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ScienceDirect

Procedia Engineering 147 (2016) 394 – 400

Procedia Engineering

www.elsevier.com/locate/procedia

11th conference of the International Sports Engineering Association, ISEA 2016

A Method for Measuring the Bending and Torsional Stiffness Distributions of Alpine Skis

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Abstract

A novel non-destructive method for quickly, accurately and simultaneously measuring the bending and torsional stiffness distributions of an alpine ski is presented. This method, named SMAD (Stiffness Measurement through Angular Deformations), is based on measuring the angular deformations resulting from a known combined bending and torsion load. The method's accuracy and repeatability is investigated and are on average under 2% and 3%, respectively. The coupling in the measurement of the bending and torsional deformations during combined loading due to ski misalignment in the test machine is investigated. The measured torsional deformation was found to be independent of the bending load. The measured bending deformation was found to be dependent on the torsional load but this effect could be limited by careful alignment of the ski in the test machine.

Peer-review under responsibility of the organizing committee of ISEA 2016

Keywords: Stiffness; Rigidity, Bending, Flexural, Torsional, Measurement

1. Introduction

An accurate method for the measurement of the bending and torsional stiffness distributions of alpine skis is highly desirable, as these mechanical properties play a major role in determining how a ski will perform [1]. Such a method can find many applications in the areas of research and development, quality control, product reviews and online retail. Over the years, numerous methods have been developed to measure an alpine ski's bending and torsional stiffnesses. ISO Standard 5902 [2] describes a test procedure to determine average bending spring constants for the forebody, afterbody and center of an alpine ski, as well as torsional spring constants for the fore and afterbody. In this method, one end of the section of interest is clamped while the deflection resulting from a known bending or torsional load applied at the free end is measured. Methods to obtain the distribution of bending stiffness (i.e., $EI(x)$, the ratio of an applied bending moment and the beam's resulting curvature) and torsional stiffness (i.e., $GJ(x)$, the ratio of an applied torque and the resulting twist angle rate-of-change) of structural beams along their length (e.g., alpine skis, golf shafts, hockey sticks) also exist and are based on the measurement of the beam deformation profile under a known load. Methods for applying a load to the ski include 3-point bending tests [3,4,5], cantilever/end-load bending tests [6], as well as cantilever/end-torque torsion tests [3,4,5]. Variations on such methods have also been proposed, such as multiple tests on short segments, where each test location is moved along the length of the beam [6]. Methods for measuring the deformation profile include measuring the vertical deflection through the use of a laser transducer [3], an LVDT transducer contacting the surface of the ski [4] as well as an infrared tracking system coupled with reflective markers mounted to the ski [4]. Another method for obtaining the deformation profile consists in estimating the curvature of the beam using a digital radius gauge [5]. Due to the variable geometry of skis and the large number of new skis to test annually, it is desirable to have a method of characterization that is both accurate and faster than existing methods.

This paper presents a novel non-destructive method for rapidly obtaining high-resolution bending and torsional stiffness distributions of an alpine ski with few manipulations. The SMAD (Stiffness Measurement through Angular Deformations)

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Peer-review under responsibility of the organizing committee of ISEA 2016
doi:10.1016/j.proeng.2016.06.326

method, described in Section 2, is particularly suitable for the acquisition of large datasets and is based on the measurement of angular deformations created by a combined bending and torsional load. Section 3 evaluates the performance of the SMAD method. More specifically, its accuracy is validated by comparing the measurements taken on a prismatic, homogeneous beam with the average bending and torsional stiffnesses obtained from a 3-point bending test and a cantilever/end-torque torsion test. Multiple measurements are also repeated on a single alpine ski in order to assess the method's repeatability and sensitivity to operator errors. Finally, the coupling between the measured bending and torsion deformations is evaluated by comparing the stiffness distributions obtained by applying combined bending and torsion loads of different relative magnitudes.

2. Method

The SMAD method is based on the measurement of angular deflections. When a combined load is applied on an alpine ski, both bending and torsional stiffness profiles can be calculated from the simultaneous measurement of the bending and torsional angular deformation profiles. This section first describes the experimental setup used to bend and twist the ski as well as the measuring instruments. Then, the calculations required to estimate the stiffnesses from the angular deformation profiles are explained.

2.1. Experimental Setup

The apparatus used to apply a load to the ski and measure the resultant angular deformations is shown in Figure 1.

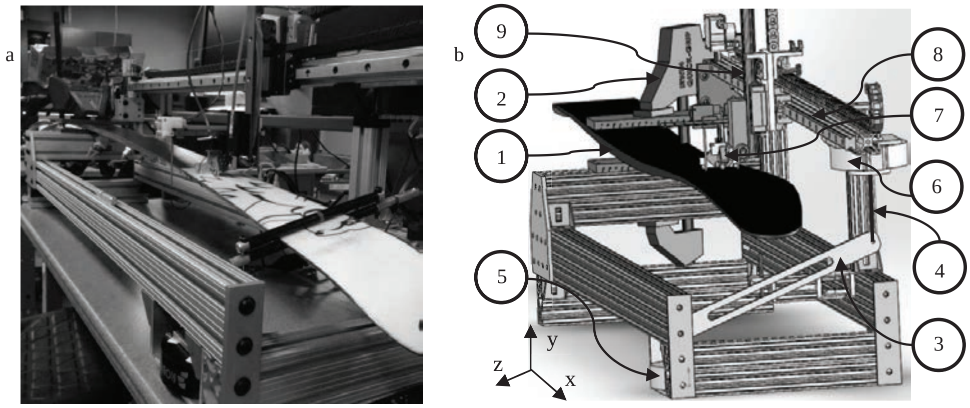

Fig. 1. Experimental setup illustrated by a a) photo of the physical apparatus and b) a CAD drawing

The ski 1 is fixed in the clamp 2 upside-down near the boot area. A combined bending and torsion load is applied near the free end (i.e., tail or tip) through the fixture 3 consisting of two cylinders. Each end of the fixture is connected through ropes 4 to 3-axis force transducers 5 and 6 to measure the load and calculate the bending and torsional moment at all points along the ski. This setup creates a triangular distribution of bending moment that roughly matches the bending stiffness profile of a half-ski (i.e., the moment is greatest near the boot area, where the stiffness is the greatest, and reaches zero at the tip).

The measurement device 7, shown in Figure 2, consists of three spherical followers sliding along the surface of the ski base due to the sliders 8 and 9. The two rear followers 10 are mounted to the body 11 that is free to rotate about an axis parallel to the ski's torsional deformation, $\phi(x)$. This body, as well as the front follower 12, is mounted to the second body 13 free to rotate about the Z-axis and corresponding to the ski's bending deformation, $\theta(x)$. These two angular deformation distributions are measured using optical encoders 14 with a resolution of 0.009°.

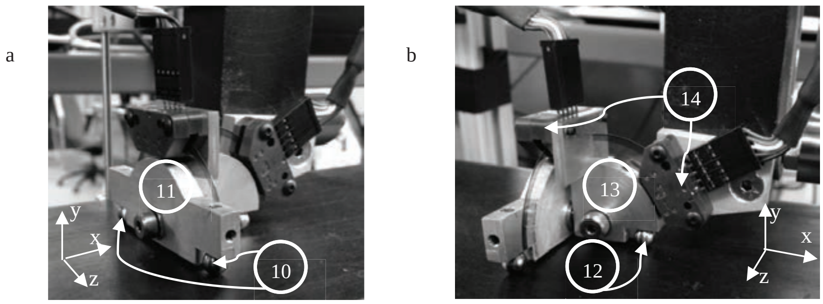

Fig. 2. Curvature measurement apparatus from a) back view and b) front view.