W. Nachbauer, P. Kaps, and M. Mössner, Determination of Kinetic Friction in Downhill Skiing, 8th Meeting of the European Society of Biomechanics, 1992

Reference: W. Nachbauer[1], P. Kaps[2], and M. Mössner[3], *Determination of Kinetic Friction in Downhill Skiing*, Book of Abstracts, 8th Meeting of the European Society of Biomechanics (ESB) (Rome, IT), 1992, p. 333.

Introduction

A thin melt water film caused by frictional heating is thought to be the reason for the low friction between skis and snow. The coefficient of kinetic friction of skis on snow appears to be influenced by several factors e.g. speed, contact area, snow type (temperature, liquid-water, hardness, texture), and ski properties (stiffness, thermal conductivity, base material, base roughness). In laboratory investigations, the coefficient of friction meters consisting of rotational devices with built-in force transducers (e.g. Kuroiwa [2]). In skiing investigations measurements were done in straight running using the towing method (e.g. Habel [1]) or the run-out method (e.g. Leino and Spring [3]). The purpose of this study was to present a method to determine the coefficient of kinetic friction in straight running on a slope with varying inclination and in traversing on an inclined plane.

Data Collection

The straight running experiments were conducted on a 342 m long run with altitudinal difference of 73 m. Nine photocells were installed about 25 cm above the snow surface and distributed along the run. Geodetic measurements of track and photocells were made using a theodolite. Time data of a skier gliding straight down the fall line in a tucked position was collected from all photocells. Several runs were recorded.

In the traverse, the path of the downhill ski boot was determined by film analysis. The length of the run was about 25 m, located on an 18° inclined plane. The traversing angle was about 40° to the horizontal. The sides of the traverse were marked by ropes equipped with black painted tennis balls that defined a 1 m reference marker system. The skier was filmed with a 16 mm high-speed camera located laterally to the plane of motion of the skier. The camera operator followed the skier with the camera. The width of the film field ranged from 4 to 6 m. The film speed was set 100 Hz. Ball-shaped markers were placed on the toe part of the binding. The skier had to traverse in a straight line in an upright position. Side slipping had not occur. Barometric pressure and air temperature were measured in order to calculate the air density. The mass of the skier including equipment was taken as well.

[1]Dept. of Sport Science, Univ. Innsbruck, AT. email: Werner.Nachbauer@uibk.ac.at
[2]Inst. for Basic Sciences in Engineering, Univ. Innsbruck, AT
[3]Dept. of Sport Science, Univ. Innsbruck, AT

Data Analysis

In straight running, one run was selected for analysis. The time history of the coordinates of the shell of the ski boot was established by the releasing times and the position of the photocells. In traversing, three runs of one skier were analyzed. In each film frame, the binding marker of the lower ski as well as 4 reference markers were digitized. The time history of the coordinates of the toe part of the binding was calculated from digitized data. The skier was modeled as a particle that moves on the surface of the slope given by $z = h(x, y)$. The track of the skier was given by its projection on the x-y-plane: $y = kx + d$. Following forces were assumed to act on the particle: the weight F_w, the aerodynamic drag F_d, and the snow friction F_f, both in the tangent direction opposite the velocity. Due to its minor influence, the lift component of the air resistance was neglected. Hence, the equation of motion was given by

$$ma = F_w + F_d + F_f + F_r, \tag{1}$$

where m denotes the mass of the skier with the equipment, a the acceleration, and F_r the reaction forces. The equation of motion combined with the geometric constraints defining the track of the skier represents an index 3 differential-algebraic equation. The numerical solution was obtained by the code MEXX21 of Lubich [4]. Note, that the reaction forces F_r must not be provided by the user , but are computed automatically by the program. The snow friction force was assumed to be proportional to the reaction force normal to the slope $F_f = \mu F_n$. The drag force was set according to $F_d = \frac{1}{2}\rho C_d A v^2$. The coefficient of kinetic friction μ and the drag area $C_d A$ were kept constant. These parameters were calculated by minimizing the sum of squared errors between computed and measured times.

Results

For straight running the computed coefficient of friction was 0.00085, which is in the same range as obtained by the towing and run-out method. The drag area was 0.22 m^2. This is in agreement with unpublished wind tunnel experiments on the Austrian Ski Federation, where the drag area of male world class racers was between 0.13 and 0.19 m^2.

In Tab 1, the traversing results for different velocities are summarized. The computed coefficients of friction were between 0.06 and 0.15. The increase of μ with increasing velocity may not be interpreted as a velocity effect, as the snow conditions varied considerably throughout the measurements due to increasing sun radiation. For the drag area the value 0 was obtained. The confidence interval was infinitely large.

Conclusions

The results of the study indicate that the applied method is adequate for the determination of the coefficient of kinetic friction in skiing. For traversing, however, we did not succeed in calculating the drag area. We believe that the accuracy of the measurements has to be improved and/or the model has to be refined by considering

μ	$\Delta\mu$	v_i [m/s]	v_f [m/s]
0.064	0.060–0.067	0.6	10.6
0.128	0.108–0.150	11.0	13.4
0.153	0.136–0.171	14.7	16.6

Tab. 1: Coefficients of kinetic friction μ, 10 % confidence intervals $\Delta\mu$, and initial v_i and final velocities v_f of the traversing measurements.

the drag area function for gliding velocity. Furthermore, the proposed method allows to calculate reaction forces which becomes important when the skier is modeled as a multibody system.

Acknowledgment

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References

[1] B. Habel, *Über die Bestimmung von Luftwiderstand und Gleitreibung beim Skilauf*, Europa-Sport **20** (1968), 950–955.

[2] D. Kuroiwa, *The Kinetic Friction on Snow and Ice*, Journal of Glaciology **19** (1977), 141–152.

[3] M.A.H. Leino and E. Spring, *Determination of the Coefficient of Kinetic Friction between Ski and Snow from Gliding Velocity of a Skier*, Report Series in Geophysics, vol. 19, University of Helsinki, FI, 1984.

[4] C. Lubich, *Extrapolation Integrators for Constrained Multibody Systems*, Impact of Computing in Science and Engineering **3** (1991), 213–234.