# Measuring System for Some Parameters of the Rolls Resulted in Finishing Process of Aluminum Foil

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*Abstract:* - This paper presents some considerations about a system that measures many parameters of the rolls resulted in aluminum processing industry. It is an intelligent measuring system that supposes two rotary incremental encoders, an interface with 80C552 microcontroller, an IBM-PC compatible computer and a driving module. The technological parameters are measured and displayed, with imposed precision, during the rewinding process. The measuring system is characterized by software flexibility and assignment of the foil width and thickness before each measuring process. The results obtained using an experimental system (with the same structure) are also presented.

*Key-Words:* - Measuring system, rotary incremental encoder, intelligent interface, microcontroller, technological parameters.

## 1 Introduction

In aluminum processing industry the resulted cold laminated foil is rolled in bales with foil thickness rigorously controlled during the technological process. The aluminum foil is then unrolled and rewound in rolls with imposed parameters, such as exterior diameter of the roll, width, thickness, length or mass of the foil. Some parameters must be measured with imposed precision, during the technological process.

The machine for adjusting aluminum foil (presented in Fig.1) prepares the rolls with some imposed parameters. This equipment contains a tambour that draws the foil from the bale. The aluminum foil is then rewound on the roll lap arbor. Two free reels stretch the foil and establish its path between bale and tambour. A special device (cutter, in Fig.1), placed between bale 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 result at the end of this rewinding process; each roll is in contact with the tambour and all three have the same tangential velocity.

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

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

Two driving motors rotate the roll shaft and tambour shaft respectively, during the finishing process of aluminum foil, so that the above conditions are satisfied.

## 2 Problem Formulation

Three parameters must be measured and displayed during the finishing process of aluminum foil:

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

The initial measuring method (presented in [1]) is based on the counting of the tambour rotations and its rigorously constant circumference ($C_T$=1000mm). A rotation counter supplies a number that represents the length of the rewound foil, in meters. So, this initial method enables only one parameter measurement, and the precision isn't always that imposed.

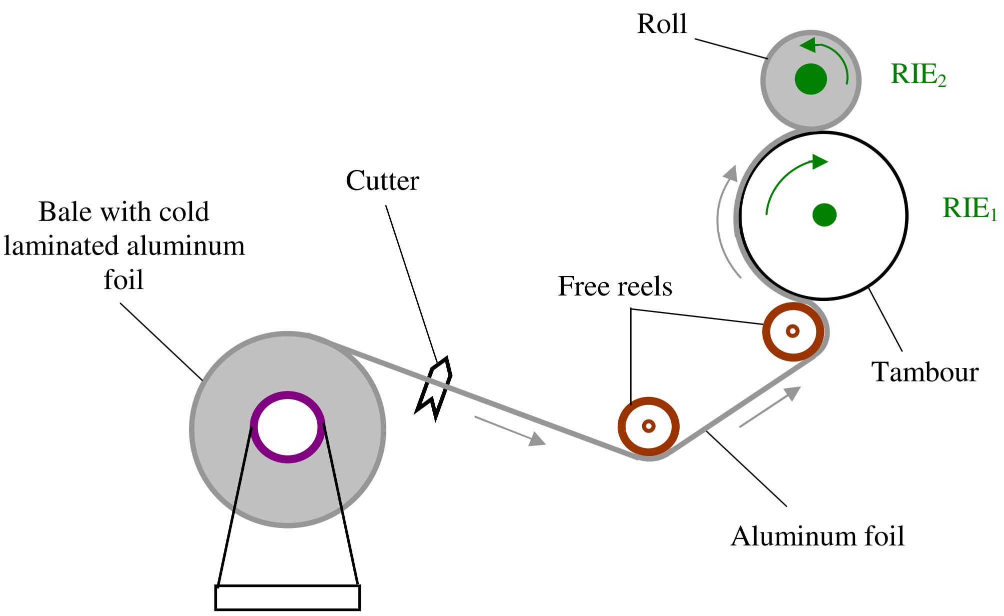


Fig.1. Machine for adjusting aluminum foil

The machine for adjusting aluminum foil must produce rolls characterized by the following final values of measured technological parameters:

- $L_f = 10...10000$ m,
- $M_f = 1...600$ kg,
- $D_f = 40...600$ mm.

The requirements to measuring system are the following:

- measurement of three technological parameters: L, M and D;
- each parameter must be measured and displayed with imposed precision;
- all parameters must be quasi-continuously measured and displayed during the finishing process of aluminum foil;
- operation facility;
- assignment of the foil width and thickness before each measuring process;
- software flexibility (for change the assigned values).

The imposed tolerances of the measured parameters are specified below:

- $\Delta L_{max} = \pm 0.05 \cdot L_f$ ;
- $\Delta M_{max} = \pm 0.05 \cdot M_f$ ;
- $\Delta D_{max} = \pm 5$ mm.

The system, presented in [1], assures the dynamic measurement of technological parameters L, M and D. This system supposes a complicated structure (it is organized around a microprocessor), push buttons for the prescribed values and many 7-segment LED displays for the measured and prescribed parameters. The prescribing block (for the foil width and thickness) and displaying block (for the measured parameters L, M and D) are presented in [2].

This paper presents an intelligent system that measures all three technological parameters: L, M and D. This system supposes two rotary incremental encoders, an interface with 80C552 microcontroller, an IBM-PC compatible computer and a driving module. The technological parameters are measured and displayed, with imposed precision, during the rewinding process. The measuring system is characterized by software flexibility and assignment of the foil width and thickness before each measuring process.

## 3 Measuring Method

The measuring system presented in this paper is based on a method that supposes two rotary incremental encoders:

- $RIE_1$ – attached on the tambour shaft (Fig.1),
- $RIE_2$ – attached on the roll shaft (Fig.1).

The rotary incremental encoder is an electro-mechanic device that converts the angular displacement of its shaft into a digital electric signal [3,4,5].

The output signals A and B (produced by the rotary incremental encoder) are used for motion sense discrimination, angular displacement and rotational speed measurement [6,7]; $90^o$ is the phase shift between A and B. The angular displacement can be measured with different resolution. A new method for resolution improvement is presented in [7]; it supposes a soft procedure that detects and counts the positive and negative fronts of the pulses A and B.

During a complete rotation of its shaft (with the same motion sense), the encoder $RIE_i$ generates $P_{Amax}$ pulses $A_i$ (or $B_i$), and a pulse $N_i$ appears after each complete rotation. The angular displacement increment is

$$\Delta\phi[\deg] = \frac{360}{4 \cdot P_{A\max}} \tag{1}$$

if the resolution of displacement measurement is four times improved [7].

A new method for measuring the technological parameters L, M, D is presented in [8]; it supposes that the machine for adjusting aluminum foil satisfies the conditions a, b, c, d, e (specified in Introduction). This method is based on the pulses $A_1$ (from $RIE_1$) and $N_2$ (from $RIE_2$) and it imposes $P_{Amax} \geq C_T$[mm].

All rewound foil is carried by tambour because the aluminum foil doesn't slip on tambour. The length of rewound foil is $C_T$[mm] and the rotary incremental encoder $RIE_1$ generates $P_{Amax}$ pulses $A_1$ during one complete rotation of tambour. We consider the moment t=0 when the rewinding starts. If $P_1$ pulses $A_1$ are counted until the moment t>0, the foil rewound until this moment is

$$L[mm] = \frac{P_1}{P_{A\max}} C_T[mm]. \tag{2}$$

The mass of aluminum foil rewound until the moment t>0 is computed based on its length L[mm], width l[mm] and thickness g[μm]:

$$M[kg] = L[mm] \cdot l[mm] \cdot g[\mu m] \cdot \rho_{Al}[kg/m^3] \cdot 10^{-12} \tag{3}$$

where $\rho_{Al} = 2674[kg/m^3]$.

$P_D$ pulses $A_1$ (generated by $RIE_1$) are counted between two consecutive pulses $N_2$ (generated by $RIE_2$, at the moments $t'$ and $t''$, $t'' > t'$):

$$P_D = P_1(t'') - P_1(t'). \tag{4}$$

The exterior diameter D of the roll (at the moment $t''$) can be computed,

$$D[mm] = \frac{P_D}{\pi P_{A\max}} C_T[mm], \tag{5}$$

if the foil is perfectly stretched (it doesn't wave) during the rewinding process and the foil moves in the same sense.

So, the exterior diameter D of the roll, the length L and mass M of the rewound foil can be computed based on the pulses $A_1$ (generated by $RIE_1$) and $N_2$ (generated by $RIE_2$), if the tambour circumference ($C_T$[mm]), the width (l[mm]) and thickness (g[μm]) of aluminum foil are known.

## 4 Error Analysis

In the following error analysis, we denote Δx the maximum probable absolute error of the parameter x. The absolute errors ΔL, ΔM and ΔD (of the measured parameters L, M, D) are computed using the derivatives' method [9], based on the absolute errors $\Delta P_1$, $\Delta C_T$, Δl, Δg, $\Delta P_D$ of the independent variables $P_1$, $C_T$, l, g, $P_D$; $\Delta P_1 = \Delta P_D = 1$ for the numbers $P_1$ and $P_D$.

*a) ΔL error analysis*

$$L = \frac{P_1}{P_{A\max}} C_T \quad , \tag{6}$$

$$\Delta L = \frac{\partial L}{\partial P_1}\Delta P_1 + \frac{\partial L}{\partial C_T}\Delta C_T, \tag{7}$$

$$\Delta L = \frac{C_T}{P_{A\max}} + \frac{P_1}{P_{A\max}}\Delta C_T. \tag{8}$$

*b) ΔM error analysis*

$$M = L \cdot l \cdot g \cdot \rho_{Al} \cdot 10^{-12}, \tag{9}$$

$$\Delta M = \frac{\partial M}{\partial L}\Delta L + \frac{\partial M}{\partial l}\Delta l + \frac{\partial M}{\partial g}\Delta g, \tag{10}$$

$$\Delta M = l \cdot g \cdot \rho_{Al} \cdot 10^{-12} \cdot \Delta L + L \cdot g \cdot \rho_{Al} \cdot 10^{-12} \cdot \Delta l + L \cdot l \cdot \rho_{Al} \cdot 10^{-12} \cdot \Delta g \,. \quad (11)$$

*c) ΔD error analysis*

$$D = \frac{P_D}{\pi P_{A\max}} C_T \,, \quad (12)$$

$$\Delta D = \frac{\partial D}{\partial P_D} \Delta P_D + \frac{\partial D}{\partial C_T} \Delta C_T \,, \quad (13)$$

$$\Delta D = \frac{C_T}{\pi P_{A\max}} + \frac{P_D}{\pi P_{A\max}} \Delta C_T \,. \quad (14)$$

Table 1. ΔL depends on $\Delta C_T$ and L

| L[m] | Conditions | | **ΔL[m]** | T[m] |
|---|---|---|---|---|
| 10 | $P_{Amax}=10^3$ | $\Delta C_T$=1mm | **0.011** | ±0.5 |
| | | $\Delta C_T$=0 | **0.001** | |
| $10^4$ | $P_{Amax}=10^3$ | $\Delta C_T$=1mm | **10.001** | ±500 |
| | | $\Delta C_T$=0 | **0.001** | |

Table 2. ΔM depends on $\Delta C_T$ and L

| M[kg] | Conditions | | **ΔM[kg]** | T[kg] |
|---|---|---|---|---|
| 1.069 | L=10m<br>l=125mm<br>g=300μm | $\Delta C_T$=1mm | **0.0483** | ±0.55 |
| | | $\Delta C_T$=0 | **0.0473** | |
| 588.3 | L=$10^7$m<br>l=$10^3$ mm<br>g=22μm | $\Delta C_T$=1mm | **24.72** | ±29.4 |
| | | $\Delta C_T$=0 | **24.12** | |

Table 3. ΔD depends on $\Delta C_T$ and D

| D [mm] | Conditions | | **ΔD [mm]** | T [mm] |
|---|---|---|---|---|
| 40.18 | $P_{Amax}=10^3$ | $\Delta C_T$=1mm | **0.358** | ±5 |
| | | $\Delta C_T$=0 | **0.318** | |
| 600 | $P_{Amax}=10^3$ | $\Delta C_T$=1mm | **0.918** | |
| | | $\Delta C_T$=0 | **0.318** | |

*Discussion*

- The units of measurement for M, L, D, $C_T$, l, g, $\rho_{Al}$ are those specified in (2), (3), (5).
- All estimated errors depend on $\Delta C_T$:
  - ΔL drastically increases with $\Delta C_T>0$ for great values of L (see Table 1, where T[m] is the tolerance).
  - ΔM is almost insensible to $\Delta C_T$ (see Table 2, where T[kg] is the tolerance).
  - When the diameter value increases, the sensibility of ΔD increases slowly with $\Delta C_T$ (see Table 3, where T[mm] is the tolerance).
- ΔL depends on L, and ΔD depends on D only if $\Delta C_T>0$.
- The most restrictive tolerance is $\Delta M_{max}$; it imposes a precise measurement of foil width and thickness.

## 5 Overview of Measuring System

The system for measuring the parameters L, M, D is based on the above presented method. This system supposes an intelligent interface, an IBM-PC compatible computer, two rotary incremental encoders and a driving module.

The intelligent interface UCV-02 (Fig.2) is configured around a microcontroller from the 80C552 family (Philips Semiconductors [10]); this device is very flexible and versatile, with excellent control possibilities in various industrial applications [11,12].

Fig.2. Intelligent interface UCV-02

The block diagram of UCV-02 central unit is presented in Fig.3, where

- 80C552 – 16-bit microcontroller;
- BA – address bus;
- REG – memory register for A0 ... A7 bits of the multiplexed address/data bus;
- BUFFER – bi-directional bus buffer, that assures the access to the internal data bus of the central unit;
- DEC – address demultiplexer; it forms selections for the ports that will be connected to the internal bus;
- RTC – real-time clock;

- TXD and RXD – communication lines for RS-232;
- P1.0 ... P1.7, P4.0 ...P4.7 – digital input/output ports;
- P5.0 ... P5.7- analogue inputs;
- PWM0, PWM1 – width-modulated analogue outputs.

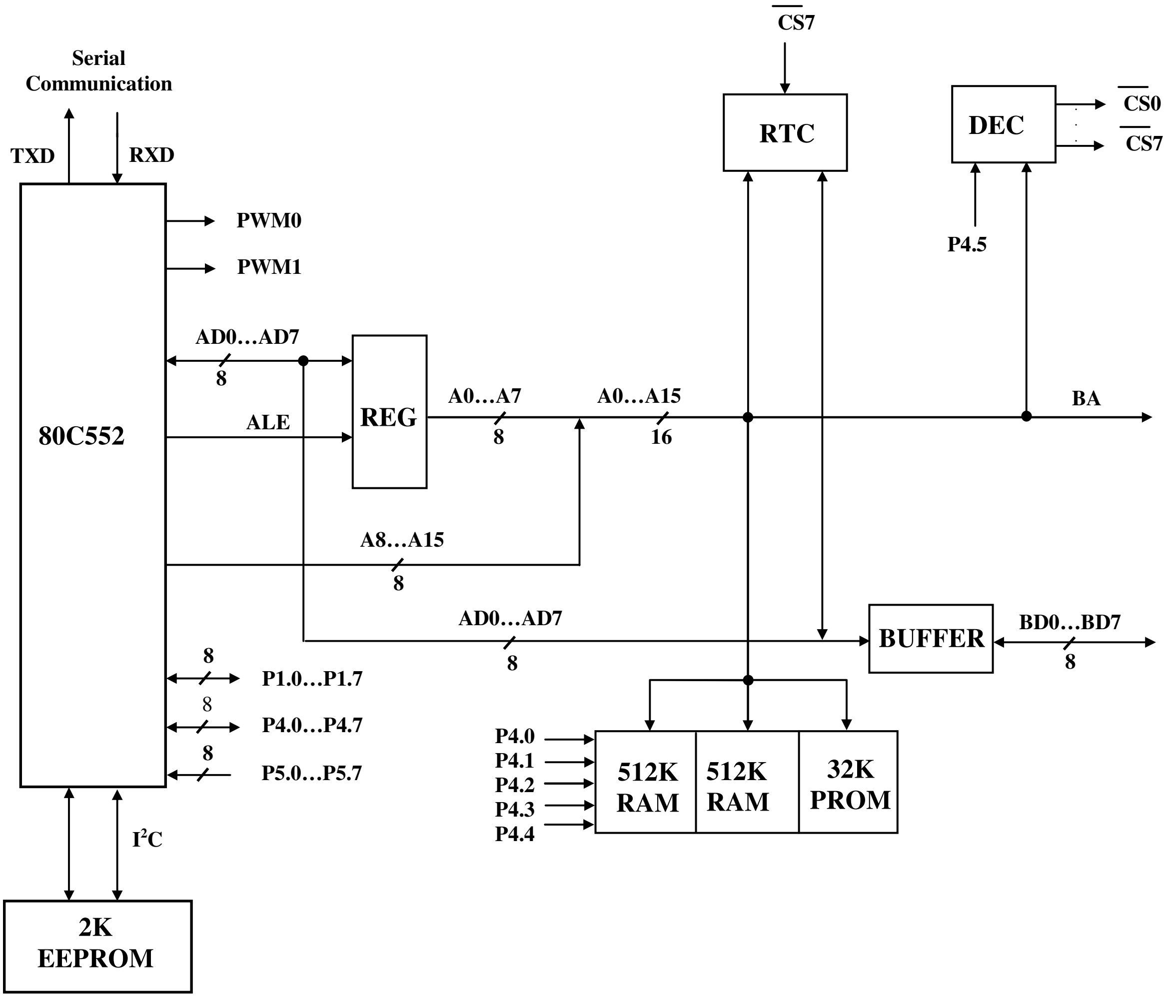


Fig.3. Block diagram of UCV-02

The main features of this intelligent interface are the following:

- microcontroller frequency: 11.0592MHz;
- maximum 1Mbyte external data memory (RAM);
- 32K bytes external program memory (EPROM);
- EEPROM memory (24C16), connected to $I^2C$ serial line;
- real-time clock – RTC 72421.

Hardware resources of this interface enable engendering of some digital or analogue commands and acquisition of many digital or analogue signals for computing some motion variables or technological parameters. The program modules at the intelligent interface level are written in the assembly language and C for 80C552 microcontroller.

Between 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 parameters,
- assures a simple dialogue with the user.

This measuring system is simulated using an experimental system with the same structure, but using only one rotary incremental encoder because the technological process cannot be perfectly simulated.

## 6 Experimental Measuring System

The experimental measuring system (Fig.4) contains only one rotary incremental encoder because only the pulses generated by $RIE_1$ can be simulated. So, only two technological parameters (the length L and mass M of the rewound foil) can be computed.

The encoder under test is of SUMTAK origin, the LBL-007-1000 type; it is characterized by $P_{Amax}$=1000. The resolution of the displacement measurement is $\Delta\phi = 0.09\deg$ because the method for resolution improvement [7] is used.

The tambour circumference is $C_T$=1000mm in this simulation and the foil length is measured with 0.25mm resolution.

Fig.4. Overview of experimental measuring system

The intelligent interface commands the motor driving circuit and the motor moves the encoder shift. The interface is endowed with adequate software resources for connecting the rotary incremental encoder, for improvement its resolution, for computing motion variables. Each program module implements an elementary function: serial dialogue with computer, control of mechanical subsystem, acquisition of analogue and digital signals etc.

This experimental system imposes the assignment of the foil width and thickness, before each measurement process; all assigned and measured parameters are displayed with imposed precision. Because the technological process cannot be perfectly simulated, only two parameters (L and M) are measured.

If the option *Application* is selected, the fields *Motor*, *Assigned Values* and *Measured Values* appear on the display (Fig.5).

The foil width and thickness must be assigned before each measuring process (Fig.6). Each prescribed value is accepted if it is included in the value domain specified for width / thickness. The measuring process doesn't begin for any wrong prescribed value.

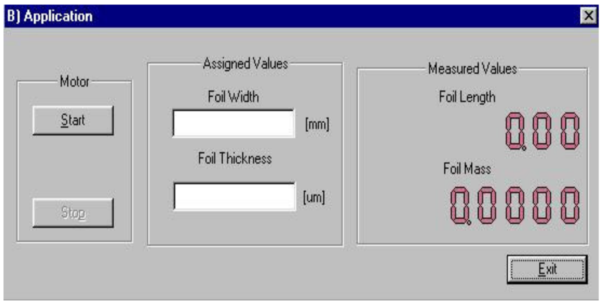


Fig.5. Dialog window after *Application* option is selected

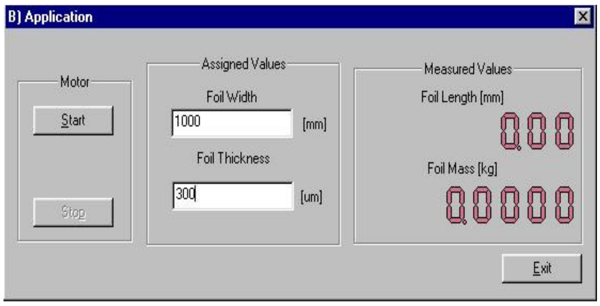


Fig.6. Value assignment

The measuring process begins when button *Start* is activated and only if the assigned values are correct prescribed. The foil length (in mm) and foil mass (in kg) are then quasi-continuously displayed (with imposed precision) in the field *Measured Values* (Fig.7).

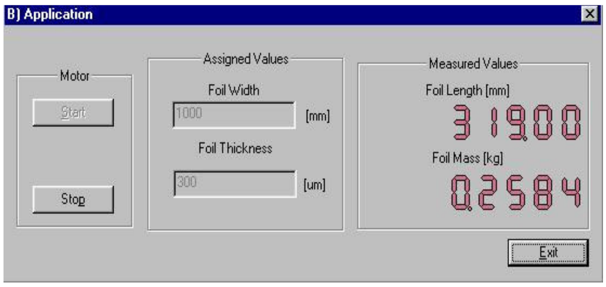


Fig.7. Measured technological parameters

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. The motor must be stopped and the *Exit* button should be activated for quit this application.

# 7 Discussion

- The measurement system presented in this paper satisfies all requirements imposed in Problem formulation.
- The software flexibility enables the change of value domain for the assigned parameters and the change of constant $C_T$ (when the tambour circumference is grinded).
- All absolute errors of the measured parameters depend on $\Delta C_T$, but $\Delta M$ is almost insensible to $\Delta C_T$.
- An important decrease of $\Delta M$ is possible only if the tolerance $\Delta g$ decreases.
- This experimental system has many other 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;
  - other industrial application of the rotary incremental encoder can be studied.

  Such experimental system is very useful in higher education and in research activities.

# 8 Conclusion

The paper presents a measuring system that solves a practical problem in aluminum processing industry: the precise measuring of some parameters of the rolls resulted in finishing process of aluminum foil. The technological parameters are measured and displayed, with imposed precision, during the rewinding process. The measurement method is based on the working conditions of the machine for adjusting aluminum foil. The technological parameters are computed using the pulses generated by two rotary incremental encoders.

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