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Microcomputer Based Wide Range Digital Tachometer

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Introduction

Digital tachometer is a basic electronic instrument for measurement of angular velocity, otherwise measures the speed of a rotating shaft, as in an engine or other machine. Motor rotational speed is linearly connected to angular speed and there is no difference between them from aspect of the instrument realization. Both analog and digital instruments are used for the measurement of the angular speed. The advantage of the analog instruments lies in continuity of the analog information on their outputs. However, it is not convenient for further (digital) processing. Digital tachometer has discrete output equivalent to the angular speed, which may be appear as a disadvantage. However, considering the development of the microcomputer technology, resolution is significantly improved so that the above mentioned disadvantage can be neglected. The simplicity of the output information processing and simpler system design make the digital tachometers superior to analog. An incremental encoder-plastic or metal disc with determined number of markers on its edge - is the most frequently used transducer for digital method measurements [1, 2]. Encoder's markers combined with optocouplers produce pulses during encoder's rotation which define the rotational speed.

Counting and reciprocal measurement methods [3], as classical digital measurement methods, aren't suitable for low and high rotational speed, respectively. Combined methods are developed in order to overcome these problems, such as method of the constant elapsed time (CET), and method of adaptive optimization [4, 5].

The goal of this paper is to analyze the real advantages of these methods, particularly the CET method. The concrete realization based on this method will be shown and analyzed, as well as the experimental results of the developed digital tachometer. In addition to that, the possibility to modify this method in order to eliminate the possible rough errors is pointed out. Microcomputer system enables the connection of this instrument with a personal computer, which makes the tachometer an intelligent measurement module.

Classical measurement methods

The counting measurement method is based on the measurement of encoder output pulses frequency, [3, 4]. The measurement is based on counting the encoder output pulses during fixed time interval T_C. Block diagram of the method is shown in Fig. 1.

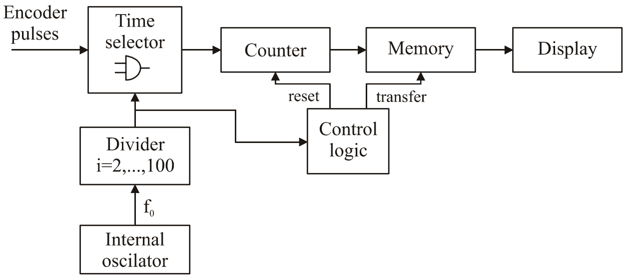

Fig. 1. Block diagram of an instrument for measurement of the average angular speed

Pulses from the encoder are applied to a time selector which is controlled by an internal oscillator. The encoder pulses are passed through the time selector during time interval Tc which presents a half of the period of the signal obtained by dividing internal oscillator's frequency f_0 by integer i.

Output of the time selector, which is in fact an AND gate, is applied to modulo n counter which counts the time selected encoder pulses. Control logic controls the operation of the instrument. After the time interval T_C has elapsed, control logic inhibits the counter, transfers the counted number of pulses into memory, resets the counter and enables displaying of the measurement result. Time interval, T_C, during which the time selector passes encoder pulses, is equal to

$$T_c = \left(i/2 f_0\right). \quad (1)$$

In this case only high logic level portion of i/f_0 is active; during low logic level portion transfer of data from counter into memory and eventual data processing are made. If the number of encoder's markers is P and angular rotational speed is ω, then frequency of the encoder output pulses is

$$f_{VA} = (\omega P / 60). \qquad (2)$$

The number of pulses that counter has counted is

$$c_p = T_c f_{VA} = (i\omega P / 120 f_0). \qquad (3)$$

It is clear that there is a linear connection between the number of counted pulses and rotational speed

$$c_p = k\omega. \qquad (4)$$

By analyzing operation of the tachometer, it is easy to conclude that lower rotational speed has higher measurement error. Since the counter content is an integer number of the counted pulses, values of rotational speed between the two adjacent counter contents cannot be measured. Let us introduce the following rotation:

ω_{cp} - rotational speed which corresponds to the counter content C_p

ω_{cp+1} - rotational speed which corresponds to the counter content C_{p+1}, i.e. the value at C_p is increased by 1

Relative measurement error, calculated in relation to the accurate value of the rotational speed, is

$$\delta(\%) = (\omega_A - \omega_M) 100\% / \omega_A, \qquad (5)$$

where subscripts A and M denote the accurate and the measured value, respectively. If the value of the rotational speed ω is such that $\omega_{cp} \leq \omega < \omega_{cp+1}$, then ω will be measured as ω_{cp}, and the measurement error will be

$$\delta(\%) = (\omega - \omega_{cp})(100\%)/\omega = [1 - (\omega_{cp}/\omega)] 100\%, \qquad (6)$$

whose diagram is given in Fig. 2.

From the Fig. 2 it may be seen that for $\omega = \omega_{cp}$ the error δ is equal to zero, while for $\omega \rightarrow \omega_{cp+1}$ the error δ, according to the last equation, is equal to $1/(c_p+1)$.

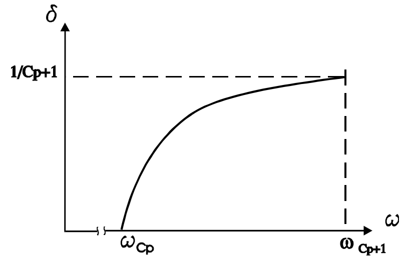

Fig. 2. Relative error versus the rotation number on the segment between two measurable rotation numbers

By observing ω at different segments a diagram of the dependence δ=f(ω) is obtained and shown in Fig. 3. It may be seen from the diagram that the maximal relative error within a segment decreases with increasing rotational speed. Therefore, such type of tachometer is appropriate for measurement of high angular speed.

Lower limit of the angular speed which could be measured is determined by the maximal allowable relative error. Maximal relative error, according to the above mentioned consideration and to the fact that the expected counter content c_p=m, in the m-th segment is equal to

$$\delta(\%) = 100\%/(m+1). \qquad (7)$$

Based on the maximal allowable relative error, the C_{pmin} counter contents i.e. the interval i may be calculated by using the after mentioned equation. For counter contents greater than C_{pmin}, maximal relative error is less than maximum allowable one. The lower limit of the angular speed which could be measured is obtained by using equation that presents dependence of the counter content and rotational speed.

$$\omega_{lower} = \frac{60}{iP} C_{p\min} = \frac{60}{PT_c} m = \frac{60}{PT_c} = \frac{60}{PT_c}\left(\frac{1}{\delta_{\max}} - 1\right). \qquad (8)$$

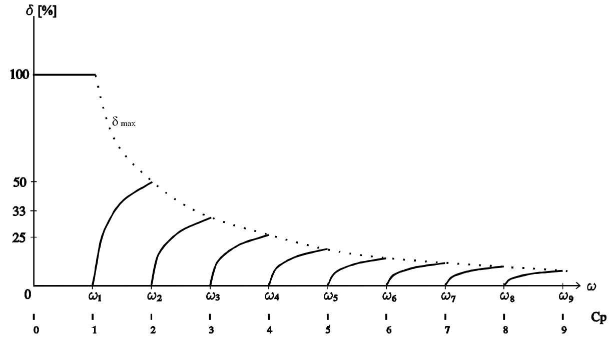

Fig. 3. Dependence the relative error versus rotation number

Increasing the number of encoder markers and/or extending the measurement time T_c may additionally decrease the lower limit of the rotational speed. The upper limit of the speed is determined by characteristics of the used counter: its modulus and maximum operating frequency.

The reciprocal measurement method is based on the measurement of encoder pulses period, [3]. Block diagram of the tachometer for measurement of the rotational speed by this method, realized by either software or hardware is presented in Fig. 4.

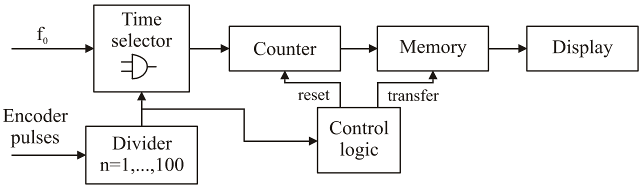

Fig. 4. Block diagram of an instrument for measurement of temporary angular speed

The time selector (i.e. an AND gate) passes through the pulses from the local oscillator when it is open (gated) by encoder output pulse. The active (high) portion of the encoder pulse may be extended by using frequency divider, therefore allowing the measurement of higher angular speed. The width of the active portion of the encoder pulse is inversely proportional to the rotational speed of the shaft on which the encoder is fastened, i.e.

$$\Delta t = (60n)/(2\omega P), \qquad (9)$$

where n is the frequency division ratio for the encoder pulses frequency, and P is the number of encoder markers. During this time pulses from the local oscillator, whose frequency is f_0, are passed through the time selector and applied to the counter. During time Δt the counter will count C_p pulses, i.e.

$$C_p=f_0\Delta t. \tag{10}$$

By combining the last two equations, it is obtained that

$$C_p=(60nf_0)/(2P\omega)=k/\omega \tag{11}$$

k is constant proportionality factor.

Since C_p is an integer number, and ω is a real number, it means that there are values at the angular speed ω which cannot be 100% accurately measured. By an analysis, similar to that used for the previous method, the maximal relative error in a given interval, defined by two adjacent counter contents, is obtained as

$$\delta_{\max}(\%)=\frac{\omega_{cp}-\omega_{cp+1}}{\omega_{cp+1}}=\left(\frac{C_p+1}{C_p}-1\right)100\%=\frac{1}{C_p}100\% \tag{12}$$

For values of ω_{cp} which correspond to counter contents $C_p=1$, $C_{p\max}$ relative error δ is equal to zero. By observing ω in all intervals defined by the adjacent counter contents, the dependence of relative measurement error on the angular speed is obtained and presented in the Fig. 5.

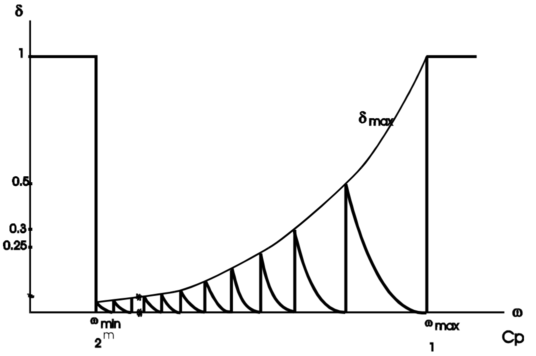

Fig. 5. Measurement error of the rotational number by reciprocal method

It may be seen from the Fig. 5 that maximal relative measurement error increases with increasing angular speed. The maximal allowable relative measurement error is used in order to determine the upper limit of the rotational speed. By using the last equation for $\delta_{allow.}=\delta_{max.}$, the minimum counter content

$$C_{p\min}=(100\%)/\delta_{allow.}(\%), \tag{13}$$

$$\omega_{upper}=\frac{60nf_0}{2P}\frac{1}{C_{p\min}}=\frac{60nf_0}{2P}\frac{\delta_{allow}(\%)}{100\%}, \tag{14}$$

is obtained for which the relative measurement error is equal to the maximal allowable relative error. By putting $C_{p\min}$ in the equation that relates the counter content and the rotational speed, the upper limit of the rotational speed is obtained, for which the accuracy of the tachometer is equal to δ_{allow}. The lower limit of the rotational speed is determined by the maximal counter count (i.e. the counter capacity). Since the measurement error for the reciprocal method increases with increasing measured angular speed, Fig. 5, reducing the number of encoder markers can reduce it.

Method of constant elapsed time

Method of constant elapsed time interval, the CET method, is based on two operations: counting the encoder pulses and measuring the encoder pulses period, [5]. Requirements for both short measurement time and short pauses are completely satisfied in this method. Generally speaking, the CET method is a compromise between resolution and measurement time. Results of comparison of this method with the classical methods are presented in Table 1. The time interval Δt is measured by using auxiliary pulses from the internal oscillator (usually clock pulses for microcontroller's timer). The measured time interval is selected to be equal to the allowed CET interval T_{el}, or to be longer than T_{el}, and it is an integer multiple of the encoder pulse period.

The principle of the measurement is shown in fig.6. Two counters, one for counting encoder pulses and the other for measuring of time interval, are both started at the same time by the positive going edge at the encoder pulse. The encoder pulses counter is stopped by the first positive going edge of the encoder pulse which appears after the CET time interval T_{el} has elapsed.

The content of the encoder pulses counter is then C_p. The content of the timer counter is C_t, which is the number of the counted clock pulses. The angular speed may be calculated as a ratio Δφ/Δt. Δφ is the increment of the rotation angle during the time interval Δt, so we have

$$\Delta\varphi=C_p 2\pi/P \text{ (rad)}, \tag{15}$$

$$\Delta t=C_t T_0 \text{ (sec)}, \tag{16}$$

where P is the number of the encoder disc markers. By combining aforementioned equations, the rotational speed is obtained as

$$\omega=\frac{60C_p}{PT_0C_t}=\frac{60f_0}{P}\frac{C_p}{C_t}\left(\min^{-1}\right). \tag{17}$$

By analyzing the measurement process, it may be seen that Δt depends on the measurement speed, with variations less then 1:2. Δt is longer than the encoder pulses period, and shorter than the time $2T_{el}$. is presented in Fig. 6b.

At very low rotational speeds, the encoder pulses period increases and finally exceeds the usual variations of $2T_{el}$. Therefore, at low rotational speeds the CET method is identical to the method of measurement at the encoder pulses period (in a sense that the time interval between the two adjacent pulses is being measured).

Table 1. Comparison of the CET method with the classical methods for measurement of the rotational speed

Δn/n	Pulse counting	Pulse duration measurement	CET method
at 30 rot./min at 3000 rot./min	85% 0,85%	0,025% 2,5%	0,025% 0,05%
Measurement time	Pulse counting	Pulse duration Measurement	CET method
at 3000 rot/min at 30 rot/min	2,3 ms 2,3 ms	0,02ms 1,95ms	1,02ms 1,95ms

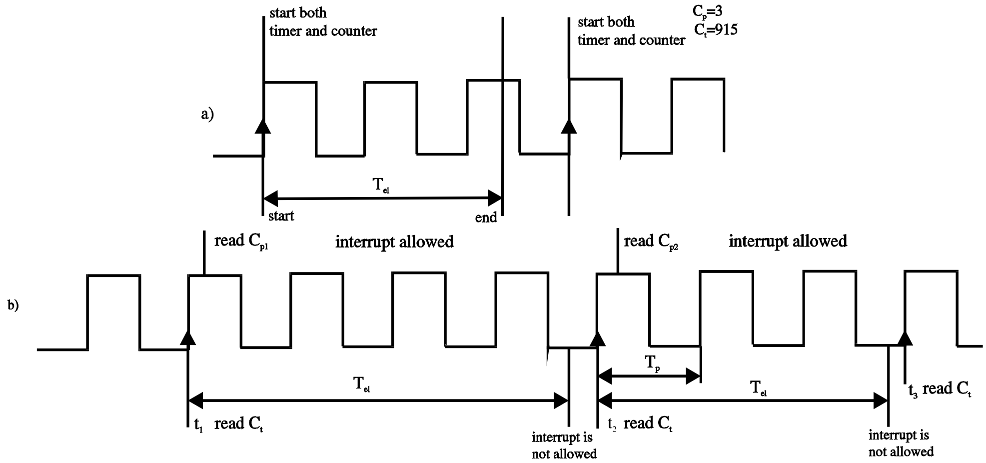

Fig 6. Illustration of measurement of the rotational speed by the CET method (a) calculation after every reading, (b) calculation after several reading

If the encoder pulse period exceeds $T_{max}=2T_{el}$, measurement result will be 0 rotation/min. Instead of that, the measurement could be restricted to the minimal measurable rotational speed where T_{max} is used, which is defined as

$$\omega_{\min} = \frac{60}{T_{\max} P}. \tag{18}$$

Unlike other methods, for this measurement it is not necessary to repeat (i.e. to restart) encoder pulses which are measured. The time counter is implemented in the system. At new starting and stopping of the counter, some time is spent. Since that time affects the measurement time, it is necessary to reduce it as much as possible. Reading of the counter content is made after every measurement interval has elapsed and then the rotational speed is calculated.

The time diagram illustrating such a way of operation is presented in Fig. 6b.

Realization of the digital tachometer

Here we have microcomputer based realization which enables flexibility and maximization of the digital tachometer characteristics, Fig. 7. The 8031 micro-controller with two timers (counter registers is used because it is very cost-effective for this purpose). According to the CET method, one timer/counter is used for the time interval measurement, i.e. it is used as a timer (TXO register), while the other counter TX1 is used to count encoder pulses. M2764 EPROM and 74HC573 latch register are also used in the microcomputer system built around 8031 microcontroller. A D/A converter may also be used in case when realized tachometer is applied in continual control systems. Extensive experimental examination of the realized digital tachometer pointed out the disadvantage of the proposed CET method and the possible error of the realization presented in [5]. For adopted $T_{max}=2T_{el}$, the problem of the ″false zero″ occurs at the rotational speed which is two times higher than the minimal speed.

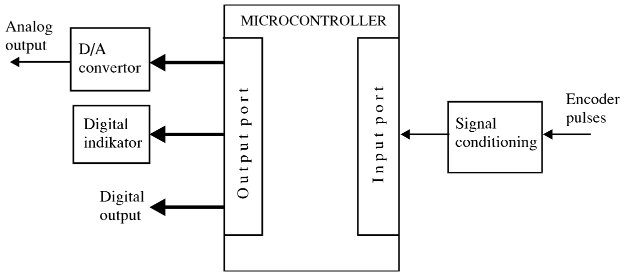

Fig. 7. Block diagram of the realized digital tachometer

Due to the delay caused by correcting of the timer content, which is necessary in all realizations, the microcomputer is not able to detect the positive going edge of the signal at the input port which should stop both timer and counter, Fig. 8a. Although the TX1 counter detects it, the next positive going edge is being waited for, and since it is outside the T_{max} interval the rotational speed is detected as "zero". This problem is eliminated by adopting values for T_{max} which are longer than $2T_{el}$, Fig. 8b.

The timer operates on 1MHz frequency, because the 12MHz-quartz oscillator is applied. It is adopted that T_{el}=29,952 ms and T_{max}=65,535 ms. If faster measurements are required, lower value for T_{el} may be adopted ($T_{max}>2T_{el}$), and according to that the value of correction must be changed. The possibility of connection of the realized tachometer with the computer via serial interface is very important. It is possible to read the instant motor rotational speed on the computer's terminal, as well as to monitor the graphical representation of the measured quantity in real time. The two-way communication between the computer and the realized digital tachometer also enables fast changing of certain parameters, such as the measurement time.

For realization of such instrument, LabVIEW software was used which provide a high-quality presentation of measurement results. One virtual instrument is realized in accordance with current trends of using virtual instrumentation in industry. Initial research, represented in [6,7], is got a final form with this realization, and results of testing are validate the high performance of realized virtual instrument. Induced modifications of CET method are provided irreproachable functioning of instrument.

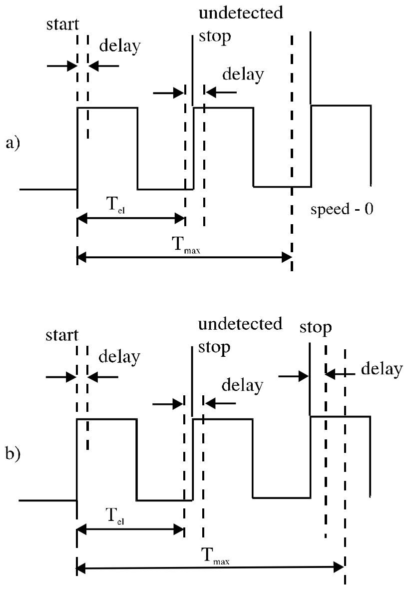

Fig. 8. Elimination of the "false zero": a) $T_{max}=2T_{el}$, b) $T_{max}>2T_{el}$

In order to test the realized digital tachometer, pulses from digital pulse generator are applied to the tachometer's input instead of pulses from encoder. Frequency of the digital pulse generator, which is measured by a high accuracy digital counter HP 5316B, may be varied in a wide range. For the proposed encoder disc with P=36 markers, equivalent rotational speed is calculated as n=60f/36 (rpm) (revolutions per minute) and it is compared with the measured speed read from the seven digit display, the number of decimal digits is fixed to two digits. The lowest speed which could be measured is experimentally determined to be 25.5 rpm, while the highest speed is 833333 rpm.

Applying lower operating frequency quartz crystal for determining the microcontroller clock may proportionally reduce the highest speed. Experimental results show that the relative error is almost constant within the whole measurement range and oscillates around 0,05%. Maximum error was found to be 0.068 %. These results point out the possibility of correcting the noticed systematic error. The best results are achieved by a small correction of the timer content. Maximum value of the residual error for improved realization of the digital tachometer is experimentally determined to be 0.02%.

The performances of the realized digital tachometer are significantly better than those which could be achieved by the application of the classical measurement methods.

Microcomputer system enables the connection of this instrument with a personal computer, which makes the tachometer an intelligent measurement module.

Conclusion

An increase of tachometer accuracy usually leads to increased measurement time and narrower measurement range. Therefore, a compromise must be found in certain applications. The CET method is a good choice which assures high accuracy which is almost constant within the whole rotational speed measurement range. Realization based on the microcomputer offers certain flexibility which is in this case used to maximize the digital tachometer characteristics. In addition to that, the two-way communication with the computer contribute to great flexibility of the realized tachometer and offers possibility of a high quality monitoring of the process in real time.

Using of LabVIEW software and realisation of digital tachometer as virtual instrument increases possibility of wide application of this device. With this approach realised intelligent measurement module can be constituting part of some complex multifunctioning virtual instruments, which is often requested in today industrial applications.

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Digital tachometer is one of the electronic instruments that are very frequently used in industry. In this paper an overview of the most frequently used methods for the angular speed measurement is presented and the concrete realization of an instrument which works according to method of the constant elapsed time is presented. This is one upgraded realization of digital tachometer which offers additional features. Microcomputer system enables the connection of this instrument with a personal computer, which makes the tachometer an intelligent measurement module. Using LabVIEW software, realized module is very easy modifying to virtual instrument with high performance. Ill. 8, bibl. 7 (in English; summaries in English, Russian and Lithuanian).

Д. Денич, Г. Милькович, Д. Живагович. Микрокомпьютерный цифровой тахометр широкого диапазона // Электроника и электротехника. – Каунас: Технология, 2006. – № 3(67). – С. 31–36.

Описывается цифровой тахометр, широко используемый в промышленности. Представлен анализ методов измерения угловой скорости, а также реализация данного способа предложенным измерительным методом. Анализируется реализация цифрового тахометра, в котором применяется микрокомпьютерная система. Данный способ реализации позволяет использовать персональный компьютер, и в свою очередь, такую измерительную систему можно считать интеллектуальной. Подчеркивается, что предложенная модель в среде LabVIEW легко модифицировать и получить эффективный виртуальный инструмент. Ил. 8, библ. 7 (на английском языке; рефераты на английском, русском и литовском, яз.).

D. Denić, G. Miljković, D. Živanović. Mikrokompiuterinis plataus diapazono skaitmeninis tachometras // Electronika ir Elektrotechnika. – Kaunas: Technologija, 2006. – No. 3(67). – P. 31–36.

Skaitmeninis tachometras yra vienas iš pramonėje plačiai naudojamų elektroninių instrumentų. Pateikta dažniausiai taikomų kampinio greičio matavimo metodų apžvalga ir konkreti instrumento realizacija remiantis pastovios laiko trukmės matavimo metodu. Tai yra patobulintas skaitmeninio tachometro variantas, kuriame įgyvendintos papildomos funkcijos. Mikrokompiuterinė sistema leidžia prijungti šį instrumentą prie asmeninio kompiuterio, todėl tachometras gali būti laikomas intelektualios matavimų sistemos moduliu. LabVIEW terpėje sukurtą modulį labai lengva modifikuoti iki labai efektyvaus virtualaus instrumento. Il. 8, bibl. 7 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).

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