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Reproducibility of refiner performance

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Abstract: The reproducibility of a laboratory refiner’s performance was analyzed. The results showed that among the parameters examined, the warm-up time before recording no-load power affects the reproducibility, especially at low-intensity refining. Already a 12% change in no-load power was found to cause significant variability in the refining result when pulp was refined at low 0.3 J/m intensity. A sufficient warm-up time is recommended in order to guarantee good reproducibility of refiner performance.

Laboratory refiners, which allow the specific edge load (SEL) and specific energy to be controlled, are used for evaluating chemical pulps. Because high-speed paper machines demand paper with good strength properties, the accuracy of refining is increasingly important. Less variation in web strength is tolerated. Stable refiner performance and refiner control is necessary. Furthermore, a laboratory refiner equipped with a process logic controller offers additional potential as a research tool. In this context, the need for reproducibility increases, because the experiment should be accurately repeatable. The purpose of this study was to find out if a recently commissioned laboratory refiner performs reproducibly, and an effort was made to trace potential sources of variability in laboratory refining.

Mill refining results may vary for several reasons. The pulp recirculation and minimum incremental change and action time of the refiner controller may limit rapid changes in refining. If the possibilities of measuring the process accurately in terms of flow, consistency and power are limited, the variability in pulp properties may increase [1]. The estimate of the refiner’s no-load power is used to calculate the target total power. The no-load power is part of the power that is consumed by mechanical friction and fluid transport, without actually treating the fibres [2]. Usually, the no-load power is estimated after commissioning of the refiner, or infrequently, depending on the mill’s interest in this aspect. In net specific energy control, the no-load power is normally a constant in the control algorithm, and not a field input. Thus, there is no control difference between no-load and total power [1]. Since no-load power is not estimated regularly, an incorrect value in control set-ups may lead to inaccuracies in fibre development [3], with the refiner’s no-load power affecting refining efficiency and affecting the strength development of pulp [4].

It has been reported that the no-load power may change due to the mechanical condition of the refiner, changes in stock throughput and the condition of fillings. After maintenance of refiner component wear and bearings, the no-load power may decrease by 25% [3]. McCaw [4] reports changes of more than 100% in no-load power because of mechanical problems with floating rotating assemblies of double- and multidisc refiners. Siewert and Selder [2] report linear dependence between filling groove depth and no-load power. The no-load power of fresh plate fillings decreases by about 50% due to bar wear over a period of several months. Contrary to the above, the findings of Luminainen [5] indicate that the proportion of no-load power in a modern industrial refiner is only 15-30% of total power, and that no serious consequences follow if it is forgotten, whereas in a laboratory refiner the share of no-load power is higher and should be considered more carefully.

There appear to be fewer sources of variability in laboratory refining than in mill refining. In the short term, bar height wear can be assumed to be insignificant in a laboratory refiner, since its operating time is shorter, and since filler-containing pulp is not used with the fillings utilized in kraft refining. The pulp consistency does not vary during refining and a hydraulic screw pump gives stable flow, which is insensitive to counter-pressure variations. The level of no-load power is estimated daily. However, it was found that the reproducibility of the refiner’s performance may change, unless the equipment is properly warmed up before no-load recording. A long enough warm-up time of 1,200 s guarantees that the no-load power is accurately recorded and refining at low 0.3 J/m intensity is reproducible.

MATERIALS, METHODS

Refiner: A new Voith LR 40 laboratory refiner was used to treat fibres. The basic operating principle of the refiner is described by Sepke, Pott and Melzer [6] and by Wulch and Flucher [7]. The SEL theory was applied to control refining intensity. Specific energy was calculated from the net power, from the pulp mass lost in the system and from the refining time. The net power is total power less the estimated no-load power. The no-load power was estimated daily before the trials. The recorded value is an average for the last 20 s of the warm-up sequence. For example, in the third trial series (no-load power) the warm-up time sequence was set to either 300 or 1,200 s.
When water was used for no-load power estimation, the gap was about 1 mm (refining position less 1 mm). For stock no-load estimation, the stator was in backg

ing position. With plate fillings, the gap was then about 17 mm and with conical fillings, about 22 mm. The position of the stator, total power and outlet pressure were recorded by the WinCC program.

A hydraulic screw pump was used to circulate the pulp from the pulper to the filling casing and back to the pulper. The basic trial operation and sampling were fully automatic. The controller opens an automatic valve, and a pulp sample is released into a bucket on the balance board. The sampling time is short; the maximum opening time of the valve is 2 s. A typical sample amount is from 1.5 to 2.0 l. The rotational speed of the stator was 2,000 rpm. A Siemens S7 process logic controller controls valves, main and gear motors, and the movement of the stator filling which determines the direction of the power is calculated from the torque, which is measured by a sensor fitted on the shaft.

**Experimental Design:**

—First random experiments - comparison of trial mean values: The trial series included a comparison of mean values of randomly refined hardwood kraft (HWK) and softwood kraft (SWK) pulps. The Shopper Riegler value (SR), density, tensile index and light scattering were selected as response variables, illustrating the effects of refining on fibres and paper. Experiments were carried out over a period of 1 day to 1.5 months. HWK pulp was refined with conical fillings and at two different intensities: 0.5 and 1.5 J/m. Altogether three trial series were executed with HWK, each with two or three replicates. One series was conducted in between trials, and twice, fillings were changed. Tests with SWK pulp included three replicates refined during one day with plate fillings at 2.75 J/m intensity. The fillings were not changed between the trials, and the refining time was the same. Table I shows the process parameters. The refining time of the trials varied slightly, because the amount of pulp in the pulper was not exactly the same. Theoretically, this leads to variations in the number of passages through the refining zone. Even so, the results showed good reproducibility for pulps with different refining times, indicating that time differences of this magnitude are irrelevant for the final refining result. Later on, in the other test series of this study, the pulp amount was fixed, eliminating the potential variability caused by differences in refining time.

In addition to actual refining experiments, the shape of curves of recorded no-load power was checked in order to detect infrequent and long-term disturbances, because the no-load power curve occasionally showed an unexpected peak. If a peak occurred, the no-load power measurement was repeated to guarantee as correct an estimate as possible.

—Three-factor factorial experiments: warm-up time, fluid type, and filling change: The effect of three factors: warm-up time (factor A), type of fluid in determining the no-load power (factor B) and filling change (factor C) on the reproducibility of refiner performance was tested. All the factors have two levels, and a single replicate [8]. Table II illustrates the experiment. SR, density and tensile index were selected as response variables. The Matlab 7.0 program was used to calculate the analysis of variance and P-values, and a normal probability plot was drawn to estimate possible main factor effects (factors without replicates). Refining intensity was 2.75 J/m and specific energy 200/4kWh/t and SWK pulp consistency was 4.2-4.4%. Similar plate fillings as in previous experiments were used. The procedure of filling change was improved by inscribing a symbol on the filling, guaranteeing exact positioning of the stator filling and to avoid rotation of the filling when putting it back into the frame. In addition, the temperature of the bearing casing was measured with a thermometer from two points on the casing's surface.

—No-load power 300 or 1,200 s and specific energy varied. Intensity 1.0 J/m: Earlier experiments indicated that the refiner can reproduce results without problems, but the exact role of the accurately measured no-load power at lower intensity remained unclear. The third part of the experiments included a two-factor factorial experiment with two replicates, using a refining intensity of 1.0 J/m.

The time sequence before actual no-load power recording: warm-up time (fact

oring change) was varied. The refiner order was random. The analysis of variance and P-values were calculated to indicate factor main effects. Specific energy was known to affect the level of response variables, but it was assumed that this information could be used later for other purposes. Table III shows the refining parameters. Process data, i.e., stator position (gap), power, and inlet pressure were analysed with the Storage program, which allows transfer of process data into Microsoft Excel.

—No-load power after 100, 300 or 1,200 s and specific energy varied. Intensity 0.3 J/m: The set-up of the trial series was similar to that of the previous one, except that the refining intensity was reduced to 0.3 J/m and an additional level of 100 s was used for the warm-up time in order to cause clear changes in the estimated no-load power. In addition, narrow bar hardwood fillings with greater cutting edge length were used. Table IV illustrates the parameters used in the trial series.

**Data Analysis and Testing:** The analysis of variance and P-values were calculated for factorial experiments [8, 9]. The Shopper Riegler (SR) value, density, tensile index, and light scattering coefficient was selected as response variables to illustrate the effect of refining. Among the selected refining variables, the tensile index correlates relatively well with the number of impacts in refining [10, 11], which increases fibre swelling and fibre flexibility. SR is affected by several fibre properties modified in refining: fibre fibrillation, fines formation and fibre shortening. In measuring SR, from 5 to 7 parallel measurements were made from the sample.

**Pulps:** A bleached HWK pulp and a bleached SWK pulp, both produced in Finnish pulp mills, were refined. Both pulps had a dry content of about 94%. The SWK was a mixture of 44% spruce (Picea abies) and 56% pine (Pinus silvestris). The HWK consisted of 97% birch. Both pulps were stored at room temperature in darkness. Pulp and paper properties were measured according to SCAN and TAPPI standards.

**RESULTS**

First Random Experiments - Comparison of Trial Mean Values: In two series of HWK refining, the reproducibility was found to be insufficient. Mean values of SR, density, light scattering and tensile strength differed clearly. In one series, good reproducibility between the mean values of three trials was found, even though the variation in refining time was largest in this series; in one trial the refining time was 25% shorter than in the other two. The SWK series showed good reproducibility. The filling change between trials appeared to be the only factor connecting poorly reproduced refining. However, these refining trials were used for commissioning and the procedure for filling change was not planned in detail. It remained unclear whether the fillings were adjusted into exactly the same positions after the change. A change in the position after the change could explain the variability, in view of the fact that, during the first day after a filling change, a mill refiner produces pulp of varying quality until the bar surfaces have adapted against each other.

In addition, the shape of the power curve was found to vary. Occasionally, the power curve formed a peak during the warm-up sequence, e.g. increasing from 2.2 to 3.05 kW after running for 100-200 s. If a peak occurred, the warm-up sequence and no-load recording were repeated in order to overcome the problem. During the second no-load recording, the power curve was always stable. During actual refining no sudden power or gap changes were detected.

Figure 1 illustrates a typical power curve for a two times repeated no-load power recording. Usually, when a cold
machine is started, the level of total power is about 3 kW, dropping quickly to about 2.3 kW after 600 s. The origin of the peaking problem remained unclear, but it disappeared after greasing of the bearings. Consequently, the problems found in the test series led to careful consideration of potential sources of variability and correct estimation of the role of no-load power.

Three-Factor Factorial Experiments: Warm-up Time, Fluid Type, and Filling Change: The normal probability plot and calculated P-values indicated that the factors had no significant effect on the mean values of response variables, even if the pulp was refined to a high specific energy of 200 kWh/t. Only the SR probability plot indicated that A could be a main factor. However, other response variables did not support this. Temperature measurements indicated that refiner bearings may have reached a relatively stable state after about 1,200 s of running, as illustrated in Fig. 1, since the casing surface was already close to maximum temperature. The surface temperature stabilised after about 1,800 s. The results indicate that the warm-up time used for recording no-load power needs to be longer than the original set-up value of 300 s. In a new procedure applied in other refining trials outside this study, a sequence of two times 600 s was used.

No-Load Power 300 or 1,200 s and Specific Energy Varied —Intensity 1.0 J/m: Calculated statistics showed that the mean value of response variables did not vary significantly. Again, good reproducibility was supported. The different warm-up time caused an average difference of 0.17 kW in no-load power, resulting in a corresponding increase in total power from 3.28 kW to 3.45 kW.

Analysis of total power, stator position and inlet pressure of replicates indicated that in this type of refiner the sampling may also cause variation. Between replicates of 300 s no-load sequence, the time used for gap readjustment was found to vary from about 30 to 60 s, but for other replicates (1,200 s no-load), the time to reach the set point was about the same. The amount of the sample cannot be controlled very accurately. The sampling valve is open as long as the controller assumes this to be needed for the target sample.

**FIG. 1.** No-load power sequence two times 600 s measured with water and plate filling.

**FIG. 2.** Temperature of casing surface surrounding bearings.
weight. During sampling, the pressure in the pipe at the outlet side of the refiner drops, which increases the refiner gap. After sampling, the controller reacts to the gap change and moves the stator filling forward so that set point power is reached again. It should be noted here that the number of analysed data points is too small to allow drawing accurate conclusions. As a whole, the controller appeared to function well. Overshooting in the adjustment of power was not detected.

**No-Load Power After 100, 300 or 1,200 s and Specific Energy Varied—Intensity 0.3 J/m:** A decrease in warm-up time increases the level of no-load power, and consequently the calculated set-up value for total power increases. Figure 3 illustrates the average percentage increase in total power caused by changes in warm-up time and consequently in no-load power. The zero level is recorded at 1,200 s warm-up time. The actual power (kW) values are illustrated in Fig. 4.

The calculated P-values indicated that factor A, warm-up time, significantly affects mean values of SR, apparent density and light scattering. Calculated statistics are shown in Table V. Response variables are illustrated graphically in Figs. 5 and 6. The largest effect is caused by the shortest warm-up time of 100 s and when specific energy was high, 100 kWh/t. This increased the no-load power from 2.29 to 2.56 kW (a 12% increase from 100 s to 300 s), and the SR increased from 45 to 54 (Fig. 5). A similar trend was seen in the light scattering coefficient, as illustrated in Fig. 6, as well as in apparent density.

**Long-Term Changes:** No-load power was found to vary over a longer period of time. Especially after commissioning, the level of no-load power showed an marked decrease. Figure 7 illustrates the level of no-load power for conical and plate fillings. With conical fillings, the power decreased from 2.14 to 1.82 kW, equating to a 15% decrease. Previously, it was shown that already a 12% increase in no-load power causes variability in the refining result, if refining intensity is low, i.e. 0.3 J/m. Most of the no-load values from 2002 were recorded once after 300 s warm-up time, but some values were recorded after two times 300 s. This may cause slight variability and in the results measured before August 13, 2002.

**DISCUSSION**

A starting point for the study on the reproducibility of refiner performance was to confirm findings by simple experiments. The first trial series included a comparison of mean values of randomly refined pulp. The results indicated that the reproducibility of the refiner's performance was not always good enough, which may be due to filling changes between the trials. Overall, development of pulp properties due specific energy was as expected, though differences in mean values was detected. Unfortunately, in the first random experiments it remains unclear whether the stator filling position was changed accidentally when filling was put back into the frame. A change in its position might explain the variability, in view of the fact that the refining result of mill refiners changes after a filling change. A certain time must pass until the fillings adapt against each other and start producing stable quality.

Thus, the first test series can be criticized for insufficient planning of the test procedure. However, this led to more detailed planning of the following experiments and more careful consideration of sources of variability in laboratory refining. As a result, the effects of several factors, i.e., the warm-up time before no-load power recording, the type of fluid (water or pulp) in no-load power recording and filling change, were tested in order to identify sources of variability.

In summary, a long enough warm-up time is needed to heat the bearings and
achieve stable operating conditions. After that, the no-load power can be estimated correctly. The correct estimate is important especially when the refining intensity is low (0.3 J/m) otherwise pulp and paper properties are not reproducible. At an intensity over 1.0 J/m, the detected variation in no-load power was not seen in pulp and paper properties. The results are as expected, because the proportion of no-load power increases when refining intensity decreases and an error in the estimated no-load power becomes more significant.

CONCLUSIONS

The results showed that correct estimation of no-load power is important for a reproducible refining result. At low-intensity refining a 12% increase in no-load power has a significant effect on the final refining result. In addition to short-term changes, the level of no-load power of a laboratory refiner appears to vary over a longer period of time. Changes of up to 50% in the no-load power of industrial refiners after commissioning have been reported in the literature. The results of this study suggest that to ensure more accurate calculation of target power, intensity, and specific energy, more attention should be paid to regular detection of no-load power of all types of chemical pulp refiner.

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LITERATURE


Résumé: Nous avons analysé la reproductibilité de la performance d'un raffineur de laboratoire. Les résultats ont démontré que, parmi les paramètres examinés, le temps de réchauffement avant d'enregistrer la puissance à vide a une incidence sur la reproductibilité, particulièrement lors du raffinage à faible intensité. Un changement de 12 % à charge nulle a entraîné une variabilité importante dans le résultat du raffinage lorsque la pâte était raffinée à une faible intensité de 0,3 J/m. Il est donc recommandé de procéder à un temps de réchauffement suffisamment long si l'on veut obtenir une bonne reproductibilité de la performance du raffineur.


Keywords: REFINERS, REPRODUCIBILITY, PERFORMANCE, LABORATORIES, VARIABILITY.