Detecting the Direction of the Shaft Rotation by Using Incremental and Virtual Absolute Encoders

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***Abstract* – The position encoders are widely used sensors for detection of angular and linear motion in many systems such as machine tools, industrial robots, a variety of instruments, computer peripherals. The classification and the main properties of position encoders are presented in this paper. Special attention is given to the optical rotary encoders i.e. incremental, absolute and virtual absolute encoders. In the second part of the paper are presented solutions for detecting the movement direction of the shaft by using incremental and virtual absolute encoders. The solutions are implemented and tested in LabVIEW environment.**

***Keywords* – Optical rotary encoders, Rotation direction, Virtual instrumentation, LabVIEW**

I. Introduction

Linear and angular position measurement of a movable system (MS) is essential for the functioning of many systems, such as machines and robots in industry, computer peripherals, generators in power plants, radars, telescopes, etc. These measurements are usually performed by using the position encoders [1]. The easiness with which position encoders are interfaced to digital systems made them very popular. Due to increased complexity of the modern automated industrial systems, which increase demands for position measurement in sense of resolution, reliability, accuracy and etc., the different types of encoders were developed over time. The Section 2 of this paper will be devoted to the classification of different types of position encoders. After the Section 3, where the key features of incremental, absolute and virtual absolute encoders will be mentioned, two different solutions for determination of shaft rotation direction will be presented, and they can be applied with incremental and virtual absolute encoders.

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II. Classification of Position Encoders

By observing the classification shown in Fig. 1, the first division of encoders to non-contact and contact encoder types is done depending on whether there is the physical contact during code reading. The group of non-contact encoders is consisted of magnetic, inductive and optical encoders, where the division is made according to the operation principle of the sensing element of encoder. The most common contact encoder type is electrical. Each of the previously mentioned encoder types can be further divided, by the shape of coding scale, into rotary and linear types. In this paper will be analyzed the properties of rotary optical encoders, so there will not be given further classification and analysis of other types of encoders. By the position finding method, optical rotary encoders can be divided into absolute, incremental and virtual absolute encoders [1].

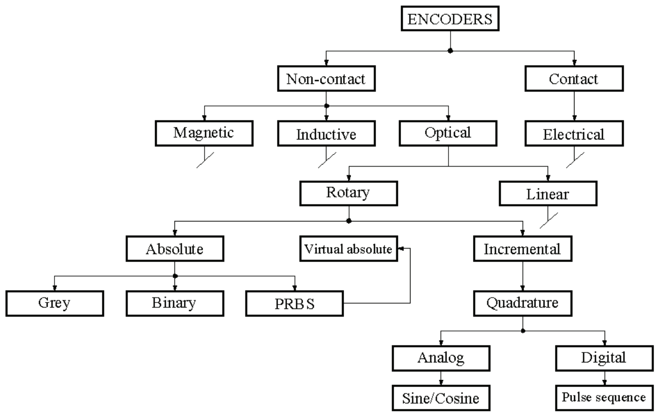


Fig. 1. The classification of position encoders

Absolute encoders give the position information in unique digital form, while the incremental encoders determine position by counting pulses. Virtual absolute encoders are new type of absolute encoders, and also the result of effort to avoid the application of a large number of coding tracks used in the absolute encoders for high resolution measurements. This was achieved by using pseudorandom binary sequences (PRBS). Except pseudorandom binary sequences, widely used with absolute encoders are two more position coding methods - binary (so-called natural) coding and Gray coding. The final classification is based on the type of coding method in case of absolute, and on the type of output signal in case of incremental encoders. In the case of incremental encoders at the output are generated quadrature signals, phase shifted by quarter of signal period, i.e. 90°. Quadrature signals can have analog format (sine and cosine signals) and digital format (sequence of rectangular pulses).

III. Characteristics of Optical Rotary Encoders

Optical rotary encoders have perforated code disc made of glass, Mylar film or metal, over which surface the adequate sequences of transparent and non-transparent parts are placed, along one or more concentric code tracks (see Fig. 2). The code disc is placed between the light source and photodetector. Environment to which the equipment will be subjected (temperature, humidity, shock, cleanliness) should be considered when choosing code disc material.

a) b) c)

Fig. 2. Code disc examples for: a) Incremental, b) Absolute and c) Virtual absolute encoder

Incremental encoders are the cost-effective and simple devices for measuring the position, but they do not give information about absolute position. In the simplest variant one pulse sequence is used, whereat the pulses are counted in order to obtain information about the position and in this way information about direction of rotation can not be provided. In that case, quadrature incremental encoder which generates two pulse sequences, mutually phase shifted by 90°, are used to determine the direction of rotation. Often, incremental encoders have a third, so called, index channel, which generates one pulse per revolution, which is used to define the reference "zero" position, and to record whole revolutions. The advantages of incremental encoders are lower cost, simpler structure and smaller dimensions, while the disadvantages are low reliability and error accumulation. The fact that incremental encoders lose the information about previous position with the loss of power, or signal transmission error, is also disadvantage. Another important parameter of position encoders is resolution, and its values are taken from GPI (Gurley Precision Instruments) encoders manufacturer catalogue, so this value for incremental encoder goes up to 7,2 million counts/revolution (this is not native resolution, it is the number of counts per revolution with electronic divide-by-four and interpolation) [4].

In the case of absolute encoders the number of code tracks on a code disc defines the number of bits, and so resolution of position determination. Absolute encoders contain *n* optical sensors that in parallel generate a set of *n* digital outputs which together describe the position of the rotating shaft. Set of *n* digital outputs represents *n* bit long digital word. Single and multiturn absolute encoders are available. The advantages of absolute encoders are: they give absolute position at the output, the information about previous position is remembered even after loss of power, and high reliability, while the disadvantages are: they have complex structure, they are expensive and have larger dimensions. Their resolution goes up to 25 bits, which also depends on code disc diameter [4].

Virtual absolute encoder [2, 3] is a pseudorandom absolute encoder with serial code reading. The virtual absolute encoder code disc is similar to the incremental encoder code disc. The difference is that the index track of incremental encoder is replaced with pseudorandom code track. The advantages of virtual absolute encoders are: they give absolute position at the output, they are cheaper than absolute encoders, because of smaller number of code tracks they have simpler structure than absolute encoders, they have high reliability and possibility of automatic adjustment of zero position when mounting. The disadvantages are: large dimensions, necessity of initial moving after the first powering on and the problem of code reading synchronization. The resolution value for virtual absolute encoders goes up to 24 bits [4].

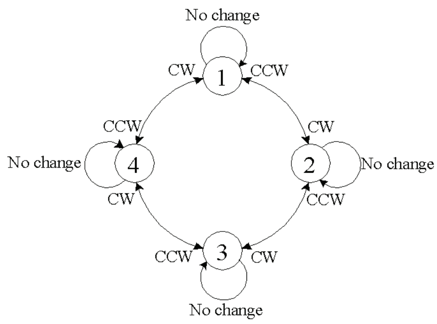
IV. Determining of Shaft Rotation Direction

In this section, solutions for determination of shaft rotation direction by using the incremental and virtual absolute encoders, will be worked out [5]. In order to ensure the reliability of the information, the impact of the oscillation of rotating shaft in the direction of motion will be considered. The oscillations of rotating shaft at the border of two states can disturb determining of shaft rotation direction. That "hysteresis" is good in the light of reduction of error which could occur during direction determination.

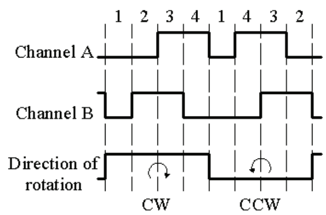
A. Determining the rotation direction without "hysteresis"

The signal obtained from one sensor head of the incremental encoder does not carry information about the rotation direction. To obtain information about the rotation direction at least two sensors should be used. Distance between them is determined by the required phase shift of output signals. The required phase shift is usually 90°.

The time characteristic of output signals, in the form of logic signals A and B, is shown in Fig. 3b).



a)



b)

Fig. 3. a) State diagram, b) Output signals

If the individual levels of the output signals A and B are determined by logic values 0 and 1, then a pair of logic signals AB can appear in one of four states: 00,01,11,10 [6]. Those states are respectively marked with 1, 2, 3 and 4. States are cyclic linked, and transitions between states 1-3 and 2-4 are not allowed. The principle of transition between two adjacent states is shown in Fig. 3a), with a simple state diagram. CW and CCW represent outputs of the circuit for determining the rotation direction (CW-clockwise, CCW-counter-clockwise). The state diagram points out the fact that reliable recognition of the direction assumes knowledge of the initial state and the current state. Values of the logic signals A and B should be taken at regular time intervals, which is achieved by using clock pulses. This is how, in certain time instants, synchronization values As, Bs are determined, while the values Ao, Bo are stored from the previous time instant. The time period of clock pulses, at the maximum angular speed of rotation, must be shorter than one-half of the width of pulses A and B.

The group of signals As, Bs, Ao, Bo is a group of four logic variables which provide sixteen different combinations. Each individual combination, except the forbidden, defines values of logic functions CW and CCW, see Table I. One software implementation of this solution, based on application of a virtual instrumentation concept, is presented below.

TABLE I
STATES SEQUENCE AND CORRESPONDING VALUES OF LOGIC FUNCTIONS CW AND CCW WITHOUT "HYSTERESIS"

A_S	B_S	A_0	B_0	CW	CCW
0	0	0	0	0	0
0	0	0	1	0	1
0	1	0	0	1	0
0	1	0	1	0	0
0	0	1	0	1	0
0	0	1	1	-	-
0	1	1	0	-	-
0	1	1	1	0	1
1	0	0	0	0	1
1	0	0	1	-	-
1	1	0	0	-	-
1	1	0	1	1	0
1	0	1	0	0	0
1	0	1	1	1	0
1	1	1	0	0	1
1	1	1	1	0	0

B. Determining the rotation direction with "hysteresis"

In order to avoid errors in determining direction during the oscillations of rotating shaft at the border of two states, the knowledge about states in two successive discrete time intervals is not enough. The knowledge about the previous state is required, or in other words, the knowledge about state prior to the initial state. A sequence of previous, initial and current state would now define the values of logic functions CW and CCW, Table II. Sequences of states that occur due to interruption of rotation or oscillations at the border of two states should be marked with passive values of logic functions CW and CCW. In this paper is suggested that the forbidden sequences of states (413, 124, etc.) should also be taken into consideration, because these sequences can occur due to contamination of the incremental track. Adoption of the fact that the forbidden sequence of states does not lead to the change in information about the shaft rotation direction, is also proposed. This is a realistic assumption, because it is unlikely that the transition which just has been detected, in the next moment will not be detected. However, to avoid increase of the maximum error caused by the forbidden sequence of states, retaining of the passive values of logic functions CW and CCW is suggested. Also, this solution with “hysteresis” is implemented and tested in LabVIEW environment, which is presented below.

TABLE II
STATES SEQUENCE AND CORRESPONDING VALUES OF LOGIC FUNCTIONS CW AND CCW WITH "HYSTERESIS"

SEQUENCE OF STATES			CW	CCW
4	1	4	0	0
4	1	1	0	0
4	1	2	1	0
4	1	3	0	0
1	2	1	0	0
1	2	2	0	0
1	2	3	1	0
1	2	4	0	0
2	3	2	0	0
2	3	3	0	0
2	3	4	1	0
2	3	1	0	0
3	4	3	0	0
3	4	4	0	0
3	4	1	1	0
3	4	2	0	0
1	4	3	0	1
1	4	4	0	0
1	4	1	0	0
1	4	2	0	0
2	1	4	0	1
2	1	1	0	0
2	1	2	0	0
2	1	3	0	0
3	2	1	0	1
3	2	2	0	0
3	2	3	0	0
3	2	4	0	0
4	3	2	0	1
4	3	3	0	0
4	3	4	0	0
4	3	1	0	0

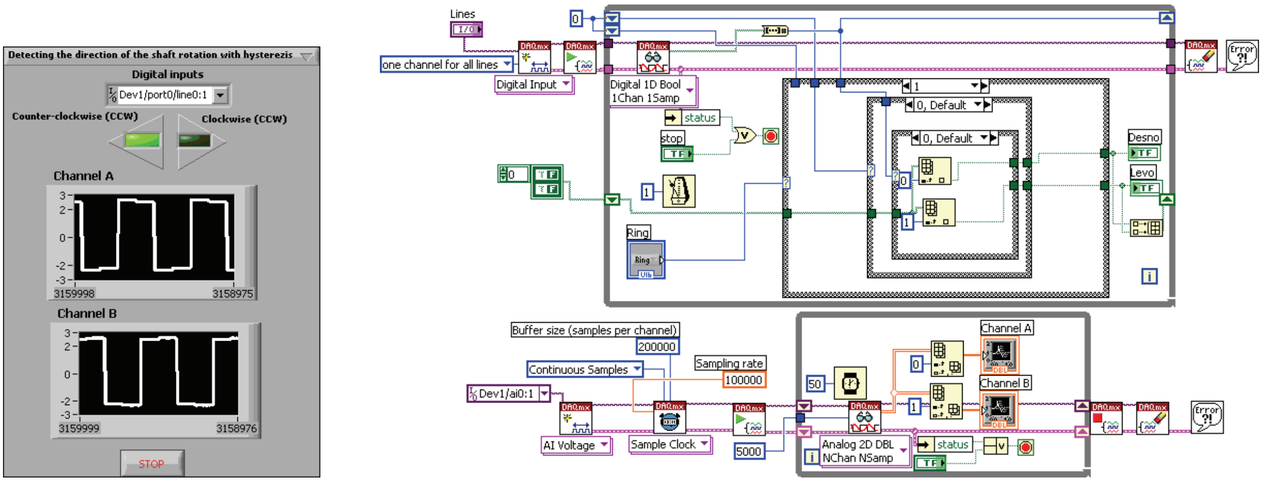


Fig. 4. Front panel and block diagram of realized virtual instrument for direction detection of shaft rotation

C. Implementation and testing of proposed solutions in LabVIEW environment

Virtual instrumentation concept is widely applied for purpose of measurement and testing during research work [7]. The virtual instrumentation in this paper is firstly used for simulation of output signals of incremental encoder and for generating of different test sequences. Simulator of incremental quadrature encoder shown on Fig. 5, provides the choice of number of revolutions per minute, number of pulses per revolution and direction of rotation.

Either of proposed solutions (with and without “hysteresis”) for rotation direction determination is implemented in one common virtual instrument by using LAbVIEW 8.0 software and acquisition boards PCI 6251 and USB 6008, see Fig. 4. The output signals from incremental encoder simulator are brought on two digital inputs of USB 6008 acquisition board, and any type of acquisition board which has digital inputs, can be used for this purpose [8].

The output information about shaft rotation direction is obtained by applying of Tables I and II using shift register and case structure functions in the block diagram. The input signals can be seen on the front panel and the choice of used method for rotation direction determination is realized through ring control. This virtual instrument can be implemented within solution for angular position or velocity determination.

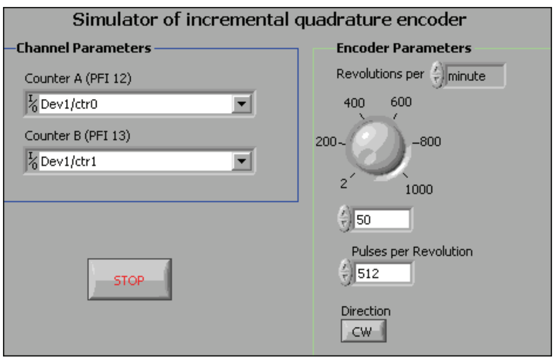


Fig. 5. Simulation of incremental encoder

V. CONCLUSION

To make the position or angular velocity information of the rotating object complete, among other parameters, the direction of rotation must be known. In this paper are proposed solutions for determining the rotation direction with and without the presence of oscillations of the rotating shaft on the border of two adjacent states, and each of them was implemented in LabVIEW software environment. These realizations can be used as an SubVI into instrument structure which measure displacement or angular velocity. The aforementioned solutions can have grater importance as part of complex systems for remote monitoring of movable objects in the industry, than in the case of individual application.

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