DIGITAL CONTROL SYSTEM TO GENERATE ENERGETICALLY ADVANTAGEOUS CUTTING TOOL TRAJECTORIES FOR HYDRAULIC EXCAVATORS

Wiesław Trąmpczyński, Leszek Płonecki, Wacław Gierulski, Julian Cendrowicz, Kazimierz Sokołowski

Kielce University of Technology , Poland

Abstract: The computer control system for the backhoe hydraulic excavator is presented and discussed in the paper. It can be used to help the operator during the shoving process to generate energetically advantageous trajectories obtained as automatic tool leading along the previously generated slip lines. The results of experiments, carried out for the loading type kinematics under the plane strain conditions and for the bucket with side walls, confirm the efficiency of such trajectories. Experimental results for K-lll backhoe excavator are also presented here. It is shown, that the automatic system enables the realization of tool trajectories with proper precision.

Keywords: Digital control, hydraulic excavators, and energetically efficient trajectories.

1. PREFACE

Soil shoving process with machine tools for earthwork is a strong nonlinear dynamic process. Technical requirements and economic factors force the necessity of execution of works with technical parameters given from the beginning, including economic factors as well. Hence the systems aiding an operator are applied more often – thus enabling more accurate control of machine operating movements.

The systems applied till now do not allow making more complicated movements, or according to assumed criteria. It also concerns the movements along energetically advantageous trajectories, which enable to get considerable savings of shoving energy.

Experimental tests of shoving process for coherent medium with use of tools of machines for earth works have shown that the medium deformation is realized in a form of rigid blocks movement along the slip lines, created during that process [2]. It has been shown, during searching for energetically advantageous trajectories of a tool in a process of soil shoving, that this is a trajectory, in which the end of moving and turning tool is led along the previously generated slip line.

In real conditions, the soil is of non-homogeneous type. Slip lines are not always generated during the ”entry phase” and slip lines formed during the process are not the straight lines. Hence, in real conditions, practical use of energetically advantageous trajectories is possible only with use of the system, which enables automatic leading of a tool end along the slide line of optional shape.

Control of the system, enabling the

realization of complicated trajectories with assumed criteria, can be realized with use of digital control system. Such system, which is the system aiding the operator [3], adapted for control of hydraulic backhoe excavator – has been built on the basis of a PC computer and run tests have shown its full usability [1, 4, 5].

This paper has shown the application of that system for the purpose of generation of energetically advantageous trajectories.

2. THE CHARACTERISTICS OF CONTROL SYSTEM AND TESTING STAND.

The operation of the system for control of the tool movements [4,5] is based on application of control systems of the attachment hydraulic cylinders positions and forces developed by these cylinders. That system uses a computer breaks, and the synchronization of movements of individual cylinders of the attachment – which is necessary for planning of a cutting tool trajectory – is all the time assured.

Two versions of a control system have been made. One – for K-111 excavator attachment and second – for a laboratory stand, designed for testing of excavator and loader equipment control. The differences between these versions mainly consist in ways of programming of operating movements, adapted to the kinematics of both machines.

The researches concerning the applications of the system for automatic generating of energetically advantageous trajectories have been made on a special laboratory stand - enabling the simulation of a backhoe excavator bucket movement. Next the worked-out programs have been included to the system for control of the attachment of a typical backhoe excavator (a stand with K-111 excavator attachment).

The experimental tests, which have been made till now showed full suitability of the computer control system for control of backhoe excavator attachment, designed for:

- tool movement along the assigned trajectory,
- movement of a supplying tool with use of a model (phantom),
- movement of a tool with geometrical limits,
- movement of a tool with assigned values for cutting forces, e.g. maximum horizontal force,
- automatic generating of trajectories according to the assumed criteria.

A scheme of a laboratory stand is shown on Figure 1.

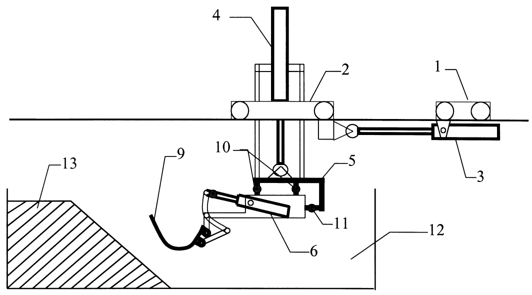

Figure 1. The laboratory stand.

Trajectory of a cutting tool of an excavator bucket model (9) results as a sum of horizontal movement of a carriage (2) driven with hydraulic cylinder (3), vertical movement of a frame (5) driven by hydraulic cylinder (4), and turn of a bucket driven by hydraulic cylinder (6). The model of an excavator bucket is fixed with a frame by tensometric force sensors (10) and (11) enabling to measure the force components loading a bucket. A bucket moves in a channel (12), of which one side wall is made of glass.

3. AUTOMATIC GENERATING OF ENERGETICALLY ADVANTAGEOUS TRAJECTORIES OF A TOOL

Regarding the system made and tested on a laboratory stand in a plane strain conditions, and for a bucket with side walls- it enables automatic leading of a tool along the previously created slip line [6]. The system used the following phenomenon: if a tool is still led horizontally after slip line is made, then after slip line zone is exceeded and a tool enters into a solid material- horizontal force increases

Tool movement along the slip line is as follows: a tool moves horizontally till the assigned component value of a horizontal force (F_1) is reached. If there are no slip lines, formed during the horizontal movement, then they can be caused by e.g. turn of a tool for an assigned angle. Next a tool is withdrawn, what results in force decrease till to an assigned value (F_2). Next the tool moves vertically with simultaneous turn for assigned angle value, and next it moves again in horizontal direction. In this way the tool moves in a „step way" along the line with clear change of cohesion – i.e. along the slip line.

During the movement of " step way" a bucket is filled with excavated material, what is controlled by an operator. Operator, in a suitable moment, changes his control from automatic to manual, to unload the tool and to start next movement. So the described system can be treated as an element of the system which supports an operator.

Fig. 2 and 3 show the results of testing performed under plane strain conditions on a laboratory stand.

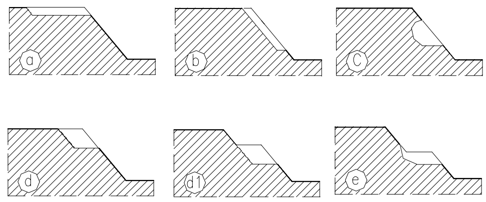

Figure 2. The different trajectories of a tool.

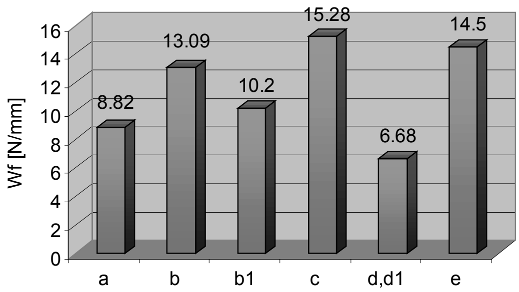

Figure 3. The average unit energy for trajectories presented in Fig.2.

Fig. 3 shows the results of unit energy testing of the bucket operation, as shown in Fig. 2, including as follows: horizontal slopping (Fig.2a), angle slopping (Fig. 2b), bucket type excavation (Fig. 2c), trajectory generated automatically for sequential shoving (Fig.2 d, d1), bucket type excavation for non typical shape of surcharge (Fig. 2e).

In all the cases the quantities of excavated material were similar. The moment when a tool end cuts the slope outline has been treated as the end of shoving process.

Trajectories shown in Fig.2 a-c, e were the previously planned trajectories, while those shown in Fig. 2d, d1 were the trajectories obtained with applications of automatic system for slip line generating and next following it up.

The average unit energy for given trajectories has been shown in Fig. 3. Energy is related to a side cross-section of the selected material, hence has non typical unit (Nmm/mm^2). Unit energy of the trajectory generated automatically, where a tool is led along the previously generated slip line, is the smallest. Unit energy for shoving along horizontal slopping- is 32% higher. Unit energy for shoving along angle slopping, including the energy of excavated material lifting – is 53% higher. Unit energy of bucket type shoving (Fig. 2e) is 117 % higher than energy for the proposed movement, generated automatically.

The presented testing results show that proposed sequential mining is the most advantageous from energetic point of view and can considerably decrease the energy of shoving process in comparison with traditional shoving.

The testing of a bucket with side walls, operating in conditions which are very similar to real conditions – have been performed on a stand of width with increased up to 1.300 mm (from width of 497 mm).

The program of a bucket filling, similar as presented above, has been realized on such arranged stand – for slopes inclined, as previously, at angle 50°. The trajectories shown in Fig. 4 a, b, c, e were the previously planned trajectories.

Trajectory shown in Fig.4d has been developed automatically, with use of the

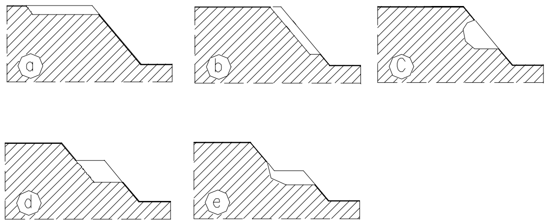

Figure 4. The slope outlines and trajectories for a bucket with side walls.

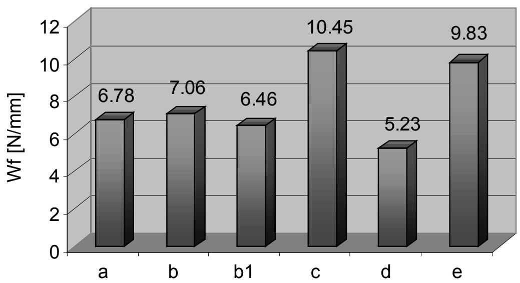

Figure 5. Unit energy of shoving for the trajectories as in Fig.4.

same procedure as previously, for the assumed values F_1=150 N, and F_2=100 N.

The average unit energies of shoving for a bucket with side walls have been shown in Fig. 5

Unit energy of the trajectory generated automatically is the lowest.

Unit energy for shoving in a form of horizontal and angle slopping, after the lifting energy is removed, is clearly higher (for 30% and 24 %).

Unit energy of a bucket type shoving is almost two times higher (for 88%) than the energy for a proposed automatic operation.

The testing results presented here are in principle the same as the results of testing for an opened type bucket – made in a plane strain conditions. They show, that the proposed sequential shoving with automatic leading of a tool is energetically the most advantageous also for a bucket with side walls.

4. COMPUTER CONTROL SYSTEM FOR THE ATTACHMENT OF A BACKHOE EXCAVATOR

The testing results presented above have been obtained on a stand, where the tool movement resulted from the sum of the horizontal-, vertical- and rotary- type movements. The realization of such type of movements for an excavator attachment is indeed possible from technical point of view, but with computer control system – it causes the groundless complication of control procedures. Hence the testing of an automatic system operation on a stand equipped with K-111 excavator have been made with use of a slight different principle of the system operation.

The tool movement in an excavator results as the sum of turns of: a boom, arm and bucket.

The described above procedure of automatic movement of a tool has been modified. The modification is as follows: horizontal movement was replaced by an arm turn, vertical movement was replaced by a boom turn. Next that procedure operation has been tested for a model material. The purpose of these testing was to verify if the control system is able to lead a tool along the slope optionally formed from that material – what simulates the tool movement along the slide line, which is a border of two mediums of a considerable difference of material cohesion.

Foamed polystyrene plate has been taken as a model material. The plate thickness was selected so, to obtain – during the penetration with a bucket edge -the module of dependence of horizontal force on the movement as two times lower than in relation to the soil, to show greater sensitivity of the system to the changes of medium properties.

The tool movement was realized with use of two control algorithms. First of them consisted in the execution of mutually alternating movements of an arm, till to the moment, when the set force (F_1) on bucket is reached and movements of a boom till to the moment when the force decreased to the second set value (F_2). Servo units operated with movements according to previously set speeds.

The second of presented algorithms differed from the previous in it, that the servo unit of an arm moved in an uniform motion with a given speed, while the boom servo unit started its movements when force on teeth exceeded F_1 value, and stopped when that force decreased below F_2 value.

Figure 6 shows an example of the movements of the excavator bucket end, with use of first procedure and model material. The arm was moving till to the moment, when force increase 500 N was achieved.

Observation of the bucket end movements, also registered with use of film camera, has shown that it had moved along the profiled slope.

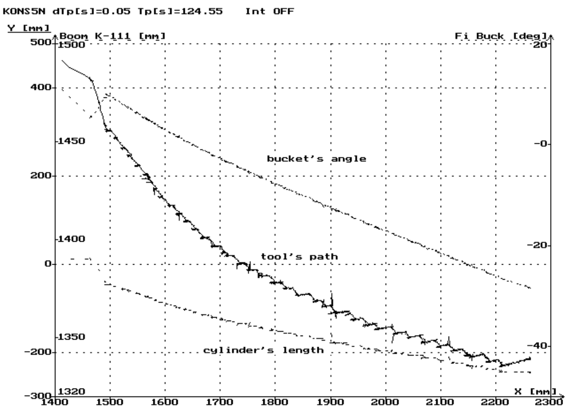

Figure 6. An example of K-111 excavator tool movement along the model medium border.

The presented figures show correct operation of the automatic system proposed for backhoe excavator equipment.

5. CONCLUSIONS

The testing of automatic control system have been made for a backhoe excavator and for excavator tool moving along the border of a model material – i.e. a foamed polystyrene of suitably selected width. The obtained results show, that constructed automatic control system, which enables the realization of energetically advantageous shoving trajectories, can be also applied for that type of equipment.

REFERENCES

[1] Cendrowicz, J., Gierulski, W., Płonecki, L., Trąmpczyński, W., "The laboratory stand for the soil shoving processes due to an excavator bucket" (in Polish), Proc. of III Conf. Experimental Methods in the Building and Exploitation of the Machines, Wrocław – Szklarska Poręba, 1997.

[2] Jarzębowski, A., Maciejewski, J., Szyba, D., Trąmpczyński, W., "On the energetically most efficient trajectories for heavy machine shoving process", Engineering Transaction, Vol. 43, 1-2, 1995.

[3] Płonecki, L., Cendrowicz, J., "A concept of the assisting system for the hydraulic excavator operator" (in Polish), Proc. of X Conf. Problems of Working Machines Development, Zakopane, 1997.

[4] Płonecki, L., Trąmpczyński, W., Cendrowicz, J., "A concept of digital control system to assist the operator of hydraulic excavators", Automation in Construction, Elsevier, 7/1998.

[5] Płonecki, L., Cendrowicz, J., Gierulski, W., Trąmpczyński, W., "On the trajectory planning for the robotised laboratory, soil shoving machine" (in Polish), Reports of the Institute of Technical Cybernetics, Technical University of Wrocław, 1998.

[6] Płonecki, L., " The computer control of the fixture of machines for earthworks on example of the single-bucket hydraulic excavator" (in Polish), Reports of Technical University of Kielce, 16/1999.

[7] Płonecki, L., Trąmpczyński, W., Gierulski, W., Cendrowicz, J., Sokołowski, K., "Computer control system for heavy machine fixtures motion and its application for automatic generation of cutting tool trajectories according to the given criteria", Engineering Transaction, 48/2000.