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Analytic Method for Determination of the Amplitude-Phase Transmission Errors between Selsyns

Gabriel GHIDUS, Alecsandru SIMION, Leonard LIVADARU, Sorin MIHAI
Gheorghe Asachi Technical University of Iasi
51-53, D. Mangeron Blvd. RO-700050 Iasi
gghidus@ee.tuiasi.ro, asimion@ee.tuiasi.ro, livadaru@ee.tuiasi.ro, mihai_sorin@ee.tuiasi.ro

***Abstract* — The paper presents an analytic method capable to evaluate the transmission errors between two synchros. The method is validated by experimental tests. The system created in this way allows the determination of small errors, like seconds in the transmission of the angular position between a transmitter selsyn and a receiver selsyn.**

***Index Terms* — analytic method, selsyn, transmission errors**

I. INTRODUCTION

In a simple transmission chain created by connecting a transmitting selsyn to a receiving selsyn, the visual determination of the transmission errors of the angular position between the two synchros is if not impossible at least inefficient (subjective). This is due to the fact that the indexes of the two synchros cannot show significant angular differences between transmitter and receiver, no matter how many trials we might make. The perception of the human eye, with the highest acuity, suggests that in all *n* cases the angles are equal. As such, it appears as a clear necessity, finding other methods to determine the errors in the transmission of the angular position between a transmitter and a receiver, with a more accurate precision.

II. STRUCTURE OF THE EXPERIMENTAL TEST BENCH

An electric drive system designed to solve this problem was created in the following configuration:

- a transmitting selsyn, type ND-404, connected to a receiving selsyn, type NS-404 (they have the stator windings interconnected and the rotor windings supplied with a single-phase alternating voltage of 110V / 50Hz);

- an angular position transducer resolver, type 21 RX-100-8-0,5 supplied with a cue voltage of 4-7V and a frequency of 7kHz (its rotor is attached rigidly through a swivel pin with the rotor of the receiving selsyn);

- an oscillator, type Escort EFG-3210, which provides a signal of sinusoidal shape of 4-7V and a frequency of 7kHz necessary for the supply of the resolver advance windings;

- an adjustable transformer, type METREL HSN 260/8, which provides the supply voltage for the rotor windings of the two selsyns with the value of 110V and the frequency of 50Hz;

- an oscilloscope Sefrom 5264 necessary for the observation of the wave forms on the two stator windings of the receiving selsyn, which are 90° shifted in space;

- a PC necessary for passing the wave forms from the oscilloscope display to a magnetic support, observation on the monitor, respectively printing them on paper for analysis.

The electrical diagram of the system created by interconnecting the mentioned devices is shown in Fig.1.

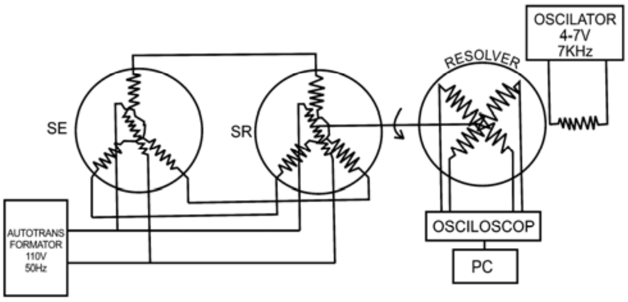

Figure 1. Test bench structure.

The problem of bringing the indicator needle of the transmitting selsyn at the same angular position, within successive attempts, has been resolved by placing a second resolver on the transmitting selsyn shaft. The voltages on its stator windings displayed on the oscilloscope, by comparison, confirm that within the respective attempts the same angle has been adopted. That resolver is not represented in the diagram of the experimental test bench since it only has a complementary role, as reference point, for checking the correctness of the position of the transmitting selsyn rotor.

III. THE OPERATION PRINCIPLE OF THE SYSTEM

Any angular movement of the rotor of the transmitting selsyn will be practically instantaneously reproduced to the rotor of the receiving selsyn. The revolution of the rotors of both synchros (transmitter and receiver) will determine the instantaneous revolution (they are connected on the same shaft) of the resolver rotors. The modification of the advance windings on the resolver rotor to the two windings staggered with 90° on this stator will determine on those windings the appearance of some electrical signals in proportion to the sine respectively cosine of the angle between them and the rotor winding. The two signals on the windings of the stator of resolver are displayed on the oscilloscope and from the oscilloscope sent to the PC in order to observe them on the monitor, pass them on magnetic support respectively printed on paper for analysis.

By setting the oscilloscope on the function "peak to peak voltage" and overlapping the sine curves of the two wave forms, at an „n" number of adopting a certain angular position of the rotor SE we can identify differences of millivolts between the wave forms generated by the resolver windings for the same angular position.

In this way, for example, at a number of 3 attempts for the same angle θ_E=300° on the channels 1 and 2 specific to the two types of waves generated by the resolver, there have been obtained the following values, determined by multiplying with 2, because the oscilloscope was disposed on the function "attenuation 1/10" and the differential probes on the function "attenuation 1/20":

The first trial:

θ_E=300°; U_{c1}=5,48V; U_{c2}=0,92V;

The second trial:

θ'_E=300°; U'_{c1}=5,44V; U'_{c2}=0,96V;

The third trial:

θ''_E=300°; U''_{c1}=5,52V; U''_{c2}=0,88V.

At an analysis of the 6 values, there are obvious differences between the size of the shifts made by the rotor of the resolver (and implicitly of the receiving selsyn rotor) in the three cases.

$U'_{c1}-U_{c1}$=5,44V-5,48V=-0,04V

$U_{c2}-U'_{c2}$=0,92V-0,96V=-0,04V

$U'_{c1}-U''_{c1}$=5,44V-5,52V=-0,08V

$U''_{c2}-U'_{c2}$=0,88V-0,96V=-0,08V

$U''_{c1}-U_{c1}$=5,52V-5,48V=0,04V

$U_{c2}-U''_{c2}$=0,92V-0,88V=0,04V

These differences represent for sure, transmission errors between synchros in each of the three cases, errors, whose perception was not possible with the help of the visual system.

In the purpose of obtaining a more complete analysis of the transmission errors determined through the method explained above we made 57 trials for the angles θ_E of the synchro transmitter 20° in20°, that is thrice the trigonometric arc, or 3x19 trials, for the same angles from 0° to 360° and we obtained characteristics for each of them in the form from image 2:

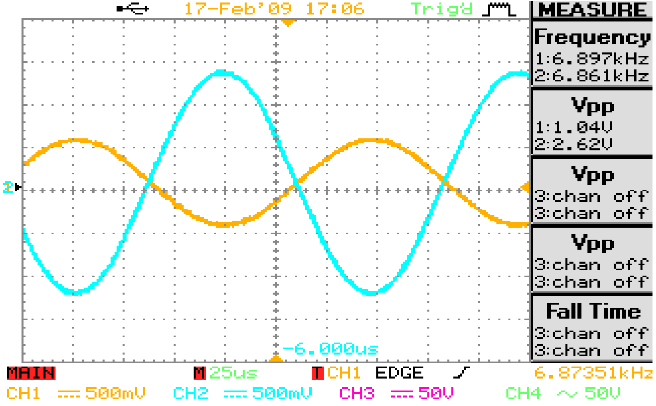

Figure 2. The characteristics corresponding to the angle θ_E=0°, on the first trial.

The values obtained for each of the three trials are comprised in the following tables:

TABLE I. THE FIRST TRIAL

Nr. crt.	θ_E[°]	U_{c1} [V]	U_{c2} [V]	f_1 [kHz]	f_2 [kHz]
1	0	2,08	5,24	6,897	6,861
2	20	0,20	5,52	6,897	6,897
3	40	1,84	5,20	6,873	6,861
4	60	3,52	4,32	6,849	6,867
5	80	5,08	3,04	6,944	6,978
6	100	5,48	1,08	6,878	6,791
7	120	5,52	1,00	6,861	6,885
8	140	4,96	2,80	6,838	6,849
9	160	3,72	4,20	6,873	6,897
10	180	1,92	5,20	6,873	6,885
11	200	0,20	5,48	6,865	6,865
12	220	1,92	5,16	6,928	6,865
13	240	3,64	4,24	6,826	6,873
14	260	4,76	2,84	6,897	6,897
15	280	5,44	1,12	6,859	6,849
16	300	5,48	0,92	6,881	6,944
17	320	4,84	2,76	6,847	6,897
18	340	3,72	4,20	6,873	6,865
19	360	2,00	5,20	6,865	6,867

TABLE II. THE SECOND TRIAL

Nr. crt.	θ'_E[°]	U'_{c1} [V]	U'_{c2} [V]	f'_1 [kHz]	f'_2 [kHz]
1	0	2,04	5,16	6,803	6,873
2	20	0,20	5,52	6,861	6,861
3	40	1,84	5,20	6,796	6,867
4	60	3,52	4,24	6,874	6,814
5	80	4,76	2,84	6,868	6,897
6	100	5,48	1,08	6,865	6,787
7	120	5,52	0,96	6,851	6,849
8	140	4,84	2,80	6,861	6,885
9	160	3,68	4,20	6,861	6,867
10	180	2,04	5,20	6,826	6,861
11	200	0,28	5,52	6,838	6,838
12	220	1,96	5,32	6,854	6,920
13	240	3,56	4,28	6,840	6,862
14	260	4,76	2,84	6,891	6,803
15	280	5,44	1,12	6,849	6,768
16	300	5,44	0,96	6,853	6,854
17	320	4,84	2,80	6,849	6,873
18	340	3,64	4,16	6,810	6,849
19	360	2,08	5,16	6,803	6,849

TABLE III. THE THIRD TRIAL

Nr. crt.	θ''_E[°]	U''_{c1} [V]	U''_{c2} [V]	f''_1 [kHz]	f''_2 [kHz]
1	0	2,00	5,12	6,849	6,865
2	20	0,24	5,48	6,873	6,873
3	40	1,80	5,20	6,810	6,849
4	60	3,48	4,28	6,817	6,893
5	80	4,76	2,92	6,897	6,849
6	100	5,40	1,16	6,861	6,932
7	120	5,48	0,92	6,889	6,772
8	140	4,76	2,76	6,870	6,930
9	160	3,68	4,24	6,867	6,849
10	180	1,96	5,16	6,860	6,873
11	200	0,24	5,48	6,849	6,849
12	220	1,88	5,16	6,932	6,826
13	240	3,56	4,24	6,787	6,849
14	260	4,76	2,88	6,809	6,887
15	280	5,40	1,12	6,849	6,865
16	300	5,52	0,88	6,844	6,897
17	320	4,88	2,72	6,873	6,906
18	340	3,68	4,16	6,881	6,849
19	360	2,12	5,40	6,897	6,903

The comparative data for each of the three trials are comprised in the following tables:

TABLE IV. THE FIRST TRIAL

Nr. crt.	θ_E [°]	$\lvert U_{c1}-U'_{c1}\rvert$ [V]	$\lvert U_{c2}-U'_{c2}\rvert$ [V]	$\frac{\lvert U_{c1}-U'_{c1}\rvert+\lvert U_{c2}-U'_{c2}\rvert}{2}$ [V]
1	0	0,04	0,08	0,06
2	20	0	0	0
3	40	0	0	0
4	60	0	0,08	0,04
5	80	0,32	0,20	0,26
6	100	0	0	0
7	120	0	0,04	0,02
8	140	0,12	0	0,06
9	160	0,04	0	0,02
10	180	0,12	0	0,06
11	200	0,08	0,04	0,06
12	220	0,04	0,16	0,10
13	240	0,08	0,04	0,06
14	260	0	0	0
15	280	0	0	0
16	300	0,04	0,04	0,04
17	320	0	0,04	0,02
18	340	0,08	0,04	0,06
19	360	0,08	0,04	0,06

TABLE V. THE SECOND TRIAL

Nr. crt.	θ_E [°]	$\lvert U'_{c1}-U''_{c1}\rvert$ [V]	$\lvert U'_{c2}-U''_{c2}\rvert$ [V]	$\frac{\lvert U'_{c1}-U''_{c1}\rvert+\lvert U'_{c2}-U''_{c2}\rvert}{2}$ [V]
1	0	0,04	0,04	0,04
2	20	0,04	0,04	0,04
3	40	0,04	0	0,02
4	60	0,04	0,04	0,04
5	80	0	0,08	0,04
6	100	0,08	0,08	0,08
7	120	0,04	0,04	0,04
8	140	0,08	0,04	0,06
9	160	0	0,04	0,02
10	180	0,08	0,04	0,06
11	200	0,04	0,04	0,04
12	220	0,08	0,16	0,12
13	240	0	0,04	0,02
14	260	0	0,04	0,02
15	280	0,04	0	0,02
16	300	0,08	0,08	0,08
17	320	0,04	0,08	0,06
18	340	0,04	0	0,02
19	360	0,04	0,24	0,14

TABLE VI. THE THIRD TRIAL

Nr. crt.	θ_E [°]	$\lvert U_{c1}-U''_{c1}\rvert$ [V]	$\lvert U_{c2}-U''_{c2}\rvert$ [V]	$\frac{\lvert U_{c1}-U''_{c1}\rvert+\lvert U_{c2}-U''_{c2}\rvert}{2}$ [V]
1	0	0,08	0,12	0,10
2	20	0,04	0,04	0,04
3	40	0,04	0	0,02
4	60	0,04	0,04	0,04
5	80	0,32	0,12	0,22
6	100	0,08	0,08	0,08
7	120	0,04	0,08	0,06
8	140	0,20	0,04	0,12
9	160	0,04	0,04	0,04
10	180	0,04	0,04	0,04
11	200	0,04	0	0,02
12	220	0,04	0	0,02
13	240	0,08	0	0,04
14	260	0	0,04	0,02
15	280	0,04	0	0,02
16	300	0,04	0,04	0,04
17	320	0,04	0,04	0,04
18	340	0,04	0,04	0,04
19	360	0,12	0,20	0,16

At an analyze of the medium arithmetical values of the voltage differences between the same channels, at the same angular position but on successive attempts, one can observe that the maximum gap in the evolution of these differences is of 0,26 V (first attempt, no.5, θ_E =80°).

This gap of 0,26V represents the transmission error between the two synchros, a significantly small error reported to the electrical dimension of 0,26V.

For the quantification of these transmission errors expressed in mV, or more precisely for the conversion from mV to degrees, we identified the following method.

It is taken as example the results obtained at the first attempt, no. 10, θ_E =180°, where U_{c1} =1,92V and U_{c2} =5,2V. Since

$$U_{\max}\sin(\theta_E+x)=U_{c1} \qquad (1)$$

and

$$U_{\max}\cos(\theta_E+y)=U_{c2} \qquad (2)$$

for these values of U_{c1} and U_{c2} we can write the equations :

$$U_{\max}\sin(180°+x)=1{,}92 \qquad (3)$$

şi

$$U_{\max}\cos(180°+y)=5{,}2 \qquad (4)$$

where x and y are the initial positioning angles of the synchro and implicitly of the resolver.

By summating these equation squares we will obtain the following expression:

$$U_{\max}^2=3{,}68+27{,}04=30{,}72 \qquad (5)$$

The value of $U_{\max}$ results from (6):

$$U_{\max}=\sqrt{U_{c1}^2+U_{c2}^2}=5{,}54V \qquad (6)$$

Introducing the value of $U_{\max}$ successively in the relations (1) and respectively (2), we obtain:

$$\sin(\theta_E^{\circ}+x)=\frac{U_{c1}}{U_{\max}}=0{,}346 \qquad (7)$$

and

$$\cos(\theta_E^{\circ}+y)=\frac{U_{c2}}{U_{\max}}=0{,}938 \qquad (8)$$

By calculating the synchro (resolver) positioning angle for every winding in the case of the angle θ_E mentioned previously, we obtain the following values:

$$x=\arcsin\frac{U_{c1}}{U_{\max}}-\theta_E=159{,}75° \qquad (9)$$

$$y=\arccos\frac{U_{c2}}{U_{\max}}-\theta_E=159{,}71° \qquad (10)$$

The average of the two values specific for every winding will be:

$$e_{med}=\frac{159{,}75°+159{,}71°}{2}=159{,}73° \qquad (11)$$

In a similar manner we calculate the e_{med} values for the other values of the θ_E ° angle.

The data obtained according to the calculation algorithm described above are presented in the tables 7-9.

In order to establish the scales in which the angles calculated according to the mentioned algorithm and therefore their signs enter into, we created a graphic representation of the evolution of the determined electrical sizes (U_{c1} and U_{c2}) and implicitly of the signs associated to their absolute sizes, determined by the vibration frequency meter:

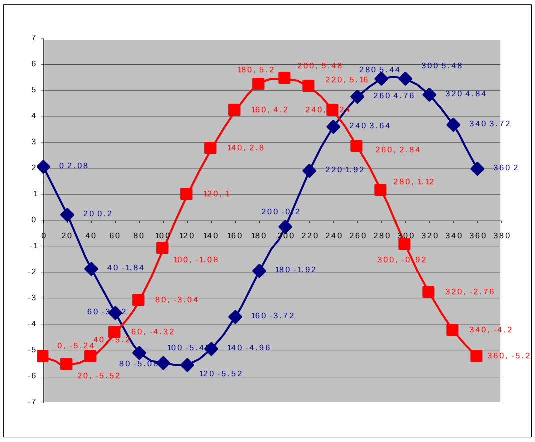

Figure 3. Graphic representation of the voltages' evolution on the windings of the resolver: blue-U_{c1} , red-U_{c2} .

TABLE VII.

Nr. crt.	θ_E [°]	U_{c1} [V]	U_{c2} [V]	$U_{\max}=\sqrt{U_{c1}^2+U_{c2}^2}$ [V]
1	0	2,08	-5,24	5,63
2	20	0,20	-5,52	5,524
3	40	-1,84	-5,20	5,51
4	60	-3,52	-4,32	5,57
5	80	-5,08	-3,04	5,92
6	100	-5,48	-1,08	5,58
7	120	-5,52	1,00	5,60
8	140	-4,96	2,80	5,69
9	160	-3,72	4,20	5,61
10	180	-1,92	5,20	5,54
11	200	-0,20	5,48	5,484
12	220	1,92	5,16	5,50
13	240	3,64	4,24	5,58
14	260	4,76	2,84	5,54
15	280	5,44	1,12	5,55
16	300	5,48	-0,92	5,55
17	320	4,84	-2,76	5,57
18	340	3,72	-4,20	5,61
19	360	2,00	-5,20	5,57

TABLE VIII.

Nr. crt.	θ_E [°]	$\sin(\theta_E^{\circ}+x)=\frac{U_{c1}}{U_{\max}}[rad]$	$x=\arcsin\frac{U_{c1}}{U_{\max}}-\theta_E[°]$
1	0	0,369	158,34
2	20	0,036	157,93
3	40	-0,333	159,45
4	60	-0,631	159,12
5	80	-0,858	159,09
6	100	-0,982	159,11
7	120	-0,985	159,93
8	140	-0,871	159,42
9	160	-0,663	158,47
10	180	-0,346	159,75
11	200	-0,036	157,93
12	220	0,349	160,42
13	240	0,652	160,69
14	260	0,859	159,20
15	280	0,980	158,52
16	300	0,987	159,24
17	320	0,868	159,77
18	340	0,663	158,47
19	360	0,359	158,96

TABLE IX

θ_E [°]	$\cos(\theta_E^{\circ}+y)=\frac{U_{c2}}{U_{\max}}[rad]$	$y=\arccos\frac{U_{c2}}{U_{\max}}-\theta_E[°]$	emed [°]
0	-0,930	158,43	158,38
20	-0,999	157,43	157,68
40	-0,943	159,43	159,44
60	-0,775	159,19	159,15
80	-0,513	159,13	159,11
100	-0,193	158,87	158,99
120	0,178	160,25	160,09
140	0,492	159,47	159,44
160	0,748	158,41	158,44
180	0,938	159,71	159,73
200	0,999	157,43	157,68
220	0,938	160,28	160,35
240	0,759	160,62	160,65
260	0,512	159,92	159,56
280	0,201	158,40	158,46
300	-0,165	159,49	159,36
320	-0,495	159,66	159,71
340	-0,748	158,41	158,44
360	-0,933	158,90	158,93

At an expectation of the results thus obtained, we may easily observe the fact that an evaluation of the transmission errors between the synchros is not relevant if we judge in general the values obtained experimentally for the stipulated angles, the differences between them being rather big (from 157,68° to 160,65°, that is 2,97°). But comparing the values obtained for two-three consecutive angles, we may notice a very small difference between the sizes thus obtained: between the angle θ_E=60° and the angle θ_E=80° for example, the positioning difference is 159,15°-159,11°=0,04°, that is in the line of seconds. This may be explained by the fact that at a full rotation of the synchros that pass through the 19 positions taken into consideration, the errors cumulate, and the mathematical calculus sums up the differences that are apparently transmission errors, but in reality they are mathematical calculus errors. But judging by comparison two consecutive angles, the transmission error between them appears as true.

IV. CONCLUSIONS

By reading the values on the vibration frequency meter set on the function "peak to peak voltage" we determined in fact a double amplitude of the voltages oscillations on the resolver windings.

As a consequence the errors determined through the algorithm described above, actually will be equal to half of the values previously determined. Thus the variation deviation of the transmission errors will be 1,48°, and the minimal error determined between two consecutive angles θ_E will be 0,02°.

The mathematic aspect has a very important part in this method of determining the errors. For certain values of the angle θ_E (θ_E=20° and θ_E=200°), the third decimal fraction of the value U_{max} had a very important part in the mathematical calculus, by giving meaning to the trigonometric functions used in the calculation algorithm.

In the method for determining the transmission errors exemplified above, we have presented the results obtained during a single 360° rotation of the synchros, the rather conclusive results thus obtained did not require supplementary rotations. But in the elaboration of a statistical study of these transmission errors, conducting a higher number of 360° rotations of the synchros would reveal more accurately the transmission errors thus determined. These very small errors denote a framing of the synchros in a good precision class.

One cannot neglect some aspects that can doubt the truthfulness of the obtained data. For example the frequency of the sinus signal generated by the oscillator is not perfectly constant, which can be observed from the values f_1, f_2, f'_1, f'_2, f''_1 f''_2 within the tables. This can generate errors that we could consider transmission errors, but in reality they are not. As well the oscilloscope capacity to faithfully present the parameters of wave forms generated by the resolver is controversial.

Still the system created in this way allows the determination of small errors, like seconds, as it has been already demonstrated.

The system can be improved through direct connection with a data acquisition system, its processing being made automatically. This alternative but without data acquisition, has been conceived to identify a methodology to determine the errors from the analogical and not digital point of view.

It would be relevant to determine the parameters generated by the created system not only in static regime but also in the dynamic one; these new conditions may become the topic for new research.

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