# Experimental Measuring System with Rotary Incremental Encoder

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*Abstract:* - The output signals of the rotary incremental encoder are used for motion sense discrimination, angular displacement and rotational speed measurement of the encoder shaft. The angular displacement can be measured with different resolutions. This paper presents an experimental system that enables the study of the rotary incremental encoder: working modes and methods for resolution improvement, displacement and speed measurement, sense discrimination. It is an intelligent measuring system that consists in one rotary incremental encoder, an IBM-PC compatible computer, an intelligent interface (with 80C552 microcontroller), a mechanical subsystem and a driving module. This experimental system is very useful in higher education and research activities because it illustrates how the same sensor can measure different physical variables, it enables the application of different knowledge (about sensors, signal conditioning and processing, microcontrollers, computers, analogue and digital circuits, motors and their electric control etc.), a soft method for resolution improvement and sense discrimination can be studied and verified, an industrial application of the rotary incremental encoders can be studied step by step. Many experimental results are presented to highlight the usefulness of this experimental measuring system.

*Key-Words:* - Rotary incremental encoder, education, measuring system, displacement, resolution, industrial application.

## 1 Introduction

Motion measurements are extremely useful in controlling mechanical responses and interactions in dynamic systems. A one-to-one relationship may not always exist between a measuring device and a measured variable. Furthermore, the same device may be used to measure different variables, using appropriate electronic circuits and data processing techniques [1,2].

The rotary incremental encoder converts the angular displacement of its shaft into a digital electric signal. A collimated light beam is aimed against two radial reticules: static and moving (incremental disc). Light (that can pass through both reticules) drops on a photo-sensor placed immediately over the disc. The disc is marked with a series of uniform lines in a single track around the perimeter [1]. When the lines interrupt the light beam, “increments” of information are produced in the form of a square pulse train (output signal A). The frequency of the pulses relates to the number of lines on the disc and the disc speed. The pulse amplitude relates to the excitation supply. A single line placed on the disc provides a marker pulse R for reference purpose. The basic signal A provides information on single direction rotational movement and $P_{Amax}$ pulses are generated during a complete rotation of the encoder shaft; $\Delta\phi[\deg] = \frac{360}{P_{A\max}}$ is the angular displacement increment. Using two scanning heads, it is possible to produce a second wave train B, with 90$^{o}$ displacement; the direction of rotation can be detected and the pulses are up or down counted for the position measurement.

The output signals A and B of the rotary incremental encoder are used for motion sense discrimination, angular displacement and rotational speed measurement. The angular displacement can be measured with different resolution [2,3]. The usual method for resolution improvement (presented in [3]) supposes adequate electronic circuits that detect and count the positive ($A_1$, $B_1$) and negative ($A_2$, $B_2$) fronts of the pulses A and B. The output signal is

$$u_o = A_1 + A_2 + B_1 + B_2 \quad (1)$$

and $\frac{\Delta\phi}{4}$ is its spatial period. So, if the number of the pulses $u_o$, at the moment t, is multiplied with $\frac{\Delta\phi}{4}$, the angular displacement of the shaft, until the moment t, is obtained. The resolution of the displacement measurement is four times improved in this way.

The motion sense of the incremental disc can be also detected if

- the addition of each pulse $A_1$ or $A_2$ is conditioned by the level of B, measured at the moment of pulse detection, and
- the addition of each pulse $B_1$ or $B_2$ is conditioned by the level of A, measured at the moment of pulse detection.

An electronic module generates two output signals, denoted P and M:

$$P = A_1 \cdot B + B_1 \cdot \overline{A} + A_2 \cdot \overline{B} + B_2 \cdot A, \quad (2)$$

$$M = A_1 \cdot \overline{B} + B_1 \cdot A + A_2 \cdot B + B_2 \cdot \overline{A}. \quad (3)$$

Three situations can appear:

a) the motion sense is positive, when $M = 0$ and P is a square pulse train:

$$P = A_1 + B_1 + A_2 + B_2; \quad (4)$$

b) the motion sense is negative, when $P = 0$ and M is a square pulse train:

$$M = A_1 + B_1 + A_2 + B_2; \quad (5)$$

c) the incremental disc doesn't move, when $P = 0$ and $M = 0$.

For the displacement measurement,

- the pulses $P = u_o$ must be counted, if the motion sense is positive,
- the pulses $M = u_o$ must be counted, if the motion sense is negative.

The shaft position can be also measured if the pulses P are counted up and the pulses M are counted down in the position-counter.

The paper [3] proposes a soft method for angular displacement and rotational speed measurement, resolution improvement and sense discrimination, based on two output signals (A and B) of the rotary incremental encoder. This method is adequate for the computerised study of the encoder, using an experimental system and an intelligent interface similar with those presented in [4,5]. The positive and negative fronts of the signals A and B are soft detected and processed for angular displacement measurement and sense discrimination. A mean value of the rotational speed, in revolutions per minute, is computed based on the number of all positive and negative fronts counted during a pre-established period.

The study of the rotary incremental encoder (working modes, methods for resolution improvement, method for displacement and speed measurement, methods for sense discrimination) is very useful in higher education and research activities [6,7]. An experimental system, that enables the study of the rotary incremental encoder, is presented in this paper. It is an intelligent measuring system that consists in a rotary incremental encoder, an IBM-PC compatible computer, an intelligent interface, a mechanical subsystem and a driving module. Using this experimental system, the students or researchers

- can study
  - methods for angular displacement and rotational speed measurement,
  - methods for sense discrimination,
  - methods for resolution improvement,
  - an industrial application

  based on rotary incremental encoder;
- can use the previous knowledge about sensors, signal conditioning and data processing, computers, microcontrollers, analogue and digital circuits, motors, electric control etc.

Using this experimental measuring system, some real industrial projects can be included in the study plan of the universities [7].

# 2 System Description

## 2.1 Summarised System Details

The experimental measuring system, presented in this paper, contains a rotary incremental encoder (RIE), a mechanical subsystem, a driving module, an intelligent interface with 80C552 microcontroller [8] and an IBM-PC compatible computer (Fig.1). The encoder under test is of SUMTAK origin, the LBL-007-1000 type; it is characterised by $P_{Amax}$=1000 and $\Delta\phi = 0.36\,\text{deg}$.

This experimental system has many advantages:

- it illustrates how the same device can measure different physical variables;
- a soft method for resolution improvement and sense discrimination can be studied and verified;

- the hard and soft previous knowledge about microcontroller can be applied;
- an industrial application of the rotary incremental encoder can be studied.

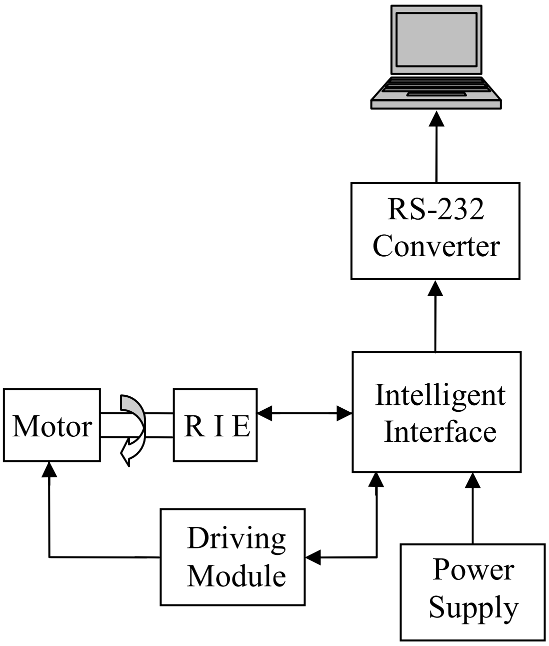


Fig.1. Overall structure of the experimental measuring system

The intelligent interface commands the motor driving circuit and the motor moves the encoder shift. The interface is similar with that presented in [5] and it is organised around a microcontroller from the 80C552 family (Philips Semiconductors), which is very flexible and versatile, with excellent control possibilities in various industrial applications. Hardware resources of the interface enable the engendering of some digital or analogue commands (for the motion control or sensor supply) and the acquisition of many digital or analogue signals necessary for computing some motion variables or technological parameters. The interface is endowed with adequate software resources for connecting the rotary incremental encoder, for improvement its resolution, for computing motion variables. Between the interface and computer there is a soft interaction. The intelligent interface is serial connected to IBM-PC compatible computer that

- assures the final data processing,
- displays the measured variables and computed parameters,
- assures a simple dialogue with the user.

Program modules (to the intelligent interface level and computer level) enable the study of encoder and its application. The program modules at the intelligent interface are written in the assembly language and C for 80C552 microcontroller; each program module implements an elementary function (serial dialogue with the computer, control of the mechanical subsystem, acquisition of the analogue and digital signals etc.).

The main source file of this application (at the intelligent interface level) is presented in [4] and it assures the resolution improvement, sense discrimination, angular displacement and rotational speed measurement.

### 2.2 Method for Displacement Measurement, Resolution Improvement and Sense Discrimination

The signal B is phase-shifted in time, related to signal A, depending on the motion sense.

For a constant rotational speed, let us consider

- signal B phase-shifted before signal A, if the motion sense is positive,
- signal B phase-shifted after signal A, if the motion sense is negative.

So, a correlation exists between the logic levels of signals A and B, before and after a new front of pulses A or B.

The microcontroller master program (in assembly language) reads the digital inputs A and B, after each 115µs (when 80C552 receives an interrupt from an internal timer); the exact value of this period is 115.017361µs.

The acquisition routine compares the last ($Q_{A1}$, $Q_{B1}$) with the last but one ($Q_{A0}$, $Q_{B0}$) logic levels of the signals A and B, to detect the motion sense and compute the angular displacement. Each new front of pulses A and B must be detected.

The main steps of the algorithm for resolution improvement, motion sense discrimination and angular displacement measurement are presented below.

a) Two variables (X and Y) memorise the last and the last but one, respectively logic levels of the signals A and B: $X=Q_{A1}Q_{B1}$ and $Y=Q_{A0}Q_{B0}$.
b) A logic operation XOR between X and Y enables the detection of each new front (positive or negative) of the pulses A or B; a non-zero result indicates the change of the logic level of A or B (so, a new front).
c) The last and the last but one logic levels of the digital inputs A and B form the number $Q_{A0}Q_{B0}Q_{A1}Q_{B1}$, where $Q_{A0}$ is LSB; let us consider S its equivalent in decimal code.

   Three situations can appear [9]:
   - Positive motion sense, if S=2, S=4, S=11 or S=13;

- Negative motion sense, if S=1, S=7, S=8 or S=14;
- Unknown motion sense (impossible situation or the same level of each signal A or B), if S=0, S=3, S=5, S=6, S=9, S=10, S=12 or S=15.

The displacement-counter always counts up the last detected front of A or B. The resulted number is multiplied with $\frac{\Delta\phi}{4}$ to obtain the angular displacement of the shaft. In this way, the experimental system measures the displacement with a resolution divided-by-four, and the motion sense is detected too.

### 2.3 Method for Mean Rotational Speed Measurement

During a complete rotation of the shift encoder, 4000 fronts (of signals A or B) are detected and counted; so, each new front corresponds to $\frac{1}{4000}$ rotations. $N_S$ fronts are detected in the period $\Delta T_S = 1\text{s}$, if the shaft encoder moves in the same sense during this period. The number $N_S$ corresponds to the mean rotational speed of the shaft, in revolutions per minute:

$$n[\text{r.p.m.}] = N_S \frac{60}{4 \cdot P_{A\max}} = N_S \cdot n_o[\text{r.p.m.}], \qquad (6)$$

where $n_o$ is the rotational speed increment. So, the resolution of the rotational speed measurement is $n_o$. For the encoder under test, $P_{A\max}$=1000 and $n_o$=0,015 r.p.m.

### 2.4 Technological Parameter Measurement Using Rotary Incremental Encoders

In the aluminum processing industry, the resulted cold laminated foil is rolled in bales with certain foil thickness (rigorously controlled during the technological process). The aluminum foil is then unrolled and rewound in rolls with some imposed parameters, such as exterior diameter of the roll, width, thickness, length or mass of the foil [9]. These parameters must be measured with imposed precision, during the technological process. This finishing process develops on the machine for adjusting aluminum foil. The tambour draws the foil from the bale and then the foil is rewound on the roll shift (with imposed interior diameter). Two free reels stretch the foil and establish its path between the bale and the tambour. A special device, placed between the ball and the first free reel, cuts the foil to the assigned width (with imposed precision). If the bale contains a double foil, two identical rolls will result at the end of this finishing process.

The machine for adjusting aluminum foil assures the achievement of following conditions:

- linear velocity of the foil is equal to the tangential velocity of the tambour;
- aluminum foil doesn't slip on the tambour;
- foil is perfectly stretched (it doesn't wave) during the rewinding process;
- tambour circumference ($C_T$[mm]) is known and rigorously constant;
- successive aluminum sheets are in perfect contact on each roll.

During the finishing process of the aluminum foil, three parameters must be measured and displayed:

- L – the length of the rewound foil;
- M – the mass of the rewound foil;
- D – the exterior diameter of the roll.

The requirements to the measuring system are the following:

- the measurement precision must be satisfied for each parameter;
- the foil width and thickness must be assigned before each measuring process;
- all parameters must be measured and displayed quasi-continuously during the finishing process.

A method for measuring the parameters L, M, D, with imposed precision, supposes two rotary incremental encoders: $RIE_1$ – attached on the tambour shaft, and $RIE_2$ – attached on the roll shaft. During a complete rotation of its shaft, the encoder $RIE_i$ generates $P_{A\max}$ pulses A (denoted $A_{Ri}$), and a pulse $R_i$ appears after each complete rotation. The exterior diameter D of the roll, the length L and mass M of the rewound foil can be computed based on the pulses $A_{R1}$ and $R_2$, if the tambour circumference ($C_T$[mm]), the width (l[mm]) and thickness (g[μm]) of the foil are known.

All rewound foil is carried by tambour because the aluminum foil doesn't slip on the tambour. During one complete rotation of the tambour, the length of the rewound foil is $C_T$[mm] and the rotary incremental encoder $RIE_1$ generates $P_{A\max}$ pulses $A_{R1}$. We consider the moment t=0 when the rewinding starts. If $P_1(t)$ pulses $A_{R1}$ are counted until the moment t, the foil rewound until this moment is

$$L(t) = \frac{P_1(t)}{P_{A\max}} C_T, \qquad (7)$$

where L[mm] and $C_T$[mm].
The mass M(t) of the aluminum foil (rewound until the moment t) is computed based on its length L(t), width (l) and thickness (g):

$$M(t) = L(t) \cdot l \cdot g \cdot \rho_{Al} \cdot 10^{-12} \qquad (8)$$

where M[kg], L[mm], l[mm], g[µm] and $\rho_{Al} = 2674[kg/m^3]$.

Between two consecutive pulses $R_2$, generated at the moments t' and t'' ($t'' > t'$), $P_D(t'')$ pulses $A_{R1}$ are counted:

$$P_D(t'') = P_I(t'') - P_I(t') . \qquad (9)$$

Because the foil is perfectly stretched (it doesn't wave) during the rewinding process, the exterior diameter of the roll can be computed based on the number $P_D(t'')$:

$$D(t'') = \frac{P_D(t'')}{\pi P_{A\,max}} C_T , \qquad (10)$$

where D[mm] and $C_T$[mm].

The measuring system, based on the above-presented method, can be simulated using the experimental system, presented in this paper. Only two technological parameters (the length L and mass M of the rewound foil) can be computed because only the pulses generated by a single rotary incremental encoder ($RIE_1$) can be processed. The tambour circumference is $C_T$=1000mm in this simulation. The foil length is measured with 0.25mm resolution, because the above-presented method for displacement measurement with resolution improvement is used. The IBM-PC compatible computer

- displays the measured values,
- enables the parameter prescribing and
- assures a simple dialog with the user.

## 3 Experimental Results

The procedure for studying the rotary incremental encoder and its application enables

- displacement measurement, with 0.09deg. resolution,
- mean rotational speed measurement, with 0.015 r.p.m. resolution,
- sense discrimination,
- simulation of one industrial application.

When accessing the main program, two options will appear (Fig. 2):
A) Utility;
B) Application.

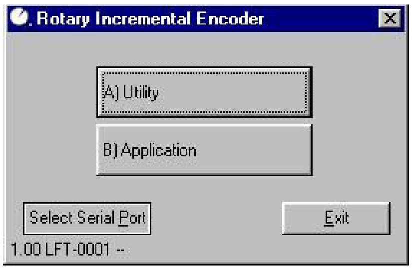


Fig.2. Application program options

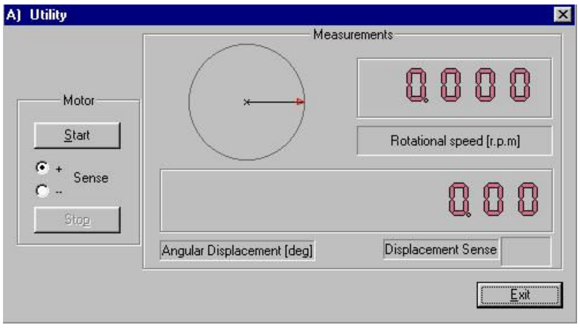


Fig.3. Dialog window after the *Utility* option is selected

If the option *Utility* is selected, the fields *Motor* and *Measurements* appear on the display (Fig.3). A vector, on its initial position on a circle, is also represented. The measuring process starts when the motion sense of the motor shaft is selected and the button *Start* is then activated.

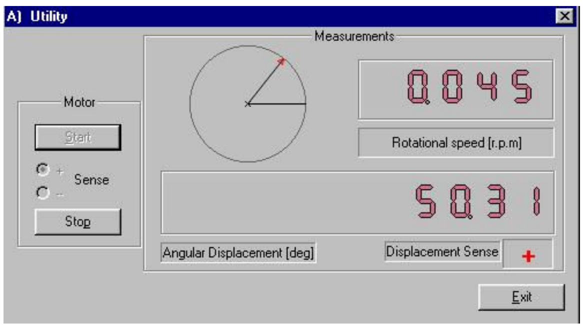


Fig.4. Measurements for positive motion sense

During the measuring process, the mean value of the rotational speed (in r.p.m.), angular displacement (in deg.) and displacement sense (positive or negative) are displayed (Fig.4 and 5). The vector position reflects the measured angular displacement; the vector moves in counterclock-wise when the motion sense is positive.

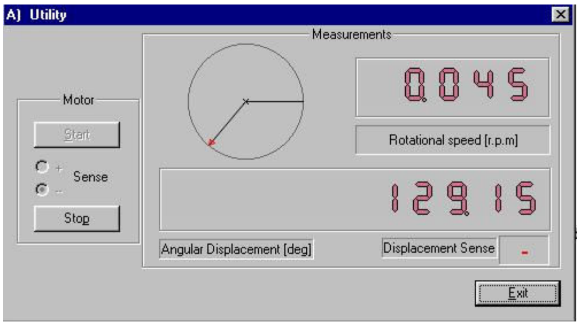


Fig.5. Measurements for negative motion sense

If the button *Stop* is activated, the motion stops, the last measured displacement is memorised, the rotational speed becomes zero, the vector rests in its last position and the motion sense is not displayed. The next motion sense of its shaft can be changed only if the motor is stopped. The displacement and rotational speed become zero when the button *Start* is activated again. To return in the main program, the motor must be stopped and the *Exit* button should be activated.

If the option *Application* is selected, the fields *Motor*, *Assigned Values* and *Measured Values* appear on the display (Fig. 6).

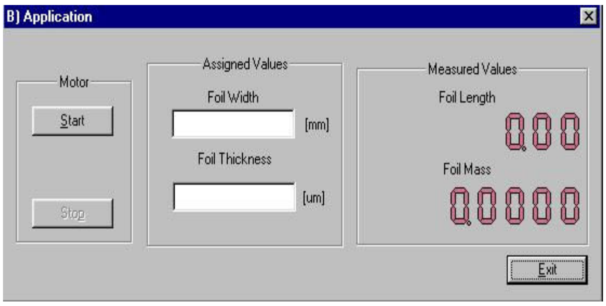


Fig.6. Dialog window after the *Application* option is selected

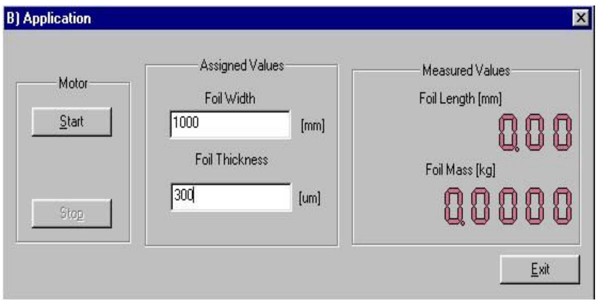


Fig.7. Value assignment

The foil width and thickness must be assigned before each measuring process (Fig.7).

The measuring process begins when button *Start* is activated and only if the assigned values are prescribed. The motion sense is only positive in this application. The foil length (in mm) and foil mass (in kg) are then displayed in the field *Measured Values* (Fig.8).

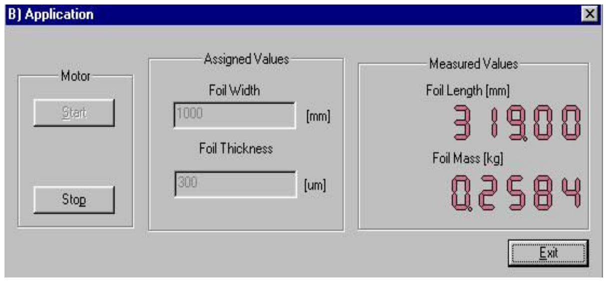


Fig.8. Measured technological parameters

The measuring process is interrupted if the button *Stop* is activated; the assigned values and the last measured values rest displayed when the motor is stopped. The button *Start* can be then activated again and the measured values increase further on. To return in the main program, the motor must be stopped and the *Exit* button should be activated.

## 4 Conclusion

The paper presents an experimental measuring system that performs the study of rotary incremental encoders. This experimental system is very useful in higher education and in research activities. It is an intelligent measuring system that consists in one rotary incremental encoder, an IBM-PC compatible computer, an intelligent interface, a mechanical subsystem and a driving module. Using this experimental system, the students or researchers

- apply hard and soft previous knowledge about microcontrollers and computers;
- understand the possibility of measuring different physical variables, using the same rotary incremental encoder;
- study and verify a soft method for resolution improvement and for sense discrimination;
- perform a detailed study on an industrial application of the rotary incremental encoder (requirements to measuring system, measuring method, interface with the user).

The intelligent interface of this experimental system can be used for study many other sensors and various measuring methods.

*References:*

[1] A. Helfrick, W. Cooper, *Modern Electronic Instrumentation and Measurement Techniques,* Prentice-Hall International Editions, 1990.

[2] P. Koči, J. Tůma, Incremental Rotary Encoders Accuracy, *Proc. 7th International Carpathian Control Conference*, Ostrava – Beskydy, Czech Republic, 2006, pp. 257-260.

[3] D.M. Purcaru, E. Niculescu, An Alternative Method for Resolution Improvement to Rotary Incremental Encoder, *Proc. 2nd WSEAS/IASME International Conference on Educational Technologies,* Bucharest, Romania, 2006, pp. 33-38.

[4] D.M. Purcaru, E. Niculescu, I. Purcaru, Measuring Method for Computerized Study of Rotary Incremental Encoders, *WSEAS Transactions on Electronics, Vol. 3,* 2006, pp. 349-355.

[5] I. Purcaru, D.M. Purcaru, Intelligent Interface for Studying Different Sensors, *Proc. 10th International Symposium SINTES 10,* Craiova, Romania, 2000, pp. E75-E78.

[6] V.I. Gurumurthy, N. Mastorakis, Quantity and Quality in Engineering Education and Research, *Proc. of the 9th WSEAS International Conference on Engineering Education,* Athens, Greece, 2006, pp. 535-414.

[7] R. Farana, L. Smuthny, Industrial Grant Projects as a Part of Study Plan at the University, *Proc. of the 4th WSEAS/IASME International Conference on Engineering Education,* Crete Island, Greece, 2007, pp.242-245.

[8] V.C. Petre, The Technician's Point of View in Microcontroller Based Measurements, *WSEAS Transactions on Advances in Engineering Education,* Issue 8, Vol.3, 2006, pp. 779-782.

[9] D.M. Purcaru, E. Niculescu, A Possible Method for Measuring Some Technological Parameters, *Proc. of the 11th WSEAS International Multiconference on Circuits, Systems, Communications, Computers, Vol.1,* Crete Island, Greece, 2007, pp. 77-81.