# ADAPTATION OF FUZZY LOGIC CONTROLER TO HYDRAULIC BACKHOE EXCAVATOR.

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Abstract: Results of research on automation of a hydraulic backhoe excavator are described in this paper. The excavator works under an algorithm, which maximises the working force. A fuzzy logic control system is used to realise this algorithm.

Keywords: building machinery, hydraulic excavator, modelling, simulation, automation, fuzzy logic,

## 1. INTRODUCTION

Nowadays, there are sharply growing demands for excavators work performance. These demands concern primarily work precision, low fuel consumption, preservation of the nature as well as work safety.

A level of the mentioned demands related to control of the work, often exceeds capacity of an excavator operator. Therefor, it is necessary to adapt systems, which can assist the operator in his work. The assistance can be achieved by partial automation of an excavator. Automation of a hydraulic backhoe excavator is focused on two directions. The first direction is related to automation of the functional motion and the second one is related to automation of a drive unit.

There is ongoing research effort for new controller solutions, which can assist an operator in his work. It is necessary to develop various controlling algorithms for microprocessor based controllers. Classical solutions with an application of PID loop control or even adaptive control are not sufficient. The control system should guarantee realisation of the algorithm in real time. Excavators work in various conditions i.e. different categories of soil and outdoor temperatures, so the natural work environment of an excavator is variable. The machine state parameters are changing in a specified range. These features incline to undertake studies on fuzzy logic control systems.

## 2. OPTIMISATION OF SOIL EXCAVATING PROCESS

In most cases, forces effecting an excavator bucket during manual machine control do not reach a half of their maximum value. Therefore, the authors decided to increase utilisation of the power factor through optimisation of the process by maximising the digging force.

The power demand is estimated based upon the equilibrium equation of the machine. Two components determine the effective power:

- power supplied by the hydraulic system,
- power resulting from mutual relationship of equipment elements (boom, arm and bucket) weight

During the digging process, controlled by an operator, an arm's move is the basic motion of the process while a boom's move is used to set up the machine in the digging position.

In order to increase the excavator power factor the boom's move was introduced as an additional motion in the digging process and realised simultaneously along with the arm's move. The boom's hydraulic actuator is controlled by a computer, independently of the operator.

It was assumed in the research, that the arm's move is a source of the tangent component of the digging force - $R_T$ and the boom's move is a source of the normal component of that force - $R_N$ (fig. 1).

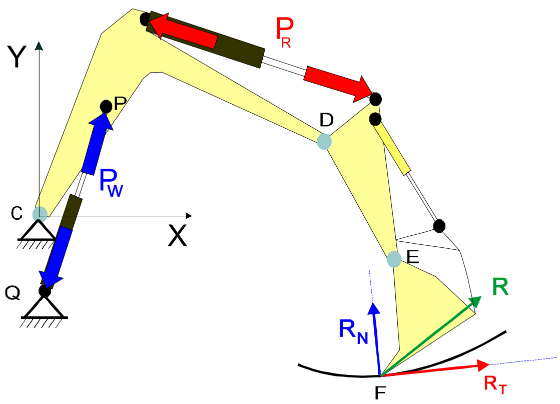


Fig. 1. Scheme of loading boom, arm and bucket

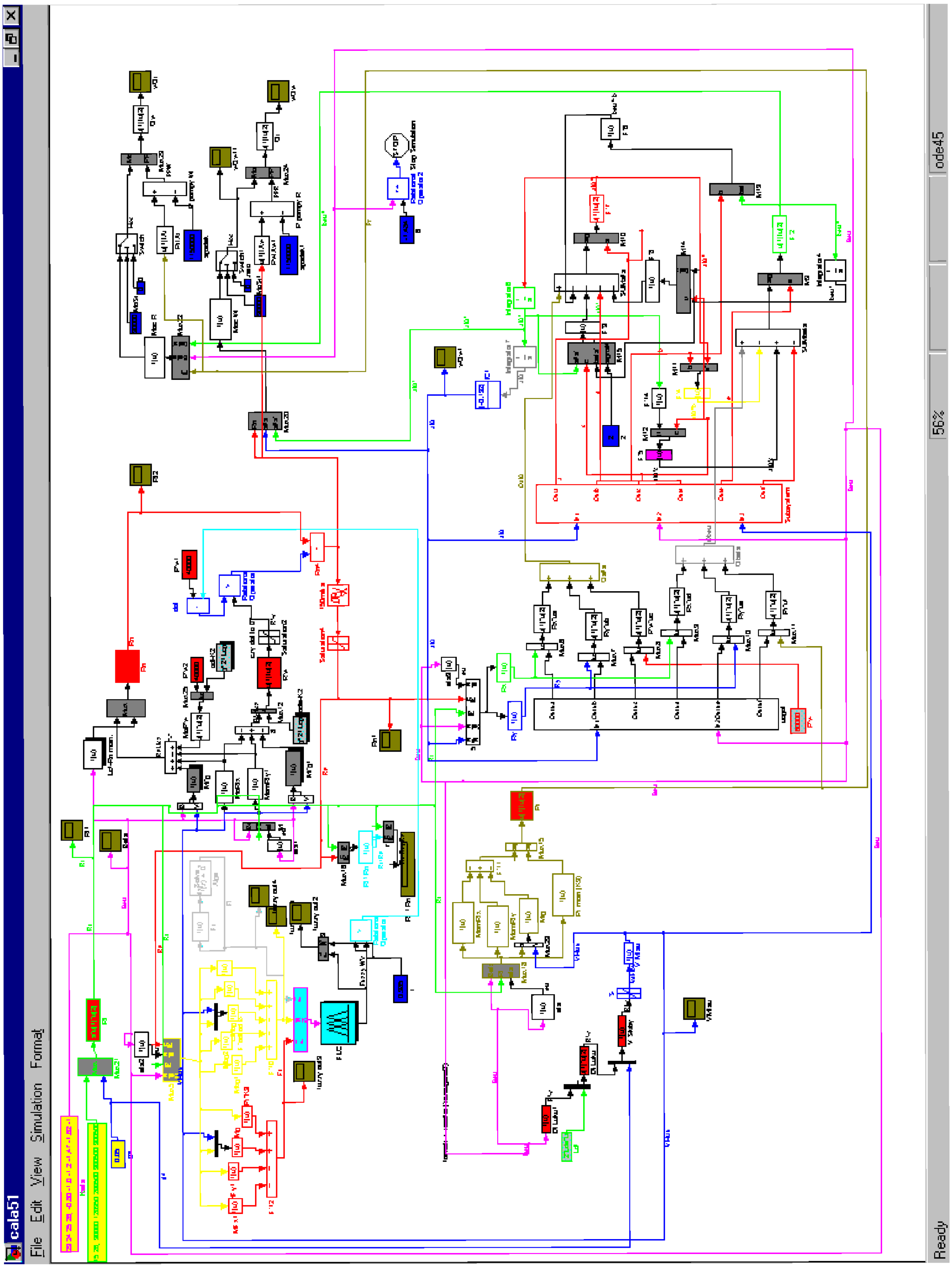


Fig. 2. Scheme of the excavator simulation program built based on *Matlab Simulink* program

In case of controlling the boom position, to maximise the effective power, optimisation is realised based on the state of the machine described by values of pressure in the actuators, the loading forces and a position of the boom, arm and bucket [2, 3].

## 3. DESCRIPTION OF EXCAVATOR SIMULATION PROGRAM

The excavator simulation program was build to verify efficiency of the digging force optimisation algorithm using fuzzy logic.

*Matlab 5.3 (R11)* program with interactive package *Simulink* - for modelling and simulation - was used as a tool to build the simulation program. The control system was created using the special program's library *Matlab – Fuzzy Logic Toolbox,* appropriate for programming controllers in the fuzzy sets space (fig. 2).

At the beginning of the program data containing the physical excavator parameters is entered. Then, the excavator load generated by the cutting soil process is provided. It represents the soil reaction acting at the bucket. This value is dependent on:

- thickness of furrow - slice,
- specific resistance of digging process

The arm's move is given as the default value. A soil reaction value and change of arm position (angle) represent the state of machine controlled by an operator where the main functional move is the arm's move.

An additional boom's move is feasible when reaction of the arm's move with the boom is smaller than a force, which can be generated in the boom actuator. Because of this, calculation of the reaction value is realised. The reaction value and a value produced by a force in the boom actuator are compared to check possibility of generating this motion.

The further step is calculation of the reaction $R_N$ acting at the bucket during the digging process. The actual values of the digging force are calculated based on a hodograph of the disposable loosening rock force (fig. 3). The given and counted values in the program are entered into the equations. Based on these equations the fuzzy logic controller (FLC) makes decision about additional motion of the boom. If this motion is generated by the controller, the digging force is composed of two components - tangent $R_T$ and normal $R_N$. If the motion is not generated by the controller then the digging force is created by the reaction $R_T$.

After inference done in the FLC, the program makes calculations related to dynamics of the excavator based on equations of the motion. It provides a base for calculating the power which is generated in hydraulic actuators of the boom, arm and bucket and connecting the mechanical parts with the supply system.

The supply system was modelled in the program from the point of view of checking capacity of the hydraulic system; for realisation simultaneous automatic moves of the arm and boom controlled by the operator and FLC.

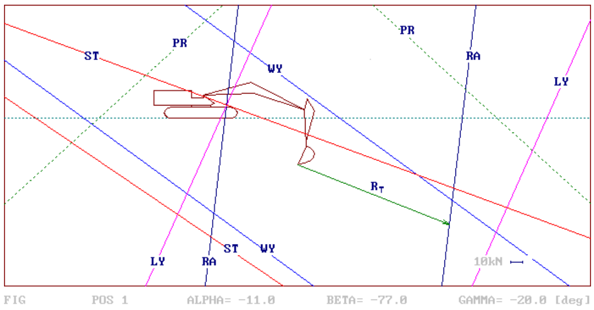


Fig. 3 The hodograph of the disposable loosening rock force

## 4. TESTING FUZZY LOGIC CONTROL SYSTEM TO GOVERN MOTION OF BOOM

A unit intended for simulation contains mechanical parts of the machine (boom, arm and bucket) and a power supply, assuring their moves. The computer simulation was realised based on the mathematical model of an excavator build for needs of this research. The simulation research was conducted for different input values of the program.

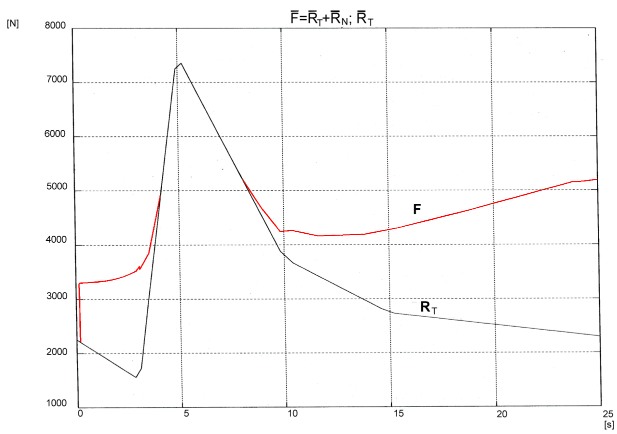


Fig. 4. I variant of excavator load [1]

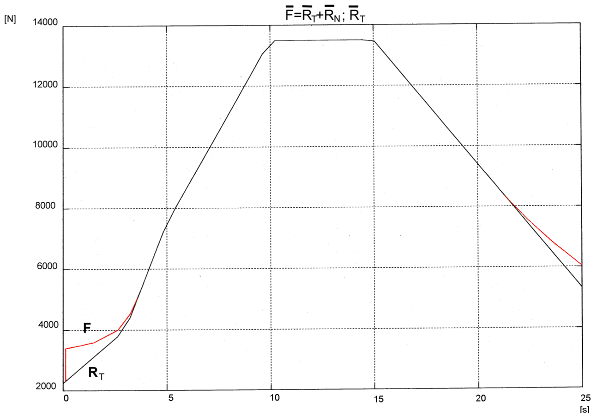


Fig. 5. II variant of excavator load [1]

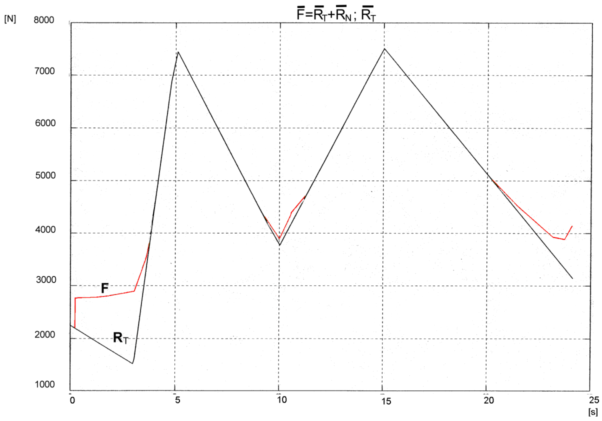


Fig. 6. III variant excavator load [1]

Optimisation of the digging force, controlled by the FLC, allowed to obtain smoother process of the force, what is especially visible on the graphs in places of sudden decrease of the load. The obtained graphs have smoother process and also loosening rock force reaches higher values that improve the excavator power efficiency. The acquired improvement of the digging force reached up to 120% comparing to the results when excavator was controlled without the computer (I variant).

Maximisation of the digging force falls through when the machine load is near its maximum (II variant), what is related to obtaining extreme values by variables in the member functions.

Additional motion of the boom is impossible in cases when reaction caused by the arm motion influencing the boom is bigger than a force, which can be generated in the boom actuator (I variant and III variant).

## 5. CONCLUSIONS

By formulating the optimisation criteria - maximisation of the digging force - the authors aimed at its implementation in the real work environment of an excavator. Because automation of functional motion requires complex control algorithms, a fuzzy logic control system was proposed.

A question asked, whether it makes sense to use a fuzzy logic controller for automating of excavator moves in order to maximise the digging force, has been successfully answered based on the conducted research.

Non-linearity of an object and difficult identification process do not stand in automation path when using a fuzzy logic controller. The linguistic notation of control rulers allowed for putting knowledge describing an object to the controller without needs to developing complex and energy consuming calculations.

An excavator during its work is applying changing loads, what is unfavourable to its durability. The changing loads are related to incomplete utilisation of the machine power.

A system created based on fuzzy logic and assumed criteria of optimisation profitably influenced reduction of these problems. Irregularity of excavated soil causes changes of the load what is partly compensated by using maximisation of the digging force.

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