Frictional Impulse in Mechanical Wood Grinding

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ABSTRACT

A frictional impulse was tested in wood grinding by employment of data produced on a laboratory scale implying that grindstone and wood quality may be considered unchanged. It means that the grinding parameters can be studied sufficiently, also because any effects of the grindstone curvature can practically be eliminated, since the grinding opening is small.

The frictional impulse is defined as a ratio between the compression force and the peripheral grindstone speed. Both factors are basically independently selectable, and they affect the wood advance rate (fiberising speed) and drag/shear force (fibrillation degree and coarse fiber content), which hence are dependent factors.

Obtained results confirm that the frictional impulse better than compression force described the grinding in terms of wood advance rate and drag force. Their linear correlation coefficients at peripheral speeds of 15-30 m/s were 0.98-0.99. In a later study the correlation coefficients were 0.94-0.99 at 30 m/s. It seems that grinding may well be described by the frictional impulse proposed.

Freeness obtained at 30 m/s peripheral speed is a function of the frictional impulse with a correlation coefficient of 0.88-0.99, where the lower values are representative for PGW. It also appears that the coarse fiber fraction (+28 mesh) followed the entire frictional impulse data obtained at 3.5-30 m/s GW grindings with a correlation coefficient of 0.86. The linear correlation coefficients for coarse fiber fraction, sheet density, tensile index and light scattering coefficient as functions of the frictional impulse at limited, but specific freeness levels ranged from about 0.80 to 0.99. At the freeness level 110-125 ml it was 0.85-0.99.

INTRODUCTION

In mechanical wood grinding a wood log surface is treated by grindstone grits due to their compression against and sliding over the wood surface. Assuming that the wood and its surface as well as the grindstone surface remain unchanged during a grinding experiment, one may expect that the compression and sliding should affect the grinding and the fiber properties. In practice, compression and sliding can be expressed by the corresponding machine parameters, i.e. the compression force and the grindstone peripheral speed. However, due to wood elasticity, the true compression or speed occurring in the wood cell material is probably not equivalent with the machine parameter numerical values. Grinding results must always be evaluated by considering also the grindstone structure and the wood quality in a broad sense. Grindstone structure is described by grit distribution, grit size and sharpness, as it is obvious that grits affect the true compression. Wood quality again can be expressed by tree species and hardness, moisture content, basic density as well as by the annual growth structure and cell structure, and last but not least by its temperature.

Subsequently, once a wood cell is hit by grits, the cell and its wall is somehow distorted at least in the areas of contact. The grits thus introduce shearing forces that may release the cell from wood, or if treatment is “premature”, the shearing forces may rather cause fibrillation of the cell wall. Both fiberising and fibrillation are required, as they contribute to productivity and fiber flexibility. It is obvious that grinding conditions should be selected to sufficiently release wood cells with suitable fiber properties, e.g. maintained length and fibrillation. The best grinding results may thus be achieved by combining compression force and peripheral speed to suit the paper grade produced. Most mills have done this already, but as soon as the grindstone surface or wood quality varies, the prerequisites for grinding change as well.
Each wood cell is surrounded by a thin middle lamella and thus separated from neighbor cells, which might affect grinding productivity due to its amorphous properties implying a low softening temperature. The cell wall again may be considered crystalline due to the cellulose, which has a comparatively high softening temperature. However, grinding is probably not dependent only on these two components, because also hemicelluloses exist in the cell wall, mainly surrounding crystalline cellulose fibrils. Subsequently, if the internal compression and shear forces introduced by grits follow a general hysteresis theory, heat should be generated and thus increase the middle lamella (lignin) and hemicellulose temperatures to their respective softening behavior. As a result of this, fibers with suitable fibrillation can be produced. Since this is just a theoretical case, one must be prepared to see variable effects on cell walls, which effects probably are dependent on how compression and shear speed are combined.

A “simplified” grinding procedure described above is still very complicated, and therefore the effects of grindstone dullness [1], wood moisture content [2,3,4] and temperature [4,5] are not treated in this context, since these factors would imply further complication.

EXPERIMENTAL

Background

The introduction clarified that compression and shear speed in wood grinding must be combined in a way that provides good productivity and suitable fibrillation. Simple examples support this. If compression is too low relative to shear speed, cells will be torn off before they have received sufficient fibrillation. This resembles more or less the common mill situation. On the other hand, high compression and low shear speed provide low pulp production, but good fibrillation. Such a grinding procedure has earlier been demonstrated by laboratory experiments [6,7,8,9].

But what would simultaneously describe compression and shearing in the wood or cells?

Frictional impulse

It has earlier been suggested that an impulse might sufficiently explain mechanical grinding [10,11]. The impulse is basically represented by the product of a force and the corresponding time of that force in action. As has been shown earlier, the coefficient of friction [8,9], which is described by a ratio of the required drag force and the introduced compression force, might be replaced for an effect-related frictional coefficient, which is defined as a ratio between the drag effect and the compression effect. This coefficient would thus describe not only the forces involved, but in addition the speeds that also are measurable machine parameters. The effects are thus given by a product of a force and the associated speed, \( F \cdot v \), and the effective frictional coefficient is thus given by

\[
\mu_p = \frac{(F_d \cdot v_c)}{(F_c \cdot v_d)} \quad \text{(Equation 1)}
\]

where the indices \( P, d \) and \( c \) stand for effect, dragging (shearing) and compression, respectively. To approach the impulse hypothesis Eq. 1 is rewritten as follows

\[
\mu_p = \frac{(F_d / v_d)}{(F_c / v_c)} \quad \text{or} \quad 1/\mu_p = \frac{(F_c / v_c)}{(F_d / v_d)} \quad \text{(Equations 2a and 2b)}
\]

Eq. 2b is basically the same as Eq. 1, but now compression force and drag (peripheral) speed appear in a combined form, \( F_c / v_d \), which is closer to the definition of impulse, \( F \cdot t \). The quantity \( F_c / v_d \), called the frictional impulse, is dependent on the introduced compression force and the grindstone drag (peripheral) speed, which as machine parameters may be freely selected. The drag force \( F_d \) required and the wood advance rate \( v_c \) are also dependent on grindstone structure and wood quality in a broad sense.

Assuming that grindstone surface and wood material have constant structural properties, which is the case in well controlled laboratory experiments, one should be able to determine the best suitable grinding conditions to achieve the wanted pulping productivity and fiber properties.

Grinding conditions

The grindings were conducted on a laboratory scale, which of course eliminates uncertainties associated with the grindstone curvature, and variations in grindstone surface structure and wood raw material. Two different
grinding series [6,7,8 and 12,13,14] were consulted for data including at least the machine parameters $F_c$ and $v_d$ as well as the dependent parameters $F_d$ and $v_c$ that more or less describe motor load and pulp production. Data specifying the slurry, pulp and sheet properties were freeness, McNett +28 mesh fraction, sheet density, tensile index and light scattering coefficient.

The frictional impulse can be set by varying the compression at a constant grindstone peripheral speed, which is the current situation at any mill, but it can also be controlled by simultaneously varying compression and peripheral speed. This preferable alternative would enable groundwood pulp with an optimum of pulp production and fiber quality (fiberising and fibrillation). The data extracted represent therefore grindstone peripheral speeds ranging from about 10 to 30 m/s, as mill grinders run at constant speeds from 20 to 30 m/s. The laboratory grinders applied had a grindstone of 300 mm in diameter and 50 mm in width.

RESULTS

Grinding

Figures 1 and 2: Frictional impulse $F_c/v_d$ data [6,7,8] correlates more distinctively with the wood advance rate $v_c$ than does compression force $F_c$. The linear correlation coefficients (LCC) are in both diagrams 0.99 for 30 and 15 m/s grindstone speeds, 0.97 for 7 m/s and 0.92 for 3.5 m/s.

Figures 3 and 4: A similar observation can be made that drag force $F_d$ appears to correlate better with the frictional impulse than with compression force. LCC is again 0.99 for the highest speeds, but only 0.80 for 7 m/s and 0.70 for 3.5 m/s.

Figure 5: Corresponding functions as above are illustrated for data from GW and PGW grindings [12,13,14]. The LCC between wood advance rate and frictional impulse at 30 m/s speed is 0.97 for GW and 0.94 for PGW, and even higher at 10 m/s.

Figure 6: Drag force is probably the same for GW and PGW grindings at both 30 and 10 m/s speeds. LCC is 0.99 and 0.97 for GW and PGW grindings at 30 m/s.
GW and PGW Grinding of spruce wood; variable $v_d$

Figures 5 and 6. Effects of frictional impulse on wood advance rate (left) and drag force (right); GW and PGW.

Slurry and pulp properties
Figure 7: The LCC is 0.99, 0.98, 0.90 and 0.75 for freeness lines representing 30, 15, 7 and 3.5 m/s speeds respectively.
Figure 8: At 30 m/s speed GW grinding produces a lower freeness than PGW, as the difference is uncertain at 10 m/s. The corresponding LCCs obtained at 30 m/s are 0.93 and 0.88, and at 10 m/s roughly the same.

Figures 7 and 8. Effects of frictional impulse on freeness; GW (left), and GW and PGW (right).

Figure 9: Whether sufficient grinding treatment of wood occurs is indicated by the coarse pulp fraction (+28 mesh), which in general appears to increase with increasing frictional impulse. The specific LCC for 30, 7 and 3.5 m/s is 0.79, 0.95 and 0.52 respectively, as it would be 0.86 for a master line combining all data. At respective freeness levels of 35-55 ml, 110-125 ml and 180-240 ml the corresponding LCCs are 0.85, 0.99 and 0.99
Figure 10: GW grinding produces a coarse fiber fraction below 20%, as it exceeds 30% for PGW. If the GW lines are considered representing one single line, the LCC would be 0.88, as it accordingly would be 0.71 for PGW.

Figures 9 and 10. Effects of frictional impulse on the McNett +28 mesh fraction; GW (left), and GW and PGW (right).
Sheet properties

Figure 11: GW grinding conditions providing high amounts of coarse fibers result unexpectedly in high sheet density (low bulk), as is indicated by the picture. The LCC is -0.99, -0.96, -0.85 and -0.81 at 30, 15, 7 and 3.5 m/s speeds respectively. At freeness levels of 35-55 ml and 180-240 ml the corresponding LCCs are 0.83 and 0.99.

Figure 12: The sheet density obtained by GW grinding does appear higher than by PGW, as one would expect. The GW line has the LCC -0.99 at 30 m/s speed, as PGW accordingly has -0.81. At 10 m/s the numbers are generally of the same order.

Figures 11 and 12. Effects of frictional impulse on sheet density; GW (left), and GW and PGW (right).

Figure 13: The tensile index versus frictional impulse shows LCCs of -0.99, -0.93, -0.99 and -0.89 for 30, 15, 7 and 3.5 m/s speeds respectively. At respective freeness levels of 35-55 ml, 110-125 ml and 180-240 ml the corresponding LCCs would be 0.79, 0.99 and 0.99.

Figure 14: GW and PGW grinding data plotted in the same tensile-scale diagram as above illustrate a lower tensile index level. The low level may probably be explained by a not sufficiently conditioned grindstone and/or by differences in wood density and fiber length. The LCC is -0.97 for GW grinding at 30 m/s, and for PGW at 20 m/s -0.94.

Figures 13 and 14. Effects of frictional impulse on tensile index; GW (left), and GW and PGW (right).

Figure 15: Increasing frictional impulse indicates in general that the sheet light scattering coefficient improves. The LCCs for the light scattering lines obtained at 30, 15 and 3.5 m/s are -0.99, -0.80 and -0.90, while it would be 0.85 at a freeness level of 110-125 ml.

Figure 16: GW grinding results in higher light scattering, at a high peripheral speed. The LCC for GW grinding at 30 m/s is -0.99 and for PGW -0.92.
The hypothesis appears to be confirmed that a frictional impulse defined as the ratio between compression force and drag/shear speed, $F_c/v_d$, would help understanding the mechanical wood grinding and later also help controlling the technical process. In fact, frictional impulse provided the same linear correlation coefficient (LCC) as the compression force $F_c$, but it results in higher LCCs for the wood advance rate $v_c$ in plots with a certain freeness level. At freeness levels of 35–55, 110–125 and 180–240 ml the corresponding LCCs were -0.98, -0.79 and -0.96 respectively, as they were -0.43, -0.72 and 0.37 for functions of the compression force.

The LCC for GW freeness as a function of the frictional impulse was 0.98-0.99 at 15-30 m/s. PGW provided some lower LCCs. The corresponding coarse fiber fraction LCC was 0.86-0.88 in GW grindings comprising all speeds applied, as PGW had only 0.71. The coarse fiber content (+28 mesh) had the LCC as high as 0.99 when evaluated at a freeness level of 110-125 ml. The same LCC levels were obtained for sheet density, tensile index and light scattering coefficient.

In conclusion, it seems that the proposed frictional impulse $F_c/v_d$ also passed the current tests where a variable peripheral speed was employed, which has not been the case in earlier works. The ideal case would of course be performing test runs with possibilities for simultaneous variation of both compression force and peripheral speed independently of each other. Such a technical system would most likely ensure smooth pulp quality at lower energy consumption, and it would also reduce web breaks at the paper machine.

REFERENCES


4. Lind, T., “Pretreatments of Norway Spruce Pulpwood for Pressure Groundwood Production”, Laboratory of Pulping Technology, Faculty of Chemical Engineering, Åbo Akademi University, Åbo 2005, 113 p, Doctoral Thesis.


