Design and analysis of side dump bucket for wheel loader using CAD/CAE/CAM technologies

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Abstract. In this paper the author presents a wheel loader equipped with side dump bucket modelled with modern technologies used in mechanical engineering fields (SolidWorks, Femap and NX 11 manufacturing). The various behaviours that acting on the bucket during technological process were analysed with finite element method. The obtained results validate appropriate dimensioning of main elements of bucket ensemble in proposed constructive variant.

1. Introduction
In many applications at construction, mining and other industrial environments, it is reasonable to use the loader as multipurpose machine. Our days, a variety of attachments for loaders are available on the market for increased their functionality.

In this paper, for an industrial project we wanted to verify and validate the design analysis concept of the side dump bucket mounted on the wheel loader by using of the modern methods of design (CAD/CAE/CAM technologies) as modern tools that allow to efficiently conducting the time-consuming and costly stages in the process of creating a new product [1–5]. In addition, with help of these software it can create a database of documentation according to the standard ISO 10303-21:2016 - Industrial automation systems and integration.

2. CAD modelling of the side dump bucket attachment
As is known, the CAD software is used to generate surfaces and volumes, analysis processing (mass, moment of inertia) and create various geometry formats that can be imported by other tools (CAE, CAM etc.). Firstly, in this industrial project, for building of a complex geometrical model and handling all the elements to be integrated, it is important to have an opened geometric model of the loader bucket.

The solids are parameterized, and the model is controlled and monitored by a set of formulas, checks and rules. A system of checks has been implemented to monitor the integrity of the geometry and dimension specification after changes. Solid Works is the often used to design 3D model of the main pars of the wheel loader. For the beginning, the sequence of operations required to achieve the bucket is presented and illustrated (figure 1) in the following:

- cutting the size of the sheet forming the outside of the bucket;
- bending the sheet to form the bucket profile;
- unsymmetrical lateral cutting of the sheet at an angle of 40º;
- forming the side walls of the bucket;
• making the eyelets on the equipment frame;
• creating a support for gripping the hydraulic cylinder to drive the bucket.

**Figure 1.** 3D CAD model of the loader’s bucket.

The three-dimensional modeling steps of the component elements of the bucket support system on the basic machine chassis are shown in the figure 2.

**Figure 2.** 3D CAD model of the frame’s bucket.

According to the relationship between the loader components, the parts are assembled taking into account by the constraint conditions in SolidWorks assembly. Assembly model is shown in figure 3. The side bucket is mounted instead of the standard bucket, thus expanding the range of tasks performed with this construction equipment.

**Figure 3.** Assembly of the wheel loader with side dump bucket.

Conceiving the final shape of the side dump bucket was a process consisting of several intermediate phases resulting from modifying constructive parameters, boundary constraints or kinematic analysis. This aspects it were possible because the great advantage of these CAD systems that consist on their ability to permit changes to the models (dimensions or shape), in a relatively fast way, without the need to reconstruct the entire model again. This fact is important in the increase of productivity and quality in relation to component development, in that more alternatives can be analysed, in regard to the available time period for the development of the project. Other advantages of the 3-D solid modeling are: better visualization, easy creation of the cross-sections and auxiliary views, can evaluate weight, center of gravity, inertia, design for assembly, easy assembly creation for checking interferences in three dimensions, and improved interfaces with other disciplines which is very important for the integration of all phases of the product within the CAD/CAE/CAM.
environment. From CAD program the models can be exported as .DXF File and, respectively, from CAM program as .NC File to CNC machine.

3. **FEM analysis of the loader bucket**

Today, the modal analysis is a procedure to find the existent dynamic characteristics of any mechanical structure in form of mode shapes, natural frequency and damping factors so that we can generate a mathematical model for its dynamic behavior. Once the parts model of mechanical structure were created, it can be used FEM analysis. Thus, on the basis of the data of the 3D solid modelling of the bucket loader modal analysis will be required. The following assumptions for the modal analysis of the bucket were made: the model has stable hardness and rigid-body motions. As results, in the figure 4 are shown the five lowest mode shapes of the bucket.

![Figure 4. Lowest mode shapes of the side dump bucket.](image)

Both characteristics of dynamic behavior of the bucket, such as natural frequencies and higher displacement amplitude developed for these five mode shapes are centralized in table 1.

| Mode shape | Frequency, [Hz] | Amplitude max.,[mm] |
|------------|----------------|---------------------|
| 1          | 10.69          | 0.105               |
| 2          | 27.85          | 0.143               |
| 3          | 37.92          | 0.078               |
| 4          | 52.05          | 0.140               |
| 5          | 62.62          | 0.242               |

First 5 mode shapes are determined, natural frequencies (f = 10 Hz – 65 Hz) are calculated and, respectively, the displacement amplitude has values between 0.1 mm – 0.242 mm. The frequencies of the bucket are situated in the lower spectrum area which is significantly distant from the spectrum area where the frequencies generating resonance and structural damage of any external force are situated (that appear to impact with an obstacle, quickly discharging of material etc.). Furthermore, the FEM analysis enables the response of the bucket model to three practical situations during charging process:

| Property name               | Value          | U. M.    |
|-----------------------------|----------------|----------|
| Density                     | 7850           | kg/m³    |
| Longitudinal elastic modulus| 2.1x10¹¹       | N/m²     |
| Transversal elastic modulus | 8.1x10¹¹       | N/m²     |
| Yield strength              | (160…170)x10⁶  | N/m²     |
| Poisson’s ratio             | 0.3            | -        |
3.1. Case 1
It is assumed that the loader performs the bucket loading with the penetration force equal to \( F_i = 8050 \) daN that acts perpendicularly and uniformly over the width of the blade’s bucket. Modes for defining constrains conditions are illustrated in figure 5a and results of the finite element analysis are presented in figure 5b.

![Figure 5](image)

(a) Restraints and load  (b) states of strength

**Figure 5.** FEM analysis results for case 1.

3.2. Case 2
It is considered that the loader is moving toward the pile and bucket hits an obstacle eccentrically positioned to machine's longitudinal axis. It chooses the most unfavourable case, namely the edge of the bucket have impact with an apparent obstacle.

The same fixed holes as case I (figure 5a) are considered, but the force that are acting at the edge of the bucket (figure 6a) is \( R_e = 3940 \) daN (resulting from the stability requirement of the loader). The results of the finite element analysis are shown in figure 6b.

![Figure 6](image)

(b) Restraints and load  (b) states of strength

**Figure 6.** FEM analysis results for case 2.

3.3. Case 3
It is considered that the bucket discharges the material with the weight 4700 daN by means of the hydraulic cylinder that develops a force of 18140 daN upon linkages. The support in this case will only be in the holes and are of the embedding type. Restraints and loads are given in figure 7a and the results of the finite element analysis are presented in figure 7b.
It should be noted that in all three cases numerically simulated, was intended to observe real situations that may occur in the components of the maximum stresses of work equipment subject to the proposed cases. In conclusion, in all the practical cases, it is observed that the analyzed elements are not in danger of failure in terms of stresses.

It is also noted that the displacements of the nodes belonging to the analyzed structures do not have high values. This confirms the feasibility of the adopted approach in modeling and analyzing the dynamic bucket behavior.

4. **Manufacturing process for cylinder piston rod**

Computer aided manufacturing (CAM) has been considered as software converts three dimensions (3D) models generated in CAD into a numerical control programming tools to generate computer numerical control (CNC) code.

The CAM environment is used to shorten the manufacturing technology's start-up time, as well as the use of high-performance machine tools to increase productivity and implicitly reduce production costs. The typical process for machine tool programming, for example, in NX 11 manufacturing contains the following work steps:

- creating the manufacturing assembly and parent groups;
- creating operations and entering parameters that influence the tool trajectory;
- generating and verifying the tool trajectory to minimize errors;
- post-processing the tool trajectory through G-code machine generating;
- creating technical documentation (i.e. lists of materials, tools, comments, etc.).

Of all the parts of the bucket, above it will be described the steps in order to perform the operations of the cylinder piston rod processing (using NX 11 manufacturing software). After the validation of the kinematics simulation, the mechanism for discharging of the bucket loader must satisfy the design requirements, and to provide a theoretical basis for the adoption of the hydraulic cylinder (with double-acting type Φ70xΦ100 and stroke 590 mm – figure 8).

![Figure 7. FEM analysis results for case 3.](image)

**Figure 7.** FEM analysis results for case 3.

**Figure 8.** 3D CAD model of the hydraulic cylinder.

As example, we described the technological processes that will be covered for processing the hydraulic cylinder piston rod, thus:

a) roughing operation of the tie rod cylinder: choice of laminated material with Φ70 diameter and 480 mm length; frontal turning at Φ30x5; profiling;
b) roughing operation of the eyelet cylinder: obtaining the blank by molding (2 mm added); front side milling at 68±2 mm; turning and milling the other side; frontal milling at 70 mm; drilling hole at Φ96; milling hole at Φ30°0.05;

c) final processing.

Some steps from product design to hydraulic cylinder piston rod manufacturing (above mentioned) are illustrated in the images centralized in the figure 9.

Figure 9. Stages of development of hydraulic cylinder piston rod in Siemens NX11 Manufacturing.

5. Conclusions
In this paper the author describes a methodology used for the development of the new wheel loader attachment as side dump bucket, in order to expand their work tasks.

Nowadays, with help of the CAD/CAM/CAE software any product can be built through an optimized design based on interactive and creative tasks to identify and resolve the changes in the easily way. Thus, the paper shows a practical application of the product development processes that have involved in manufacturing of the side dump bucket.

Integration of the CAD/CAM/CAE together as a system implemented deals to achieve the quality in the product development system according to the requirements of the EU Standards refer to industrial process measurement and control.

As conclusion, the computer-aided technologies in engineering fields have a significant expansion of options to allow achieving a complex industrial projects, such an example being given in this work.

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