About Computer Tools Available for Dynamic Analysis of Mechanic and Hydraulic Systems of the Loader Bucket

Prof. Dr. Eng. **Carmen Nicoleta DEBELEAC**[1,*]

[1]"Dunarea de Jos" University of Galati, Engineering and Agronomy Faculty in Braila,

Research Center for Mechanics of Machines and Technological Equipments

* carmen.debeleac@ugal.ro

Abstract: *The paper focuses on modelling and simulation a feedlot bucket (0.7 m³ capacity) from skid steer loader, with hydraulic acting, using specialized engineering computer-based environments. It was highlighted the capabilities of these design tools by exemplifying some case analyzes (drawing 2D and 3D shape of component elements, testing the mechanical resistance, evaluating the kinematic parameters, building the hydraulic circuit in order to simulate the system behavior).*

Keywords: *Feedlot bucket, hydraulic cylinder, dynamics, simulation, Matlab*

1. Introduction

Modeling and simulation constitute powerful tools which permit designers to test the complex systems and processes using virtual environments instead of real experiments. Moreover, numerical simulation becomes indispensable when the designers coupled multi-disciplinary systems, where different components (mechanical, hydraulic, pneumatic etc.) work together to obtain optimal responses in exploitation. Thus, computer-aided systems for industrial area of product development have been widely developed during the last two decades. Specialized CAD applications, like Catia, Nastran, Solid Edge, Solid Work, Inventor etc., improving quality of the work environment, allowing engineers to quickly manufacture prototypes [1-3]. Basically, the product form (as 3D technical design) is imported from the CAD environments and transferred to the CAE environments in order to analyze it's for static or/and dynamic behavior.
In this paper, it is provided a brief overview of some computer applications that allow testing of driving mechanism of the feedlot bucket usually mounted as attachment on the wheel loader. In Figure 1 representative examples of these kind of buckets are shown.

Fig. 1. Examples of feedlot buckets for hydraulic loader [4-6]

These feedlot buckets feature clamps, actioned by one or two hydraulic cylinders, to allow large capacities of irregular shaped of materials (e.g., logs, construction materials resulting from demolitions, round bales etc.), to be handled efficiently and accurately for gripping, loading, sorting and transport. The drive mechanism for clamp motion (hydraulic cylinder / actuator) will be involve for better understanding of possibilities to analyze it using computer-aided methods [7,8].

2. Conceptual design for feedlot bucket

Equipment design focuses on the basic conceptual principles taking into account the actual desideratum: to be able to perform working specific requirements with maximum economy and efficiency. Starting from these aspects, a basic constructive solution of a virtual prototype of feedlot bucket (with 0.7 m^3 capacity) it was drawn in Figure 2.

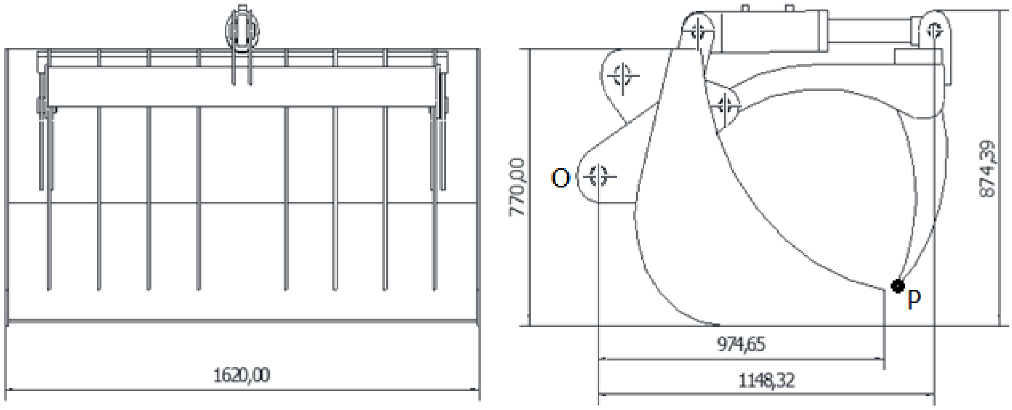


Fig. 2. 2D technical drawing of feedlot bucket

To operate the feedlot bucket, it is required a skid steer loader (as base machine) with power P_m = 45 HP and angular speed n_m = 2400 rpm, able to provide a minimum flow of 2 m^3/h for attachment driving. The model of pump with constant parameters will be assumed, functioning at 200 bar pressure. The discharge valve acts as a protection of the circuit when the maximum value of the working pressure is exceeded (preset to 115 bar).

2. Dynamic simulation of the feedlot bucket

The components of the bucket were three-dimensional designed and assembled in the Autodesk Inventor software, for analysis of model motion containing constraints between bodies, contacts, forces, and actuator [9]. In order to simulate the functionality of the bucket ensemble, a group of main parameters (Table 1 and 2) are required to be set within the dialog box through the values entered by the users.

Table 1: Operational parameters of feedlot bucket

Parameter	Value
Overall load bucket	9000 N
Bucket capacity	0.4 m^3
Bucket width	1.6 m

Table 2: Cylinder feedlot bucket properties

Parameter	Value
Diameter	50/32 mm
Stroke cylinder	0.156 m
Pressure	115 bar
Piston velocity	0.052 m/s

Testing the functionality of clamp mechanism before it will be physically achieved is a very simple process with help of computer simulation. Thus, 3D CAD model will be transferred to the *Dynamic Simulation* module of Inventor environment, the loads that acting on bucket will be setup with the help of specific tools, and the responses will be gained as evolutive diagrams, by sets of specific values or directly in graphic representation forms, as it can be seen in Figure 3.
Design revisions are easier to perform if motion problems are identified before practical achievement of the physical assembly of feedlot bucket. In addition, with help of *Dynamic*

Simulation module capabilities it can be easily solve a lot of problems regarding the kinetics of structural elements of analyzed mechanical system.

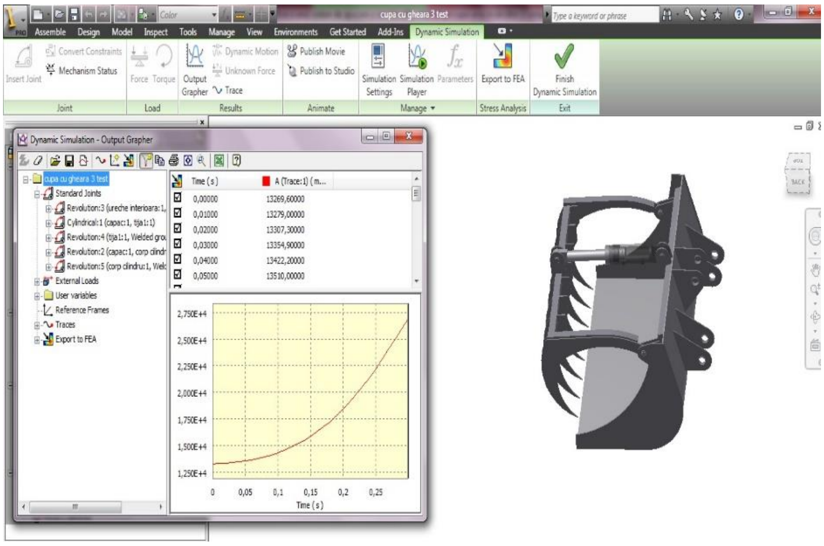
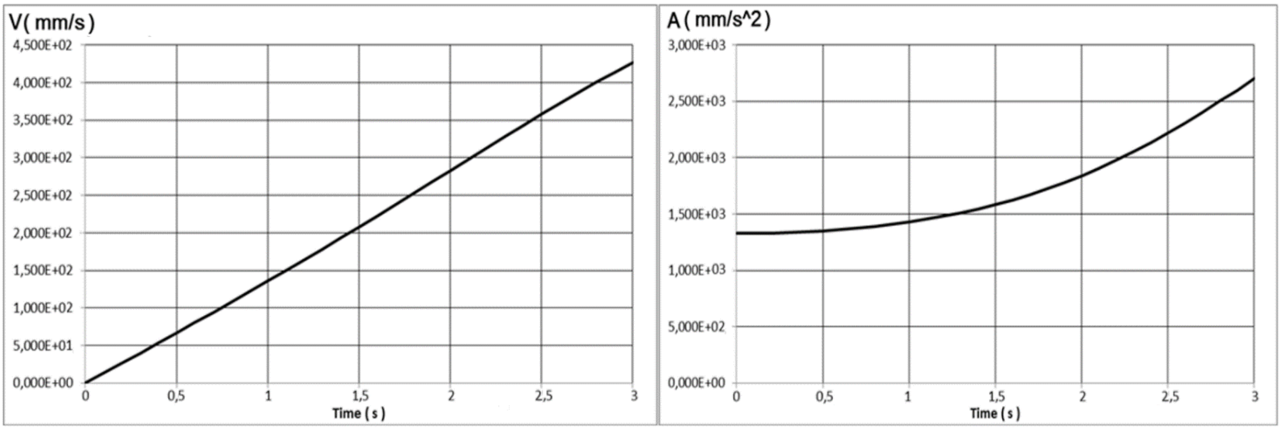


Fig. 3. Feedlot bucket model implemented in Inventor environment

Therefore, using the module dedicated to kinematic analysis, in *Dynamic Simulation* module within Inventor, it is possible to evaluate the values of specific parameters (e. g. speed, acceleration etc.) for the elements in motion, as parts of the assembly. As example, it was considered an extreme point on the clamp (see point P in fig. 3) for which it was evaluated the speed and, respectively, the acceleration. The graphic representation of time variation of these parameters is given in Figure 4.



a) b)

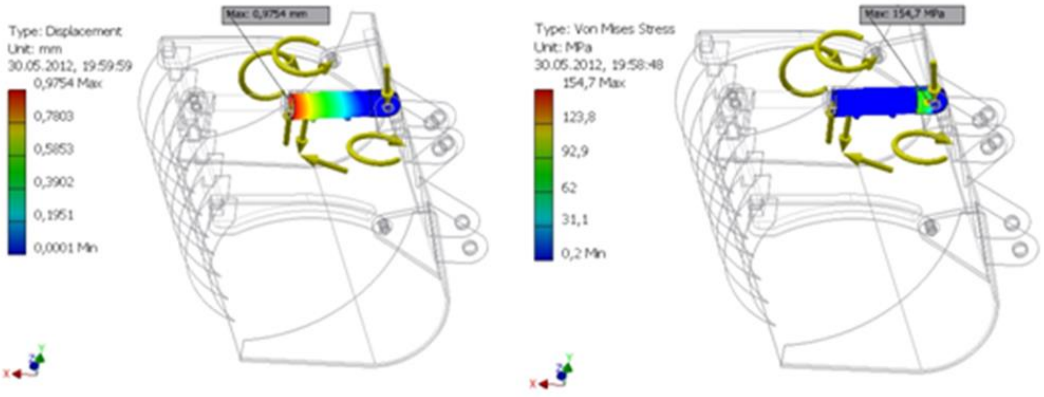
Fig. 4. Kinematical parameters of end of clamp (in terms of timed evolution):
a) velocity; b) acceleration.

The results give the numerical information that is necessary to fully understand the dynamic evolution and the operational performances of the clamp design. As you make the initial design results that, through systematically step-by-step model changes, you can compare initial with actual datum, in order to verify design improvement. If we change the velocity of the piston movement in extension stroke, the clamping elements will acquire different kinematical parameters and, respectively, the cycle time for operational tasks with the feedlot bucket will be adjusted.

The next step, after the dynamic simulation of the motion bucket, supposes that the previously created model will be exported to the FEA module, using the *Export to FEA option* from the *Dynamic Simulation module*. The aim is to analyze the acting element consist on hydraulic cylinder (linear actuator), in order to verify its mechanical stress (see Figures 5 and 6).

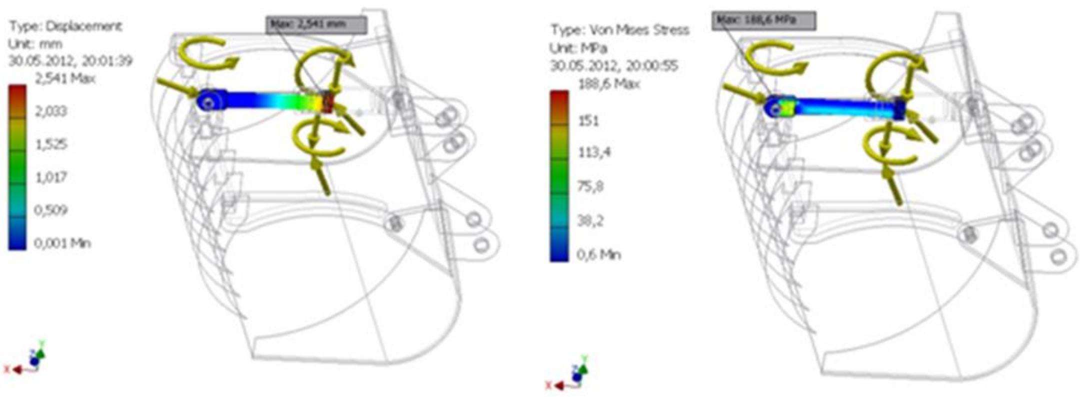
By discretizing the model, using the *INVENTOR / FEA* specific option, a total of 1284 elements and

2536 nodes were result. Mechanical properties of material ASTM A572used for FEM analysis are: density: 785 kg/m^3; Young's modulus: 199947.96 N/mm^2; Poisson's ratio: 0.29; yield point: 290 MPa; tensile strength: 415 MPa. After the boundary conditions were established (revolute joints for both ends of cylinder and cylindrical joints for piston), the individual parts of the cylinder (rod and barrel) were analyzed.



a) b)

Fig. 5. FEM analysis results from actuator's barrel:
a) displacement; b) Von Mises Stress.



a) b)

Fig. 6. FEM analysis results from actuator's piston rod:
a) displacement; b) Von Mises Stress.

The finite element analysis was conducted in order to estimate the behavior of clamp cylinder when loads were applied, along with boundary conditions [10]. Results obtained from the simulation, for both main parts of the clamp actuator, were centralized in Table 3.

Table 3: FEM simulation results

	Displacement [mm]		**Von Mises Stress [Pa]**	
	Barrel	**Piston rod**	**Barrel**	**Piston rod**
Min.	0	0	0.2	0.6
Max.	0.9754	2.541	154.7	188.6

The verification of the clamp actuator model (both FEA and dynamic simulation) is a necessary process to assure that this model is correctly designed and implemented [11,12]. As can be seen, the obtained results conduct to model validation at this stage, but its optimization according to the imposed criteria is not excluded in the future.

3. Simulation of the hydraulic system behavior for clamp bucket acting

A simple configuration of a hydraulic system mainly comprises a few basic groups of components, interconnected to perform a specific function, as: hydraulic power supply, control elements, actuators and other auxiliary elements. Matlab is one of the most popular and recognizable program for constructing simulation models with different types of power transmissions (e. g. hydraulic, pneumatic, mechanic, electric, electronic etc.). Starting from this idea, the cylinder actuation system in Matlab/Simscape environment can be performed through the step-by-step model building. If we want to connect the hydraulic system to mechanical system, then we can build a simple scheme (see Figure 7), by dragging the predefined blocks from the Matlab libraries.

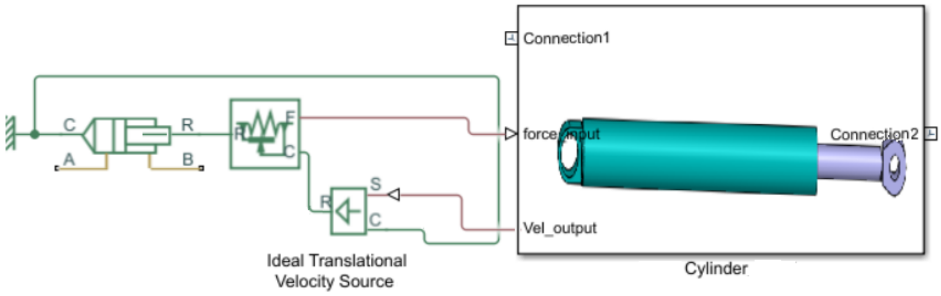


Fig. 7. Connection of the cylinder in mechanical system

An example of an actuation scheme, for the clamp driving cylinder and considering that this is a part of the front loader attachment [13], is presented in Figure 8.
The model contains the basic components required by the hydraulic drive system of these type of heavy machine (e. g. motor, pump, directional valve with 6 ways and 3 positions, actuator, control device, fluid, pipelines). The pump is driven by a diesel engine simulated with a model that takes into account the change in speed caused by the load on the output shaft. All blocks are controlled by the same position signal, provided through the physical signal port *S*. The clamp actuator is controlled by an open center directional valve.

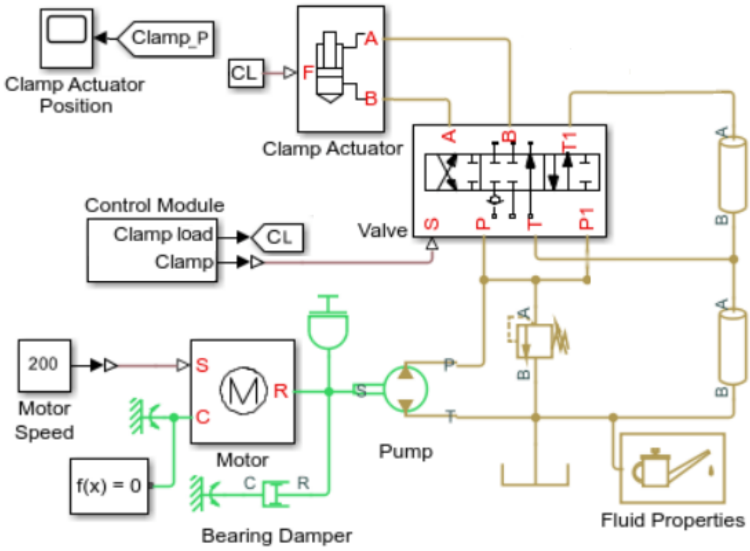


Fig. 8. Actuation system of clamp cylinder simulated in MATLAB/Simscape environment

The actuation system is simulated with the motion and load commands generated as a function of time (see *Clamp load* and *Clamp* as input signals in *Control Module*, fig. 8) that have particular laws depending on the characteristics of the base machine (loader, excavator, tractor etc.), on the inertial forces of working equipment being in motion (tilt / lift), on the operational load etc.
Thus, the hydraulic actuator draws oil flows (denoted Q_A and Q_B in fig. 8) and provides mechanical displacement to the clamp of bucket. By changing the parameters in above scheme (such as

pressure, pipe diameters, piston area, stroke, different fluid types etc.) we can find the optimum parameters values of the hydraulic system in order to be fulfilled the operational requirements at high performance [3,10]. The dynamics of the mechanical system is affected by the mass variation of the moving elements (e. g. clamp) and the external forces acting at working tool. Therefore, these parameters must be estimated carefully if dynamics of the system has the highest priority. In addition, the valve response time can be crucial for fast dynamics and longtime of the valve response must be avoided (only for particular cases when a certain rotation speed is required for feedlot bucket). Furthermore, another important parameter that alters the system dynamics is represented by the bulk modulus and this must be carefully evaluated during the modeling and simulation processes.

4. Conclusions

A feedlot bucket acting the clamp by a single hydraulic cylinder was successfully designed and analyzed using dedicated software that is able to provide necessary information in order to manufacture this attachment on the hydraulic loader instead of basic bucket. Thus, *Dynamic Simulation module* and *Export to FEA* was two powerful instruments useful for hydraulic cylinder analysis, providing results in order to validate the proposed solution, both from the point of view of functionality and operational safety. Testing of the hydraulic system can be performed in the specific programming environment (Matlab, in the present case). Having predefined the main hydraulic elements, the model of hydraulic scheme become easily to build only by taking over the symbols in libraries and drawing the connections between added elements within the diagram. This software application allows deeply investigation of the characteristics of the hydraulic system that are acting the working tool (e. g. feedlot bucket) and gives useful information about operational efficiency, system stability, time response to the commands etc.
The aspects presented in this paper highlight computational tools for 3D generating of geometric forms, intended for evaluation of its dynamic behavior and for comparing to the objective functions usually used in optimization process (such as: mass minimization, easy execution technology, short manufacturing time, high reliability, short time response etc.).

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