

The simulation model of the grapple loader operation

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Abstract. The main objective of the study was to develop a simulation model for the operation of the T-214 CYKLOP grapple loader using the MATLAB package. The created model allowed assessment of the behaviour of the real object in the operating conditions under variable loads and in the system overload. The simulation of the boom operation was carried out in four combinations: (1) at power take-off speed = 1000 rpm without load and (2) at 1000 kg load, (4) at power take-off speed = 540 rpm without load and (4) at 1000 kg load. The results show that the system works properly. The correct functioning of the system is evidenced by the fact that changes in force and acceleration occur on both pistons when only one of the cylinders is operating (the cylinder at rest acts as a shock absorber for the forces resulting from the inertia of the arms and the load). Apart from the increased forces on the pistons of the hydraulic cylinders, the additional load resulted in a slight reduction in acceleration values and an increase in the time needed to change the arm tilt angles.

1 Introduction

Currently, industrial production is showing an extremely dynamic development. This applies, to the same extent, to the manufacture of food products, cars or very precise specialised production machines.

This huge qualitative change is, *inter alia*, due to the manufacturers' efforts to satisfy as many different consumer needs as possible, as well as the globalisation of sales markets [1-3]. These two factors have led to the situation in which producers, in order to achieve market success, have to offer their customers not only the highest-quality goods but also need to ensure that such goods fulfil as many functions as possible and that they will always be regarded as modern products.

Furthermore, each manufacturer strives to shorten the time of developing a new product: from the time when the demand is generated to the design, creation and testing stages. Nowadays, manufacturers do not wait for the new customer needs to emerge but create such needs by marketing new products. The continuous development of information technology and computerisation of design processes have also allowed them to shorten the product testing time. Modern highly efficient computers support engineering programs and allow producers to merge multiple – thus far separate – stages of the product development process consequently reducing their cost.

One of the examples of such a program is MATLAB and its extensions [4-8]. It is a software package for

creating and testing virtual systems modelled on real objects. With its ability for cooperation and free data exchange with many other programs, as well as the ease of its use, high performance and a huge number of functions, it has become the most popular design and testing program in the world. The advantages of using it are undeniable, and it is also certain that this type of software will become increasingly important in the future.

The main purpose of this paper was to develop a simulation model for the operation of the T-214 CYKLOP grapple loader using the MATLAB package. The grapple loader is intended for loading and unloading transport vehicles (sand, gravel, mineral fertilisers, lime, manure, straw) to be used in agriculture and transportation [9, 10]. The model will assess the behaviour of the real object in the operating conditions with variable loads and overloaded system, which will determine properties of the real object and select and verify the settings that ensure optimal behaviour of the object [11-22].

2 Materials and method

The subject of this investigation is the arm (boom) of the grapple loader. The loader is coupled with an agricultural tractor by means of a lower agricultural coupling and powered by the tractor output shaft. The loader boom (Fig. 1) consists of two steel arms connected with a bolt, which allows their free rotation,

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limited by the stroke of hydraulic cylinders. The first arm is attached to the rotating body and supported by an actuator. The second one is connected to the first by means of the pin and the hydraulic cylinder, at its end is attached to the selected working tool (gripper for loose materials, root crops, grass plants or manure).

Analyses were performed using a part of the MATLAB - SIMULINK mathematical package, used for modelling, simulation and analysis of dynamic systems. It is a powerful solution which handles both linear and non-linear systems modelled in continuous, discrete or hybrid time, in which one part of the system operates in discrete and the other in continuous time [23-25]. Simulink is capable of building simulation models using the graphical interface and the so-called blocks. Simulink is mainly used (due to the fact that it enables continuous simulations) in digital signal processing, analysis of electrical circuits and control theory [26-30].



Fig. 1. The boom of the T-214 “CYKLOP” grapple loader.

The finished simulation model (Fig. 2) consists of separate blocks, *i.e.* the simulation models of the boom performance elements, such as control elements, actuators and boom arms. Moreover, oscilloscopes are added to the model in order to display simulation results and simulation visualisation developed in the Virtual Reality Toolbox.

The created models were based on calculations and the kinematic analysis.

The analysis was performed assuming that the dimensions of the adopted cells are fixed, and the stiffness of these cells is infinitely large. The purpose was to determine the position and trajectories of movement of characteristic points (A, B, C and C'), as well as their velocity and accelerations (Fig. 3).

The simulation of the boom operation was carried out in four combinations:

- at PTO speed = 1000 rpm without any load and with a load of 1000 kg,
- at PTO speed = 540 rpm without any load and with a load of 1000 kg.

3 Results

As a result of the simulation, charts were developed, as recorded in the windows of the oscilloscopes, and visualisation was created in the Virtual Reality Toolbox application. The latter is not an artificially created animation and the movements of the performance

elements depend on the operation of the models responsible for them (Fig. 4). Repeatability and smoothness of the arms movement during each test of the boom model allows us to conclude that it works correctly and the obtained results are reliable.

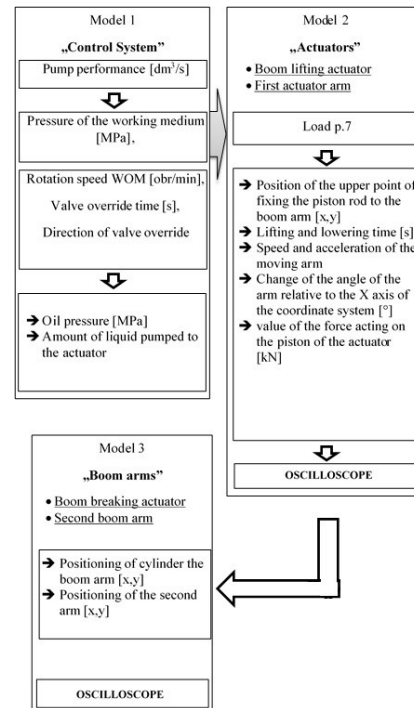


Fig. 2. The structure of the grapple loader.

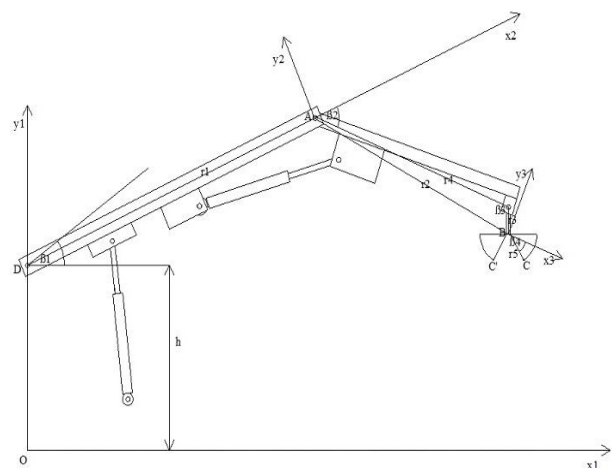


Fig. 3. Simulation model of the grapple loader.

For each case, two graphs were obtained, showing:

- the control signal,
- the angle of inclination of the arm to the OX axis,
- the value of the rotational speed of the arm,
- the value of force on the actuator piston responsible for the movement of the arm.

Each time, the simulation was carried out repeatedly, and the results obtained were fully comparable. Accordingly, it can be concluded that the created models

operate correctly and reflect the behaviour of the original model.

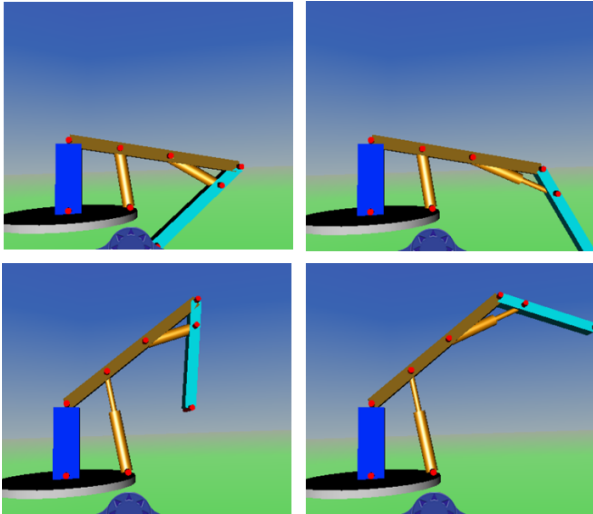


Fig. 4. Visualisation showing extreme positions of the boom arms.

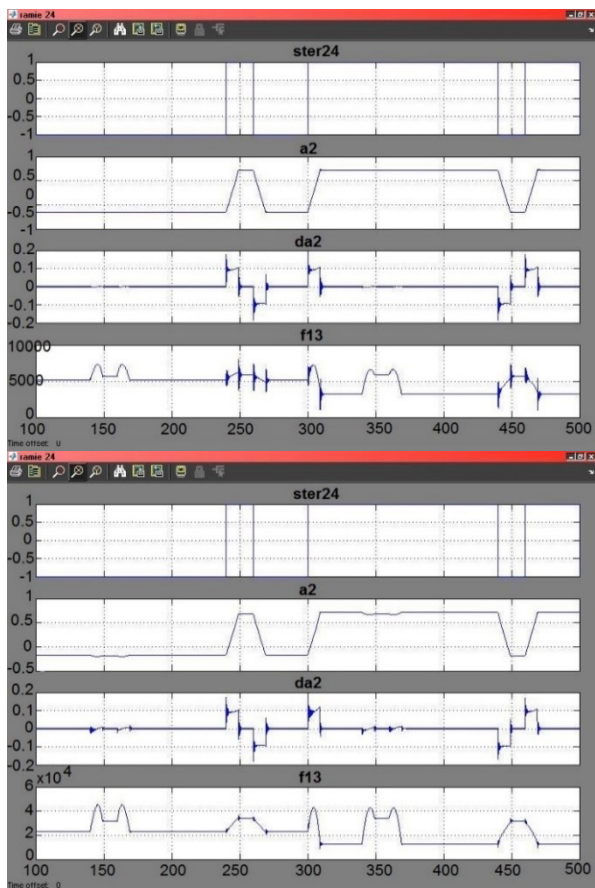


Fig. 5. Parameters of movements of arm 24 at PTO = 1000 rpm, at the top: without any load, at the bottom: with a load = 1000 kg: ster24 - control signal; a2 - inclination angle of the arm to the OX axis; da2 - value of the rotational speed of the arm; f13 - the value of force on the actuator piston responsible for the movement of the arm.

Moreover, the conducted analysis took into account the results of laboratory measurements available in the literature. For example, comparisons of the grabbing

forces between calculated and measured forces are shown in [31].

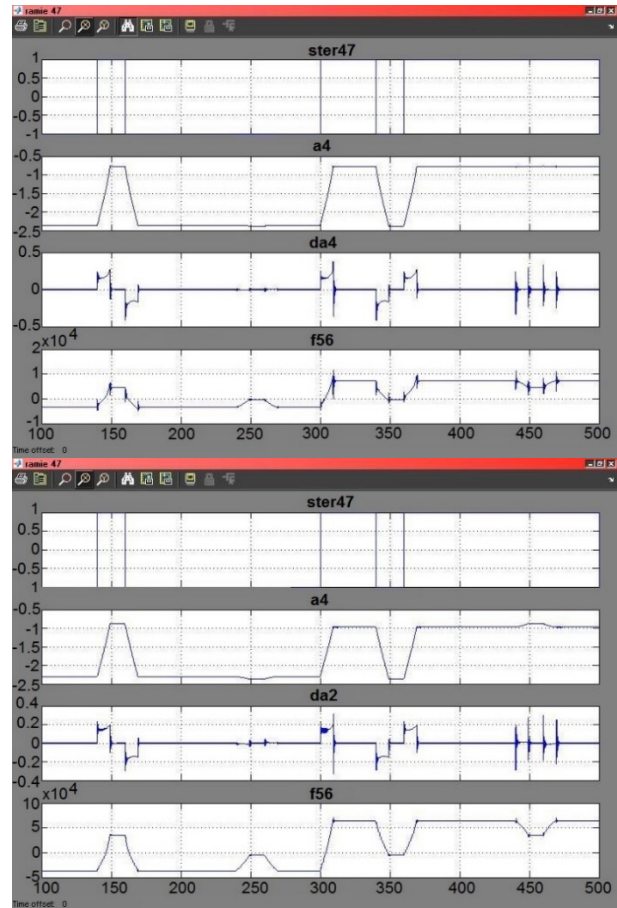


Fig. 6. Parameters of movements of arm 47, at PTO = 1000 rpm, at the top: without any load, at the bottom: with a load = 1000 kg: ster47 - control signal; a4 - inclination angle of the arm to the OX axis; da2 - value of the rotational speed of the arm; f56 - the value of force on the actuator piston responsible for the movement of the arm.

Based on the graphs developed for the first case, it is evident that the system works properly (Fig. 5). The system reacts correctly to the control signal, once the signal is there, the force acting on the piston of the actuator appears and the actuator begins to move, as evidenced by the acceleration and the change in the values of arm inclination. It is also clearly visible that when the control signal changes, the system stabilises (the arm falls completely or rises to its maximum height - no changes of the "a" angle), acceleration reaches zero and the force on the piston also stabilises. The correctness of the system operation is also evidenced by the appearance of changes in the force and acceleration on both pistons when only one of the cylinders is in operation (the cylinder at rest acts as a shock absorber of forces resulting from the inertia of the arms and load). This is evident at time $t = 350$ and $t = 450$. At time $t = 350$, arm 47 straightens with the raised arm 24, it is clearly visible that when the actuator starts working, some of the forces are transferred to the cylinder. Similarly, at time $t = 450$, the raised arm 24 lowers, with

the straight arm 47, and the force on the actuator visibly decreases.

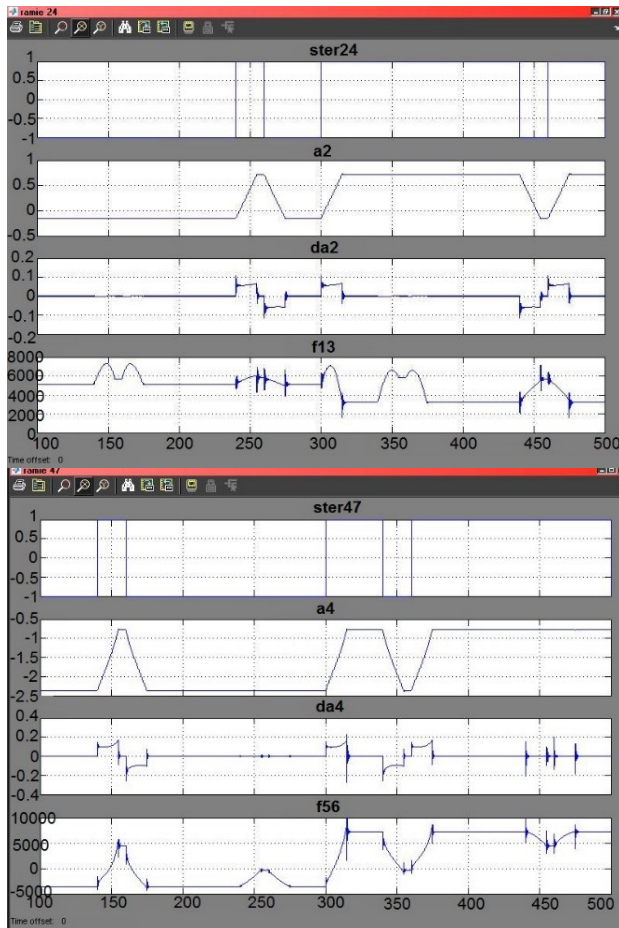


Fig. 7. Parameters of movements of arm 24 at PTO = 540 rpm, at the top: without any load, at the bottom: with a load = 1000 kg: ster24 - control signal; bottom: with a load = 1000 kg: ster47 - control signal; a4, a2 - inclination angle of the arm to the OX axis; da2, da4 - value of the rotational speed of the arm; f13, f56 - the value of force on the actuator piston responsible for the movement of the arm.

The graphs also show that in addition to the increase of forces on the pistons of the hydraulic cylinders, additional load also caused a slight decrease in the value of accelerations and increased times of change of arm tilt angles.

In the second case described, the PTO speed was reduced to 540 rpm (Fig. 7 and Fig. 8) and the system exhibited stability and repeatability, which evidences the same properties, hence confirming its credibility.

The only differences shown by the PTO driven system with a reduced number of rotations result from the smaller pump output, and thus the reduced pressure in the hydraulic system. This can be clearly observed in the increased time of maximum extension of hydraulic actuators.

4 Summary

The paper presents the process of developing a virtual model of a real machine using MATLAB software and the Simulink and Virtual Reality Toolbox applications. Developing each model, including the virtual one,

requires certain simplifications, i.e. omitting elements that have a marginal impact on the final result and make the model unnecessarily complex (such as the impact of wind force, atmospheric pressure, non-perpendicular machine positioning in relation to the ground, etc.).

The scope of the simulation included mapping the operation of the loader boom. It was divided into key elements (actuators and boom arms), which were presented in the form of models. The models obtained in this manner, after connecting them, were used to create the boom model.

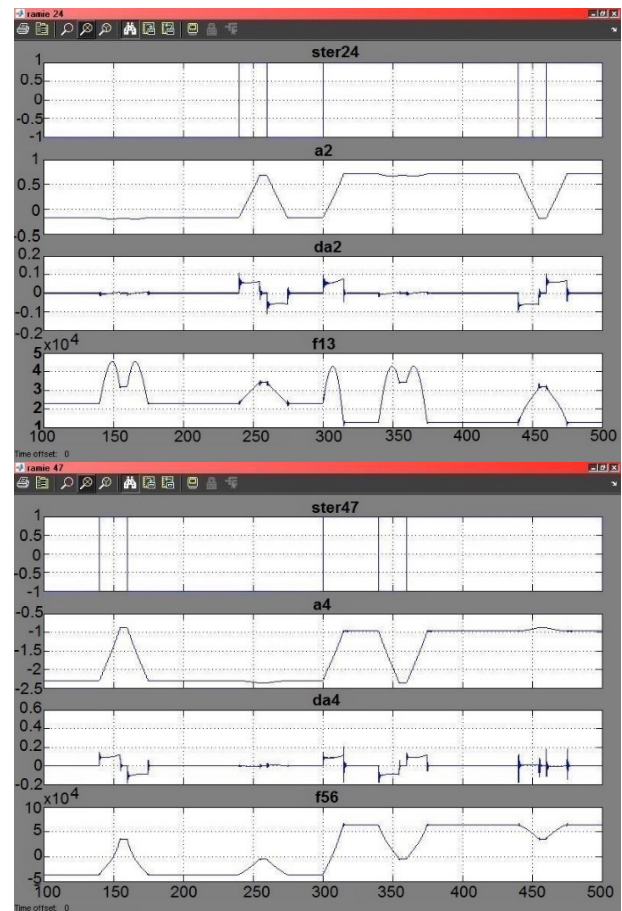


Fig. 8. Parameters of movements of arm 47 at PTO = 540 rpm, at the top: without any load, at the bottom: with a load = 1000 kg: ster47 - control signal; bottom: with a load = 1000 kg: ster47 - control signal; a4, a2 - inclination angle of the arm to the OX axis; da2, da4 - value of the rotational speed of the arm; f13, f56 - the value of force on the actuator piston responsible for the movement of the arm.

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