# Temperature variations and spark generation from rock contact in hot saws

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## Abstract

A study was conducted of the fire ignition potential of high-speed disk cutting saws (hotsaws). Surface temperature increases for the operating saw blade were measured during normal cutting and when stopping the disk using friction against a stump. Observed temperature increases during normal operation were as high as 17° C above ambient. Tooth temperatures tended to be highest, but were not observed to be vastly different from global saw disk temperatures. Dynamic increases in temperature at the cutting interface of saw disk and tree tended to be on the order of a few degrees C. Stopping the blade by dropping it on a stump caused much higher temperatures on the stump itself (to the point of charring), but average saw blade temperatures increased by only an additional 10° C. An additional test of sparking tendencies of various rocks found that the number of visible sparks thrown varied by rock type, with basalt-type rocks having the highest numbers.

## Introduction

A wide range of human activities are the most commonly cited reasons for forest fire ignition (Stephens, 2005). Among human activities, performing any number of forest operations can involve many potential ignition sources. One report (Nichols, 2006), for example, stated about 5 percent of human-caused fires in Oregon were ignited by forest operations. Timber harvesting is an operation involving use of heavy equipment and its fire risks include those related to operating with internal combustion engines and associated hot surfaces. States in fire-prone regions typically have laws requiring, for example, spark arresters and extinguishers on equipment to deal with those risks.

The felling component of timber harvest is normally done using large, high-speed, disk saws (‘hot saws’, see Figure 1) mounted on mobile carriers. Besides the risks associated with heavy IC-engine-powered equipment, these hot saws have been known to ignite forest fires from sparking caused by striking rocks, or other hard debris, while in operation (see, for example, Fields, 2002). This type of ignition source is particularly difficult to deal with in that it may not produce an immediate blaze and it can be difficult to detect the collision of the saw and an object given the amount of noise and dust normally encountered during felling. The probability of causing this type of fire will be related to the number and type of surface rocks on a site as well as the moisture conditions of the organic material on the ground. Little data are available, however, to characterize the magnitude of the fire risk of hot saw sparking when operating on a given site.

Another potential fire danger from operating hot saws is the possibility of frictional heating of wood surfaces by the saw blade. A hot saw disk is large, steel, and rotates at speeds typically in excess of 1000 rpm. If a high contact force were maintained between the saw disk and a wood surface, the energy transfer rates could easily exceed those required to spontaneously ignite wood (1.3 - 3 W $cm^{-2}$, Simms and Law, 1967). Although fires ignited in this manner are less common (Nichols, 2006), they are still a possibility and little data are available on normal operating temperatures of hot saws.

This study was conducted to investigate aspects of operating rotating disk felling heads that may contribute to ignition of fires. In particular, normal operating temperatures of the saw itself were characterized in order to determine if they might reach a level that could ignite a fire. Sparking characteristics of several rock types were also investigated with the intention to qualitatively rank them in their likelihood to cause fires. Specific objectives were as follows:

- Characterize average surface operating temperatures of disk saws and determine if dynamic heating during the felling process increased temperatures to levels known to cause ignition of wood.
- Measure differences in spark formation among rocks of parent materials common in the interior mountain west of the US resulting from contact with spinning metallic blades.

Figure 1: An example of a typical hotsaw felling head mounted on a tracked carrier.

## Methods

### Operating Temperatures

It was expected that the saw disk would achieve a steady state condition after lengthy operation in which the average temperature over the entire system would remain nearly constant, although variation with position on the disk might occur. It was further expected that the variations with position would be a result of frictional heating from contact with trees either while cutting or from the butt sitting on the spinning blade after severing. These two temperature regimes - a global average, or an instantaneous rise due to friction - were referred to as ‘static’ and ‘dynamic’ measurements, respectively, and were characterized in this study.

### Static temperatures

Static measurements were used to evaluate long-term average temperatures that could be expected from normal felling operations. These temperatures were measured using (a) an infrared camera (FLIR Model B20) and (b) thermocouples mounted in felling head teeth. In both cases, temperatures were verified using an hand-held infrared thermometer (Fluke Model 61). The infrared camera was used to inspect the variation in temperature across the saw disk surface. Thermocouples, on the other hand, were used to measure temperature at the point the disk was felt most likely to reach the highest average localized temperature, the cutting tooth itself.

Thermocouples were placed near the saw teeth by mounting them in two bolts used to secure teeth to the saw disk. Small holes (about 4 mm diameter) were drilled through the bolts and a steel freeze plug was placed into the hole on the threaded end of each. A copper/constantan thermocouple was placed in contact with the plug by threading it into the hole from the head end and then filling the hole with epoxy. A connector for the thermocouple was also epoxied to the head end of the bolt (see figure 2).

Figure 2: Modified bolts with thermocouples in place.

There were no formal experiments established to measure a true average temperature of the saw blade as observed using the thermal imaging camera. Images were taken of several feller-bunchers and the highest observed temperatures on the saw blade surfaces were noted, along with a qualitative evaluation of the areal extent of the higher temperatures. The temperature values collected represented the best guess of the highest increment in temperature above ambient for an area of appreciable size. These numbers were used principally to establish a range of somewhat typical operating temperatures, but no statistical analyses of the values was attempted.

A tracked feller-buncher on which the thermocouple-equipped bolts had been installed was operated for over 1 hour in relatively warm conditions (once about 32° C ambient temperature, the other 26). Three observations of temperature were made at 15 minute intervals following the 1-hour warmup period.

### Dynamic temperatures

Because the thermal mass of the saw was quite large, it seemed possible that the instantaneous temperatures experienced while the saw was in physical contact with a tree might be much higher than the average for the entire saw and that some of the excess heat could be transferred to smaller particles exiting the sawhead and their temperature be sufficient to start a fire. A method was developed, therefore, to observe and record dynamic changes in temperatures near the tree/saw interface during the cutting operation. This was achieved using a non-contact temperature sensor with response time on the order of 10 milliseconds (Optris CT Fast) and a high speed data acquisition system.

The infrared sensor was mounted in a hole in the deck of the felling saw just above the teeth. The sensor output (a voltage proportional to temperature) was read using a microcontroller (SunSPOT) with 10-bit analog data acquisition capability that also included a radio communications link. The microcontroller waited for a trigger command from a host computer then read the sensor continuously at a rate of about 150 Hz and uploaded its observations to the host in near real time. The host could be operated at a distance up to 150 m. Figure 3 shows the felling head with sensor and data acquisition positioned for operation. The box housed the microcontroller and the trail of tape covered the wire leading to the sensor. The sensor was mounted in the hole normally used to lower a stop into the blade for transport.

Figure 3: Data acquisition system for the dynamic temperature measurements mounted on felling head.

Measurements of temperature during severing were made on ten trees. The process involved initiation of a data recording program on the remote computer then signaling the feller operator to cut the tree after which the data collection program was stopped. A calibration equation relating sensor output voltage to temperature was developed for a temperature range similar to that expected in the experiments.

**Frictional heating**

Figure 4: Stopping the saw disk on a stump.

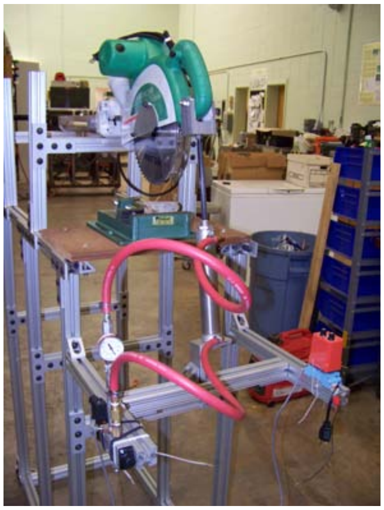
In discussions with feller operators, their opinion was that a fire would be difficult to ignite under normal operating conditions in the absence of a spark from collision with a rock or other hard object. They did, however, feel it would be more likely to start a fire if the saw was first heated by stopping the disk on a stump, a common procedure when parking the machine. This process obviously heated the stump, as evidenced by smoke when in progress and charring afterwards (see figure 4), but it was not known how hot the saw itself got after undergoing the procedure.

The change in temperature associated with stopping the disk on a stump was measured on the two days that tooth temperatures were measured. In both instances the saw was stopped multiple times on a stump and surface temperatures of the saw disk were measured using an infrared thermometer, plus tooth temperatures using the thermocouples.

## Spark Generation

Spark formation from the operation of hotsaws has been reported mostly from an anecdotal standpoint, but is a phenomenon widely known to occur. It is difficult, however, to characterize the probability of its occurrence, or its severity for a given rock/saw combination, quantitatively. Our objective in this study was to evaluate the relative amount of sparking that might be associated with different types of rock. The rock types were not rigorously defined, but rather samples of what forest managers from western states thought were common in their particular forests.

Figure 5: Photo of spark test bed control system.



It was considered much too dangerous and expensive to test sparking of a full-scale hotsaw. A substitute saw fixture was therefore constructed using a commercial 10-inch radial chop saw. We felt a combination of a smaller saw with pneumatic control of saw actuation would provide a feasible means of simulating contact between a spinning saw and a rock, and be able to accomplish it in a repeatable fashion. Our saw test bench consisted of the saw mechanism plus a pneumatic cylinder connected to a solenoid-operated, 4-way, 2-position directional control valve, a pressure regulator, and a manual flow control. The solenoid was energized using a repeat-cycle relay. The pressure regulator limited the maximum force that could be generated using the cylinder and the flow control valve was used to set the speed at which the saw was forced onto the rock surface. The directional control (McMaster part 6124K513, mcmaster.com) was used to initiate the contact sequence as well as limit the total duration of contact between the saw and the rock. Figure 5 is a photo of the spark testing system as used in the study.

Rocks were shipped to the US Forest Service Forest Operations Research Unit facility in Auburn, AL. The rocks were about the size of a softball and represented a range of parent material and hardness. A flat surface was cut on selected rock samples using a tile saw. Rocks were mounted for testing flat-face-up in the saw test bed using a vise. Figure 6 is a photo of the cut surface of the rocks after testing.

The test procedure involved lowering the saw onto a rock sample for a specific amount of time and at a specified pressure. Contact time was about 1 second with 'contact' being the period during which some portion of the saw blade was below the rock surface level (i.e. it included both lowering and raising time). The timing was set based on the air flow rate into the cylinder which was set once and not varied. Pressure was fixed using the regulator and also not varied between tests. The function of the system was sensitive to operating conditions, but once it had been cycled a few times the contact durations stabilized and provided consistent test runs.

The contact test for a specific rock involved mounting the sample in a vise, in as flat a position as possible, and then raising or lowering the sample to provide a specified distance to the saw blade at its resting position. Fixing this distance ensured uniform contact duration between samples. Once mounted in place, the repeat interval relay was started which began the lowering/raising sequence of the saw blade. When operating properly and all data acquisition was judged to be ready, the saw was started at the beginning of the lower/raise cycle and, after one full contact cycle had occurred, the saw was shut off.

Each contact was recorded using a high-speed camera (3000 FPS). The recordings were started and stopped manually by the camera operator. Recordings were made with lighting optimized both to show sparks as they were created and details of the saw and rock contact.

Figure 6: Rocks used in the sparking test, post testing.

A total of 8 rock samples were tested (see table 1). A single brand of carbide-tipped saw blades were used in the tests with a fresh blade put on between rocks. For each rock, three contacts (and associated videos) were made. A 0.1-second duration interval beginning and ending 0.05-second before and after, respectively, of the midpoint of contact was selected from each video and used for measurements. Number of visible sparks traveling in excess of 4 cm were counted and averaged as an index of spark potential. In addition, the furthest distance traveled by a single spark for each contact was measured. Samples from each of the rocks were also sent to a commercial laboratory for elemental analysis.

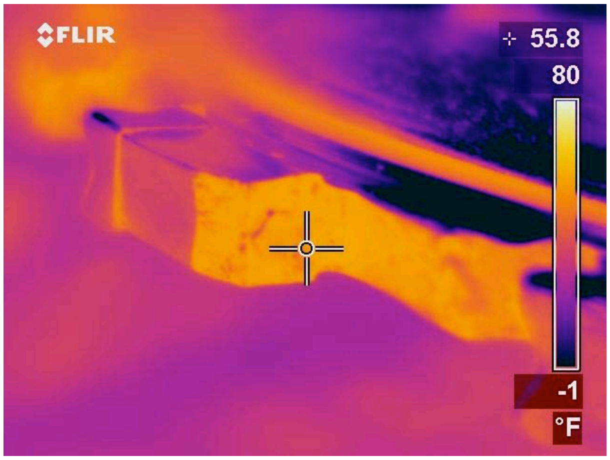
# Results

## Operating Temperatures

### Steady State Temperature Rise

Observations during both hot and cold conditions indicated maximum saw temperatures were about 6 to 17° C above ambient. The location of the highest temperatures was most often found on the felling teeth or on the mounting points holding them in place. An example of the observed temperature and variability is shown in figure 7, an infrared image taken on a day with relatively cold ambient temperatures (near freezing).

Figure 7: Infrared image showing temperature variation on the felling head.



The observed temperature changes were likely influenced a great deal by condition of the saw, the sharpness of the teeth, and the type and spacing of the timber in which the machine was being operated. These factors, however, were not evaluated systematically. For the highest temperature

Table 1: Description of rock types and classification.

| Rock | Type | Description |
|---|---|---|
| 2 | A | quartzite, structure more crystalline than 9 |
| 3 | B | granite, shows fine layering, fine-grained |
| 4 | D | limonite, i.e. weathered basalt |
| 5 | C | basalt |
| 6 | E | diorite |
| 7 | C | basalt, coarsely crystalline, with feldspar inclusions |
| 8 | B | granite, or ‘granite-like’, with garnet inclusions |
| 9 | A | quartzite, coarsely crystalline |

rises observed, the saws were in general not found to be hot enough to cause ignition simply from contact with logging debris or other residues. Spontaneous, short duration ignition temperatures of wood construction materials from radiant heat sources are typically in excess of 300° C (somebody). For fine, dry woody residues the temperatures can be much lower (down to about 200° C), depending on numerous factors such as moisture content, bulk density, air flow, and time of exposure (Liodakis and others, 2008).

Temperature increases for the teeth bolts were on the order of 12° C above ambient in all observed cases. A single felling machine and hot saw were used in these tests and the condition of the saw was nearly new. As a result, the temperature changes were relatively small and consistent.

## Frictional Heating

Tests of the increase in blade temperature as a result of stopping the saw on a stump were carried out on two separate days. Day one had ambient temperature around 33° C at the time of testing. The blade was stopped three times on the same green stump (hardwood) and temperatures of the stump itself and the tooth temperatures were measured. At the onset of the test, tooth temperatures averaged 43° C. Average temperatures after stopping one, two, and three times were: 47, 50, and 51° C, respectively. The blade temperature measured using an infrared thermometer had increased to 54.5° C after three stops. There was significant smoke and associated charring of the stump with each stop of the blade (see figure 8).

Figure 8: Condition of a stump following two stops of the disk.

For the second test (27° C ambient), stump temperatures following blade stoppage were also measured using the infrared thermometer. In this case, tooth and blade temperatures did not increase after the first stop, remaining about 49° C. Stump temperature was quite variable, depending on the spot being measured, but ranged from 54 to 81° C. There was again a great deal of smoke and charring of the stump.

The fire danger from stopping the blade on a stump and then setting the heated saw head on debris or leaf litter seemed very small, unless perhaps some other malfunction was heating the saw as well. Blade temperatures after stopping were higher than typical when operating, but still well below the spontaneous ignition point. A fire would be slightly more likely from nearby debris being blown onto a stump heated by stopping a blade, but the probability of such an occurrence seemed low. It was very clear, however, that woody debris in contact with the spinning blade even for short durations could be heated to ignition temperatures if there were sufficient force holding the two together. This situation could easily occur with debris being lodged in the saw head. The high air velocities resulting from the spinning blade and the likelihood of ejecting smoldering particles from the head because of lodged material also would tend to promote ignition of nearby material if in a dry state.

### Dynamic Temperatures

Temperatures during the cutting process did increase, but only by a small amount. The plots below show temperature variation while cutting a tree for two instances. In the first (figure 9 upper, red graph) the saw had just begun operation and its average temperature was relatively low. The cutting cycle temporarily increased the temperature by about 2° C, but for a brief time only and then returned to its previous level. The second (lower, blue) graph shows the increase after the saw has heated up to a more typical operating range. In that case, the temperature went up by about 1° C, again for a short time, and then returned to a lower level. It appeared from the measurements that temperature during the actual cutting cycle was variable, increased during severing, but not by an amount likely to cause ignition of fires.

## Spark Generation

Number of sparks resulting from contact between a variety of rocks and a carbide-tipped saw blade is summarized in table 2. There was a clear gradient in the number of sparks by rock species. One rock in particular (number 4) was very soft and showed almost no sparking. It was also clear that the initial strike of the saw onto a rock typically produced a greater number of sparks, but that the sparking intensity reduced to a more uniform, lower level for the next two strikes.

There were no significant differences by saw rock type when data for all three strikes of the saw blade were included in the analysis. This was due to very large variability introduced by the proportionately greater number of sparks observed on the first strike. Removing the data for first strikes from the analysis, significant differences were found between rock types exhibiting the highest number of sparks (basalt and diorite) and that exhibiting the lowest (limonite). All other comparisons, however, were not significant (table 3).

Elemental data were also collected from samples of the rocks sent to a lab for analysis. Constituent elements tended to be highly correlated between the rock samples, with only a few elements identified as being independent (Ba, Cr, La, V, Sr, Mn, Zn). Of these elements, there was a strong linear

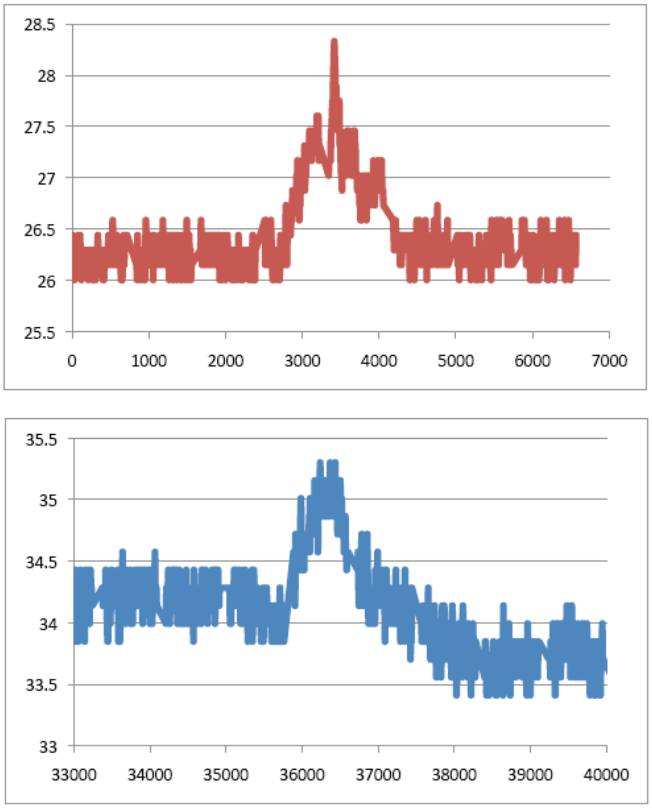
Table 2: Summary of sparks generated by rock number.

| Rock | N | Number of Sparks in 0.1-s Period | | | |
|---|---|---|---|---|---|
| | | Mean | Standard Dev | Min | Max |
| 2 | 3 | 174 | 250 | 24 | 463 |
| 3 | 3 | 158 | 177.5 | 47 | 363 |
| 7 | 3 | 140 | 5.6 | 134 | 145 |
| 6 | 3 | 127 | 69.8 | 68 | 204 |
| 8 | 3 | 112 | 44.3 | 81 | 163 |
| 9 | 3 | 90.7 | 15.2 | 77 | 107 |
| 5 | 3 | 83.7 | 20.6 | 68 | 107 |
| 4 | 3 | 0.7 | 1.2 | 0 | 2 |

Table 3: Summary of number of sparks generated by rock type. Number is the average of the second and third replications.

| Rock Type | Mean Number of Sparks ($\sigma$) |
|---|---|
| C | $105^{A}$<br>(38) |
| E | $89^{A}$<br>(29) |
| B | $72^{AB}$<br>(20) |
| A | $61^{AB}$<br>(38) |
| D | $1^{B}$<br>(1.4) |

Figure 9: Variation in observed temperature during cutting of stems.



correlation observed between two elements (La, Cr) and number of sparks. A regression model fit predicting number of sparks (all three strikes) from elemental concentrations of these two elements was significant (P <0.008), with a reasonably high adjusted coefficient of determination ($R^2 = 0.8$). Both coefficients were significant with (P <0.01):

$$N = 142.7 \quad 0.375La \quad 0.736Cr$$

where $N$ was number of sparks, and $La$ and $Cr$ were concentrations (ppm).

Model results were similar when analyzing the spark production from the two final saw contacts. In that case, the 2-component model having the highest coefficient of determination included the elements La and Zn:

$$N = 116.2 \quad 0.313La \quad 0.124Zn$$

where adjusted $R^2$ was 0.77 (P <0.01). The model using La and Cr fit to the reduced data set (final two contacts) had slightly lower $R^2 = 0.71$, but was still significant (P <0.02).

It was clear from the results that blade contact with some species of rock would produce higher numbers of sparks. The relationship between spark numbers and probability of starting a fire, on the other hand, could not be stated with any certainty. Results from other studies have demonstrated that flaming firebrands of even very small mass (0.5–1.5 g) are almost certainly going to ignite dry forest litter (Manzello and others, 2006). Smoldering (non-flaming) particles, however, are far from certain to ignite even loose, dry paper. It seems logical that an increase in the number of sparks would also increase the likelihood that a single, larger spark could be generated and cause ignition, or that multiple sparks could land in a fuel bed in close proximity and be more likely to ignite a fire. It would seem, however, that size, number, and location of rocks relative to trees would be the most crucial information requirement in deciding whether or not to allow operation on a given site. Types of rocks, although important given that a strike occurs, would be of lower concern than the probability that the strike itself happens.

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