Develop Methods to Reduce Circular Saw Guide Water Usage

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Abstract

A guide lubrication system that uses less water, while maintaining the conditions for good saw performance will reduce water (and oil) consumption, lessens issues with water pooling in conveyors and sawmill basement, corrosion, and results in dryer sawdust, which reduces shipping and drying costs. Experimental tests to determine the cooling capability of various guide pad designs, as measured by the convection coefficient, showed that an open guide pad design, with no pocket, just two lands was the most effective. Tests with clear guide pads made out of Plexiglas, so the flow inside the pad could be seen, showed that a tear-drop orifice shape got water onto the lands, where it is needed, and avoided premature escape of water from the pad. Experimental tests showed that no pressure is built up inside the pocket. Lastly, water flow increases linearly with increasing the orifice size, therefore adjusting orifice size may be a method for balancing lubrication flow to multiple guides.

1 Introduction

Circular saw guide water causes several problems in saw mills:

- Moisture content of sawdust is increased, which increases shipping and drying cost if it is used for pellets;
- Water can pool in conveyors and basements; in cold weather wet sawdust can freeze and jam conveyors; and corrosion of machines and conveyor chains increases.
- Many mills have a limited water supply and may not have sufficient water for saw guides, resulting in sawing issues.

The objective of this project is to develop a guide design that ensures all guide bearing surfaces receive adequate lubrication, allowing for reduced cooling water.

The approach is to develop a guide lubrication system that uses less water while maintaining the conditions for good sawing performance. In addition, previous studies showed the adverse effect of saw heating on increased sawing variation [1]. Therefore an effective cooling system has also improves sawing, by minimizing the temperature gradient between the rim to eye to avoid dishing or snaking [1].

2 Method

2.1 Evaluation of Cooling Capacity

To demonstrate the principles of saw heating-cooling, two temperature sensors were installed one close to the blade rim (point A in Figure 1), and one close to the eye of the saw (point B). The temperature sensors measured the temperature of the blade during cutting. For more details on the method of measuring saw blade temperature, refer to the saw monitoring reports [2 and 3]). Table 1 summarizes the physical properties of the blade and test speeds.

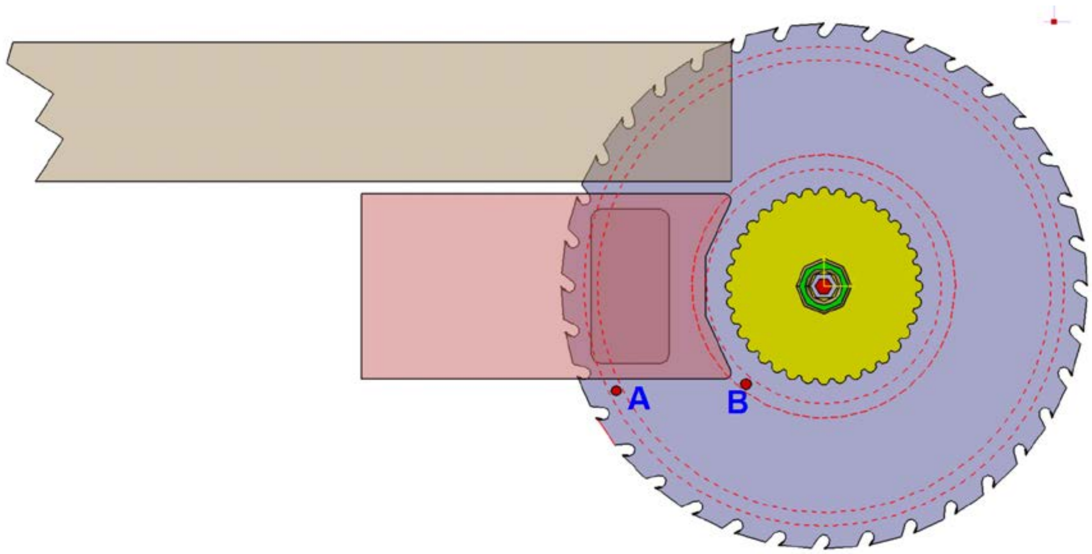


Figure 1 - Schematic of experimental temperature measurement of saw blade

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 (FPM)	50
Depth of Cut (in)	6
Wood	Stack of 3 Douglas-Fir boards of 2×10s
Density of steel (kg/m3)	7800
Thermal capacity of steel (J/KgC)	420

As an example, Figure 2 shows the variation of temperature-time during one of the cutting tests. The feed speed in these tests was chosen to be very slow (50 FPM) for generation of heat. As can be seen from this graph, there is significant difference between rim and eye temperatures. Temperature differences between the rim and the eye of a circular saw have major effects on saw stiffness [4].

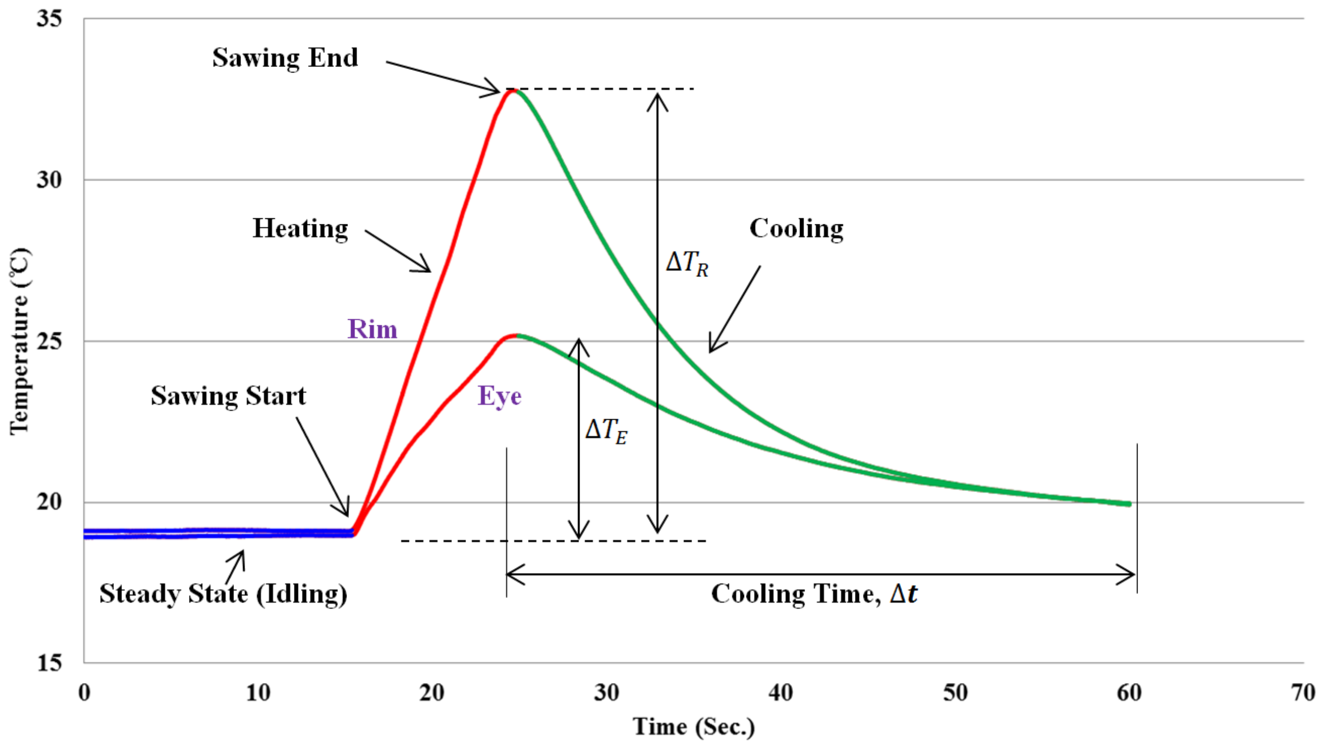


Figure 2 - Experimental measurement of saw blade rim and eye temperatures

As the Figure 2 illustrates, ΔT_E and $\Delta T_R$are the maximum blade temperatures at the saw eye and rim at the end of the cut, and Δt is defined as the time it takes for the blade temperature to become steady after a cut. It should be noticed that Δt is dependent on the cooling rate as well as the temperature at the end of the cut which are not constant for different cuts. Therefore, these variables do not capture the physics of cooling behaviour of the saw.

In order to quantify the cooling behaviour of the saw, it is assumed during idling (cooling time) there is no heat source (in fact, there is guide friction which generates heat, but it is assumed to be negligible relative to the heat generated during cutting), and the heat is dissipated through air and water. Although most heat transfer is by conduction of the blade to the water, and then the water spinning off the saw, it is assumed, for simplicity, that the convection coefficient h, accounts for both heat removal by water and air.

The formula governing the rate of the change in temperature due to convection is:

$$\frac{\mathrm{dT}}{\mathrm{dt}} = -\frac{2\mathrm{hA}}{\mathrm{mc}}\,(\mathrm{T} - \mathrm{T}_\infty) = -\frac{2\mathrm{h}}{\rho l c}\,(\mathrm{T} - \mathrm{T}_\infty) = -\gamma\,(\mathrm{T} - \mathrm{T}_\infty) \qquad (1)$$

Where $\gamma = \frac{2\mathrm{h}}{\rho l c}$, C is the thermal capacity of the material, T is the temperature of the material and T_∞ is the ambient temperature.

The solution to this linear first order differential equation is:

$$T = T_\infty + \beta e^{-\gamma t} \quad (2)$$

The constants β and γ are found by fitting an exponential curve to the cooling portion of the experimental temperature data, from which the convection coefficient h can be computed as:

$$h = \frac{1}{2}\gamma l \rho c \quad (3)$$

As an example, the convection coefficient h for the above graph and the saw properties in Table 1 and an ambient temperature of 19 C is computed as:

Rim: $\mathrm{h = 312\ W/m^2\ C}$

Eye: $\mathrm{h = 217\ W/m^2\ C}$

As a comparison, the convection coefficients from just air flow around a spinning blade are [4]:

Rim: $\mathrm{h = 85\ W/m^2\ C}$

Eye: $\mathrm{h = 5\ W/m^2\ C}$

2.2 Water Flow through Orifices

The flow of water through a range of orifice sizes from 0.052 inch to 0.25 inches was measured by flowing water from a bucket through the orifice using the set up in Figure 3. (Note that 0.25 in is common diameter for the internal channels in guide arms)

The water pressure in this test was very low:

$$P = \rho g H = \left(1000\frac{Kg}{m^3}\right)\left(9.81\frac{m}{s^2}\right)(1.8m) = 18(10^3)\ Pa = 2.6\ Psi.$$

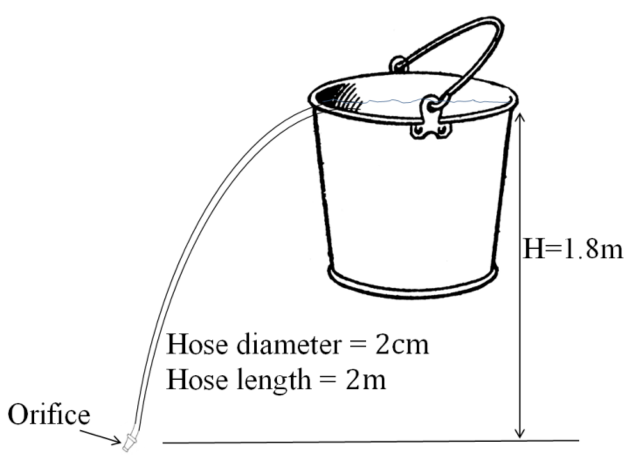


Figure 3 - Measurement of Flow through Orifices

2.3 Guide Pad Designs

Figure 4 illustrates Valadez's [5] recommendation of a guide pad design. The recommended design suggests only two inlets for water/oil at the two corners of the pad. Valadez suggested that having the orifice holes only at A and B (for saw rotating clock wise) and at C and D (for saw rotating counter clock wise), shown in Figure 4, promotes the rotating blade to drag the water and oil on the lands at about eye and rim of the saw blade which provides an efficient lubrication and coolant for saw. ("Lands" are the surfaces of the pad that contact the saw plate). There are alternatives of this design which are common that have one or two orifices inside the pocket.

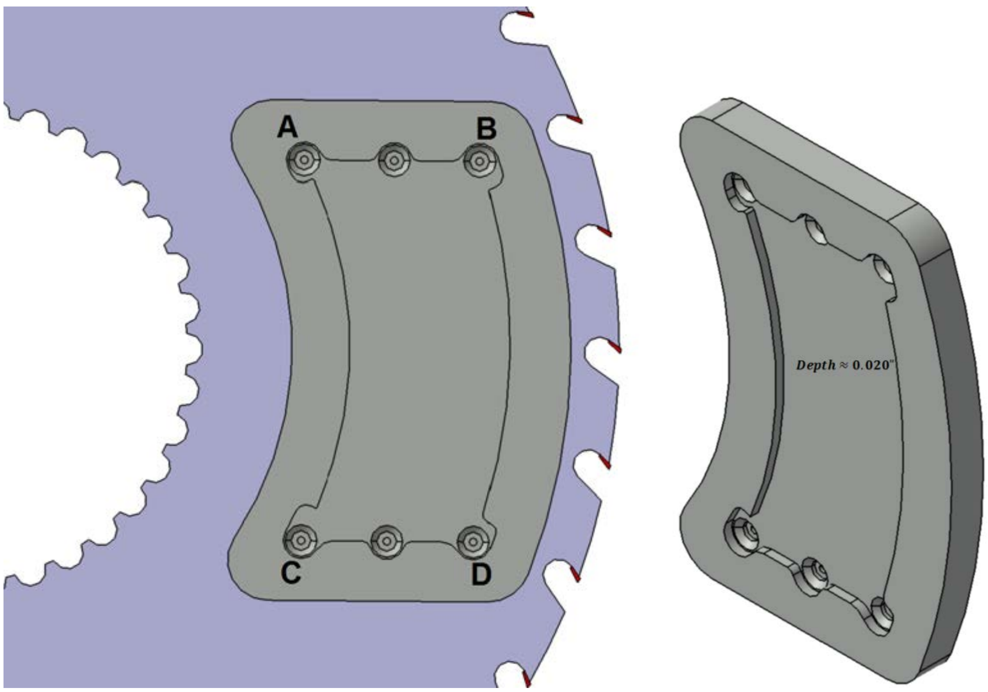


Figure 4 - Circular saw guide pad design recommended by Valadez [5].

There is not a consistent suggestion for choosing the depth of pocket, amount of coolant, and air pressure. For example, some prefer shallower pocket (i.e. 0.010 inches) while others are suggesting deeper pocket (i.e. 0.060 inches). A combination of water, oil and pressured air is normally used as the coolant. As a rule of thumb, 5-10 GPH/saw is the water requirement. Oil is also added to provide better lubrication. Air pressure is commonly 10-20 PSI. It is postulated that pressured air provide even distribution of water on the pads: it is assumed that pressured air is used to bias the water flow where it is needed on the guides. Using higher pressures (i.e. 30-40 PSI) is also common. It is possible that air in pocket keeps guide pressurized. A common assumption is that pressure develops inside the pocket that provides a water-air cushion for the blade. Also, it is assumed that water in the pocket can act as a reservoir providing added cooling for the blade. Both of these hypotheses were tested in the following sections.

In this project, as a first step, different guide pad designs were tested at the FPI lumber manufacturing pilot plant. In order to compare these designs, a temperature sensor was used to measure the temperatures of the blade near the rim and eye of the saw during cutting. (For more details on the method of measuring saw blade temperature refer to the saw monitoring reports [2 and 3]). For better comparison, all the tests were conducted with a same blade (Table 1) and the guide clearances were set meticulously to be equal for all of the pads (0.003 inches). The cants was a stack of three 2×10 inches Douglas-Fir. In total, 10 guide pad configurations were prototyped and tested. After each cut the surface of the cuts was measured by a laser scanner and the deviation of cuts were calculated. The rotation speed was chosen to be 3600 RPM (above second critical speed) and feed speed 50 FPM: A slow speed chosen for the laboratory tests as the most reliable way to generate temperature changes in the saw.

Experimental cutting tests were conducted for various guide pad configurations. The designs were chosen to include the current guide designs which are used in many sawmills, with orifice configurations in the land, inside the pocket, and both, no pocket, and ways to guide the water to flow in certain paths on the pads. The guide pad designs are illustrated in Figure 5 to Figure 14.

Five cuts were conducted for each guide pad design. For each cut the change in the temperature of the blade during a cut, near the blade rim (ΔT_R) and near the blade eye (ΔT_E) as a function of time, was recorded. Also the time it takes for the blade to cool (Δt) was recorded. Based on the procedure explained in the method section, the average value of the convection coefficient, h, was computed for each guide configuration.

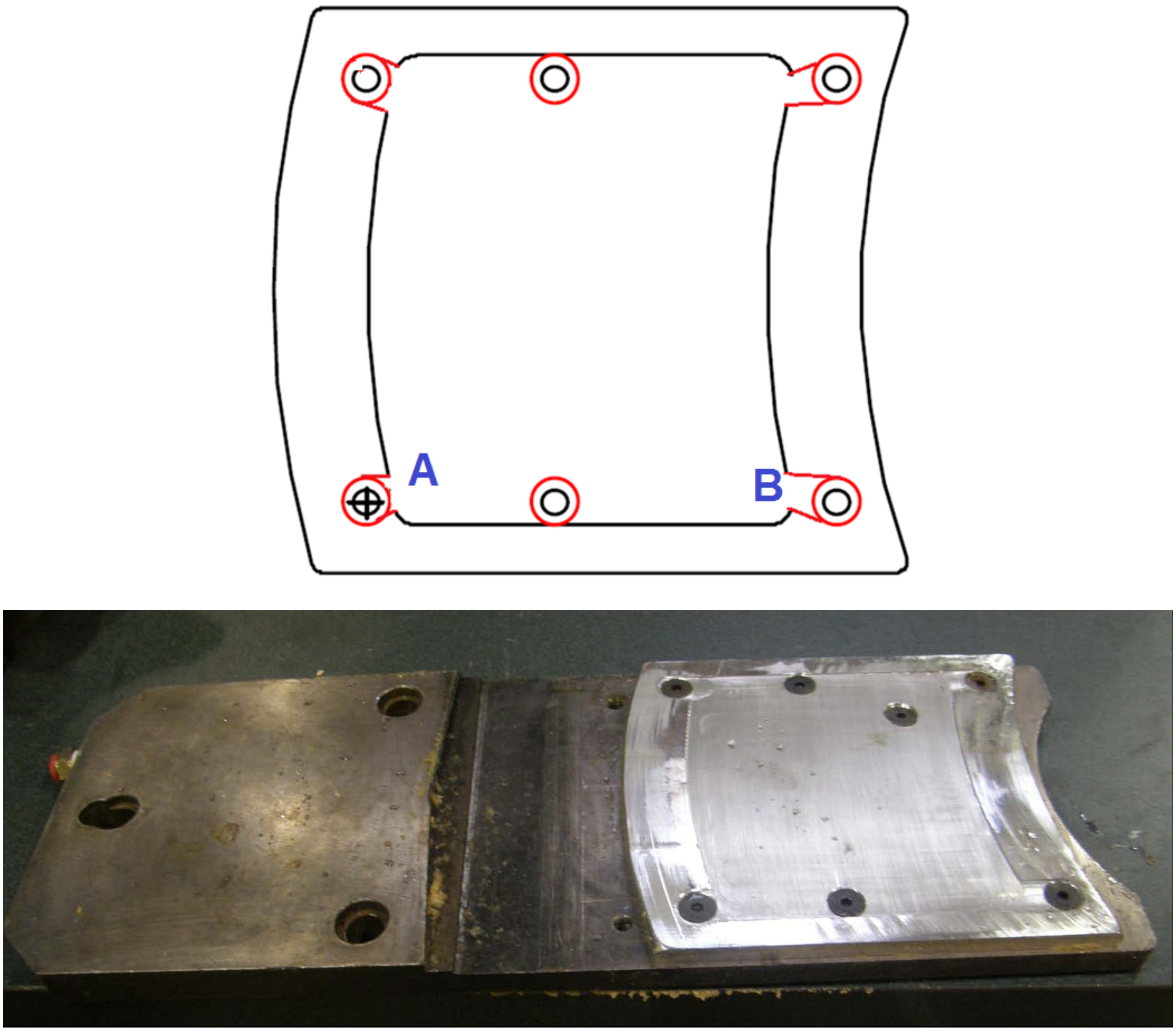


Figure 5 - Original Design (Orifice at A and B)

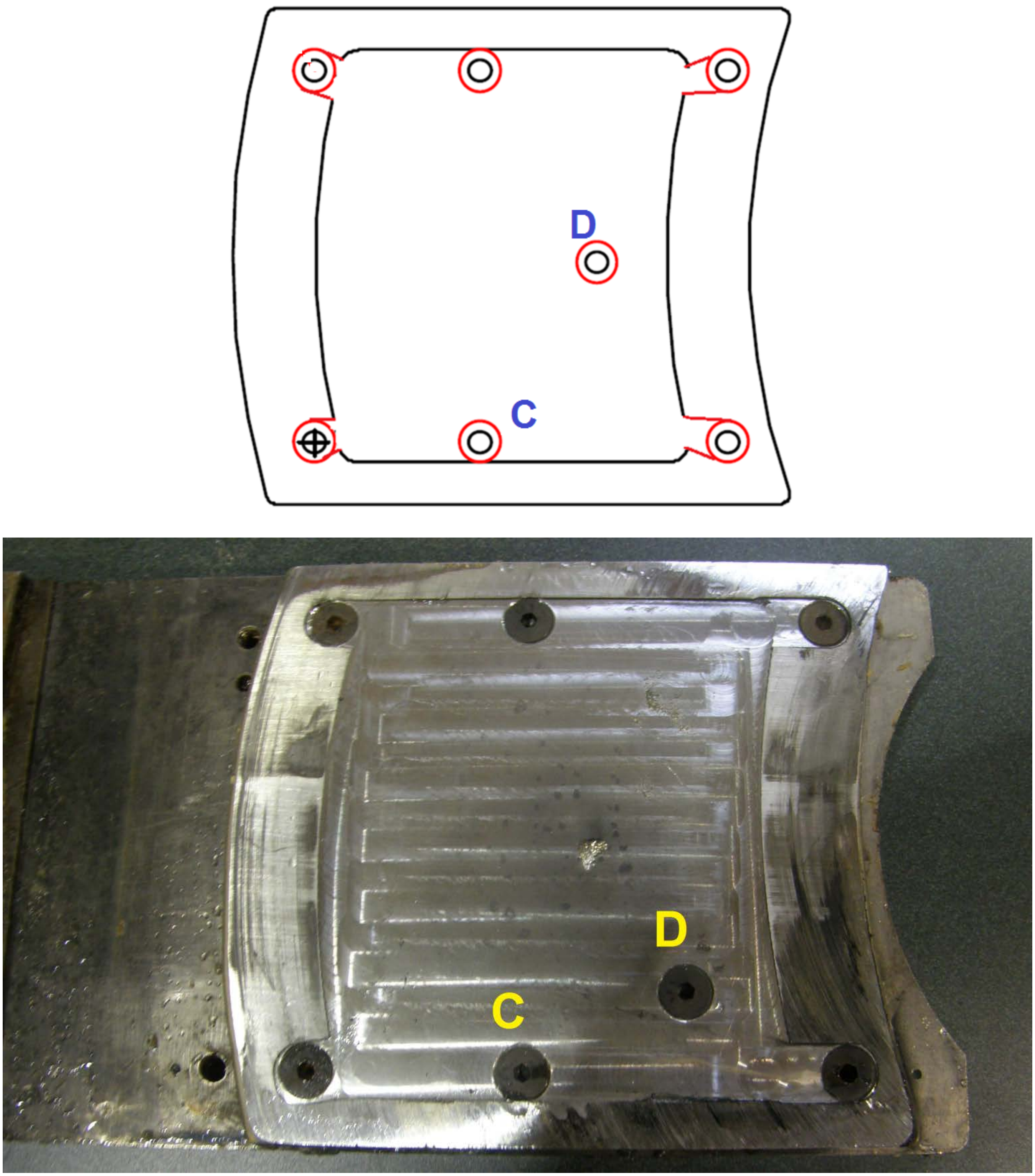


Figure 6 - Original Design (Orifice at C and D)

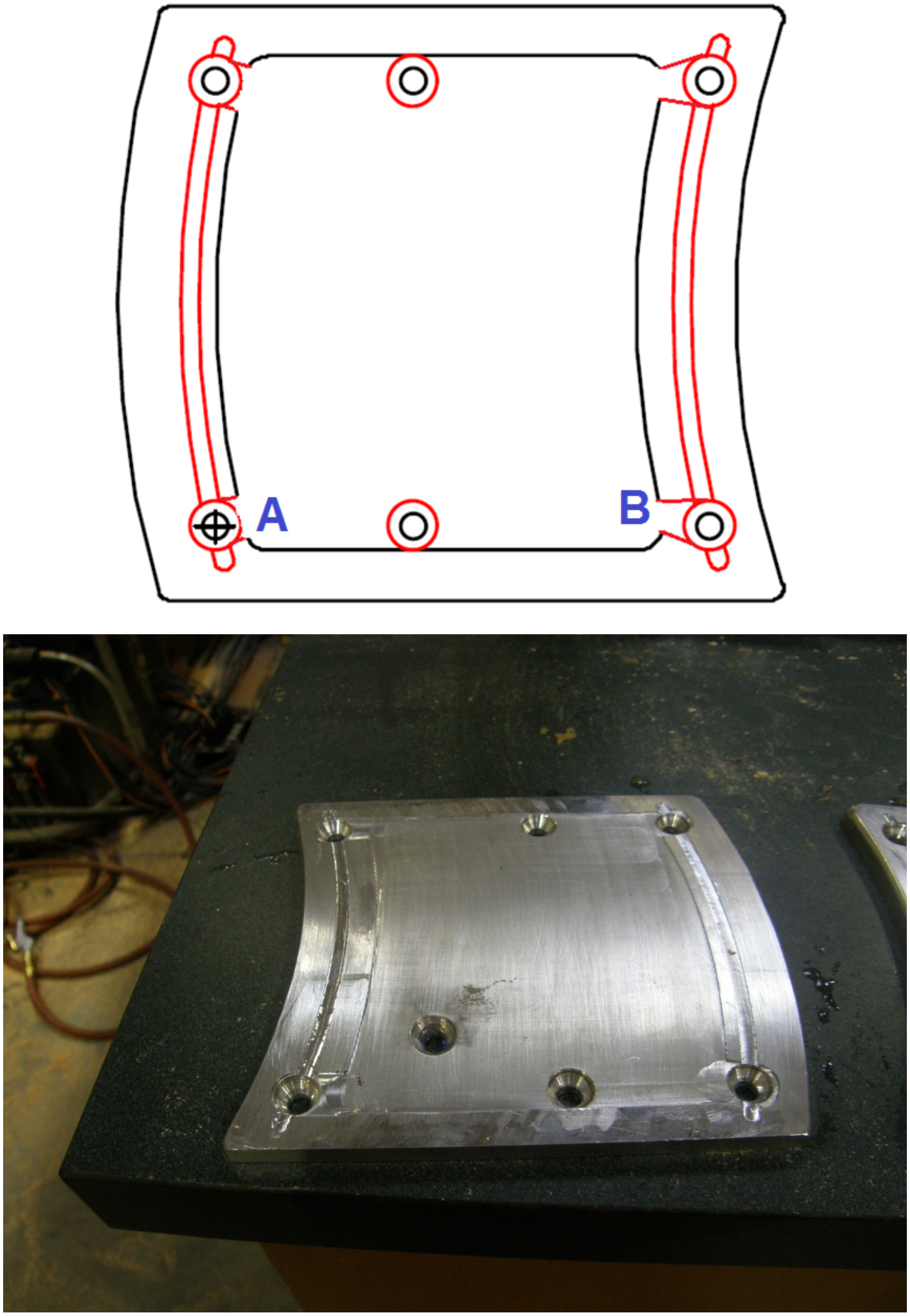


Figure 7 - Original Design with Channels.

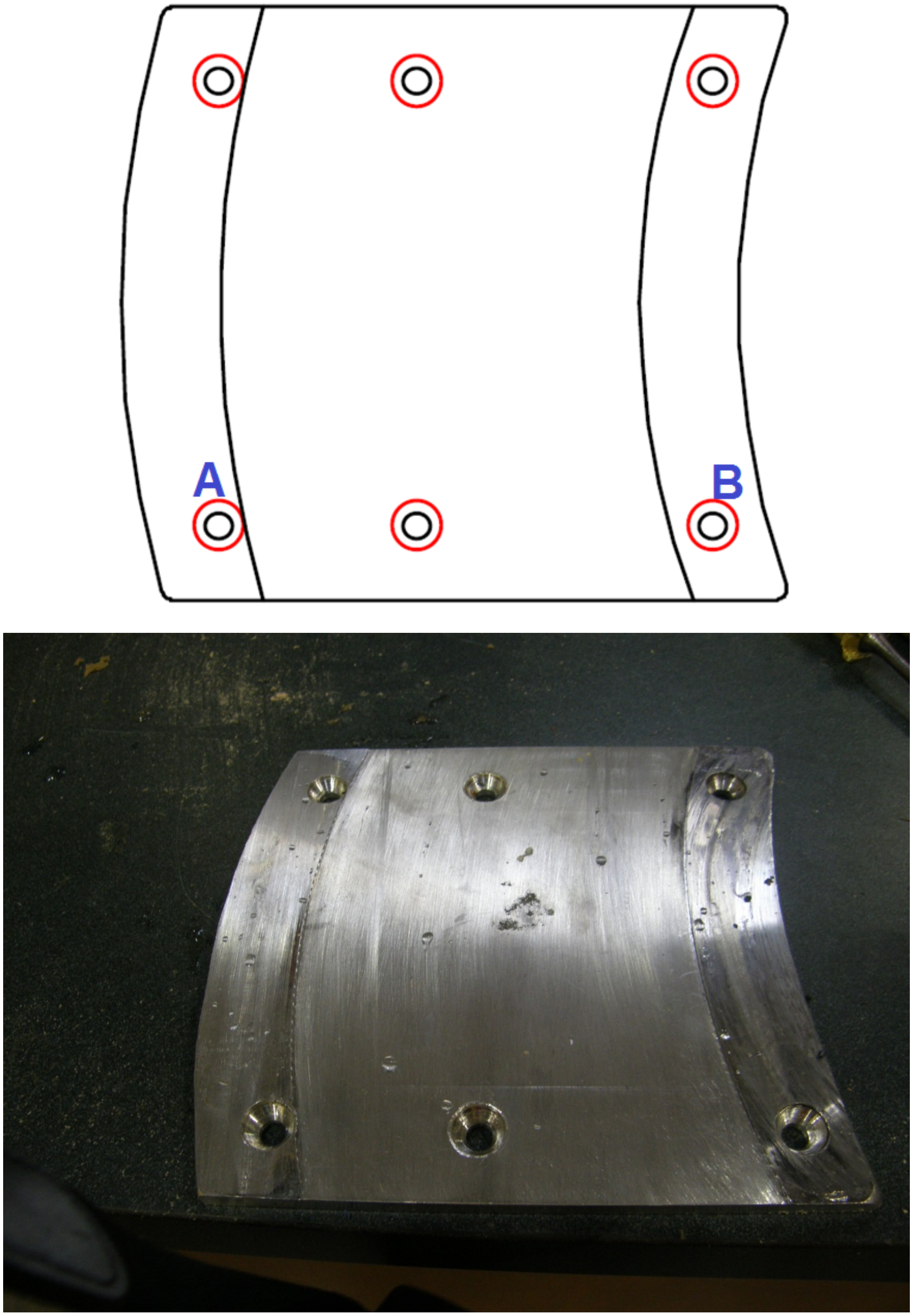


Figure 8 - Open Guide (No Pocket)

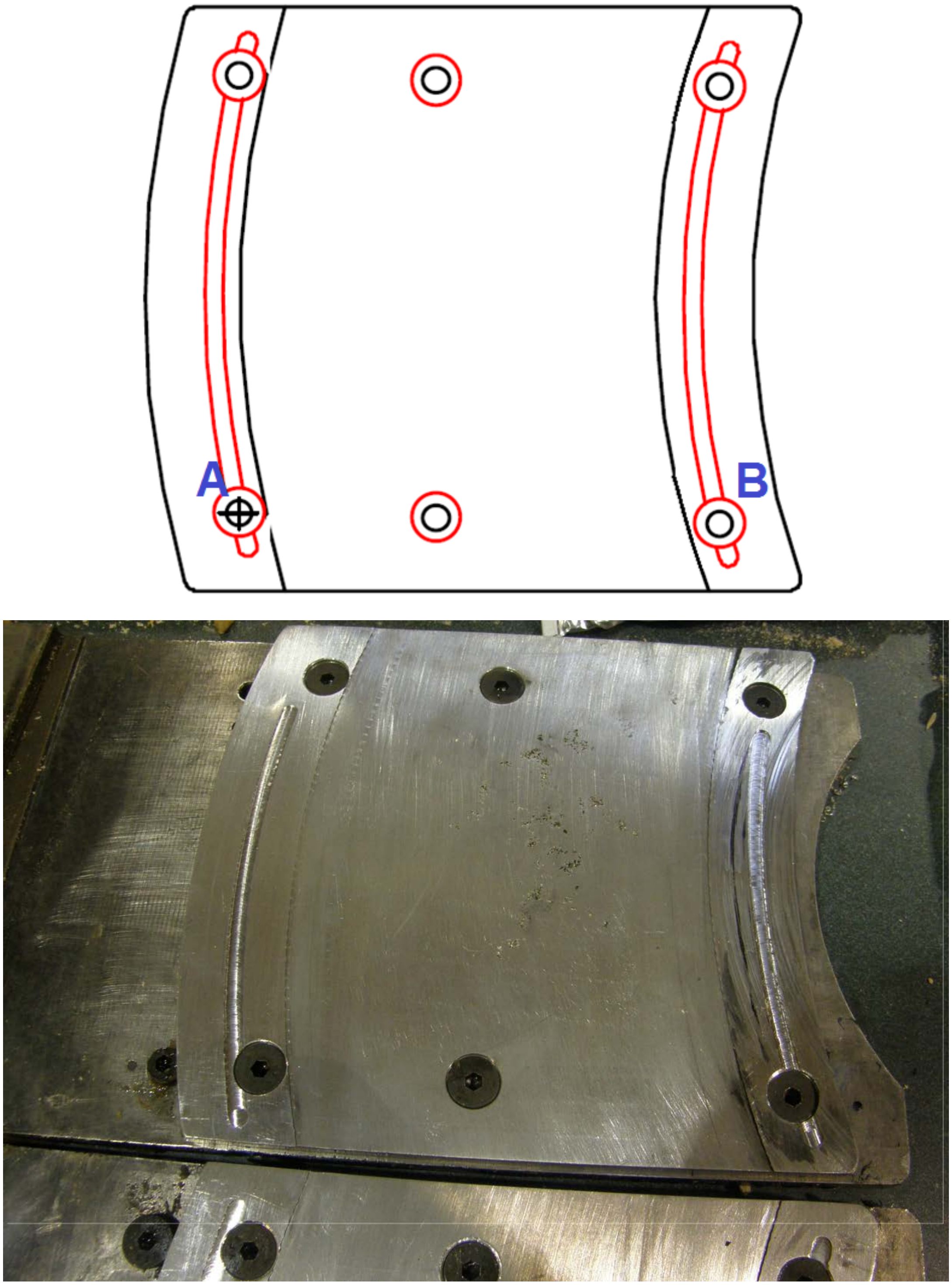


Figure 9 - Open Guide with Channels

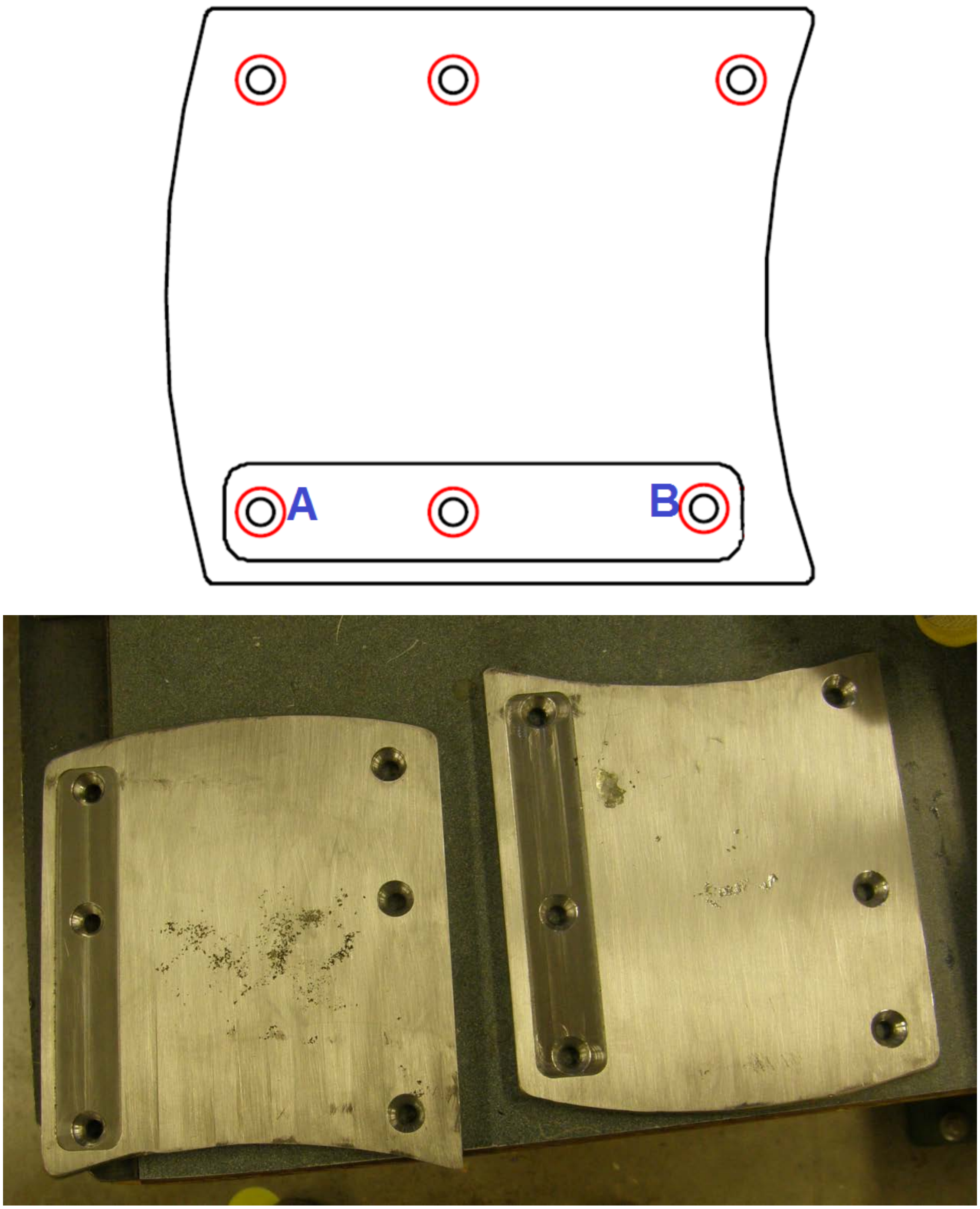


Figure 10 - Horizontal Bottom Narrow Pocket

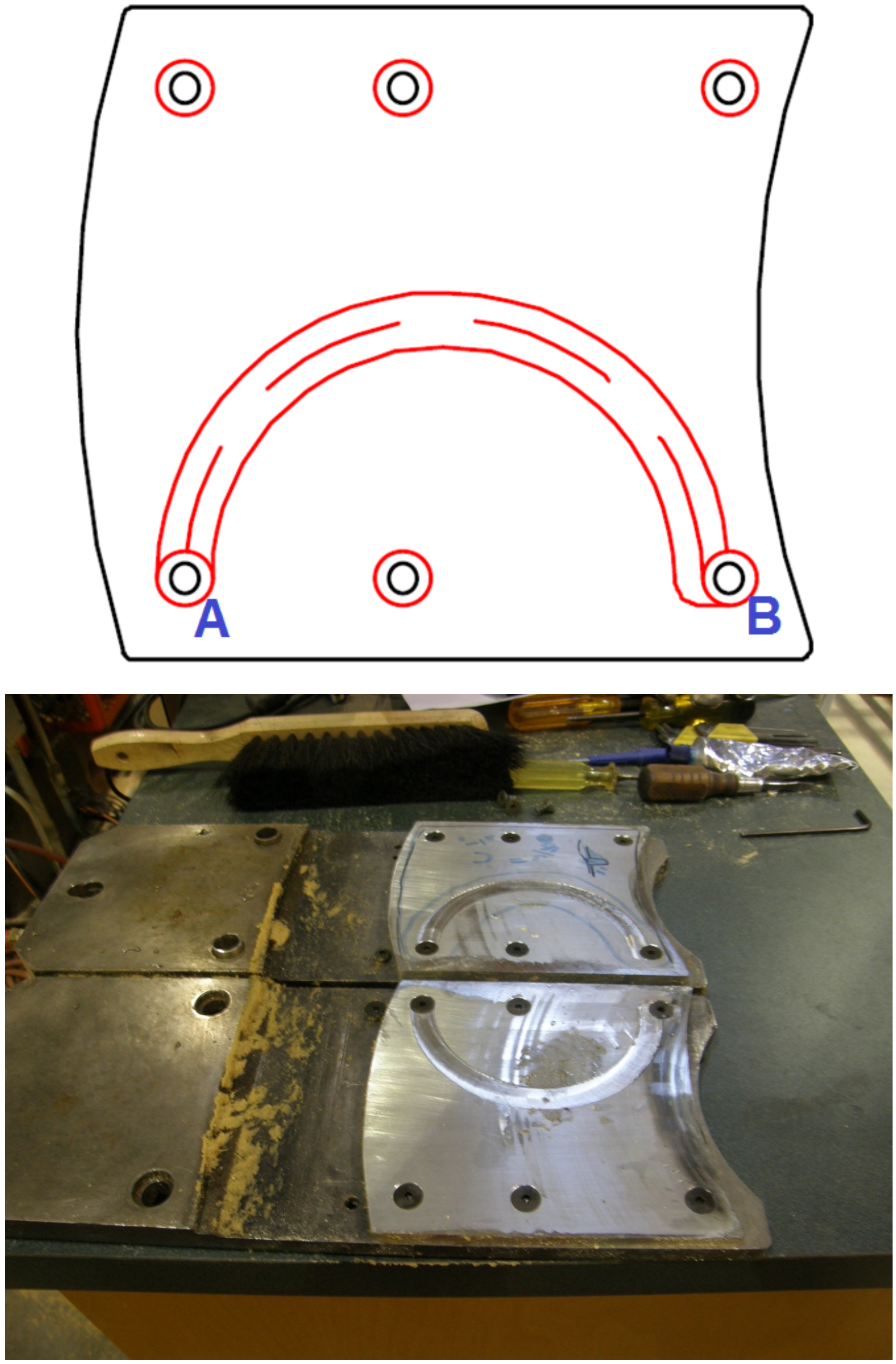
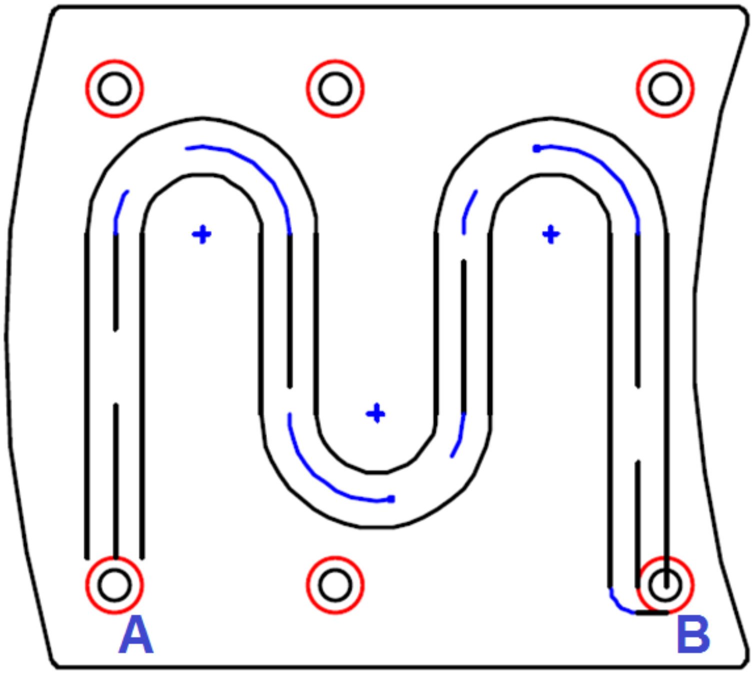


Figure 11 - Semi-Circle Pocket



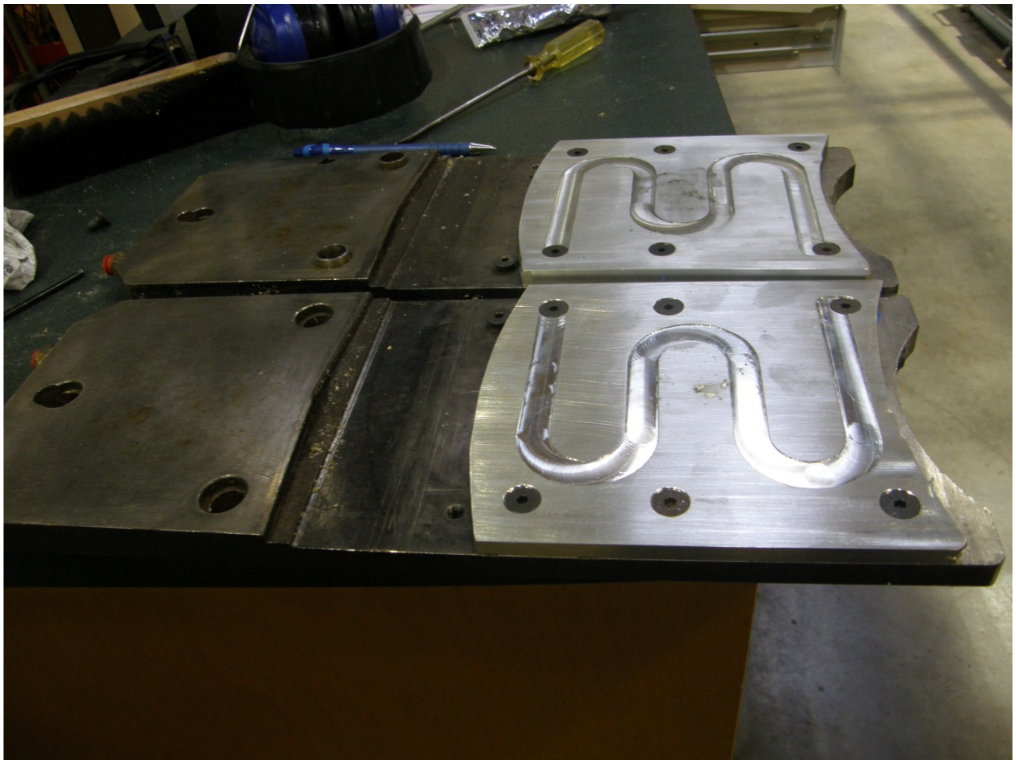


Figure 12 - Camel Pocket

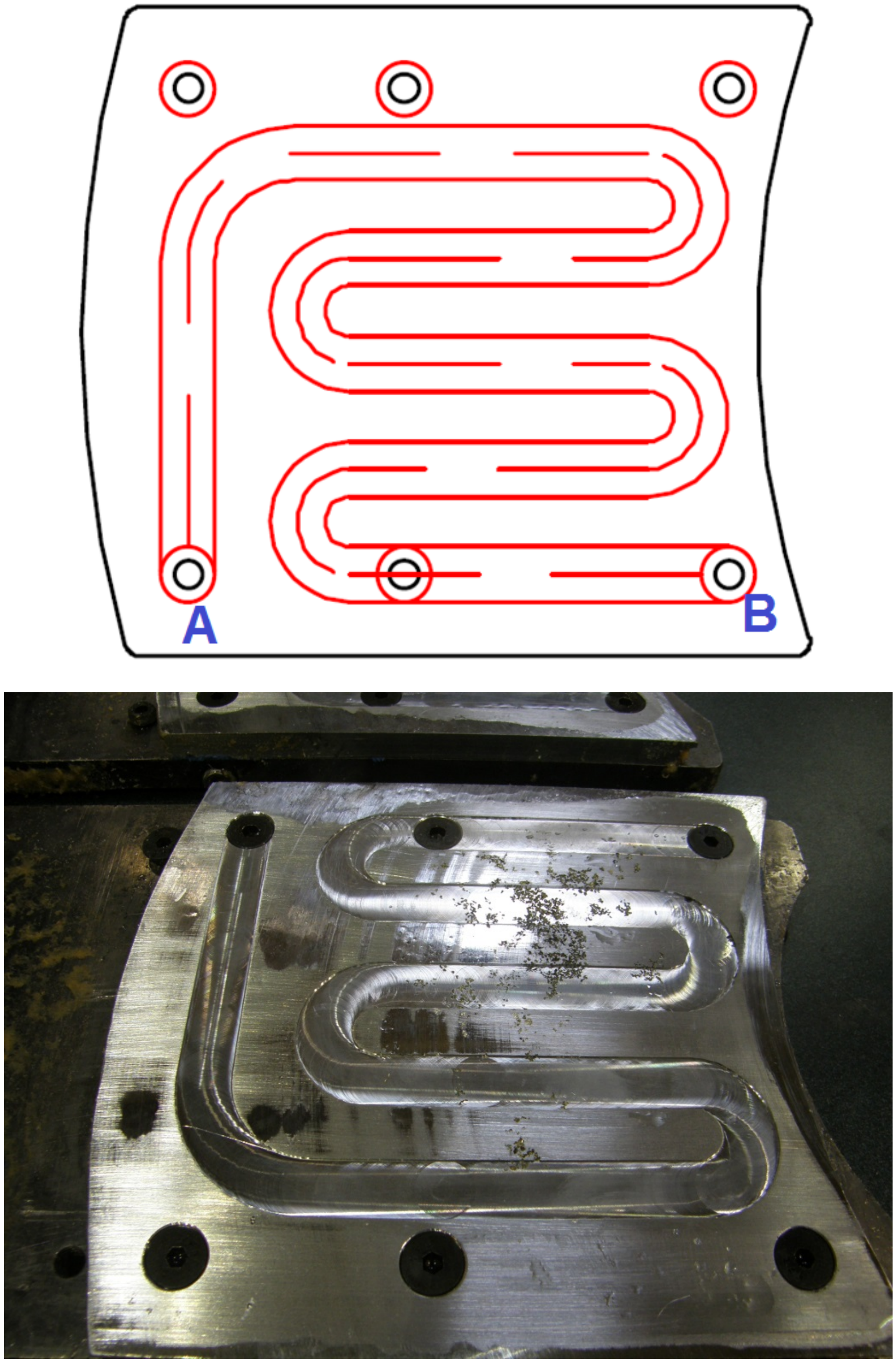


Figure 13 - Snake Pocket

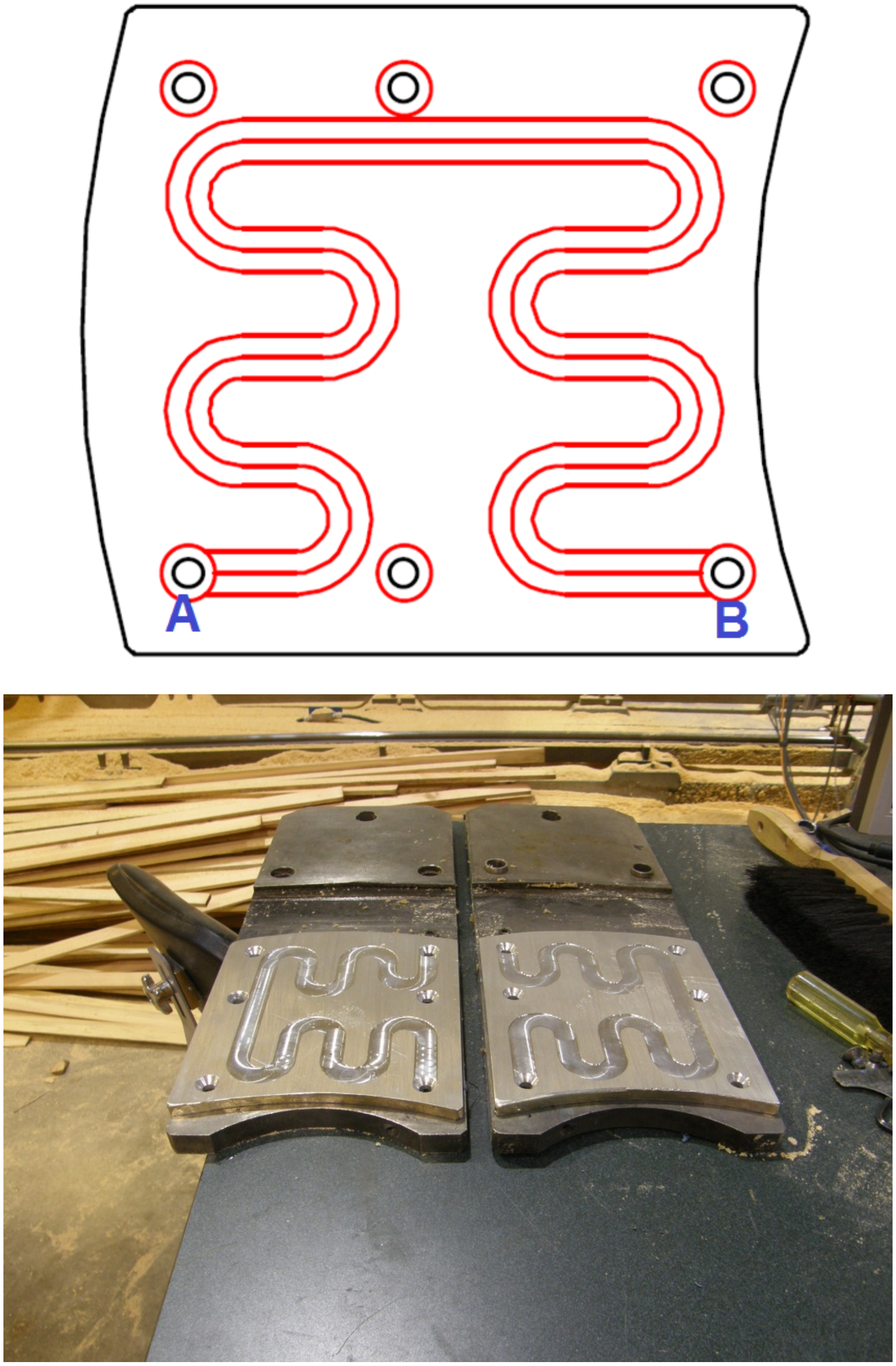


Figure 14 - Sea-Serpent Pocket

2.4 Water Flow Visualization

To investigate the distribution of water over the guide surface, clear guide pads were machined from acrylic sheet (plexi-glass). Two guide pads were studied using the plexi-glass, the conventional guide pads, with a pocket (Figure 5), and the open guide pad (Figure 8). In the case of pads with a pocket, a pressure gage was installed into the pocket to measure the pressure inside the pocket. Figure 15 shows the experimental setup. Two different configurations were built:

- The guide pads with water orifice at the two bottom corners, and
- The guide pads with water orifice inside the pocket

A green dye was manually injected into the air/water stream to increase visibility of water interaction in the guide pad.

The following properties (Table 2) were kept constant for the entire tests unless otherwise is stated:

Table 2 - Plexi-glass experimental tests properties.

Source water pressure (shop pressure)	85 PSI
Water flow	3 GPH
Air pressure	25 PSI
Orifice diameter	0.0625 in

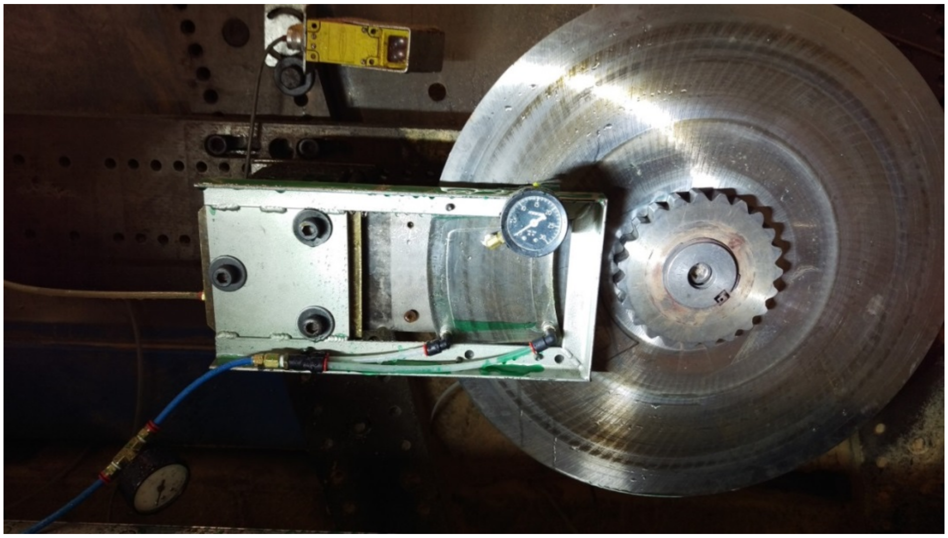


Figure 15 - Experimental setup of flow visualization tests

To understand how the shape of the lubrication port affected flow into the guide pad three different configurations were considered, which are illustrated in Table 3. As an example of one of the configurations, Figure 16 shows the plexi-glass guide with closed teardrop port.

Table 3 - Port Shapes.

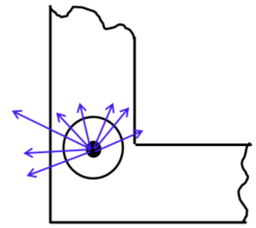
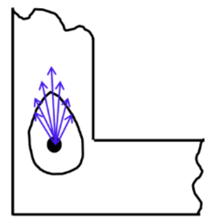
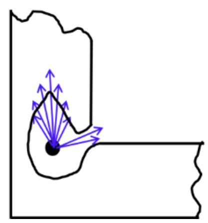
No.	Design Configuration	
1	Closed Hole Orifice	
2	Closed Teardrop Orifice	
3	Opened Teardrop Orifice	

Figure 16 - Plexi-glass guide with closed teardrop style ports

3 Results

3.1 The Effect of Orifice Size

The results of the experiment to determine the effect of orifice size on flow are given in Table 4 and Figure 17.

Table 4 - Flow through varying orifice size test, Water Pressure 0

Orifice Diameter (in)	Orifice Area (in^2)	Flow	
		Litres per Miinute	Gallons per Hour
0.250	0.0625	3.77	59.75
0.159	0.0253	2.00	31.70
0.120	0.0144	1.24	19.65
0.093	0.0087	0.780	12.36
0.052	0.0027	0.230	3.65

The results show that the flow goes up as the orifice size increases, which is illustrated in Figure 17. An application of the effect of orifice size on flow rate is to balance lubrication flow to multiple guides or orifices.

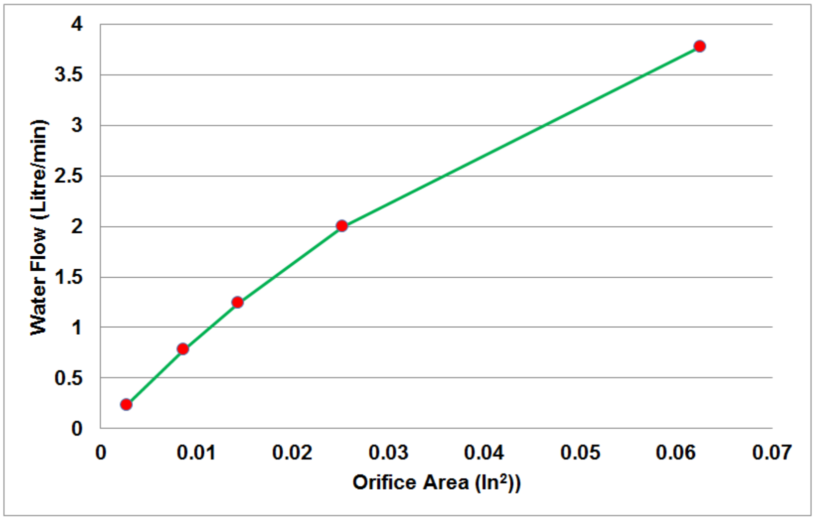


Figure 17 - Water Flow as a Function of Orifice Size

3.2 Experimental Tests with Clear Guide Pads

Note that the following figures were taken from a video record during the tests, so the quality of figures is not that good.

Figure 18 is a photo from the test where water was introduced to the lower corners of guide pad directly into the lands with no channel into the pocket. A water film developed between the lands and saw plate up to approximately three quarters of the height of the land and no pressure was developed in the pocket. The tests was repeated several times with water flow of 3, 5, 10, and 18 GPH and it was confirmed that, as measured by the pressure gage shown, no pressure is being build up inside the pocket.

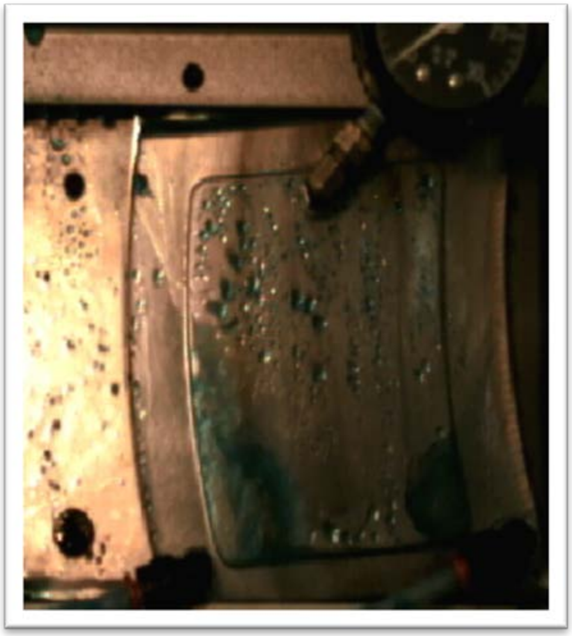


Figure 18 - Experimental Test with Clear Guide pads, Orifices on the Land at the Two Lower corners with no Channel into the pocket

In the next test, a small channel from the orifice to the pocket was added to reduce water lost to the outside of the saw guide via the narrow land next to the orifice. Figure 19 is a photo of this test taken from the recorded video. Adding the small channel allows more of a water force upward inside the pocket, however not too much improvement on development of the film between guide pad lands and the saw. This confirms that the accumulated water inside the pocket does not flow radially to create a film between lands and the blade. Also, similar to the previous test, it was noticed that no apparent pressure is being developed in the pocket.

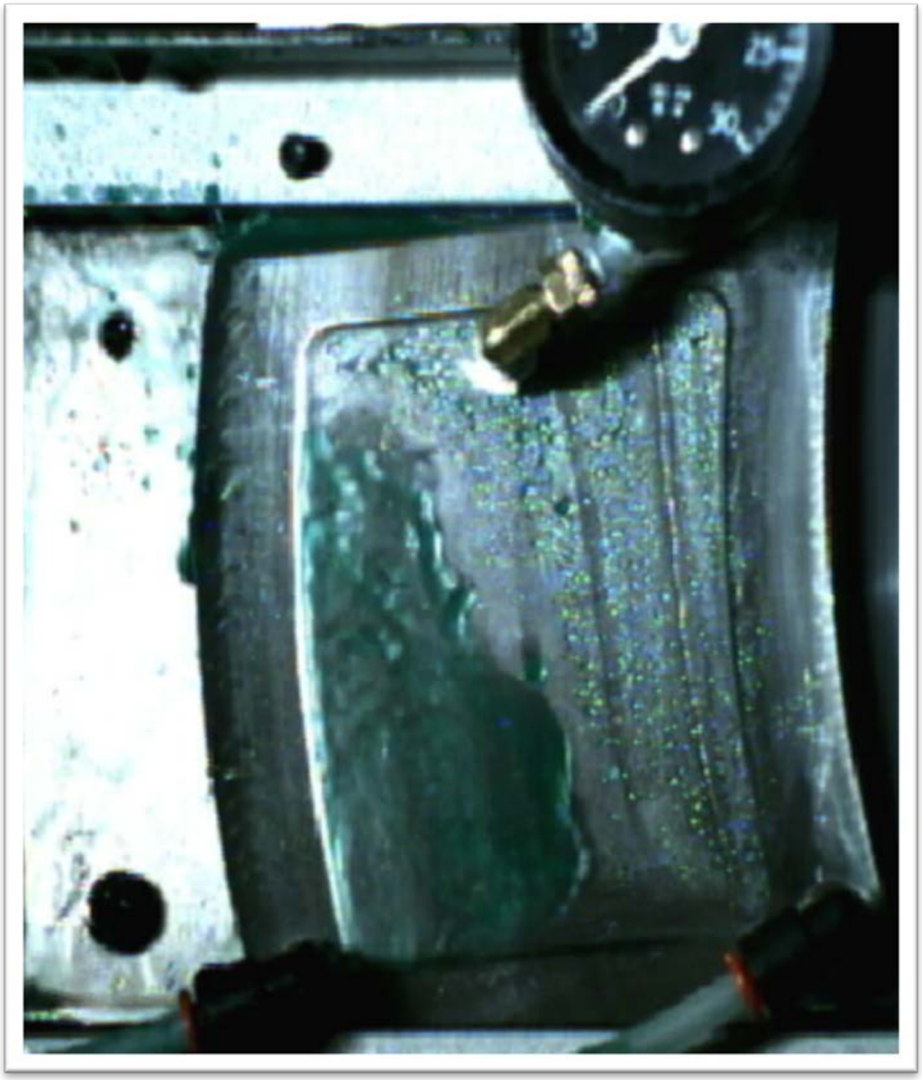


Figure 19 - Experimental Test with Clear Guide pads, Orifices at the Two Lower corners with a Small Channel from the Orifice to the Pocket

In another test, water is introduced only into the pocket of the guide pad. Figure 20 shows that very little water is ending up between the guide pad lands and saw plate.

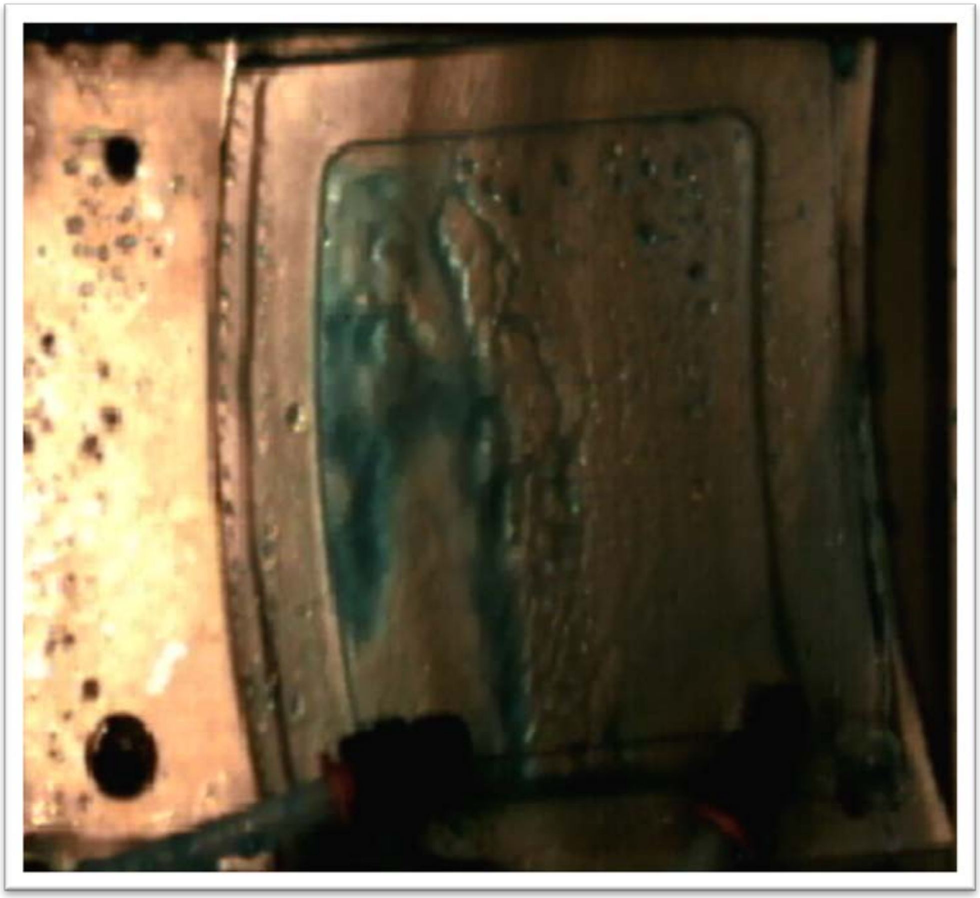


Figure 20 - Experimental Test with Clear Guide pads, Two Orifices inside the Pocket

Similar tests were repeated with the “open guide pad”. Figure 21 shows that a consistent water film was maintained between the saw and the lands up to the top of the guide.

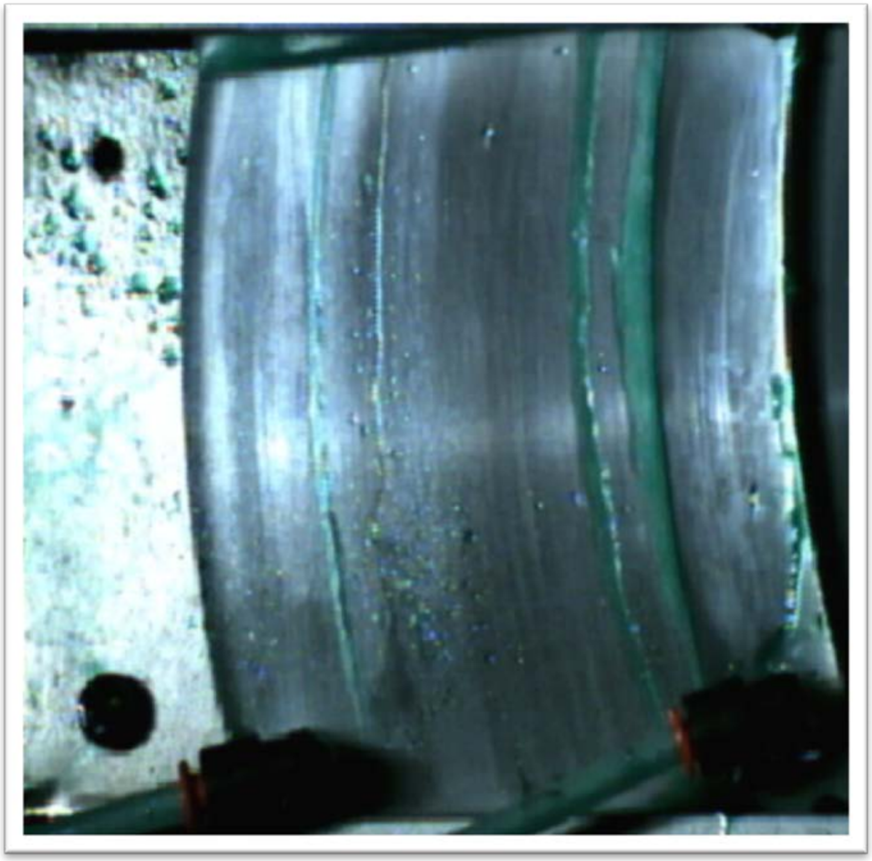


Figure 21 - Experimental Test with Clear Open Guide Pads, Orifices at two points at the Lower corner of the lands

It was observed that some of water escapes the guide pads near the orifices. Therefore, pads were modified to have teardrop style ports (Figure 16). Figure 22 shows that the teardrop style port directed more of the water onto the land, as opposed to the water escaping through the side of the pad, and had the most coverage on both inside and outside lands of all the designs tested.

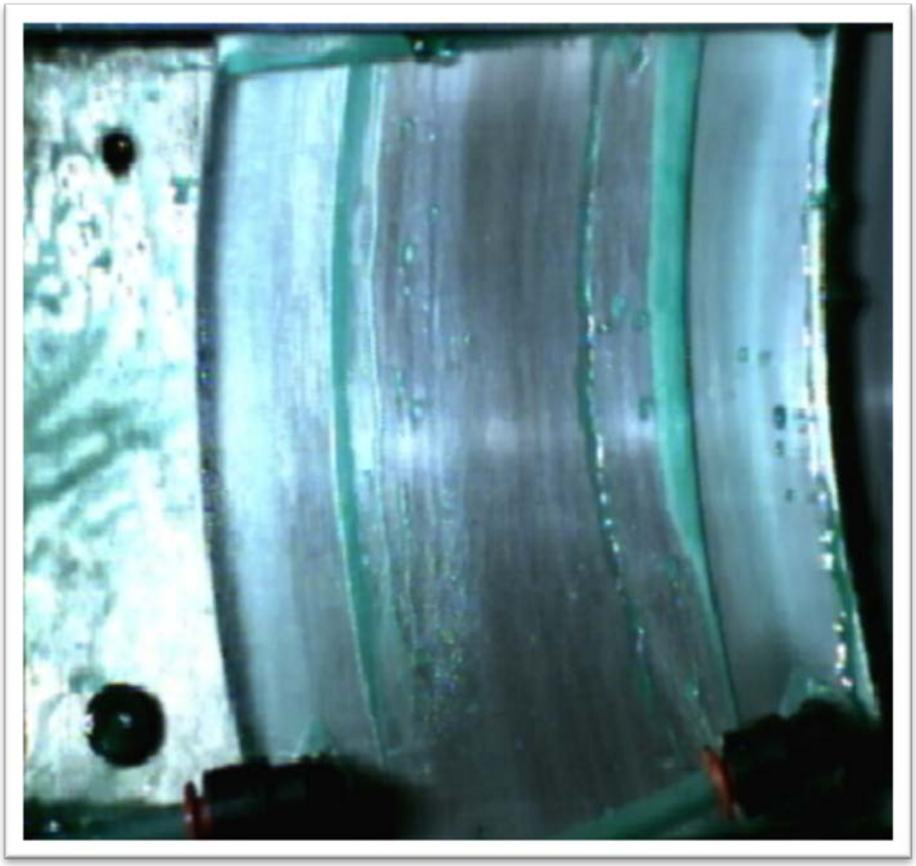
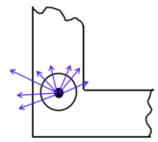
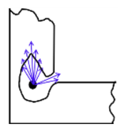


Figure 22 - Experimental Test with Clear Open Guide Pads, Teardrop Orifices at Two Points at the Lower Corner of the Lands

Table 5 summarizes how water flows from the three different orifice designs: “closed port orifice”, “closed teardrop”, and “open teardrop”. A large portion of the water escapes around the orifice in the “closed port orifice” instead of flowing on the land. The teardrop shape caused less water to escape by guiding the water to flow on the land. To prevent the port from being plugged by sawdust, the “closed teardrop orifice” can be modified to the “open teardrop orifice” design.

Table 5 - Effect of Orifice Design on water Injection

No.	Design Configuration		Observations
1	Closed Hole Orifice		Water escapes easily into the pocket and from the pad (to the left)
2	Closed Teardrop Orifice		Less water escapes from pad
3	Open Teardrop Orifice		Less water escapes from pad Flow into pocket helps to keep orifice clean of sawdust

3.3 Effect of Pad Design on Saw Cooling

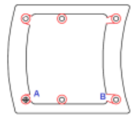
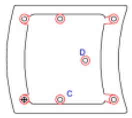
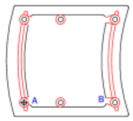
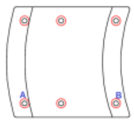
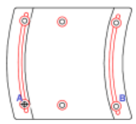
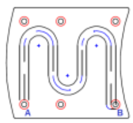
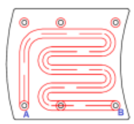
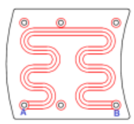
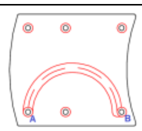
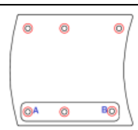
The convection cooling coefficients based on the saw temperature cooling curves are summarized in Table 6. (For the result details and the calculations see the Appendix)

The results indicate that, based on the convection coefficient as a measure of cooling capacity, the “Open Guide” (Design #4) is by far the most efficient, followed by the “Original with water into the Lands” (Design #1).

These results also illustrate that:

- Adding narrow channels (Design#5) makes the “Open Guide” (Design#4) less effective.
- Injecting water to the land is the most effective, and injecting water into the pocket is not effective.
- The radiator-shape guides (Camel, Snake, and Sea-Serpent) show average effectiveness.

Table 6. Experimental Tests Results

Design	Description		Convection Coefficients		
			Rim h_e $(\mathrm{W/m^2\ C})$	Eye h_r $(\mathrm{W/m^2\ C})$	Average h_{ave} $(\mathrm{W/m^2\ C}$
1	Original: water in lands		158	158	158
2	Original: water in pocket		120	120	120
3	Original with narrow slots lands and water in land		118	118	118
4	Open Guide		355	395	375
5	Open Guide with narrow slots		197	197	197
6	Camel		79	118	98
7	Snake		118	158	138
8	Sea-Serpent		79	79	79
9	Semi-Circle		39	39	39
10	Bottom narrow pocket		118	79	98

4 Discussion

The following are some general consideration for designing a guide pads, based on the laboratory tests and observations from sawmills:

- Alignment, wood control and gullets loading are still the key issues that determine how much heat has to be taken away by the water. In fact, if cutting is straight (good alignment and wood control) then less heat is generated and little water is needed [2].
- Ideally, each guide would have its own lube line, so that non-cutting saws get less water. A further refinement would be to base lubricant flow on measurements of the saw temperature.
- It needs to be examined if the relative function of water is cooling, or as a lubricant. Oil is a substantial lubricant that can take the thrust loads when the blade is pushed hard against the guides. It is important to notice that due to high viscosity, oil can also generate heat.
- Having a guide pocket reduces the viscous drag in the guides by reducing the area where there is a small gap and the viscous forces are large. In fact, if there were no pocket, the saw would have to drag water across the full surface. One has to ensure the whole surface of the guide is flat; otherwise the not perfectly flat saws could bind in the guides. With a pocket, only the area around the edges needs to be in a precise plane.
- Sometimes, extra water is needed to make the sawdust heavier, to avoid saw-box getting packed up with sawdust.
- Some have noticed that a possible problem of the pocket is that it is a place for fine sawdust to accumulate and pack against the blade, generating heat. In addition, cracks and voids in the babbitt trap fine sawdust. One solution for this issue might be injection molding of the babbitt into the mold.
- The sawdust packing issue inside the pocket may be one reason for using air. Using pressurized air might have also the following effects:
    - It reduces the viscosity of the lubrication fluid.
    - Air reduces the amount of water to fill the guide gap.
    - If oil has not fully mixed with water, air drags the oil through the lines.
    - Air is needed for purging the lubrication system, mainly to avoid water freezing when the machine is not in use.

5 Conclusions

The experiment tests with various guide pad designs showed that the “Open Guide Design” (Design#4) is the most effective in terms of cooling. Since there is no pocket, it also has the advantage of preventing accumulation of fine dust in pocket. The only disadvantage of this design is the possibility of fast wear compared to the other designs, since the total land area is less than other designs, such as the “Original Design” (Design#1). However, since most observed wear is on the corners of the guides, this is not expected to be an issue. If one wants to use the original design (the conventional design), then the optimum design would be the one with water only at two corner points (Design#1) with no water orifice in pocket.

It should be noted that these results are based on the laboratory tests and the mill situation may be different. Therefore the “Open Guide” (Design#4) and the “Original Guide (Design #1)” will be tested in some sawmills. However, the experimental results confirm the following:

- Accumulated and circulated water inside the pocket does not flow radially to create a film between the lands and the blade. Water needs to get to the corners of the pad because that is where wear is usually seen.
- The tests with a regular guide (Design #1), with orifices at the two lower corners with a channel into the pocket, indicated that very little water ends up between the guide pad lands and saw plate.
- In an “Open Guide” (Design#4), with an orifice at the entry to the land, a consistent water film was maintained between the saw and the lands.
- In an “Open Guide” (Design#4), the teardrop style port helps spread the water film, as opposed to the water escaping through the side of the pad, and has the most coverage on both inside and outside lands. The teardrop port gets water onto the lands and avoids radial leakage out of the guide.
- Orifice size is an effective way to control water flow, so this can be a good method for balancing lubrication flow to multiple guides or even orifices in one guide.

In summary: first, put the water in direct contact with the saw plate which increases heat transfer from saw to the water. Second, water on lands is dragged tangentially to the opposite corners of the guide where the most wear occurs. In addition, since the pocket is not pressurized and only some of the water in the pocket flow radially onto the lands, so the best method to get lube onto the lands is to locate the orifices on the lands and to use a teardrop shape port.

Future work of this project will focus on methods to collect and reuse the cooling water (and to a lesser extent the lubrication oil). This recovery may be achieved through active or passive means and may be internal or external to the guide pad and arms. In addition, it will be tested to see if using cold water (fast refrigeration of water prior to getting into the guides) can improve the cooling effect.

6 References

1. Danielson, J. and Gary Schajer, 1993, “Saw Blade Heating and Vibration Behaviour in a Circular Gang Edger”, Proceeding of Saw Tech 93. Berkeley, California, USA.
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4. Lehmann, B., “Heating and Cooling of Circular Saws”, (Open Access: http://www.thinkerf.com/Downloads/HeatFlow.PDF)
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Appendix

Based on the developed formula for evaluation of the cooling capacity of a guided saw, the convection coefficient for the guide pad configurations can be computed as follow:

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

$$l = 0.095in = 0.002413m$$

$$\rho = 7800\,Kg/m^3$$

$$c = 420\,J/Kg°C$$

$$h = \frac{1}{2}\gamma l \rho c = \frac{1}{2} \times 0.002413 \times 7800 \times 420\gamma = 3952\gamma$$

Table A.1 summarizes the results and Table A.2 – Table A.11 shows the detail of tests results:

Table A.1 Results Summary

No.	Guide Pad Design	ΔT_e (°C)	ΔT_r (°C)	Average Δt (Sec)	γ_e	γ_r	h_e	h_r	h_{ave}	rank
1	Original water in land	3.5	1.5	35	0.04	0.04	158.08	158.08	158.08	3
2	Original water in pocket	2	2	80	0.03	0.03	118.56	118.56	118.56	5
3	Original with narrow slots lands and water in land	3	5.5	70	0.03	0.03	118.56	118.56	118.56	6
4	Open Guide	1.5	1.5	5	0.09	0.10	355.68	395.2	375.44	1
5	Open with narrow slots	3	3.5	60	0.05	0.05	197.6	197.6	197.6	2
6	Camel	1.5	2	35	0.02	0.03	79.04	118.56	98.8	8
7	Snake	3	5.5	60	0.03	0.04	118.56	158.08	138.32	4
8	Sea T	4	4	70	0.02	0.02	79.04	79.04	79.04	9
9	Semi-Circle	3	3.5	90	0.01	0.01	39.52	39.52	39.52	10
10	Bottom narrow pocket	3.5	5.5	55	0.03	0.02	118.56	79.04	98.8	7

Table A.2 Guide Configuration 1: Camel

Cuts	ΔT_e Temperature Change at Blade's Eye (℃)	ΔT_r Temperature Change at Blade's Rim (℃)	Δt Average Time for the Blade to Cool off to Its Original Temperature before the Cut (Sec)	γ_e	γ_r
Cant#1	1.5	5	40	0.02	0.03
Cant#2	3	1	45		
Cant#3	0.5	0.5	20		
Cant#4	1	2	30		
Cant#5	2	2.5	40		
Average	1.5	2	35		

Table A.3 Guide Configuration 2: Original Water in Land

Cuts	ΔT_e Temperature Change at Blade's Eye (℃)	ΔT_r Temperature Change at Blade's Rim (℃)	Δt Average Time for the Blade to Cool off to Its Original Temperature before the Cut (Sec)	γ_e	γ_r
Cant#1	2.5	1.5	40	0.04	0.04
Cant#2	3	1	40		
Cant#3	3	1	30		
Cant#4	4	2.5	40		
Cant#5	4.5	2.5	40		
Average	3.4	1.7	35		

Table A.4 Guide Configuration 3: Original Water in Pocket

Cuts	ΔT_e Temperature Change at Blade's Eye (℃)	ΔT_r Temperature Change at Blade's Rim (℃)	Δt Average Time for the Blade to Cool off to Its Original Temperature before the Cut (Sec)	γ_e	γ_r
Cant#1	3	1.5	80	0.03	0.03
Cant#2	1	2	70		
Cant#3	1.5	1.5	80		
Cant#4	2	3.5	100		
Cant#5	2.5	3	80		
Average	2	2.3	80		

Table A.5 Guide Configuration 4: Horizontal Bottom Narrow Pocket

Cuts	ΔT_e Temperature Change at Blade's Eye (℃)	ΔT_r Temperature Change at Blade's Rim (℃)	Δt Average Time for the Blade to Cool off to Its Original Temperature before the Cut (Sec)	γ_e	γ_r
Cant#1	4.5	2	100	0.03	0.02
Cant#2	4.5	1	30		
Cant#3	3	1	40		
Cant#4	2.5	8	50		
Cant#5	2	16	50		
Average	3.3	5.6	55		

Table A.6 Guide Configuration 5: Open Guide

Cuts	ΔT_e Temperature Change at Blade's Eye (℃)	ΔT_r Temperature Change at Blade's Rim (℃)	Δt Average Time for the Blade to Cool off to Its Original Temperature before the Cut (Sec)	γ_e	γ_r
Cant#1	0.5	2	5	0.13	0.15
Cant#2	0.5	2	10		
Cant#3	0	1	5		
Cant#4	0	1	5		
Cant#5	0	1	5		
Average	0.2	1.5	7.5		

Table A.7 Guide Configuration 6: Snake

Cuts	ΔT_e Temperature Change at Blade's Eye (℃)	ΔT_r Temperature Change at Blade's Rim (℃)	Δt Average Time for the Blade to Cool off to Its Original Temperature before the Cut (Sec)	γ_e	γ_r
Cant#1	3	7	50	0.03	0.04
Cant#2	5	7.5	70		
Cant#3	3.5	4.5	70		
Cant#4	3.5	4.5	70		
Cant#5	1	4	50		
Average	3.2	5.5	60		

Table A.8 Guide Configuration 7: Original with narrow Channel

Cuts	ΔT_e Temperature Change at Blade's Eye (℃)	ΔT_r Temperature Change at Blade's Rim (℃)	Δt Average Time for the Blade to Cool off to Its Original Temperature before the Cut (Sec)	γ_e	γ_r
Cant#1	4	7	80	0.03	0.03
Cant#2	5	9	70		
Cant#3	3	3.5	70		
Cant#4	3	3.5	80		
Cant#5	1	2.5	40		
Average	3.2	5.7	68		

Table A.9 Guide Configuration 8: SemiCircle

Cuts	ΔT_e Temperature Change at Blade's Eye (℃)	ΔT_r Temperature Change at Blade's Rim (℃)	Δt Average Time for the Blade to Cool off to Its Original Temperature before the Cut (Sec)	γ_e	γ_r
Cant#1	2.5	4.5	120	0.01	0.01
Cant#2	5	6.5	80		
Cant#3	1.5	3	70		
Cant#4	3	2.5	70		
Cant#5	2	1	70		
Average	2.8	3.5	90		

Table A.10 Guide Configuration 9: Sea T

Cuts	ΔT_e Temperature Change at Blade's Eye (℃)	ΔT_r Temperature Change at Blade's Rim (℃)	Δt Average Time for the Blade to Cool off to Its Original Temperature before the Cut (Sec)	γ_e	γ_r
Cant#1	2.5	3.5	70	0.02	0.02
Cant#2	3.5	6	70		
Cant#3	4	7	70		
Cant#4	4	3	70		
Cant#5	5	2.5	70		
Average	3.8	4.4	70		

Table A.11 Guide Configuration 10: Open with Slot

Cuts	ΔT_e Temperature Change at Blade's Eye (℃)	ΔT_r Temperature Change at Blade's Rim (℃)	Δt Average Time for the Blade to Cool off to Its Original Temperature before the Cut (Sec)	γ_e	γ_r
Cant#1	3.5	4.5	50	0.05	0.05
Cant#2	5	7	70		
Cant#3	4	3.5	60		
Cant#4	2	2.5	70		
Cant#5	1	1	40		
Average	3.1	3.7	58		

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