Aspects regarding 3d modelling and finite element analysis of a crusher bucket

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Abstract. The highest consumption of solid materials, especially rocks extracted from quarries, has the construction materials industry. These materials can be used either in natural form (gravel, sand), or after a reduced processing (marble, large stone, for foundations), or after a complex processing (lime, plaster, cement, sandstone, clay). The crusher buckets are used to grind materials in order to reach optimal or convenient sizes of processed materials in order to carry out a good technological process. The study of the shredding processes and of the equipment related to these processes is done in order to reduce the energy consumption necessary to reduce the dimensions of the raw materials to dimensions necessary for further processing. This study is of particular importance due to the fact that the shredding operation is energy intensive. This paper presents aspects regarding the geometric modelling of a crusher bucket and the finite element analysis of the bucket housing. All the components of the bucket were modelled in the Inventor software and then assembled to obtain the assembly. The modelling was based on an example of a crusher bucket taken from the literature. Finite element analysis was performed to highlight the eigenmodes of the crusher bucket in order to estimate the eigenfrequencies range of this equipment.

1. Introduction
The construction materials industry consumes a large amount of rocks extracted from quarries. They can be used in natural form or in processed form. The rock-type materials are crushed to reach optimal dimensions in order to carry out a good technological process. The optimal dimensions of the materials allow the development of the technological process for each product at a maximum efficiency [1].

Solid materials subjected to crushing initially have very varied geometric shapes and dimensions and physical-mechanical properties specific to their nature. The purpose of crushing raw materials is to reduce their size.

The purpose of designing a crushing machine is to determine the conditions necessary to increase the probability of crushing particles of certain dimensions and to obtain a distribution of the desired dimensions to the final product. The crushing process must be carried out in such a way that the processed material does not suffer undesirable changes, such as impurification or excessive heating [2].

The operations necessary for crushing solid materials are crushing, grinding and granulation.

The crusher is the machine used for crushing and it breaks the hard materials into smaller pieces. If it is desired that the crushing result has rounded shapes, the granulation operation is resorted to. When
the final result is desired to be of a fine granularity, the materials are ground with the help of the crushing mills [2, 3].

2. Theoretical considerations on crushers
According to the main way of the piece of material solicitation, the crushing machines can be divided into two main classes [2]:

- machines that perform crushing by compression and friction (jaw crushers, rotary crushers, roller crushers, rolling mills);
- machines that perform crushing by shock (impact crushers with hammers, rotary drum mills with free bodies, jet mills).

Quite indicatively, a distinction can be made between crushers and crushing mills according to the input size of the lumps or particles. If the input size exceeds 0.02-0.025 m, it is called a crusher, and if the size is below this value, the machine is called a crushing mill.

The object of this paper is a jaw crusher.
Jaw crushers are characterized by gripping pieces of material between two robust pieces of large mass, whose surfaces, through approach, exert a compressive force on the material.

The jaw crusher is used for crushing various high hardness materials (limestone, ferroalloys, various ores).

The crushers are used if, following a single crushing step, a fairly well-dispersed mixture of crushed particles must be obtained.

The crushers grind brittle materials very well and are less effective for wet products or those that contain a large amount of fat. The jaw crushers are mainly used for coarse crushing but in some cases also for medium crushing [2, 3].

They are most often used in the mining industry, the industry of materials for construction but also in the food industry, especially the sugar industry, for crushing lime stone that enters into the technological process of sugar manufacturing.

The figure 1 shows a model of a jaw crusher made by FLSmiith, year of manufacture 2017 [4].

![FLSmidth jaw crusher](image_url)

Figure 1. FLSmiith jaw crusher [4]

1 - abrasion resistant plates; 2 - the assembly of frame with screws; 3 - mobile jaw; 4 - mobile jaw switching system; 5 - hydraulic cylinder of the locking system; 6 - safety bolt; 7 - spherical roller bearings with multi-pass labyrinth system.
The advantages of jaw crushers are [1,2]:
- simple construction and maintenance;
- high operational safety;
- low mass and low cost.

The disadvantages of jaw crushers are [1,2]:
- cyclic operation, with large masses in oscillation, which cannot be fully balanced and determines the vibrant operation with high noise;
- the need for a heavy fly-wheel and an expensive foundation.

3. Case study

For the virtual modeling of the crushing equipment, an existing model in the specialized literature was taken as an idea. The model is produced by Meccanica Breganzese (MB) and the type of crushing bucket is BF 135.8 (figure 2) [5].

![Figure 2. MB BF 135.8 crusher bucket [5].](image)

It was chosen that the 3D modeling of the crushing bucket be made in the Inventor software.
Inventor has a multitude of advanced 3D modeling tools. A 3D model is based on a sketch of the main profile of the piece.
The realization of the sketch is extraordinarily convenient even compared to AutoCAD because it involves a series of simple steps: free drawing of a contour close to the final one, geometric restriction of the lines that compose the contour and dimensional restriction by linear and angular dimensions of the contour [6].

As the essence of the Inventor is parametric design, it can always go back to any contour to edit and redefine the constraints.

In order to generate the bucket model proposed in this paper, it started with the execution of the main sketch, necessary to model the crusher bucket housing.

Depending on the geometry and shape of the component parts, primary tools were used such as: Extrude, Revolve, Sweep, Loft, Shell, Fillet and the 3D modeling of the parts was completed (figure 3).

It was continued with the modification of the bucket in terms of shape, by cutting or adding material in the areas where the components are to be assembled and stiffening in areas where the bucket presents a tendency to deform. All these operations were performed using well-defined sketches. In addition to the commands already specified, the following were also used: Mirror, Hole, Circular Pattern (figure 4).
Figure 3. 3D modeling of the crusher bucket housing.

Figure 4. Modification by processing and stiffening of the crusher bucket housing.

The component parts of the crushing bucket were generated in turn: the mobile jaw and its shield, the fixed jaw and its shield, the eccentric shaft, the flywheel, the bearings of the mobile jaw support bearings, seals, the elastic system, the adjustment system, the coupling system.

By assembling all these component elements resulted the final assembly of the crushing bucket, which is shown in figure 5.

Figure 5. The final assembly of the crushing bucket.

The housing of the crushing bucket, modified by processing and stiffening shown in figure 4 is the object of the finite elements analysis that will be performed in the next step.

The finite element method is a convenient way to obtain approximate solutions to engineering problems. The method is certainly a convenient and necessary tool in design and research calculations.

In this paper, a modal analysis will be performed, which results in the behavior of the crusher bucket housing in the first 10 eigenmodes.

Finite element analysis was performed in the Inventor software, which provides users with analysis tools for 3D models. By performing a frequency analysis, it was desired to highlight the behavior of the crusher bucket housing in terms of the displacements of the nodes of the structure in the first 10 eigenmodes. The 3D model of the bucket was automatically discretized by the Inventor software.
After completing the discretization operation, the boundary conditions were specified (in this case, performing a frequency analysis, it is only necessary to define a support set). Thus, the crusher bucket was fixed on the mounting holes of the coupling system at the housing (figure 6).

Figure 6. Defining of the support set in Inventor.

From the set of obtained results, it is interesting to visualize the behavior of the crusher bucket housing in the first 10 eigenmodes. From the existing types of frequency response, it was chosen to visualize the behavior of the crusher bucket housing when the response is a displacement. The displacement of the structure nodes in the first 10 eigenmodes is shown in figure 7.
Figure 7. Visualization of the behavior of the crusher bucket housing in the first 10 eigenmodes with highlighting the displacement of the structure nodes.

The following is a detailed drawing containing the values of the displacements of the structure nodes (figure 8) and the values of the eigenfrequencies for the 10 eigenmodes for which the analysis was performed (figure 9).
Figure 8. The values of the displacements of the nodes of the crusher bucket housing in the first 10 eigenmodes.

Figure 9. Eigenfrequencies values for the first 10 eigenmodes.

With the values of the maximum displacements and of the eigenfrequencies presented in the figures 8 and 9 a graph has been drawn up that illustrates the dependence of the two variables. The chart was made using the Excel application from the Office software and is shown in figure 10.
4. Conclusions
The analysis of the eigenmodes of the crusher bucket housing was imposed by the need to estimate the eigenfrequencies range of this type of equipment. This information is useful to highlight the possible occurrence of resonance phenomena due to the overlap of frequencies generated by the dynamics of the system during work with those in the eigenfrequency range of the structure.

It is well known that mechanical resonance can cause violent vibrations or even complete destruction in the case of incorrectly constructed structures. When it is designed a structure of any type, engineers must ensure that the mechanical resonant frequencies of the component parts are not equal to the oscillating frequencies of the motors or other oscillating parts, a phenomenon known as destructive resonance [7].

Avoiding destructive resonance is a major goal for building any type of structure. As a countermeasure, dampers can be placed to absorb the resonant frequencies and thus dissipate the accumulated energy. Also, the structures are made so that resonances occur at frequencies that are difficult to reach.

5. References
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