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Энергосберегающие технологии при
размоле волокнистых полуфабрикатов

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Energy-saving technologies at milling
of fibrous semifinished products

Проблеме энергосбережения в бумажной отрасли придается большое значение, вследствие больших энергетических затрат при размоле. Существует разные способы решения этой проблемы: а) конструктивные изменения мельниц; б) изменение технологических режимов размола. В статье подробно рассматриваются физические процессы, имеющие место при деформации волокнистых полуфабрикатов. Разработаны требования к эксплуатации мельниц и проектированию. Совокупное техническое решение мельниц и проектированию этих задач приведет к существенному энергосбережению

Ключевые слова: мельница, гарнитура, размол, энергосбережение

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A great importance attaches to problem of energy saving in paper industry due to the high-energy costs at milling process. There are different ways to solve this problem: to modify a mill design and to change the technological modes. The paper focuses on consideration of the physical processes taking place at a strain of the products. The requirements of the mill operation and design are developed. The total solution of these objectives will lead to substantial energy saving

Key words: mill, mill garniture, milling, energy saving

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Currently, a global volume production of the paper and wallboards after global financial crisis has been increasing at a stable rate [1]. The most power-consuming process in this production is the milling process of fibrous semifinished products [2]. Power consumption of the process can achieve up to 70% of total energy consumption in manufacturing. A lot of publications devoted to reduction of mill power consumption. [3,4,5,6 and etc.]. This paper examines new approaches to power-consuming

reduction during the process in mainly technological equipment as knife beating machines.

During the process in contemporary knife machines the time of deformation achieves the level of about 3×10^{-5} s. Under compression of fibrous interlayer in a knife the concentration increases up to 15-60% [6]. A generalized graph of fibrous interlayer tension from its relative compression is shown in **Figure 1**.

Figure 1. The tension in the of fibrous interlayer with its compression:
1 is an experimental curve; 2 is a theoretical curve

In the graph four characteristic zones can be distinguished.

The OA zone – the zone of elastic deformations which occurs at deformation from 0 to ε_1 at stresses in the fibrous interlayer less than σ_{01} . When the load is removed, the fibrous interlayer without hysteresis recovers its shape completely. The recovery of previous form and dimensions of the interlayer can occur almost immediately [7]. The change of characteristics of paper pulp in this zone is almost absent (**Figure 2**).

The AB zone is the zone of the elastic-plastic deformations that occurs at deformation from ε_1 to ε_2 . And it stresses in the interlayer from σ_{01} to σ_{02} . When removing such stresses the elastic part of the deformation disappears. The plastic part of the deformation leads to irreversible deformations in the fibers and causes their external and internal fibrillation [8]. In this zone, there is a small change of characteristics of pulp.

The BC zone is the zone of plastic deformations, practically characterized by constant stress σ_{02} at a changeable deformation of the interlayer from ε_2 to ε_3 . Under such stresses in the interlayer an intensive fibrillation of fibers takes place [8]. In this zone, there is a significant change of characteristics of pulp.

The CD zone is the zone of destruction of the interlayer, up to metal contact between mill garnitures, occurs at strains from ε_3 to ε_4 . And it is characterized by an abrupt increase of stresses to σ_{03} . This zone is characterized by intensive cutting and refined efforts.

Figure 2. The change of characteristic of beaten semifinished products under compression fibrous interlayer: 1 is the growth of freeness degree; 2 is the decreasing of average fiber length

The form of the graph, steep at small and sloping at large values of the interlayer compression, explained by features of its structure. At the time of water displacement from interfiber cavities and elastic compression of the fibers the normal stresses are rising rapidly at relatively small strains. Then upon reaching the yield point σ_{02} under increasing strain the normal stresses practically unchanged. The elastic properties of the interlayer appear higher with increasing degree of freeness value at the inlet of the mill. And it appears with reducing an average fiber length, concentration and using semifinished products [5]. It is experimentally established that the yield point of fibrous interlayer decreases by increasing the freeness value of mass at the inlet of the mill. It is also possible by reducing an average fiber length, concentration and using semifinished products and vice versa [6]. When there is a fibrous interlayer gap and the metal contact occurs between the blades of mill garnitures the normal stresses increase dramatically.

A model satisfies the most the model of Kelvin-Voigt at fluid friction of mill garniture of the interlayer. And the model of Hooke at boundary friction. The model parameters depend on the technological and exploitation factors of milling and have a random character.

The equations describing the model of fibrous interlayer at a fluid and boundary friction are shown below:

$$\sigma + \tau \times \frac{d\sigma}{dt} = E_2 \times \tau \times \frac{d\varepsilon}{dt} + H \times \varepsilon \text{ with } \sigma < \sigma_{02}, \quad (1)$$

$$\sigma = \sigma_{02} + E_M \varepsilon \text{ with } \sigma \geq \sigma_{02}, \quad (2)$$

where σ , $\frac{\sigma}{dt}$ are the voltage and speed of deformation of the interlayer accordingly; ε , $\frac{\varepsilon}{dt}$ are the relative strain and deformation speed of the interlayer accordingly; σ_{02} is the interlayer yield point; E_M is the modulus of elasticity of the garniture metal contact; $H = \frac{E_r \times E_k}{E_r + E_k}$ is the modulus of elasticity with prolonged loading time; $\tau = \frac{b}{E_r \times E_k}$ is the time stress relaxation.

The fibrous layer between rotor and stator is exposed to voltage in the form of periodically repeating pulses that can be expanded in Fourier-series. The cyclic stresses and strains of the interlayer at a fluid and boundary friction are shown in **Figure 3**. The changes of the interlayer deformation are delayed toward to a change in voltage at a knife crossing. At removal of the load deformation is not reduced immediately, but with a certain delay. After relief of stress the deformation will fall exponentially.

Figure 3. The cyclic influence on the fibrous interlayer between the rotor and stator: a) the voltage pulses; b) strain pulses in the liquid friction; c) deformation pulses at a boundary friction

The main purpose of the directed beating is obtaining flexible and elastic fibers maximally approximate to its natural length. This is achieved as a result of repeated loading above the elastic limit of the fibers. But this is not exceeding the tensile strength of the fibers σ_f . At loading, which is greater then σ_f , the destruction of the fibers occurs both across and along the fibers.

If it is assumed that the required growth of quality indicators of fibrous material at achieving a certain strain $\varepsilon_{\max}$, it is possible to write the following condition. The condition of the required growth of the indicators during the beating:

$$\varepsilon_{\max} = \sum_{i=1}^n [(\varepsilon_e)_i + (\varepsilon_{de})_i + (\varepsilon_{pl})_i], \quad (3)$$

where $(\varepsilon_e)_i$, $(\varepsilon_{de})_i$, $(\varepsilon_{pl})_i$ are the elastic, delayed elastic and plastic deformations, respectively, for the i -th load cycle.

It can be concluded that in order to achieve $\varepsilon_{\max}$ and, hence, to increase efficiency and power-consuming of the beating. It is necessary to increase the number of loading cycles and voltage in the cycle. And to reduce the time of interlayer recovery and value of the viscoelastic properties of semifinished products.

Performing the first and second conditions can be achieved by increasing the number of garniture blades and rotor rotational speed. However, it is necessary to consider their mechanical strength and capacity of mill garniture with increasing number of blades. Performing the third condition is achieved by thermal or chemical treatment of the product before beating. The fourth one is achieved by changing the influence effort of knives for the product, i.e. by changing the mill additive.

Thus, it is possible to approach purposefully to design and frequency exposure of the garniture on the product and recommend the modes of mill operation.

In the beating zone, it is appropriate to use the rolling friction instead of sliding friction. This will reduce the mill power-consuming and reduction of chopping effects of the blades on the product. The use of the friction in the beating zone is offered in knife beating machines backed by patents [9,10,11].

Eventually, the main directions of the energy-saving technologies at beating of the products are identified in this paper. The optimal thermal and chemical treatment of the product before beating and frequency exposure of mill garniture on the semifinished product are also distinguished. And it is typical for the optimal control modes and a creation of the new mill designs using the rolling friction in the beating zone.

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