Development of a pressure distribution measurement device for cross-country skis

Pre-master report
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Abstract

This report is a master thesis preparation that is meant to build an understanding of the requirements for an improved concept measuring pressure distribution of cross-country skis, and how to develop it. The performance of skis is critical for top level cross country skiers, and minor changes in the properties of a ski can improve its performance significantly. Skis have several important properties that influences their performance, such as curvature, sti□ness, flex, and pressure distribution. These properties are correlated and influence each other strongly. The construction and properties of a ski results in two contact areas, located towards the tip and the tail of the ski. These are therefore the areas of interest. The knowledge gained on ski properties and performance suggests that the most important requirements for a pressure distribution concept are high resolution in the direction of the length of the ski, minimal time use, great repeatability, and low cost. Using load cells or force sensing resistors seems to be possible solutions focusing on simplicity, e□ciency and accuracy.

Abstrakt

Denne rapporten er et master-forberedende dokument som er ment for å danne en forståelse av kravspesifikasjoner for et forbedret konsept som måler trykkfordeling på langrennsski, og hvordan man utvikler det. Å ha gode ski er kritisk for en skiløper på toppnivå, og små endringer i skiegenskaper kan påvirke hvor gode skiene er nevneverdig. Det er flere skiegenskaper som er viktige i denne sammenheng, som kurve på skien, stivhet, spenn, og trykkfordeling. Disse egenskapene korrelerer og påvirker hverandre. Konstruksjonen og egenskapene til en ski resulterer i to kontaktsoner, mot tuppen og enden av skien. Dette er områdene av interesse i denne oppgaven. Med kunnskapen opparbeidet om egenskaper og skiens prestasjon er de viktigste kravspesifikasjonene høy oppløsning i retning av lengden av skien, minimal tidsbruk, god repeterbarhet, og lav kostnad. Bruk av lastceller eller FSR-sensorer kan være mulige løsninger som fokuserer på enkelhet, e□ektivitet, og nøyaktighet.

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1 Introduction

Cross-country skiing is considered the national sport of Norway. Having the best possible skis is critical to be able to compete on the highest level. Measuring di erent properties of skis has been a part of the sport of skiing for decades, both when it comes to professional skiing and recreational skiing. Earlier, measuring and choosing the right skis for an athlete has been considered craftsmanship. This is still somewhat true for certain aspects of nding a great pair of skis, but technology has made it possible to measure a wider range of properties accurately. After every season professional skiers spend a signi cant amount of time testing new skis to potentially replace their best pairs of skis from the previous season. Throughout the summer and fall season the number of pairs of skis is gradually decreased to a reasonable number, typically 10-15 pairs.

1.1 Norwegian Olympic Foundation

The master thesis will be written in cooporation with the Norwegian Olympic Foundation (hereafter OLT). OLT is responsible for the development in Norwegian elite sports and has the full responsibility for the Norwegian results. OLT is also responsible for the Norwegian participation in the Olympic and Paralympic games [11].

Dr. Felix Breitschädel is the co-supervisor for the upcoming master thesis. Dr. Breitschädel is responsible for research and development towards prioritized sports within OLT. Breitschädel is also responsible for being in contact with students and supervising their projects on sports technology[12].

OLTs ultimate goal is to be able to measure the important properties of a new pair of skis and by the results decide on which weight and which conditions this pair of skis will perform the best.

1.2 Problem

Today's measuring devices measure ski properties well, but far from optimal. To be able to compare and nd the critical properties of a ski it is necessary to measure the important characteristics of a ski accurately. This is not the case with the technology OLT possesses currently.

1.3 Project scope

1.3.1 Objectives

This project's objective is to get a solid understanding on how a cross-country ski is constructed and what properties of the ski is critical for top performance on the highest level of skiing. This knowledge will be used as a base to understand the requirements for a pressure distribution measurement. This understanding will be used to develop a suitable measuring concept and device. The report focuses on giving a su cient understanding on cross-country skis without going unnecessary deep into theoretical aspects of less importance. The project will not go deeper into the understanding of friction and base material, but will touch the topic as it is relevant to understand skis su ciently.

1.3.2 Limitations

One signi cant limitation on the topic is that cross-country skiing is a small sport. This means that the amount of literature available is limited.

Another limitation is that the di erent ski manufacturers keep their information con den-tial due to the competitive market. As Bäckström [13] says: It is almost impossible to obtain more explicit information from the manufacturers of skis about their construction methods and design to achieve certain ski characteristics. This is treated as business secrets and is used as a sales argument for high-end race skis. Hence, many of the manufacturers do have their own equipment/method to classify their skis.

1.4 Methodology

The information and data collected for this report was found primarily through literature stud-ies, but also through testing and understanding of the current technology, and OLTs knowledge base. To ensure quality sources, Oria and Google Scholar was used together with sources presented by Dr. Breitschädel.

1.5 Report structure

The report rst discusses the construction and properties of cross-country skis before it uses this knowledge to specify the requirements of a pressure distribution measurement concept. These requirements are then used to discuss several possible solutions.

2 | Ski construction and properties

To be able to construct a well functioning measuring concept and device it is crucial to understand the properties of a ski and how it is constructed.

2.1 Basics of a cross-country ski

Classic skis are typically 180-210cm long, while skate skis are 160-195cm long, depending on the height of the skier. Classic skis are longer as they are only moving straight forward. Skate skis, on the other hand, move in a combination of straight forward and sideways. This means that a shorter ski is necessary to ski with proper technique without stumbling.

Figure 2.1: Classic skis (top) and skate skis (bottom)[1]

Figure 2.1 shows a pair of top racing skis for the two di erent techniques, classic and skate. As seen in the gure the skis are thinner towards the front and back of the ski. The bindings, where the ski boot is attached, is located towards the center of the ski, close to the balance point. Standing up and down on both legs means that the center of mass is around 14cm behind the tip of the toe. A racing ski weighs in the range of 900 and 1100 grams, depending on the length and manufacturer of the ski.

Figure 2.2: Ski core construction - Fischer and Madshus, respectively [2][3]

Figure 2.2 shows how the core of a Fischer and Madshus racing-ski is constructed. For the Fischer ski, an air core in combination with carbon bre creates a light and strong construction[2]. Madshus uses a high performance Rohacell foam core, originally developed for extreme strength-to-weight applications in aeronautics. This core helps provide dampening properties and adds

strength and sti ness to the ski without extra weight[3].

Although di erent ski manufacturers construct their ski cores di erently they all aim on providing the skiers the ultimate ski with focus on the same properties. It is crucial to have the right balance between weight and stability on the snow when constructing a ski. Therefore, an extremely light ski is not preferable. Fischer skis, as the most commonly used brand, will hereafter be used as a representation of a cross-country ski for simpli cation.

2.2 Ski properties

2.2.1 Curvature and camber

The curvature and camber of a cross-country ski varies depending on the conditions it is supposed to be used on. Figure 2.3 shows a simpli ed comparison between skis used on three di erent conditions.

Figure 2.3: Ski curvature - cold conditions (blue), medium conditions (red), and warm/soft conditions (yellow)

The ski represented in yellow shows a typical ski curvature for warm conditions when the ski is loaded. For a classic ski, the higher peak curvature, also known as pocket , is present because kick wax for warm conditions is thicker than for cold conditions, hence it needs a higher pocket. The di erences in the curvature of the tip of the ski comes from the fact that warmer conditions means softer snow. For the ski to travel as smooth as possible over the snow it is therefore important that the tip is soft in soft snow. This is relevant for both classic and skate skis. Using a sti tip on warm conditions will result in the tip digging into the snow when skiing.

As seen in Figure 2.3 the surface contact area for the ski is longer for the colder skis. This is discussed further in section 2.2.3.

2.2.2 Sti ness and ex

Sti ness is the capacity of a mechanical system to sustain loads without excessive changes to its geometry [14]. Sti ness is important in skiing as it in uences the properties of a ski signi cantly. The sti ness is distributed over the full length of the ski. This distribution varies depending on what type of conditions the ski is intended to be used on.

Flex and ex height goes hand in hand with sti ness. The ex without any load is similar for skate and classic skis. Typically the skis have a contact zone approximately 10cm behind the tip and in front of the tail of the ski, both approximately 5cm long. This ex is a result of how the ski was originally made.

As discussed earlier, classic skis have kick wax on them to ensure the possibility of forward

motion in uphills. To be able to get grip on the snow it is necessary to push the kick wax in contact with the snow. Still, to assure maximal glide it is crucial that the kick wax is not in contact with the snow in the downhills. Figure 2.4 shows a typical ex height of a classic ski. As seen in the gure the maximum ex height is approximately 1mm at half weight. Kick wax is typically applied from ex height of 0.1mm at half weight to right under the heel of the athlete. A ski is typically marked at 0.1, 0.2, and 0.3mm ex height to allow for kick wax of di erent thickness to be applied. Naturally, the length of the 'pocket' for kick wax in uences pressure distribution and contact areas, properties that will be further discussed in the next section.

Figure 2.4: Flex height with half and full weight - classic ski, with ski length on the x-axis and ex height on the y-axis

Figure 2.5 shows the height of the ex for a skate ski. As seen in the gure, the ex height is signi cantly higher for both half and full weight. As opposed to for a classic ski, the ex height of a skate ski only a ects how the ski feels and behaves on the snow as kick wax is irrelevant. Similarly as for classic skis, it also a ects the pressure distribution and contact areas.

Figure 2.5: Flex height with half and full weight - skate ski, with ski length on the x-axis and ex height on the y-axis

2.2.3 Pressure distribution

Friction

To understand the importance of contact areas and pressure distribution it is necessary to understand the role friction is playing. Friction can be de ned as dissipation of energy between sliding bodies [15]. This energy loss can be transferred into heat or it can result in wear or deformation on the softest of the sliding surfaces. When skis are sliding on snow, the friction heat may result in a phase change, which is ice or snow transforming into water. This water lm will then be used as a lubrication source that smooths the surface and lowers the coe cient of friction. Naturally, a low coe cient of friction will give low friction force and improved glide[16].

There are three di erent friction mechanisms for snow, namely dry plouging, lubricated, and capillary suction, as shown in Figure 2.6. Dry plouging does not have a water lm between the ski base and the snow, and typically happen in very low temperatures. This means higher friction as the ski must overcome the asperities in the snow. The lubricated friction phase is the most ideal. In this phase the lm thickness is su cient to avoid the asperities in the snow, and still thin enough to avoid suction, a phenomena that is present in wet snow. Suction means that the tension of the water lm breaks resulting in an increase in friction.

Figure 2.6: The three main friction mechanisms on snow [4]

Naturally, the lowest possible friction is desired for a ski to maximize the gliding capabilities and a signi cant contributor to this is the pressure distribution. Skis for cold conditions typically have a long contact area. Theoretically, for cold conditions, it is preferable to have the contact areas as close to each other as possible because of more heating of the snow, but, since contact areas further apart means more stable skis, this is not ideal. Skis for warmer conditions, on the other hand, often has shorter contact areas.

Pressure distribution

As shown in Figure 2.3 there are two main areas throughout the length of the ski in contact with the snow, located in front of and behind the binding. Looking at this theoretically the nominal area of contact between ski and snow A_n, can be de ned as[17]:

$$A_n = l_f w_f + l_b w_b \tag{2.1}$$

where:

l_f - nominal contact length on the forebody of the ski, m

w_f - nominal contact width on the forebody of the ski, m

l_b - nominal contact length on the backbody of the ski, m

w_b - nominal contact width on the backbody of the ski, m

From this the nominal pressure distribution $p_n(x)$ along the ski in the x-direction can then be de ned as:

$$p_n(x) = \frac{N}{A_n} (x);$$

$$\frac{1}{2(l_1 + l_2)} \left[\int_{l_1} {}_1(x)dx + \int_{l_2} {}_2(x)dx \right] = 1 \tag{2.2}$$

where:

N - normal load on the ski from skier, N

(x) - total nominal pressure distribution function for a ski

${}_1(x)$ - total nominal pressure distribution function for the forebody of a ski

${}_2(x)$ - total nominal pressure distribution function for the backbody of a ski

l_1 - half nominal contact length on the forebody of a ski ($l_1 = l_f/2$), m

l_2 - half nominal contact length on the backbody of a ski ($l_2 = l_b/2$), m

It is the length of the contact area and the pressure distribution function on this area that in uences the gliding capabilities of the ski.

Contact area

As discussed, there are two contact areas. Figure 2.7 shows the contact areas for ve di erent pairs of ski with both half weight and full weight load, which in this case is 36 and 72kg, respectively. It is clear from the gure that there is a signi cant gap between the contact areas. Consequently, this area does not need to have a pressure distribution measurement as the ski is never in contact with the surface.

Figure 2.7: Contact areas for ve di erent skis loaded with 36 kg (lower ve pairs) and 72 kg (upper ve pairs). The coloured bars represent the contact areas.[5]

Figure 2.8 can be used to see how big of a load is necessary to close this gap. Looking at the plots labeled at it is clear that it takes extensive overweight to narrow the gap. In other words, it is con rmed that no pressure distribution setup is necessary in this area. The overall length of which pressure distribution has to be measured seems to be roughly 120-140cm.

Figure 2.8: Comparison of contact length between warm ski and intermediate cold ski with loads up to 170% of body weight.[5]

A ects from base and grind

Another signi cant contributor to the gliding performance of the ski is the base and its grind. The base of the ski, which is the part of the ski in contact with the snow, is primarily made out of Ultra High Molecular Weight Polyethylene (UHMWPE). Other elements, such as carbon, our particles, and graphite, are added for improved performance depending on the snow

conditions the base is made for[8].

Figure 2.9: Examples of grinds for warm and cold conditions, respectively.[6]

For maximal gliding the base is grinded. Figure 2.9 shows typical grinds for warm and cold conditions. A structure is applied to the base to create the lowest possible friction on the snow. Explained with simplicity, in cold conditions ner structure is used to heat up the contact area between the snow and the ski to reduce the friction, which again improves the gliding. For warmer conditions a coarser structure is used to drain water away from the base, also to reduce the friction. Although the base and the grind is not directly relevant for this master thesis, it is important to understand that the quality of the base and the grind can in uence the performance of the ski signi cantly. This is one of the aspects that increases the di culty of categorizing properties of a top ski. Two identically constructed skis can perform signi cantly di erent with di erent grinds and base material composition when tested.

2.2.4 Ski brand di erences

The di erent properties discussed earlier are all very important for a ski to perform as well as possible. Still, as mentioned, there are di erent ski manufacturers making skis. This means that a great ski from one manufacturer with a certain set of properties not necessarily would be a great ski from a di erent manufacturer with the exact same properties.

3 | OLTs existing technology

OLTs measuring device measures three di erent properties in three di erent setups. The properties are ex anf ex height, surface pressure distribution, and the sti ness of the ski. The original xture measures the camber height only. As the need to measure other properties was present, setups for measuring pressure distribution and sti ness was added by OLT. Standing up and down on a pair of this on both legs means that the center of mass is around 14cm behind the tip of the toe. When skiing standing on one ski the pressure is typically applied 8cm behind the tip of the toe. Consequently, 14 and 8 centimeters is used as a measurement standard by OLT and is used in this setup.

Even though the pressure distribution is the setup and measurement of interest in this project it is important to look into how ex height and sti ness is measured also as the future goal is to have an integrated system for all the measurements.

3.1 Setup and procedure

3.1.1 Flex height

The ex height is measured under two di erent loads, half weight and full weight of the skier. This is because these are the loads distributed on the skis when skiing. Obviously, there is a uctuation in load as the skier moves, but this variation is not taken into consideration for simpli cation. When the ski is loaded, as shown in Figure 3.1, a laser is moved under the full length of the ski. The laser can be seen in Figure 3.2. The laser is calibrated before measuring. The laser measurement is then plotted on a graph in excel.