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CONTROL OF A SINGLE BUCKET EXCAVATOR'S WORKING PROCESSES USING THE OPERATOR'S COMPUTER AIDED SYSTEM

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SUMMARY

The functional structure of operator's computer aided system in control of single bucket excavator's work is presented. There is described two control algorithms making possible the realization of earth moving process and copying of working motions by computer aided system that were showed earlier by operator. The exemplary results of experimental researches indicate that the described system and control algorithms make possible the effective realization of technological tasks that are carried out by the single bucket excavators.

1. Introduction

The single bucket excavators are the building machines of cyclic work and their cycle of work in time of carrying out the most of earth moving, land melioration, loading and unloading works can be divided up into four basic phases:

1 - earth moving work (digging) or loading of a working tool (loading of a material),
2 - transport of the load bucket ,
3 - unloading (most often on spoil or transport equipment),
4 - return of the bucket to a borrow pit (place of loading)

In many cases when the digging is not unloaded on the transport equipment, the phases 2 - 4 - taking even 80% of working cycle's time [1, 4, 5] repeat very often. Making assumption that space of collision of the excavator [6, 7] is not complied with essential deformations during changing a work station of the excavator so the realization of control of the working motions in these phases can be transferred to computer aided system. It allows to relieve the operator of carrying out a relatively simple repeating and boring tasks. In this way he may focus on realization the earth moving work (digging) phase. That is individual for each working cycle and takes about 20% of its total time [1] at an angle to obtain a high filling ratio of the bucket. It generates a good capacity which is obtained in this phase.

For the needs of the experimental researches was elaborated experimental computer aided system of operator work in the control process of machine's work (Fig. 1). In time of shaping of its structure the rule of man's superiority in control process was taken into consideration and possibility of an acting of the computer aided system only according to command of the operator. This way he may independently control the work of the machine when the computer aided system is switched off (generating the control signals $\bar{u}_{OS}$ due to stimulus feedback $\bar{b}_{SW}$) using the information $\bar{i}$ generated by this system (received by him as a visual stimulus $\bar{w}_O$) or to allow to take over the control by computer aided system (generating the switching signals $\bar{u}_{OP}$ and activating ones $\bar{s}_A$). In this last case the controller activates suitable control algorithm indicating signal $\bar{u}_{AS}$ controlling by the electromechanical module (the real integrating element with a time-constant 0.2 s and amplification factor 30 mms^{-1}) the position of a bar of a injection pump and the signals $\bar{u}_{AR}$ controlling by a block of conversion and amplification of the signals which control the position of the hydraulic valve sliders. This block is the amplifier element with amplification $k = 1$ for signals $\bar{u}^i_{OR}$ (then suitable switch-over signals generated by controller $\bar{u}^i_{AP} = 0$) and inertial element (with amplification $k = 0.3$ MPaV^{-1} and time-constant 0.05-0.1 s), when the inputs are the signals $\bar{u}^i_{AR}$ (the suitable switch-over signals are generated by a controller $\bar{u}^i_{AP} = 1$). Computer-aided system for determination of these signals uses the information about run of process in the excavator's engine, hydraulic and mechanical system of machine $(\bar{w}_S, \bar{w}_{TE}, \bar{w}_{UM})$ and about existence of the control signals generated by the man $(\bar{w}_L, \bar{w}_P)$. In this case he may stop currently realized algorithm through:

- switch on the stand-by or switch off the controller,
- switch off the proper switch-over signal,
- to attempt of generation the contrary control signal to the signal currently generated by the computer-aided system.

Such a structure of control system the cooperation between operator and computer-aided system in control processes of the single bucket excavator makes flexible.

In this paper two examples of using the elaborated system for control of a work of Polish K-426 wheeled single bucket excavator (bucket capacity - 0.4 m^3) are presented.

2. Control of the earth moving process keeping a constant pressure in a stick cylinder

The earth moving process executed by hydraulic crawler-mounted hoe of excavator is carried out mainly by a swing of a stick. The bucket and boom cylinders carry out the correction motions and the change of depth of digging and angle of cutting make possible [1,2,3]. On the base of run description of such a process and researches that are presented in [3,4,5] - algorithm of control the realization such a technological task was elaborated (see Fig. 2). Making assumption that in an initial phase of process the bucket cylinder is used for setting of assumed angle of cutting γ. In the earth moving phase (loading of the bucket), in time of „closing" the stick ($u_{R-R} = 1$) - the boom cylinder executes the correction motions to keep the pressure p_{R-ZZ} in an piston chamber of stick cylinder in assumed interval (p^D_{R-RZ}, p^G_{R-ZZ}). In case when the pressure in this cylinder is lower than p^D_{R-RZ} the boom is gone down and when the pressure in the cylinder exceed the value p^G_{R-RZ} then boom is raised. When the pressure in stick cylinder reaches the value assumed as maximal p^{MAX}_{R-RZ} (amounting 0.8-0.9 of a overflow valve setting) follows the stoppage of a closing motion of the stick. In the next phase the setting of the bucket in position making possible its raising together with load over the ground level is realized.

On the fig. 3 is presented the oscillogram from the earth moving researches which were carried out due to discussed algorithm. There were experimental determined the threshold value of pressure in stick cylinder [$p^D_{R-RZ} = 6$ MPa, $p^G_{R-RZ} = 7$ MPa, $p^{MAX}_{R-RZ} = 10$ MPa (the setting of overflow valve 12.5 MPa) and level of signal controlling the valve of the boom u_{R-W} (properly - 0.3 and 0.4 for going down and raising up of the boom in the earth moving phase and 0.8 in the final phase).

It was found that a cutting angle ought to fulfil a condition: $\gamma - \varphi_{OS} \geq (8-10)^0$; φ_{OS} - a bucket's teeth wedge angle. It ensures digging by excavator without indentation of the bucket in the bottom of the excavating dug in a total time of the earth moving process (particularly when the boom is gone down).

Elaborated algorithm the automatic realisation of earth moving process by hoe of excavator makes possible. However there is necessary the experimental selection of a threshold value and shape of the boom control signals in depends on the state and kind of the ground and depth of digging.

3. Repetition by computer-aided system motion sequences showed earlier by operator

For realization such the tasks by computer-aided system (CAS) the special algorithm was elaborated (Fig.4). It consists of the option that was called „Teach-in" in which operator shows the working motions and the „Execution" option where the repetition by CAS is possible. After activation the first option the working motions realized by operator are in proper way written in the memory. There is created a matrix of intermediate states in which the information about existence of control signals, the ranges of working motions and stoppages. In time of creation of the matrix there was assumed that two working motion can be executed simultaneously according to rule that one pump supplies only one receiver (a hydraulic cylinder or engine). In this matrix, there is written neither the information of a trajectory of the bucket cutting edge nor position individual elements of excavator's hoe and angle of swing of its body in following moments of time - unlike to the robots and manipulators [6,7]. There is made a storage only these values that determine the configuration of the hoe in changes of logical values of control signals (0 - lack of control signals, 1 - their occurrence). In this case the bucket's trajectory is checked up in K_C points (K_C - the number of intermediate states in showed sequence of motion). The matrix consists of K_C rows and ten columns for making storage of four working motion. The created matrix is made in operating store of the controller and it may be used after switching on the „Execution" option by the operator (Fig.4). In its initial phase there are measured the positions of the hoe elements (determined as the start position) and compared with the initial position (written in the first row of the matrix). There is assumed that the differences oughtn't to exceed 10 % of total pitch of the pistons the hydraulic cylinders and $\pm 30°$ for the swing angle of the excavator's body. In opposite case the operator is warned against wrong start position and the option is not executed. When the operator corrects the position there is realized the essential part of option. There are currently determined and analysed in turn of the rows of states' matrix (at every turn: a former, current and next). On this base the state of motions for individual executive mechanism is determined (out of action, starting, motion with a constant value of control signals or breaking). When the number of states K_C is used up or the operator breaks the action of the algorithm there is realized the breaking process of eventually working motions and a finish of the „Execution" option. It may be reactivated by operator and the whole sequence of motions is repeated.

The way of recording the realization of the working motions sequence and their reproduction doesn't fully ensure to copy the trajectory of the bucket cutting edge motion - Fig.5. As follow from inserted diagrams there is not accurate time of correlation between the control signals generated by the operator and determined by CAS. That is a result of assumed rule of reproduction of working motions on base on the state changes matrix. The computer-aided system also doesn't consider the shape and value of the control signals but only theirs logical value. The starting and breaking algorithms used in the option realized the working motions due to earlier programmed sequences. The shapes of control signals in phases of starting and breaking were determined experimentally.

The discrepancies of the position of individual elements of the excavator's hoe and body were determined in relation to the total hydraulic cylinder pitch and for the angle of swing body directly in degrees. On the proper diagrams the values of these discrepancies after finish of execution the particular motion in realized sequence are determined. They show that for the boom and swing motions there is necessary to elaborate more perfect algorithms of breaking of realization to achieve lower discrepancies between trajectory of motion realized by operator and copied by computer aided system CAS.

4. Conclusions

The presented examples show synonymously that by the proper selection of the structure of the machine's control system and control algorithms may effectively realize some different technological tasks taking into consideration the man-operator preferences.

The accepted convention of recording the states of changes not trajectory of the hoe elements motions doesn't require a big memory and by selection of the shape control signals in the starting and breaking phases allows to find the compromise between contradictory with themselves criteria:

- efficiency (determined by time of realization of working motions in the hoe manoeuvring and particularly by run the bucket loading process),
- accuracy of reproduction of the bucket motion trajectory,
- dynamic overloads (assessed on base on the run and value of pressure in the selected points of hydraulic system of the excavator).

However, there are necessary the further theoretical works and experimental researches to find the idea of shaping of the control algorithms of the work of the excavators and another working machines with automatic realization of technological tasks and computer-aided of the operator.

5. References (in Polish)

[1] J. BRACH, *Koparki jednonaczyniowe*, WNT, Warszawa 1982.

[2] E. BUDNY, *Podstawy racjonalnego projektowania układów maszyn roboczych na przykładzie koparek hydraulicznych*, Rozprawa habilitacyjna, Wydawnictwa Politechniki Warsza-wskiej, Warszawa 1993.

[3] S. KONOPKA, *Obciążenia osprzętu roboczego maszyn do prac ziemnych w procesie urabiania gruntu*, Rozprawa habilitacyjna, WAT, Warszawa 1991.

[4] F. KUCZMARSKI, *Badania gąsienicowych koparek hydraulicznych z osprzętem podsiębiernym pod kątem możliwości zwiększenia dokładności wykonywania prac ziemnych*, Praca doktorska WAT, Warszawa 1983.

[5] SPRAWOZDANIA Z REALIZACJI PROJEKTU BADAWCZEGO KBN NR 3 3135 92 03, *Dobór parametrów systemu sterowania pracą podstawowych maszyn budowlanych, badania symulacyjne i doświadczalne, weryfikacja na przykładzie koparki jednonaczyniowej*, WAT, Warszawa 1994.

[6] J.J. CRAIG, *Wprowadzenie do robotyki, Mechanika i Sterowanie*, WNT, Warszawa 1993.

[7] A. MORECKI I INNI, *Podstawy robotyki, Teoria i elementy manipulatorów i robotów*, WNT, Warszawa 1993.

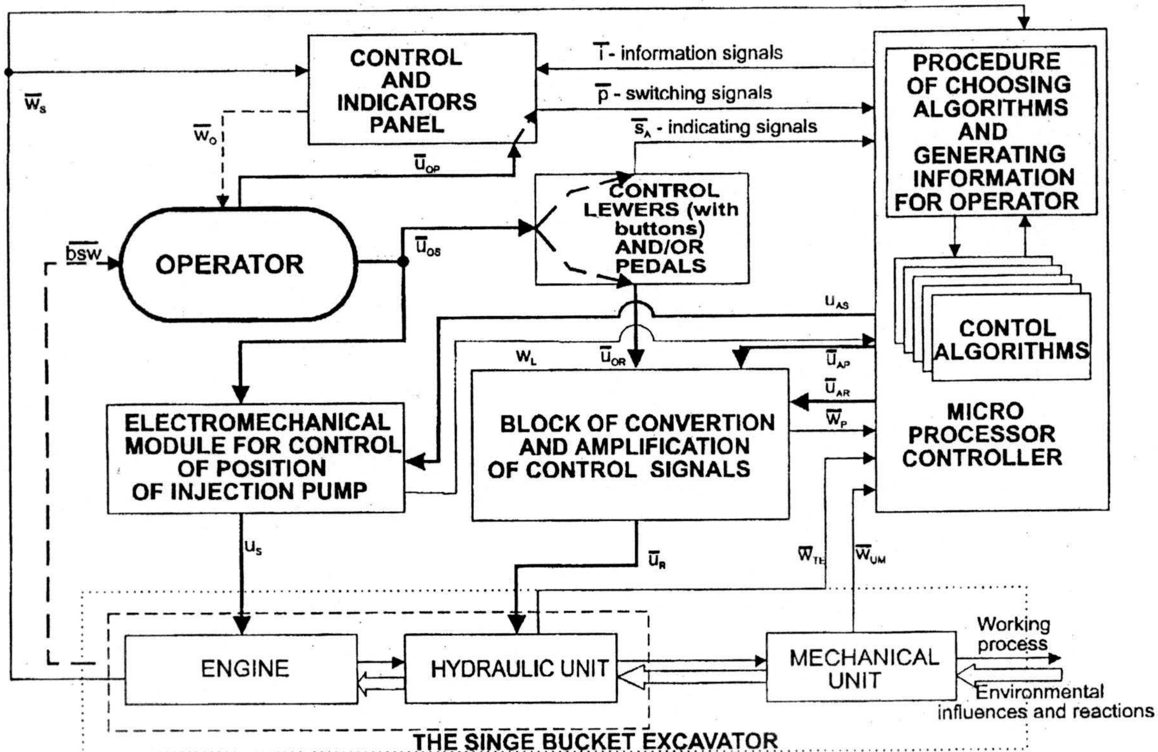

Fig. 1. The functional scheme of the computer - aided system of the operator of the single bucket excavator

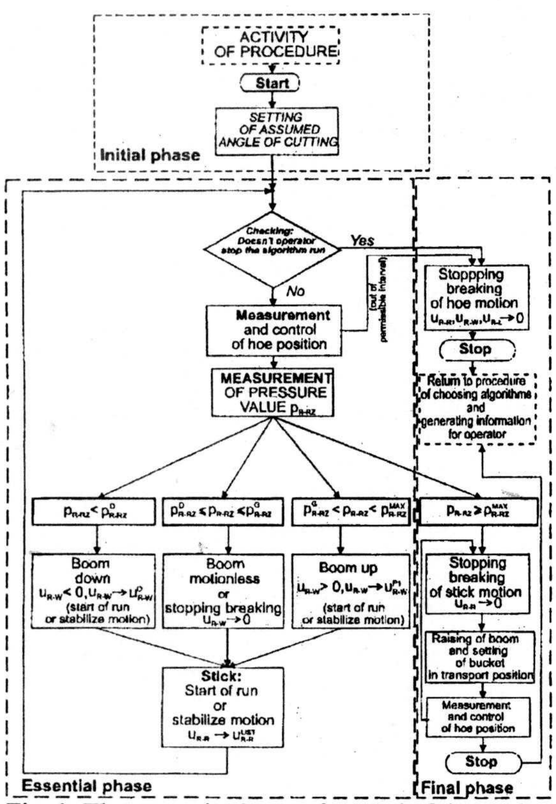

Fig. 2. The general scheme of control of the earth moving process

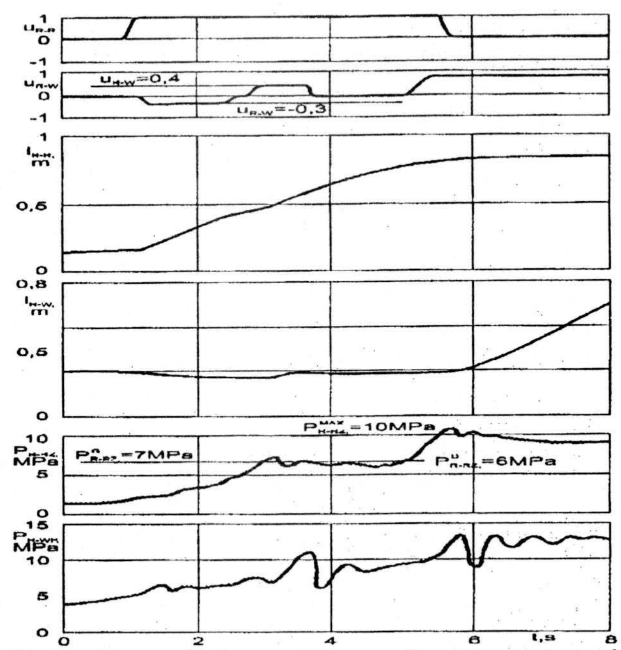

Fig. 3. The exemplary oscillogram from researches of earth moving process using the control processes to keep the pressure p_{R-RZ} (in phase of earth moving) in the stick cylinder in assumed interval: l_{R-R}, l_{R-W} properly pitch of pistons of the stick: and boom, p_{R-WP} - pressure in the boom cylinder

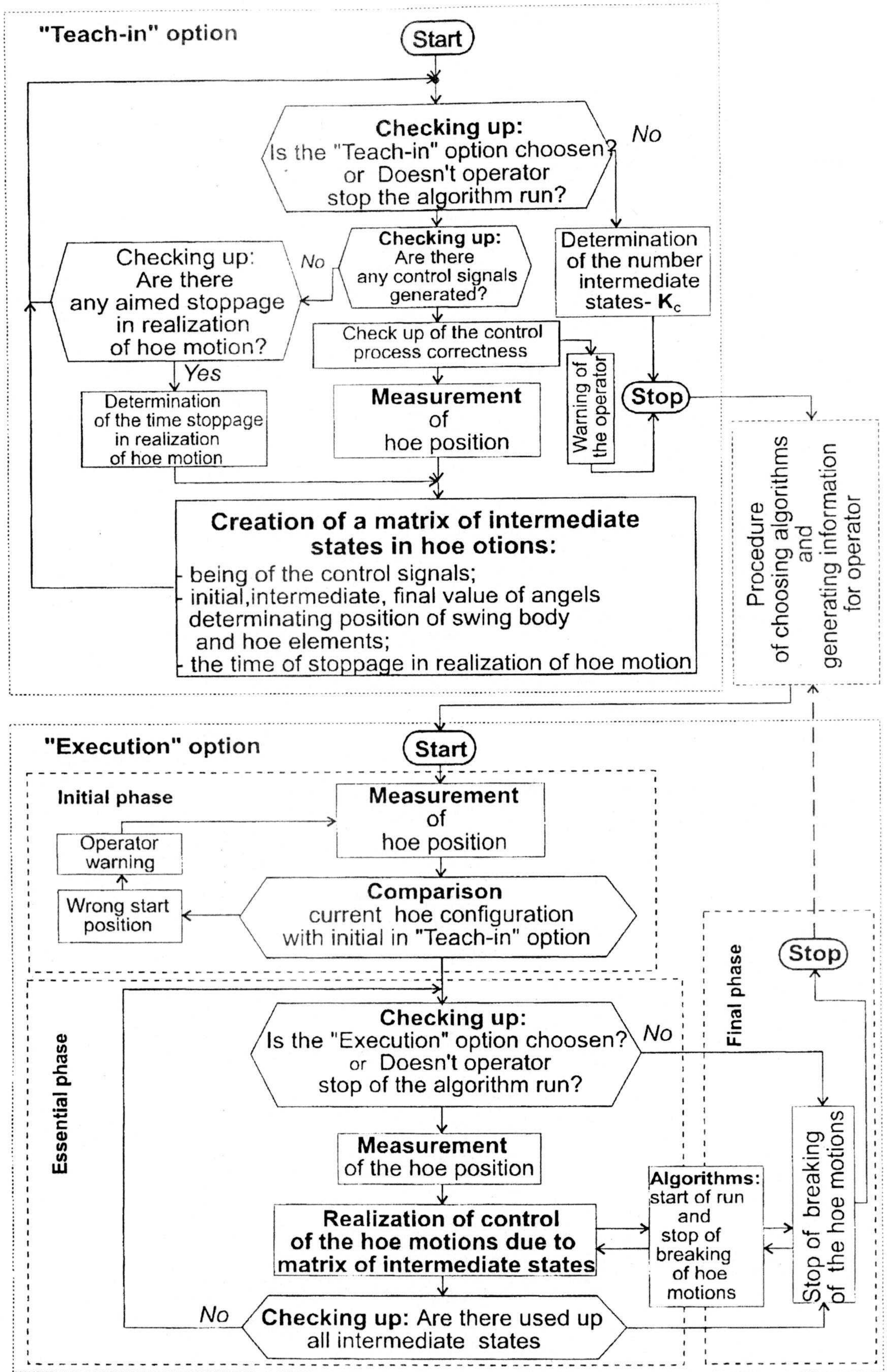

Fig. 4. The scheme of algorithm of realization of reproduction of working motions sequence that are showed by operator

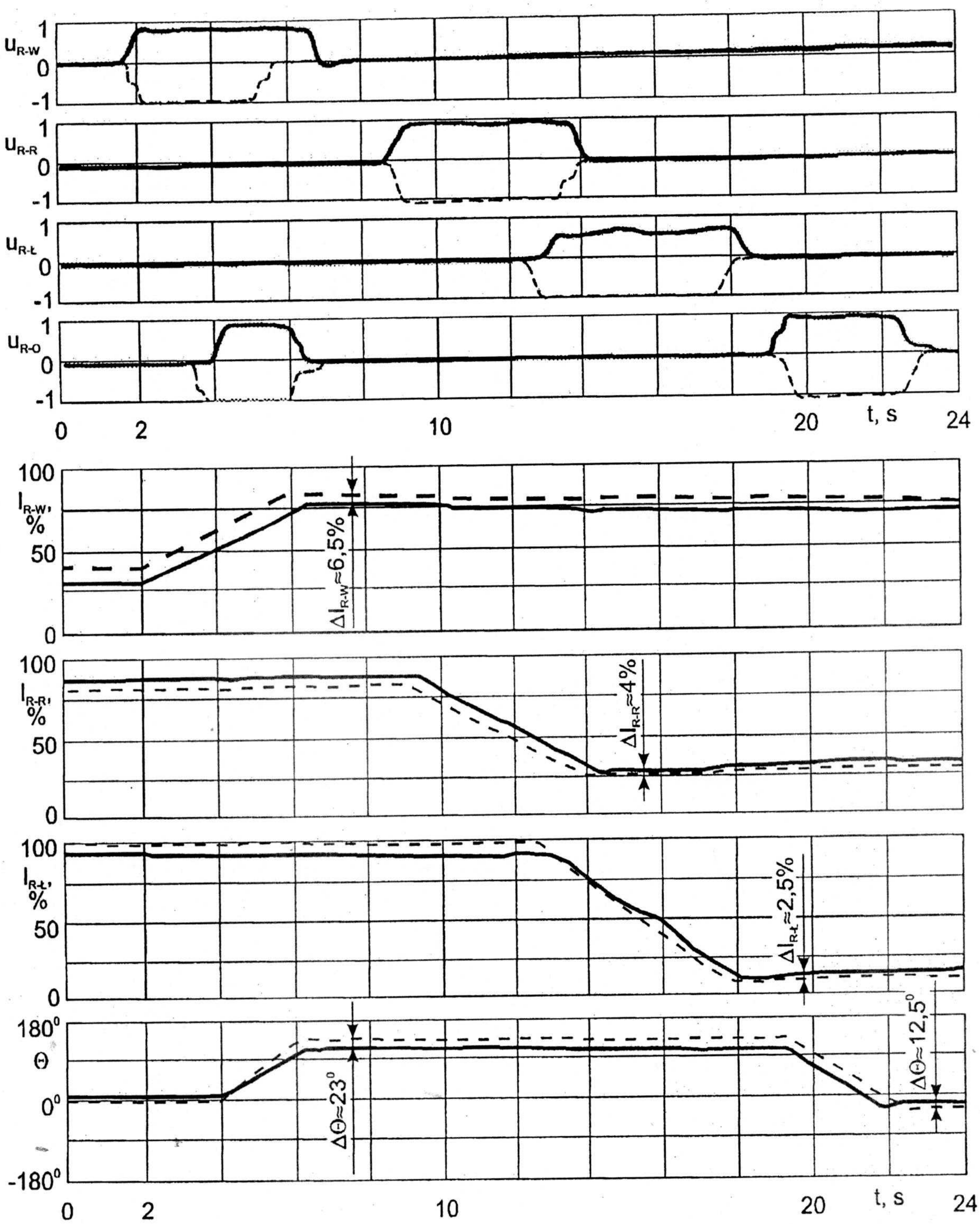

Fig. 5. Oscillogram from researches of the algorithm which realizes the recording of working cycle (full lines - the „teach-in" option) and their reproduction by computer - aided system (broken lines - the „execution" option), (initial speed of engine ω = 157 1/s (1500 r.p.m.), unload bucket - motions sequence which are realized by excavator's operator: $u_{R-W}, u_{R-R}, u_{R-L}, u_{R-O}$ - properly the control signals of the valve of the boom, stick, bucket and swing (for clearing of the figure, the line of control signals for the „execution" option is presented as a mirror reflection) - $l_{R-W}, l_{R-R}, l_{R-L}$ - properly the pitch (in %) of the cylinder piston of the boom, stick, bucket, Θ - the body swing angle relative to longitudinal axle of the undercarriage ($\Theta > 0$ - left turn)