Virtual Instrumentation used for Adaptive Angular Velocity Measurements

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Abstract **– In many applications where some kind of motion is performed, for example in robotics, it is of high importance the angular velocity measurement. Concept of virtual instrumentation is more and more incorporated in modern industrial system, and therefore the capabilities of virtual instrumentation for angular velocity measurement are tested and presented in this paper. It is presented the realized virtual instrument for angular velocity measurement, which applies some known classical and one adaptive method for measurement. The adaptive method for angular velocity measurement had the main goal maintaining good measurement accuracy and resolution in wide velocity range.**

Keywords **– Angular velocity measurement, virtual instrumentation, LabVIEW.**

I. Introduction

Nowadays, as computers and microprocessors are more often implemented in modern industrial measurement and control systems, the digital techniques for angular velocity measurement becomes more and more dominate in relation to analog techniques. Digital techniques have some clear advantages such as error reduction, easier processing, easier presentation, easier data transfer, etc. The digital tachometer is the most frequently used digital device for angular velocity measurement [1]. High-quality digital tachometers are usually incorporated in every application which requires high-accuracy motion control. These applications can be in servo, mechatronic, robotic and precision production systems. To improve stability and smoothness of digital motor control, the velocity feedback is added along with position feedback.

An incremental digital encoder mounted on the shaft of some machine provides pulses for both position and velocity estimation. Different methods of encoder pulses processing for velocity estimation are developed, and implemented using different hardware. The first discovered, so-called classical measurement methods which are used in velocity estimation are direct counting method (or M method) and the indirect counting method (or T method).

The M method [2] is based on counted pulses from the optical encoder in fixed-time intervals. In this method, one counter is needed for counting of encoder pulses and one timer for determination of fixed time interval. Disadvantage of this method is poor accuracy in low speed range, but it is used in some applications due to its simplicity, low cost and minimal required hardware. For improving accuracy of the method, the averaging of counter values in more than two successive time intervals is applied, but in this case measurement time is not constant.

The T method [3] is especially applicable in a low speed range because it measures duration between two successive encoder pulses. The internal clock signal is used for measurement of the time interval, and counter determines number of clock pulses between two successive encoder pulses. In contrast to previous method this method has poor accuracy in high speed range.

In order to obtain a method which would be applicable in wide speed range, more complex method is designed as a combination of previous two methods (M/T method) [4]. So, a constant elapsed time (CET) method is developed [5], which is based on counting encoder pulses in a prescribed time interval. The buffered method [6] is based on both pulse counting and measurement of the fractional pulse period during the fixed sampling period. To reduce sensitivity to sensor nonideality, the new PEM-CSDT (parallel edge measurement, constant sample-time digital tachometer) structure is proposed, implemented by employing an FPGA [7]. For four possible transitions from two encoder channels, it uses four independent sets of counters. Lygouras in his paper [8] describes a new approach to velocity estimation based on adaptive sampling period according to the instant rotational velocity, and in this way better response times are achieved at medium or high speed ranges.

So far, the microprocessors are the most often used for implementation of various velocity measurement methods. FPGA circuits have become popular in the last decade because of its reasonable cost and very good performance. Virtual instrumentation, based on PC, powerful software and modular hardware, has reached mainstream acceptance and is used in thousands of applications in the industry. Flexibility, relatively easy learning of graphical programming, easy modifications of the realized methods, powerful data presentation are some of advantages. In this paper, the initial idea was to explore capabilities of virtual instrumentation in angular velocity measurement [9]. The multifunctional acquisition boards are used, concretely National Instruments PCI 6251 board [10], which has two general purpose 32-bit counters on-board. So, the first step was the realization of classical methods for angular velocity measurement such as M method, and T method. Then, one adaptive method with improved accuracy in wide speed range is developed as virtual instrument. The experimental results of the realized methods are presented, compared and analyzed.

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II. CLASSICAL METHODS FOR ANGULAR VELOCITY MEASUREMENT

The concept of virtual instrumentation delivers solutions with faster development time, lower costs, and greater flexibility. In order to explore the capabilities of virtual instrumentation for the angular velocity measurement, we started with realization of simple methods such as M and T method. PCI multifunctional acquisition board NI 6251, PC with installed LabVIEW 8.0 software and pulse/function generator HP 8116A for encoder pulses simulation are used for realizations and testing of this methods. Universal counter HP 5316B was used for the accurate measurement of the function generator output frequency. The acquisition board has two general purpose counters, which are used in realization of various methods for angular velocity measurement. Also, it has internal 80 MHz clock.

Firstly, it was realized virtual instrument for implementation of previously mentioned methods M and T method. M method or direct counting method is simple and widely used method, and it is based on counting of pulses in fixed time interval. C_P denotes the number of counted pulses in fixed sampling period T_S. The measured velocity ω is expressed as follows:

$$\omega = \frac{60 C_P}{P T_S} \text{ [rpm]}, \tag{1}$$

where P denotes the encoder pulse number per rotation, and it can be changed in the front panel of the realized virtual instrument, which depends on the applied encoder type. Measurement time is equal to the sampling period T_S, and it is constant. One counter is used for determination of sampling period and the other counter is used for counting the encoder pulses (Fig. 1). This method has good accuracy at high speed.

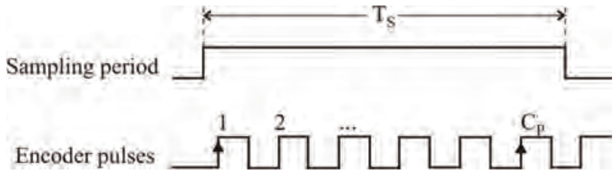

Fig. 1. Principle of the M method

Measurement of velocity with the T method or indirect counting method is based on the time interval measurement of the encoder pulse period. Accuracy of the method depends on the resolution of the time interval measurement, and in this case the internal 80 MHz clock (f_c) is used for that purpose (Fig. 2). Velocity can be evaluated based on relation,

$$\omega = \frac{60 f_c}{P C_t} \text{ [rpm]}, \tag{2}$$

where C_t denotes the number of the counted clock pulses.

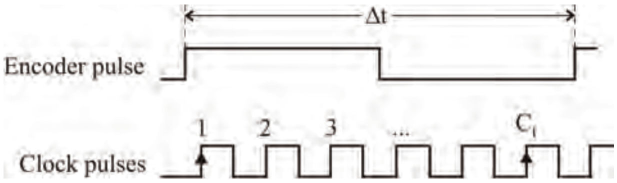

Fig. 2. Principle of the T method

This method has good accuracy at low speed. Disadvantages of this method are the variable measurement time which depends on the velocity, and low accuracy at high speed.

The errors which appear in angular velocity measurement by using virtual instrumentation are generally classified to: the errors introduced from quartz oscillator on acquisition board δ_{f_c}, the triggering errors due to noise in signal $\delta_{trigger}$ and the quantization error δ_q:

$$\delta_\omega = \frac{\Delta\omega}{\omega} = \delta_{f_c} + \delta_{trigger} + \delta_q , \tag{3}$$

Error values introduced from quartz oscillator on acquisition board can be determined from manufacturer's specifications. Oscillator accuracy of PCI 6251 acquisition board is about $5\text{x}10^{-5}$, but this error can be reduced by calibrating the designed virtual instrument with more accurate external instrument.

The triggering error due to noise in signal depends on the signal quality at the acquisition board input, and can be reduced with the appropriate conditioning circuits. This error does not dominate if M method is performed, or if measurement with averaging of several input signal periods is performed.

The quantization error is defined by relation:

$$\delta_q = \left| \frac{\omega(C+1) - \omega(C)}{\omega(C)} \right| , \tag{4}$$

where C is counter value.

Regardless of the method used to determine the angular velocity, either by M method or by T method, it can be derived that the quantization error directly depends on the counter value [1],

$$\delta_q \approx \frac{1}{C} . \tag{5}$$

III. ADAPTIVE ANGULAR VELOCITY MEASUREMENT

The virtual instrumentation is then utilized for implementation of one adaptive method for angular velocity measurement. In basic T method it is measured time interval of one encoder pulse period, and here is proposed solution which is based on time interval measurement of k input signal periods. This variable value k will help in maintaining quantization error within specified boundaries. This value is very important for measurement because if it's too big it can cause counter overflow or too long measurement. On the other hand, if it's too small, it can not be sufficient to increase measurement resolution, i.e. decrease quantization error.

Block diagram of realized virtual instrument determines itself the value of multiplication factor k according to previously defined maximal quantization error. In that way, the minimal measurement time for the defined quantization error is also achieved.

Principle of using counters on-board during realization of the suggested adaptive method and signal waveforms are shown in Fig. 3. One counter is used for the adaptive multiplication of the encoder output signal period, and second counter for clock period counting contained in obtained sampling period. According to the proposed method, the angular velocity is calculated based on relation

$$\omega = \frac{60 f_c k}{P C_t} \text{ [rpm]}, \qquad (6)$$

where f_c is the clock frequency, and C_t is the number of clock periods counted by second counter.

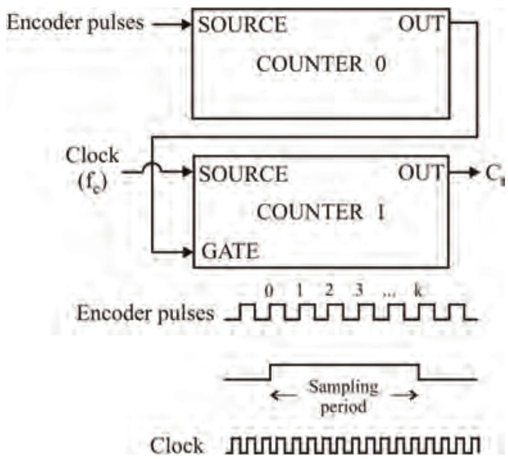

Fig. 3. Principle of adaptive method

Two-step measurement method which is based on using the adaptive multiplication factor *k* is explained in detail in algorithm shown in Fig. 4. Measurement using the method for multiperiod measurement for value *k*=4 is performed in the first step. Changing the value of *k* is then performed depending on the obtained counter content C_t. Then, the next measurement with new value of *k* is performed. It can be seen in the algorithm that the value of multiplication factor *k* in second step is within range of 4 to 200000, depending on the instant angular velocity. In that way, the final counter content of approximately 200000 is achieved in a wide range of measurement, producing also constant value of the quantization error. The method is developed and tested for angular velocities of up to approximately 300000 rpm. Value of 200000, which is used in algorithm to determine the adaptive multiplication factor, is chosen to achieve compromise between the smallest possible measurement time and the smallest possible quantization error. However, the quantization error must not be unrealistically small in relation to the total error and the on-board quartz oscillator instability. Value of *k* is determined over and over again in each sampling period.

The front panel and block diagram of the realized virtual instrument for angular velocity measurements are shown in Fig. 5 and 6, respectively. The number of encoder pulses per rotation can be entered in the front panel. Also, the angular velocity measurement results can be seen on the numerical indicator during measurement, and number of counted pulses. Input signal can be seen on waveform chart. In block diagram is used flat sequence structure for two-step measurement.

The experimental results of velocity measurement which are obtained by using these three methods are presented in Table I. One can see testing frequency, measurement this frequency with external counter, calculated angular velocity, measurement results of three methods, and obtained relative errors. Last row presents values of multiplication factor *k* for each particular measurement. The relative errors obtained by proposed adaptive method are in wide measurement range equalized and somewhere less than the values obtained with classical methods, as it can be seen from Table I.

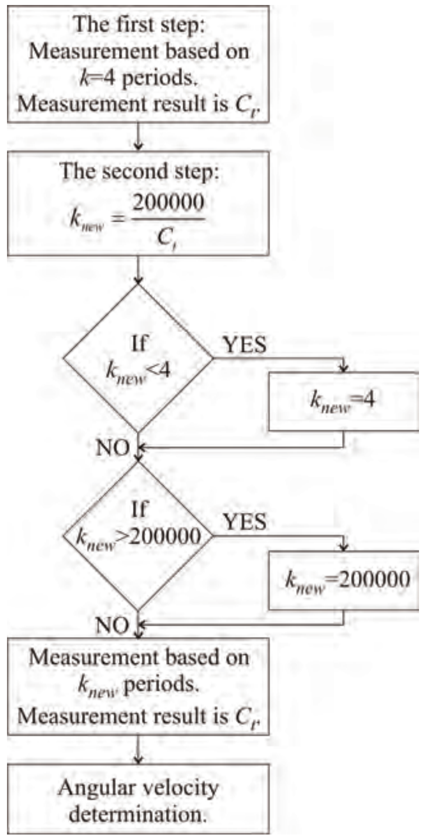

Fig. 4. Algorithm of adaptive angular velocity measurement

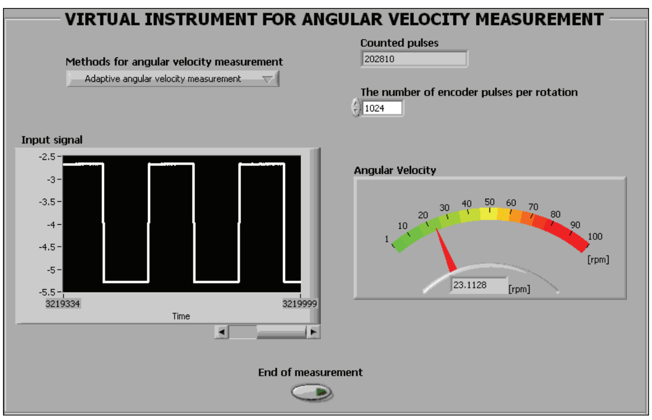

Fig. 5. Front panel of realized virtual instrument for angular velocity measurements

The digital tachometer, realized in the described way, uses only counters on the acquisition board. Therefore, additional resources of the board, such as analog and digital inputs and outputs, can be used for other purposes.

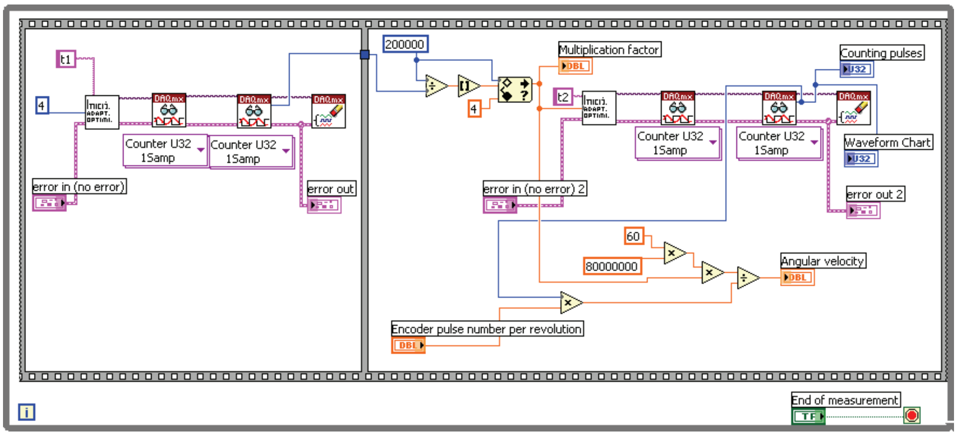

Fig. 6. Block diagram for adaptive method

TABLE I

EXPERIMENTAL RESULTS OF ANGULAR VELOCITY MEASUREMENTS

Output of function generator		10 Hz	100 Hz	1 kHz	10 kHz	100 kHz	1 MHz	2 MHz	5 MHz
Frequency counter reading		10.09 Hz	99.39 Hz	1.0071 kHz	10.031 kHz	103.054 kHz	1.0389 MHz	2.0678 MHz	5.126 MHz
Equivalent angular velocity (for P = 1024) [rpm]		0.5912	5.8236	59.0097	587.754	6038.32	60873.0	121160	300351
M method	**Velocity [rpm]**	0.538	5.55	58.85	587.95	6037.7	60868.1	121155	300349
	Relative error [%]	8.96	4.698	0.27	0.033	0.01	0.008	0.004	0.0006
T method	**Velocity [rpm]**	0.591198	5.8238	59.0085	587.748	6036.5	60325.1	114980.8	278875.9
	Relative error [%]	0.0003	0.0034	0.002	0.001	0.03	0.9	5.1	7.15
Adaptive method	**Velocity [rpm]**	0.591199	5.82375	59.008	587.77	6038.2	60873.8	121158	300370
	Relative error [%]	0.00016	0.0026	0.0029	0.003	0.002	0.001	0.002	0.006
	k	4	4	4	6	62	625	1250	3125

IV. CONCLUSION

Capabilities of virtual instrumentation for angular velocity measurement are examined in the paper. The experimental results can be easy memorized or analyzed in LabVIEW.

Proposed adaptation method of the angular velocity measurement is realized using standard acquisition board which has two counters. The achieved relative errors are in wide measurement range equalized. This method is not suitable for fast changing angular velocities, and the measurement time is not constant which can be drawback in some applications.

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REFERENCES

[1] D. Denic, G. Miljkovic, D. Zivanovic, “Microcomputer based wide range digital tachometer”, Electronics and Electrical Engineering, vol. 3, no. 67, pp. 31-36, 2006.

[2] N. Kirianaki, S. Yurish, N. Shpak, and V. Deynega, “Data acquisition and signal processing for smart sensors”, John Wiley & Sons Ltd, ISBN: 0-470-84317-9, 2002.

[3] C.D. Cenzo, B. Szabados and N. K. Sinha, “Digital measurement of angular velocity for instrumentation and control”, IEEE Trans. Ind. Electron. Contr. Instrum., vol. IECI-23, pp 83-86, 1976.

[4] T. Ohmae, T. Matsuda, K. Kamiyama, M. Tachikawa, “A microprocessor-controlled high-accuracy wide-range speed regulator for motor-drives”, IEEE Transactions on Industrial Electronics, vol. 29, no. 3, pp. 207–211, 1982.

[5] R. Bonert, “Design of a high performance digital tachometer with a microcontroller”, IEEE Transactions on Instrumentation and Measurement, vol. 38, no. 6, pp. 1104–1108, 1989.

[6] M. Prokin, “Double buffered wide-range frequency measurement method for digital tachometers”, IEEE Trans. on Instrumentation and Measurement, vol. 40, no. 3, pp. 606-610, 1991.

[7] R.C. Kavanagh, “Improved digital tachometer with reduced sensitivity to sensor nonideality”, IEEE Transactions on Industrial Electronics, vol. 47, no. 4, pp. 890–897, 2000.

[8] J.N. Lygouras, “Accurate velocity evaluation using adaptive sampling interval”, Microprocessors and Microsystems, vol. 24, no. 5, pp. 269–275, 2000.

[9] N. Patrascoiu, A. Poanta, A. Tomus and B. Sochirca, “Virtual instrumentation used for displacement and angular speed measurements”, International Journal of Circuits, Systems and Signal Processing, issue 2, vol. 5, pp. 168-175, 2010.

[10] DAQ M Series User Manual, National Instruments, 2008.