RESOLVER–TO–DIGITAL CONVERTER

Prof. Eng. **Gheorghe BĂLUȚĂ** PhD[1], Eng. **Cristina-Nicoleta DIACONESCU** PhD student[1], Eng. **Gheorghe URSANU** PhD[1]

[1]"Gheorghe Asachi" Technical University of Iasi, blvd. D. Mangeron, no. 53, RO-700050 Iasi

REZUMAT. Rezolverul este folosit pentru comanda motoarelor electrice fără perii. Avantajul rezolverului este că acesta furnizează în permanenţă o mărime corespunzătoare poziţiei unghiulare a rotorului, inconvenientul constând în faptul că furnizează o mărime analogică şi care depinde de o funcţie trigonometrică. Pentru a obţine informaţia de poziţie sub formă digitală, s-au conceput convertoarele rezolver–digital.

Cuvinte cheie: pozitie, rezolver, convertor rezolver-digital.

ABSTRACT. The resolver is used to command the brushless electrical motors. The advantage of resolver is the providing of a magnitude corresponding to the rotor angular position. Its drawback consists of analogical magnitude provided, magnitude that depends on a trigonometric function. Resolver-to-digital converters (RDC) were realized in order to obtain the position information in digital mode.

Keywords: position, resolver, resolver-to-digital convertor.

1. INTRODUCTION

The resolvers are electrical micromachines having similar construction with asynchronous micromotors with a wound rotor. Resolvers have two winding on the stator and two on the rotor, sinusoidal distributed and placed one from another at 90 el. degrees [1], [2]. Rotor and stator windings are placed in slots, their ends being taken out at four terminals for stator. For resolvers with one rotor winding (for usual applications) the ends of rotor and stator windings are taken out at two rings, the connection with the exterior being realized through two brushes (see Fig. 1).

In most of the application, resolvers are used with single phase power on rotor and two phase output on stator. The sinusoidal voltage with constant amplitude is applied on input terminals R_1-R_2 [3]:

$$u_{R1-R2} = \sqrt{2} \cdot U_e \cdot sin(2\pi f \cdot t), \qquad (1)$$

where, U_e is the effective value applied on the excitation winding, f is the frequency.

The output voltages from stator windings terminals are (see Fig. 1):

$$\begin{cases} u_{S1-S3} = K \cdot u_{R1-R2} \cdot cos\,\theta \\ u_{S2-S4} = K \cdot u_{R1-R2} \cdot sin\,\theta \end{cases}, \qquad (2)$$

where, K is the transformation ratio.

An indication of the angle θ is achieved by processing the stator voltages, for example:

$$tg\theta = u_{S2-S4} / u_{S1-S3} \Rightarrow \theta = arctg(u_{S2-S4} / u_{S1-S3}) \qquad (3)$$

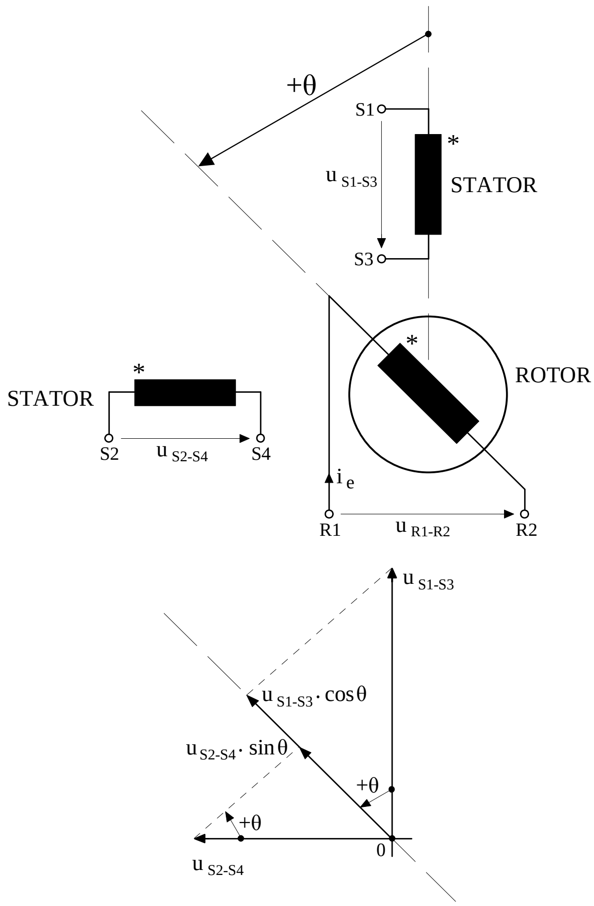

Fig. 1. Classical resolver.

Because the processing by division is not profitable, the variants with stator supply are preffered, in this case the rotor being the armature. In this sitution, two distinct methods of use can be highlighted:

-the amplitude modulation;

-the phase modulation.

In first case, to measure the angular position of a shaft (wich drives the rotor), relative to a reference position α, the two stator windings are supplied with the voltages:

$$\begin{cases} u_{S1-S3} = U \cdot sin\alpha \cdot sin\omega t \\ u_{S2-S4} = U \cdot cos\alpha \cdot sin\omega t \end{cases} \quad (4)$$

The voltage induced in rotor, for an angular position θ of rotor axis relative to the winding axis S_1-S_2, is (see Fig. 1):

$$u_{R1-R2} = U_{S1-S3}\, cos\theta + U_{S2-S4}\, sin\theta = \\ = U\, sin(\alpha+\theta)\cdot sin\omega t \quad (5)$$

The (+) sign in the expression $\sin(\alpha+\theta)$ is determined by the S_1-S_3, S_2-S_4 windings crossing sense. When the winding S_2-S_4 is crossed in opposite direction the voltage induced in rotor is:

$$u_{R1-R2} = U_{S1-S3}\, cos\theta - U_{S2-S4}\, sin\theta = \\ = U\, sin(\alpha-\theta)\cdot sin\omega t \quad (6)$$

Also, it is obvious when is used:

$$\begin{cases} u_{S1-S3} = U \cdot cos\alpha \cdot sin\omega t \\ u_{S2-S4} = U \cdot sin\alpha \cdot sin\omega t \end{cases}, \quad (7)$$

the rotor voltage is:

$$u_{R1-R2} = U\, cos(\alpha-\theta)\cdot sin\omega t \quad (8)$$

Therefore, the output is a voltage modulated in amplitude with the sine (or cosine) of the angle $\Delta = \alpha - \theta$ that represents the deviation from prescribed position α.

In the second case, the stator is fed with two voltages that have the same frequency and amplitude, but spaced at 90 el. degrees:

$$\begin{cases} u_{S1-S3} = U \cdot sin\omega t \\ u_{S2-S4} = U \cdot sin(\omega t + \frac{\pi}{2}) = U \cdot cos\omega t \end{cases} \quad (9)$$

The voltage induced in rotor is (see Fig. 1):

$$u_{R1-R2} = U_{S1-S3}\, cos\theta + U_{S2-S4}\, sin\theta = \\ = U\, sin(\omega t + \theta) \quad (10)$$

Therefore, the resultant voltage has one phase proportional with the angle that characterizes the relative position between stator and rotor.

Nowadays, resolver is used to command the brushless electrical motors [3], [6]. The advantage of resolver is the providing of a magnitude corresponding to the rotor angular position. Its drawback consists of analogical magnitude provided, magnitude that depends on a trigonometric function. Resolver-to-digital converters (RDC) were realized in order to obtain the position information in digital mode [7], [8].

2. RESOLVER-TO-DIGITAL CONVERTER

The bloc diagram that illustrates the RDC operation principle is presented in Fig. 2. There have been made the following notations:

- TB = time base;

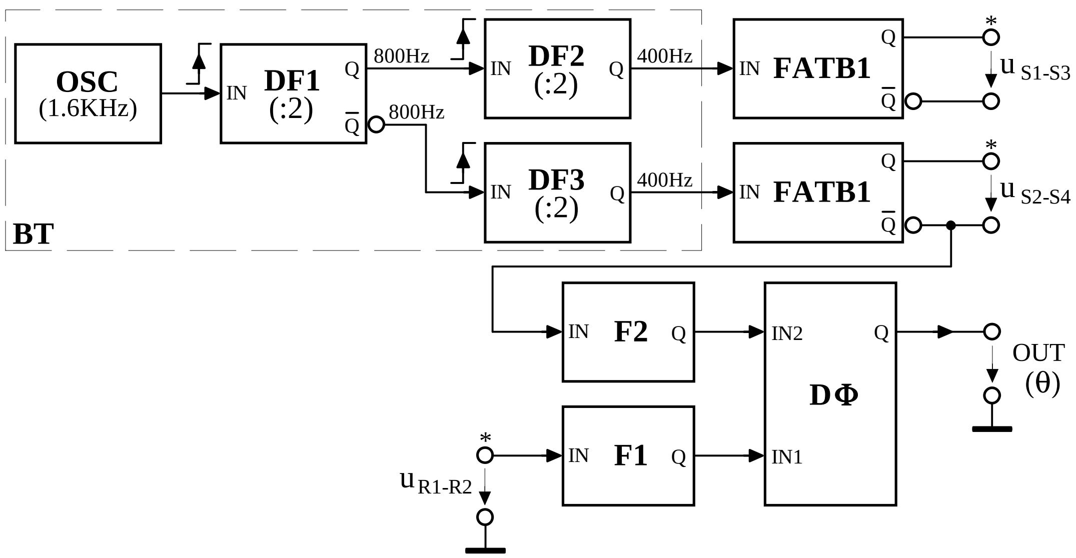

Fig. 2. Functional bloc diagram.

- OSC = oscillator (f=1.6 KHz);
- $DF_1 \div DF_3$ = frequency dividers (dividers by 2);
- $FATB_1$, $FATB_2$ = band-pass active filters;
- F_1, F_2 = pulse shaper circuits;
- DΦ = phase detector.

The time base (BT) is composed by an oscillator realized with integrated circuit βE555 (I_1, see Fig. 3). The digital signal from the oscillator output has a frequency of 1.6KHz that is fixed through the S_1 trimmer [5]:

$$T = (1600)^{-1} = [(S_1 + R_1) + 2 \cdot R_2] \cdot C_2 \cdot \ln 2 \qquad (11)$$

In order to obtain a digital signal with a duty cycle of 50%, the signal generated by the oscillator is applied to the frequency divider realized with circuit I_{2A} (bistable D type, MMC4013), in divider by two configuration (see Fig. 3). Through another two dividers by 2 (I_{2B} and I_{3A}, bistable D type, MMC4013), two digital signals out of phase by 90 el. degrees are achieved (OUT_1, OUT_2, see Fig. 4).

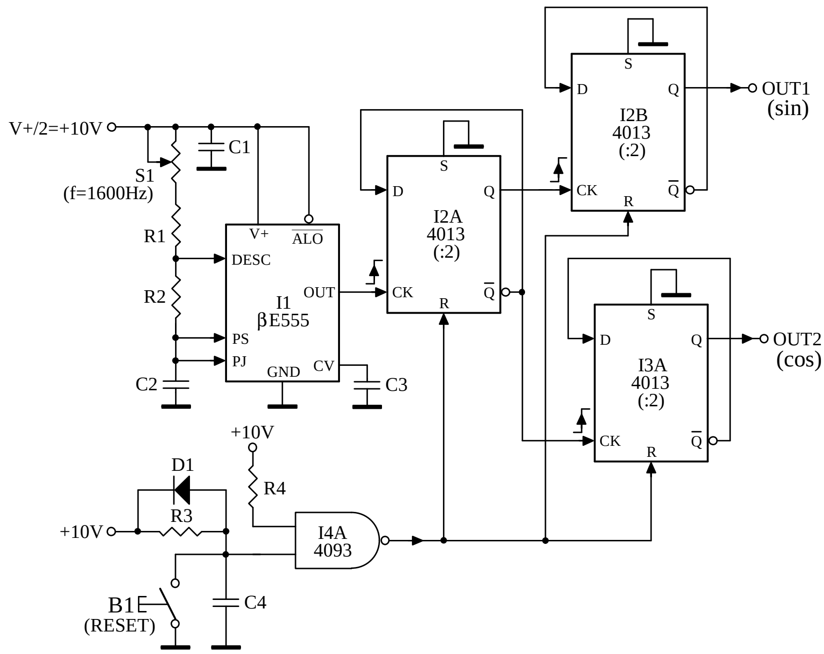

Fig. 3. Electrical schematic of the BT.

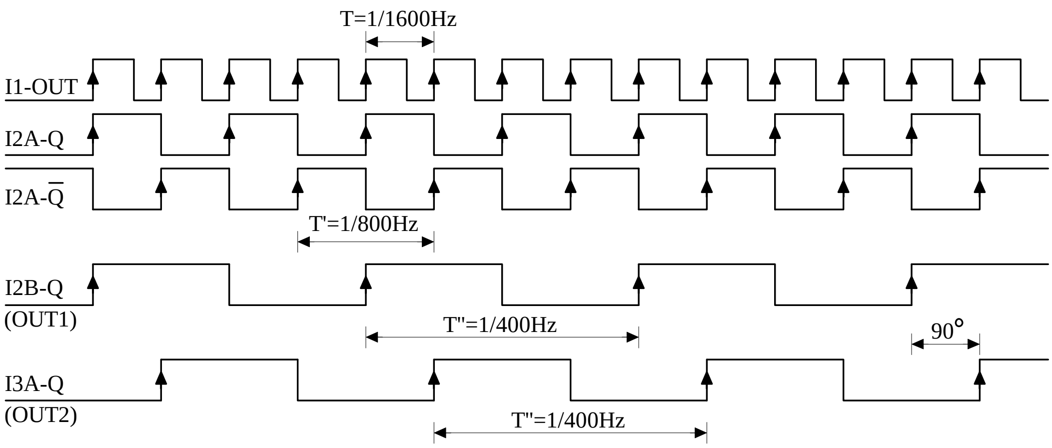

Fig. 4. Waveforms of the BT.

Through two band-pass active filters, $FATB_1$, $FATB_2$, the two supply voltages for resolver stator winding are obtained [4]. The electrical schematic of a band-pass active filter is presented in Fig. 5.

A FATB with multiple reaction has been used. It was realized with operational amplifiers I_1, I_2, βA741 type. The signal from filter output has been fixed on $V^+/2$=+10V because it has not been used a dual power supply.

The continue component from output signal waveform is removed through a inverter realized with the operational amplifier I_3 (βA741, see Fig. 6):

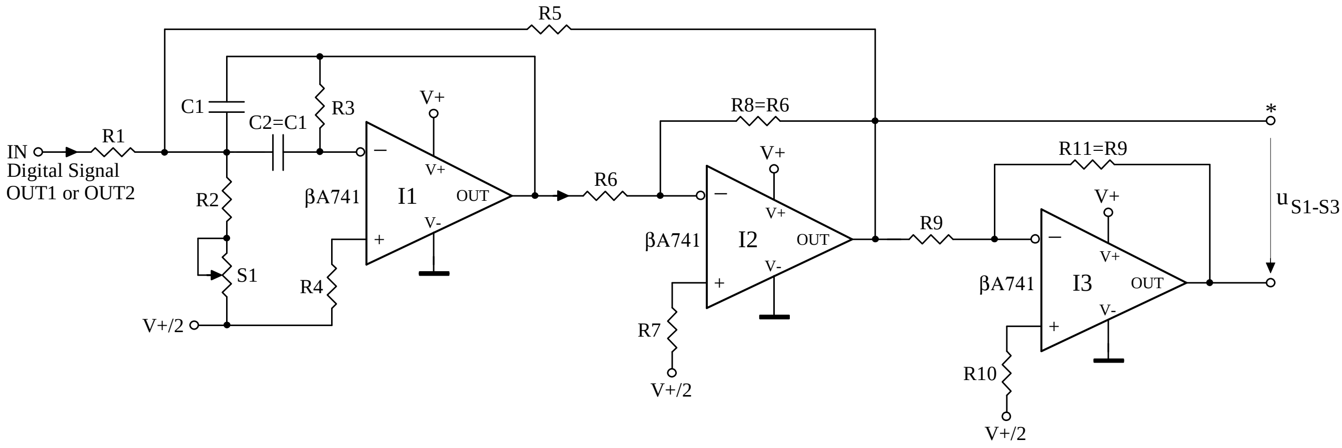

Fig. 5. Electrical schematic of the FATB.

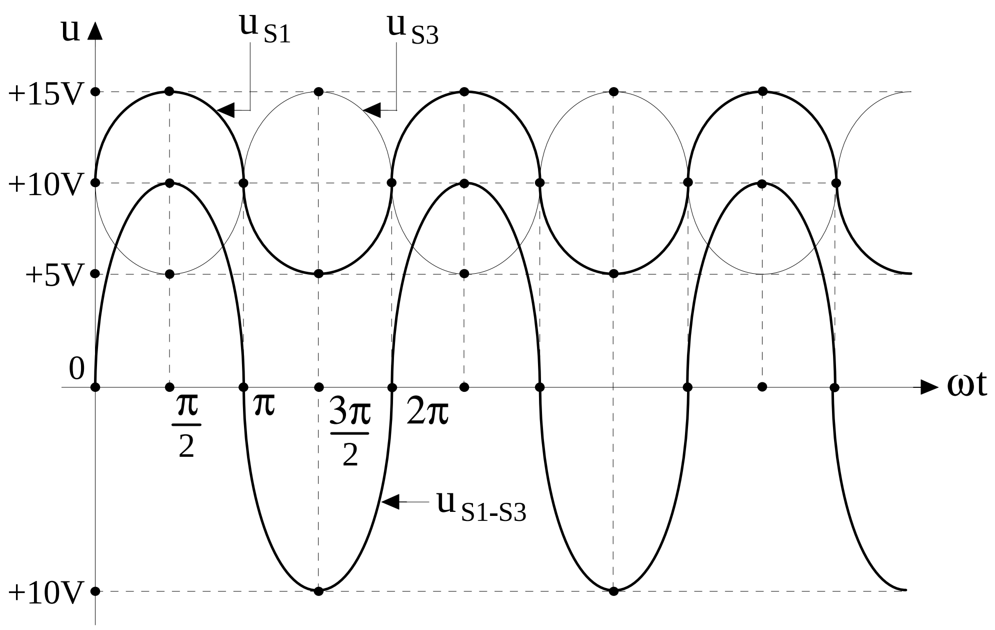

Fig. 6. Waveforms of the FATB.

$$\begin{cases} u_{S1} = \sqrt{2} \cdot U \cdot sin(\omega t) + 10V \\ u_{S3} = -\sqrt{2} \cdot U \cdot sin(\omega t) + 10V \end{cases} \quad (12)$$

Therefore, the voltage supply for stator winding is:

$$u_{S1-S3} = u_{S1} - u_{S2} = 2\sqrt{2} \cdot U \cdot sin(\omega t) = \\ = \sqrt{2} \cdot U' \cdot sin(\omega t), \quad (13)$$

where, $\omega = 2\pi f$, f = *400 Hz*, and U' = *10 V* is the effective value.

The voltage supply for the S_2-S_4 stator phase is obtained in a similar manner (see Fig. 7).

The electrical schematic of the phase detector (DΦ) is presented in Fig. 8. This consists of D type bistable (I_{3A}, MMC4013) in divider by two configuration. The clock signal (CK) active on rising edge is achieved by processing the u_{S2-S4} stator voltage: CMOS forming with comparator I_{1A} (βA339) and monostable I_{2A} (MMC4098). The initialization signal (R) active on high is obtained by processing u_{R1-R2} rotor voltage: CMOS forming with comparator I_{1B} (βA339) and monostable I_{2B} (MMC4098). The two pulses have a period of 1μs:

$$\tau = 2.47 \cdot R_4 \cdot C_3 = 2.47 \cdot R_{10} \cdot C_6 = 1\mu s \quad (14)$$

In Fig. 9 is seen that a digital signal having the frequency equal with the frequency of the two signals (*f = 400 Hz*) and the period equal with the phase shift between the two voltages is obtained. Therewith, the phase shift of the two voltages represents the angular displacement of resolver (motor) shaft.

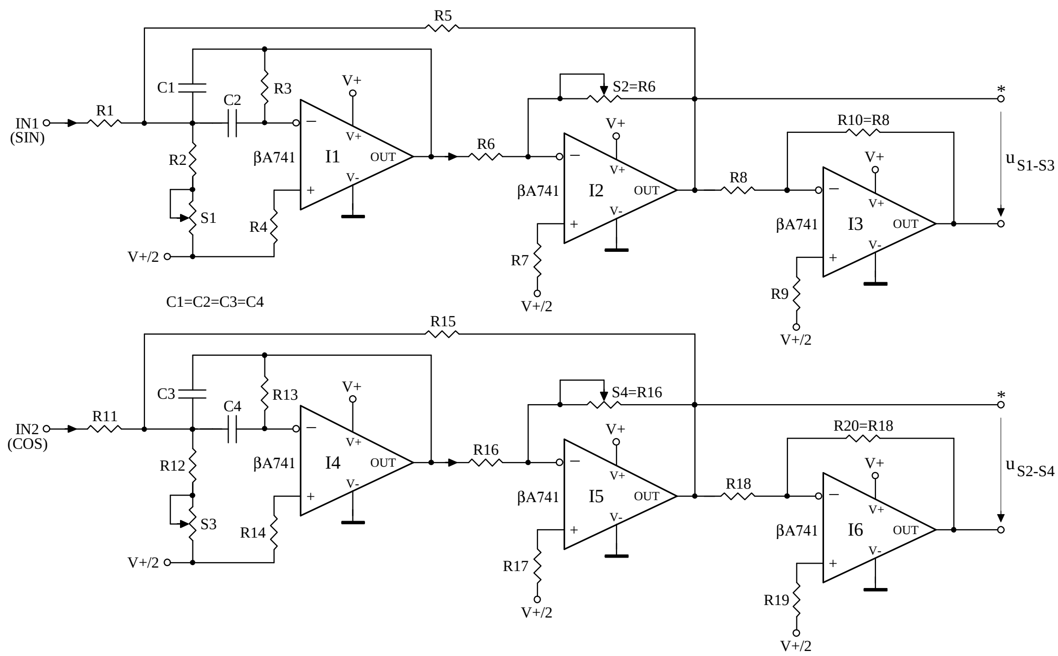

Fig. 7. Electrical schematic of the $FATB_1$, $FATB_2$.

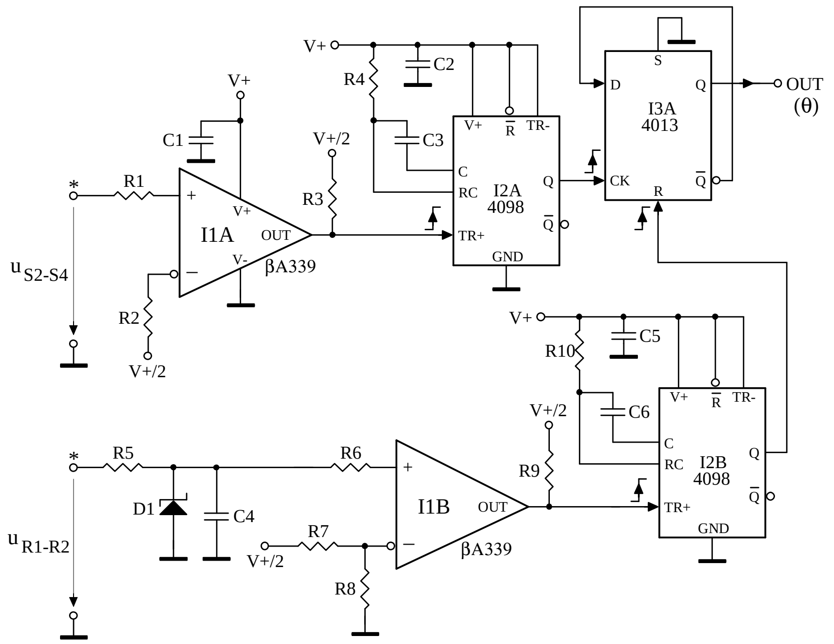

Fig. 8. Electrical schematic of the DΦ.

3. EXPERIMENTAL RESULTS. CONCLUSIONS

The RDC design, realization and experimentation were realized in the Electrical Drives Laboratory of ”Gheorghe Asachi“ Technical University from Iasi. The general view of RDC is presented in Fig. 10.

In the Laboratory it has been used a resolver manufactured by S.C. I.C.P.E. S.A. Bucuresti, 08-RX-20-2-0.454 type, having the following parameters:

-input voltage U_e = 4.4 V;
-maximum input current I_e = 6 mA;
-frequency f = 400 Hz;
-transformation ratio K = 0.454 ± 5%;
-accuracy = ± 12 min.arc;
-stator winding resistance = 70 ± 10Ω;
-rotor winding resistance = 55 ± 8Ω.

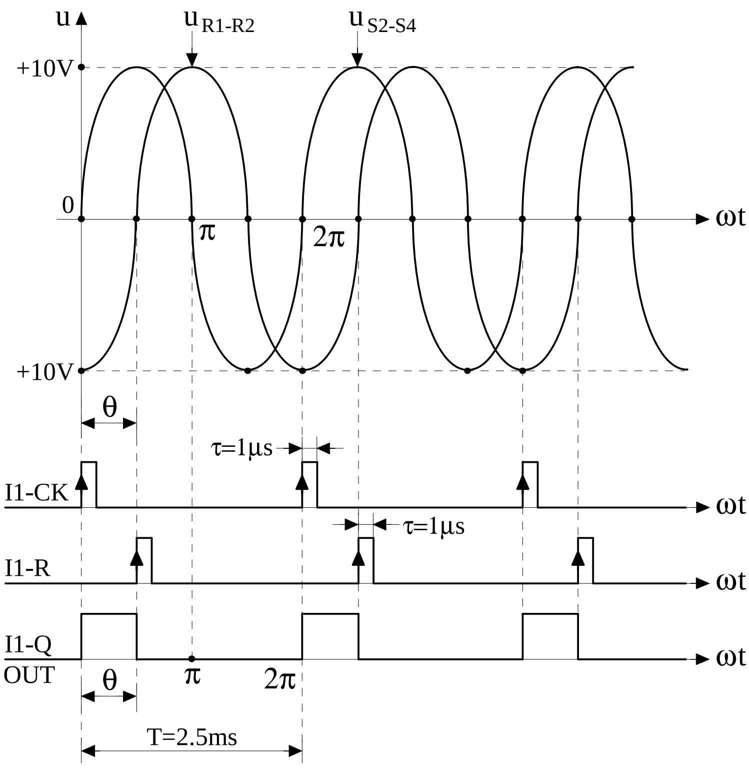

Fig. 9. Waveforms of the DΦ.

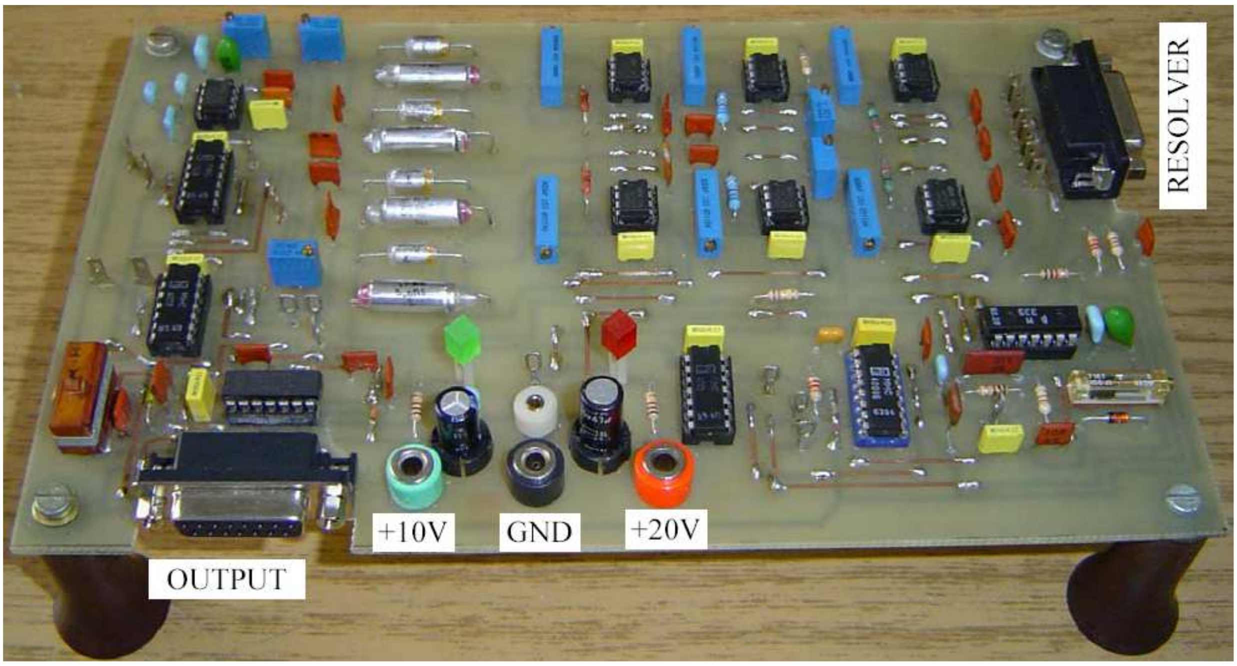

Fig. 10. General view of the RDC.

As experimental results are presented the time diagrams of:

-the digital signals with $f = 400\ Hz$ and phase shift of 90 degrees (Fig. 11);

-the supply voltages of stator windings (Fig. 12);

-the $u_{S2\text{-}S4}$ and $u_{R1\text{-}R2}$ voltages for $\theta=0$ degrees (Fig. 13), and $\theta=180$ degrees (Fig. 14);

-the output (Ch. 1) and reset (Ch. 2) signals for $\theta=90$ degrees (Fig. 15), $\theta=180$ degrees (Fig. 16), $\theta=270$ degrees (Fig. 17), and $\theta=360$ degrees (Fig. 18).

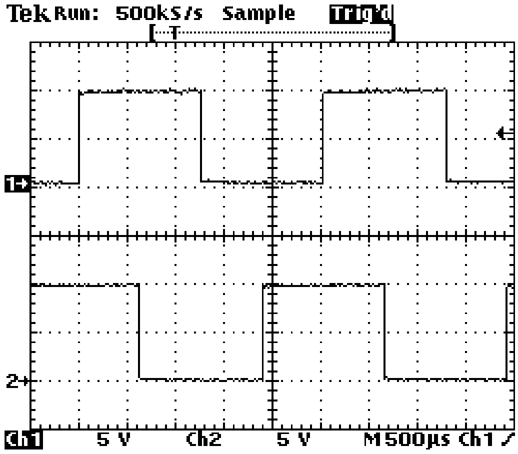

Fig. 11. Digital signals with *f=400Hz* and phase shift of *90* degrees.

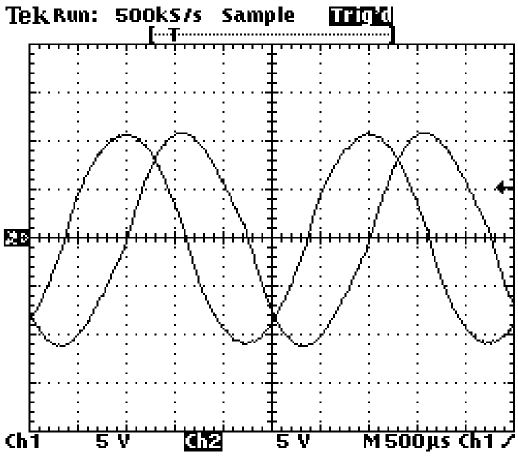

Fig. 12. $u_{S1\text{-}S3}$ (Ch.2) și $u_{S2\text{-}S4}$ (Ch.1) supply voltages of stator windings.

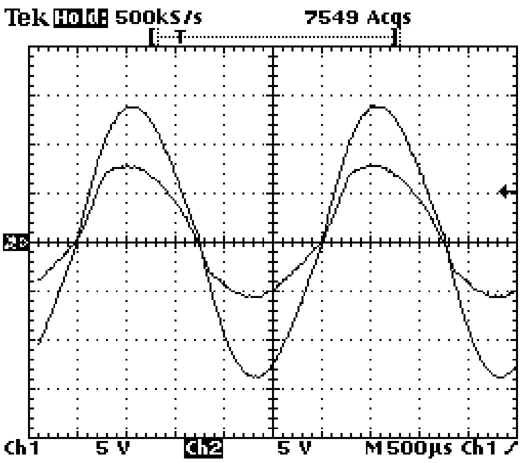

Fig. 13. $u_{S2\text{-}S4}$ (Ch. 1) and $u_{R1\text{-}R2}$ (Ch. 2) voltages for $\theta=0$ degrees.

The resolver–to–digital converter realized presents the following advantages:

-simplicity and high accuracy (under a quartz oscillator);

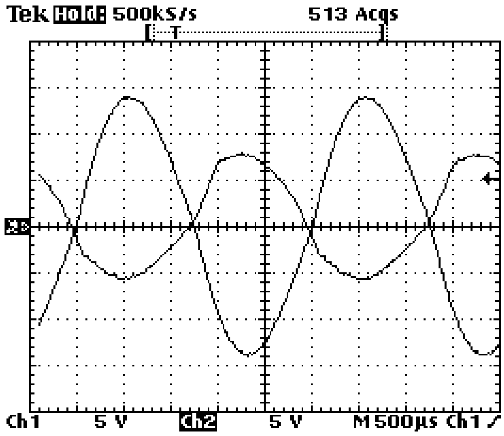

Fig. 14. $u_{S2\text{-}S4}$ (Ch. 1) and $u_{R1\text{-}R2}$ (Ch. 2) voltages for $\theta=180$ degrees.

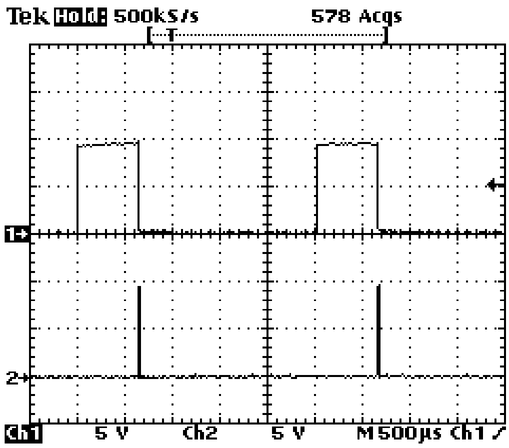

Fig. 15. Output (Ch. 1) and reset (Ch. 2, DΦ) signals for $\theta=90$ degrees.

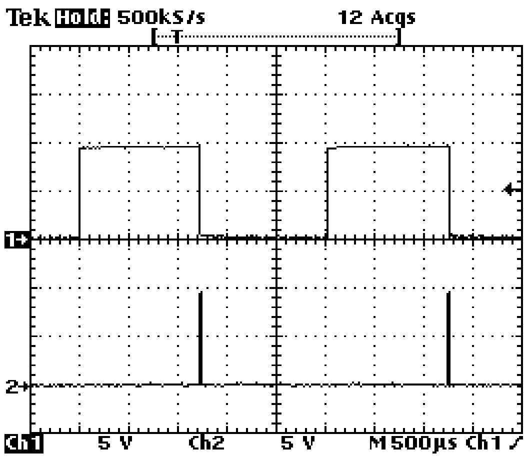

Fig. 16. Output (Ch. 1) and reset (Ch. 2, , DΦ) signals for $\theta=180$ degrees.

-increased safety in operation and low power consumption because it is made with CMOS digital circuits;

-the output information is provided as a digital signal with a frequency of 400 Hz whose high period is equal with the displacement (position) performed by resolver (motor) shaft.

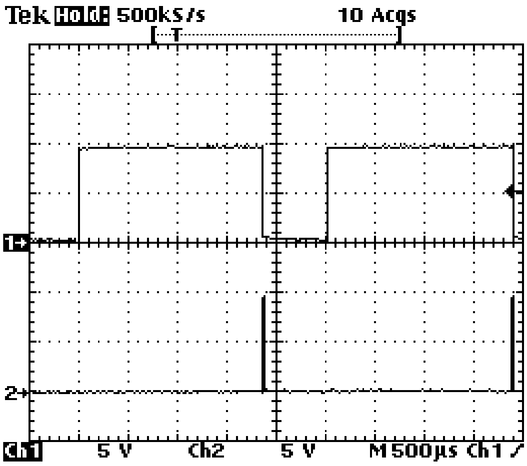

Fig. 17. Output (Ch. 1) and reset (Ch. 2, DΦ) signals for $\theta=270$ degrees.

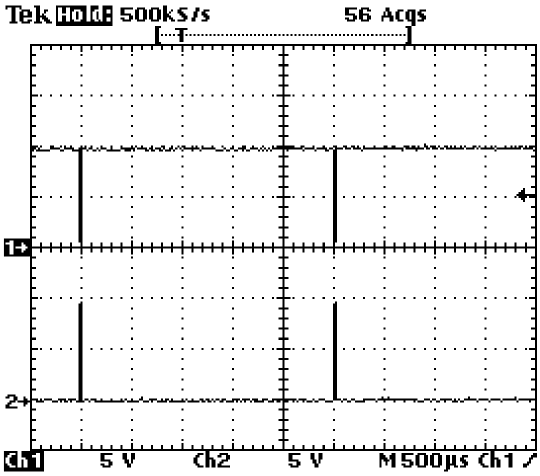

Fig. 18. Output (Ch. 1) and reset (Ch. 2, DΦ) signals for $\theta=360$ degrees.

BIBLIOGRAPHY

[1] **Măgureanu, R.**, *Maşini electrice speciale pentru sisteme automate*, Editura Tehnică, Bucureşti, 1980.

[2] **Simion, Al.**, *Maşini electrice speciale pentru automatizări*, Editura Universitas, Chişinău, 1993.

[3] **Diaconescu, M.P.**, **Rață, M.**, *Complemente de acționări electrice reglabile cu motoare asincrone*, Editură Venus, Iași, 2005.

[4] **Ciucudean, M., Tiponuț, V., Tănase, M.E., Bogdanov, I., Cârstea, H., Filip, A.**, *Circuite integrate liniare. Aplicații*, Editura Facla, Timișoara, 1986.

[5] **Băluță, Gh.**, *Circuite numerice. Aplicații*, Editura Matrix-Rom, București, 1999.

[6] **Băluță, Gh.**, *Acționări electrice de mică putere. Aplicații*, Editura Politehnium, Iasi, 2004.

[7] **Kester, W.**, *MT30: Resolver-to-Digital Converter*, Analog Devices, 2006.

[8] ******* AD2S1200 (ANALOG DEVICE), Data Manual, 2013.

About the authors

Prof. Eng. **Gheorghe BALUTA** , PhD.
”Gheorghe Asachi” Technical University from Iasi, Faculty of Electrical Engineering, Department of Energy Utilisation, Electrical Drives and Industrial Automation, 23 Prof.dr.docent Dimitrie Mangeron Street, Iasi, zip code 700050, Romania.
email: gbaluta@tuiasi.ro

Graduated from ”Gheorghe Asachi” Technical University of Iasi, Faculty of Electrical Engineering, study program – Electrical Drives. PhD. graduate from ”Gheorghe Asachi” Technical University of Iasi, Faculty of Electrical Engineering, Study program – Electrical Drives. He has been working at the Faculty of Electrical Engineering since 1986.

Eng. **Cristina DIACONESCU**, PhD Student.
”Gheorghe Asachi” Technical University from Iasi, Faculty of Electrical Engineering, Department of Energy Utilisation, Electrical Drives and Industrial Automation, 23 Prof.dr.docent Dimitrie Mangeron Street, Iasi, zip code 700050, Romania.
email: cdiaconescu@ee.tuiasi.ro

Graduated from ”Gheorghe Asachi” Technical University of Iasi, Faculty of Electrical Engineering, study program – Electrical Drives. After graduation she worked at Delphi Company in Iasi. PhD Student in Electrical Engineering.

Eng. **Gheorghe URSANU**, PhD Student.
”Gheorghe Asachi” Technical University from Iasi, Faculty of Electrical Engineering, Department of Energy Utilisation, Electrical Drives and Industrial Automation, 23 Prof.dr.docent Dimitrie Mangeron Street, Iasi, zip code 700050, Romania.
email: gursanu@ee.tuiasi.ro

Graduated from ”Gheorghe Asachi” Technical University of Iasi, Faculty of Electrical Engineering, study program – Electrical Drives. After graduation he worked at Rel Computer Company in Iasi. PhD Student in Electrical Engineering.