Aspects regarding FEM simulation of stress in hammer mill working tool

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Abstract. Considering the need for development and improvement of biomass processing equipment, researchers bring contribution by making suggestions to design also through simulation and modelling of different stresses that occur on equipment's working tools. In this paper the stress in hammer mill working tools was analysed using FEM simulation with the help of SolidWorks 2016 Premium, projecting the geometric model and FEM simulation for a MC 22 hammer mill. The hammer mill has a four bolts rotor on which are the hammer disposed. The hammer mills rotor frequency is about 2940 rot/min. An important result in FEM simulation was the fact that the maximum reaction in the hammer joint was 11635 N. After FEM simulation experimental research were done using shredded miscanthus and energetic willow, the mill being equipped alternately with 4 types of hammers, with corners processed differently.

1 Introduction

According to data provided by Eurostat, renewable energy produced from biomass represents about 60%. Also, in 2016 the total amount of biomass used for bioenergy was 140Mtoe, 96% of which was obtained in the European Union and the other 4% was imported outside EU [1]. Considering this fact scientists are continuously researching for the optimum process to transform biomass in bioenergy. The main purpose of all process improvements is to reduce the energy consumption also on biomass harvesting process. [2].

Considering that the size reduction process is very high energy consumer for biomass processing, scientists tried to determine the optimal size reduction level. They used miscanthus and switchgrass as raw material and applied a combination of modelling and experimental tests. Their conclusions expressed the fact that cost would not increase if the grinded particle size is in the range of 4 to 6 mm. [3].

As specialized literature shows that the machine tool dynamic it is very important in analysing different elements of machining cutting operation such as simulating the cutting

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forces and making the model. In order to improve the equipment performance, the elements mentioned are very important, an input in chatter vibration modelling [4 - 7].

Also, scientists are researching through different modelling techniques the dynamics of the machine tool. In paper [8] researchers used a 3D Finite Element Modelling of holder tool assembly in order to obtain stability in milling process. Scientists presented the fact that they applied a 3D FE modelling technique instead of 1D beam modelling. This experiment presented the advantage of connecting element without requiring lumped stiffness. Their results expressed the fact that the number of experiments required were reduced, the iterative identification process was not necessary and also though experimental validation it could be said that proposed modelling technique achieves high accuracy in toolkit dynamics prediction [8].

Considering a hammer mill in paper [9] scientists analysed through numerical modelling the computational fluid dynamics. The grinding process is highly influenced by the flow characteristics in a hammer mill. A MB 7.5 hammer mill was used for the study which also had 4 hammers, a rotor distributed from 4 rows and a 4 mm sieve opening dimension. The fluid flow in the hammer mill was considered turbulent and unsteady because of the rotating of the hammer mill inside the grinding chamber that in known to be turbulent. After simulation the conclusions expressed a higher fluid velocity at the circumference of the grinding chamber and the total pressure inside had a normal distribution [9]. Also, scientists stated that the design of hammer mill structure can be improved by parameters with high reliability. This statement was possible after they used SolidWorks software for hammer mill modelling [10].

Continuing the analysis on hammer mills, from the point of view of modelling and simulation, in paper [11], researchers analysed the design of a hammer mill crusher and made an analysis of the rotor shaft assembly. Both the shaft and the rotor assembly of the hammer mill were modelled using ANSYS. The data obtained presented a deflection of shaft in Ansys analysis of 0.007 mm while in theoretical calculation this deflection was 0.009 mm. Also, the maximum stress identified by applying ANSYS modelling was 36.15 N/mm², a value much smaller that yield strength of the material of 45 N/mm², which led to the conclusion that the shaft will not fail under the conditions applied [11].

Also, except modelling and simulation scientists contributed to better understanding the biomass processing process, through mathematical model and analysis [12,13].

Because this processing process involves different stages an element analysed frequently by researchers consists in different aspects that can be used in obtaining the raw material for pelletizing, the influence of a various of recipes for obtaining the best biomass pellets and also different methods of lignocellulosic biomass pre-treatment used for biofuel production [14, 15, 16]. All these aspects are relevant in analysing the overall process of biomass processing process and the way it could be used for obtaining the optimum process to transform biomass in bioenergy.

Considering all presented in this paper the stress in hammer mill working tools was analysed using FEM simulation with the help of SolidWorks 2016 Premium, projecting the geometric model and FEM simulation for a MC 22 hammer mill. The simulation was accompanied experimental research done using shredded miscanthus and energetic willow.

2 Material and methods

In order to analyse the particle grinding process following hits from the hammers at the entry time of the grinding chamber, we consider the hypothesis that the hammer rotor spins with the ω =constant, and the centrifugal force maintains the hammers in a radial position. Starting from the conversation laws for impulse and momentum, and also from the

hypothesis according to which the hammer angular speed before the shock $\omega 1 = 0$, and the direction of the shock is perpendicular on the hammer edge, the fact that during hammer hits with material particles, it was seen that the hammers get an oscillation movement inverse to the rotor spin, and are disposed following a α angle. So, in this case the collisions between the hammer and the material particles (biomass). Knowing these data as well as the equations for speed after the shock for both the particles and hammer, in this paper finite element simulation for hammer mill working organ stresses accompanied by experimental data, were realized.

2.1 Simulation process

For the equipment used for biomass mechanical processing to respond to economic and viability stresses, the models realized by designers and constructors need to go through a series of stages like modelling, simulation and computer aided analysis.

Design process is described by differential equations with partial derivates. Resolving these equations is realized through following three distinct directions: finite difference method, finite element method, frontier element method.

During the paper, finite element method (FEM) was applied for hammer mill working organs structural analysis. FEM simulation can be realized, in general, only after clarifying some aspects like: beneficiary requests, imposed costs, available materials and technology, product durability. So, for a certain product/part/assembly, we can take some restrictions into considerations: static load and/or dynamic, deformation maximum values, different values of safety coefficients, permitted tolerances, vibration frequencies, product life span, material weight, part shape and its inertia moments, rigidity at different stresses, static and/or dynamic stability, behaviour at different simultaneous loads, etc.

For hammer mill working process simulation, we used Solidworks 2016 Premium software, which permits both design as well as resolving difficult issues in a quick and efficient manner. In order to solve the paper's problem, we used a working station with the following hardware resources: processor Intel I7 64-bit, 3.6 GHz, Videoboard Nvidia 2 Gb, RAM Kingstone 12 GB, operating system Windows 10 Profesional SSD 572 GB.

The first phase for this modelling process was to generate the geometric model, followed by generating the meshing model. Working organ geometry was realized with the help of SolidWorks software and is presented in figure 1 a.

Working organs were created starting from known dimensions for discs, hammers and the rotation shaft.

Assembled model was initially subjected to cinematic and dynamic analysis, with the help of Motion module from SolidWorks. For analysis, the value for rotor speed was chosen at 3000 rpm (usual value in practice). A stabilization for the rotor was observed from the start until the maximum speed in just 1.2 s. Before applying graphical simulation for movement, assemble components between which it exists a 3D contact were mentioned.

Working precision was of 10⁻⁴, and the maximum iteration number was of 50.



Fig. 1. a. Assembly geometric model. B. Finite element meshing of the model

2.2 Experimental research

Used material during tests was obtained from *Miscanthus x Giganteus*, harvested from the experimental field of the INMA Bucharest institute, as well as from the dried grinded mix of energetic willow (Salix Vinimalis). Both materials were kept in optimum conditions so that the physical-mechanical characteristics, especially the moisture content, remain mostly unchanged. For experimental tests, 5 kg of both miscanthus and energetic willow were used. Particle sizes were measured for the harvested material in a chopped state and average particle dimensions were determined.

So, miscanthus particles had average dimensions of 123-127 mm, while energetic willow had dimensions of 25-47 mm (over 85% of the material).

Equipment used for biomass grinding was a MC-22 hammer mill from the INMA Bucharest testing laboratory.

The hammer mill had a 0.33-0.50 kg·s⁻¹productivity on grinding corn stalks, respectively 0.22-0.42 kg·s⁻¹ on grinding packaged hay, using a sieve with Ø4 mm orifice size. MC-22 hammer mill is equipped with a 22-kW electrical engine, it has a 220 mm hammer rotor diameter and a rotor length of 500 mm. All 24 hammers are set up in a parallel distribution and have a length of 135 mm. The mills rotor frequency applied was 3000 rpm, 2850 rpm, 2700 rpm, 2550 rpm, 2400 rpm. The hammer used for testing are presented in figure 2.



Fig. 2. a. Hammer mill MC 22 (hammer mill; 2. exhauster; 3. cyclone with support and dust collector bag; 4. grinding material evacuation vent; 5. electrical engine; 6. grinded material.), b. four types of hammer (A – one step hammer; B – two steps hammer; C- three steps hammer; D – triangle hammer)

3 Results and discussions

3.1 Simulation process

During the finite element simulation, the maximum reaction in the hammer joint was determined. From the resulting graph presented in figure 3 we can observe a stabilization for hammer oscillations after 2 seconds. The number of frames per second was set at 12000. Determined reaction force represents the force with which the joint bolt acts on the hammer, on the contact surface between the two.

If we select the point in which the reaction is maximum in the hammer articulation, we can observe that it was of 11635 N. Also, from analysing the realized move resulted the speed variation graph.

Starting from the value of reaction, a static analysis was realized, out of which the movements, tensions, as well as frequencies for hammer motion were resulted. In case of static analysis, the subjected material to analysis breaks in the spot where the calculated efforts overcome the material rupture limit.



Fig. 3. Reaction force in the hammer joints

Frequency analysis was realized in order to identify if there are any inherent frequencies that coincide with the rotor functioning frequency or if they are lower. We could see that the first inherent frequency for the assembly is 5395.8 Hz, a much superior value to the rotor functioning frequency 314 rad/s.

The model following finite element meshing presented 24279 elements with 44120 nods. For finite element simulation, inside the programme, the model in which the parts were fixed together, the stress positioning and movement restrictions were defined.



Fig.4. a. Positioning stresses and movement restrictions b. Lateral movement restriction; c. Radial movement restriction

After applying load and fixing conditions for the assembly, the simulation was realized. From the results obtained we could see a maximum deformation of 0.036 mm at the tip of the hammers, due to centrifugal force during the experiment (fig.5). Also, the stresses represent half of the elasticity limit, and the equivalent unitary effort is manifested on the hammers on the surface contact of each hammer and each shaft.



Fig.5. Assembly deformation through applying frequency analysis for different inherent frequencies

3.2 Experimental research

Experimental researches which follow the finite element analysis of stresses that appear in the hammer mill working organs present data and resulted curves for the two-step hammer (figure 2b). These point out, for both types of biomass, the way in which the consumed specific energy varied according to the diameter of sieve orifices and the hammer rotor speed, as well as to the average particle dimension variation in relation to the rotor speed.



Fig.6. Consumed specific energy variation in relation to sieve orifice dimensions for the two-step hammer (fig 2b), a. Miscanthus X Giganteus, b. Salix Vinimalis

From figure 6, we can observe a normal energy variation in relation to the sieve orifices, also, speeds of under 2700 rpm, but if we disregard the obtained values for the sieve of

 ϕ 16 mm, we can say that both small and large orifices for the sieves can be used, but in this situation, the determining factor is given by the destination of the grinded biomass (for pellets, briquettes or for usual burning).



Fig.7. Consumed specific energy variation during grinding in relation to rotor speed for the two-step hammer type B, a. Miscanthus X Giganteus, b. Salix Vinimalis

In the case of miscanthus biomass, hammers with two steps showed non-uniform variation for the specific energy curves for grinding, according to the rotor speed, and observing that there are speed values that can't be used for optimizing the process, due to the fact that they do not fit in mathematical rules. With abstraction to some rotor speed values, the process could be optimized within certain limits, according to the used sieve and the destination of the grinded material if the physical properties remain unchanged. In this case, a relative normal variation for the consumed energy when grinding according to the sieve orifice dimensions was recorded for the $\phi 16$ mm, with values of 47 kJ/kg to 114 kJ/kg. Also, we mention the fact that for the $\phi 10$ mm sieve, the minimum specific energy consumption (approx. 75 kJ/kg for miscanthus biomass) was recorded for speed of 2700 rpm, because for smaller or larger speeds the energy consumption was higher.

Variation curves for the two-step knive and the mix of chopped batch of salix vinimalis presents a high energy consumption for the $\phi 16$ mm at 3000 rpm and a minimum point for energy consumption for the $\phi 10$ mm sieve and speeds of 2400 and 2700 rpm. We can thus conclude that optimizing the grinding process is possible for each sieve, but at different rotor speeds, if two-step hammers are used (figure 2b).



Fig.8. Particle average dimension variation in relation to the rotor speed for two step hammer, a. Miscanthus X Giganteus, b. Salix Vinimalis

From the presented graphs we can say that distribution of variation curves for grinded particle dimensions, in the case of type B hammer, miscanthus, for which the most values are under the dimension of sieve orifices, is normal. Still, these values are relatively close to the dimension of orifices which proves once again the important influence of the air current realized by the mill vent.

In the case of Salix Vinimalis biomass, curve tendency is also in a decreasing pattern if the 3000 rpm speed for the ϕ 7 mm is disregarded. Also, in the case of the sieve with ϕ 7 mm

there also exist average speeds (2700 - 2850 rpm) to which the grinded average dimensions are smaller, which could recommend them for practice use.

4 Conclusions

Grinding vegetal biomass is one of the factors which influence the final product quality destined to consumers as pellets/briquettes. It is very important that the material which represents the biggest component from the agropellet/briquette creation process, is uniformly grinded and the dimension permits an optimum working flux during the following processes from the technological line. Still, we can express the following conclusions:

- Through finite element simulation of the hammer mill working process, a maximum deformation of 0.036 mm at the tip of the hammers due to centrifugal force during functioning was concluded;

- Tensions were half the limit of elasticity, and the equivalent unitary effort is manifested on the contact surface of the hammer with the shaft or with the joint.

- Maximum reaction for hammer joint was of 11635 N;

- For miscanthus biomass, the consumed energy variation in relation to the used sieve orifice diameter and the hammer mill speed, presents an overall decreasing tendency;

- The same general tendency was also observed for willow biomass, even if there are values of the rotor speed which present a random variation;

Dimensions of the grinded material and the energy consumption are influenced mainly by the future material destination, but also by its initial properties, as well as by the adopted working regime.

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