Design Process of Energy Effective Shredding Machines for Biomass Treatment

Juraj Beniak, Juraj Ondruška, Viliam Čačko

Faculty of Mechanical Engineering, Slovak University of Technology in Bratislava, Institute of production systems, environmental technology and quality management, Nám. Slobody 17, Bratislava, Slovakia

Corresponding author: juraj.beniak@stuba.sk

Abstract

The shredding process has not been sufficiently investigated for the design of better, energy and material saving shredding machines. In connection with present-day concern about the environment, ecology, energy saving, recycling, and finding new sources of energy, we need to look at the design of shredding machinery, the efficiency of the machines that we using, and ways of improving them to save electric energy for their operation. This paper deals with sizing and designing shredding machines from the point of view of energy consumption and optimization for specific types of processed material.

Keywords: shredding, disintegration, shredding machines.

1 Introduction

Research and development for new types of machinery requires knowledge of each structural node and each machine part. On the basis of this knowledge, and with the help of practical experience, we can optimize the design of the device, minimize its input power and achieve optimal performance.

A feature of shredding (disintegrating) machinery is the broad range of disintegration processes and raw materials that are processed. Disintegration technology is stochastic as regards the basic principle of disintegration and the raw material that is to be processed. This is the main reason why the field has received such sparse scientific investigation, and why the design process for new machinery is mainly based on experience. The design and production of new types of devices has been delayed by lack of research and development. In order to be able to describe the process, it is necessary to make measurements on specially adapted devices.

An experimental stand was therefore designed for measuring the basic parameters that influence the disintegration process. The stand was designed to allow direct and indirect measurement of the analyzed parameters. On the measurement stand, we can make measurements on the wedge to determine directly the force necessary for disintegrating a material, or we can determine the force indirectly by converting the torque moment, which can be measured on the clutch between the drive and the measurement stand.

A methodology and an experimental plan were designed [3]. We used the complete plan of the experiment to measure the torque moment, with four selected variables. We used the averages analysis method (ANOM) and the dispersion analysis method to obtain the significance of these factors [7].

Experimental tests supported the working hypothesis [1] that the value of the disintegrative force also affects the face angle. The aim of our experiment was to verify this working hypothesis.

The primary assumption, based on an analysis of the theoretical problem, was that the size of the tool angles, together with other cutting conditions, is decisive for the productivity of tools and machines, and for the cost-effectiveness of all types of material working [8], see Fig. 1. Incorrectly selected cutting angles can accelerate blunting of the tool, reduce the lifetime of the machine, increase the cutting resistance, and affect the productivity and cost-effectiveness of the machinery. Fig. 2 shows the geometry of a disintegrative tool [6] (α — back angle; β — disintegrative wedge angle; γ — face angle).

2 Impact assessment of selected parameters

Based on the proposed experiment plan, one of the measured parameters was the impact of changes in face angle γ on the torque moment that is necessary for disintegrating the material samples. On the basis of the measurement results, modifications were made to the basic form of the mathematical model describing the disintegration process, and the following form was reached [1]:

$$M_{\mathrm{k}} = \tau R S_{\mathrm{m}}(1-\tan\gamma),$$
$$F_{\mathrm{D1}} = \tau S_{\mathrm{m}}(1-\tan\gamma),$$

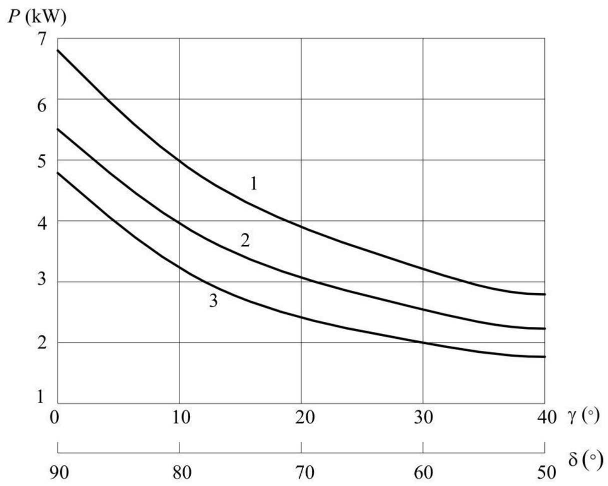

Figure 1: Impact of the geometry of a disintegrative tool on input power [6]: 1 — hardwood, 2, 3—softwood.

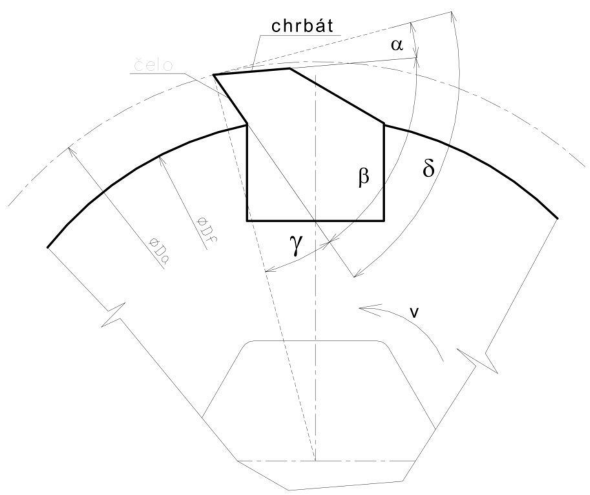

Figure 2: Geometry of a disintegrative wedge.

where: M_k — torque moment (in Nm); τ — shear strength of material (in MPa); R — disintegrative disk radius (in mm); S_m — disintegrative surface area (in mm^2); γ — face angle (in degrees); $F_{\mathrm{D}1}$ — disintegrative force for a single wedge (in N).

The mathematical model was created on the basis of experimental measurements that took into account the geometry of the disintegrative wedge (Fig. 2, face angle γ and back angle α), rotor rotating frequency n and the disintegrating material section surface area S_m, taking into account the width b and the height h of the disintegrative wedge and the thickness of the processed material h_m.

This formula produced some parameter dependences, or, more precisely, indicated how the parameters exert the necessary force (either torque moment or input power) to disintegrate the materials. The relation among the parameters is also expressed numerically (Tables 1–4). There is no rotor rotating frequency parameter, because this parameter was evaluated as insignificant, and we therefore neglected it in rest of our study. Other parameters, e.g. the width and height of the wedge and the thickness of the processed material are considered within parameter S_m.

γ (in °)	M_k (in Nm)	P (in kW)
−10	557.5	2.6
0	473.9	2.2
10	390.4	1.8
20	301.4	1.4
30	200.3	0.9
40	76.3	0.4

Table 1: Values of the torque moment and power for the selected face angle.

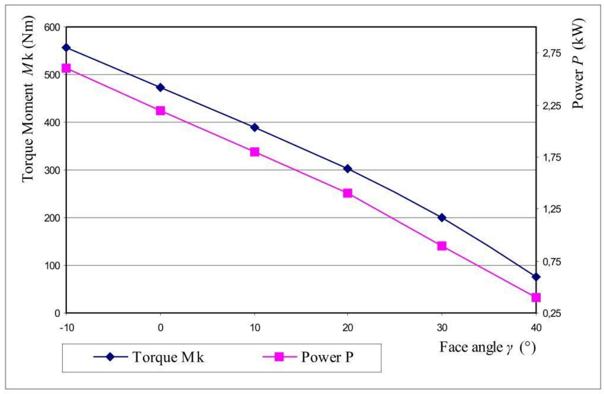

Figure 3: Torque and Input Power in relation to the shredding face angle.

The most obvious and the biggest impact on the necessary input power is due to face angle γ (Fig. 3, Tab. 1). The bigger this angle is, the smaller the force that is necessary to overcome the resistance of the material that this wedge leaks into. This is because when there is disintegration with face angle $\gamma = -10°$, the whole surface of the tool face presses on the material, so that there is a bigger surface to leak into the disintegrating material. When the face angle is $\gamma = 40°$, the wedge leaks into the material progressively. It therefore does not need to disintegrate a big section all at once, but can disintegrate it progressively.

This fact was evident not only from the measured values, but also visually and acoustically, according to how the device is loaded. When the face angle of the wedge is 40°, the device runs considerably more easily and more smoothly. When we look at the power that is needed as the face angle changes, we can observe that as the face angle increases the nec-

R (in mm)	M_k (in Nm)	P (in kW)
70	335.0	1.6
80	382.8	1.8
90	430.7	2.0
100	478.6	2.3
110	526.4	2.5
120	574.3	2.7
130	622.1	2.9

Table 2: Torque moment and power values for selected disk radii.

h (in mm)	M_k (in Nm)	P (in kW)
16	546.5	2.6
18	590.6	2.8
20	634.6	3.0
22	678.7	3.2
24	722.8	3.4
26	766.9	3.6
28	810.9	3.8

Table 3: Torque moment and power values for selected wedge height.

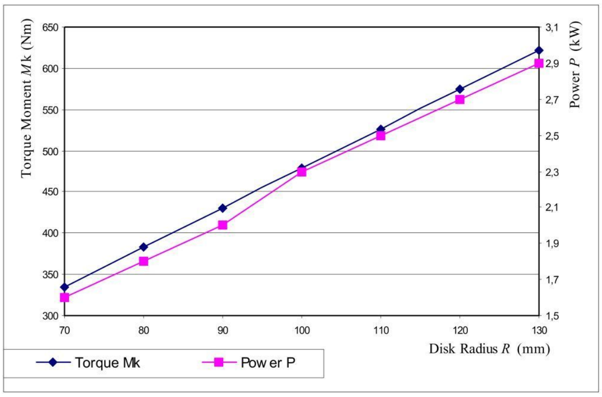

Figure 4: Torque and input power in relation to the radius of the shredding disk.

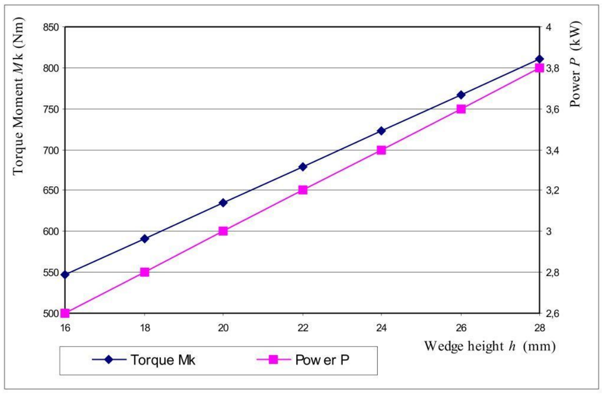

Figure 5: Torque and input power in relation to shredding face angle.

essary power input decreases. The total change for the reported range is as much as 6.5 times more. In comparison with the other parameters (Tables 2–4), this is the biggest change.

The experiment presented in [2] was performed with spruce wood samples with various cross-sections. However, it is also necessary to design an experiment for other types of materials and for other subsidiary parameters that can affect the process of material disintegration, and thus increase the energy consumed in these processes (by these devices).

The complete plan of the experiment presented in [1] for eight selected factors that can be changed on the measuring stand, for a minimum of three levels of each factor, and for ten repeated measurements for each combination, gives us a total of 65610 repetitions, which is not a practicable number. In practice, we used not more than 5 factors for the complete plan of the experiment. For this reason, incomplete and reduced experimental plans are used [3, 4, 5], or specific experimental plans, as e.g. in the experiment carried out by Taguchy [9, 10].

The experimental plan designed by Taguchy for eight factors, when one factor has two levels and the seven other factors have three levels, with ten repetitions for each combination, requires a total of 180 experiments (measurements). This is much more acceptable, and can also be performed much more quickly than the complete experimental plan (65610 repetitions). Each of the diagrams (Figures 3–6) and also the tables of calculated values (Tables 1–4) show how a small change in tool geometry leads to big changes in the loading of the disintegrative machine. This can finally be expressed in terms of the cost of the drive and in terms of electricity consumption. The initial cost for purchasing a bigger drive for the device is a once-off expense, whereas electricity consumption is a running cost. If we need to use a bigger drive, there will be permanently higher costs for electricity consumption, which is an important consideration with the present-day prices of electricity.

We assume that not only face angle but also material moisture will have a major impact on power requirements, and also on the input power of the device. In the case of material moisture, we have some practical experience, but we have not carried out any

b (in mm)	M_k (in Nm)	P (in kW)
16	539.9	2.5
18	561.9	2.6
20	584.0	2.8
22	606.0	2.9
24	628.0	3.0
26	650.1	3.1
28	672.1	3.2

Table 4: Torque moment and power values for selected wedge width.

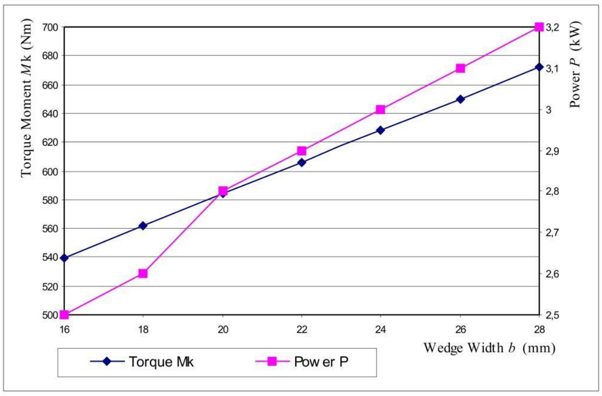

Figure 6: Torque and input power in relation to the width of the shredding wedge.

scientific experiments. We can therefore only work with suppositions and assumptions, and with analyses drawn from other fields of wood material processing. Fig. 7 [6] shows the impact of moisture on the shear strength of pine and spruce wood material. As the moisture value increases, the shear strength of pine and spruce wood material decreases. This information is taken from the field of wood treatment, which is a related field, though the principle is different.

3 Conclusion

We have attempted to show the importance of correct adjustment of device parameters for energy efficiency. Devices need to be adjusted for the specific conditions under which they will be running. It is necessary to take all input parameters into consideration, e.g. the processed material and its moisture, and to design the device on the basis of all relevant parameters.

This attitude is not applicable to all standard mass production machines, as there are cases when we cannot define the marginal conditions in advance. In

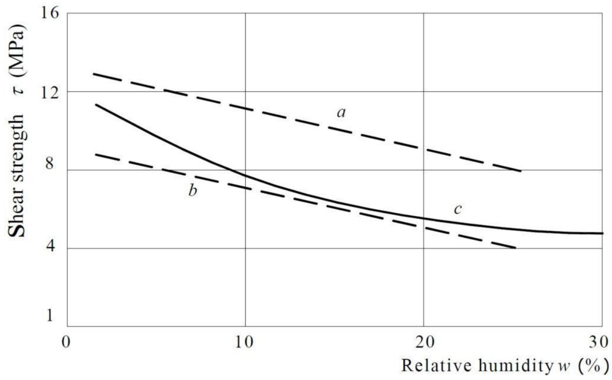

Figure 7: Impact of moisture and type of wood on the shear strength of a disintegrating material [6]: a,b — Swedish pine (Schlyter), c — spruce (Newlin).

addition, a wide assortment of materials sometimes has to be processed, e.g. municipal blended wastes, which consist of heterogeneous materials.

Acknowledgements

This paper is one of the outcomes of the project "Developing of progressive technology of biomass compaction and production of prototypes and highly productive tools" (ITMS code: 26240220017), supported by the Research and Development Operational Programme, funded by the European Regional Development Fund.

References

[1] J. Beniak. *Optimalizácia konštrukcie dezintegračného stroja.* Dizertačná práca, Katedra výrobnej techniky, SjF STU Bratislava, 2007.

[2] J. Beniak, E. Kureková. Design of experiment for measurement of torque of the disintegration device. In *Mechanical Engineering 2007: the 11th International Scientific Conference*, Bratislava, 2007.

[3] V. Chudý, R. Palenčár, E. Kureková et al. *Meranie technických veličín.* Vydavateľstvo STU v Bratislave, 1999.

[4] E. Jarošová. *Navrhování experimentů.* Česká společnost pro jakost, 1997.

[5] E. Kureková, M. Halaj, A. Bohunický. Návrh plánu experimentu na zistenie opakovanej presnosti polohovania plazmového rezacieho stroja. In *4th International Conference APLIMAT 2005*, Brno, 2005.

[6] J. Lisičan. *Teória a technika spracovania dreva.* Matcentrum, Zvolen 1996.

[7] R. Palenčár, J.-M. Ruiz, I. Janiga et al. *Štatistické metódy v metrologických a skúšobných laboratóriách.* Grafické štúdio Ing. Peter Juriga, 2001.

[8] S. Prokeš. *Obrábění dřeva a nových hmot ze dřeva.* SNTL Praha, 1982.

[9] Six Sigma. Taguchiho Orthogonal Arrays. http://www.micquality.com/reference_tables/taguchi.htm#L27, [15 May 2007].

[10] Taguchi. http://www.uni-kassel.de/fb15/lbk/Downloads/DOE/Taguchi/, [15 May 2007].