ELECTRONIC SYSTEM FOR SYNCHRONOUS MOTION

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This is an examination on electronic system for synchronous motion of two machines (or two parts of one machine). The drive on every machine (or part) is made with standard three phase asynchronous motor and a batch produced electronic variable speed controller. There is a possibility to set up and sustain definite difference between the speeds of the two machines (parts). This system for synchronization is developed and tested in industrial conditions in four different versions with two types of variable speed controllers with or without industrial programmable controller. The accuracy of the synchronization on every variant is evaluated. In result of the research are made recommendations in which occasion incremental encoders and industrial programmable controller may not be used in electronically operated control of synchronized motion of asynchronous motors with variable speed controllers.

Keywords: synchronous motion; electronic synchronization

PURPOSE OF THE RESEARCHES

Recommendations have to be made in which occasion incremental encoders and industrial programmable controller may not be used in electronically operated control of synchronized motion of asynchronous motors with modern variable speed controllers.

MATERIALS AND METHODS

This is an examination on electronic system for synchronous motion of two machines (or two parts of one machine). The drive on every machine (or part) is realized with standard three phase asynchronous motor with a short-circuited rotor (Lenze, f_R = 50 Hz, f_{MAX} = 87 Hz) [9] and a batch produced electronic variable speed controller (Altivar of Telemecanique) [4, 15, 16]. One of the motors is leading (Lenze-3M090-32, 1.5 kW, 1420 rpm) and according to its motion is operating the tracer (other one) motor (Lenze-3M071-32, 0.37 kW, 1400 rpm) through changes in the job of the inverter of the tracer motor. The synchronization is monitored by incremental encoder (Omron-E6B2, 360 ppr, 5-24 V) [12, 14] and oscilloscope (Tektronix-2236, 100 MHz) [17]. There is a possibility to set up and sustain definite difference (up to ± 10 %) between the speeds of the two machines (parts).

This system for synchronization is developed and tested in industrial conditions in four different variants with two types of variable speed controllers with or without industrial programmable controller.

Variant 1 - with speed controllers *Altivar-28* [15, 16] and industrial programmable controller *Index-6* [1], which uses the information of incremental encoder to control the tracer motor;

Variant 2 - with speed controllers *Altivar-31* [4] and industrial programmable controller *Index-6*, which uses the information of incremental encoder to control the tracer motor;

Variant 3 - with speed controllers *Altivar-28* and the frequency inverter of leading motor controls the frequency inverter of tracer motor;

Variant 4 - with speed controllers *Altivar-31*, and the frequency inverter of leading motor controls the frequency inverter of tracer motor.

Fig.1 shows the control set realizing the first two variants (1 & 2) of electronic synchronization using programmable controller and two types of variable speed controllers. On Fig.2 is shown the control set realizing the other two variants (3 & 4) with two types of variable speed controllers without the use of industrial programmable controller.

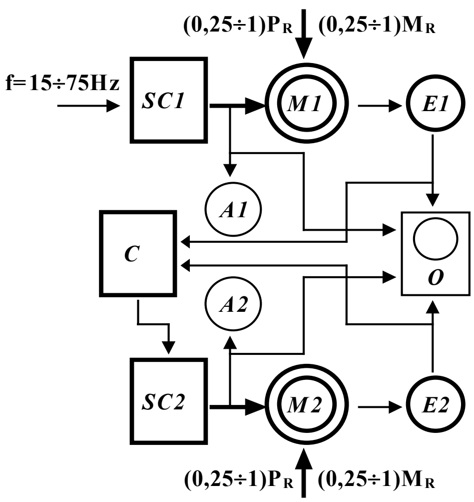

Fig.1

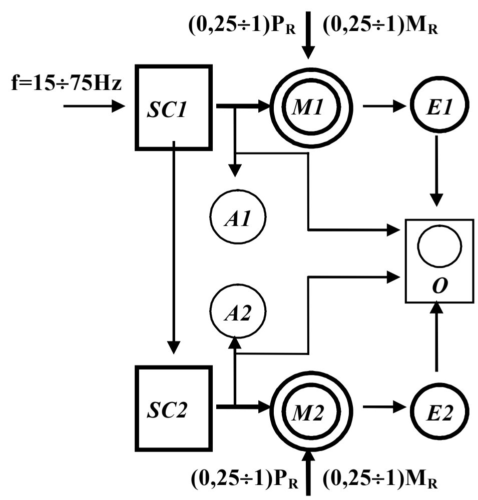

Fig.2

Abbreviations: *SC1* & *SC2* - variable speed controllers; *M1* & *M2* - leading and tracer (follow up) motor; *E1* & *E2* - incremental encoders; *C* - industrial programmable controller; *A1* & *A2* - current-measurement; *O* - oscilloscope; f - leading frequency; P_R - rated capacity of the motor; M_R - torque at rated load of the motor.

When using variant 1 industrial controller controls motorpotentiometer (Inelta-675, 10 kΩ, 10 s duration for turning) [7, 8], which defines the job of the frequency inverter of tracer motor. When using variant 2 the control is accomplished by electronic potentiometer, which is built in inverters *Altivar-31* [4].

Leading motor's frequency was given in range from 15 Hz to 75 Hz (at intervals of 15 Hz), because most of asynchronous motors work up to frequency 60 Hz [5, 6, 9, 11, 13] and torque is decreasing [5, 9, 10] when frequency under 15-20 Hz is used. That flaw can not be removed with frequency inverter's control [4, 10, 15, 16]. The frequency was given with precision ± 0,1 Hz [4, 15, 16] and was measured through indications of corresponding inverter and by oscilloscope (using its frequency meter) with relative error 0,2 % [4, 15, 16, 17].

The motors load (torque M) at different frequencies was changing in range from $0{,}25M_{\mathbf{R}}$ up to $1{,}0M_{\mathbf{R}}$ (at intervals of $0{,}25M_{\mathbf{R}}$). There is a direct [2] connection between torque and capacity and for frequencies 60 Hz and 75 Hz the load approximately [2, 9] corresponds to capacity respectively from $0{,}25P_{\mathbf{R}}$ to $1{,}0P_{\mathbf{R}}$ (at intervals of $0{,}25P_{\mathbf{R}}$). Constant torque is necessary for proper work of mechanical equipment and besides that is one of the possible regimes of frequency inverters [4, 10, 11, 12, 13, 15, 16]. The torque was measured indirectly through the current electricity (measured with relative error ± 0,5 %) of the motor [2, 3]. For that purpose before fitting in relevant equipment (machine) dependency between the torque and the current on each of two motors (*M1 & M2*) was obtained on different frequencies according to the methods given in [2]. The possibility of frequency inverter to measure current of connected motor was used also [4, 15, 16].

In operational mode it was very difficult to support constant load (M = const) over the machines (machine). For that reason, in spite of multiple experiments and applied statistical work, the common relative error, with which torque was measured is comparatively big - 2,5 %.

The accuracy of the synchronization on every variant was evaluated. The relative error is under 0,1 %, thanks to qualitative incremental encoders and frequency meter [7, 12, 14, 17] that were used. With the same accuracy was measured the revolutions of two motors (n_1 & n_2).

RESULTS AND DISCUSSION

The accuracy of the synchronization was measured through relative error (δ) of tracer motor (M2) turning frequency (n_2) towards frequency (n_1) given by the leading (first) motor (*M1*) with the formula

$$\delta = 100(n_2 - n_1)/ n_1 \quad .$$

The values of errors in synchronization at different frequencies (f) and loads M/M_R for variants 1 and 2 are almost equal (statistically indistinguishable) and are shown on table 1.

Table 1: Error δ values for variants 1 and 2

f	M/M_R			
Hz	0,25	0,5	0,75	1
15	± 1,8	± 1,7	± 1,8	± 1,8
30	± 1,5	± 1,5	± 1,5	± 1,6
45	± 1,4	± 1,4	± 1,5	± 1,5
60	± 1,4	± 1,4	± 1,5	± 1,5
75	± 1,4	± 1,4	± 1,4	± 1,4

The equal results are determined in the first two variants by the presence of incremental encoders and of well programmed controller in synchronization control set. That ensures equal and good results regardless of the load, turning frequency and the type of frequency inverter.

It must be noticed, that by objective - δ ≤ 2 %. That reflects on the program of the controller and therefore the error is bigger in the lowest frequencies.

Variant 2 is a little bit better because of its high quality frequency inverter.

The values of errors in synchronization at different frequencies (f) and loads M/M_R for variant 3 are shown in table 2 and for variant 4 in table 3.

Table 2: Values of the error δ for variant 3

f	M/M_R			
Hz	0,25	0,5	0,75	1
15	± 6,0	± 5,9	± 6,1	± 6,2
30	± 5,1	± 5,2	± 5,2	± 5,3
45	± 4,5	± 4,4	± 4,5	± 4,6
60	± 4,4	± 4,5	± 4,6	± 4,5
75	± 4,4	± 4,4	± 4,5	± 4,5

Table 3: Values of the error δ for variant 4

f	M/M_R			
Hz	0,25	0,5	0,75	1
15	± 4,2	± 4,1	± 4,2	± 4,2
30	± 3,3	± 3,4	± 3,5	± 3,5
45	± 3,0	± 2,9	± 3,0	± 3,1
60	± 3,1	± 3,1	± 3,0	± 3,1
75	± 3,0	± 3,0	± 3,1	± 3,1

The synchronization is better in variant 4 because of the smaller error on leading inputs and outputs of used frequency inverter Altivar 31 in comparison with Altivar 28 (variant 3). There are bigger errors in low-revolutions [4, 10, 11, 13, 15] because of unstable work of inverter and motor in such mode. Difficulties in setting and supporting relevant torque values may be the cause of some fluctuations of the data.

In the above researches the motor load has been changing simultaneously and equally, which is normal for the real synchronously moving machines (or part of machines). Turning frequency will change equally [2, 5, 6, 9, 13] and performance capabilities will have little influence over error of synchronization if controlled motors are made from one company and are from same class.

Using electronic system for synchronous motion, transient regimes exist when loads of the motors did not change equally and simultaneously. It is possible motors to be badly chosen and one of the motors to be always less loaded while the other overloaded. In those cases increased error must be expected especially in variants 3 and 4.

The same variants were made again but with load (M/M_R) increasing in one of the motors and decreasing in the other.

The synchronous control set of variants 1 and 2 successfully handles that situation with no considerable differences from results in table 1.

In transient regimes synchronization of variant 2 is better because of built in Altivar 31 electronic potentiometer (in comparison with motorpotentiometer in variant 1).

In variant 4 the differences are the largest. In it to a comparatively small error is added the difference in revelations of not loaded and loaded motor reaching 5% [2, 5]. The results of that research are shown in table 4.

Table 4: Values of the error δ for variant 4 with differently loaded motors

Leading, M/M_R	0,25	0,5	0,75	1
Follow-up, M/M_R	1	0,75	0,5	0,25
15 Hz	± 6,1	± 5,4	± 5,3	± 6,2
30 Hz	± 5,9	± 4,9	± 5,0	± 6,0
45 Hz	± 5,6	± 4,1	± 4,1	± 5,6
60 Hz	± 5,7	± 4,1	± 4,2	± 5,8
75 Hz	± 5,6	± 4,2	± 4,1	± 5,7

The values of the error δ for corresponding variants is preserved when leading motor speed up or slows down with 10 %. The objective of tracer motor is changed with ±10% and the formula is

$$\delta = 100(1{,}1n_2 - n_1)/ n_1 \quad \text{or}$$

$$\delta = 100(0{,}9n_2 - n_1)/ n_1 \quad .$$

There is a little increase of error with frequencies under 15 Hz.

CONCLUSIONS

This is an examination on electronic system for synchronous motion of two machines (or two parts of one machine).

The used frequency inverters are from a well-known west-European company [4, 7, 15, 16] that has offices in larger cities in our country and good offers.

Asynchronous motors [9] which were used had bigger capabilities and higher price. For a frequency range of 20-60 Hz any other (cheaper) motor [5, 6, 9, 13] can be used.

Incremental encoders and industrial programmable controller may not be used, if requirements to error of synchronization are bigger than 3-5 %. In that case motors should be from same company and from the same type, and slightly loaded (up to 50-60% of motor's rated power). Also motor's loads must be almost equal.

A change of speed of machines (parts) one towards another (up to ± 10 %) do not influence over the quality of synchronization.

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