ABSTRACT: Measuring and tracking changes in the properties of snow layers is important for avalanche forecasting. The accuracy of collecting snow data is dependent on the operator and the tool being used. De Quervain introduced the hand test in 1950; which operators have been using almost exclusively to provide a classification for the hand hardness index. Issues exist with applied Newton force, hand and glove size, measuring small layers less than 2cm in thickness and the +/− scale adopted by today’s forecasters not being classified under international classifications. The thin-blade tool introduced by Borstad and McClung in 2011 offered an alternative to current hardness and strength testing methods. The question we aimed to answer was whether or not buried surface hoar could be tracked over time using thin-blade resistance and whether a thin-blade tool specific for snow use could be built for measuring snow hardness. This paper describes the methods taken to track increasing strength in buried surface hoar layers and those taken to build a thin-blade tool. Multiple snow study pits were used for data in order to test the consistency of the device and demonstrate the feasibility of such a tool for use in snow hardness and strength measurements.

KEYWORDS: snow hardness, thin-blade, handheld device, penetration resistance

1. INTRODUCTION

Snow hardness is an important measurement in avalanche forecasting. The hand hardness test is currently the most widely used by operators in the field and poses challenges to the accuracy: bias amongst users, failure for the operator consistently apply 10-15N, inconsistent +/− scale and varying size of operator hand/glove sizes. The method is typically subjective to the user and challenges the credibility of measuring thin soft layers of deposited snow.

Early work in push gauge tools used circular discs to measure snow hardness in the 1940s (Klein, 1950). The discs varied in size from 100, 10, 1 and 0.1 cm2 and were pushed horizontally into a wall of snow. The force loaded onto a spring force gauge was recorded to measure snow hardness.

Penetrometers have also been used to measure the hardness of snow by vertically descending the probe through a snowpack. However, as the tip of the penetrometer descends into the snow, a bulb shape compaction is created below and sideways from the tip, causing a disturbance in the snow prior to measurements (Floyer, 2008) thus causing unwanted spikes in the hardness measurement.

1.1 Thin-blade Tool

Improving on the design, the thin-blade was created as a repeatable measure of penetration resistance (Borstad and McClung, 2011). A thin-blade (100mm wide and 0.6mm thick) was designed to minimize snow compaction ahead of the penetrating tip and to measure resistance on the order of 10-100 grains. Results were in favor of the thin-blade’s ability to produce consistent data over multiple users and multiple penetration rates. Furthermore, a correlation was shown between the gauge’s index and snow hardness as well as the gauge’s index and snow tensile strength. Measuring tensile strength has been shown to be important when understanding crack propagation of slab avalanches (Schweizer et al, 2014).

Thin-blade resistance was used to measure resistance of snow crust layers (Buhler, 2013). The thin-blade tracked the evolution of crust layers over time and showed a correlation to penetration resistance and density. Correlation was also shown between penetration resistance and hardness of laminations within the crust; which is an important aspect of avalanche forecasting.
1.2 Tracking Surface Hoar Layers

Buried surface hoar (SH) layers are known to be the failure plane for avalanche occurrences. Tracking surface hoar over time where snowpacks remain dry show an increase in strength (Jamieson and Schweizer, 2000). Taking measurements of 1 cm thick layers in the field can be problematic when the layer is very soft or soft in hardness. Operators will gauge the hardness of a small F or 4F layer using a pencil or knife resulting in a qualitative value. Tracking thin-blade measurements of a SH layer over time can be useful in avalanche forecasting.

2. OBJECTIVES

Having the ability to quantitatively measure snow hardness can present data for analyzing snow characteristics and avalanche risk. Prior work on thin-blade research has involved the use of commercially available force gauges. These tools can be expensive and bulky, which is less than ideal for avalanche forecasters and operators.

The goal of this research is to:

- Track changes in penetration resistance of buried SH layers over time using thin-blade resistance
- Develop a thin-blade push gauge tool specific for snow use, maintaining the 100x0.6 mm blade and measure a range in force Newtons consistent with known penetration resistances.

3. METHODS

3.1 Surface Hoar Layers

Kootney Pass is located in the Selkirk mountains of southern British Columbia. McClung spent several winters in this area tracking SH layers and the change in penetration resistance over time. The thin-blade tool has the advantage of quantitatively measuring thin layers of snow normally difficult in hand hardness and strength measurements.

SH layers were observed on specific dates known to the observer (both in 2013 and 2014). The research involved returning to a snow study pit at multiple future dates in order to take measurements. After digging a snow pit, the particular SH layer was identified and the thin-blade device was used for taking multiple penetration resistance measurements. The blade is positioned perpendicular to slope normal. The operator applies a consistent force and the blade penetrates the snow layer.

3.2 Thin-blade Device Design

A stainless steel paint scraper was used as the blade and is similar to the approach taken by Borstad in earlier work (100x50x0.6mm). 3D printing was used to build the enclosure and the necessary components for attaching the thin-blade to the force sensor. This allowed for a custom enclosure to be created which was small in size (91x45x13mm), lightweight and waterproof. However, no water resistance IP rating was given to the device. The distance between the thin-blade and the enclosure was minimized to increase perpendicular force accuracy as torsion and lateral forces would be minimized.

An early version of the product (Fig. 1) had a small distance between the blade and the attachment (<10mm) which caused errors with measurements. Users reported issues where the protruding attachment was accidentally penetrated into the snow, erroneously increasing the force measured. A longer distance between the blade (40mm) was designed and recreated for data collection.

A 5kg (49.03N) force sensor was used to measure the penetration resistance of the thin-blade. The force sensor was rated to be 0.1% accurate, ensuring that a range of 0.05-49N could be measured by the device. The display on the device was capable of displaying the force with a precision of two decimal places.

![Fig. 1: The first iteration of the tool.](image)

No weather stripping was placed between the thin-blade and the force sensor. This ensured that no
force would be lost to the force of friction between the force sensor and the thin-blade.

A custom PCB (Printed Circuit Board) was created to facilitate reading the force sensor and displaying the value to the user. All components and circuitry selected on the PCB were operational to -40°C. The selected force sensor had an corrected temperature rating of -10°C with an operational rating of -20°C.

3.3 Thin-blade Device Use

Common practice in avalanche forecasting involves digging a snow pit to expose the various layers of snow. The thin-blade tool is used by an individual either single handedly or with both hands (Fig. 2). A consistent force is applied to the tool and the blade is pushed parallel to the layer of snow.

The maximum force is measured and displayed to the operator who is able to record the value. The maximum force can be reset for a subsequent penetration measurement.

The operation of the new force gauge behaves in the same manner as prior research (Borstad and McClung, 2011).

4. RESULTS

4.1 Tracking Surface Hoar Layers

McClung collected measurements of a surface hoar (SH) layer which was deposited on January 23, 2013. Fifty penetration resistance measurements of the SH layer for each day. These measurements were taken on Jan. 29, Feb. 15 and Mar. 25 (Tbl. 2).

The median force measured increased by 48% from Jan. 29 to Feb. 15 and by 209% from Feb. 15 to Mar. 25. The increase in thin-blade resistance indicates an increase in strength (Borstad and McClung, 2011).

Tbl. 1: Jan 23, 2013 surface hoar resistance

<table>
<thead>
<tr>
<th>Date</th>
<th>Median (N)</th>
<th>Mean (N)</th>
<th>Increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan 29</td>
<td>2.3</td>
<td>2.6</td>
<td></td>
</tr>
<tr>
<td>Feb 15</td>
<td>3.4</td>
<td>3.3</td>
<td>48%</td>
</tr>
<tr>
<td>Mar 25</td>
<td>10.5</td>
<td>10.7</td>
<td>209%</td>
</tr>
</tbody>
</table>

The subsequent year in Kootenay Pass, a surface hoar layer was observed on January 9, 2014. The layer was measured on February 8 and then again on March 23. A total of 35 measurements were taken for each day (Tbl. 2).

The SH layer was measured to be down 15 cm on February 8 and down 134 cm on March 23. Furthermore the temperature of the SH layer on February 8 was -12°C and increased to -2°C on March 23.

An increase in resistance was calculated to be 968% from the two dates of measurement indicating a significant increase in strength of the SH layer.

Tbl. 2: January 9, 2014 surface hoar resistance

<table>
<thead>
<tr>
<th>Date</th>
<th>Median (N)</th>
<th>Mean (N)</th>
<th>Increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feb 8</td>
<td>0.92</td>
<td>1.01</td>
<td></td>
</tr>
<tr>
<td>Mar 23</td>
<td>9.83</td>
<td>10.05</td>
<td>968%</td>
</tr>
</tbody>
</table>

The thin-blade measurements demonstrate the increase in strength of the buried surface hoar layer over time. The size of the measured layers were 1-2 cm in size.

4.2 Whistler Blackcomb Snow Profile

The manufactured thin-blade tool was provided to Whistler Blackcomb. A snow profile was completed by a single member of the ski patrol on January 1, 2016.

Fig. 2: Using the thin-blade tool to measure penetration resistance.
Nine layers were observed in the snow profile and the hand hardness was measured along with the thin-blade tool for each of the nine layers. The layers were observed to a depth of 120 cm. Measurements from a typical snow profile demonstrate the increasing thin-blade force with an increasing observed hand hardness (Tbl. 1).

### Tbl. 1: Hand hardness and measured resistance

<table>
<thead>
<tr>
<th>Observed Hand Hardness</th>
<th>Median Thin-blade Measurements (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>F</td>
<td>1.6</td>
</tr>
<tr>
<td>4F+</td>
<td>2.2</td>
</tr>
<tr>
<td>1F+</td>
<td>4.5</td>
</tr>
<tr>
<td>P-</td>
<td>6.3</td>
</tr>
<tr>
<td>P</td>
<td>15.0</td>
</tr>
</tbody>
</table>

4.3 *Kootney Pass Penetration Resistance*

McClung collected data on January 14, 2016 at Kootenay Pass with the manufactured thin-blade tool.

A total of 30 samples were taken using the thin-blade, 15 of which were on a 4F layer, and 15 on a 1F layer. The 4F layer ranged from 0.85 to 1.79 (mean 1.31, median 1.32, σ 0.24). The 1F layer ranged from 1.35 to 3.62 (mean 2.25, median 2.23, σ 0.54).

There exists a small overlap in force values between the two different layers as seen in box plot (Fig. 3). However, this overlap is caused by the max value from the 4F layer and the min value from the 1F layer. Removing these two values from the data set results in no overlapping forces. The data shows consistent force values for the given layer of interest.

5. DISCUSSION

5.1 *As a proxy for hand hardness*

The thin-blade tool can be useful as a replacement for measuring hand hardness. Results show the ability to distinguish 4F layers from 1F layers. Further data is needed throughout the full hardness index to validate the hypothesis.

A single operator from Whistler Blackcomb demonstrated the ability to distinguish between different hardness using the tool. However, it would have been beneficial for multiple members of Whistler Blackcomb ski patrol to be present during the experiment. Multiple operators potentially could have observed different values in hand hardness and shown bias. Furthermore, by having multiple operators use the thin-blade tool on a common layer of snow, the data sets could be statistically analyzed to present repeatability in the thin-blade tool.

5.2 *Tracking Weak Layers Over Time*

This study focused on measuring the change in penetration resistance of SH layers. Significant advances were shown in changes to strength over a period of 2 months on the buried layers.

Further research can measure the interface above and below the SH layer. With time the crystal structure can change and bond with the interfacing layers. Using the thin-bade tool, the strength of the failure point in the weak layer can be measured.

5.3 *Future research with Parks Canada*

Parks Canada will contribute to further research for the 2016/2017 winter. An important component of visitor safety within park boundaries involves monitoring and reporting on the avalanche risk. Avalanche technicians in Glacier National Park will perform approximately 200 snow profiles over the winter and will use the thin-blade device...
to track penetration resistance alongside hand hardness measurements in regular snow profiles.
Further assistance from Banff/Yoho/Kootney National Parks will come with supplemental testing and data collection.

5.4 Conclusion
The thin-blade tool manufactured was able to produce repeatable results for measuring snow hardness and the changing strength of buried SH layers. The tool was developed specifically for snow use and has advantages over commercially available force gauges, having a shorter distance between blade and sensor, smaller and lightweight.

The overall goal of said products are to increase accuracy and remove operator bias while conducting avalanche forecasting. Collecting accurate data offers important information for operators and valuable metrics for future research.

CONFLICT OF INTEREST
The author of this paper is involved with the development of the said handheld device and is founder of Fraser Instruments Ltd.

ACKNOWLEDGEMENTS
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