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The Kreisel in Winterberg – speed and acceleration

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Abstract

When bobsledding, accelerations act in all 3 spatial axes. In addition, there are rotations and tilts. The accelerations perpendicular to the direction of travel can assume values of up to 4g, which has a direct effect on the friction between the ice and the runner. An indirect influence on the friction is caused by the effect of the accelerations in and transverse to the direction of travel. The acceleration in the direction of travel is a consequence of the transverse acceleration, which depends to a large extent on the steering movements.

What was examined?

When a bobsled travels down the track, accelerations occur in and against the direction of travel as well as transverse and perpendicular to it, triggered by the downhill force. Acceleration perpendicular to the direction of travel combines the effects of gravity and centrifugal force. Such accelerations can reach four times the acceleration due to gravity, i.e., values greater than 40 m/s^2 [1]. The lateral acceleration results mainly from the steering movements. In the direction of travel, acceleration occurs during push-off and through decelerations caused by steering. The rotational movements in the direction of travel are referred to as pitching, transverse to the bob as rolling and perpendicular to the bob as yawing. While pitch is determined by the track inclination, the bob rolls when cornering and yaws when it breaks out in the direction of travel or is placed transversely by the steering movement.

It is clearly evident that the accelerations in and against the direction of travel affect the speed. This is not so obvious for the components in the vertical and transverse directions. Vertical to the direction of travel, the force pushing the runners onto and into the ice (normal force F_n) increases with increasing acceleration. The assumption that the lubricating water film is formed by pressure melting is still very widespread. However, this assumption has turned out to be wrong. More realistic is the theory that the water film formation is driven by shear melting, which is caused by the acting friction power density P:

$$P = \frac{\mu F_n v}{A_r} = \frac{F_r v}{A_r} \qquad (1)$$

This equation contains the fraction F_n/A_r, which has the dimension of a pressure, but enters the equation through the friction law $\mu = F_r/F_n$. μ is the friction coefficient, A_r is the real contact area between the runner and the ice, F_r is the friction force, and v is the velocity. Thus, the runner produces its own film of water during the run, which reinforces the nanometer-thin film that is on the ice surface anyway. The real contact area is a function of the elastic modulus as well as the Poisson's ratio of runner and ice and the radius of the runner. Furthermore, it depends on the normal force. And here again gravity and centrifugal force interact.

Transverse to the bob, accelerations act, which are caused by the intervention of the pilot. The accelerations occur when the bobsled breaks out on the straight or in curves, depending on which line of travel the bobsled pilot chooses. Depending on how tight the preferred curve line is, the more the acceleration is directed outward.

How was examined?

Acceleration Measurements
Measurements were made using a three-axis accelerometer from Swiss-Timing. In addition to accelerations, roll angle and velocity were recorded at a sampling rate of 100 Hz. By means of radar the velocity measurement was realized.

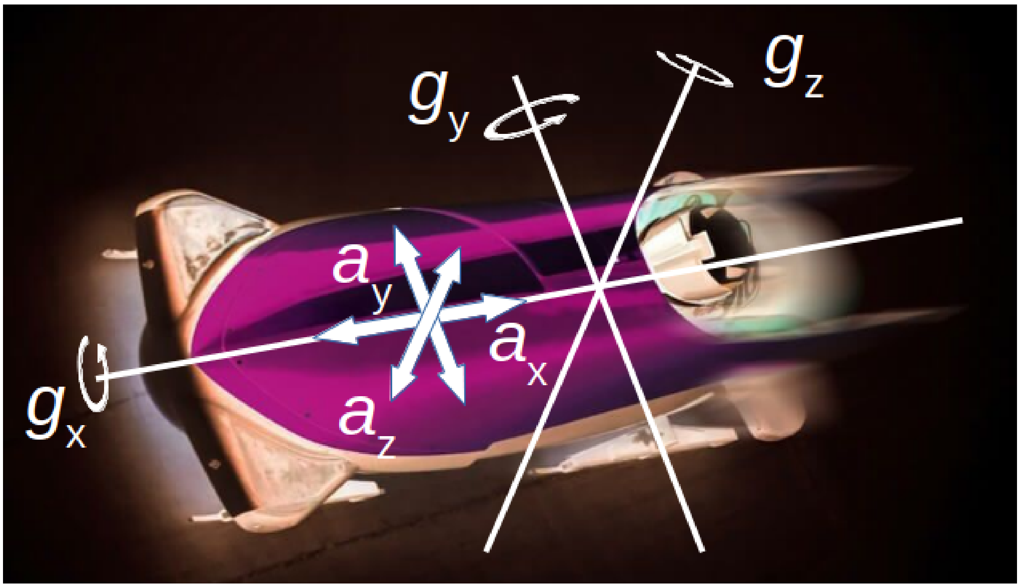

Figure 1: Accelerations and inclinations in the direction of travel (x-direction), transverse (y-direction) and perpendicular to it (z-direction).

Data Evaluation
For the evaluation 143 data sets of bobsleigh runs on the track in Winterberg with above mentioned parameters were available. The programming was done with Python.

Results

Overall Picture
The overall view in Fig. 2 shows the velocity, lateral acceleration, and roll angle as a function of travel time. An initial near-linear increase in velocity is followed by some decreases in response to large curves, e.g., Omega, Kreisel, and finish curve. The maximum speed is just over 130 km/h. The roll angles show maximum values greater than 80 degrees. The double maxima in the large curves are striking. The lateral accelerations are multiplied by a factor of 10, so that the maxima of this run are about 40 m/s^2. One recognizes in this representation no connection between acceleration and velocity.

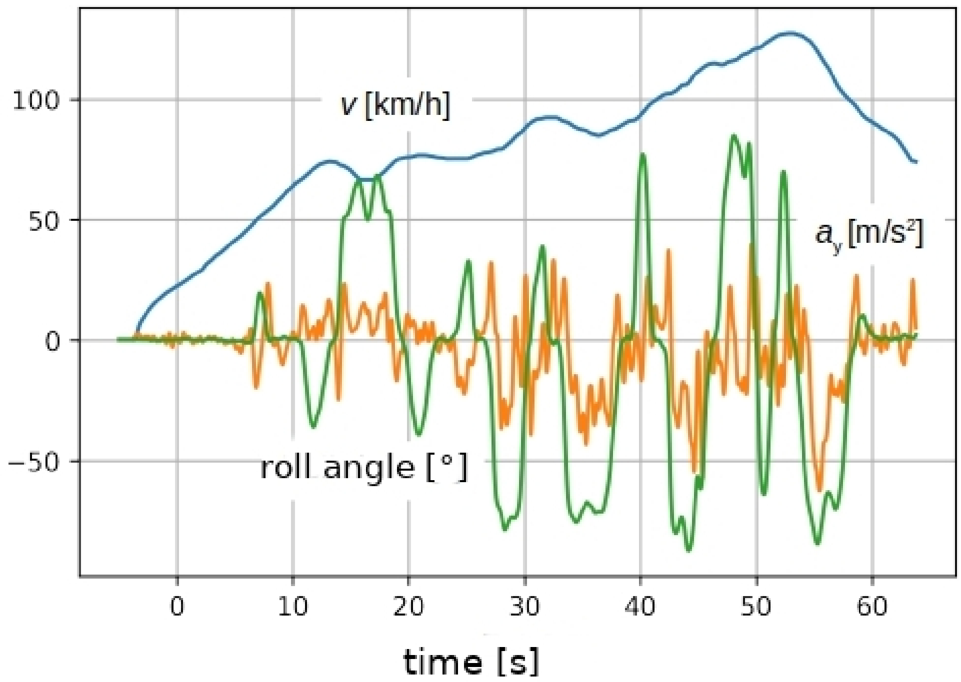

Figure 2: Measurement data acquisition on the track in Winterberg.

Accelerations
The acceleration in and against the direction of travel are a consequence of the transverse accelerations occurring. Both quantities are thus coupled and a representation of both accelerations in one diagram results in a convoluted curve as shown in Figure 3.

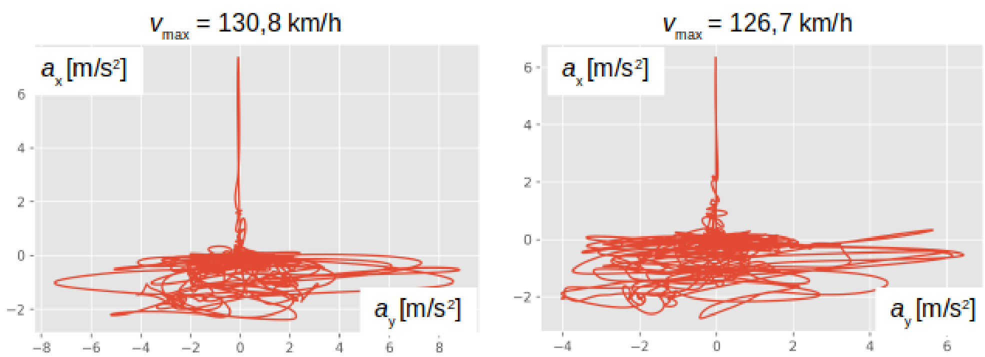

Figure 3: Accelerations at different speeds.

In addition to the accelerations, the figure shows the maximum speed achieved in these runs, which differs by almost 4 km/h. The accelerations in the direction of travel occur almost exclusively in the negative range. The positive values reflect the push start. The larger the part of the accelerations in the negative range and the more parts occur at larger negative values, the slower is the bob, which can be seen well in the right picture. In the left picture, the main part of the accelerations is between 0 and -1 m/s^2, whereas on the right side the values in the range between 0 and -2 m/s^2 are about equally distributed.

The lateral accelerations vary between -8 m/s^2 and 9 m/s^2 for the faster ride and for the slower travel -4 m/s^2 and 6 m/s^2. By means of gradient analysis da_x/da_y the degree of blurring was analyzed. It could be proved that during the slower travel there were much more changes in the transverse accelerations, so the acceleration curve is much more tangled.

Analysis of Critical Points
The Kreisel was selected as the critical area and the effect of the average transverse accelerations in the Kreisel on the exit speed was analyzed for all 143 runs. Only the analysis of this large number of runs reveals a dependence, see Fig. 4.

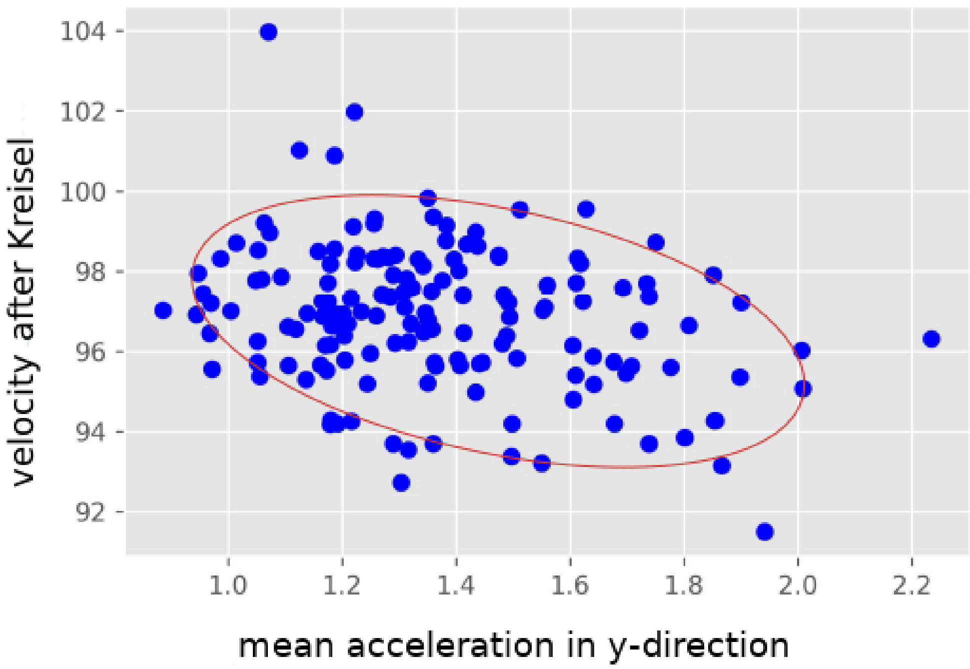

Figure 4: Speed as function of mean transverse accelerations.

The obtained point cloud has the shape of a cigar and shows smaller velocities for larger average transverse accelerations.

Discussion

The analyses allow a whole series of conclusions that should be familiar to specialists, but can now be supported with data.

Braking too much makes you slow
Indeed, it has been shown that most of the x-accelerations occur in the negative range, thus arguing for braking. However, since there is no active braking before the finish line, the deceleration must have other causes. First and foremost, steering processes associated with the turning of the runners have a braking effect. The coefficient of friction in the longitudinal direction of the runner is about 0.005 to 0.009 when the runner is moving at high speed [2], and it increases tenfold transversely. Downstream are changes in ice hardness, which can be caused by differences in cooling power along the track. But changes in z-acceleration can also have a braking effect. For example, the higher the bob travels through the curve, the lower the contribution of the acceleration due to gravity to the normal force. According to equation 1, this reduces the frictional power and less water is formed. It has been shown that the trajectories that allow the greatest z-accelerations also allow the highest velocities [3].

The harmony makes it
The more harmonious, i.e. jerk-free, the bobsled slides from start to finish, the faster it will travel. Frequent changes in lateral acceleration slow it down. The maximum magnitude of the acceleration is not important. What is decisive is the average lateral acceleration.

What else is in the data?
The analyses presented here cover only a very small part of the possible investigation possibilities. Besides the analysis of accelerations at critical points of the trajectories, the steering behavior of the pilot can be included by means of an additional sensor. Equally illuminating should be the coupling of the values obtained with video data, in order to relate exactly the reaction of the bobsled to the conditions of the track.

Acknowledgement

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About the Author

Matthias Scherge is a professor of tribology. This is the science of friction, wear and lubrication. Prof. Scherge heads the Fraunhofer MikroTribologie Centrum, teaches at the Karlsruhe Institute of Technology and manages Team Snowstorm. He also advises the Nordic Paralympic Team Germany on scientific and technical issues.

References

[1] Christian Hainzlmaier. *A new tribologically optimized bobsleigh runner*. PhD thesis, Technische Universität München, 2005.

[2] Matthias Scherge, Roman Böttcher, Mike Richter, and Udo Gurgel. High-Speed Ice Friction Experiments under Lab Conditions : On the Influence of Speed and Normal Force. *ISRN Tribology*, 2013:1–7, 2013.

[3] Matthias Scherge. Acceleration analysis in bobsledding – more questions than answers. *Gliding*, 1:8–12, 2021.