FBG - deformation measurement of skis during riding

Feasibility study for a measurement system with fiber Bragg gratings

Abstract

This project investigates the feasibility of integrating fiber Bragg gratings (FBGs) in a ski and measuring the deformation during skiing. An exact understanding of the ski behavior during riding is one important component of investigating the complete skiing system, containing snow conditions, ski, binding, boot and the athlete himself. An improvement of this system allows improving the skiing technology towards safer skis, without losing any performance. In this project a giant slalom ski is equipped with 25 FBGs in total, at ten positions over the length of the ski.

The necessary thermal and mechanical calibrations are carried out and programmed in the interrogator software. A completely portable measurement system is developed, allowing the test rider to carry it in a backpack. The test rides prove the stability and outdoor capability of the fragile and humidity sensitive FBGs, thus the feasibility of the measurement system. A first idea of the maximal twist and bending occurring during riding are derived from the test ride analysis.

Materials & Methods

Fiber Bragg gratings

The occurring strains in the ski are measured by FBGs. These sensors reflect incoming LASER light at a wavelength defined by the grating distance. Strain changes this distance and the reflected wavelength is changed.

Compared to resistive strain gauges this provides several advantages:

- Lighter weight due to multiplexing
- Easy thermal calibration
- Once in a lifetime calibration

The change of the reflected peak wavelength $\Delta \lambda_B$ is described by:

$$\Delta \lambda_B = \frac{\alpha_f}{\alpha_s} + \frac{\varphi}{P_e} \varepsilon + \frac{\gamma}{P_e} \Delta T$$

Compared to resistive sensors this provides the following advantages:

- Lower weight due to multiplexing
- Easy thermal calibration
- Once in a lifetime calibration

Optical fiber integration

(01) A groove for the optical fiber integration is machined according the sensor layout plan.
(02) The fibers containing the FBG are bonded in the groves.
(03) All fibers are protected and sealed by adhesive (Sikaflex-252).
(04) The finished ski containing 25 FBG within 3 optical fibers.

Calibration

The FBG sensors are calibrated in three steps, where every physical quantity is treated isolated. First the thermal calibration is carried out at different temperatures. The occurring strains in standardized testing procedures are then correlated with the measured ski deformations for both the bending curvature and the torsion twist angle:

1) Thermal calibration: $F_{BG, XT} = a \cdot F_{BG, T} + b$
2) Bending curvature $F_{BG, \text{strain}} = \frac{1}{a + b \cdot \text{curvature radius}}$
3) Torsion twist angle $\text{twist angle} = a \left( \frac{\text{FBG strain} - \text{sensor left} + \text{sensor right}}{2} \right) + b$

Results

Figure 5 shows the occurring strains at sensor position 3 during the test ride. The different phases during a ride become visible:
- Manual bending for synchronization
- The starting steps
- 7 turns
- Breaking and walking at the end of the ride

Figure 6 shows the torsion angle analysis at sensor position 3 for the test ride. The following key results can be stated:
- Maximal twist angle: 9.5° in turn 5
- Twisting to the unloaded side (to the right in left turns)
- Higher twist angle when the ski is the outside ski (odd turn numbers)

Figure 7 shows two reconstructed ski shapes (side view) during turn 5. The red shape is captured at 10.569 seconds, and the blue shape is captured at 10.962 seconds. Note the super elevated scale on the deformation axis.

Conclusion & Outlook

Conclusion

- The FBG measurement system is proven feasible
- The portable measurement system is stable in the outdoor skiing environment
- The ski deformation can be reconstructed from the measurement data

Outlook

- Synchronizing the ski deformation during skiing with other measurements (e.g. muscle activity, forces in the binding plate, high speed video images) is planned for the future. This might provide a complete understanding of the interaction between athlete, material and slope properties.
- Some additional validation measurements may increase the measurement accuracy
- Automated data analysis will decrease the evaluation workload in the future

Acknowledgement

I would like to thank my supervisors, Antoine Sigg (LTC, EPFL) and Fabian Wolfsperger (SLF, WSL), Prof. Véronique Michaud (LTC, EPFL), Mathieu Fauve (Stöckli Ski), Hansueli Rhyner (SLF, WSL), Samuel Stutz (LMAF, EPFL) and Daniele Costantini, the Stöckli Ski Company in Malters, the technicians in the mechanical workshops at SLF and EPFL, the test rider Philip Crivelli and the camera operators Anke Buttgereit and Benjamin Hinterberger.