Considerations on the Behavior of Selsyns for the Synchronous Transmission of the Movement, within the Kinematic Chain

Gabriel GHIDUS, Alecsandru SIMION, Leonard LIVADARU, Sorin MIHAI
"Gheorghe Asachi" Technical University of Iasi
Bd. D. Mangeron, No. 51-53, 700050 Iasi, ROMANIA
gghidus@ee.tuiasi.ro, asimion@ee.tuiasi.ro

Abstract—**The paper presents an experimental analysis concerning the possibility of minimizing the transmission errors in kinematic chains that include selsyns (synchros).**

Index Terms—**synchro, angular position, transmission errors**

I. INTRODUCTION

In a simple transmission chain created by connecting a synchro transmitter to a synchro receiver the visual determination of the errors in the transmission of the angular position between the two units, 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 have. 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 TEST BENCH

A system of electric drive designed to solve this problem was created from a constructional point of view in the following configuration:

- a synchro transmitter type ND-404 connected to a synchro receiver type NS-404 (they have the stator windings connected among them and the rotor windings supplied with a single phase alternating voltage of 110V / 50Hz);
- an angular position transducer (resolver of type 21 RX-100-8-0,5) supplied with a cue voltage of 4-7V and a frequency of 7kHz (its rotor being attached rigidly through a swivel pin with the rotor of the synchro transmitter).
- a second similar resolver with the rotor connected to the synchro receiver).
- 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 of the synchros rotor windings with the value of 110V and the frequency of 50Hz.
- an oscilloscope Tektronix TDS 2024 B with 4 spots necessary for the observation of the wave forms on the two stator windings staggered with 90° of each of the two resolvers placed on the synchros.
- a PC necessary for passing the wave forms from the oscilloscopes display on 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:

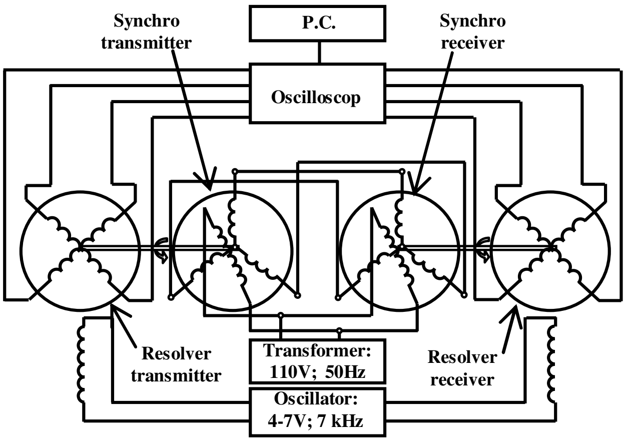

Fig. 1 Electric diagram of the test bench

III. OPERATION PRINCIPLE OF THE SYSTEM

The principle of operation is the following. Any transmission to the rotor of the synchro transmitter of a certain angular position determines a similar and practically instantaneous rotation of the rotor of the synchro receiver. The revolution of the rotors of both synchros (transmitter and receiver) will determine the instantaneous revolution (being connected to corresponding shafts) of the resolvers rotors. The modification of the advance windings on the resolvers rotors to the two windings staggered with 90° on their stators 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 rotors windings. The two signals on the windings of the stator of each resolver are observed 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 „knife shaped voltage" and overlapping the sine curves of the two wave forms for each resolver, at an „n" number of adopting a certain angular position of the rotor ST we can identify differences of millivolts between the wave forms generated by the resolver windings for the same angular position. Thus, for example, at a number of 2 trials for the same angle $\theta_E=20°$ on channels 1 and 2 specific for the two wave forms generated by the resolver of the synchro transmitter, and on channels 3 and 4 specific for the two wave forms generated by the resolver of the synchro receiver, one obtained the values:

The first trial:

$\theta_E=20°$; $U_{c1}=6{,}24V$; $U_{c2}=480mV$;
$U_{c3}=5{,}76V$; $U_{c4}=2{,}56V$;

The second trial:

$\theta'_E=20°$; $U'_{c1}=6{,}24V$; $U'_{c2}=560mV$;
$U'_{c3}=5{,}84V$; $U'_{c4}=2{,}48V$;

The analysis of the 8 values, put in view obvious differences between the size of the shifts made by the rotors of the two synchro-resolvers (and implicitly of the synchro rotors) in the three cases.

It must be analyzed the differences between the values of the voltages on channels C_1 and C_3 respectively C_2 and C_4 (ex. $U_{c1}-U_{c3}$, $U'_{c1}-U'_{c3}$, $U''_{c1}-U''_{c3}$) in successive trials and not the differences between the values of the voltages of the same channel in successive trials (ex. $U'_{c1}-U_{c1}$, $U''_{c1}-U'_{c1}$, $U'_{c1}-U''_{c1}$, or $U'_{c3}-U_{c3}$, $U''_{c3}-U'_{c3}$, $U'_{c3}-U''_{c3}$) in order to avoid the disadvantages related to the manual positioning of the synchro indexes, and thus the determination of some transmission errors belonging to manual positioning and not to the electric machines in discussion. Practically, the evolution of the voltage differences between the corresponding channels 1-3 and 2-4, to different values of the angle θ_E can be observed. The differences between the size of the shifts made by the rotors of the two synchro-resolvers (and implicitly of the synchro-resolvers) in the two cases are:

$|U_{c1}-U_{c3}|=|6{,}24V-5{,}76V|=0{,}48V$;
$|U_{c2}-U_{c4}|=|480mV-2{,}56V|=2{,}08V$;
$|U'_{c1}-U'_{c3}|=|6{,}24V-5{,}84V|=0{,}4V$;
$|U'_{c2}-U'_{c4}|=|560mV-2{,}48V|=1{,}92V$;

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 order to obtain a more complete analysis of the transmission errors determined through the method explained above, 38 trials for the angles θ_E of the synchro transmitter were performed (each 20°, that is twice the trigonometric arc, or 2x19 trials, for the same angles from 0° to 360°). The obtained characteristics for each of them in Fig. 2 are presented:

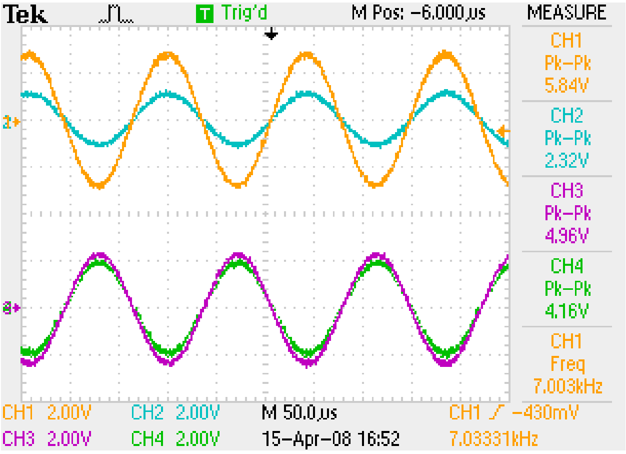

Fig. 2 The characteristics corresponding to the angle $\theta_E=0°$, on the first trial

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

TABLE I. THE FIRST TRIAL

Nr. crt.	**θ_E [°]**	**U_{c1} [V]**	**U_{c2} [V]**	**U_{c3} [V]**	**U_{c4} [V]**
1	0	5,84	2,32	4,96	4,16
2	20	6,24	0,480	5,76	2,56
3	40	5,92	2,24	6,08	0,480
4	60	4,96	4,08	5,68	2,56
5	80	3,52	5,36	4,48	4,32
6	100	1,60	6,08	2,96	5,60
7	120	1,12	6,08	1,12	6,24
8	140	3,04	5,60	1,44	6,32
9	160	4,72	4,40	3,12	5,76
10	180	5,76	2,72	4,56	4,48
11	200	6,24	0,720	5,60	2,80
12	220	6,00	2,00	6,00	0,640
13	240	4,96	3,84	5,60	2,32
14	260	3,44	5,20	4,48	4,24
15	280	1,60	6,00	2,72	5,68
16	300	1,28	6,08	0,800	6,24
17	320	3,20	5,44	1,76	6,24
18	340	4,80	4,08	3,52	5,44
19	360	5,84	2,40	4,96	4,08

TABLE II. THE SECOND TRIAL

Nr. crt.	**θ_E [°]**	**U_{c1} [V]**	**U_{c2} [V]**	**U_{c3} [V]**	**U_{c4} [V]**
1	0	5,92	2,40	4,96	4,16
2	20	6,24	0,560	5,84	2,48
3	40	5,92	2,24	6,16	0,480
4	60	4,96	4,00	5,68	2,56
5	80	3,52	5,36	4,64	4,32
6	100	1,60	6,16	3,04	5,60
7	120	1,12	6,08	1,12	6,32
8	140	2,96	5,60	1,36	6,40
9	160	4,72	4,40	3,12	5,76
10	180	5,76	2,64	4,64	4,48
11	200	6,24	0,800	5,68	2,80
12	220	5,92	1,92	6,08	0,640
13	240	5,04	3,76	5,60	2,32
14	260	3,36	5,20	4,48	4,24
15	280	1,52	6,00	2,72	5,60
16	300	1,28	6,08	0,800	6,24
17	320	3,28	5,44	1,68	6,08
18	340	4,88	4,16	3,52	5,44
19	360	5,84	2,40	4,96	4,24

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

TABLE III. THE FIRST TRIAL

Nr. crt.	θ_E [°]	U_{c1}-U_{c3}[V]	U_{c2}-U_{c4}[V]
1	0	0,88	-1,84
2	20	0,48	-2,08
3	40	-0,16	1,76
4	60	-0,72	1,52
5	80	-0,96	1,04
6	100	-1,36	0,48
7	120	0	-0,16
8	140	1,6	-0,72
9	160	1,6	-1,36
10	180	1,2	-1,76
11	200	0,64	-2,08
12	220	0	1,36
13	240	-0,64	1,52
14	***260***	***-1,04***	***0,96***
15	280	-1,12	0,32
16	300	0,48	-0,16
17	320	1,44	-0,8
18	340	1,28	-1,36
19	360	0,88	-1,68

TABLE IV. THE SECOND TRIAL

Nr. crt.	θ_E [°]	U_{c1}-U_{c3}[V]	U_{c2}-U_{c4}[V]
1	0	0,96	-1,76
2	20	0,4	-1,92
3	40	-0,24	1,76
4	60	-0,72	1,44
5	80	-1,12	1,04
6	100	-1,44	0,56
7	120	0	-0,24
8	140	1,6	-0,8
9	160	1,6	-1,36
10	180	1,12	-1,84
11	200	0,56	-2
12	220	-0,16	1,28
13	240	-0,56	1,44
14	***260***	***-1,12***	***0,96***
15	280	-1,2	0,4
16	300	0,48	-0,16
17	320	1,6	-0,64
18	340	1,36	-1,28
19	360	0,88	-1,84

At an analysis of the differences between the values of the voltages on the corresponding channels C_1-C_3 respectively C_2-C_4 to the 2x19 successive trials, one observe that the maximum deviation in which the evolution of these differences fits is of 240mV, that is the minimum value of -1,12 V from the second trial, the current number 14 (θ_E=260°) and the maximum value of -1,04 V from the first trial, current number 14 (θ_E =260°), for channels 1-3.

These minimum and maximum values, specific for every size of angle θ_E, as well as the differences between them, are revealed by the following tables:

TABLE V. CORRESPONDING CHANNELS C_1-C_3

Nr. crt.	θ_E [°]	Min. value (U_{c1}-U_{c3})[V]	Max. value (U_{c1}-U_{c3})[V]	(Max. value - Min. value)[V]
1	0	0,88	0,96	0,08
2	20	0,4	0,48	0,08
3	40	-0,24	-0,16	0,08
4	60	-0,72	-0,72	0
5	80	-1,12	-0,96	0,16
6	100	-1,44	-1,36	0,08
7	120	0	0	0
8	140	1,6	1,6	0
9	160	1,6	1,6	0
10	180	1,12	1,2	0,08
11	200	0,56	0,64	0,08
12	220	-0,16	0	0,16
13	240	-0,64	-0,56	0,08
14	***260***	***-1,12***	***-1,04***	***0,24***
15	280	-1,2	-1,12	0,08
16	300	0,48	0,48	0
17	320	1,44	1,6	0,16
18	340	1,28	1,36	0,08
19	360	0,88	0,88	0

TABLE VI. CORRESPONDING CHANNELS C_2-C_4

Nr. crt.	θ_E [°]	Min. value (U_{c2}-U_{c4})[V]	Max. value (U_{c2}-U_{c4})[V]	(Max. value - Min. value)[V]
1	0	-1,84	-1,76	0,08
2	20	-2,08	-1,92	0,16
3	40	1,76	1,76	0
4	60	1,44	1,52	0,08
5	80	1,04	1,04	0
6	100	0,48	0,56	0,08
7	120	-0,24	-0,16	0,08
8	140	-0,8	-0,72	0,08
9	160	-1,36	-1,36	0
10	180	-1,84	-1,76	0,08
11	200	-2,08	-2	0,08
12	220	1,28	1,36	0,08
13	240	1,44	1,52	0,08
14	260	0,96	0,96	0
15	280	0,32	0,4	0,08
16	300	-0,16	-0,16	0
17	320	-0,8	-0,64	0,16
18	340	-1,36	-1,28	0,08
19	360	-1,84	-1,68	0,16

This deviation of 240 mV represents the transmission error, between the two synchros, a rather small error in relation to the electric size represented by the 240mV.

For the quantification of these transmission errors expressed in mV, or more precise for the conversion from mV in degrees, one identified the following method. We use, as example, the results obtained on the first trial current number 1, θ_E =0°, where U_{c1}=5,84V and U_{c2}=2,32mV. The ratio of the maximum backing-off voltages on the two windings is:

$$tg(\alpha_{01} + 0°) = U_{c1} / U_{c2} = 5,84 / 2,32 = 2,51$$

where α_0 is the initial deviation angle between the position of the synchro transmitter's index and the advance winding's position on the resolver rotor. One determines then the total angle α_0 +0°, that is the initial deviation angle between the position of the synchro indicator's index and the position of the advance winding on the resolver rotor, plus the angle of 0° transmitted to the synchro rotor.

$$\alpha_{01} + 0° = \text{arc tg } 2,51 = 68,33°$$

The initial deviation angle α_0 will thus be

$$\alpha_{01} = 68{,}33° - 0° = 68{,}33°$$

In a similar manner one calculates the initial deviation angle between the position of the synchro index and the position of the advance winding on the resolver rotor for all the positions of the index, in the case of the synchro transmitter and in the case of the synchro receiver with the adequate resolver.

The determined results are comprised in the following tables:

TABLE VII. CALCULATION OF α_{01} ON THE FIRST TRIAL

θ_E [°]	**$\alpha_{01}+\theta_E$ [°]**	**U_{c1} [V]**	**U_{c2} [V]**	**U_{c1}/U_{c2}**	**arctg (U_{c1}/U_{c2}) [°]**	**α_{01} = arctg(U_{c1}/U_{c2})- θ_E[°]**
0	$\alpha_{01}+0$	5,84	2,32	2,517	68,33	68,33
20	$\alpha_{01}+20$	6,24	0,48	13	85,60	65,60
40	$\alpha_{01}+40$	5,92	2,24	-2,642	110,73	70,73
60	$\alpha_{01}+60$	4,96	4,08	-1,215	129,45	69,45
80	$\alpha_{01}+80$	3,52	5,36	-0,656	146,73	66,73
100	$\alpha_{01}+100$	1,60	6,08	-0,263	165,26	65,26
120	$\alpha_{01}+120$	1,12	6,08	0,184	190,42	70,42
140	$\alpha_{01}+140$	3,04	5,60	0,542	208,45	68,45
160	$\alpha_{01}+160$	4,72	4,40	1,072	226,99	66,99
180	$\alpha_{01}+180$	5,76	2,72	2,117	244,71	64,71
200	$\alpha_{01}+200$	6,24	0,72	8,666	263,41	63,41
220	$\alpha_{01}+220$	6,00	2,00	-3	288,43	68,43
240	$\alpha_{01}+240$	4,96	3,84	-1,291	307,76	67,76
260	$\alpha_{01}+260$	3,44	5,20	-0,661	326,53	66,53
280	$\alpha_{01}+280$	1,60	6,00	-0,266	345,10	65,1
300	$\alpha_{01}+300$	1,28	6,08	0,21	371,85	71,85
320	$\alpha_{01}+320$	3,20	5,44	0,588	390,45	70,45
340	$\alpha_{01}+340$	4,80	4,08	1,176	409,62	69,62
360	$\alpha_{01}+360$	5,84	2,40	2,433	427,65	67,65

TABLE VIII. CALCULATION OF β_{01} ON THE FIRST TRIAL

θ_E [°]	**$\beta_{01}+\theta_E$ [°]**	**U_{c3} [V]**	**U_{c4} [V]**	**U_{c3}/U_{c4}**	**arctg (U_{c3}/U_{c4}) [°]**	**β_{01}=arctg (U_{c3}/U_{c4})- -θ_E [°]**
0	$\beta_{01}+0$	4,96	4,16	1,192	50	50
20	$\beta_{01}+20$	5,76	2,56	2,25	66,03	46,03
40	$\beta_{01}+40$	6,08	0,48	12,666	85,48	45,48
60	$\beta_{01}+60$	5,68	2,56	-2,218	114,26	54,26
80	$\beta_{01}+80$	4,48	4,32	-1,037	133,95	53,95
100	$\beta_{01}+100$	2,96	5,60	-0,528	152,16	52,16
120	$\beta_{01}+120$	1,12	6,24	-0,179	169,85	49,85
140	$\beta_{01}+140$	1,44	6,32	0,227	192,78	52,78
160	$\beta_{01}+160$	3,12	5,76	0,541	208,41	48,41
180	$\beta_{01}+180$	4,56	4,48	1,017	225,48	45,48
200	$\beta_{01}+200$	5,60	2,80	2	243,43	43,43
220	$\beta_{01}+220$	6,00	0,64	9,375	263,91	43,91
240	$\beta_{01}+240$	5,60	2,32	-2,413	292,51	52,51
260	$\beta_{01}+260$	4,48	4,24	-1,056	313,43	53,43
280	$\beta_{01}+280$	2,72	5,68	-0,478	334,45	54,45
300	$\beta_{01}+300$	0,80	6,24	-0,128	352,70	52,70
320	$\beta_{01}+320$	1,76	6,24	0,282	375,74	55,74
340	$\beta_{01}+340$	3,52	5,44	0,647	392,90	52,90
360	$\beta_{01}+360$	4,96	4,08	1,215	410,54	50,54

Afterwards one calculates the difference between the initial deviation angles between the two resolvers, difference which is written as $\theta_E = \alpha_{01} - \beta_{01}$:

TABLE IX. CALCULATION OF θ_{E1} ON THE FIRST TRIAL

θ_E [°]	**$\theta_E = \alpha_{01} - \beta_{01}$[°]**
0	18,33
20	19,57
40	25,25
60	15,19
80	12,78
100	13,1
120	20,57
140	15,67
160	18,58
180	19,23
200	19,98
220	24,52
240	15,25
260	13,1
280	10,65
300	19,15
320	14,71
340	16,72
360	17,11

In a similar manner the calculus for the second trial has been performed and the following values were obtained:

TABLE X. CALCULATION OF α_{02} ON THE SECOND TRIAL

θ_E [°]	**$\alpha_{02}+\theta_E$ [°]**	**U_{c1} [V]**	**U_{c2} [V]**	**U_{c1}/U_{c2}**	**arctg (U_{c1}/U_{c2}) [°]**	**α_2 = arctg(U_{c1}/U_{c2})- θ_E[°]**
0	$\alpha_{02}+0$	5,92	2,40	2,466	67,92	67,92
20	$\alpha_{02}+20$	6,24	0,56	1,142	84,871	64,87
40	$\alpha_{02}+40$	5,92	2,24	-2,642	110,73	70,73
60	$\alpha_{02}+60$	4,96	4	-1,24	128,88	68,88
80	$\alpha_{02}+80$	3,52	5,36	-0,656	146,73	66,73
100	$\alpha_{02}+100$	1,60	6,16	-0,259	165,47	65,47
120	$\alpha_{02}+120$	1,12	6,08	0,184	190,42	70,42
140	$\alpha_{02}+140$	2,96	5,60	0,528	207,83	67,83
160	$\alpha_{02}+160$	4,72	4,40	1,072	226,99	66,99
180	$\alpha_{02}+180$	5,76	2,64	2,181	245,39	65,39
200	$\alpha_{02}+200$	6,24	0,80	7,8	262,69	62,69
220	$\alpha_{02}+220$	5,92	1,92	-3,08	287,98	67,98
240	$\alpha_{02}+240$	5,04	3,76	-1,34	306,73	66,73
260	$\alpha_{02}+260$	3,36	5,20	-0,646	327,13	67,13
280	$\alpha_{02}+280$	1,52	6	-0,253	345,80	65,80
300	$\alpha_{02}+300$	1,28	6,08	0,210	371,85	71,85
320	$\alpha_{02}+320$	3,28	5,44	0,602	391,04	71,04
340	$\alpha_{02}+340$	4,88	4,16	1,173	409,55	69,55
360	$\alpha_{02}+360$	5,84	2,40	2,433	427,65	67,65

TABLE XI. CALCULATION OF β_{02} ON THE SECOND TRIAL

θ_E [°]	**$\beta_{02}+\theta_E$ [°]**	**U_{c3} [V]**	**U_{c4} [V]**	**U_{c3}/U_{c4}**	**arctg (U_{c3}/U_{c4}) [°]**	**β_{02}=arctg (U_{c3}/U_{c4})- -θ_E [°]**
0	$\beta_{02}+0$	4,96	4,16	1,192	50,01	50,01
20	$\beta_{02}+20$	5,84	2,48	2,354	66,99	46,99
40	$\beta_{02}+40$	6,16	0,48	12,833	85,54	45,54
60	$\beta_{02}+60$	5,68	2,56	-2,218	114,26	54,26
80	$\beta_{02}+80$	4,64	4,32	-1,074	132,95	52,95
100	$\beta_{02}+100$	3,04	5,60	-0,542	151,50	51,50
120	$\beta_{02}+120$	1,12	6,32	-0,177	169,95	49,95
140	$\beta_{02}+140$	1,36	6,40	0,212	191,99	51,99
160	$\beta_{02}+160$	3,12	5,76	0,541	208,44	48,44
180	$\beta_{02}+180$	4,64	4,48	1,035	226	46
200	$\beta_{02}+200$	5,68	2,80	2,028	243,75	43,75
220	$\beta_{02}+220$	6,08	0,64	9,5	263,99	43,99
240	$\beta_{02}+240$	5,60	2,32	-2,413	292,50	52,50
260	$\beta_{02}+260$	4,48	4,24	-1,056	313,42	53,42
280	$\beta_{02}+280$	2,72	5,60	-0,485	334,09	54,09
300	$\beta_{02}+300$	0,80	6,24	-0,128	352,69	52,69
320	$\beta_{02}+320$	1,68	6,08	0,276	375,44	55,44
340	$\beta_{02}+340$	3,52	5,44	0,647	392,90	52,90
360	$\beta_{02}+360$	4,96	4,24	1,169	409,47	49,47

Afterwards one calculates the difference between the initial deviation angles between the two resolvers difference which is written as $\theta_{E2} = \alpha_{02} - \beta_{02}$:

TABLE XII. CALCULATION OF θ_{E2} ON THE SECOND TRIAL

θ_E [°]	$\theta_{E2} = \alpha_{02} - \beta_{02}$[°]
0	17,91
20	17,88
40	25,19
60	14,62
80	13,78
100	13,97
120	20,47
140	15,84
160	18,55
180	19,39
200	18,94
220	23,99
240	14,23
260	13,71
280	11,71
300	19,16
320	15,6
340	16,65
360	18,18

Afterwards one observes if the difference between the initial deviation angles between the two resolvers maintained, making the difference between θ_{E1} and θ_{E2}. This difference is written as θ_E and represents the error of movement transmission between the two synchros for the first two trials:

TABLE XIII. CALCULATION OF THE ERROR OF MOVEMENT TRANSMISSION BETWEEN THE TWO SYNCHROS -θ_E

θ_E [°]	$\theta_E = \theta_{E1} - \theta_{E2}$ [°]
0	0,42
20	1,69
40	0,06
60	0,57
80	1
100	0,87
120	0,1
140	0,17
160	0,03
180	0,16
200	1,04
220	0,53
240	1,02
260	0,61
280	1,06
300	0,01
320	0,89
340	0,07
360	1,07

By calculating the arithmetic mean of the 19 values, one determines the average value of the errors of movement transmission between the two synchros. This is of 0,598° at a complete revolution of 360°. Having this value, one can determine the accuracy class:

$$C = 0{,}598 \times 100 / 360 = 0{,}166\ \%$$

IV. CONCLUSION

Given this very small error (0,166 %), one can state that the synchros fit in a very good accuracy class: 5.

It remains arguable the oscilloscope's capacity to present in an accurate manner the parameters of the wave forms generated by the resolvers, considering that the frequency of the generated sinusoidal signal generated by the oscillator is not perfectly constant.

Through the created system, we eliminated the possibility of some errors which could have been interpreted as transmission errors, while in fact they were of a different nature. It is not necessary to discuss the accuracy with which the index of the synchro transmitter is set every time to the desired angular value, taking into consideration only the differences between the values of the voltages on the corresponding channels at different angles and not the values of those voltages themselves.

The system allows the determination of the smallest errors in the range of seconds, as it was proven above.

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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