

## Dariusz ŚWISULSKI

GDAŃSK UNIVERSITY OF TECHNOLOGY, FACULTY OF ELECTRICAL AND CONTROL ENGINEERING, DEPARTMENT OF ELECTRICAL MEASUREMENT

# Measurement of pulse signal period from incremental encoder by counters of multifunction DAQ devices

Dr inż. Dariusz ŚWISULSKI

He received the M.Sc. degree in Electrical Engineering from Gdańsk University of Technology in 1987 and the Ph.D. degree in 1995. He is working in the Chair of Electrical Measurements, Faculty of Electrical and Control Engineering, Gdańsk University of Technology. Dariusz Świsulski has more than 100 scientific publications. His research interests include measurement systems, electrical measurements and instrumentation, virtual instruments.

dswis@ely.pg.gda.pl



### Abstract

In the paper, examples of systems for measurement and recording of rotational speed based on incremental encoder connected to counters of plug-in Data Acquisition boards are presented. Applications of virtual instruments for recording of rotational speed at steady state as well as at transient state are described. Software was prepared using LabVIEW package of National Instruments.

### Streszczenie

W artykule omówiono parametry liczników znajdujących się na wielofunkcyjnych kartach akwizycji sygnałów pomiarowych. Przedstawiono przygotowane w środowisku programowania LabVIEW aplikacje wykorzystujące te liczniki. Służą one do pomiaru i rejestracji długości zadanej liczby okresów mierzonego sygnału oraz liczby okresów uzależnionej od ich długości (metoda zliczania zależnego z wydłużonym czasem pomiaru). Aplikacje te zostały wykorzystane do rejestracji prędkości obrotowej na podstawie sygnału z inkrementalnego przetwornika obrotowo-impulsowego, zarówno w stanach ustalonych (wyznaczanie nierównomierności prędkości), jak i w stanach nieustalonych (np. rozruch silnika).

**Keywords:** data acquisition board, counters, measurement of rotational speed

**Słowa kluczowe:** karta akwizycji, liczniki, pomiar prędkości obrotowej

## 1. Introduction

Plug-in Data Acquisition boards are mounted in slots on the PC motherboard. They are connected to computer system by PCI (Peripheral Component Interconnect) bus or, earlier, by ISA (Industry Standard Architecture) bus [1]. Because they are connected directly to the bus, they have a high speed of data transmission. Another advantage is low cost because their housing, power supply and cooling is provided by the computer. The principal function of DAQ boards is analog-to-digital conversion of voltage signal. Multifunction DAQ devices have several additional circuits, e.g. for analog outputs, digital input-output and counter/timers.

The counters can be used in many applications, including measuring the pulse width, frequency and period, counting signal transitions and elapsed time, dividing the frequency, measuring position using incremental encoders, generating square waves and pulses.

Devices of National Instruments have chips 8253/54, Am9513, DAQ-STC or TIO-ASIC [2]. Depending on the counter chip, a DAQ board allows to use different numbers of counters. Each counter has two inputs: gate (to enable or disable function of the counter), source (to connect the signal whose edges will be counted) and one output (to generate square signal output).

The 8253/54 chip has three programmable 16 bit counters [3]. Depending on the instruction word they can count in binary code (from 65535 to 0) or in decimal code (from 10000 to 0). The 8253 chip can co-operate with the clock up to 2,6 MHz and the 8254 chip

up to 10 MHz. The Am9513 counter has a 16-bit register too. They can count both low-to-high and high-to-low transitions. The counters from TIO-ASIC and DAQ-STC chips can count both low-to-high and high-to-low transitions of the CLK input too. The TIO-ASIC counter has 32-bit register and DAQ-STC 24-bit. Both of the chips can work in buffered mode.

## 2. Recording of time given pulses number

The method based on measurement of the duration of one or more pulses. The measuring system consists of personal computer equipped with a DAQ board. In the realized system, an AT-MIO-16E2 device with DAQ-STC chip was used. The board has two 24-bit counters: the first counter was used for generation of single pulses as a gating signal for the second counter (fig. 1).

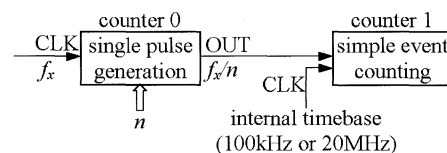


Fig. 1. Block diagram of a system measuring the time of a given number of pulses  
Rys. 1. Schemat blokowy systemu do pomiaru czasu zadanej liczby impulsów

The number of pulses in one measurement depend on the value of frequency  $f_x$  [4]. On the one hand, it is limited by the counter's capacity ( $2^{24}-1$ ). On the other hand, it is limited by the quantization error [5].

The signal period  $T_x$  is calculated from the number of counted pulses  $C_x$ , frequency of standard generator  $f_g$  and number of measured periods in one measurement  $n$ :

$$T_x = \frac{C_x}{n \cdot f_g} \quad (1)$$

The number of measurements is given on the panel of virtual instrument. Measurements can be interrupted when the counter is overflowing or when the time of waiting for the measured signal pulse is exceeded.

The presented method does not make it possible to perform measurements in continuous mode. In order to assure the continuity of measurement it is necessary to use buffered period measurement. In this mode at each edge of GATE signal the counter value is written to FIFO memory.

Fig. 2 presents a diagram of a virtual instrument for recording of duration of a give-number of pulses in continuous mode. Software of the application was prepared in graphical language LabVIEW from National Instruments. The application is similar to the previous. Similarly to that application, two counters are used: the first counter works as frequency divisor, the second one counts the duration of measurement signal periods [6].

Measured signal is connected to CLK input of first counter. The "Group Config" function sets this counter in pulse train generation mode and the "Set Attribute" function sets the parameters of these pulses. The output signal of counter 0 has frequency  $n$  times smaller than the input frequency and the pulse-duty factor equals half.

Output signal of first counter is connected to GATE input of second counter (counter1). This counter is set in buffered period measurement mode. The "Setup Gate" function sets the counter gate's polarity, the "Setup Source" function sets the counter source

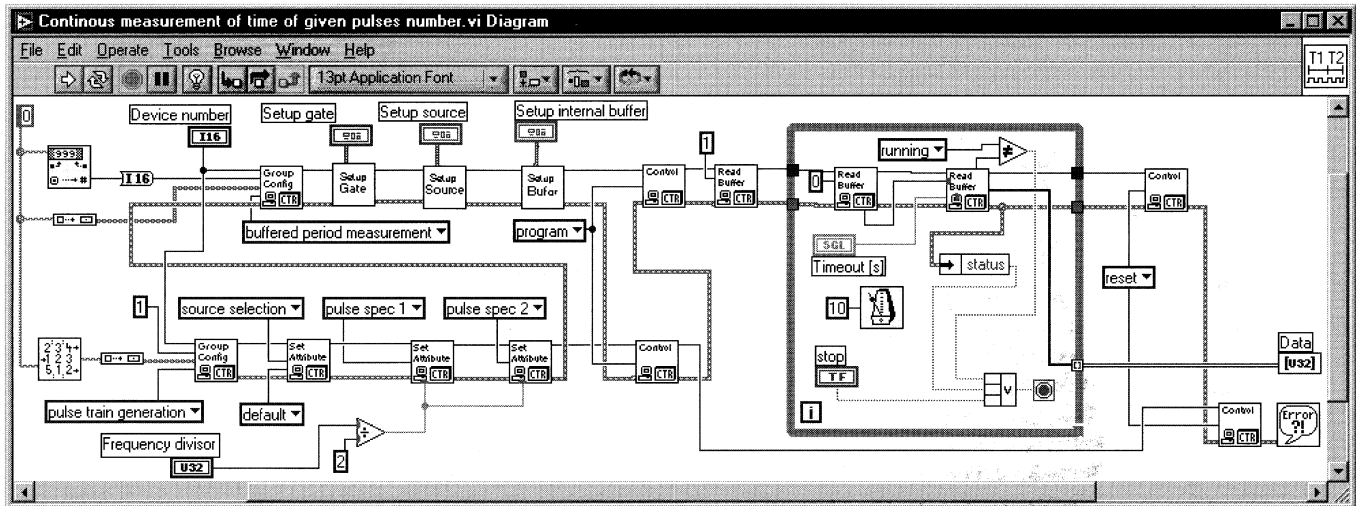


Fig. 2. Diagram of virtual instrument for recording of duration of a give-number of pulses in continuous mode

Rys. 2. Diagram przyrządu wirtualnego do rejestracji czasu zadanej liczby impulsów w trybie pracy ciągłej

(internal time base 100 kHz or 20 MHz) and the "Setup Bufor" function sets internal buffer's size and buffer's mode (finite or continuous).

The counters start after being armed by the "Control" function. The "Read Buffer" functions in while loop structure are used for reading a number of new results in memory and for reading these results. The measurement is ended after obtaining a given number of measurements or when the measurement is interrupted.

available, for generation of gate signal a digital-to-analog converter with external flip-flop circuit was used [4].

The first counter of DAQ-STC chip is used for counting pulses of measured signal, the second one for counting pulses of internal time base. The diagram of virtual instrument is presented in fig. 3.

The counter, which counts periods from standard generator of internal time base, is set in buffered semiperiod measurement mode. Buffered semiperiod measurement is similar to buffered period measurement, but the successive measurements are written at each edge of GATE signal. The "Set Attribute" function sets the source of CLK signal (internal time base 100 kHz or 20 MHz) and the "Setup Bufor" function sets the internal buffer's size and buffer's mode. The counter is armed by the "Control" function.

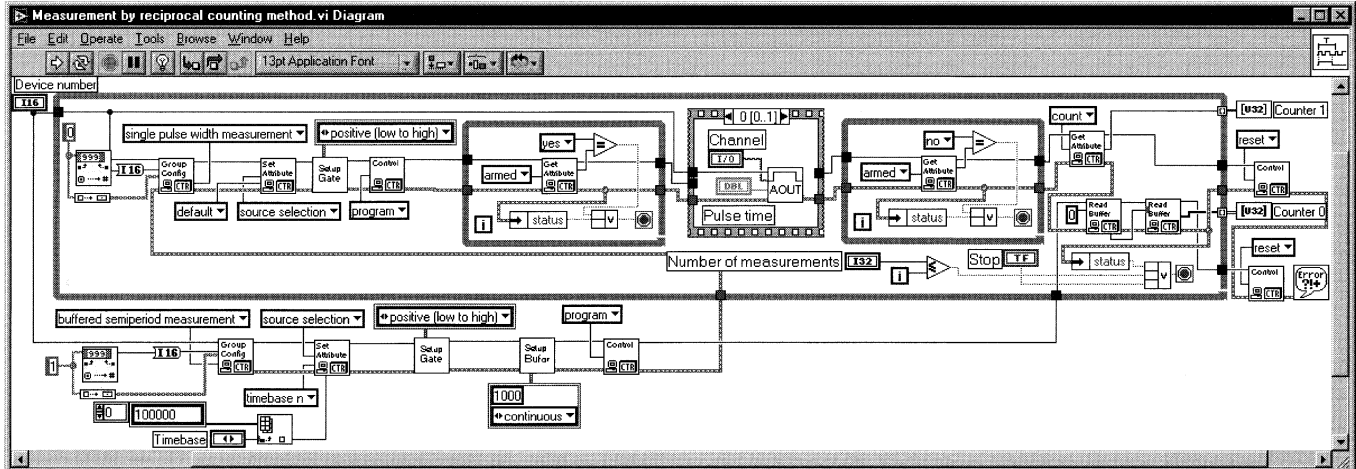


Fig. 3. Diagram of virtual instrument for recording of pulse signal by reciprocal counting method

Rys. 3. Diagram przyrządu wirtualnego do rejestracji sygnału impulsowego metodą zliczania zależnego

### 3. Realisation of reciprocal counting method

The number of periods, during which the measurement is taken, can be strictly determined for subsequent measurements or may also depend on the period value in a given measurement. In the reciprocal method [7, 8, 9], at the instant of change in state of the measured signal, counting of the assumed minimal measurement time begins, as well as - simultaneously - counting the signal periods from the standard generator. The first change of state of the measured signal after the minimal measurement time has passed, ends the measurement, while the period is determined on the basis of the number of counted periods of the measured signal and the number of counted periods from the standard generator.

Measurement system for recording of pulse signal period by reciprocal method was realized as virtual instrument based on multifunction DAQ device, too. In this instrument AT-MIO16-E2 module with DAQ-STC chip was used. Because in the chip only two counters are

The second counter is set in pulse width measurement mode by the "Group Config" function. The "Set Attribute" function sets the source of CLK signal and the "Setup Gate" function sets the counter gate's polarity. This counter is armed by the "Control" function too. Expectation for arming of the counter is realized by the "Get Attribute" function in while loop structure.

At the moment of counter's start, on the output of the digital-to-analog converter, begins a pulse of a given time duration. The output of this converter is connected to S input of external D flip-flop circuit. Because the measured signal is connected to C input of the flip-flop and D also R inputs are connected to low potential, the pulse at the output of flip-flop will be extended to the to first edge of measured signal. Expectation for end of given measurement is realized in while loop structure by the "Get Attribute" function.

The "Read Attribute" function (count mode) is used to read the capacity of the counter and the "Read Buffer" function is used to read from memory the number of pulses counted by the second counter. These operations are repeated for a given number of measurements.

The presented application, as a result of additional measurements of time between the measured pulses, allows to mark out the beginning and end of successive measurements.

#### 4. Recording of irregularity of rotational speed

The irregularity of rotational speed determines the quality of driving systems. In the electrical driving system, these deviations are caused by the distortions of supply voltage delivered by semiconductor regulation circuits, frequency variations in the grid system, unbalance of rotor [10]. The irregularity of rotational speed can be easily evaluated by the measuring system with DAQ board and incremental encoder coupled with the shaft of an examined motor.

The operation principle of the incremental encoder consists in the generation of the consecutive pulses due to the angular displacement of the shaft [11].

Assume that the incremental encoder delivers  $C_e$  pulses per shaft revolution. Let the actual speed be a sum of the following two components: a constant speed  $\omega_0 = 50$  rps, and a sinusoidally varying term of amplitude  $\omega_m = 20$  rps and frequency  $f_p = 50$  Hz:

$$\omega(t) = 50 \text{ rps} + 20 \text{ rps} \cdot \sin((2\pi / 0,02s)t) \quad (2)$$

The latter term can represent, for instance, speed fluctuations due to a malfunction in the power converter feeding the motor.

The edges of the output signal from incremental encoder appear at times, when average frequency of pulse signal in time since last pulse is equal to the number of the incremental encoder  $C_e$  pulses per shaft revolution multiplied by average speed in time since the last pulse [12]. Fig. 4 presents generation of signal from incremental encoder for  $C_e = 10$ .

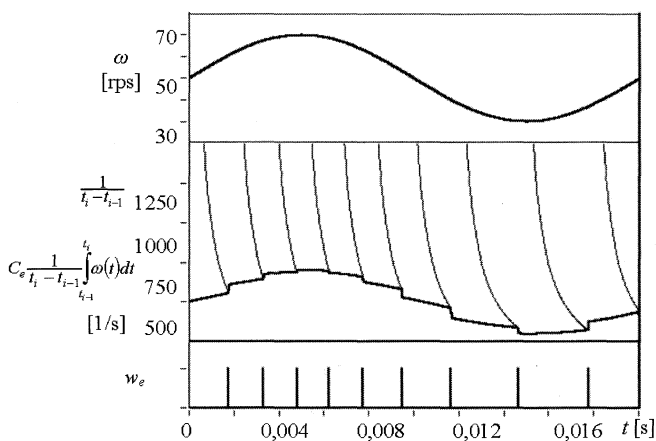


Fig. 4. The output pulse signal of incremental encoder

Rys. 4. Wyjściowy sygnał impulsowy z przetwornika obrotowo-impulsowego

As an example, results of rotational speed recording of asynchronous motor Sg 80-4B will be presented. Power rating of the motor equals  $P_n = 0,75$  kW and rated speed  $n_n = 1400$  rpm. The motor was coupled with the incremental encoder OG 6 of Hübner Elektromaschinen AG with  $C_e = 5000$ .

Preliminary measurements showed that the speed has a constant component 24,96 rps with varying component of amplitude about 0,2 rps.

As was shown in [5] the value of quotient  $T_m/T_p$  (where  $T_m$  is a period of measured pulse signal and  $T_p$  is a period of the measured signal variation) that minimizes the total error, can be evaluated from (3). For the case of off-line postprocessing, the quotient  $T_m/T_p$  is given by (4).

$$\left(\frac{T_m}{T_p}\right)_0 = \sqrt{\frac{T_g}{T_p} \cdot \frac{3 \cdot X_m}{X_0}}, \quad \left(\frac{T_m}{T_p}\right)_{01} = \frac{1}{\pi} \sqrt[3]{\frac{3 \cdot T_g}{T_p} \cdot \frac{X_m}{X_0}} \quad (3, 4)$$

where  $X_m/X_0$  is a relation of the varying to the constant component in measured signal.

For frequency of standard generator  $f_g = 20$  MHz we obtain  $(T_m/T_p)_0 = 0,0072$  and  $(T_m/T_p)_{01} = 0,025$ . On this base it was assumed that in one period of measured signal (in one revolution) 100 measurements will be executed. Therefore the ratio of frequency divider for  $C_e = 5000$  equals  $D = 50$ .

The value of rotational speed  $\omega$  in single  $i$ -th measurement can be obtained on the base of the number of standard generator pulses  $C_i$  counted in this measurement:

$$\omega_i = \frac{D \cdot f_g}{C_e \cdot C_i} \quad (5)$$

The principle of measurement is based on evaluation of the value of time corresponding to a precisely defined angle of revolution. The value of this angle is equal to  $D/C_e$  part of one revolution. As the value of time of each measuring cycle is corresponding to a chosen displacement of the motors shaft, the results of measurements are presented in the form of tables or curves for strictly defined values of rotational angles.

In many cases, it is more convenient to present the results of measurements as a function of time, especially when the variations of rotational speed are great or when the disturbances of supply voltage on the work of driving systems are investigated [13]. In order to fulfil this demand, the times of successive measurements were calculated.

As was presented in [14], the times  $t_i$  of successive results of measurements can be assigned to central points of measurement intervals:

$$t_i = \sum_{j=1}^{i-1} T_j + \frac{1}{2} T_i \quad (6)$$

When we make these times dependent as a function of the number of counted pulses  $C_p$ , the times can be obtained from formulae (7).

$$t_i = \sum_{j=1}^{i-1} \frac{C_j}{f_g} + \frac{C_i}{2f_g} \quad (7)$$

In fig. 5 there the variations of rotational speed of the investigated motor are presented as a function of time.

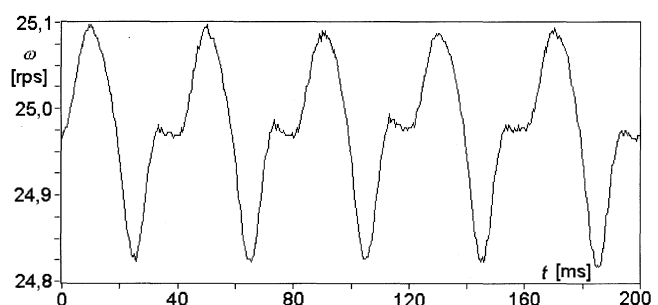


Fig. 5. Measured values of rotational speed by  $f_g = 20$  MHz and  $D/C_e = 1/100$

Rys. 5. Wartości mierzonej prędkości obrotowej dla  $f_g = 20$  MHz i  $D/C_e = 1/100$

## 5. Recording of rotational speed in transient state

Measurements of rotational speed are performed in transient state often, e.g. at time of starting, braking or reverse of an engine [15]. As an example, results of rotational speed recording of asynchronous motor Sg 80-4B by starting will be present. The motor was supplied from a Eurotherm 605 converter and coupled with the OG 6 incremental encoder with  $C_e=5000$ .

At the time of motor's starting the rotational speed has large changes and the frequency of signal from incremental encoder has large changes too. Therefore the reciprocal counting method was used for recording.

A system presented in chapter 3 with minimal measurement time equal to 10 ms and standard generator frequency  $f_g=20$  MHz was used. The quantization error for this condition amounts to  $\delta_k < 5 \cdot 10^{-6}$ .

At the recording, three series of numbers were obtained:

$C_{ni}$  - the number of periods of signal from incremental encoder, counted in time of single  $i$ -th measurement,

$C_{tai}$  - the number of periods of signal from standard generator, counted in time of single  $i$ -th measurement,

$C_{tbi}$  - the number of periods of signal from standard generator, counted in time between end of single  $i$ -th measurement and beginning of next measurement.

The rotational speed in a single  $i$ -th measurement can be calculated on the base of the number of periods from incremental encoder  $C_{ni}$  and number of periods from standard generator  $C_{tai}$  counted in this measurement:

$$\omega_i = \frac{C_{ni} \cdot f_g}{C_{tai} \cdot C_e} \quad (8)$$

The single measurement's result can be assigned to the moment at center of interval of  $i$ -th measurement. For calculating these moments, the time of space between measurements as the number  $C_{tbi}$  is used:

$$t_i = \frac{1}{f_g} \left( \sum_{j=1}^{i-1} (C_{taj} + C_{tbj}) + \frac{1}{2} C_{tai} \right) \quad (9)$$

On the base on formulae (8) and (9) the graph of variations of rotational speed presented in Figure 6 was prepared.

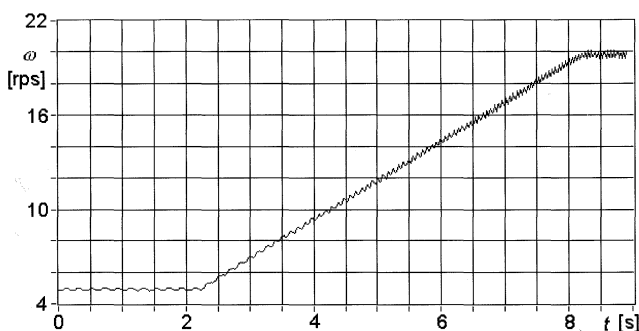


Fig. 6. Variation of rotational speed by spin-up from 20% to 80% of rated speed  
Rys. 6. Zmiany prędkości obrotowej przy zwiększaniu prędkości od 20% do 80% prędkości znamionowej

## 6. Conclusion

In the paper, applications for recording of rotational speed at stable state as well as at transient state were presented. As a result of realizations of these applications as virtual instrument with DAQ boards, the cost of the system is not great. Software of the system allows to process measurement data and presents it in a convenient form, e.g. as a graph in function of angle of rotation or in function of time.

The counter DAQ-STC makes it possible to use two signals from incremental encoder shifted by 90° of the phase. In this case, the

position and direction of rotation can be measured. The counter will increment its contents when the incremental encoder rotates in one direction and decrement when it rotates in opposite direction.

In some situations, when the incremental encoder vibrates back and forth, the result of measurement can be incorrect. The problem can be solved by using a special converter e.g. LS7084. The device conditions the incremental encoder signal to obviate errors due to vibration, noise or jitter [16].

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**Tytuł:** Pomiar okresu sygnału impulsowego z przetwornika obrotowo-impulsowego licznikami wielofunkcyjnych kart akwizycji