***6*** through the impulses coming from the crystal oscillator ***7*.**

Defining the frequency instability of the oscillator

-The absolute frequency instability of the oscillator [**2**] *is:*

$$\Delta f = f_2 - f_1 \tag{1}$$

with: f_1 being the frequency before the impact of a destabilizing factor;
f_2 – after the impact.

- the relative instability of the oscillator frequency is:

$$\Delta f / f = (f_2 - f_1) / f \tag{2}$$

- Impact of destabilizing factors

As a rule destabilizing factors do not have a simultaneous impact and their combination is not likely to occur, therefore the concept 'average square change of frequency' has become widely accepted.

$$\left(\frac{\Delta f}{f}\right)_\sigma = \sqrt{\sum_{i=1}^{n}\left(\frac{\Delta f}{f}\right)_i^2}\ , \tag{3}$$

with: $\left(\frac{\Delta f}{f}\right)_\sigma$ being the total instability of the frequency;

$\left(\frac{\Delta f}{f}\right)_i$ is the frequency instability under the impact of the destabilizing factors.

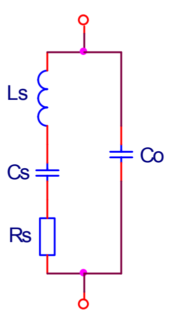
- Frequency change in normal conditions due to inaccuracy of the setting: $(\Delta f / f)_H$.

Total deviation of frequency from its nominal value (face value) $(\Delta f / f)_\Sigma$ can be defined as a sum of $(\Delta f / f)_\sigma$ and $(\Delta f / f)_H$:

$$\left(\frac{\Delta f}{f}\right)_\Sigma = \left(\frac{\Delta f}{f}\right)_H + \left(\frac{\Delta f}{f}\right)_\sigma = \left(\frac{\Delta f}{f}\right)_H + \sqrt{\sum_{i=1}^{n}\left(\frac{\Delta f}{f}\right)_i^2} \tag{4}$$

Qualities of the crystal resonator close to resonance

The change of frequency leads to a change of resistance of the crystal resonator in accordance with the equivalent electric circuit. To facilitate the analysis of the operation of the crystal resonator, the electric circuit from *Figure 2* is presented as equivalent including the series connection of a reactance and a resistance.



The crystal resonators with the widest application are made with the so-called "*A-T–cut*". They operate in the frequency range f = 0,5 ÷ 20MHz and use a fundamental mechanical harmonic **[3]**.

Typical for them are the following values:
$C_S \approx 10^{-2}$ pF, $C_0 \approx 10^2$ pF; $r_S = 2\ \Omega \div 2\ k\Omega$.

Fig.2. Equivalent circuit of a crystal resonator.

The impedance is defined by the expressions:

$$\dot{Z}' = R_S + i.\left(\omega.L_S - \frac{1}{\omega.C_S}\right) = R_S + i.X_S \tag{5}$$

$$\dot{Z}'' = \frac{1}{i\omega.C_0} \tag{6}$$

The oscillator frequency in accordance with that of the series resonance of the crystal resonator is as follows:

$$f_G = f_S = \frac{1}{2\pi.\sqrt{L_S.C_S}} \tag{7}$$

When *a measured Cx capacitor is connected in series with the crystal resonator* (*Figure 3*) the frequency of the series resonance is changed to the following value:

$$f_S' = \frac{1}{2\pi.\sqrt{L_S.\frac{C_S.C_X}{C_S+C_X}}} \tag{8}$$

From (8) follows that:

$$f_S' = \frac{1}{2\pi.\sqrt{L_S.\frac{C_S.C_X}{C_X.\left(1+\frac{C_S}{C_X}\right)}}} = \frac{\sqrt{1+\frac{C_S}{C_X}}}{2.\pi.\sqrt{L_S.C_S}} = f_S.\sqrt{1+\frac{C_S}{C_X}} \tag{9}$$

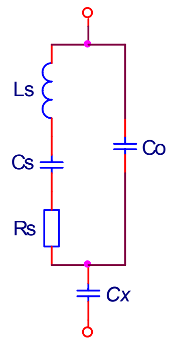


Fig.3 Cx capacitor connected in series with a crystal resonator

After some equivalent mathematic transformations from (9) follows that:

$$f_S'' \cong f_S.\left(1+\frac{1}{2}.\frac{C_S}{C_X}\right) = f_S + \frac{1}{2}.f_S.\frac{C_S}{C_X} = f_S + \Delta f_S \tag{10}$$

and from there the value of the *frequency change* is defined as:

$$\Delta f_S \cong \frac{1}{2}.f_S.\frac{C_S}{C_X} \tag{11}$$

The results of the change of f_S' frequency of a crystal oscillator with a frequency of the series resonance f_S = 1 MHz and parameters - $C_S \approx 10^{-2}$ pF, $C_0 \approx 10^2$ pF, when there is a change of capacity of the Cx capacitor connected in series with the crystal resonator within the range of 0,1 ÷ 10 pF, in accordance with expression (9) and the change of f_S" in accordance with expression (10), are given in *Table 1*. The results from both expressions are very close.

Table 1

C_X [pF]	F_S' [MHz]	F_S" [MHz]
0.1	1,05	1,048809
0.2	1,025	1,024695
0.3	1,016667	1,01653

0.5	1,01	1,00995
1	1,005	1,004988
2	1,0025	1,002497
4	1,00125	1,001249
6	1,000833	1,000833
8	1,000625	1,000625
10	1,0005	1,0005

The results from the change of frequency of *a frequency change* of the crystal oscillator Δf_S, with a frequency of the series resonance f_S = 1 MHz and parameters - $C_S \approx 10^{-2}$ pF, $C_0 \approx 10^2$ pF, when there is a change of capacity of the Cx capacitor connected in series with the crystal resonator within the range of 0,1 ÷ 10 pF, in accordance with the expression (11), are given in Table 2.

Table 2

C_X [pF]	$\Delta F_S''$ [MHz]
0.1	0,048809
0.2	0,024695
0.3	0,01653
0.5	0,00995
1	0,004988
2	0,002497
4	0,001249
6	0,000833
8	0,000625
10	0,0005

This dependence is shown graphically in *Figure 4*.

The dependence is in accordance with the results from the experiment given in **[4]** and **[5]**.

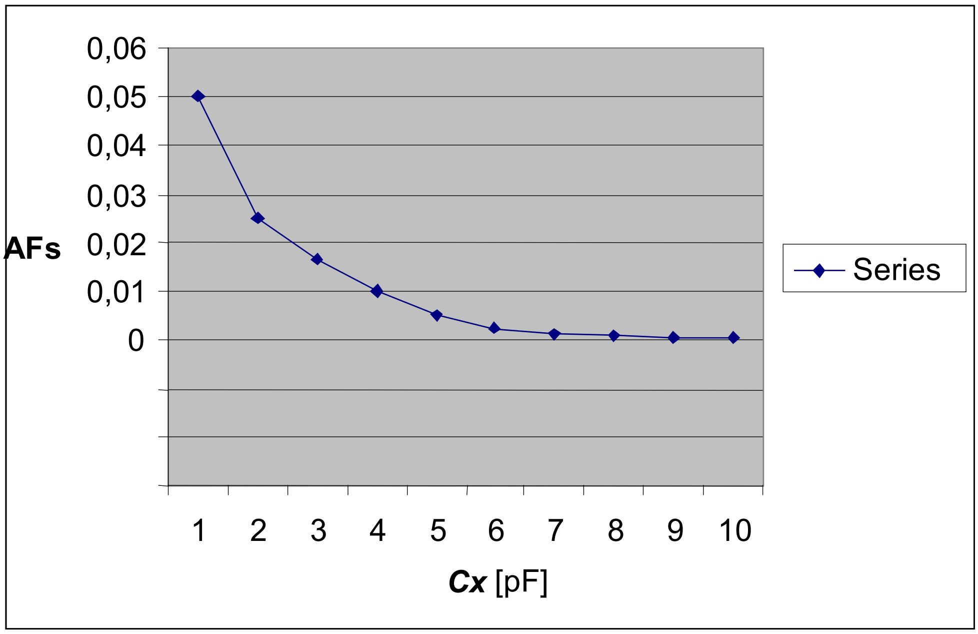


Fig.4. Dependence of the Δf_S *frequency* change on the change of *the* C_X *capacitor*

2. CONCLUSIONS

1. The frequency of the crystal oscillator, which works at the frequency of the series resonance of a crystal resonator, is changed very little - for the given values of the *Cs* and *Co* capacitors the change is about 10^{-4}.

2. The instability of frequency is extremely small; it depends above all on the instability of the crystal resonator parameters which define its resonance frequency at series resonance fS, as extremely small – about $10^{-5} \div 10^{-7}$ / ºC.

3. The dependence of the $\boldsymbol{f_x}$ frequency on the value of the *Cx* capacitor - fx=φ(Cx) is non-linear, which is a prerequisite for its application mainly for the measuring of capacity changes.

4. The sensitivity of the capacity converter increases with the decrease of the maximum value of the *Cx* capacitor which is a prerequisite for its use to control very small changes of capacity – as small as pF and even parts of pF.

5. When measuring the level of bulk material with greater dielectric permeability, high sensitivity not being necessary, the construction or the size of the primary converter can be changed. A better technological solution, however, is the use of an additional Ct capacitor which regulates the sensitivity of the converter.

In based equation (11) is realize device for controlling the level of bulk material in silos **[1],** typical high sensitivity and stability level parameters **[4]**, **[5]**.

3. REFERENCE

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