Critical Temperature of Guided Circular Saws

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ABSTRACT

When sawing problems occur, as much data as possible is needed to understand how the saw responds under normal and upset conditions. The recent development of a circular saw temperature sensor makes the measurement of saw temperature possible. Several sawmill tests confirmed that monitoring saw temperature during sawing can provide useful information to diagnose sawing and guide lubrication issues. It is known that a difference in temperature between saw eye and rim results in thermal stresses in the plate that will reduce its stiffness, and ultimately cause the plate to buckle. However, the safe ranges for saw temperature or the critical temperature where the saw loses its stiffness; consequently, causing snaking or mismatch is unknown.

A computer model of dynamic behaviour of a guided circular saw, subjected to cutting loads, heat sources (at saw rim, eye, and body), and saw rotation was built using a Finite Element Model (FEM) of a rotating disk. The model considers the effect of heat on the thermoelastic behaviour of the saw. The model was used to predict the critical temperature for a saw, based on its geometry, and the rotation speed. In order to run the model and compute the critical temperature, the convection coefficient is needed; which can be found by conducting few hours of temperature measurement, using the temperature sensor. As an example, the critical temperature was computed for one guided saw system, based on the actual tests in a sawmill; and the results are presented in this paper.

Keywords: Guided Circular Saw, Temperature Sensor, Critical Temperature.

INTRODUCTION

Poor cutting of a circular saw machine may be due to many factors, such as guide misalignment, insufficient lubricant, saw running at flutter speed, and gullet overloading. Any of these may result in elevated temperature levels in the blade, and consequently have an adverse effect on sawing variation. In addition, an excessive temperature gradient between the rim to the saw eye can result in dishing or snaking. A trouble-shooting process for a machine with poor cutting is to check the saw speed, feed speeds, machine alignment, and monitor the saw temperature during cutting.

The recent development of a circular saw temperature sensor makes the measurement of saw temperature possible. Experimental tests and mill tests confirmed that monitoring saw temperature during sawing provided useful information to diagnose sawing and lubrication issues. FPInnovations developed a wireless sensor to measure saw temperature during sawing (2017). In addition, a method to measure the convection coefficient of saw guides was developed based on temperature data which is used to evaluate the cooling capacity of system (2017). Several sawmill tests were conducted in previous years and data were collected for different machines. The collected data were used to show some highlights on how saw temperature can be used for trouble-shooting and some control options, such as the gap between the cuts, and the amount of water and oil feed into the saw guides (2016). In addition, previous studies showed the adverse effect of saw heating on increased sawing variation (1993). Overall, an effective cooling system improves sawing by minimizing the temperature gradient between the rim to eye to avoid dishing or snaking (1993).

The maximum stable operation speed of guided saws is known to be its flutter speed (2015-2017), but change in the blade temperature, or the temperature gradient between saw rim and eye might change the saw stiffness and alter this maximum speed. In general, if saw temperatures are kept within a safe range, then reduced kerf, longer saw runs, less sawing deviation and faster trouble-shooting are possible. However, the safe ranges for saw temperature or, the critical temperature where the saw loses its stiffness and, consequently, causing snaking or mismatch are unknown as number of studies addressing this subject is limited. Danielson and Schajer (1993) conducted experimental studies to identify the effect of three adverse factors, blade over-tensioning, heating, and guide movement during sawing, which were expected to increase sawing deviation. They concluded that heating the inner centre of the saw resulted in saw dishing, and heating near the rim caused the saw to vibrate erratically at the rim. Lehmann (2001) developed a numerical method for studying the heating and cooling in a stationary circular disk. Takeuti and Noda (1973) developed a numerical method for computing the transient thermal stresses in a stationary disk, subjected to impulse heat source at a concentrated point on the disk. Warbhe et. al. (2017) studied the effect of temperature on a thin hollow circular disk deflection in the context of fractional-order heat conduction by quasi-static approach. This study was limited to a stationary disk and subjected to uniform heat distribution.

In this study, a computer model of a guided circular saw was built using FEA (Finite Element Analysis). The recorded data from a sawmill were used as an input for the computer model, and the critical temperature for the saw which results in saw buckling was computed.

MATERIALS AND METHODS

The following sections explains the method for measuring saw temperature, calculating the convection coefficient of a guided saw system, and the finite element modelling of a spinning guided disk, subjected to heat, and cutting forces.

Measurement of saw temperature

A temperature sensor was designed and prototyped at FPInnovations which enables real-time accurate temperature measurements of circular saw blades during cutting. These sensors provide real-time accurate temperature measurements of circular saw blades during cutting. The sensor wirelessly transmits the data to a base station where the values become available on the network. A monitoring application records the temperatures at each sensor at each saw over time. Several sawmill trials confirm the feasibility of measuring circular saw temperatures in a saw-box during cutting. The sensor can be easily mounted to the guide arms. Figure 1 shows the schematic of the sensor which is installed below the guide, and measure the saw temperature at two points, near saw rim, and near saw eye.

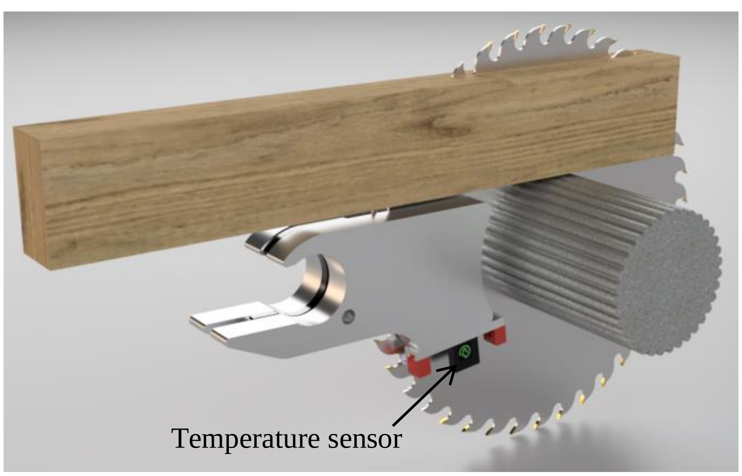

Figure 1. A guided circular saw with temperature sensors mounted under the guide.

In order to quantify the cooling behaviour of the saw, the convection coefficient h, which accounts for both heat removal by water and air, is estimated by (Mohammadpanah, et.al. 2017):

$$h = \frac{1}{2}\gamma l \rho c$$

where ρ and C are density and thermal capacity of the material, l is the plate thickness and γ is an empirical constant which can be found by fitting an exponential curve to the cooling portion of the experimental temperature data (2017). Table 1 summarizes the physical properties of the blade and test speeds.

Table 1. Experimental cutting conditions and parameters.

Blade Diameter (in)	21
Arbour Size (in)	6
Thickness (in)	0.095
Guide Clearance (in)	0.003
Number of teeth	40
Operation Speed (RPM)	3600
Feed Speed for Full Depth of Cut (FPM)	350
Depth of Cut (in)	6
Wood	Stack of 3 Douglas-Fir boards 2×10
Density of steel ($kg/m^{3)}$	7800
Thermal capacity of steel (J/KgC)	420

Finite element modelling of a spinning guided disk, subjected to heat

A computer model of dynamic behaviour of a guided saw, subjected to cutting loads, heat sources, lateral constraint from guides, contact between saw and arbor, and saw rotation was built using a Finite Element Model (FEM) of a rotating disk using COMSOL software. The model includes the rotation stresses and the effect of heat on the thermoelastic behaviour of the saw.

Figure 2 illustrates the possible sources of heat for a saw. The model also takes into account the effect of cutting loads, as shown in Figure 3.

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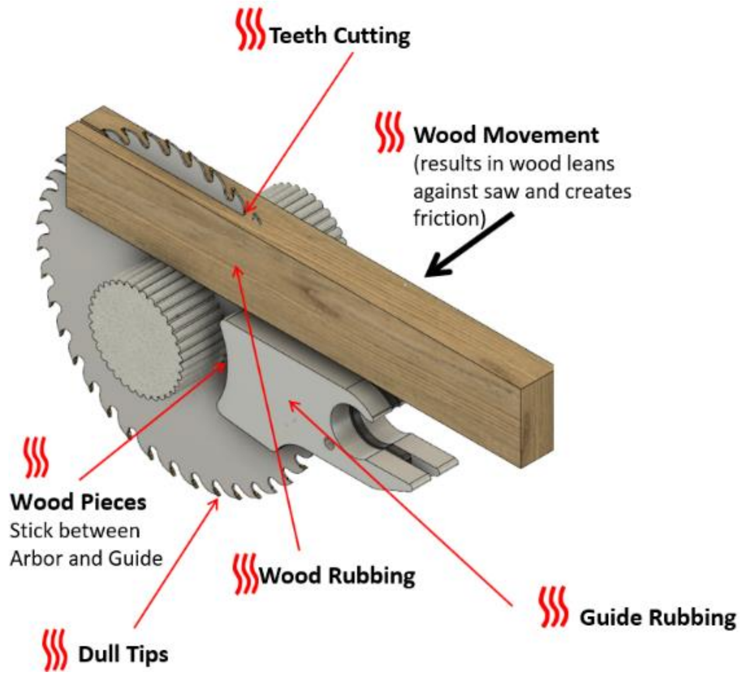


Figure 2. Possible sources of heat in a guided circular saw

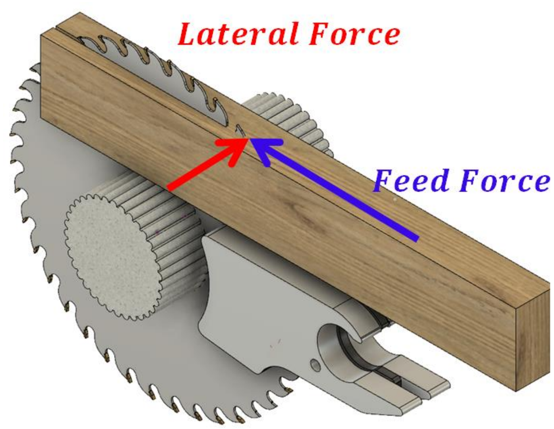


Figure 3. Schematic of cutting forces for a guided circular saw

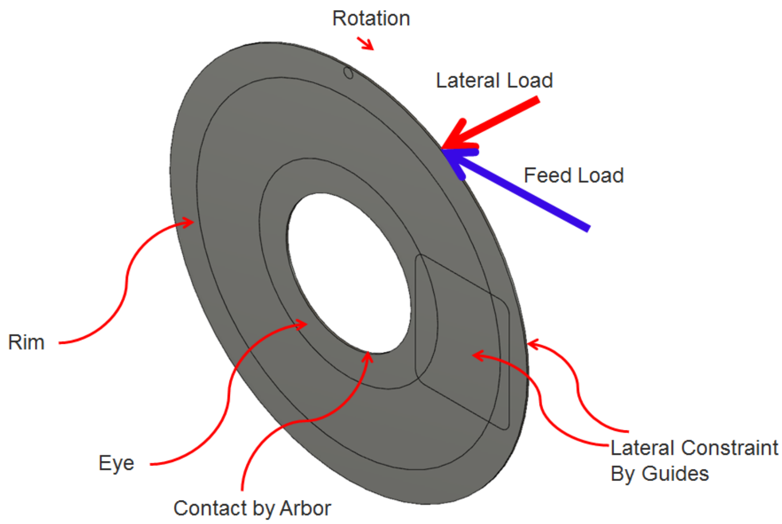


Figure 4. Schematic of computer model

In this study, saw rim and eye are referred to the area on the saw within a width of 1 inch from outer and inner radius of the saw respectively. The saw body is the area between rim and eye. Critical temperature of the saw is defined as the minimum temperature when the saw buckles under any of the following three different scenarios:

- **Hot Rim:** It is assumed that the heat source is at the rim and heat can be transferred by conduction through the saw; the heat can also be transferred to the environment (cooling by the guide pads) by convection with a constant convention coefficient. The change in the eye temperature is insignificant and stays close to the environment temperature (computed). There is a monotonous and uniform increase in the saw temperature from eye to rim.
- **Hot Eye:** It is assumed that the heat source is at the eye and heat can be transferred by conduction through the saw; the heat can also be transferred to the environment (cooling by the guide pads) by convection with a constant convention coefficient. The change in the rim temperature is insignificant and stays close to the environment temperature. There is an increase in the saw temperature from rim to eye.
- **Hot Body:** It is assumed that the heat source is at the body (a ring of 1 inch width in the middle of the saw between outer and inner edge) and heat can be transferred by conduction through the saw; the heat can also be transferred to the environment (cooling by the guide pads) by convection with a constant convention coefficient. The change in the rim and eye temperature is insignificant and stays close to the environment temperature.

Figure 5 illustrates each of these three scenarios. It should be noted that these three cases are the most extreme cases, however they are not unrealistic. For example, in practice, the case with hot rim may happen due to gullet overloading, dull tips, or a plugged lubrication port at the rim. The case with hot eye can happen due to wood pieces wedged between the arbor and the guide and rubbing against the saw, or a plugged lubrication port at the eye. The hot body may happen due to saw dust packing in the guide pocket, which is very common.

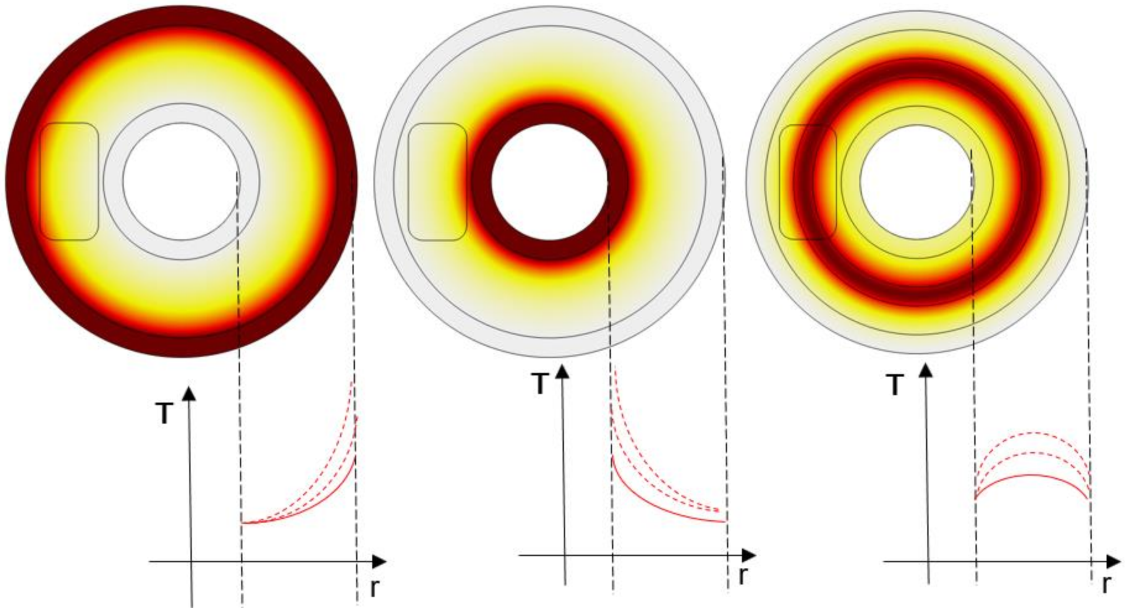


Figure 5. Three scenarios of temperature gradient in a saw

The model is solved for each of the three above cases and the temperature in which the blade buckles is calculated for each case. The minimum of these three temperatures is considered the critical temperature. In the model, the amount and location of heat is required as input. For example for case one, the rate of heat at the rim. However, heat generation during cutting wood is very complicated; so a numerical trial and error method was used to estimate the rates of heat input that generated the temperature profiles in Figure 5. After solving the model, based on these initial parameters, in the model the heat rate is increased incrementally until the blade buckles. The minimum temperature for each of the cases (rim, eye, or body) which results in buckling is considered the critical temperature.

In summary, for finding the critical temperature of a saw, knowing the following parameters is essential:

- Saw geometry
- Rotation speed
- Convection coefficient
- At least the temperature at saw rim and eye

In order to calculate the convection coefficient, which quantifies the heat removed from the saw by the water and air flow cooling, and saw temperature; at least one shift (few hours) of recorded temperature of the saw during cutting is required. The FPInnovations saw temperature sensor (explained in the first section), was used to measure the variation of saw temperature near saw rim and eye in a sawmill. The collected data is used to calculate the convection coefficient, based on the procedure explained in section two. The average convection coefficient, the initial rim and eye temperature, and other available information such as the saw geometry and the saw rotation are used in the computer model.

RESULTS AND DISCUSSION

As a case study, the measured temperature data of the saws in a curve-sawing circular saw in a mill were used to first calculate the convection coefficient. The temperature probes were installed on the guide arms to measure the temperature of the curve-sawing gang saws during cutting at two points, near the saw rim, and near the saw eye. Table 2 gives the saw blade properties, rotation speed and the average convection coefficient. The convection coefficient was calculated from this data.

Table 2. Saw Properties in the Curve Saw Machine

Property	Value
Blade diameter	19 in
Arbor number	# 3
Blade thickness	0.125 in
Number of Teeth	40
Maximum Gullet Load (GFI)	0.36
Saw Speed	3240 RPM

Figure 6 illustrates the temperature changes during cutting for a few hours. In general, the results indicate that the average saw temperature near the rim and eye was in the range of 30 to 32 C. The temperature difference between the saw rim and eye was insignificant. The cooling coefficient was computed using the formula and procedure explained above. For example, Figure 6 shows a selection of recorded data on this machine and illustrates five selected points where the cooling curve could fit. Using these data the convection coefficient was calculated for each curve.

Using the formula explained is the method section, the computed convection coefficient for these five points were h_0=140, h_1=75, h_2=125, h_3=135, and h_4=115 W/m^{2}C. The coefficient of 75 W/m^{2}C is considered an outlier likely caused some temporary issue with the guide such as sawdust packing or flow of lubrication was blocked in the port for this guide. The next measured convection coefficient returned back to the normal condition: perhaps the sawdust was removed, or lubrication port was cleared out. During this period of test there was no change in the lubrication system, and the sawing performance reported by quality control was consistent. Therefore, by ignoring this number, then the average of convection coefficient for this system is calculated about 130 W/m^{2}C.

The FEM was built based on the properties summarized in Table 2. Figure 7 shows the temperature distribution and the buckling mode for each of the three scenarios (hot rim, hot body, and hot eye) for the situation when the temperature for each of these cases reaches to its critical temperature. The FEA results indicate that the critical temperature for the three scenarios of hot rim, hot body, and hot eye were 55 C, 85 C, and 87 C respectively. Therefore, the critical temperature for this saw is when the rim reaches 55 C.

The results indicate that the dominant mode of buckling for the case with hot rim is a two nodal mode (a quartering mode). This mode of deformation usually results in saw snaking. On the other hand, the hot eye will result in saw dishing which can causes stepping or mismatch during sawing. The hot body has a behaviour between the other two cases.

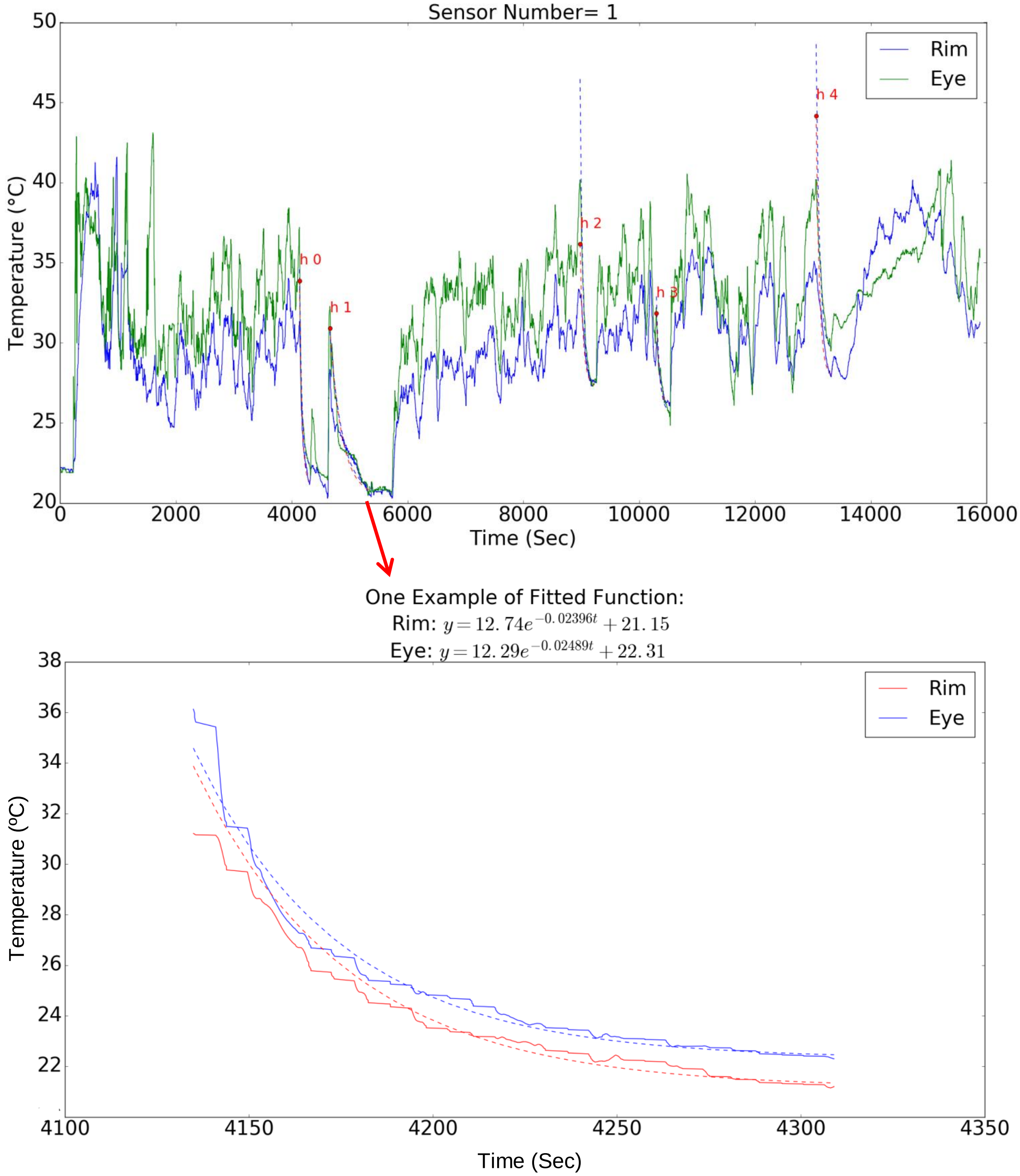
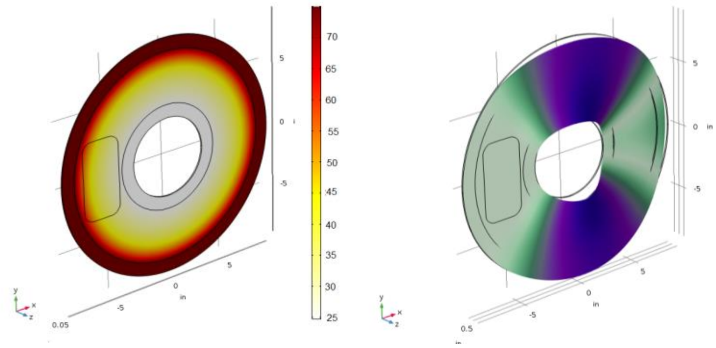
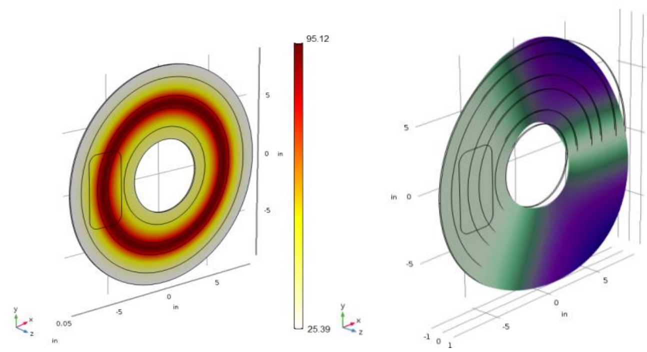


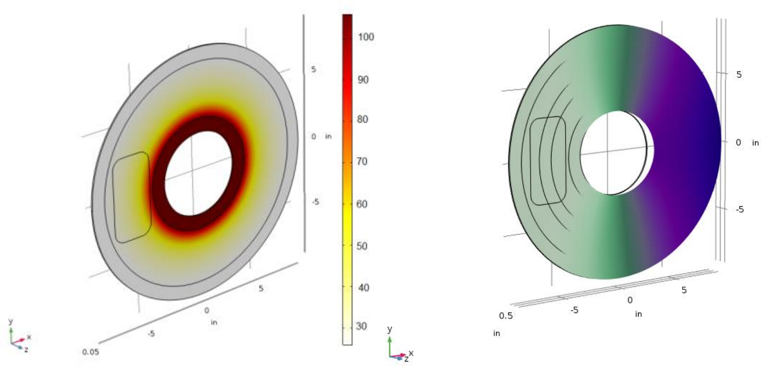
Figure 6. Selected intervals for computing the convection coefficient, variation of saw temperature



a) Hot Rim



b) Hot Body



c) Hot Eye

Figure 7. Critical temperature and the buckling mode for the three cases

CONCLUSIONS

Saw temperature measurement is being used for monitoring the average change in the saw temperature and evaluating the guide cooling capacity which is measured by the convection coefficient of guides during cutting. Knowing the critical temperature for a saw and the safe temperature margin, before a saw loses its stiffness and buckles provides useful information for the operator. The preliminary results of this study indicate that hot rim is the most vulnerable case, and the saw stiffness is more sensitive to a hot rim, as indicated by the lower critical temperature, compared with the other two cases, the hot body and the hot eye. In practice, there are many parameters involved in saw cooling/heating and the interactions of these parameters are complicated; however, the developed computer model can be used to estimate the critical temperature of a saw. Conducting experimental tests, in order to verify the computer model is essential and is the future work of this study.

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