FORCES DURING BAR-PASSING EVENTS IN LOW CONSISTENCY REFINING: EFFECTS OF REFINER TRAM
Brett Prairie, Graduate Student
Peter Wild, Associate Professor
Peter Byrnes, Research Engineer
D. Olender, Graduate Student
D. W. Francis, Research Engineer
D. Ouellet, Research Engineer
1 Department of Mechanical Engineering, University of Victoria, B.C., Canada
2 Pulp and Paper Research Institute of Canada (Paprican), Vancouver, BC, Canada

ABSTRACT
A piezo-ceramic sensor was used to measure normal and tangential shear forces applied to a bar at one location in the refining zone of a Sunds Defibrator Conflo® JC-00 conical refiner. Both the normal and shear force signals demonstrated significant periodicity, synchronous with the speed of rotor rotation. Force magnitudes vary by as much as a factor of 3 over one revolution. This periodicity was caused by rotor out-of-tram of only 0.06 mm.

INTRODUCTION
Forces on bars in low consistency (LC) refiners have been measured by a number of researchers. In the late 1960’s and early 1970’s, Goncharov and co-workers [1-2] used strain gauges to measure the normal and shear forces over a small section of a refiner bar in low consistency disc and conical refiners. These sensors were limited to frequencies below 1.3 kHz due to the low first-natural frequency of the design. Subsequently, Nordman et al. [3] used pressure transducers to measure the pressures surrounding bars and grooves in low consistency refiners. The large relative size of these sensors and their complex geometry could limit their ability to be installed in many refiners. In the laboratory, a single-bar refiner has been used to estimate the normal and shear forces on individual flocs at both low and high consistencies [4-9].

The authors have, over the past five years, developed sensors to simultaneously measure normal and shear forces on bars in high consistency refining. Measurements have been made in a laboratory-scale refiner [10], a pilot-scale refiner [11] and an industrial scale refiner [12]. In the current research, the sensor design used in these studies has been adapted for use in a Sunds Defibrator Conflo® JC-00 conical refiner.

Ohls and Syrjänen [13] studied refiner tram in a Jylha Disc SD 48 refiner and show that correcting this reduces motor load fluctuations and substantially improves average pulp properties. Frazier [14] investigated the effects of refiner tram for a disc refiner using hydrodynamic lubrication theory and concluded that an optimal tram angle could be found which preserves fibre length but does not increase shive level.

EXPERIMENTAL METHODS
The Sensor
The sensor, as shown in Figure 1, is comprised of a housing from which protrudes a probe that matches the profile of the refiner bar. A hole was bored in the stator of a Sunds Defibrator Conflo® JC-00 conical refiner at the Vancouver Laboratory of the Pulp and Paper Research Institute of Canada, shown in Figure 2. The hole was centred at the mid-span point of a refiner bar. The sensor was mounted into this hole such that the probe replaced a short (i.e. 5 mm) segment of a bar, as shown in Figure 3. The sensor housing is retained in the hole using a locking nut configuration.
The probe is supported, within the sensor housing, by two piezo ceramic elements. When a normal force is applied to the probe the two piezo elements share the applied load equally, as shown in Figure 4a. When a shear force is applied to the probe, as shown in Figure 4b, the left hand element is subjected to increased compression while the right hand element is subjected to reduced compression. The voltages that are generated in response to these loads are processed so that shear and normal forces are independently determined.

**Fig. 4 Operation of the Force Sensor**

Experiments
Chem-Thermo Mechanical Pulp (CTMP) at 3.15% consistency was fed through the Conflo® refiner at flow rates ranging from 136 – 516 litres/s. The refiner was operated at a constant rotational speed of 900 rpm. The resulting specific energies ranged from 40 – 100 kWh/t at a number of specific edge loads ranging from 0.33 – 0.5 J/m.

Time periods were identified during which operating conditions were relatively stable and sensor data blocks were then extracted for these periods. These data blocks were subsequently subjected to in-depth analysis. Custom software was used to process the sensor data to generate normal and shear force profiles associated with individual bar passing events.

**RESULTS**

Typical time domain data for normal and shear forces is shown in Figure 5. Each peak in shear and normal force coincides with a rotor bar passing across the stator bar in which the sensor is located. The negative values shown in Figure 5 do not represent negative forces. The signals from the piezo elements are related to the change in the applied load since piezo-based sensors do not pass steady or DC signals. Thus, the force magnitudes for each bar crossing are measured from the base of the trough preceding peak.

The magnitude of these force peaks varies with operating conditions but the ratio of the magnitudes of the shear and normal force peaks is relatively constant. Detailed analyses of the relationships between operating conditions and the distributions of these force magnitudes will be reported in subsequent publications.

**Fig. 5 Typical shear and normal force profiles associated with bar-passing events (Experiment: S9B1: SEL = 0.468 [J/m])**

Over a wide range of operating conditions, periodic variations in the peak magnitudes of the shear and normal forces were observed. An example of these variations is presented in Figures 6 and 7. The period of these variations is approximately 67 ms which corresponds closely to the rotational speed of 900 rpm. Comparing the lowest values in one revolution to the highest, these variations are on the order of 300%.

**Fig. 6 Normal Force Data Showing the Effect of Out-of-Tram (Experiment: S9B1: SEL = 0.468 [J/m])**
The power spectrum for the data block from which the data in Figures 6 and 7 were taken is shown in Figure 8. In this spectrum, the bar-passing frequency (2.0 kHz), the segment passing frequency (104 Hz) and the rotational frequency (15 Hz) can be identified. The segment passing frequency arises from the seven segments of bar patterns on the rotor. The bar passing frequency arises from the 18 bars in each of the seven rotor segments.

At the time that this periodicity in the data was detected, the out-of-tram of the rotor was measured to be 0.06 mm. Although the rotor-stator gap was not measured in the experiments, it is known by the operators that, under normal operating conditions, it is on the order of 0.15 mm. This suggests that out-of-tram on the order of 40% of the gap can result in variations in peak forces on the order of 300%.

To further study the effect of out-of-tram, the force data was processed so that the forces associated with each of the seven rotor segments could be reported separately. An investigation of the number of impacts recorded for each bar within each plate segment resulted in a characteristic signature for one of the segments, as shown in Figure 9a. Figure 9b shows the impact count on a typical plate segment. The segment shown in Figure 9a was readily identifiable in the data and was used as a reference for numbering the segments.

Median peak normal forces were calculated for each segment for each of the data blocks. In all cases, a similar pattern emerged, as illustrated by the three examples presented in Figure 10. It can be seen in these examples that the force is varying in a cyclic manner as the rotor rotates past the sensor. Assuming that higher forces are related to smaller gaps, the smallest gap occurs at segment 4 and the largest at segment 1.

It was found that a proportional relationship exists between the median peak normal force and the Specific Edge Load (SEL) for the entire rotor, as shown in Figure 11. This relationship was also investigated at the level of individual segments. It was found that, depending upon the segment, the slope and the $R^2$ varied dramatically, as shown in Figure 12 and Table 1.

Median Normal Force \[ N \] for the entire rotor versus SEL

y = -1.234 + 12.930x

$R^2 = 0.814$
CONCLUSIONS
Measurements of shear and normal forces during bar crossing events of a Sunds Defibrator Conflo® JC-00 refiner have revealed a strong relationship between refiner tram and force magnitudes. Out-of-tram on the order of 40% of the gap can result in variations in peak forces on the order of 300%. Assuming the out-of-tram in industrial refiners can be at equivalent levels, it is apparent that tram plays an important role in the distribution of forces that occur in low consistency refining.

ACKNOWLEDGEMENTS
The authors gratefully acknowledge: funding provided by the Natural Sciences and Engineering Research Council, Andritz Ltd., and Paprican; access to experimental facilities provided by Paprican; and the contributions provided by Dr. Richard Kerekes of the Pulp and Paper Centre, University of British Columbia.

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