Milling equipment modernization: a unit for utilizing fibrous waste of woodworking production

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Abstract. Reprocessing of natural and technogenic materials, recycling of industrial waste, production of goods at the first stage is associated with grinding of materials. Standard grinders often do not meet the performance requirements, while having high energy and significant metal consumption. When woodworking industry waste is recycled in order to produce thermal insulation, technologies, including standard equipment, both for processing of raw materials and producing the end product in the form of compressed granular material are used. This research examines a method of producing thermal insulation materials and solving the issues of grinding organic fibrous materials in a multifunctional grinding unit.

1. Introduction
Today, just over 50% of the world's wood waste is recycled. The number of paper waste processing plants is constantly growing. Since moisture content in wood pulp is high, fibers of products made from it are securely connected to each other by hydrogen bonding. However, by each new processing cycle of such fibers only 80% of these bonds are recovered. After four or five cycles, the fiber can no longer form strong enough bonds and becomes unusable. In the construction materials industry (CMI), production of polymer and composite materials is increasingly growing. Today's industry is characterized by great technological capability and production capacities, which ensure gigantic volume and range of production. Wood chip production includes three main technology processes: pulpwood debarking, milling in a woodchipper and sorting of the resulting wood particles by size.

The most complex operation in the production of wood chips is the milling of debarked pulpwood in a woodchipper. Stochasticity of the milling process, due to the equipment design and the need to use pulpwood of different diameters and lengths, leads to the formation of wood particles that significantly differ in size and shape. To solve issues of light-weight waste utilization for a number of standard production lines, modernization of the production section by introducing a high-performance milling unit can be recommended.

2. Method of heat-insulating material production
In order to produce thermal insulation from technogenic organic materials, a technological system should be adapted to recycle secondary raw materials of woodworking industry (Figure 1).

The process is as follows: using motor vehicles 1, wood processing waste is delivered to a raw material warehouse 2. Then via a telpher 3, it is loaded into the receiving hopper 4. Moving along the belt conveyor 5, material undergoes preliminary coarse milling in the shredder 6. It is a hydraulic system that pushes processed material onto a running rotor with cutters. Material feeding into the receiving
hopper of the shredder can be both manual and mechanical. A hydraulic presser forces the incoming material against a cutting shaft. At this stage, material is milled. The pressure force of the hydraulic presser is adjusted automatically and depends on the degree of material resistance to the main shaft rotation. If overloaded and the pressure on the cutting shaft becomes extreme, the presser automatically stops feeding the material.

**Figure 1.** Process flow diagram for production of thermal insulation from technogenic organic materials.

The milled material is further pushed onto a sieve with cells of a certain size for obtaining the required particle size. Wood particles that are larger than the cells are returned to the cutting rotor. After that, material is moved by a scraping transporter 7 to the rotor centrifugal unit (RCU) 8. From a hopper 9, additives, binding and modifying agents are added to the material in the RCU. Further, the material is moved into a centrifugal separator 10, and then into the granulator 11, where granules are produced: a rolling press forces crushed fibers through radial holes of the ring die.

Granules that are pressed out of ring die holes are snapped by a fixed knife, fall down and through a case hose are moved further down the production line. As they have a high temperature and are fragile, they are transported to the cooler. A fan blows air through a layer of granules, which cools the granules down and at the same time filters non-granulated material (spillage) by suction. During the cooling process, the moisture content of the granules decreases, and as a result of physical and chemical processes, they acquire the required hardness, temperature and humidity.

As a cooler fills with granules, they are transported to a classifying drum 12, where they are separated from the spillage and via the elevator 13 are moved to a measuring hopper 14. Via belt conveyors 15 and 16, granulated material is moved to a packaging unit 17 and 18, and then to the end product warehouse 19.

3. **Design and principles of operation of the rotor centrifugal unit**

The key issue addressed in this research is design development of such multifunctional milling units that they will allow for implementing energy-efficient combined effect for the processed material (impact, cut, abrasion, rupture, etc.) [1,2]. Operative parts of the machine should have high self-cleaning, wear-resisting and durability properties, and their structural design should be simple, reliable and easy to maintain and operate [6-10].

For engineering hypothesis proposes, as operative parts of impact grinders core elements are suggested: they are made of high-strength spring steel, assembled in fagots, bunches, becketors or brushes so that after they are placed on a rotor, their ends face in the direction of the milled material and fit fairly tightly.
One of the simplest implementation variants of this concept is usage of cutting mills, brushes of various designs, line and fagot segments, etc. mounted on the rotors as impact operative parts. Performance of impact operative parts mounted on the rotor will be used as an example. If compared with working surfaces of traditional impact bars, metal rods of brushes or fagot radically change the whole process of grinding. Firstly, a number of impact zones with milled material concentration is drastically increased. Secondly, sharp ends of rods minimize the number of particles that slip through working surfaces. Thirdly, metal rods can be elastically deformed, which creates the effect of self-cleaning and makes a process adaptive to physical and mechanical properties of materials.

As experiments showed, positive effects of such RCU design include an increase in the wear resistance of the upgraded operative parts, which is a result of spring steel high-strength characteristics along the entire length of the rod elements. In addition, the operative parts in the form of brushes are made in large quantities, for a number of standard-sized milling units, and can be used as generic products.

A system for grinding fibrous materials consists of two cylindrical grinding chambers that are linked and separated by a baffle. In the working area of the system rotors are coaxially arranged, which provides coarse milling in the first chamber and finer milling material in the second one.

Milling chambers are equipped with devices for feeding raw material and removing the end product. The rotor of the first chamber is build up from of a set of disks is installed off center relative to the central axis with disk displacement along the helical curve. The rotor of the second chamber is composed of plate-like impact bars with cutting edges fixed on pins and is located inside a wire-cage roller.

This RCU configuration can be applied for processing of a large range of fibrous materials, but further intensification of the milling process is constrained by technological capabilities of the operative parts in the second chamber. This is due to the fact that cutting edges of the plate-like impact bars cannot efficiently perform fine milling of anisotropic materials, since the number of operative elements that not only impact, but also cut and break particles of the milled material, is relatively small. This structural feature does not allow for obtaining fine dispersed composition in a short period of time when air-material flow is located in the working areas.

The aim of the proposed modernization is to intensify milling process and increase homogenization of the resulting compositions by mounting sets of needle-like cutting elements and other modifications in the second chamber of the RCU [3].

![Figure 2. Rotary-centrifugal unit.](image-url)
A unit (Figure 2) contains a cylindrical body that is consisted of two horizontally mounted chambers: a coarse milling chamber 1 and a fine milling chamber 2, with covers 3 and 4. These chambers are coaxially located on two shafts 5 and 6. In the coarse milling chamber 1, a rotor 7 with disk cutting elements 8 is mounted on the shaft 5. Rotor disks are fixed with an offset relative to each other, which forms a helical channel with an angle of inclination of the screw line Y, directed towards the material unloading dock. In the upper part of the coarse milling chamber 1 hull, there is a pneumoeelastic roller feeder above the hull for material feeding. It consists of a feed tray 9 and a feed roller 10 (Figure 3). Inside the chamber 1, there is a drum 11 mounted off center relative to the axis of the cylindrical body. It is lined with removable elements (profile plates) 12 that are mounted in fixed guides 13 and have holes for material output. The drum 11 is fixed via an adjusting device 14 and held in place by springs 15 (Figure 3). The internal workspace of the chamber 1 is limited by a dividing baffle 16 (Figure 2). Chambers 1 and 2 are linked via holes 17 in the partition 18 [3].

In the second chamber 2 (the chamber for fine milling or dispersion), an operating part is mounted: a rotor that consists of a hub 19 that is rigidly fixed to a shaft 6. A hub features pins 20, in which with the help of shackles 21, impact bars 23 are mounted on the axes 22. Impact bars are made in the form of brushes 24 and consist of sections 25 rigidly mounted on axes 26. Splints 27 and bolts 28 provide for appropriate fixation of the axes 20 and 26. Impact bars can also be built of a single flat brush 29, two flat brushes 30 and 31, or an inclined brush 32, which are mounted on the holders 33 of hubs 34. The chamber 2 is lined to the chamber 1 through the inlet 35. The working area of the chamber 2 is diametrically limited by a mesh drum (ring) 36. At the inlet to the chamber 2, there is a branch pipe 37 for adding filling agents. At the top of this chamber there is a discharging branch pipe 38, which is tangential to the body.

A device for milling fibrous materials functions in a following way. Raw material is uploaded using a feed roller 10 and a feed tray 9 into the coarse milling chamber 1. There, it is pre-milled by cutting discs 8 of the rotor 7. Since the inner surface of the chamber has profiled plates 12, the milling process is intensified. Further, material milled in the chamber 1, through the screw channel formed by disks 8 of the rotor 7, via the holes of the removable elements (profiled plates) 12, as well as link holes 17 of the partition 18 and the inlet holes 35 of the chamber 2, as it is crushed, is loaded into a working area of the chamber 2. Feeding of the material coarsely milled in the chamber 1 into a fine milling (dispersing) chamber 2 is due to the air exhaustion created in the working area of the camera 2. This allows for sucking of the particles milled in the chamber 1 into the chamber 2 through the inlet. In the chamber 2, inside a mesh drum, fine milling (dispersion) and mixing of components takes place. At the same time, through a loading device (branch pipe) 37, finely dispersed additives get into the working area of the
second chamber. After the final milling to the desired fineness, material is fed out of the chamber via the discharge slot 38. [3]

The upgraded operative parts of the RCU (brush rods) can be implemented in different variants, which is determined by the operating conditions, characteristics of the milled material and requirements to the quality of the end product [4,5] (Figure 4).

![Figure 4. A RCU operating part in a form of a brush with cutting elements.](image)

4. Conclusion
A distinctive feature of the presented design of the rotor centrifugal unit with an enhanced surface of the operative parts is a combination of several types of impact methods on the material in the working area of a single unit. In the first chamber, coarse milling of the material is performed by the cutting discs. In the second chamber, material is finely milled by plates or brushes with cutting edges fixed on the pins. A unit also features a process of homogenization of compositions with modifiers and additives introduced into a mixture.

The design of the rotary-centrifugal unit considered in this research allows for the following:
1. Increase the degree of material milling and obtain a homogeneous composite mixture due to a unit design: operative parts are placed in the linked chambers and produce a complex dynamic effect on the material.
2. Reduce specific energy consumption of the unit by feeding pre-milled mixture from a coarse milling chamber to a fine milling one via an interduct, with a whirling air-material flow created by exhaustion.
3. Increase unit performance by optimizing stage-by-stage process of fibrous material milling in consecutively arranged milling chambers.

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