Modelling of movement and load of alpine skier along a curve at FIS World Cup giant slalom

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1. Introduction
Alpine skiing consists mainly from four disciplines: slalom (SL), giant slalom (GS), super giant (GS), down hill (DH). Common aim of all disciplines is the fastest possible run of gate arrangement. The course of a run consists of curves accomplished according to gates’ setting. Pozzo [4] marked out a trajectory of the skier’s centre of mass during GS in Alta Badia World Cup (in 2004) at few gates. The mean radius of a curve was 22 m at a velocity of 20 m/s. During a movement along a circle centrifugal force appears. Smaller radius of a curve and/or higher velocity, then higher centrifugal force hence higher centripetal force. This is a cause of higher friction force which breaks a movement. Mueller [3] points out that high overloading acting on a skier while running at a curve are important factors of injury’s risk. He gave reaction force data overreaching 2.5 body weight at a velocity of 80 km/h (22.2 m/s) and curve’s radius of 20 m. Ducret [2] measured a peak of force even 4000 N during a curve running. It is important the run should consist of curves with the radii as big as possible (except special situations). Trajectory consists of curves built upon triangles. Their apexes are turning poles and centres of inter-gate distances (Fig. 1). The radius of a circle can be calculated from an equation (1) and angle and length of a curve from equations (2) and (3). For example, the distance covered from the gate A to gate B consists of curve \( s_{A2} \) with the radius \( R_A \) and a curve \( s_{B1} \) with the radius \( R_B \).

\[
R_a = \frac{abc}{4\sqrt{(p-a)(p-b)(p-c)}}
\]

\[
gdzie: \quad p = \frac{a + b + c}{2}, \quad a = \frac{AB}{2}, \quad b = \frac{BC}{2}, \quad c = \frac{AC}{2}
\]

\[
s_1 = \frac{a}{2R}, \quad \sin \alpha_1 = \frac{a}{2R}, \quad \sin \alpha_2 = \frac{b}{2R}
\]

\[
s_2 = R\alpha_1, \quad s_2 = R\alpha_2
\]

Fig. 1 Theoretical model of a trajectory of a run with the highest possible radii of curves [1].

The aim of a paper was to present data on geometry of giant slalom and kinematical and dynamic data of a run of the best world competitors. The latter data allow to estimate loads acting on a skier along the whole course.

2. Methods
Three courses of alpine ski giant slalom were investigated during FIS World Cup in Alta Badia 2006, Hinterstoeder 2006, Kranjska Gora 2007. The best world skiers participated at the competitions. Position of turning poles were obtained with the use of differential global positioning system (DGPS). One GPS data logger was always in the same place. It was used to calculate errors due to changing signals from the satellites. The second data logger was carried by an investigator who ran along the whole course from one turning pole to another holding each time a hand with a device close to the pole. Above procedure enabled obtaining geometry of the whole course: distances between turning poles, angles of inclination and deviation.
Time between gates was obtained with a help of video equipment. The television coverage of running competitors shown by organizers at the large screen situated at the finish area were recorded. Having inter-gate distance and time between turning poles mean inter-gate velocity was calculated for the entire course. Based on: a) mass of 90 kg of a given competitor (body plus equipment), b) velocity and c) radius of a curve, centrifugal force was calculated (4). Next, reaction force was calculated taking into account centrifugal force and gravity force (5). Impulse of force was calculated by multiplication of force and time (6). Then, the sum of impulse forces for the whole course was calculated (7).

\[
F_c = \frac{(m \times v^2)}{R} \quad F_r = \sqrt{F_c^2 \times F_g^2} \quad \text{Imp} = F_r \times t \quad \Sigma \text{Imp} = \sum F_r \times t_i \quad (4, 5, 6, 7)
\]

where: \( m \) – mass, \( v \) – velocity, \( t \) – time, \( F_c \) – centrifugal force, \( F_r \) – reaction force, \( F_g \) – gravity force, \( \text{Imp} \) – impulse of force, \( i \) – \( i \)th item.

### 3. Results

The number of gates at the courses were from 48 to 51. The length of the whole course was from 1263 to 1585 m. The most often (more than 20) there were small (<20 m) and big (>40 m) radii of turns. Mean inter-gate velocities, taking into account a straight distance between turning poles, were about 20 m/s for turns with short radius and about 24 m/s for turns with medium and big radius. Detailed data are presented in Table.

**Table 1. Geometrical parameters and kinematical and dynamic data of giant slalom runs.**

<table>
<thead>
<tr>
<th>Quantity</th>
<th>small</th>
<th>medium</th>
<th>big</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radius</td>
<td>&lt;20m</td>
<td>20-40m</td>
<td>&gt;40m</td>
</tr>
<tr>
<td>Number of turns</td>
<td>21</td>
<td>8</td>
<td>22</td>
</tr>
<tr>
<td>Mean velocity, m/s</td>
<td>19,56</td>
<td>24,18</td>
<td>24,09</td>
</tr>
<tr>
<td>Mean centrifugal force, N</td>
<td>2450</td>
<td>1815</td>
<td>790</td>
</tr>
<tr>
<td>Mean reaction force, N</td>
<td>2916</td>
<td>2045</td>
<td>1120</td>
</tr>
<tr>
<td>Time of running of 1 curve, s</td>
<td>1,47</td>
<td>1,53</td>
<td>1,37</td>
</tr>
</tbody>
</table>

The impulse of force for the whole investigated courses equaled from 101.2 kJ to 162.3 kJ.

### 4. Discussion

The largest reaction forces were where small radii existed (mean \( F_r = 2916 \) N) despite smaller velocity, comparing to turns with bigger radii. The value of impulse of force can serve as a reference value for comparison of different fragments of a course or for different courses. Next stage of investigation could use other than circle curves approach to the description of skier’s trajectory. This approach could be by using the second or greater degree exponential equations.

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### 1. References


