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Methods and Devices of Processing Signals of Optoelectronic Position Transducers

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1. Introduction

1.1 Precise optoelectronic position transducers

In digital position measurements two opposite ideas of taking measurements can be observed. They both tend towards obtaining the most precise results. The first idea is based on the precise construction of the glass scale and construction of the optoelectronic transducer by using simple circuits of electronic processing. The second idea is based opposite, that is on precise circuits of electronic processing and simple construction of the glass scale and construction of the optoelectronic transducer.

The position transducers can be classified as quantizing (dynamic) and coding (static). The quantization transducers produce an electric impulse during shift of length or angle unit in a way that on the output of the transducer the number of impulses proportional to measured value is obtained. The coding transducers are used to make a conversion from linear or angular displacement to a number code. About measurement accuracy of optoelectronic transducers decides first of all value of discretisation error which depends on number of modulation elements, fall to number of linear or angular shift unit. Among the new optoelectronic transducers, the width of gaps modulating beam of light reaches value of 0,05..0,004 mm. It enables to construct the transducer of resolution 10000 grains per rotation at disc diameter varies from 25 to 320 mm (discretisation error 0,01%) (Heidenhein, 2003) (Holejko, 1981).

In cases where specific work conditions exist (high dustiness, high temperature) the optoelectronic transducers cannot be used. In such cases special very precise magnetization scales are used (Heidenhein, 2003) (thin layers range micrometers - elements of different residual magnetism placed alternately)

2. Optoelectronic quantizing transducers

Presently the most popular are the optoelectronic position transducers which consist of a disc (or a strip used for linear displacement measurements) which has on its circumference a sequence of transparent and non-transparent fields. They respectively let in or absorb the light. (fig.1) The optoelectronic transducers dedicated for length measurement are equipped with a glass scale. Its length is equal to the length of the measured position. In the case of measuring the angle, the optoelectronic transducers are equipped with rotating discs. (Ching-Fen & Mao-Hong, 2005) (Feel-Soon & Sung-Jun, 2005) The glass scale models a beam

of light which drops on the photoelement in such a way that the appropriate number of impulses appear at its end. These are proportional to the linear or angular movement. The linear and angular transducers (Heidenhein, 2003) (Holejko, 1981) have the glass scale and the reticle made with a period of the reticle $10\mu\text{m}$ or $20\mu\text{m}$. (fig.1)

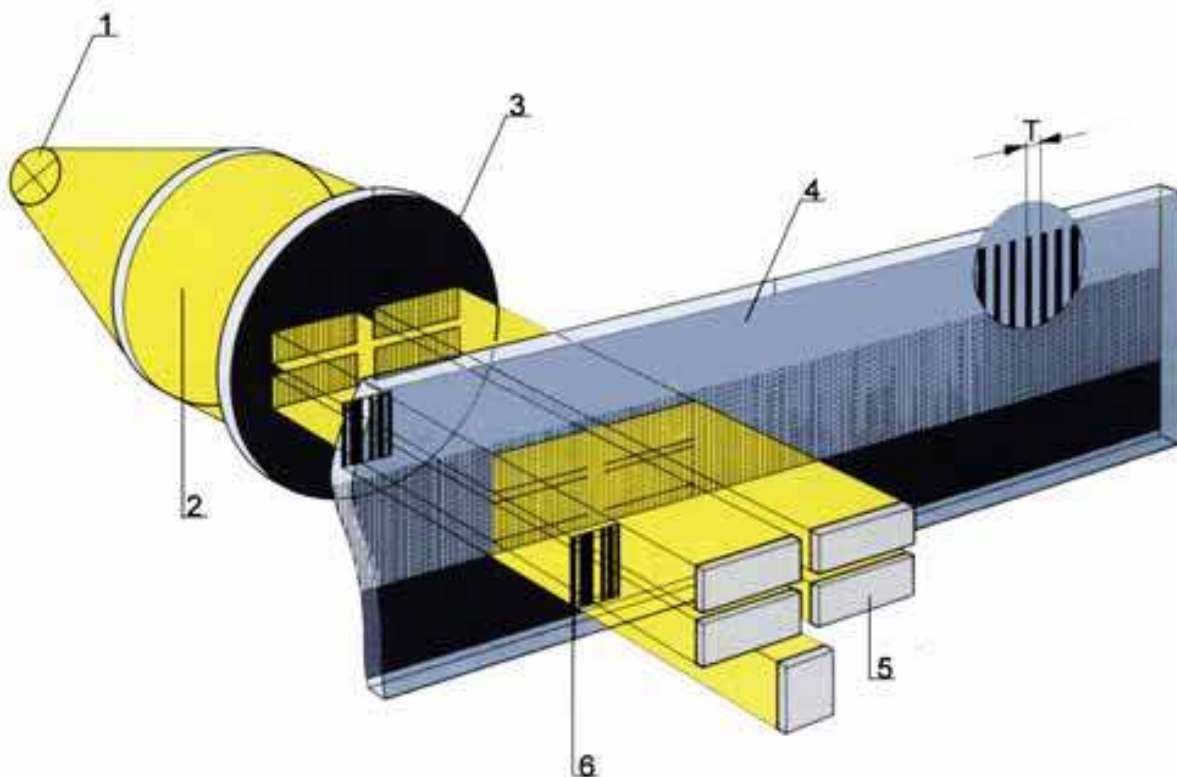


Fig. 1. The principle of photoelectric measurement with the glass scale
 1. source of light, 2. condenser lens, 3. scanning reticle, 4. glass scale, 5. solar cells
 6. reference mark

The second path (of the glass scale) transfers one or more reference marks. The scanning unit consists of: a source of light, a condenser lens used to obtain parallel beam of light for the scanning reticle, the glass scale and solar cells. When the glass scale is moved relatively to the scanning unit, the lines of the scanning reticle converge alternately with the lines or intervals of the glass scale. As a result periodic fluctuations of light intensity are converted to electrical signals by solar cells.

The transducers which use the steel scale work with reflected light. The steel scale consists of high-reflecting gold lines and light dissipating or absorbing intervals and it is used as a measuring reference. When the scale is displaced, the solar cells of the scanning unit produce periodic signals similar to those produced from the glass scale.

There are also used the linear transducers which use diffraction and interference of light waves. The measuring reference reflects the light-phase reticle with length of pitch approximately $0.2\mu\text{m}$, and a scanning unit is the corresponding diffraction grating on transparent glass. They reach high accuracy and enable very precise measuring steps.

In measuring devices (Heidenhein, 2003) (Holejko, 1981) the most important role play division carriers on which the scale, mostly in a form of the cross-hatched reticle, is manufactured. These divisions are produced precisely according to elaborated technology

and are accurate reference of the measuring devices. Divisions on the glass or glass ceramics are made by covering an extremely thin layer of Chromium where accuracy in range of division structure is in range of micrometers and more precise. The divisions on steel carriers consist of highly reflective gold dashes and metal intervals between them. Apart from high precision of laying dashes one from another they have also a considerably high sharpness of edges and they are resistant to mechanical and chemical factors. Apart from this they are sensitive to loads made by vibrations or impacts. They also demonstrate the precisely defined thermal response. Changes of air pressure or humidity do not have any effect on accuracy. Length of the scale – measuring range for the scale made on steel carriers (steel tapes) is up to 30m., whereas for the glass scale is up to 3m..

In the measuring incremental transducers it is not practical to displace an object of high distance due to repeating an algorithm of determining the starting point of the processed object. This problem has been solved by proposing both in the linear and circular scales length-coding reference marks. The scale consists of the reticle and a parallel path of reference marks. By changing, by defined rule, distance between the neighboring reference marks absolute position of each reference mark is coded.

In the linear transducers which have the length-coding reference marks, absolute position value can be once again determined by displacement over the two following reference marks that is after displacement of 20 μ m. The manufactured angular transducers with the length-coding reference marks have 36 reference marks on the discs with 900 and 18000 lines, while the scales with 36000 lines have 72 reference marks. Rotations which do not cross adequately 20° or 10° are adequate to establish another absolute position.

3. Optoelectronic coding transducers

The main element of the coding transducer (fig.2) is the rotating coding mask. Each position of the coding mask (that is each possible to distinguish by given transducer value of measured quantity) corresponds to the determined combination of transparent and nontransparent fields for stream of light. This combination presenting 0 or 1 digits of binary code is read by photoelectric reading complex which consists of a source of light and photo elements. For each transducer coding path fall separate light-sensitive element in a way that on the output of the optoelectronic transducer static code is formed. This depends on the the actual position of the modulating disc. This code can be used directly as a value of measured quantity. If necessary the decoder enabling the matching code of the transducer disc to the code of the reading device can be used. About accuracy conversion decides first of all digitization error depended on number of bites in the output signal of the transducer. In fig.2 the code transducer was shown, in practice the transducers of 100..1000 grain resolution working in binary-decimal code (8..12 -bit) or 128..1024 grain resolution working in binary code (7..10 -bit). If higher precision is required the transducers with several coding discs coupled to each other by non-backlash gears are used. In this way in the transducer with two gears (1:100) received 10⁶ resolutions. The basic advantage of the coding transducers is the generation of parallel static binary code or binary-decimal code which is the value of the measured quantity. If there is a need parallel code can be easily converted to serial code. Conversion can be achieved by subsequent reading of information from particular coding strips. The drawback of both specified codes is the sensibility to making gross read errors. It comes from strict assembly tolerances of complex: the glass scale (disc) – a reading device. Elimination of this drawback can be achieved by special construction

means (Heidenhein, 2003) (Holejko, 1981) (i.e. reader in shape of a reversed letter V) or by applying instead of binary code different codes in which during the change of measured value of 1 grain, and the change of a state occur only on one code path (i.e. Grey code). Absolute measuring devices provide actual information of the position. There are also built converters which additionally produce incremental signals. (fig.2)

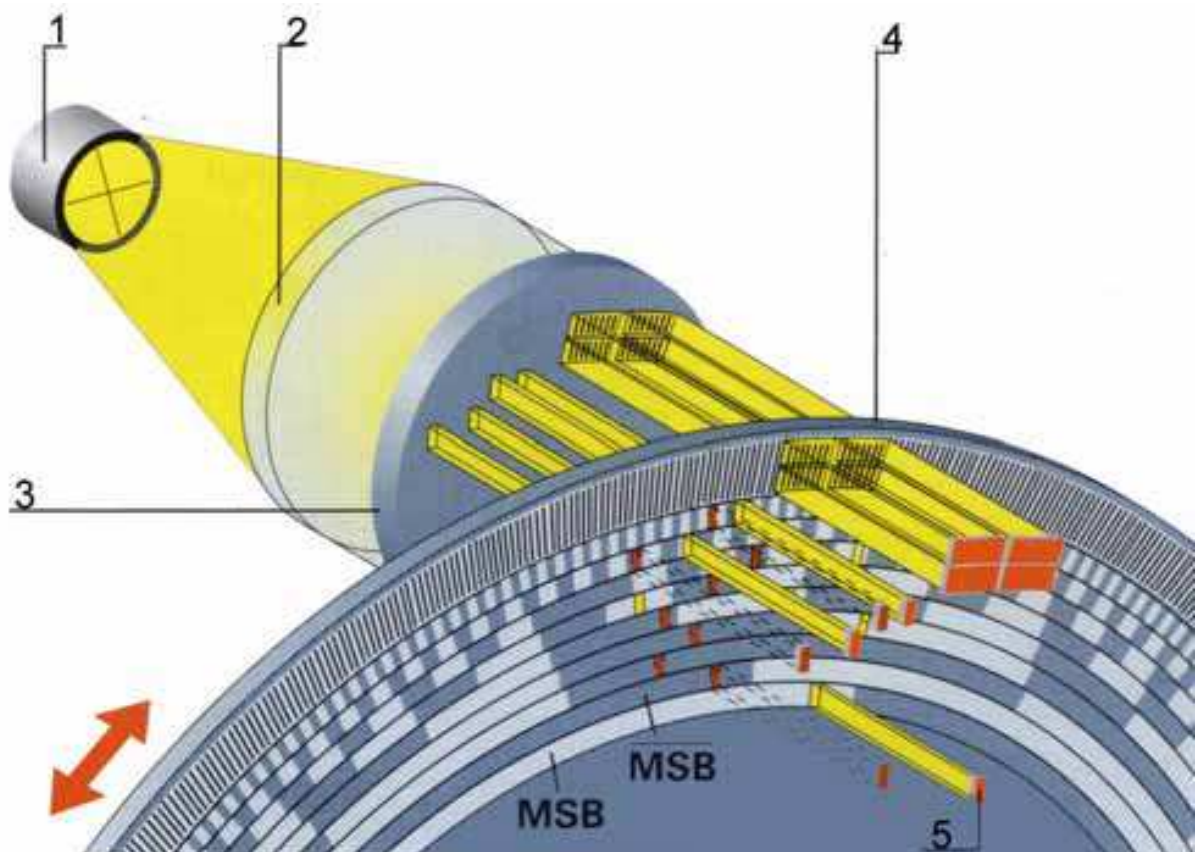


Fig. 2. The construction diagram of the code transducer for measuring angle source of light, 2- condenser lens, 3- scanning reticle, 4- glass scale, 5- solar cells

4. Method of shaping measuring sinusoidal signals of the optoelectronic transducer

On the glass scale 2, four rectangular fields with scanning reticle 1 are placed. They are assigned to individual photovoltaic cells. (fig.3)

The parallel light beam produced by the source of light and the lens is incident through the above mentioned grids on the scale of the scanning reticle and from there on the photovoltaic cell. The grids have identical widths of light, transparent and opaque fields, which is a condition for photovoltaic cells to generate sinusoidal voltage signals (Szcześniak, 2005)d (Szcześniak, 2005)g. In order to obtain sufficient signal value, it is advantageous that the measurement field should consist of N periods T of the displacement division. Then, for a specified field lit with a radiation beam of intensity E_o , at a given efficiency of the optical system, we will obtain an effective beam ϕ getting to the photooptical system U_a, U_b, U_c, U_d . We can form the beam incident on photoelements by placing a scanning reticle with appropriate relative displacement in relation to the scale index grid 2 of the transducer. The relative

displacement for the photoelectric system U_a amounts to 0° . The displacement of the photoelectric system U_b is $1/4$ of the period T in relation to the photoelectric system U_a . Its position is defined by the dependence $N_2T + 1/4T$. On the other hand, the system U_c is shifted by $1/2$ of the period T with respect to the system U_a and of the same period system U_d is shifted to U_b . The position of this photoelectric system is given by the dependence $N_1T + 1/2T$, $N_4T + 1/2T$. Exemplary positions of the reading fields are presented in the Fig.4. in which N, N_1, N_2, N_3, N_4 denote the number of periods T .

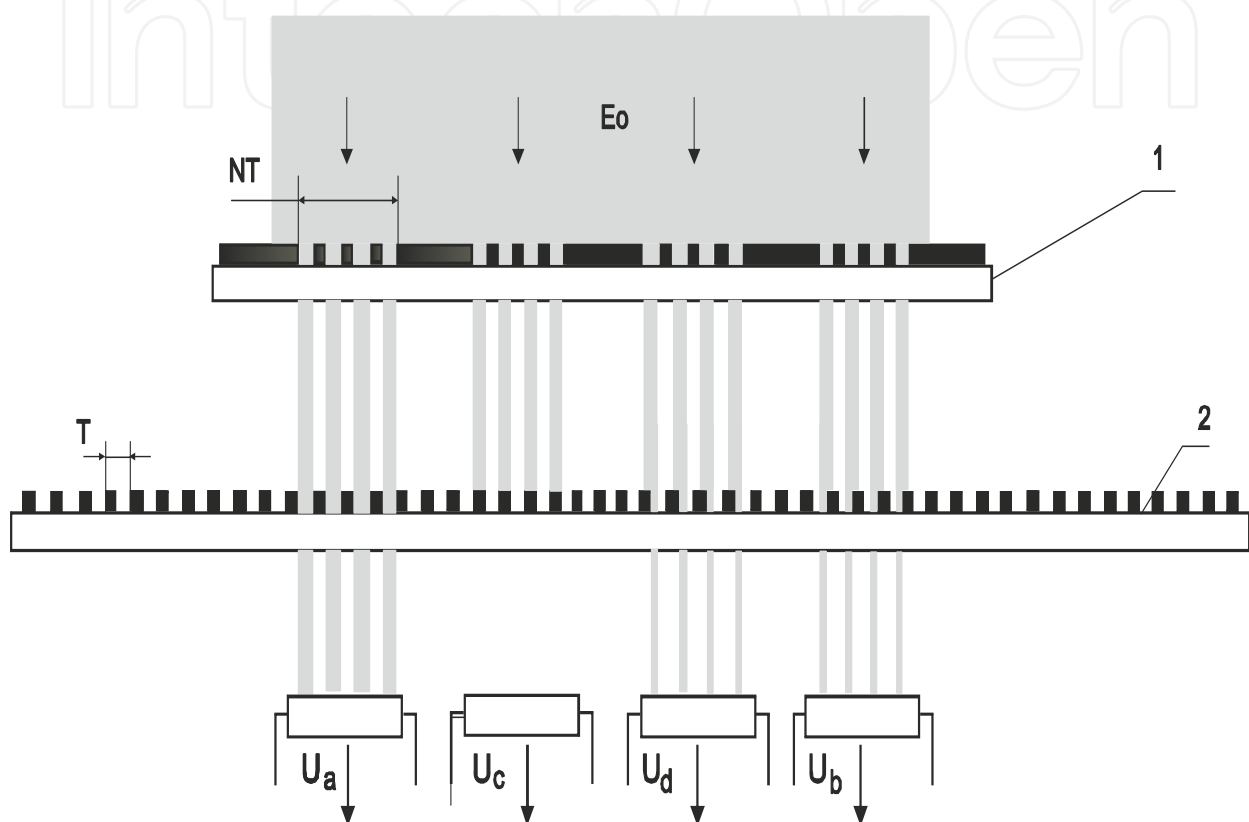


Fig. 3. Method of signal generation in photoelectric position transducer for three photoelectric systems

We can form the beam incident on photoelements by placing a scanning reticle with appropriate relative displacement in relation to the scale index grid 2 of the transducer. The relative displacement for the photoelectric system U_a amounts to 0° . The displacement of the photoelectric system U_b is $1/4$ of the period T in relation to the photoelectric system U_a . Its position is defined by the dependence $N_2T + 1/4T$. On the other hand, the system U_c is shifted by $1/2$ of the period T with respect to the system U_a and of the same period system U_d is shifted to U_b . The position of this photoelectric system is given by the dependence $N_1T + 1/2T$, $N_4T + 1/2T$. Exemplary positions of the reading fields are presented in the Fig.4. in which N, N_1, N_2, N_3, N_4 denote the number of periods T .

When the scanning distribution grating is in motion, photovoltaic cells generate sinusoidal voltage signals :

$$\begin{aligned} U_a &= A_1 \sin \varphi + A_0, & U_c &= A_1 \sin \varphi + A_0, \\ U_b &= A_1 \cos \varphi + A_0, & U_d &= A_1 \cos \varphi + A_0, \end{aligned} \quad (1)$$

where: $\varphi = 2\pi y/T$ in addition: A_1 - signal amplitude, A_0 - signal constant component, y - displacement, T - signal period.

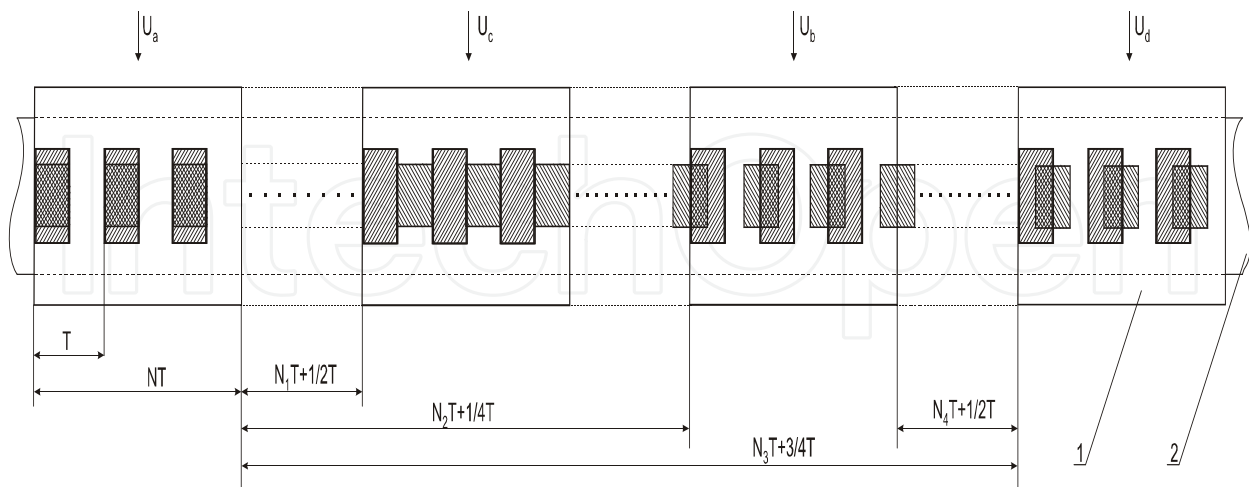


Fig. 4. Diagram of the reading fields of the measurement scale for three photoelectric systems

Subtracting sinusoidal signals U_a from U_c and U_b from U_d (signals of 180° phase shift), we get rid of the DC component and receive sinusoidal voltage signal that is symmetrical in relation to zero and shifted one from another by $1/4$ of period.

$$U_1 = A \sin \varphi \quad U_2 = A \cos \varphi \quad (2)$$

The principle of signal processing is presented in Fig.5. The signal period equals the grid period of the scale T . The method presented in the paper for the compensation of the signal DC component takes into account its dynamic changes when the transducer operates under changeable environmental conditions (temperature, humidity, dustiness, etc.).

Generated signals \sin , \cos are used to determine the motion direction. They can also be processed further in order to increase the accuracy of position measurement (Ching-Fen & Mao-Hong, 2005) (Feel-Soon & Sung-Jun, 2005) (Szcześniak & Szcześniak, VIII.2009) (Szcześniak, 2005)e.

Signals that do not contain a DC component make it possible to generate phase signals and then multiply the frequency of the signals in comparison to input signals. The generated signals are rectangular and have pulse-duty factor 0.5. Due to the lack of constant component in the signal U_1 , U_2 it is possible to directly receive from them rectangular signals U_{w1} , U_{w2} of pulse-duty factor 0.5. Constant and stable pulse-duty factor ensures obtaining uniform measurement step α presented in fig.5. The measuring step was defined as the distance between two subsequent slopes of rectangular signals U_{w1} , U_{w2} (Szcześniak, 2006)b. The number of pulses generated from the slopes of the signals and counted in the course of measurement gauge shift is the measure of position. Rectangular signals shifted in relation to each another by $1/4$ of the period and of pulse-duty factor 0.5 provide the basis for the determination of the photoelectric transducer motion direction. The method of shaping measuring signals with compensation of DC constant thus minimizing number of devices of measuring optoelectronic transducer to three presented in literature (Szcześniak, 2006)b.

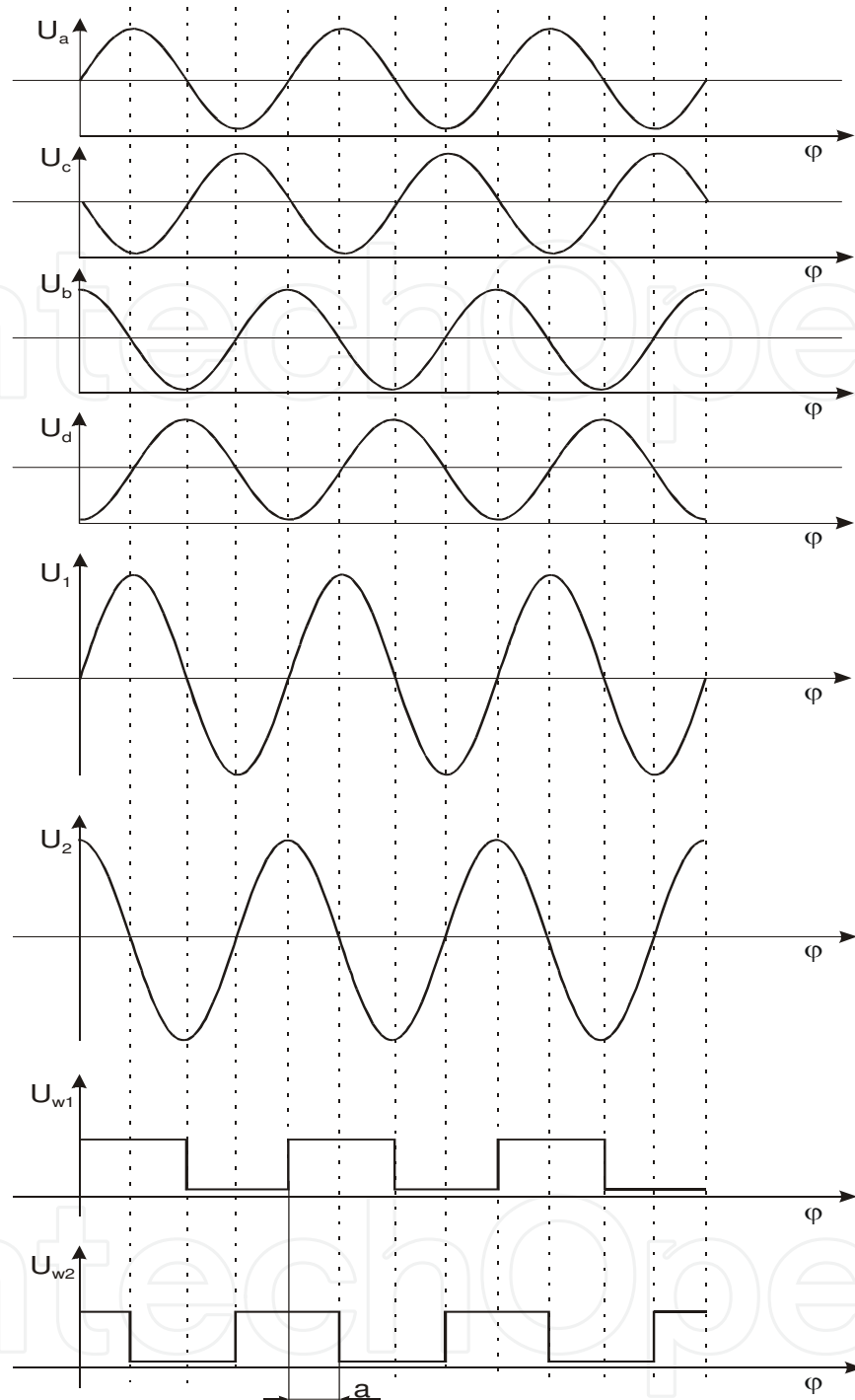


Fig. 5. Principle of signal generation in the optoelectronic quantization transducer for position measurement

5. Methods of processing electric signals of the optoelectronic position transducers to increase the accuracy of measurement and the motion direction determining

The development of specialized analog and digital systems allows for processing fast alternating signals. This means that in practice there are no limits to signal frequency on

account of measuring electronic systems. Much more significant are mechanical limits on account of the dynamic of measured object and its range.

The quantizing transducers (incremental) produce electrical impulse during shift of one unit of length or angle in a way that on the output of the transducer the number of impulses proportional to measured value is obtained (Szcześniak & Szcześniak, IV.2009).

About measurement accuracy of the optoelectronic transducers decides first of all value of discretisation error which is depended on number of modulation elements fall to number of linear or angular shift unit. The input signal of the optoelectronic transducer in a form of variable in time linear or angular velocity is integrated in time resulting in constant increasing of position $y(t)$ presented in fig.6. Uniformly spaced sequences of light transparent and nontransparent fields create a measuring scale which conducts the operation of quantization horizontally continuous in position time $y(t)$. Next, quantized signal of increasing position $y_{kw}(t)$ is differentiated in the circuit of optoelectronic transducer. Each another increase of position y of unit T (quantum) cause receiving impulse of output signal U_{wy} of frequency proportional to velocity moving mechanism. An example of time signal functions is presented in fig.6.

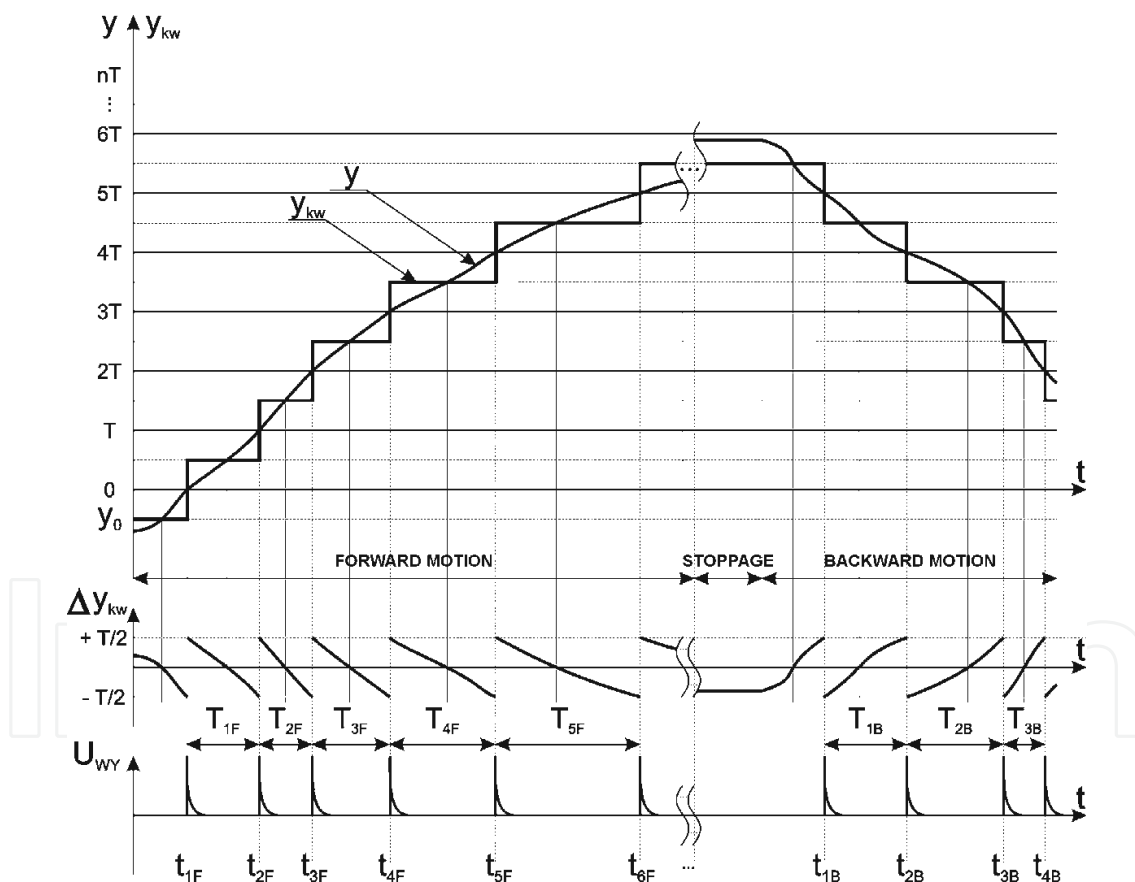


Fig. 6. Time functions of signals in the optoelectronic position transducer

Position increase from initial value y_0 with velocity proportional to value of input signal (velocity moving mechanism) and is quantized horizontally with step equals T . The position is presented for three phases of motion: forward motion, stoppage and backward motion. Error of quantization Δy_{kw} consist in a range of $\pm T/2$. In particular moment of time t_{1F} , t_{2F} , t_{3F} position y reaches following values T , $2T$, $3T$... and on the input of the sensor we receive

impulses spaced one from another in time of T_{1F} , T_{2F} , T_{3F} ... creating output signal of motion frequency in the forward direction. For the backward motion direction, impulses are generated in moments t_{1F} , t_{2F} , t_{3F} etc. In the presented figure, motion impulse is generated based on an equal step of quantization T , but in different moments depending on velocity of motion so the method of distinguishing the motion direction of the optoelectronic transducer was used. This method produces one impulse per one period of the glass scale. Below is presented the electronic method of increasing accuracy of the optoelectronic transducer by applying electronic interpolation (multiplication of signals' frequencies) and digitalization (conversion to digital form) and electronic methods of distinguishing motion direction and measurement of position with possibility of additional increase of optoelectronic transducer accuracy working with an object.

6. Method for the multiplication of the optoelectronic position transducer measurement signal frequency

Optoelectronic transducer output signals are composed of two sinusoidal signals, phase shifted with respect to each other by $\frac{1}{4}$ of the period. The signal period is equal to the period of the transducer scale grid (measurement bar). The scanning signals from transducers are first amplified and then interpolated. The interpolation method proposed by the authors relies on a network of resistors. It generates phase-shifted signals from two sinusoidal scanning signals by means of their vector summation in accordance with the description below. Voltage signals from the sensor

$$x = A \sin \varphi ; y = A \cos \varphi \quad (3)$$

where: $\varphi = 2\pi y/T$ in addition A - signal amplitude; y - displacement; T - signal period.

In method of interpolation from signals x , y signals x_1 , x_2 , x_3 etc. are created. Their phase is shifted to x signal by angle α , 2α , 3α etc. Initial signals can be written as:

$$\begin{aligned} x &= A \sin \varphi \\ x_1 &= x \cos \alpha + y \sin \alpha = A \sin(\varphi + \alpha) \\ x_2 &= x \cos 2\alpha + y \sin 2\alpha = A \sin(\varphi + 2\alpha) \end{aligned} \quad (4)$$

In the relationship above, the resistances R_1, R_2 are defined as :

$$R_1 = \frac{R}{|\sin \alpha|} \quad \text{and} \quad R_2 = \frac{R}{|\cos \alpha|} \quad (5)$$

where: α - angle of the assumed phase shift, R - adopted signal reference resistance
Generated voltage on the resistance divider is equal to:

$$U_d = A(\sin \varphi R_1 + \cos \varphi R_2) \quad (6)$$

Taking into account the above dependences and after transformation we receive

$$U_d = A_1 \sin(\varphi + \alpha) \quad (7)$$

in addition A_1 - the amplitude of a signal generated with the assumed phase shift α

For the sake of the method description clarity, it is assumed that the input signals are of constant frequencies (periods). This case represents the transducer collaboration with the object moving at constant velocity.

At the first stage of the method, signals are amplified and reversed producing four signals: \sin , \cos , $-\sin$, $-\cos$, afterwards two appropriate of them get interpolated. This creates twenty sinusoidal functions shift one from another by 18° . The principle of choosing input signals to dividers for individual parts of period presents fig.7. It is essential for the signals selected for interpolation to always have opposite signs in the period quarter that is of interest to us. For quarter I ($0^\circ - 90^\circ$) \sin and $-\cos$ signals are used, for quarter II ($90^\circ - 180^\circ$) they are \sin and \cos , for quarter III ($180^\circ - 270^\circ$) the signals are $-\sin$ and \cos , whereas for quarter IV ($270^\circ - 360^\circ$), they are $-\sin$ and $-\cos$. The signals get to twenty resistance dividers, the values of which are selected in such a way so that twenty sinusoidal waveforms are generated at their outputs. The waveforms are shifted with respect to each other by an assumed angle, which in the method presented amounts to 18° . For so assumed phase shift, for angles 0° , 90° , 180° , 270° interpolation does not occur and the signals $-\sin$, \cos , \sin , $-\cos$ are selected for further processing.

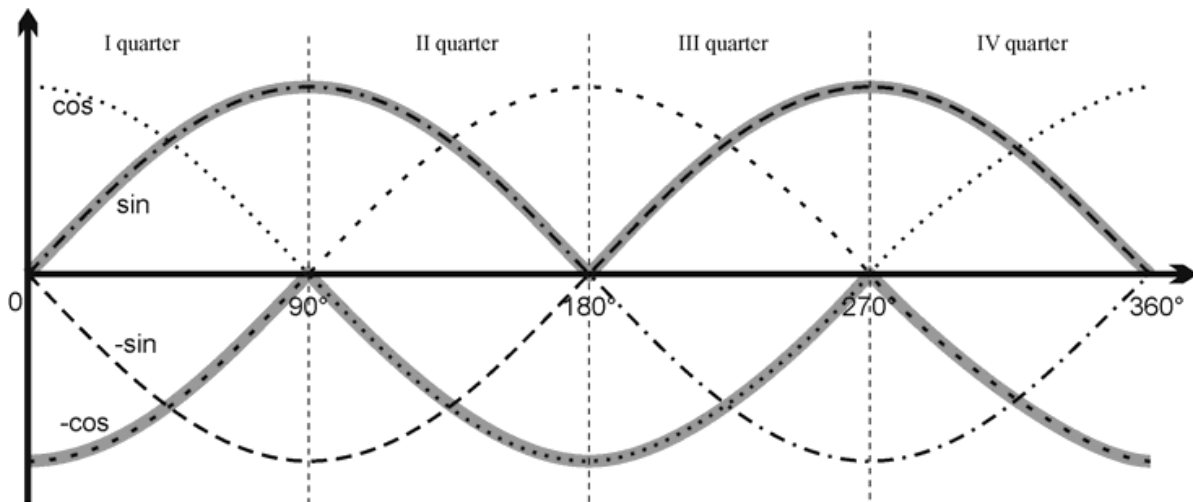


Fig. 7. Selection of signals to interpolation for following parts of period of input signal

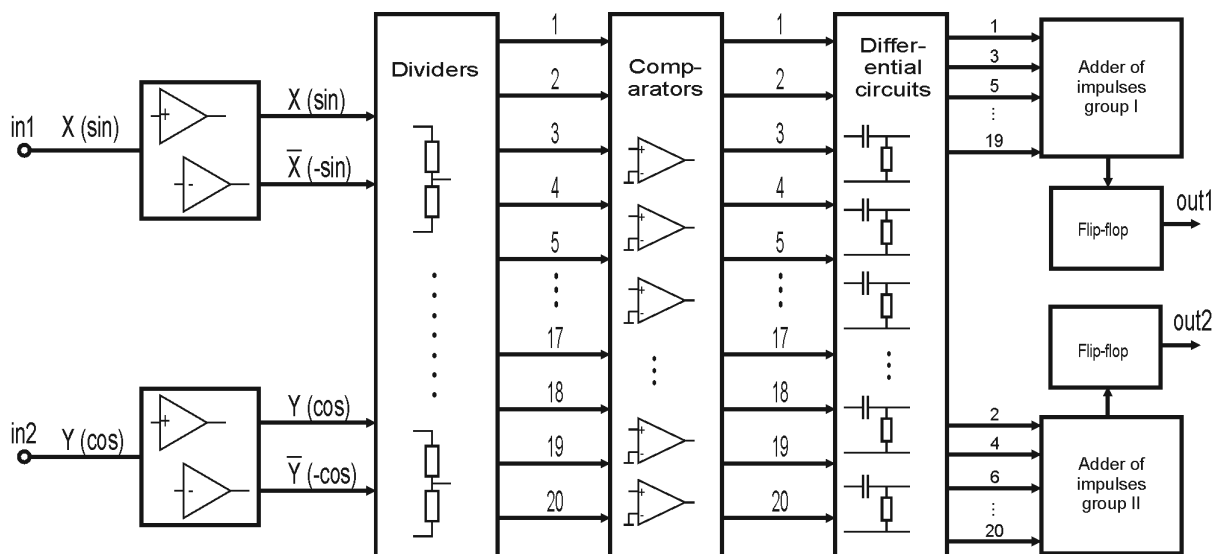


Fig. 8. The block diagram of the system of interpolation and digitalization of transducer signals

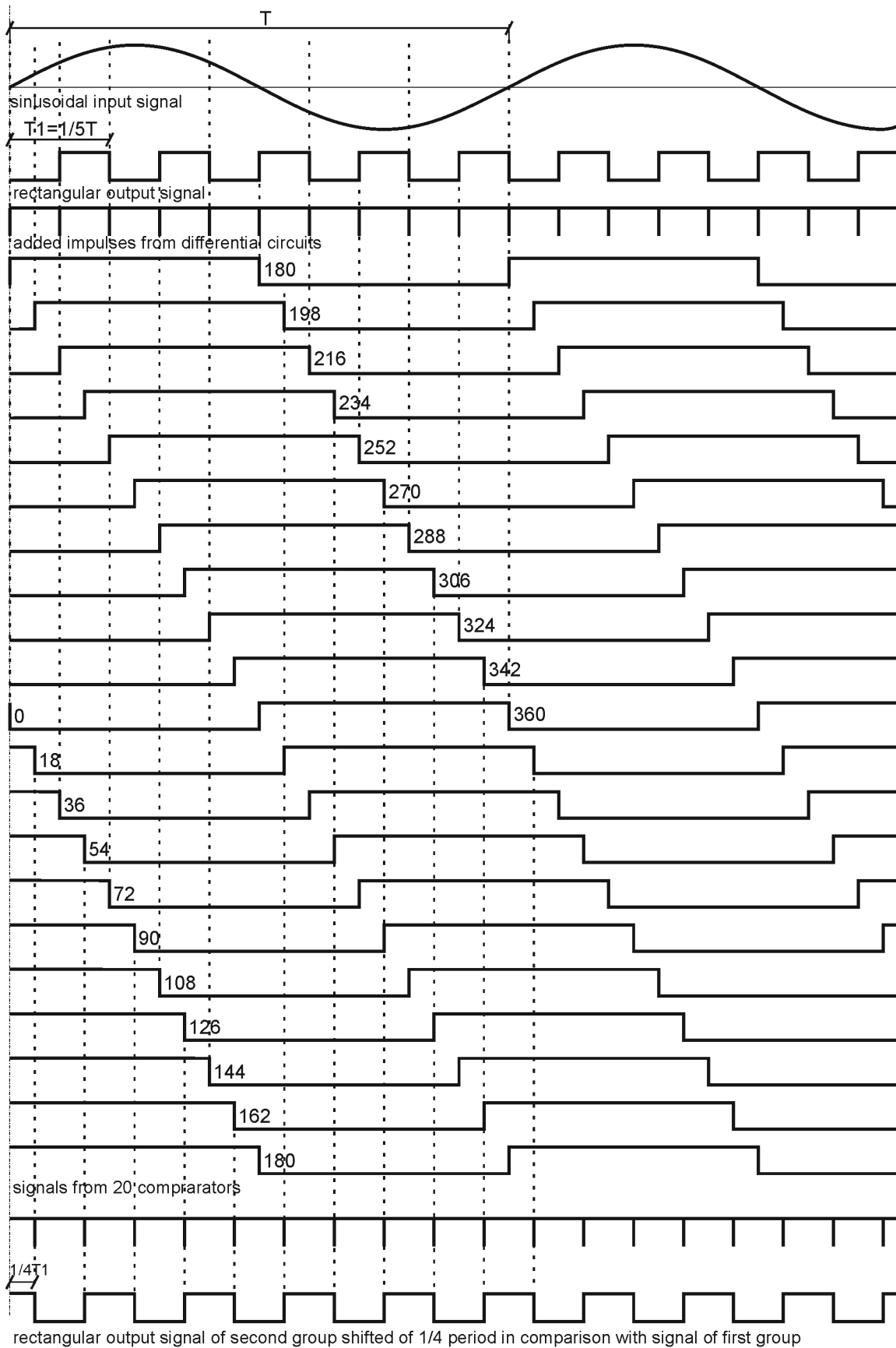


Fig. 9. Time functions of digital part of signals after interpolation

Angle α [°]	0	18	36	54	72	90	108	126	144	162
$\sin\alpha$	0,000	0,309	0,588	0,809	0,951	1,000	0,951	0,809	0,588	0,309
$\cos\alpha$	1,000	0,951	0,809	0,588	0,309	0,000	-0,309	-0,588	-0,809	-0,951
R1 [k Ω]	–	64,72	34,02	24,72	21,02	20,00	21,02	24,72	34,02	64,72
R2 [k Ω]	20,00	21,02	24,72	34,02	64,72	–	64,72	34,02	24,72	21,02
Angle α [°]	180	198	216	234	252	270	288	306	324	342
$\sin\alpha$	0,000	-0,309	-0,588	-0,809	-0,951	-1,000	-0,951	-0,809	-0,588	-0,309
$\cos\alpha$	-1,000	-0,951	-0,809	-0,588	-0,309	0,000	0,309	0,588	0,809	0,951
R1 [k Ω]	–	64,72	34,02	24,72	21,02	20,00	21,02	24,72	34,02	64,72
R2 [k Ω]	20,00	21,02	24,72	34,02	64,72	–	64,72	34,02	24,72	21,02

Table 1. Selection of resistor values for dividers from fig. 10

The generated signals are fed to one of twenty comparators which change their shapes making them rectangular signals. In addition, the change in state takes place at the site of the input signal passing zero. In this way twenty rectangular signals shifted with respect to each other by 1/20 period (18°) are generated. The signals are divided into two groups in such a manner that in each group each successive signal was shifted by 1/10 period with respect to the previous one. Two groups of signals are formed, each containing ten signals shifted by 1/10 period within the group and by 1/20 period with respect to the other group (Fig.9, Fig.10).

The next stage consists in such differentiation of waveforms so that each run would yield only one pulse in the period, i.e. one group will produce ten pulses dividing one period of input reference signal into ten equal parts, on the assumption that the frequency of input signals is constant. Pulses from two groups are summed to form two pulse waveforms of the frequency that is five times higher than the input signal (Fig.8, Fig.10). They operate as clock signals for JK triggers arranged in such a manner that each pulse of input clock signal causes the change of state to the opposite one at the trigger output. As a result, two symmetrical rectangular waveforms are created of the input frequency that is 5 times higher, i.e. there is one input sinusoidal signal period to 5 periods of output rectangular signal. The signals are shifted with respect to each other by 1/4 period and the displacement direction depends on the direction of input signal shift, which is dependent on the transducer motion direction (Pizoń et al., 1993) (Szcześniak, 2005)c (Szcześniak, 2005)f.

7. Method of optoelectronic transducer motion direction discrimination based on logical functions of the transducer signals

In the previous chapter, the method of increasing the frequency of the measuring signal in relation to the frequency resulting from quantization of position by the glass scale was presented. The output signal is shaped as two rectangular signals shifted one from another by 1/4 period. These signals are used in processing systems which distinguish the motion direction of a drive coupled with the transducer. Appropriate shaping of these signals enables additional increase of processing accuracy of the transducer. (Pizoń et al., 1993) (Szcześniak & Szcześniak, 2009)a (Szcześniak & Szcześniak, 2009)b (Szcześniak, 2006) a. The method of optoelectronic transducer motion direction discrimination of the optoelectronic transducer is illustrated by time functions in fig.11. Circuit structure of optoelectronic

transducer motion direction discrimination based on logical functions of transducer signals presents fig.12. During the transducer operation the electric rectangular signals A, G, shifted by quarter period are obtained on their two outputs (Fig.11, Fig.12). The task of the presented electronic system is counting the adequately generated motion impulses and distinguishing their sequence. The method is based on motion pulses generation on the base of the sum of the signals A+G and on the base of their product AG, what is presented in Fig. 1. Making the sum of those pulses

$$WY = \overline{A+G} + AG \quad (8)$$

it is possible to generate, during the period T, 1 or 2 pulses, which are counted in the reverse order.

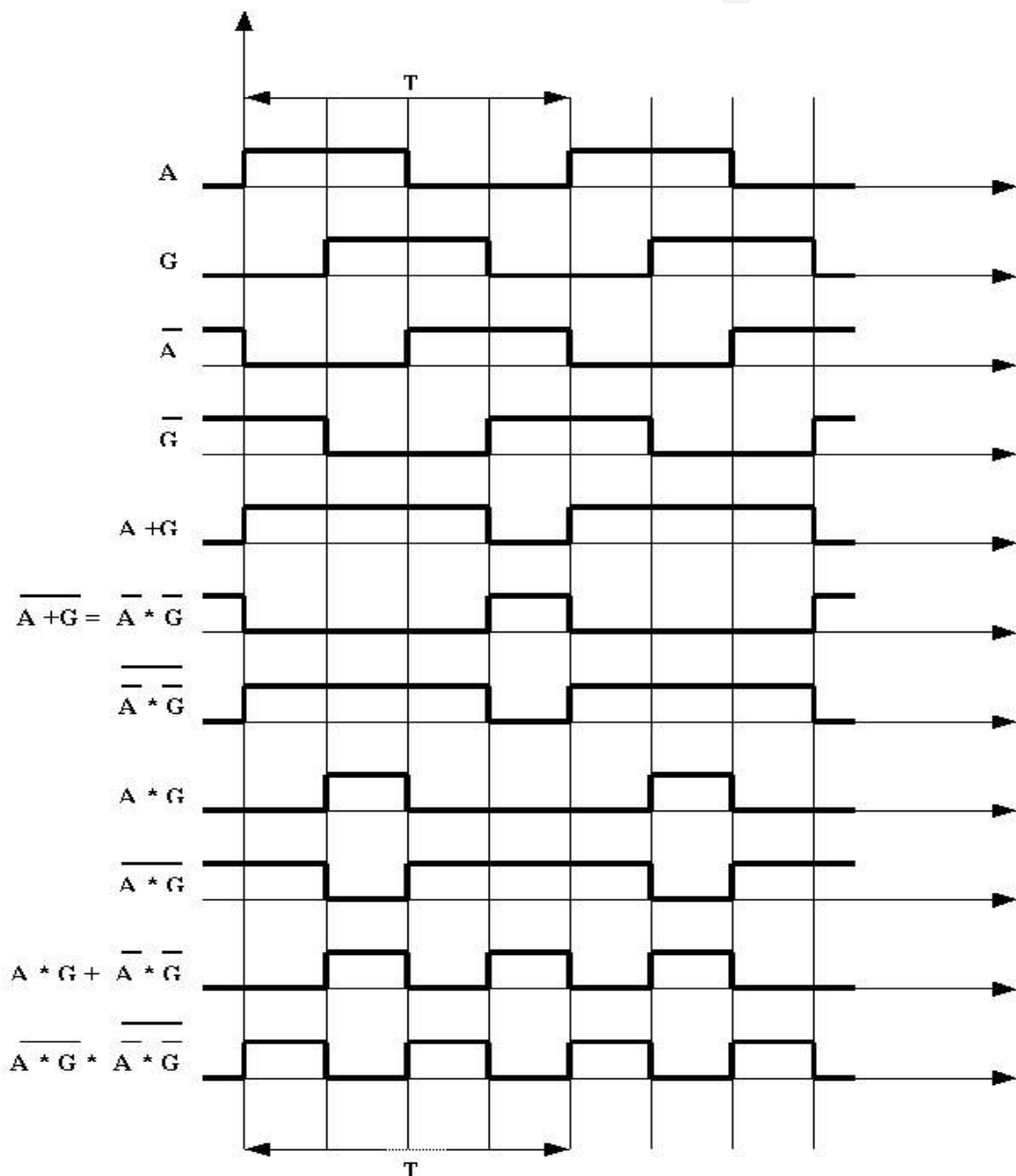


Fig. 11. Method of optoelectronic transducer motion direction discrimination based on logical functions of the transducer signals

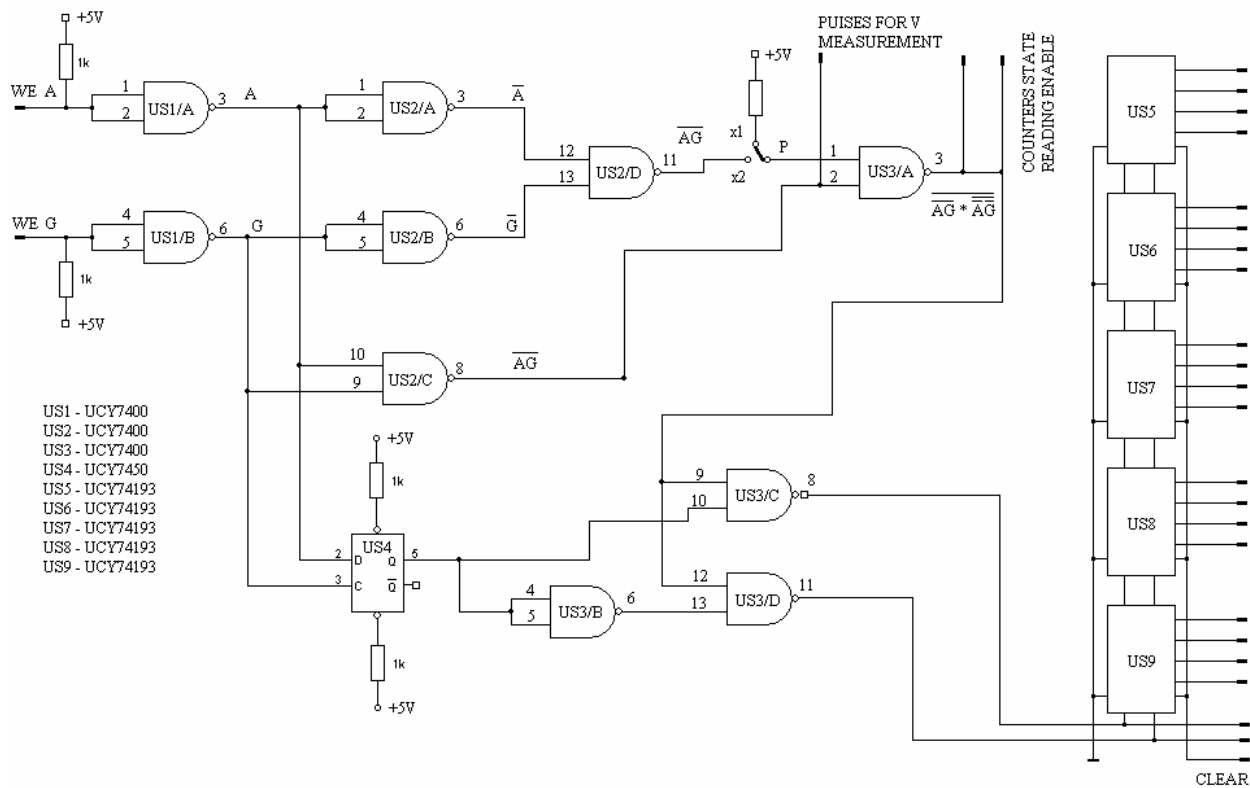


Fig. 12. System of optoelectronic transducer motion direction discrimination based on logical functions of the transducer signals

The counting order is chosen dependently on the shift between the A and G signals, what is set by the trigger. The G signal is delivered to the clock input and the A signal is delivered to the D input of the trigger. Change of the G signal from "0" to "1", when A="1", sets the Q trigger to "1". Counting to the right is then enabled. In the case when change of the G signal appears at A="0", i.e. when the G signal is leading to the A signal (change of the motion direction, the Q trigger changes its state and counting to the left is enabled. The system enables the choice of measurement accuracy x1 or x2, dependently on the setting of the P switch.

8. Method of optoelectronic transducer motion direction discrimination based on logical functions of the transducer signals and motion pulses generated in the RC circuits

In this method (Fig.13, Fig.14.), by summing the suitable products of A, \bar{A}, G, \bar{G} signals and the signals arising from generation of pulses of duration τ (from their rising edge) it is possible to count the impulses in the reverse counter, dependently on the transducer motion direction. When moving to the right the WY2 output of the NOR gate is set to "1", and on the WY1 output of the NOR gate a series of impulses repeated with the period of one transducer channel pulses is obtained:

$$WY1 = \overline{\bar{A} \cdot \bar{I}G + A \cdot IG + G \cdot \bar{I}A + \bar{G} \cdot IA} \tag{9}$$

where: IA, IG - impulses from the A, G signal edge; $\bar{I}\bar{A}, \bar{I}\bar{G}$ - impulses from the \bar{A}, \bar{G} signal edge.

When moving to the left the WY1 output of the NOR gate is set to "1", and on the WY2 output of the NOR gate a series of pulses, similar to the ones when moving to the right are obtained:

$$WY2 = \bar{A} \cdot \bar{I}\bar{G} + A \cdot IG + G \cdot \bar{I}\bar{A} + \bar{G} \cdot IA \quad (10)$$

Those impulses are subtracted from the reverse counter state when moving to the right.

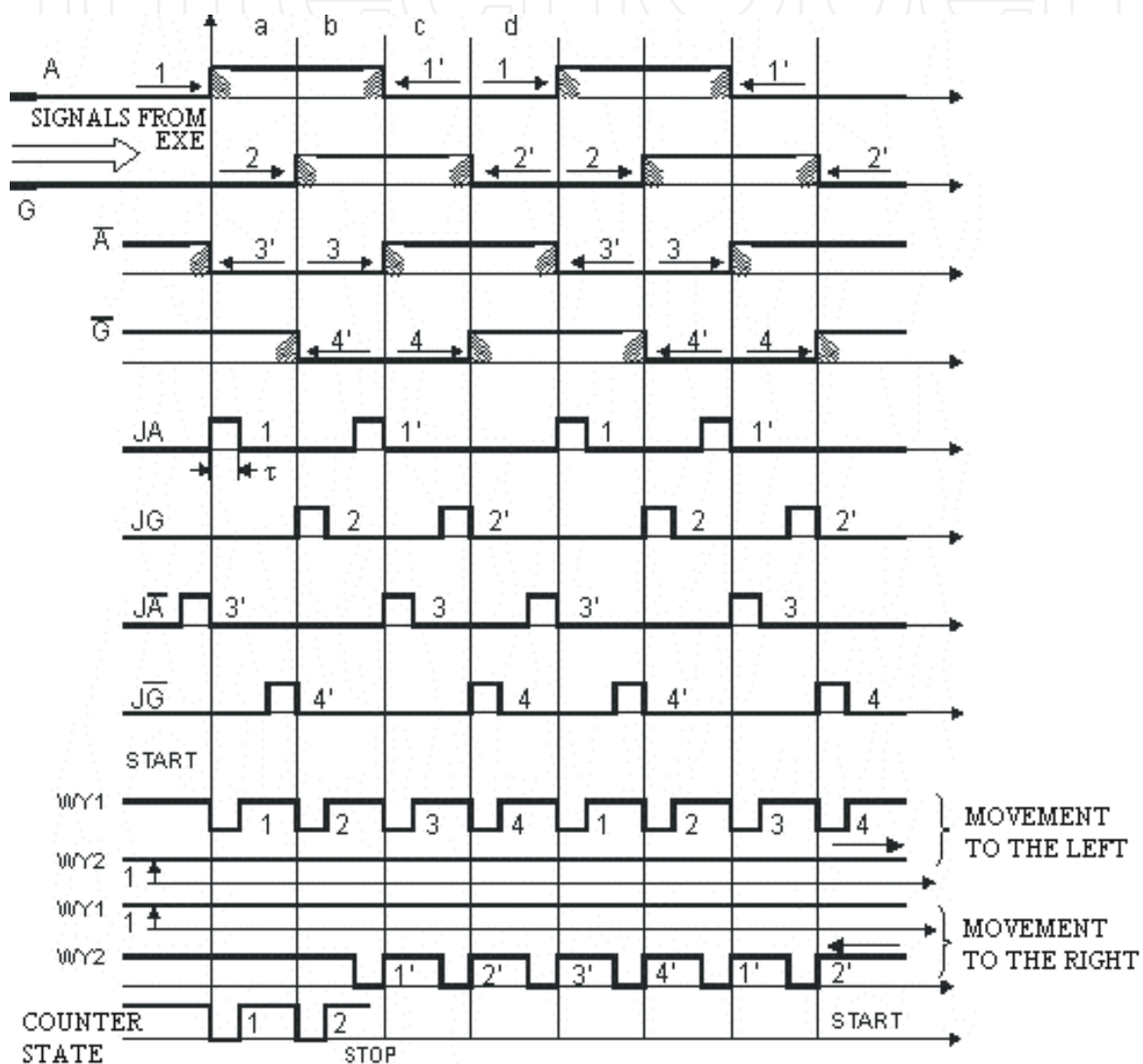


Fig. 13. Method of optoelectronic transducer motion direction discrimination based on logical functions of the transducer signals and motion pulses generated in the RC circuits

Change of the movement direction can appear in four different states a, b, c and d , as depicted in Fig.13. In every one of these states the system must respond identically, so the largest error of movement direction discrimination is equal to $\frac{1}{4}T$ (T - period of pulses in one transducer channel). It should be underlined that the system has the possibility of

controlling the number of pulses counted for one period of the input signal (1, 2, 4), dependently on the settings of P1, P2, P3 switches (Fig. 14.). In this way there is a possibility of setting the accuracy of system positioning on 1, 2 or 4 times.

9. Method of optoelectronic transducer motion direction discrimination based on logical functions of the transducer signals and motion pulses generated in the trigger circuits.

Fig. 15 presents the system of direction discrimination and the way of output impulse forming in „+”IA and „-”IG channels. There are NAND gates with Schmitt triggers at the system input. Their task is to form steep slopes of input signals and to narrow the switching zone from 1 to 0 inversely. This is important in the case of possible object vibrations and of moving direction change. The pulse counted in the given direction must be counted again, in the opposite movement direction, after having changed the moving direction.

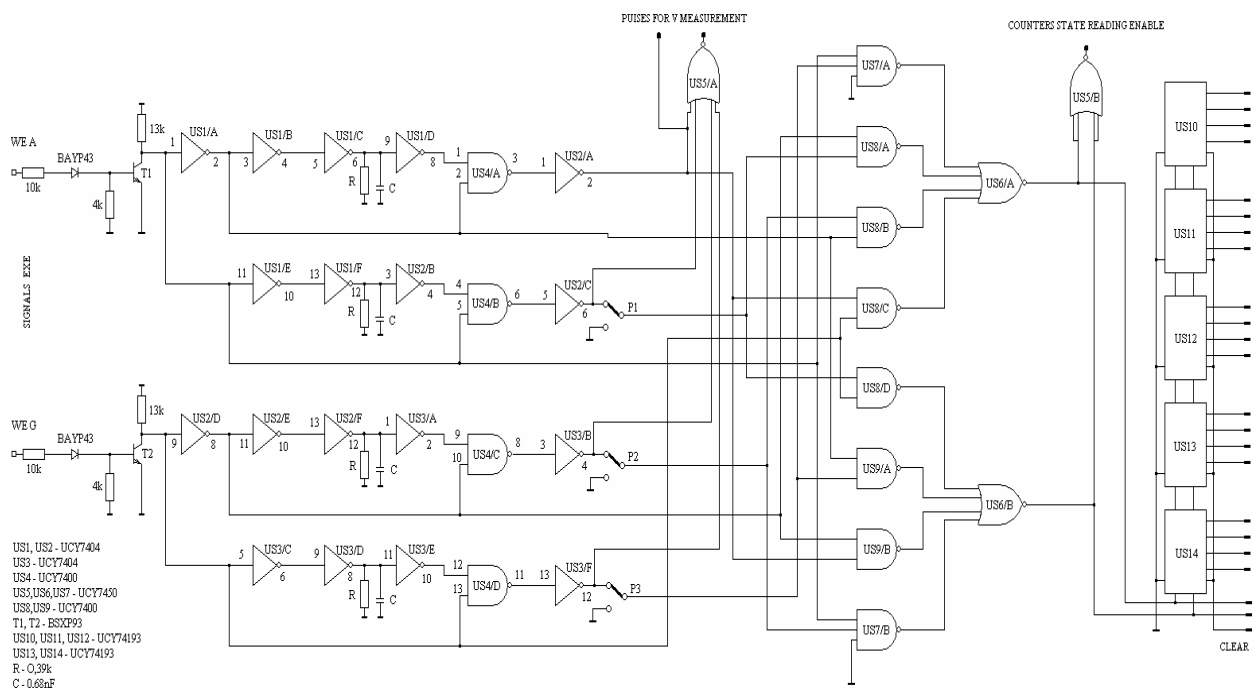


Fig. 14. System of optoelectronic transducer motion direction discrimination based on logical functions of the transducer signals and motion pulses generated in the RC circuits

The Schmitt gates formed output impulses at A and G points (Fig.15) have the polarity of rotary-pulse transducer output pulses because of the negations performed by the photoinsulator (optoelectronic coupler).

The system of JK flip-flops and gates perform basic functions of movement direction discrimination. The JK flip-flops are synchronised with the CLK clock pulses the combinational circuit performs the following function:

$$„+”IA = (C \bar{E} F) \vee (\bar{C} E \bar{F}) \tag{11}$$

$$„-”IG = (\bar{C} \bar{E} F) \vee (C E \bar{F}) \tag{12}$$

The rule of output impulse forming has been presented in Fig.16. Pulses for the positive direction are obtained at $A = „1”$ and the falling slope of the G signal and at $A = „0”$ and the rising slope of the G signal. Impulses for the direction taken as negative are obtained at $A = „1”$ and the rising slope of the G signal and at $A = „0”$ and the falling slope of the G signal. The system allows the formation of two output impulses in the given direction during one period of the input signal. The pulses are then counted in the impulse counters. The reverse counter state is the object position measure.

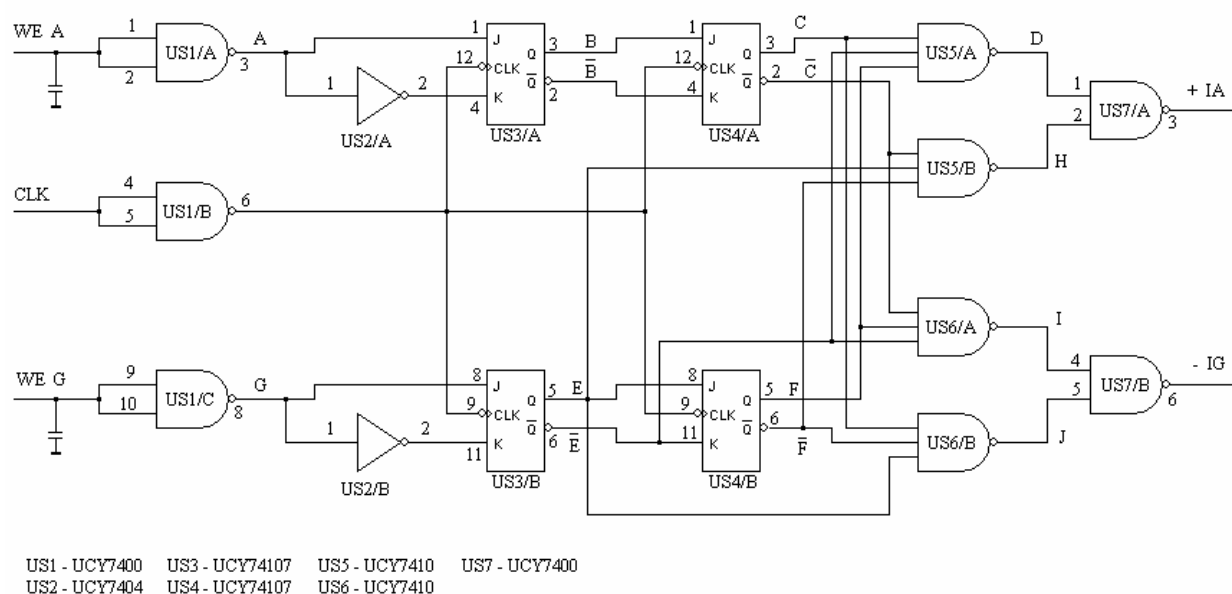


Fig. 15. System of optoelectronic transducer motion direction discrimination based on logical functions of the transducer signals and motion pulses generated in the trigger circuits

10. Application of the optoelectronic transducer to measuring velocity

The angular and linear velocity is the physical value of which measurement is used in almost all system solutions of drive controlling. Angular velocity measurement is made by analog or impulse sensors. Analog methods characterize little precision. A much higher precision of measurement can be reached by using digital methods. During measurement of displacement it is sufficient to use system counting following impulses where each impulse corresponds to specific displacement (Szcześniak, 2005)a (Szcześniak, 2005)b. During measurement of velocity additional timing needs to be assured what with considerable amount of impulses determining displacement gives in result velocity.

Presently the best solution of an impulse counting system, storing needed data, measuring time and doing calculations is a personal computer equipped with appropriate measuring-controlling interfaces (Szcześniak & Szcześniak, IV.2009) (Szcześniak & Szcześniak, VIII.2009).

In the case of using the incremental (impulse) optoelectronic transducers velocity is determined on the grounds of:

- time measurement between two following impulses generated by the photo-optic disc connected with the drive.

- number of impulses of the transducer counted in particular period of time

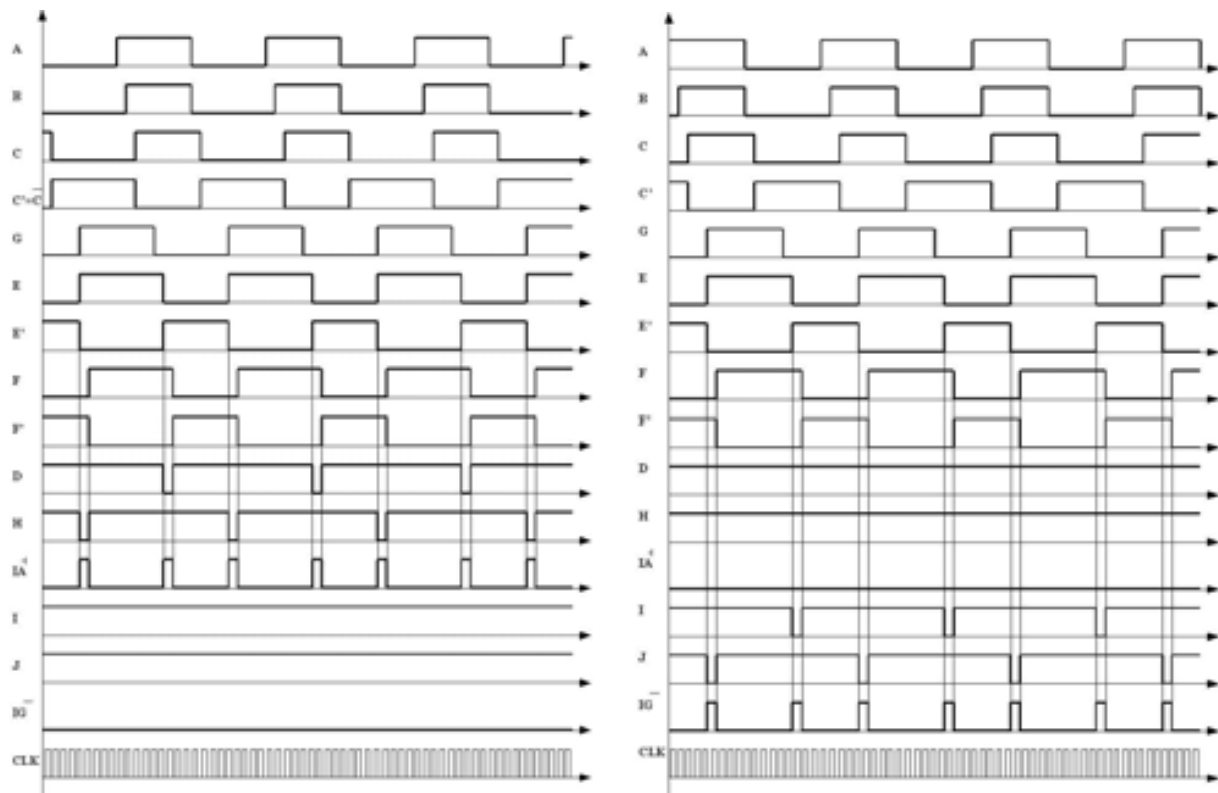


Fig. 16. Method of optoelectronic transducer motion direction discrimination based on logical functions of the transducer signals and motion pulses generated in the trigger circuits for movement to the right and to the left

In this chapter digital methods for measuring angular or linear velocity of drive were presented. Methods of measuring small and large frequencies with using the optoelectronic transducer were compared. A measuring algorithm and measuring system structure was discussed.

A measurement method of measuring high velocities is the most frequently realized by using the impulse transducers. This method is based on counting transducer pulses within the limited time T_w . The time is then sampling time. If the counter counts n impulses within the T_w time, and the path quantum is equal to ΔL or $\Delta\gamma$ and is known from construction of the transducer and co-operating systems construction, then angular speed is determined as:

$$v = \frac{N \cdot \Delta L}{T_w} \quad (13)$$

whereas for angular velocity:

$$\omega = \frac{N \cdot \Delta\gamma}{T_w} \quad (14)$$

These equations show the essence of the measurement. The idea of working of measurement system is shown in fig.17 and fig.18. The transducer coupled with moving element sends

sequence of impulses (signal UI). The model generator sends impulses G_w of model frequency f_w . A frequency divider DF sets time of measurement T_w . Time of measurement is set basing two following signals from the frequency divider. Impulses are counted by the counter in time T_w and from this, it is easy to determine velocity using presented previous equations.

The above measurement method is not very precise for small speeds, because of the small number of pulses counted within T_w time. In this situation the method based on measurement of the time between consecutive transducer impulses, corresponding to the specified displacement, should be applied fig.17, fig.18.

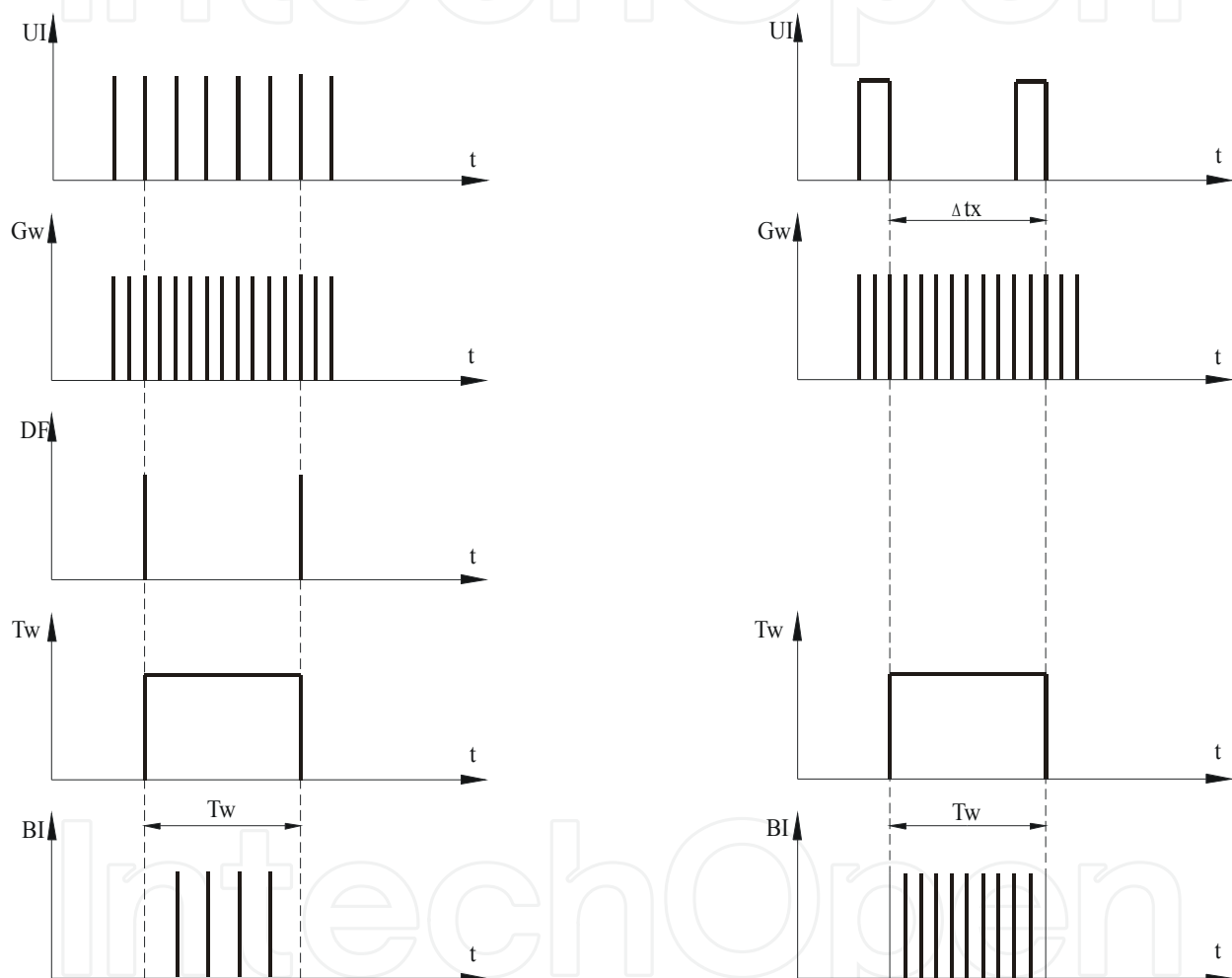


Fig. 17. Diagrams presenting way of measuring

In this method the transducer generates impulses of unknown duration Δt_x . Duration is measured between the following transducer impulses. A standard frequency generator sends standard impulses BI of known period $T_w = \frac{1}{f_w}$. The counter counts the impulses within the Δt_x time. Then linear speed is determined by the equation:

$$v = \frac{\Delta l_w}{\Delta t_x} = \frac{\Delta l_w}{N \cdot T_w} = \frac{\Delta l_w \cdot f_w}{N} \quad (15)$$

whereas angular speed:

$$\omega = \frac{\Delta\gamma_w}{\Delta t_x} = \frac{\Delta\gamma_w}{N \cdot T_w} = \frac{\Delta\gamma_w \cdot f_w}{N} \quad (16)$$

where:

Δl_w $\Delta\gamma_w$ - known displacement, Δt_x - unknown displacement time, $T_w = \frac{1}{f_w}$ - standard generator pulse period, N - number of pulses counted within the Δt_x time.

Measured velocity in method of high velocities is the number of transducer impulses counted in constant measuring time and is proportional to the measured velocity. In the second method velocity is inversely proportional to the number of impulses from the model generator (constant frequency) in fixed time dependant on the appearance of the following impulses from the transducer.

The diagram of the system to measure angular velocity using the incremental optoelectronic transducer, which idea of measurement consists in counting the number of impulses in the determined period of time is presented in fig.18.

The input transducer signals A and G (electrical signals) shifted one from another by 90°, are inserted into the system forming impulses (UI) and to the system distinguishing motion direction (UW_k), which was realized on the D flip-flop. In the (UI) system there is made multiplication of frequency of input signals and appropriate forming of impulses in order to increase resolution of velocity measurement (multiplication of frequency impulses) (Szcześniak, 2006)b.

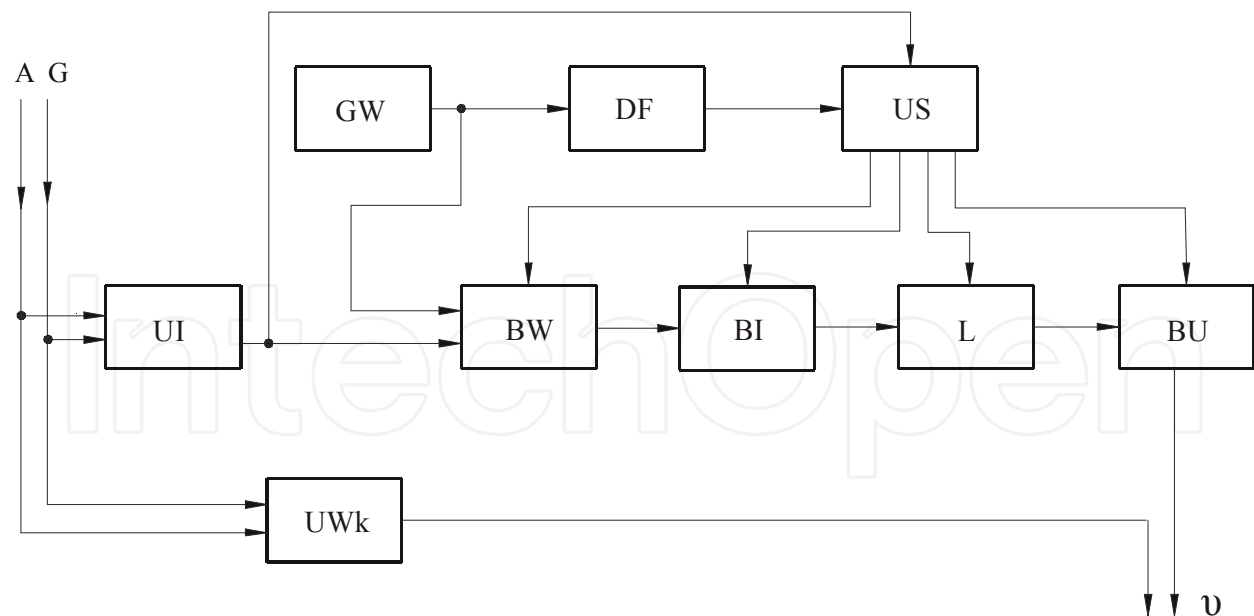


Fig. 18. The diagram of the system for measuring angular velocity

The generator stabilized by quartz (GW) and set of the frequency dividers (DF) produce clock signal. The impulse signal of increased frequency (UI) is multiplied with the input signal from the frequency divider and next is put on the input of the counters (LI). To control the counters and the buffers (BU) output signal from the frequency divider and

shaped in the control system (US) was used. Counting impulses is done during high state. Resetting the counters and putting their value to the buffers happens during low state of clock signal. In case of measuring small frequencies, the signal from the generator (choice the gate WS) is multiplied by clock signal created in the control system (US) from the two following transducer signals (UI).

With problem of choosing right measuring method of high or small velocities can help us relative error of measurement, assuming allowed relative error of measuring velocity maximum number of impulses from the transducer is determined. This number is set for determining which method should be used. Simultaneously it determines number of counted impulses from transducer determining time of counting impulses of model frequency. Model frequency (f_w) is determined from border measurement of method that is for a determined time of counting impulses (T_w) and border number (N) of impulses from the transducer (the method of high velocities). Above can be presented as:

$$N = f_w T_w \quad (17)$$

Selection of the method is determined according to the number of appearing transducer impulses in measuring time which is compared with the set number of impulses. The set number of impulses is determined according to desired accuracy of measurement of quant velocity and its range. The set number of impulses is determined according to the dynamic of a measured object (Szcześniak, 2005)d.

11. Summary

The presented ideas have important meaning to the economy consisting in creating new methods, algorithms and devices in order to increase of quality and reliability of displacement controlling. During designing measurement systems it is needed to take into consideration such things as:

1. The production of the precise optoelectronic position transducers requires advanced technologies, which involves high manufacturing costs. There has been a general tendency towards applying the optoelectronic quantization transducers of simpler design and lower accuracy which could be enhanced by electronic means.
2. In methods of processing high alternating signals of the optoelectronic transducer especially when high precision is needed, dynamic compensation of DC-component of their signals is necessary.
3. The electronic method of interpolation (multiplication of signals frequency) and digitalisation (conversion to digital form) presented in the paper makes it possible to enhance accuracy of the photoelectric transducer. The method of 5-time frequency increase is universal and can be applied to another scale of transducer signal frequency multiplication.
4. Stated that the systems of the motion direction of the transducer which shape one, two or four impulses per period can be constructed and they are additionally enable to increase accuracy of measuring displacement. Application of the presented method of interpolation and digitalization and counting impulses enables to increase accuracy of the transducer twenty times.
5. Presented methods enable correct readout of position and velocity measurement of an object independently from the motion direction and also eliminating incorrect readout

in case of vibrations of an object. Upper frequency limit which the transducer can create or the counting system count, determine criteria of selection minimal value of time T_w called measuring or average time.

6. The use of a system of high value of impulse frequency increase has significant impact on increasing accuracy of position and velocity measurement. In dependence of velocity measuring range of drive, method of measuring high or small velocities should be used. Also relative error of measurement determines using the particular method is assumed.

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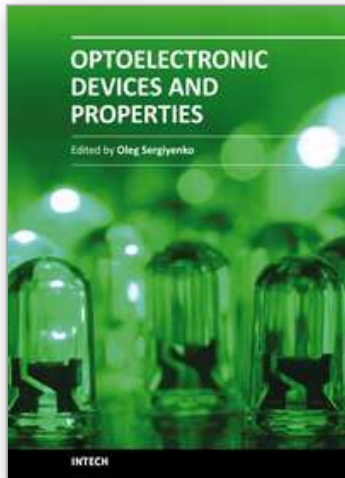
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