Conditions in an LC-refiner as observed by physical measurements

ABSTRACT

By changing the bar geometry and the running conditions of a refiner it is possible to change the mode in which the fibres are subjected to the mechanical action of the bars. These changes in the beating variables influence the conditions in the interior of the refiner. The aim of the investigations at the Finnish Pulp and Paper Research Institute was to collect data from running refiners. Most of the measurements were performed in a small conical Jyväskylä-refiner. Some additional tests were carried out with mill scale disc refiners. The refiners were equipped with transducers for the following measurements: bar clearance, in- and outgoing pressure, hydraulic pressure pulses in the grooves between the bars and at the top surface of the bars and temperature changes in different parts of the refiner.

The hydraulic pressure pulses measured in the beating gap were of an average amplitude between 0.1 bar and 0.5 bar. Individual pulses may reach values which are two to three times higher but even these are not considered to have any significant influence on the beating of the fibres.

The temperature of the pulp increases for each passage of the pulp through the refiner by 1 to 2 °C which accounts roughly for 90–95% of the input of energy. Temperature differences were noted between different locations in the refiner. The temperature of the pulp flowing in the groove was always slightly lower than the temperature of the bar at the corresponding place.

An increase in the beating load decreases the bar clearance. At a constant beating load, increasing the angular velocity causes an increase in the bar clearance. If the pulp is fed through the refiner several times the bar clearance diminishes each time. The bar geometry as well as the direction of rotation has an influence on the bar clearance. The bar clearance depends on the type of pulp beaten. The gap when refining birch sulphate pulp is thus only half of that obtained with pine sulphate pulp. The whole range of bar clearances obtained extended from about 10 µm to 400 µm. The additional tests run with mill scale disc refiners confirmed the results obtained with the conical refiner. A comparison of the bar clearance values and the dimensions of cellulose fibres seem to indicate that single fibres can pass the gap without being mechanically treated by the bars. To fill the gap fibre flocks consisting of several fibres are needed.

TIIVISTELMÄ

(Olott matatalousjauhimmessa fysiokaalisten mitausten valossa)

Vaihtelemalla jauhimen terittysgeometriaa ja ajo-oja voidaan vaikuttaa siihen, miten kat-
dur joutuvat jauhimen terien mekaaniseen vaikutukseen alaisiksi. Jauharusmuuttujat ja niissä tapahtuvat muutokset määräävät jauhi-
men sisäisiä oloja. Oy Keskuslaboratoriossa on suoritettu tutkimus, jonka tarkoituksena on ollut kerätä tietoja toimivissa matatalo-
suojajuhimissa vallitsevista oloista. Pääosa mitattuista suoritettiin pienessä karton-
muotoisessa Jyväskylä-jauhhimmessa. Täydentävää mitattavaksi tehtini kahdessa tehtaiden koko-
levyjauhimmessa. Tutkitaan jauhimen asen-
nettujen antureita seuraavien suureiden mita-
tauskien varten: teriavil, sisäännøno- ja ulos-
tulopaine, hydrauliset painepiirit sekä rei-
ten välisistä urista että niiden ylippinnalta ja 
lämpötilan muutokset jauhimen eri osissa.

Jauhimen terien välistä mitattujen hydraul-
tisten painepiirien keskimääräinen amplitu-
di vaihteli 0,1:stä 0,5:ään. Yksittäiset puls-
sit saattavat saada kaksi- tai kolmisoteresaat arvoja. Arvelaan kuitenkin, ettei edes näillä
voisi olla merkittävää vaikutusta kuitujen jau-
haruttamiseen.

Jokaisella jauhimen läpimennolla sulpan 
lämpötila kasvais 1–2 °C, mikä korkeasti ot-	aen vastaa n. 90–95%:a jauhimen sätei-
ytystä energiasta. Jauhimen eri osien välillä olivat selvät lämpötilaan eroja. Niinpä terien välissä
urissa virtaavan massan lämpötiloihin ilmo aina hie-
man alhaisempia kuin terän päällä samassa 
kohtassakin olevan massan lämpötila.

Jauhimen kuormituksen lisääminen pieni-
nettää teriäväliä. Jauhimen kierrosluokan kas-
vaessa teriäväli lisääntyy, mikäli jauhimen kuormitus pysyy vakiona. Jos sama sulppu
syötetään jauhimen läpi useaan kertaan, teriä-
väli pienenee jokaisella läpimennolla. Myös te-
ritysgeometriaa ja jauhimen kiertousmurtua vai-
tuttavat teriävillä. Lisäksi se on riippuvainen 
juhotettavasta massasta. Kuoruvuotsaaminen
juhotettaessa teriävällä on vain putoat siitä, mi-
kä se on mäntysuuntasia juhotettaessa vastas-
vissa oloissa. Mitattuista mukaan teriävillä
vaihteluvaihtoe ulottui n. 10 µm:stä aina 400
µm:in. Taidelokaisilla levylajinmullilla suor-
mitettivät mitattavat vaihtelut kertoivat kiihtä-
levyjauhimmelä elvytysten mitausten tuloksia. Mitattujen teriävä-lihvojen sekä sellukuitujen dimensio-
vertailut osoittivat, että yksittäiset kiertud pysty-
vät hyvin läpimeneämään teriävillä joutumatta 
mekaaniseen käsitettyyn. Teriävillän täyttä-
seen tarvitaan itse asiassa useiden kuitujen
muodostamiin flikkejä.

INTRODUCTION

A refiner in continuous use can be regarded as a "black box" into which we feed a pulp suspension, with a given combination of properties, and energy which is mainly of mechanical type. The output from the "black box" is a pulp suspension, with a new combination of physical properties and energy which has now mainly assumed the form of heat.
The main purpose of the refining process is that of changing the properties of the pulp suspension in a given direction: to achieve this, a number of changes can be made, either in the running conditions of the refiner, or in the tackle used. By virtue of experience gained over a long period, and abundantly documented in the literature, it is possible to bring about the desired changes in the properties with a fair degree of success. In comparison with the number of articles concerned with the relationships between refining variables and the properties of the refined pulp, very little has been written about the conditions prevailing within the "black box" or the refiner under which the changes in the fibre properties take place. Some early attempts by Halmre and Syrjänen (1) to trace the movement of the fibres in the refiner have recently been followed by systematic investigations at the Institute of Paper Chemistry by Fox and coworkers (2). Attempt to measure the hydraulic pressure distribution in the gap between the refiner bars has been studied by Šoncarov (3). Measurements made in a laboratory beater by Arjas (4) have given an estimate of the beating gap under different conditions of beating, whereas Kouachi and Young (5) have made corresponding measurements in mill refiners. Recently, measurements made by Stationwala and Arack (6) of the clearance between the discs in a chip refiner have drawn attention to the variations in the gap which can occur as a result of inaccuracies in the construction or in the setting of the refiner.

In conjunction with our investigation of how the result of beating is affected by constructional and running parameters, it was thought useful also to direct attention to the conditions in the refiner. For this purpose, the refiner was equipped with instruments for measurement of the beating gap, pressure pulsation, and the temperature conditions in various locations within the refiner. Most of the measurements were carried out in refining experiments with a 75 kW Jylhä conical refiner, but some of the gap measurements were also performed in mill-scale disc refiners, such as the 250 kW Ensso-Bauer disc refiner installed in our pilot plant, and a 450 kW Jylhä DD 720 disc refiner in a paper mill.

TRIALS WITH THE CONICAL REFINER

Investigations with the conical refiner have related to the effect of the bar geometry and the direction and speed of rotation of the rotor upon bar clearance, in- and outgoing pressure, pressure pulses in the stator grooves and between the rotor and stator bars, and finally local temperatures in different parts of the refiner. The following figures characterize the differences in bar geometry which resulted from changing the rotor and the stator shell of the refiner:

- cutting angle: 0, 36 and 90°
- bar width: 5 and 8 mm at a bar angle of 0° and a bar height of 10 mm
- bar heights of 4 and 8 mm at a cutting angle of 36° and a bar width of 4 mm
- the refiner could be run in both directions, corresponding to a pumping action and a flow-resisting action
- the angular velocity was varied at three levels: 750, 1 000 and 1 250 rpm.

To complete the picture, the influence of the fibre raw material was included by making the measurements on occasions when different pulp qualities were being beaten. The pulps were so chosen that they would cover a wide range of properties, and thus included an unbleached pine sulphate pulp with a yield of ab 55 %, a bleached pine sulphate, a bleached short fibred birch sulphate, and a bleached spruce sulphite pulp.

A description is given below of the types of transducer, and their installation in the refiner, as well as of the equipment employed for recording the various conditions. Besides this, an estimate is presented of the possible sources of error which may arise under the rigorous conditions which prevail in a refiner in operation.

Installation of the transducers

Although the principles of measurement had been tested in some cases their application caused difficulties in practice. In particular, mention is due of the drilling of the holes and cutting of the threads in the refiner tackle for installation of the transducers. In each refiner shell, more than ten transducers were installed. A schematic drawing of the instrumentation employed for recording the signals is shown in Fig. 1.

The positions and installation details of the temperature transducers are illustrated in Fig. 2. The NS transducers were of semiconductor type LX 5700; these contain a sensor, a reference voltage source, and an operational amplifier. These IC transducers were chosen by virtue of their large output signal of 10 mV/°C being insensitive to disturbances. Transducers mounted in the grooves between the bars had their sensitive sections directly in contact with the pulp suspension, the remaining faces being protected by mica sheets.

No 4, 1981 Paperi ja Puu — Papper och Trä
The bar clearance was measured by Kaman eddy current sensors, which measure the distance between the sensor itself and a metal surface in its proximity. Fig. 4 illustrates the position of the sensor in the refiner, as well as a detail of its mounting. Since the diameter of the gauge exceeded the width of the bar, a protecting holder had to be built for it. The sensor, with its holder, was installed level with the top of the bar. The sensor surface was further protected by a thin teflon layer, and as the total measuring range of the sensor is only 2 mm, the effective measuring range with the protection in place was no more than about 1 mm. The sensor requires a target surface in the rotor which is slightly larger in size than its face. This smooth target-surface was obtained by filling the groove between two rotor bars for a short distance opposite to the sensor by welding, following which the target surface was ground to the level of the bar surfaces. Two such plaques were welded on the rotor diametrically opposite to each other.

The sensitivity of the sensor allowed measurements to be taken to an accuracy of 0.001 mm. The proportionality between the signal and the changes in distance between the sensor and the target-surface was established by use of a sensitive displacement transducer, which was mounted to sense the horizontal movements of the refiner shaft. However, difficulty was experienced in establishing the zero-point. This could not be done to a sufficient degree of accuracy with a standing refiner, for reasons which included loose bearings, eccentricity, thermal effects, etc. The installation of the transducers in the refiner was achieved in the following steps:

1. The transducers were installed in the knives. The transducers were completely contained in the bar, and thus the measurement was made with the bar surface.
2. The positions of the pressure transducers were the same as those for the temperature transducers Fig. 3. The transducers mounted in the grooves were well protected against external strains, but those located at the bar surface had a tendency to break. Transducers of type Kulite XTS are provided with a sensitive foil at the top, on top of which a strain gauge bridge has been deposited by semiconductor techniques; by reason of its small size, the frequency range extends to 60 kHz. The pressure range was 3.3 bar, but the transducer can withstand a hydraulic pressure of 6.6 bar. However, shives and fibre knots caused the destruction of several of the transducers.
mal elongation and bending of the base plate. The final way of doing this, and a slightly precarious one, was that of checking the zero-point at the end of the refining test. When the motor had been disconnected, but was still rotating, the refiner rotor was pushed into metallic contact with the outer shell, and a recording made of the signal for the zero-distance. Nevertheless, we are fully aware that although the changes in bar clearance could be measured to an accuracy of 0.001 mm, the reliability of the absolute values was of the order of ±0.02 mm.

The refiner also had a triggering system, which once for each revolution gave a trigger pulse from the shaft of the refiner. This provided an opportunity to record the angular velocity of the refiner, but also set the starting point when the signal recovery method was applied for treatment of the signals from pressure measurements. The trigger pulse was also used in the bar clearance measurements as is illustrated in Fig. 5. Each target-surface induces a downward pulse from the sensor, with the distance from the zero level being proportional to the bar clearance. However, the duration of the pulse is extremely short, and during this brief period an accurate measurement of the pulse should be obtained. For this purpose, an extremely fast special HP volt meter type 3431A was brought into use. The sampling time of this voltmeter was less than 1 μs.

The meter can be externally triggered to act at the time of the measurement proper. To this end, the meter contains a delay system which is accurate to seven digits. The sampling was delayed in respect to the trigger signal, so that the bar clearance pulse was derived in the correct position, and in digital form. The bar clearance measurements made in the disc refiners followed the same pattern, with the same sensors and equipment being employed. In contrast to the difficulties experienced in establishment of the zero-point in the conical refiner, it was comparatively easy to establish the point of contact statically in the disc refiners. Consequently, in this case not only the changes in bar clearance but also their absolute values are highly accurate.

RESULTS OF MEASUREMENT

Temperature measurement in the refiner

The temperature transducers installed in the refiner as well as those in the pipes before and after the refiner enable study of the total heat development, together with its local distribution. During the course of bearing, a certain amount of energy is fed into the refiner. A part of this energy is lost in mechanical friction in the bearings, a part is used for transport of the pulp within the refiner, and a part is transferred to the pulp suspension in form of heat. Heat is generated both by internal friction in the pulp, by friction between the pulp and the bars, and often also by direct metallic bar contact. The remainder of the energy is absorbed by the fibres, and brings about the heating effects desired.

The following series of figures illustrates the temperature development in the beater measured at the eight different positions. The following observations can be made:

The temperature in the groove is regularly lower than the temperature at the bar surface. This difference in temperature varies between 0 and 3 °C.

The temperature difference increases when the angular velocity is lowered, Fig. 6. When different pulp qualities are
being refined it is found that the temperature difference is smaller for pine than for birch pulp. When pine pulp is being refined the temperature in the refiner increases more regularly along the length of the refiner. For birch pulp the temperature increases rapidly in the first part of the refiner, and then levels out or even declines slightly towards the exit section, Fig. 7.

The difference in temperature patterns when pine pulp and birch pulp are beaten may be related to the fact that under otherwise similar conditions birch pulp is accompanied by a smaller bar clearance than when pine pulp is being refined. The decrease in the angular velocity of the refiner also decreases the bar clearance; similarly we can here note an increase in the temperature difference between groove and bar face. Smaller bar clearances increase the probability of metal contact, with the consequent generation of frictional heat.

When it comes to the difference in temperature between the incoming and outgoing pulp there is, however, no general relationship between bar clearance and temperature rise. If the pulp suspension is passed several times through the refiner under constant beating conditions, the bar clearance decreases for each passage. Nevertheless there is no significant change in the temperature rise observed for the consecutive beating cycles.

If the total temperature rise, and the known pulp flow, are employed for calculation of the energy converted into heat in the refiner, it is found that between 90 and 95\% of the electrical energy is recovered as heat. With due consideration being given to the inadequate insulation of the refiner, and that it was impossible to account for other energy losses in the form of differences in the static and dynamic energy of the incoming and outgoing pulp suspension, in any event the figures obtained confirmed that no more than 5—10\% of the total energy had been irreversibly absorbed by the fibres.

**Pressure measurements**

The pulsating pressure created between the bars was analysed in various ways. Employment of the trigger system described enabled recording of the pressure pattern by signal recovery. Fig. 8 gives an example of this analysis for a bar pattern characterized by a bar angle of zero degrees. The recording indicates the pulses measured for a series of bars. Each individual bar is distinguishable, along with the irregularities in the pattern resulting from the bars being
grouped in individual segments. Fig. 9 is an enlarged trace of a few individual bars. In this instance, the pulse height from peak to peak is between 800—1 200 mbar. Fig. 10 illustrates the corresponding pressure pattern following exchange of the tackle in the refiner for another in which the bar angle was 18° or the cutting angle 36°. Here, the pulses were markedly smaller with fluctuations around 400 mbar.

The pressure recordings were also applied for calculation of the frequency spectrum. In a simplified form, Fig. 11 gives the amplitudes and frequencies found in the refiner with a bar angle of 0° and an angular velocity of 1 250 rpm. The figure illustrates the frequencies and corresponding amplitudes obtained from the bar and the neighbouring groove. The low frequencies correspond to the angular velocity of the refiner and its multiples. The high frequencies are not as easily identified but are of a magnitude which can be related to the bar number. An interesting feature is that the amplitudes are significantly higher in the groove than at the bar face and also higher in the high frequency than in the low frequency region. This is, however, no general rule and different patterns have been found e.g. when changing the bar geometry.

A convenient numerical expression for the pressure pulsation is the average pressure variation calculated, without regard to the frequency. The largest average pressure variations were apparent with bars which formed a zero angle. In this case, the values lay between 300 and 500 mbar. For bars with greater angles, the values were of the order of 100 to 300 mbar. Consequently, the amplitudes of the pressure pulses are comparatively small, and are not believed to cause any beating action. In laboratory tests, by way of example, it was found that the application of perpendicular pressure to wet fibres induced effects similar to those derived in refining. In our experiments this was achieved at a flat pressure of 2—4 MPa. We have accordingly so interpreted the results that during the course of refining in our equipment, there do not occur any hydraulic pressure pulses which can as such exert a beating effect. This must imply that the beating action is mechanical and exerted by direct contact with the bars.

The pressure transducers in the pipes before and after the refiner indicate the pressure under which the refiner is working, and the changes which are attributable to the rotation of the rotor. The following series of figures indicates the situation under different conditions of running the refiners. If only the in and the outgoing pressure are considered, Fig. 12 illustrates the change in pressure within the refiner for three different bar patterns, represented by cutting angles of 0°, 36° and 90°, when the speed of rotation has been varied on two levels, and with the direction of rotation being negative with respect to the pumping direction. For the four different types of pulp no significant differences are discernible in pressure development. For a cutting angle of 90° a negative pressure change is noted when the direction is negative whereas for lower angles a pressure increment is apparent. A lower speed gives rise to lower pressure differences. As could be expected, an increase in the bar height under otherwise similar conditions brings about an increase in the pressure difference. An increase in the bar width exerts a diminishing effect upon pressure.

Fig. 11. Frequency spectrum of pressure pulsation in the refiner for a cutting angle 0° and an angular velocity of 1 250 rpm.

Fig. 12. Change in pressure over the refiner run under constant conditions but with different bar patterns. Direction of rotation opposite to the pumping action.

Fig. 13. Change in pressure over the refiner at two angular velocities and two directions of rotation.
development within the refiner. Finally Fig. 13 compares the pressure changes in the refiner following a change in the direction of rotation.

Bar clearance measurements

Measurements of bar clearance were made under different conditions of running of the refiner as well as when different types of pulp were being refined. Fig. 14 illustrates that if the energy input is increased, a diminution occurs in the bar clearance, but that other refining parameters also have a strong influence. One of the important factors is the rotational speed.

If the pulp is passed through the refiner several times, or in other words the energy consumption increases, an increase occurs in the degree of beating. Fig. 15 presents the results obtained when a bleached pine sulphate pulp, and a bleached birch sulphate pulp are refined with knives which form a cutting angle of 90°. There is a gradual drop in the bar clearance for both pulps, but the level recorded for birch pulp is distinctly lower than that measured for the pine sulphate pulp. Fig. 16 illustrates the beating results for two other types of pulp, a high-yield pine sulphate, and a bleached spruce sulphite pulp, refined at two different speeds of rotation. Here, the cutting angle was 36°. It is clearly evident that for both pulps the bar clearance is very sensitive to changes in the speed of rotation.

Similar tests were conducted with disc refiners. The results derived both for the mill and for the pilot plant disc refiner were in line with the results with the conical refiner. As for the conical refiner, birch pulp could not support so high a bar clearance as that obtained with long fibred pulps. The influence of the speed of rotation and the power input can be seen in Fig. 17 for an unbleached pine sulphate pulp. If the results from both refiners are plotted in a diagram as a function of the specific edge load, all points fall fairly well on a straight line, Fig. 18.

The investigations clearly indicated that the changes in both the beating conditions and in the beating tackle resulted in considerable changes in the bar clearance. Furthermore, the gap was dependent upon the type of pulp beaten. Bar clearance values between 10 and 400 μm were recorded. Nonetheless, an attempt to establish a relationship between the bar clearance and the refining result, expressed in the form of tensile strength, was unsuccessful. Although no general relationship was discoverable, there are some indications that the beating gap may exercise an influence upon the severity of the mechanical action of the bars on the fibres.

The diameter of a swollen pine fibre is about 20—40 μm, and if the fibre is compressed so that the lumen disappears, the thickness becomes about 5—10 μm. The maximum bar clearance of 400 μm measured is thus equivalent to 10—20 swollen fibres, or 40—80 flattened fibres. The average bar clearance of 100 μm can thus accommodate 2—5 swollen, or 10—20 flattened fibres, on top of each other. This indicates that a
single fibre can not be compressed in the gap unless the beating conditions are such that the bar clearance drops well below 50 μm. For the creation of conditions in which fibres can receive some kind of compressive mechanical treatment in a larger gap, it is evident that fibre bundles rather than single fibres must get caught between the bars. On the other hand it has been found that the fibre dimensions and the physical conditions of the fibres are themselves responsible for the gap created.

**DISCUSSION**

In the refining investigation a large experimental material was collected of which only a part has been discussed here. The interpretation of the results has presented great difficulties and has in many cases given rise to more questions than answers, probably because the testing programme contained too many beating variables. If this study were repeated it would be advisable to restrict the number of variables e.g. by concentration on one bar pattern only.

Conclusions, which we feel safe to draw are that the probability of internal hydraulic pressure pulses being an actuator of beating effects is very remote. This would leave frictional forces either between fibres or between fibres and bar faces as well as compression of fibre bundles between rotor and stator bars as the most probable alternative beating forces.

The temperature pattern within the refiner seems to vary depending both on the beating conditions and the type of pulp beaten. If we postulate that heat is generated by friction a careful analysis of the temperature pattern could be used to point out the hot sectors in the refiner where the main beating action takes place. Additional influence is, however, exercised by the flow pattern within the refiner and the cooling caused by mixing of streams of pulp of different temperature.

Large differences in bar clearance have been observed as a consequence of the beating conditions but also the type of pulp beaten has a significant effect on the gap between the bars. In most cases the gap is several times wider than the diameter of the fibres and single fibres can consequently pass between the knives without being affected. Judging from the dimensions involved it therefore seems that only flocks or bundles of fibres are subject to a combined compressive and shearing treatment between the bars.

It should finally be noted that in carrying out the measurements the evaluations are based on averages calculated over several revolutions of the refiner. It is therefore possible that peak values may occur locally or momentarily for all the measured conditions of pressure, bar clearance and temperature and that these peak values may have effects which were deemed improbable when the average values were concerned.

**REFERENCES**


Received January 9, 1981.