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Experimental field studies of the cross-country ski running surface interaction with snow

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Abstract

The ability of the cross-country skis to glide freely is of very high importance for both sports and recreational skiing. Significant body of research and development is nowadays devoted to the materials and treatment methods for improving gliding of the ski running surfaces, as well as to the related skiing techniques for optimal use of ski gliding. One of the common concepts here is that the most significant energy loss contribution in such interaction is caused by the pure interfacial friction of the ski running surface and the snow. But this interaction is quite complex and we have proposed that other channels of the energy loss can be of significance. Among the possibilities one can point out to the effects of the snow deformation under the skis, “dragging” of snow by the skis and damping of the ski vibrations by the snow. Present paper reports on the field experimental studies of the ski interaction with the snow. These studies are aiming at developing the measurement technology allowing the assessment of gliding properties of the cross-country skis when data are collected from the sensors placed into the ski track.

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Keywords: Ski; running surface; ski-snow interaction; snow displacement; ski track deformation

1. Introduction

Resistance to the gliding of the skis is one of the major channels of the energy loss by the skier [1, 2]. Most of the research in this area is directed towards the improvements in the ski running surface (e.g. [3]), primarily targeting the reduction of interfacial friction between the skis and the snow. But other

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mechanisms such as the ploughing, displacement of the snow due to its compression and the frictional drag [4, 5], and the dumping of the ski vibrations by the snow can also lead to a significant energy loss. Thus, placing the sensors in the ski track, rather than onto the skis [6], can provide valuable information on the ski interaction with the snow including the mechanisms responsible for the significant energy loss. And it is feasible, that the data from the sensors placed into and over the snow in the ski track would allow for the assessment of gliding properties of the skis. Present paper describes the first experimental results acquired, and outlines some of the possibilities provided by this approach.

2. Experimental Setup

A dedicated setup was designed to record the pressure exerted by the skis upon the snow surface, the movements of the snow directly under the surface of the ski track and at the depth of few centimetres, and the acoustic signals travelling in the snow. Data from the sensors placed under both left and right skis are collected into a notebook computer with the LabVIEW software using multi-channel data acquisition module USB-6259 by National Instruments. Gliding speed of the skier was assessed by measuring the time of the free gliding through 100 m section of the slope using STAR Ski Wax digital chronometer with an infra-red sensors (resolution 1 ms). Field studies were carried out at a specially selected 170 m section of the ski track protected from the dominant winds, at the International Ski Stadium in Östersund, Sweden. Ski tracks were freshly prepared by snow groomer less than 4 hours before the tests. The upper 70 m part of the slope is relatively steep allowing the skier to accelerate and reach the desired speed. Lower 100 m clocking zone is quite moderate and here the skier moves with steady speed of about 10 $m \cdot s^{-1}$. When the glide conditions are poor, skier starts some higher up in the steep part of the slope allowing some more time for acceleration. Main data processing is carried out in the Laboratory later on.

Block-diagram of the measurement setup for the field experiments is shown in Figure 1(a). Two thin film pressure sensors (3) (FlexiForce® 1-617-464-45000 by TechScan) are placed over the snow on the ski track (1). Two three- axis MEMS type analogue output accelerometers (4) with selectable range (±2G or ±6G, type LIS 334 by ST Semiconductors) are put into the snow just below the surface of the ski track. Capacitive microphones (5) working in the compression mode are placed in the snow under the ski track at the depth of about 2.5 cm. Sensors are spaced at about 25 cm along the track. Two pressure switches (2) placed over the ski track surface are used to start and stop the data acquisition. Flexible feeding cables for the sensors are placed under the snow. Pressure sensors, accelerometers and microphones are connected to the battery-powered intermediate modules (6), (7) and (8), placed near the ski track. Module (6) contains signal conditioning electronics for the pressure sensors made according to the technical specifications, given by the manufacturer. Module (7) contains power stabilizer for the accelerometer chips and the sensitivity selector switch. Module (8) contains microphone amplifier. All three additional modules and two pressure switches are connected to the data acquisition unit (9) by long screened cables. Data acquisition unit is connected to the laptop computer (10) through the USB cable. Ten analogue signals are simultaneously acquired with the sampling rate of 1 kHz and resolution of 16 bit.

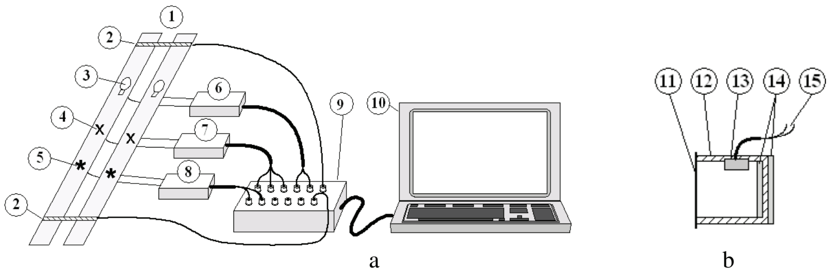

Fig. 1. (a) Block diagram of the measurement setup; (b) cross-sectional view of the microphone sensor, where (1) Ski track; (2) pressure switches; (3) pressure sensors; (4) accelerometers under the snow surface; (5) microphones inside the snow; (6), (7), (8) signal conditioning modules; (9) data acquisition unit; (10) computer; (11) rubber membrane; (12) plastic cup; (13) microphone; (14) acoustic insulation; (15) cable.

Figure 1(b) shows the cross-sectional view of the microphone sensor. Small capacitive type microphone (13) is glued to the inner side of the plastic casing (12) closed by the thin rubber membrane (11). When the pressure of the surrounding media displaces the membrane, compression of the air trapped in the cup moves the microphone membrane and generates the signal. Acoustic insulation (14) added to the bottom of the cup, and special soft feeding cables (15) are used to decrease the undesired signal pick-up.

3. Results and Discussion

Present tests were conducted on the wet spring snow (0^o C, distinctive coarse crystals). Figure 2 shows the signals from the pressure sensors, placed on the top of the snow in the ski track.

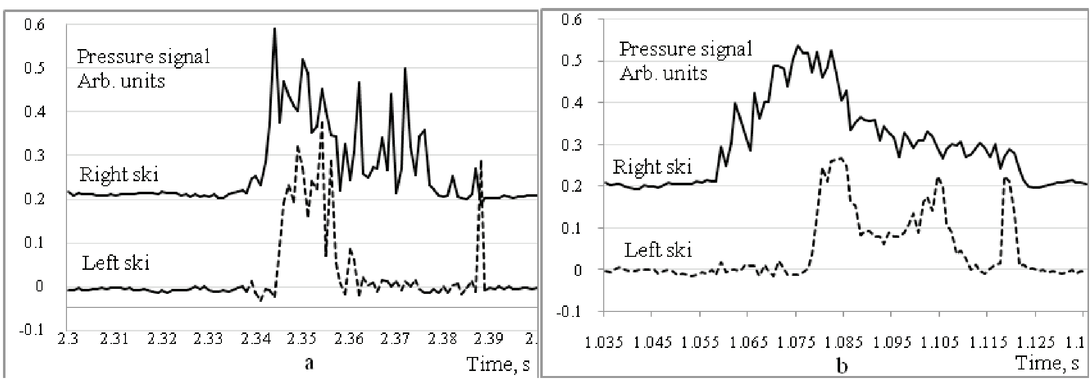

Fig. 2. Pressure signals for two different runs with different pairs of skis (shown only the 'back of the ski' part). Traces from the left and right skis in both graphs are artificially offset to clearly show both signals.

It was intuitively expected, that the signal from these sensors would show two bell-shaped profiles corresponding to the rising pressure when the front and the back end of the ski passes over the sensor. But the measured signals show significant oscillations with characteristic times of 10-30 ms and 2-5 ms). While faster oscillations (kHz range) most probably result from the crushing of the snow structures caused by the snow displacement under the ski [6], slower ones (100 Hz range) are most probably due to the vibrations of the skis [7, 8].

Figure 3 shows the signals from the accelerometers, placed in the snow just under the surface of the ski track (2-3 mm). Acceleration signals show significant dynamics of the snow movements in all three directions (Z- vertical, Y- along the ski track, X- across the ski track) with the peak acceleration values up to ± 2.5 g. Though snow movement orthogonal to the pressure direction was previously detected in the quasi-static case with the rounded probe penetrometers [8], such dynamic behaviour is more characteristic for the non-stationary compression waves.

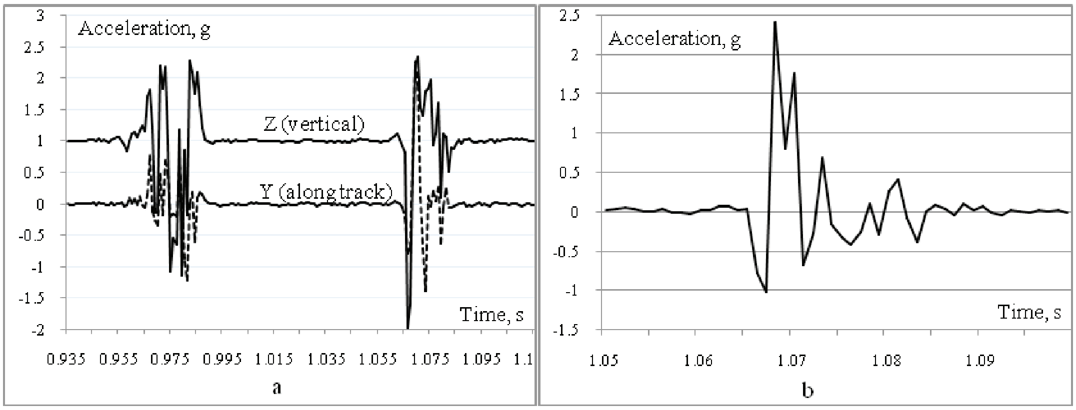

Fig. 3. (a) Accelerometer Z- and Y-signals for the right ski; (b) Y-signal 'back of the ski' part for the left ski

Simple experiment was conducted to see if the hypothesis that pressure sensors placed on the ski track can detect the vibrations of the skis is valid. The skier placed the skis over the pressure sensors and 'slapped' them over the snow, alternatively rising left and right foot. A series of the decaying peaks of the pressure caused by the ski vibrations was recorded. Even without advance analysis it is possible to clearly distinguish in these signals at least two main resonance frequencies around 30-40 Hz (strongest) and 50-65 Hz with the characteristic decay time of ~200 ms. These oscillation frequencies of the induced ski vibrations are similar to the ones determined from the pressure sensor signals (Figure 2) and accelerometer signals (Figure 3). And if the above hypothesis would be confirmed by advanced analysis and further experimental tests, sensors placed into the ski track could provide a way of analysis of the ski vibrations as they happen during the gliding.

Also, basing on the above values one can estimate the quality factors for the two main resonance modes when skis are loaded and coupled to the snow as Q~8-10 (dumping factor 0.05-0.06). This corresponds to the loss of 50% of the energy initially present in the vibrations in ~200 ms, or 75% in ~400 ms, at least for the particular resonance (for the energy considerations see, for example, [9]). Strong vibration damping by the snow is known, and was experimentally registered for both low and high frequency acoustic vibrations [10]. And this mechanism may provide a serious channel for the energy loss. But at the moment it is hard to assess its actual contribution, as the amount of energy transferred into the ski vibration during skiing is not exactly known.

Figure 4 shows the signals from the microphone-based compression sensors put at about 2.5 cm below the ski track with the membrane looking towards the snow surface. Due to the chosen microphone and amplifier, steady state parts of the pressure signals are significantly distorted, resulting in a 'partly differentiated' signal. Fast changing parts of the signals are also some distorted by the low sampling rate of the system (1 kHz). When the ski goes over the sensor a series of fast membrane movements with characteristic times of about 1 ms or shorter followed by the slow relaxation are registered (Figure 4(b), signals around 1.02 s). It is consistent with the experimentally detected movements of the penetrometer heads in the snow [6, 8]. In this case accumulating strain is occasionally released through the fast re-organization of the snow structures and its triggered movement. But two extra movements of the snow at about 1.38 and 1.77 s (200 and 600 ms after the skis have moved over the sensors) present an interesting long-term snow memory effect. Probably its nature is similar, but in this case such movements are triggered by the slow snow relaxation after the compression.

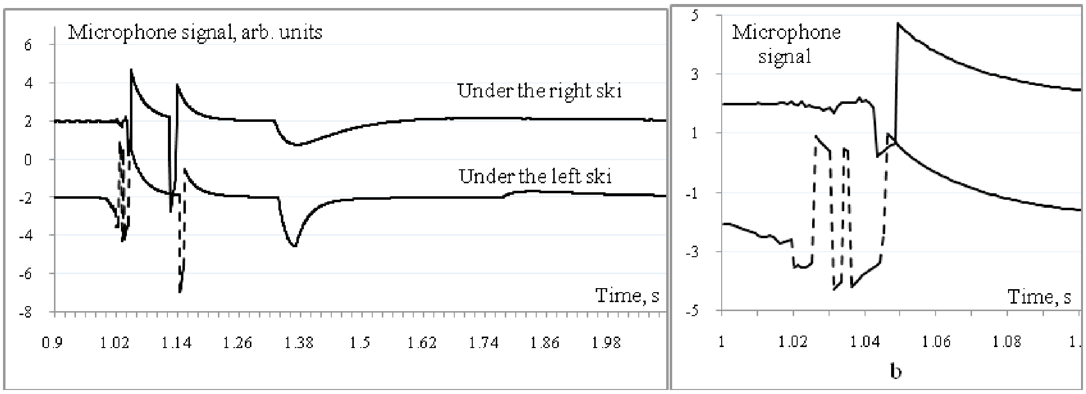

Fig. 4. (a) Microphone signal on the long time scale; (b) close-up view of the signal from the front of the ski. Traces from the left and right ski track sensors in (a) are artificially offset to clearly show both signals.

Also it was noted that in our tests the back sides of the skis were consistently generating some longer and more intense acceleration and pressure signals than the front sides (see, for example, Figure 3(a)). Thus one can conclude that our skier has the gliding posture with the centre of gravity offset towards the back of the skis. Also the skier centre of gravity offset towards the left or right side is easily detected though significantly different pressure and acceleration signals from the left and right sides. So the sensors placed on and under the ski track can help with the athlete training and finding optimal gliding posture.

The ski track near the Östersund Ski Stadium is surrounded by a coniferous forest, and it contributes to a quite high level of tarry contamination in the snow. Because both waxed and unwaxed skis easily pick up this dirt, each consecutive glide on the same pair of skis gradually becomes slower (Figure 5(a)). Figure 5(b) shows the dependence of the accelerometer signal integral (integral of the squares of all accelerometer signals over full registration time). Though this value is chosen in a rather arbitrary fashion, it shows certain correlation with the gliding time for the same pair of skis. But surprisingly, faster pair generally shows lower acceleration values up till glides number 6, when both pairs of skis were becoming quite dirty. Similar trends can be seen for the pressure signals and work integrals.

Signals from the pressure sensors employed in the present set of experiments were rather inconsistent: used sensor has a round active element 10 mm in diameter. When gliding narrow skis move across the track grove and sometimes they go only over the part of the sensor and sometimes miss it completely. In this respect accelerometer sensors appeared to be much more reliable as they do not depend on the direct contact with the ski running surface.

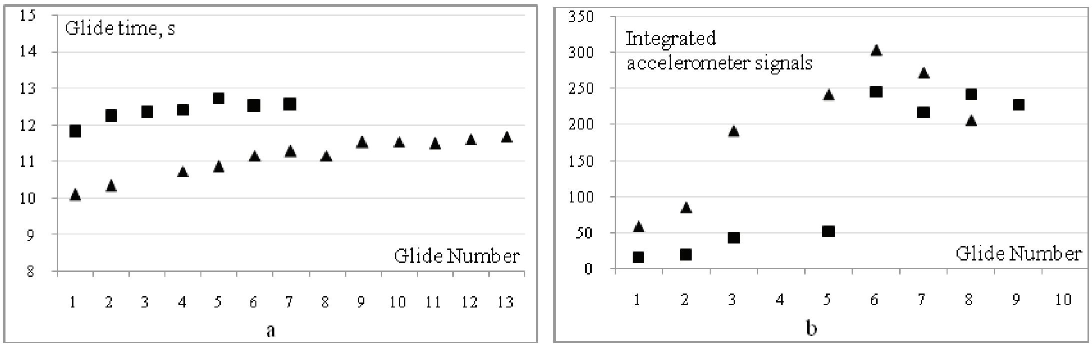

Fig. 5. (a) Glide time and (b) integrated accelerometer signals for ski pairs #377 (triangles) and #373 (squares).

4. Conclusions

Many years of our practical experience argued that skis with an optimal pressure distribution always have a good glide even if the ski running surface treatment is not perfect. It was supposed that the skis with more optimal pressure distribution should lose less energy through the interaction with the ski track. In other words, such skis should cause a lesser disturbance of the snow in the vicinity of the ski track. So the experiments described in the paper were designed to test our proposal that the sensors placed into and upon the snow of the ski track can help to select the cross- country skis with the best gliding ability. During the experiments a second hypothesis, namely that such sensors can also detect the vibrations of the gliding skis was formulated.

Though our first experiments prove that both hypotheses are sound, and no contradicting facts were found so far, further careful studies are needed in order to confirm them. But already now it can be concluded that the developed measurement method is capable of providing valuable information about multiple parameters of the gliding cross-country skis and their interaction with the snow.

Also by analysing the duration and intensity of the signals from the left and right ski track sensors it is possible to determine the instantaneous position of the skier's centre of gravity. Consequently this measurement together with video filming allows studying the skier posture when gliding, which could be valuable for the athlete's training process.

In order to realize full potential of the developed measurement method, further improvements in the measurement system are needed. In particular improved pressure sensors and recording with higher sampling rate essential for higher time resolution of the detected signals would be incorporated into the system for next set of experiments.

References

[1] Colbeck SC. *A Review of the Processes That Control Snow Friction*. Monograph 92-2, US Army Corps of Engineers, Cold Regions Research & Engineering Laboratory, Hanover NH; 1992.

[2] Giesbrecht JL, Smith P, Tervoort TA. Polymers on Snow: Towards Skiing faster. *J Polym Sci* B 2010; 48: 1543-51.

[3] Kuzmin L. *Interfacial Kinetic Ski Friction*. Mid Sweden University Doctoral Thesis 88, Östersund; 2010.

[4] Thiele T, Szabo D, Luthi A, Schneebeli M. Mechanics of the Ski-Snow Contact. *Tribol Lett* 2009; 36:223-231.

[5] Huzioka T. Studies on Ski (3). *Low temperature science, Series A, Physical sciences*.1957; 16: 31-46.

[6] Yoneyama T, Kitade M, Osada K. Investigation of the ski-snow interaction in a carved turn based on the actual measurement. *Procedia Engineering* 2010; 2:1901-06.

[7] Clerc C, Gaertner R, Trompette P. Computer aided design of skis. *Finite Elements in Analysis and Design* 1989; 5:1-14.

[8] Nordt AA, Springer GS, Kollar LP. Computing the mechanical properties of alpine skis. Sports Engineering 1999; 2:65-84.

[9] Beards FC. *Structural Vibrations: analysis and Damping*. Lightning Source Inc.; 1996, p.165-170.

[10] Iwase T, Sakuma T, Yoshihisa K. Measurements of Sound Propagation Characteristics in Snow Layer. Proc. 17th Intl. Cong. Acoust. 2001; 1:274-5.