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DESIGN AND SIMULATION OF HYDRAULIC EXCAVATOR MANIPULATOR SYSTEM

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Abstract

The focus of this paper is hydraulic excavator and its manipulator. As part of introduction to this paper, basic functions of hydraulic excavator are given. Special attention is on manipulator system, its parts and their properties, as well as types of links and joints between them in terms of defining its kinematics. After kinematics, short review of manipulator dynamics properties is presented. The main part of this paper is focused on modelling of hydraulic excavator manipulator system and simulation of its movement. Software tool used for model creation and simulation is Matlab Simulink. Each manipulator part (boom, arm and bucket) is made to be in correlation with one another and connected with hydraulic cylinders via rotating joints. The results of the simulation are presented through series of line charts, each presenting work of specific part of the model.

Key words: *hydraulic excavator, hydraulic manipulator system, simulation, optimization*

1. INTRODUCTION

Machine is defined as an apparatus using mechanical power and having several parts, each with a definite function and together performing a particular task [I]. *Hydraulic excavator* is a large machine for digging and moving earth [II]. As title itself suggests, the focus of this paper is on design and simulation. According to Oxford Dictionary *Design* is plan or drawing produced to show the look and function or workings of a building, garment, or other object before it is made [III] while *simulation* itself is imitation of a situation or process [IV].

2. STRUCTURE OF FUNCTIONS

The structure of the functions (Table 1.) describes in detail and in abstract way the total transfer function of the machine. Total transfer function of the machine (F) represents the process or technology of the machine operation. The structure of the functions is determined in such a way that total function of the machine (F) is split into partial functions (F_i) and then partial functions are split into elementary functions (F_{ij}) of the machine.
Total (primary) function (F) of hydraulic excavators is cyclical (interrupted) transport of land in a given work area. Regardless of size, primary function of any excavator consists of following partial functions (F_i): digging (excavating) land (F_1), land transfer from digging position to unloading position (F_2), unloading the land (F_3), and selection of new digger position (F_4).

Table 1. The structure of the functions of hydraulic excavator

Primary function F	Partial function F_i	Elementary function F_{ii}
Cyclical (interrupted) transport	Excavation	Excavation plane
		Excavation position
		Digging
		Excavation
	Transfer	Unloading plane
	Unloading	Unloading position
		Unloading
	Selection of new position	Working space

Elementary digger function (F_{ij}) can be achieved by using the excavating technique “towards itself” or “from itself”, which mainly depends of whether the working space is above or below the machine.

3. KINEMATIC CHAIN

Kinematic chain of the machine is an assembly of rigid bodies connected by joints (kinematic pairs) to provide constrained or desired motion with certain degree of freedom. Kinematic chain of excavator is consisted of the fifth class kinematic pairs, therefore joints have one rotational degree of freedom.

The base of the hydraulic excavator) represents a zero (fixed) member of the kinematic chain (L_0). Independently of the size of the hydraulic excavator, the kinematic chain is consisted of following members: support and movement mechanism (L_1), rotating platform (L_2), and the manipulator with boom (L_3), arm (L_4) and tool - bucket (L_5) (Figure 1.) which represents the last member of kinematic chain.

The centre of joint O_2 of the support member-rotation member kinematic pair (L_1-L_2) is the point of perpendicular intersection of the vertical axis of the joint through the horizontal plane which contains the centres of rolling elements of the slewing bearing that connects support member and movement member to the rotation member of the chain.

The centres of the manipulator joints O_3, O_4, and O_5 (Figure 1.) are the points of intersection of the axis of the joints through the plane of symmetry of the manipulator chain members (L_3, L_4, and L_5).

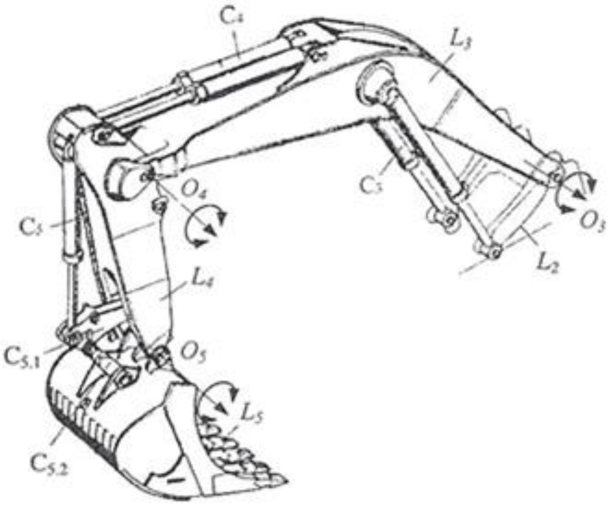

Figure 1. Kinematic chain of the hydraulic excavator [1]

3.1 **The Manipulator**

Manipulators represent the portable part of the kinematic chain of mobile machines that connects the support and movement member with the last member in chain the tool of the machine. The basic function of the manipulator is to enable the active operation of the tool to work in the specific work area of the machine. The manipulator chain, which is part of this hydraulic excavator (Figure 1.) is considered to be of planar configuration. The axes of the joints are parallel and the centres of the joints lie in the same plane which is the plane of the manipulator.

Three dimensional manipulation of the excavator is achieved by rotating the rotational platform (L_2) around the joint O_2, in both directions, relative to the support and movement mechanism (L_1).

Manipulators, whose elementary function is achieved by using the excavating technique “towards itself”, most often have four member in their kinematic chain: rotating platform (L_2), and the planar configuration consisted of boom (L_3), arm (L_4) and tool - bucket (L_5).

The boom (L_3), and with it, the entire device is lifted and lowered around the joint O_3. The joint is moved by the C_3 cylinder. At the top of the boom, there is the arm (L_4) that oscillates by work of the C_4 cylinder. The cylinder C_5 moves the bucket (L_5) indirectly via lever $C_{5.1}$ and coupling $C_{5.2}$ around the top of the arm (L_4). Excavation of land with the bucket (L_5) can be achieved by single or joint action of the C_4 cylinder and C_5 cylinder depending on the position of the manipulator. After that, the bucket (L_5) is lifted by the C_3 cylinder, with joint action of the boom (L_3) and its accompanied cylinders C_3 and C_4. In order to get to the unloading position the rotating platform (L_2), turns around fixed base of the excavator via joint O_2. At the desired position, the bucket (L_5) is emptied by the movement of C_5 cylinder. Returning to the point of excavation is achieved by aligning the action of all three cylinders with the turning of the excavator platform around joint O_2. (Figure 1.)

4. MODELLING AND SIMULATION

Analysis of complex systems requires the use of techniques consisted of modelling and simulation of that system. Modelling, as the word implies, consists of making a model, mostly mathematical rather than physical one. Mathematical model of complex system that has dynamic properties and uses numerical methods represents basic ground for simulation process. Simulation is the process of predicting the state of the real system by observing the model of that system in modelled conditions and working functions.

The process of simulation of excavator kinematic chain is consisted of defining [1]:

- the mathematical model of the excavator kinematic chain
- the mathematical model of the parameters of manipulator working movements, including trajectory of movement, partial and total time of movement, and correlation between kinematic chain and surface, as well as correlation between kinematic chain and working object

The assumptions of the mathematical model of the excavator kinematic chain are [1]:

- the support surface and kinematic chain members are modelled using rigid bodies
- during manipulation task the excavator is considered stable and not in movement in reference to the ground
- the kinematic chain of the excavator has an open configuration, bearing in mind that even though it has a closed configuration during digging operation it is still observed as an open configuration chain, whose final member – bucket is subjected to technological digging resistances

- during manipulation task, the kinematic chain of the excavator is subjected to gravitational, innate and external (technological) forces – digging resistances
- the position of the mass centre of hydraulic cylinder is in the middle of the current length of that hydraulic cylinder
- the influence of friction resistances is neglected in the kinematic chain and excavator drive mechanism joints

4.1 Modelling in Matlab/Simulink

Software tool used for this paper is Matlab/Simulink. Using SimMechanics the model of hydraulic excavator with corresponding model of hydraulic components has been developed. Rigid bodies are presented as convex surfaces because of Simulink restriction, with boom consisting of two welded convex surfaces. Any influence of this welding is neglected in the simulation process.
Used mass for modelling manipulator members and its mass moment of inertia are presented in Table 2. Since boom (L_3) is made of two rigid bodies ($L_{3.1}$ and $L_{3.2}$) and each of them has its mass and moment of inertia, they are presented separately in the table 2.

Table 2. The mass properties of the rigid bodies [2]

		L3.1	L3.2	L4	L5
Mass moment of inertia [kg m^2]	Ixx	8040.526	12051.898	4183.35	348.1
	Iyy	3853.743	27538.815	83253.75	94284.1
	Izz	1189.27	39590.713	87437.1	94632.2
Mass [kg]		1190	1810	1500	1000
		3000			

Simulink model of digging resistances to which bucket is subjected to is presented in Figure 2.

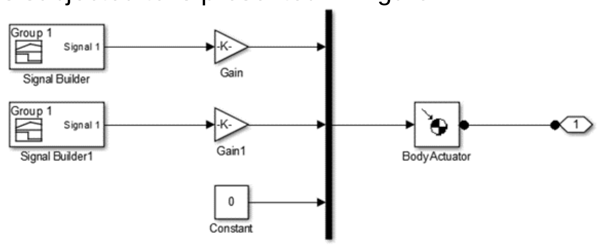

Figure 2. Simulink model of digging resistances [2]

Simulink model of hydraulic cylinders that move parts of the manipulator is presented in Figure 3.

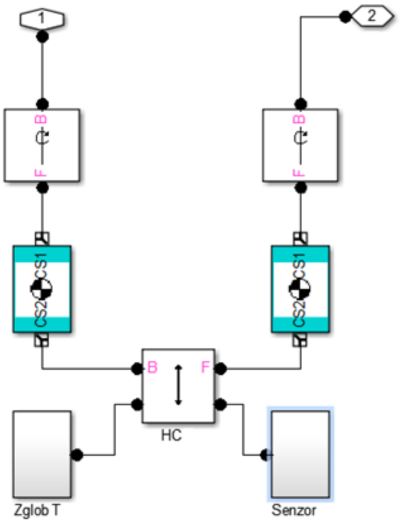

Figure 3. Simulink model of hydraulic cylinders [2]

Hydraulic cylinder are regulated by hydraulic system, whose Simulink model is presented in Figure 4.

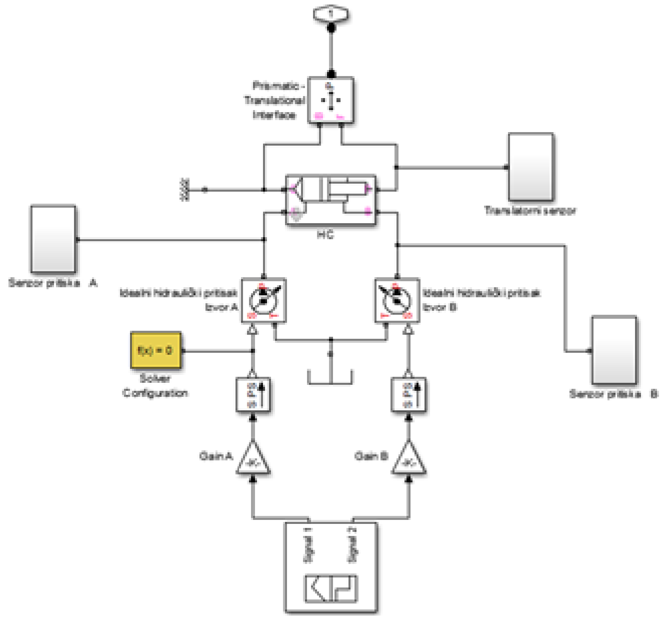

Figure 4. Simulink model of manipulator hydraulic system [2]

Simulink model of the manipulator kinematic chain of the hydraulic excavator is presented on Figure 5.

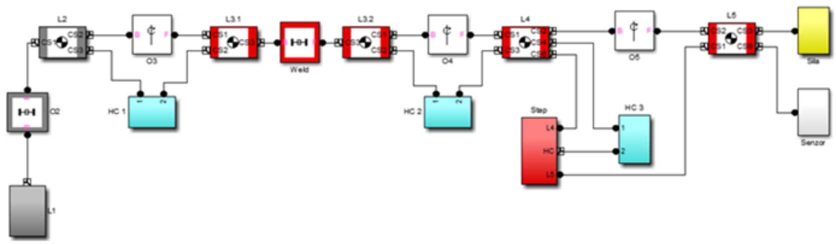

Figure 5. Simulink model of manipulator system of hydraulic excavator [2]

5. RESULTS OF SIMULATION

When simulation process is started, the simulation of manipulator movement is presented. Graphical chart of manipulator movement, presented via cutting edge point of the bucket, shows clear signs that the movement is two dimensional and that there is no movement in z-axis. (Figure 6.)

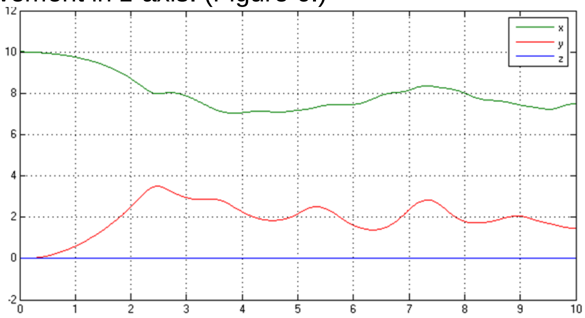

Figure 6. Trajectory of bucket (manipulate) in xy plane [2]

Data of hydraulic cylinders HC1 presented in Figure 7. indicate the force and movement data for joint O_3.

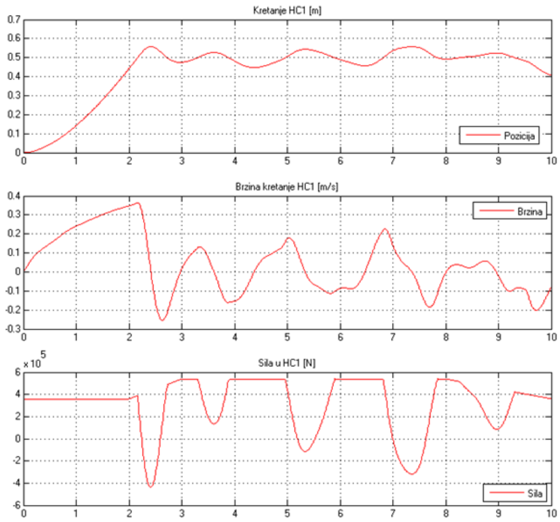

Figure 7. Trajectory, speed and force of joint O_3 [2]

Data of hydraulic cylinders HC2 presented in Figure 8. indicate the force and movement data for joint O_4.

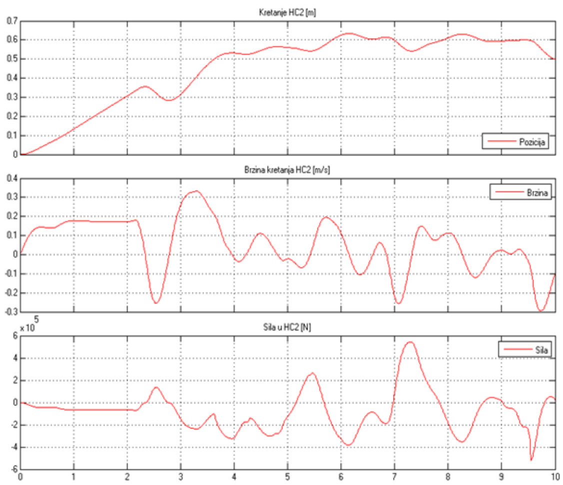

Figure 8. Trajectory, speed and force of joint O_4 [2]

Data of hydraulic cylinders HC3 presented in Figure 9. indicate the force and movement data for joint O_5.

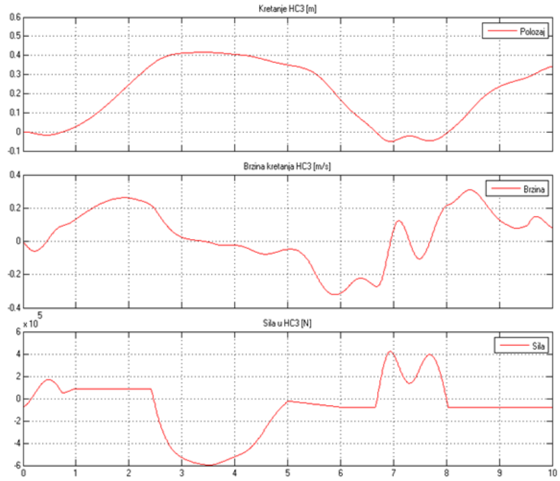

Figure 9. Trajectory, speed and force of joint O_5 [2]

6. CONCLUSION

This paper shows the use of Matlab Simulink for modelling and simulation of kinematic chain of hydraulic excavator. The focus of modern science and engineering today is in optimisation and improving the effectiveness of any given system. Thus, the model of hydraulic excavator shown in this paper, although simple and idealistic in its nature, represents starting point for further modifications and optimising in order to achieve greater effectiveness of hydraulic excavators.

7. REFERENCES

[1] Janosevic, D. (2006), "*Projektovanje mobilnih masina*", Masinski fakultet Nis, Nis, Serbia.

[2] Babovic, B. (2015), "*Projektovanje i analiza dinamike radnog uredjaja hidraulickog bagera*", Final Year Project, Faculty of Mechanical Engineering, University of Tuzla, Tuzla, Bosnia and Herzegovina.

[I] machine. 2017. In oxforddictionaries.com. Retrieved July 6, 2017, from https://en.oxforddictionaries.com/definition/machine

[II] excavator. 2017. In oxforddictionaries.com. Retrieved July 6, 2017, from https://en.oxforddictionaries.com/definition/excavator

[III] design. 2017. In oxforddictionaries.com. Retrieved July 6, 2017, from https://en.oxforddictionaries.com/definition/design

[IV] simulation. 2017. In oxforddictionaries.com. Retrieved July 6, 2017, from https://en.oxforddictionaries.com/definition/simulation