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RESEARCH ARTICLE

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Theoretical computation and analysis of benefits of wood cutting power

Abstract This paper studies the problem of high energy waste in the course of the wood fiber processing in the wood-based panel industry. In the light of the energy economy principle, the cutting theory on the micron and long-slice wood fiber was put forward. In this paper, by means of analyzing the power waste in traditional processing, a series of analytical measures, such as, cytology, super precision work theory and fiber processing, and so on were utilized in the micron wood fiber formation process, and the cutting conception of the micron and long-slice wood fiber was put forward. Accordingly, the study of the micron and long-slice wood fiber was put into the microstructure study. This paper scientifically explains the reasons why the traditional wood fiber processing consumes more energy and the fiber quality low. In an example, the cutting power on the micron and long-slice wood fiber was calculated, which was compared with the traditional cutting power. The result showed that the energy waste by machining at micron is much lower than by heat grind and the high quality and long-slice wood fiber was gained. Thus, a revolutionary step was taken in the paper-making and wood-based panel industry of China.

Keywords cutting, micrometer, wood fiber, power, theory

1 Introduction

What mankind lives on and what drives society along is energy source. Energy waste per unit of the primary products of this country is higher by 25%–90% than that of the developed countries. The energy source utilization is only 32% or so. Therefore, the economical potential is very huge and the task very difficulty. Energy source has a good relation with the wood-based panel industry. The production of the wood-based panel consumes large quantities of power. The wood-based panel industry is also one of the industries with high-energy waste. The energy waste consequently increases the production costs of the industry. The fiber processing includes separation of the fiber, molding, drying and hot-press, and so on. The separation of the fiber is the core link between the whole papermaking process and the production of the wood-based panel, is one of the working procedures that insure the product quality, and at the same time, is a working procedure that consumes much energy. The energy waste approaches nearly 50% of the total energy waste of the product line. The method of the heat grind by machining is extensively adopted to separate wood fiber. The wood slice that is warmed up is sent into the millstones of the heat grind machine and is compressed, stretched, sheared, turned, impacted, rubbed, and hydrolyzed by multi-repeated outside forces to realize the fiber decomposition (Xu, 1988). These work procedures consume much energy. In this paper, the point of study is to adopt the craft of timber micron processing to resolve the energy waste during fiber formation.

2 The power waste analysis of the traditional wood fiber processing

Table 1 shows the power waste situations of several familiar types of heat grind machines. Under the condition of the same production, among these power wastes, the least power waste is 0.014 kW/m^3. Therefore, this work procedure is a bottleneck to the energy waste in this industry.

3 The basic definition of the micron and long-slice wood fiber cutting

Wood fiber is the main material in timber. The separation of the wood fiber is a main work procedure in the processing of the papermaking and the wood-based panel. Traditionally,

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Table 1 The power waste situations of several familiar types of heat grind machines

Sequence number	Model	The size of the millstone /mm	The motor rev /(r·min^{-1})	The main machine power /kW	The unit vol. power /(kW·m^{-3})	Output /10^{4}m^3
1	QM9D	914	900	280	0.014	1–2
2	M101	914	1,500	1,000	0.033	3
3	M103	965	1,500	1,250	0.042	3
4	M200	1,066	1,500	1,400	0.028	5
5	M200A	1,066	1,500	1,800	0.036	5
6	M200A	1,219	1,500	4,000	0.050	8

the length of the fiber by heat grind is 1–3 mm or so. The equivalent diameter is 0.16–0.75 mm (Xu, 1988). But for the general timber cell, the equivalent circle diameter is 10–105 μm (Cheng, 1985). The equivalent diameter of the wood-based panel wood fiber is far larger than the equivalent circle diameter of the timber cell, so that most cell tubes in the process of heat grinding is broken. The impurities, such as, the sugar-based compounds, the colloid, and so on in the cell tube are not discharged, which means that the impurities are excessive and the fiberboard will change color. In the paper-making industry, the impurities have no choice but to be discharged because the plasma method used is chemical based. Because the chemistry preparation is imported, pollution arises (Ma, 2001). The absurd heat grind cutting method is one of the reasons for the too short and too wide wood fiber, and for the power waste. In the processing of the micron and long-slice fiber, all cell tubes are opened, so that the impurities in the cell tubes can be discharged. Therefore, in this paper, the cutting thickness of the micron and long-slice fiber is defined as 10–80 μm, the fiber length as 3–8 cm or so, and the fiber width as 3–10 mm. The defined fiber unit is called the micron and long-slice fiber (as for the fiber in the separation of fiber work procedure of the wood-based panel) (Ma, 2002). This proves that the plasma method can be replaced by machines that can miniaturize the paper-making process without pollutants and can resolve the pollution problem of the small-type paper making, so that the paper-making industry in this country can be promoted. At the same time, this method is a high-technique solution that can resolve problems, such as, large quantities of energy wastes, excessive wastes, and pollutions (Ma, 2003).

4 The mechanics of modeling the micron fiber method

The substance of the cutting process of timber is the process during which the wood is sheared, squeezed and folded with the aid of cutting tools. Timber is anisotropic material; therefore, when the cutting directions are different, the timber transformation and the forces suffered by chipping vary.

The micron and long-slice fiber method put forward in this paper is realized by longitudinal wood cutting. When wood is cut, the cutting layer is compressed. The cutting tool functions create the shearing strength among the fiber cell tube flat. The shearing strength functions to lead the timber cell unit to split, transform, and break along the cells longitudinally. When the corresponding shearing strengths change into the critical value in order, the fictile wood fiber splits upwards along the frontal surface of the cutting tool .The shearing strength is continuously delivered to the wood fiber that has not yet moved to the front of the cutting tool. The characteristic that the chippings can be formed in this course is that timber will be split continuously along the timber texture. Therefore, a smooth fiber strip is formed and the smallest cutting forces are obtained.

The traditional wood cutting theory has existed for almost a hundred years. It is a practical science based on experiments. On the basis of large a number of experiments, the traditional wood cutting theory thinks that wood cutting is a result of the function of the pressure that is created on the frontal surface of the cutting tool by chippings, with the associated help of the force of friction on the rear surface of cutting tool and the resistance created by wood splitting. With the introduction of the micron fiber processing, these forces will vary greatly. The micron fiber is very thin and the flexibility is very good. Therefore, the pressures on the frontal surface of the cutting tool can almost be negligible. But the splitting forces along the cell fiber texture and along other directions of wood are very small comparatively. Therefore, the forces of friction on the rear surface of cutting tool can just not be ignored (Xiao et al., 1992). For the sake of improving mathematical theories, the basic theory and methods of the precise cutting which are latest internationally are adopted in this paper.

According to the basic cutting theory put forward by Rubenstein et al. (1985), on the assumption that the extrusion areas and the elasticity of the recoverable areas of the cutting tool-work piece at the spot below the line of the cut have uniform static stress p_m, the cutting extrusion and the recoverable mechanism of Flexible modules is based on simplification and analysis. The mathematical models of all forces have been established on this foundation as follows:

The forces, F_x and F_y, acting on the cutting tool along two directions, are as follows:

$$F_x = p_m L W_0 \quad (1)$$

$$F_y = \mu p_m L W_0 \quad (2)$$

where L is the cutting width; W_0 is the contact length of the cutting tool and the work piece, p_m is the average positive stress acting on the cutting tool and work piece contact area, where

$$P_m = \frac{\tau_S}{\mu} \quad (3)$$

where μ is friction modulus, and τ_S is the shearing yield strength for wood.

After the lumber is cut, the rear surface of the cutting tool is in contact because of the restorable distortion. Therefore, tremendous pressure is produced. The positive pressure in the unit area of the bottom end of the cutting tool's cutting edge is maximal. As the processed surface of the work piece is approached, the positive pressure in the unit area becomes smaller. The positive pressure on the processed surface separated from the cutting tool is basically reduced to zero. Therefore, the hypothesis put forward by Rubenstein et al. (1985) has some errors. The cutting angle ϕ is confirmed according to the Merchant's cutting theory put forward by Drescher and Dow (1990, 1992) and is supposed to be always a constant. On the assumption that the contacting area of the cutting tool and the work piece has common friction modulus μ and positive stress F_p, the ultra precise mathematical model of the cutting forces is established as follows:

$$F_p = \frac{\sigma_S}{\sin\phi\cos\phi - \mu\sin^2\phi} \quad (4)$$

$$F_y = \mu F_p L d + F_p w L + \frac{1}{2} F_p w'' L + F_p w' L \quad (5)$$

$$F_x = F_p L d + \mu F_p w L + \frac{1}{2} \mu F_p w'' L \quad (6)$$

where F_p is the average positive stress created for the function of the micron and long-slice wood fiber cutting and the frontal surface of the cutting tool, ϕ is the cutting angle of the micron and long-slice wood fiber, d is the cutting thickness of the micron and long-slice wood fiber, L is the cutting width, w is the wearing width of the rear surface of the cutting tool, w'' is the contact length of the rear surface of the cutting tool and wood, w' is the acting length of the radius of the blunt circle of the cutting edge, σ_s is the resisting shearing strength along the fiber texture.

The theory put forward by Drescher aims at calculating the ultra precise cutting forces, which is the latest cutting theory. In this study, Drescher's ultra thin micron cutting theorywas used. The corresponding wood mechanics are added in this paper on the basis of his theory.

5 Qualitative analysis for the reason of power reduction in micron fiber cutting compared with heat grind method

The vegetable fiber is united by the chemical bond, the hydrogen bond, the Van Der Waals Force, the interlaced force on the surface, and so on. The fiber separation by the traditional heat grind method is a kind of multi-dimensional complex space motion. All forces received by the fiber are multi-dimensional moving load or impact load. The overwhelming majority of the forces perform some unproductive work. Some even perform negative work. The heat grind method shortens the fiber length. The majority of the cutting forces are loaded in the direction in which the destruction of the fiber takes place and therefore consumes enormous power. Therefore, massive energies are wasted. The function frequency of the forces also affects the separation output and quality of the fiber. The cutting theory of the micron long-slice fiber proposed by this paper is a pure mechanical cutting method through pure physical, best cutting direction. The cutting force used in the direction along the fiber texture is theoretically less than the cutting force on the end surface by several times. Theoretically, the reasonable distribution of force in the cutting direction only can reduce the consumption of power substantially. Splitting the fiber tissue by pure shearing uses least force thereby reducing power reduction. The micron- and long-slice fiber cutting effect can be achieved by longitudinal and overspeed cutting along the fiber texture. Not only power waste is reduced, but also the probability of cutting off the fiber is reduced. Thus, the fiber length and quality is enhancedsubstantially. The cutting theory of the micron level wood fiber is proposed in this paper. According to the computation of the cutting forces, the cutting power can be worked out quantitatively, namely, the cutting power equals the multiplication of the cutting forces and the cutting speed. Compared with the fiber separation by the traditional heat grind, the cutting power of the micron and long-slice wood fiber should be much smaller than the cutting power consumed by the mechanical grind.

6 The deduction of the calculation formulae of the micron fiber cutting power

Figure 1 shows that the cutting power equals the multiplication of the cutting force F_x at this point and the cutting speed V_x, and is expressed as

$$p_c = F_x \cdot V_x \cdot 10^{-3} \text{ (kW)} \quad (7)$$

where F_x is the main cutting force (N), V_x is the cutting speed (m/s).

By combining the formula of the cutting force and formula (7) the following formula is derived:

$$p_c = [Ld + \mu wL + \frac{1}{2}\mu w'' L] \cdot F_p V_x \quad (8)$$

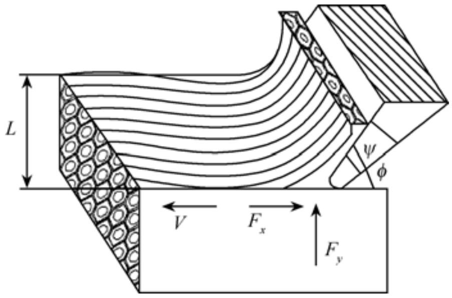

Fig. 1 The cutting sketch map of micron and long-slice wood fiber

7 The analysis of an application example

Taking for example the *Populus tomentosa* Carr, a trial of the micron cutting was performed on the experimental desk. The diameter D of the cutting tool plate was 400 mm; the rotation speed n of the principal shaft was 6,000 r/min；the cutting angle ϕ was 23°; the friction angle β was 25°; the cutting linear speed V_x was 125.6 m/s. The cutting thickness of the fiber d was 0.055 mm；the cutting length L was 80 mm； According to the cutting formula in Eq. (4), the average positive stress F_p was worked out for 18.29 Mp.When the cutting thickness of fiber was 55 μm, the cutting width was 80 mm, the width of the wearing zone on the rear surface of the cutting tool was 50 μm, and the contact length of the rear surface of the cutting tool and the work piece was 50 μm. According to the formula in Eq. (6), the cutting force in the main direction was 131.61 N. When the rotation speed reached 6,000 r/min, the cutting linear speed was 125.6 m/s. The cutting power of the fiber for the product line whose MDF output was 50,000 m^3 was worked out for 281 kW according to the formula in Eq. (8). The power saved was 80% compared with the traditional heat grind machine.

Theoretically, this paper brings forward a solution to the problems of maximal energy waste of the cutting equipments of the wood fiber in the product line whose MDF output is 50,000 m^3 per year. Compared with the power consumption worked out according to the above course with the power that the heat grind machine consumes for the same fiber, power waste can be reduced to less than half of the power waste by the mechanical heat grind method after actual implementation. The working procedures of cooking and adding chemical reagents are also eliminated in this method.

8 Conclusions

Aiming at the problem of the maximal power waste in the traditional heat grind of the wood fiber, some datum are compared and analyzed. The qualitative analysis shows that the heat grind method of the fiber cutting is a method that wastes energy. An innovative idea that the micron fiber cutting can save energy and reduce energy waste is put forward.

By arriving at the formulae of the cutting force and power of the micron and long-slice wood fiber method, the action of forces on the wood fiber and corresponding related parameters during the course of the micron and long-slice wood fiber forming are expounded.

Through assuming the concrete parameters during the processing of the micron long-slice wood fiber, the power wastes of the micron long-slice wood fiber cutting for the output of the 50,000 m^3 MDF per year are worked out. Compared with the power waste of the traditional fiber forming, more than half of the energy wastes can be saved. And the fiber filament maintains original performance of wood. Thus, high quality fiber can be obtained. It is a revolution for the wood-based panel industry. The MDF enterprise benefits can be enhanced on a large scale.

In recent years, the use of international precise cutting theory to calculate the wood cutting forces , has enhanced the computation level of the wood cutting forces . The difficult problem that has not been resolved for nearly a hundred years has been resolved fundamentally by use of another pattern to research the energy consumption of the heat grind machine.

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