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GRINDING SURFACE WITH AN ENERGY-EFFICIENT PROFILE

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ABSTRACT

A grinding surface profile was designed in order to achieve a more energy-efficient defibration. The design method used is based on the behavior of wood in mechanical loading. The objective of the design is to produce large deformations to achieve much permanent structural decomposition in the wood using only little mechanical energy. Several grinding surfaces were tested in the study. One defibration surface in this series was manufactured by profiling the surface of a conventional ceramic stone with a sinusoidal base form and by opening it with a high-pressure water jet. The trials in the semi-pilot grinder with the wave-shaped ceramic surface shows that energy-efficient base forms on the grinding surface give considerable benefits compared with conventional ceramic surfaces. A long pilot pressure grinding trial with the sine wave pulpstone surface showed that the concept has a potential to produce energy-efficiently a mechanical pulp with promising properties for use in printing papers.

KEYWORDS: CERAMICS, ENERGY CONSUMPTION, MECHANICAL PULP, PULP PROPERTIES, PULP STONE, PRESSURE GROUNDWOOD, VISCOELASTIC BEHAVIOR.

INTRODUCTION

The use of energy in mechanical pulp production is inefficient in the sense of producing new fiber surfaces. It is widely accepted that the major part of the high energy consumption is due to the fact that deformations of viscoelastic materials such as wood always dissipate energy and that deformations are necessary to make slender paper fibers from stiff wood fibers [1,2,3,4,5]. Many estimates of how much energy could be saved have been done and they differ to some extent. The main topics of fundamental low-energy research in mechanical pulping are questions connected with deformations, such as what kind of deformations should be done, and in what circumstances, to obtain a good defibration result using minimum mechanical energy. The beginning of a more rational approach to these questions goes back to the early 1960s, when D. Atack and co-researchers in their work at Paprican produced the first more explicit description of the grinding process and completed a lot of empirical research [6,7].

BACKGROUND AND DESIGN METHOD

This study is a continuation of a long-term research on fundamentals of mechanical defibration which started as a co-operation between Tampere University of Technology and KCL in the early 1990s. Certain parts of the research have been reported earlier [8,9,10,11,12,13]. One objective of the research was to develop a considerably more energy-efficient defibration surface based on modeling of the viscoelastic behavior of wood. In grinding, protrusions (grits) on the pulpstone surface causes a cyclical mechanism which weakens the wood structure. Simultaneously the same protrusions separate the fibers from the wood matrix by a combing action [6]. A new surface was designed to work efficiently in both phases, here called 1) the kneading phase and 2) the fiber separation and treatment phase. A novel approach in this research is to divide the action source of the grinding surface into two parts, 1) a large scale base profile on the surface, which mainly constitutes the first phase, and 2) a surface roughness of the profile, which mainly constitutes the second phase [11,12]. This allows these phases to be controlled independently. This possibility is new compared with the conventional grinding surface where the choice of grit size is a compromise to achieve good results for both phases. According to the adopted hypothesis, large deformations are the most efficient way to produce permanent structural changes in wood [2]. As a consequence of this hypothesis, energy savings can be achieved in the first phase (the more energy consuming phase) if the base profile of the defibration surface is designed so that a thin layer of fibers to be defibrated next completely relaxes between the deformation cycles. The second phase of the defibration can be mastered using a manufactured roughness upon the sinusoidal base form of the first phase. The amplitude of deformations generated by the roughness is many decades smaller than that generated by the base form.

In order to be able to boost the essential fatigue process in the kneading phase, a valid simulation model for temperature and strain in the wood had to be constructed. The simulation of the first model built as a Voigt-Kelvin solid was compared with temperature and pressure variation measurements from inside the wood during grinding trials [8,9]. At this stage the parameters for viscoelastic behavior in the Voigt-Kelvin solid had to be solved implicitly because there was no explicit knowledge of their temperature dependence in defibration circumstances. Later the coefficients of elasticity and viscosity were determined through indirect measurements as functions of temperature in relevant circumstances [10]. The temperature dependence of the coefficients turned out to be so strong that their space derivatives became significant inside the wood, where temperature changes a lot. Therefore the original model had to be extended to include space derivatives of the coefficients [12]. Using the extended model and the temperature dependent coefficients, the wood behavior was simulated as a Voigt-Kelvin solid. The amplitude of the sinusoidal base form was selected and the corresponding wavelength was tuned to achieve an almost complete relaxation of a thin layer of fibers between the deformation cycles, Fig. 1 [12]. The behavior of the water and fiber suspension in the grinding zone was not modeled due to great uncertainties in the existing circumstances. Instead, it was simply assumed that the suspension decreases the effective amplitude experienced by the wood surface. In this simulation the effective amplitude used was 0.18 mm when the amplitude of the surface profile was 0.24 mm. The tuning resulted in a wavelength of 17 mm. The simulated action can to some extent be considered as a semi-forced damped oscillation that is brought to amplitude resonance.

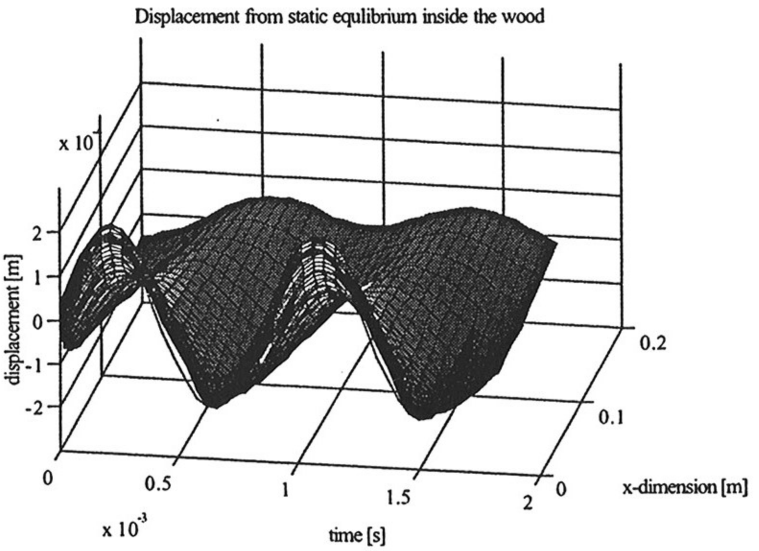

Fig. 1. Displacement from static equilibrium inside the wood in the cyclic steady state [12]. The x-dimension is perpendicular to the grinding zone so that the single wave line in the front of the figure at x = 0 represents the effective amplitude.

EXPERIMENTAL

Several grinding surfaces were tested in this study. In the initial stage of the study, grinding surfaces were manufactured by coating abrasive microstructures on metallic defibration wheels. In the course of the development of the design method, different wave pattern lengths together with several surface roughnesses were tested [11,12]. The last metallic grinding wheel with the profile described above produced very promising results. It was decided to try to verify the benefits of the base form on a normal 60-mesh ceramic pulpstone. The concept of applying a sine wave pattern to a ceramic pulpstone surface was developed as a joint research project between KCL and Tampere University of Technology [13]. The surface of a conventional 38A601 pulpstone was machined axially with the regular sine wave pattern, Fig. 2 and fig. 3. The surface was then opened by means of a high-pressure water jet device. As reference, a twin stone having the same grit construction was sharpened with a normal # 10/ 28° pattern. Norway spruce wood was ground under PGW-S 120°C conditions on KCL's pilot pressure grinder, Table 1.

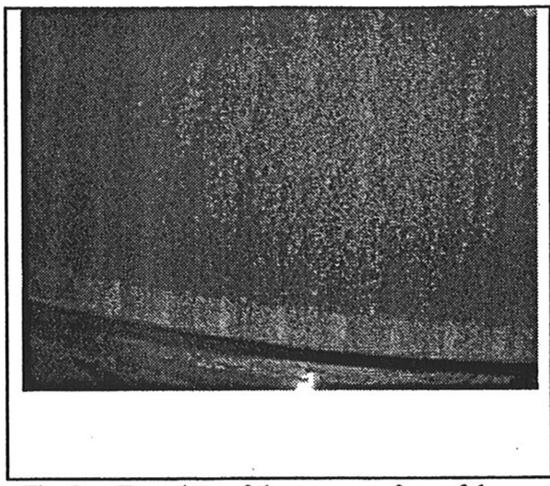

Fig. 2. Top view of the wave surface of the ceramic stone before the grinding trials.

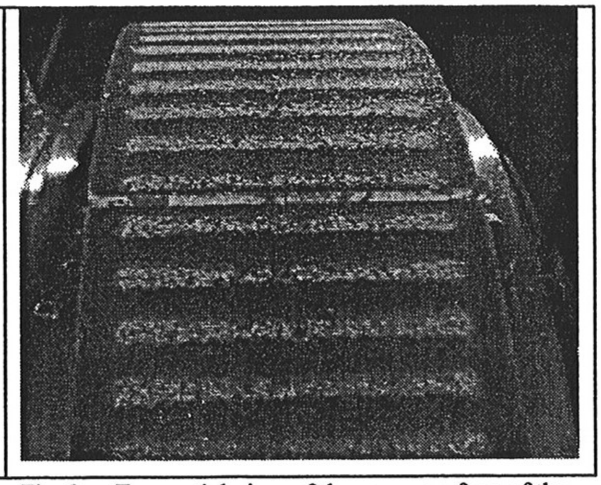

Fig. 3. Tangential view of the wave surface of the ceramic stone after several days of grinding trials.

Table 2. The process conditions used in this investigation.

Wood raw material	Norway spruce
Peripheral speed, m/s	20
Grinding control mode	constant shoe speed
Shower water temp., °C	120
Grinding consistency, %	1.5
Target CSF, ml	100 - 150

RESULTS AND DISCUSSION

Specific energy consumption

At the defibration temperature employed here, 120°C, a distinct energy saving could be noticed when grinding with the sine wave pattern was compared with grinding with the reference stone, Fig. 4. At a lower temperature (95°C) no clear energy saving could be observed, Fig. 5. The explanation for the energy reduction is that the profile was designed for high temperatures and thus the wood temperature in the immediate vicinity of the grinding zone should be sufficiently high for the wood to be able to follow the curvature of the stone. This is necessary in order for the fibers to collapse to such an extent that permanent structural changes can occur energy-efficiently.

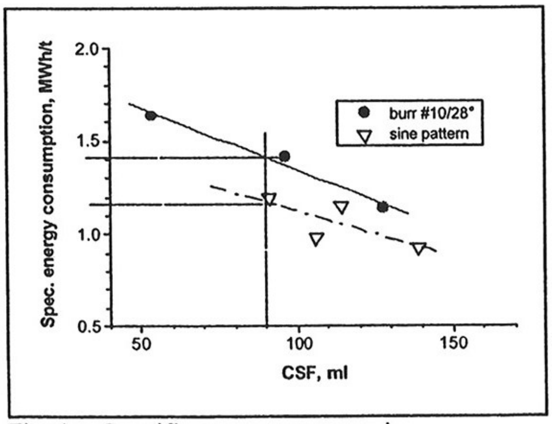

Fig. 4. Specific energy consumption versus freeness of the disintegrated pulps at shower water temperature 120°C.

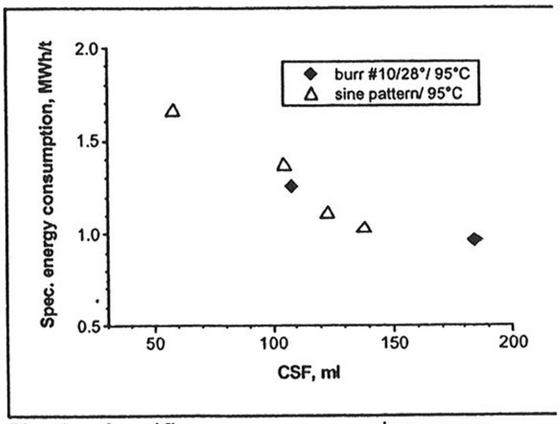

Fig. 5. Specific energy consumption versus freeness of the disintegrated pulps at shower water temperature 95°C.

Fiber length

At the same time as the fatigue action on the fibers was more efficient due to the wave pattern, fibers were loosened (peeled off) from the wood matrix with the same or even less fiber cutting compared with the reference. Both the FS 200 fiber length and the Bauer McNett +14 fraction were higher for the sine wave pulps, Fig. 6 and Fig. 7.

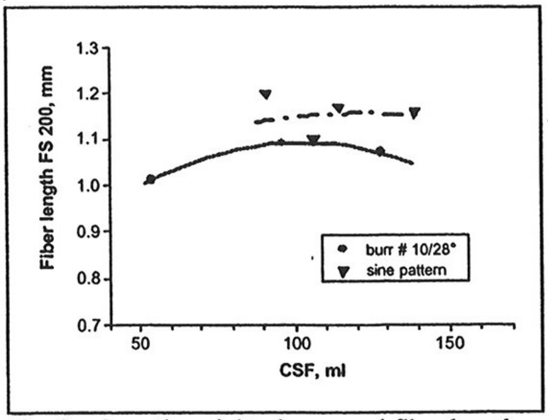

Fig. 6. Length-weighted averaged fiber length vs. freeness when grinding with normal and sine wave surfaces.

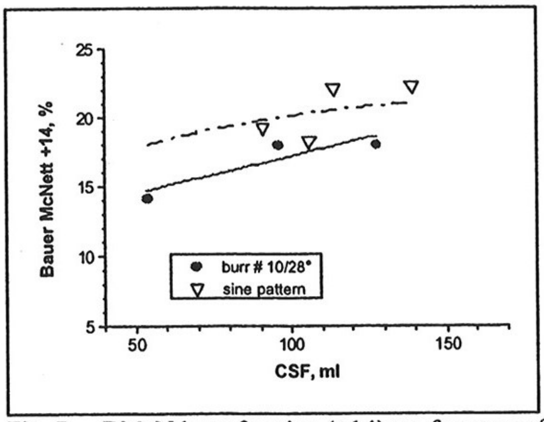

Fig. 7. BMcN long fraction (+14) vs. freeness of the pulps ground with normal and sine wave surfaces.

PFI shives

As well as having a higher fiber length, the sine wave pulps also had a higher shive content, which means that to a certain extent the sine wave pattern forces also fiber bundles together with separated fibers to be combed from the matrix, Fig. 8. This suggests a need for more reject treatment for the pit pulp produced with the sine wave pattern. The pit pulp also showed a very high latency character. Cold disintegration treatment considerably reduced both the shive content and the CSF value, fig. 9.

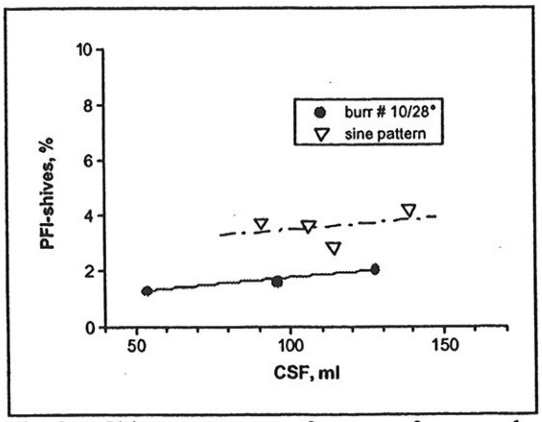

Fig. 8. Shives content vs. freeness of screened pulp.

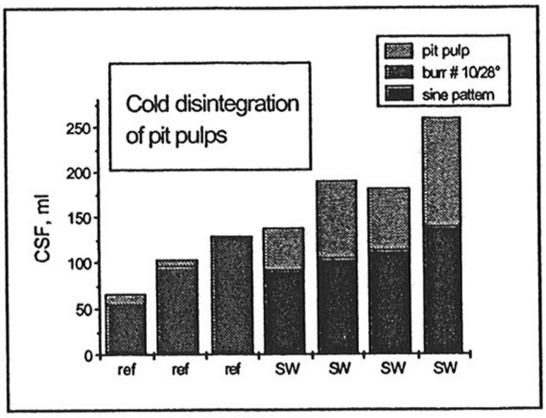

Fig. 9. Effect of cold disintegration on pulp freeness.

Strength properties

The wave surface helped to develop fiber bonding properties. As functions of both CSF and energy consumption, the tensile strengths of the sine wave pulps were some 10 and 30%, respectively, higher than those of the reference pulps, Fig. 10 and fig. 11. Even though the sine wave pulps had a higher fiber length, there was no major difference in tear strength between the sine wave pulp and the reference pulp, Fig. 12. The high fines content of the sine wave pulps could partly explain why the tear strength potential was somewhat smaller than expected.

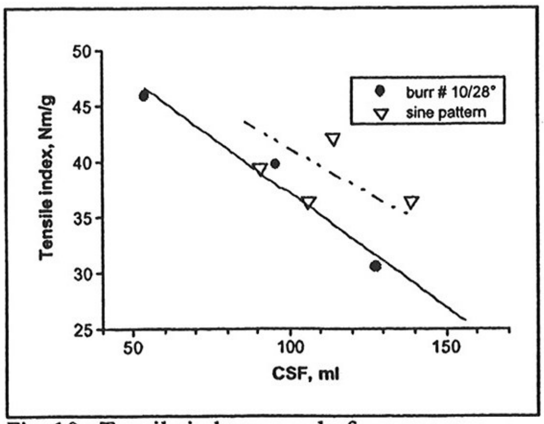

Fig. 10. Tensile index vs. pulp freeness.

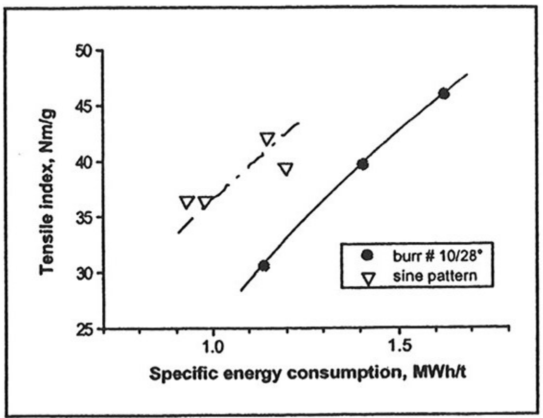

Fig. 11. Tensile index vs. specific energy consumption.

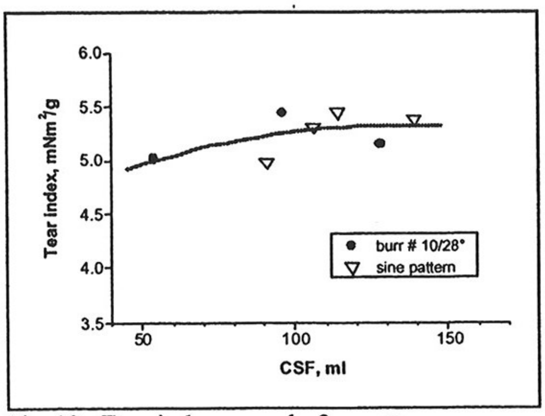

Fig. 12. Tear index vs. pulp freeness.

Optical properties

The sine wave pulpstone developed light scattering properties for the pulps that were very similar to those of the reference pulps, Fig. 13. On a rough scale, the scattering values for both the reference and sine wave pulps were high in view of the relatively high shower water-temperature used in the study. Again, considering the relatively high shower-water temperature, both pulps showed a brightness level corresponding to bright high-quality pulps. The brightness values for the sine wave pulps were, however, two to three points lower than the brightness of the reference pulps, Fig. 14.

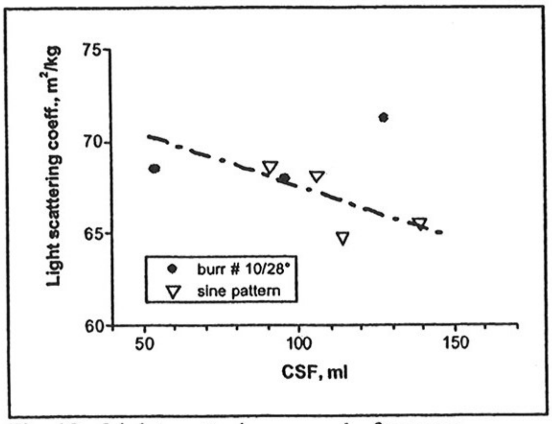

Fig. 13. Light scattering vs. pulp freeness.

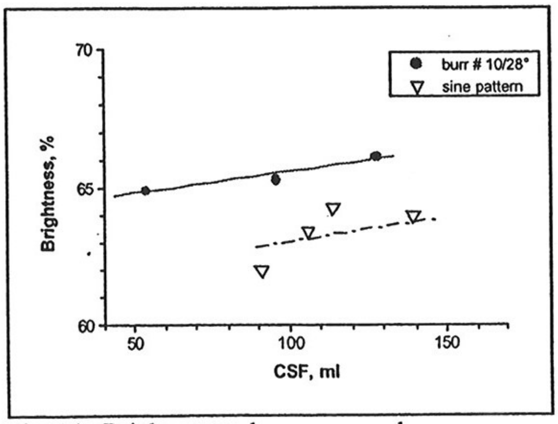

Fig. 14. Brightness values measured on laboratory sheets vs. pulp freeness.

VERIFICATION OF THE SINE WAVE CONCEPT

Purpose of the verification trial

The semi -pilot grinding trials with the sine wave pulpstone showed that although the pulp produced was equal to a high-quality pressure groundwood in most respects, the sine wave pulp had a fairly high shives content. In order to test the stability of the pulp quality in long-term grinding, a one-week trial with the KCL pressure grinder was set up. For an other project a sufficient amount of pulp was produced to satisfy the need for a pilot refiner-, screening-, and paper machine trial. The quality of the sine wave pulp is compared here before and after the refining and after the screening step.

Trial set up

Some 500 kg of pressure groundwood was produced in process conditions where fiber length and a reasonable production level could be achieved .The process conditions are given in Table 2.

Table 3. The process conditions in the verification trial.

Stone	38A601
Grinding surface pattern	17 mm sine wave
Peripheral speed	20 m/s
Tsw	150°C
Casing pressure	750 kPa
Wood species	Norway spruce
Ram speed	0.84 mm/s
Production	10 kg/h

After pressure grinding the pit pulp was disintegrated, refined, and screened.

Results

The properties of the pit pulp, the refined pulp, and the final screened pulp can be seen in Table 3.

Table 4. Properties of the pit pulp, the refined pulp, and the final screened pulp.

Pulp		**pit pulp**	**refined pulp**	**final screened pulp**
SEC	MWh/t	0.76	1.7 (*)	
CSF	ml	207	40	32
Fiber length, FS 200	mm	1.21	1.19	1.08
PFI -shives (0.08 mm)	%	8.8	1.1	0.15
BMcN+14	%	38.4	11.6	7.5
BMcN+28	%	11.1	22.5	21.4
BMcN-200	%	19.8	28.5	31.8
60 g/m^2-lab. sheets				
Density	kg/m^3	369	563	550
Tensile index	Nm/g	30	56.1	51.7
Tear index	mNm^2/g	6.18	5.35	5.22
Brightness	%	57.7	58.8	57.3
Light scattering	m^2/kg	60.8	62.7	66.9
Roughness, Bendtsen	ml/min	1310	90	65
(*) total energy consumption				

In the refining stage some 1 MWh/t was used to defibrate sine wave pulp to freeness level 40 ml without any noticeable drop in fiber length. Still, at the same time the Bauer McNett long fiber fraction +14 was reduced to a third. The tensile strength of the sine wave pulp was developed very favorably in the refining stage (30 -> 56 Nm/g). Also the PFI shives content of the pulp and the roughness value of the laboratory sheet came down to very low values in the final screened pulp.

The long pilot pressure grinding trial with the sine wave pulpstone surface showed that the concept has a potential to produce energy-efficiently a mechanical pulp with promising properties for use in printing papers. It is evident, however, that more trials are needed, preferably on a production line, in order to verify validity of the sine wave pulstone at mill scale.

CONCLUSIONS

The trials in the semi-pilot grinder with the wave-shaped ceramic surface and the reference stone (identical pulpstone with normal # 10/28 ° burr pattern) confirmed the benefits of the energy-efficient surface profile.

1) By applying a regular sine wave profile to the surface of a conventional ceramic pulpstone, specific energy consumption can be cut by about 20%.

2) With the sine wave stone the fiber length was the same as, or even better than, that for the reference pulps.

3) The latency character and the higher shive content of the sine wave pulp may necessitate more attention to screening and reject refining treatment.

4) Fiber bonding properties developed more efficiently with the sine wave stone than with the reference grinding stone pattern. At the same freeness, tensile strength increased by 10%, while at the same energy consumption, tensile strength increased by 30% when compared with the reference pulps.

5) The high fiber length values for the sine wave pulps resulted in good tear strength values.

6) At a shower-water temperature of 120°C no major impairment in scattering properties could be seen.

7) The brightness values for the sine wave pulps were two to three points lower than the brightness of the reference pulps.

Even if the results seem to be straightforward and it could at this point be easy to claim that the good results are a direct consequence of the improved fatigue process, it is worthwhile remembering that there might also be other impacts that improved the result. As an example we can mention the cyclic and significantly increased local pressure between grinding surface and wood caused by the sine-shaped surface. This in combination with the possibility to use unconventional abrasives will enable us to more freely effect the fiber separation and treatment phase.

If, however, the good results are a consequence of the improved fatigue process, it is likely that the profile used can be further developed. The basis for this statement is that so far just one profile amplitude has been examined and the design method consists of many stages which all have their uncertainties. Further, if the design method is adequate, this means that profiles can be optimized for wood with other viscoelastic properties than studied here.

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