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Stick-Slip Mechanism Considerations in Alpine Skiing – A Thought Experiment

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Abstract

Alpine skiing is a popular sport, but there are many open questions regarding vibrations of a ski. Studies so far included on slope and lab measurements but the gathered data had almost no influence on ski design besides a marketing hype. It is common knowledge that ski construction and core composition is particularly important for vibration modes of a ski, but I suggest a different approach to modeling ski vibration. The goal of the article is to show that under the assumption that no 'upward' skidding occurs (movement in direction perpendicular to the ski from outer to inner edge), there is a limit to possible amplitudes and frequencies of ski vibration.

Basic assumptions

Various sources [1] and measurements of the human body suggest 30 Hz as upper limit of induced vibrations that humans can control by their extremities, for example, when standing on an inclined vibration plate. Therefore, I assume there is a certain

(1) upper limit for amplitude and frequency of vibrations that is relevant for the skier-snow interaction.

Vibrations of tip and tail have an energy an order of magnitude lower than needed to vibrate ski boots and skiers' body. Comparing the typical mass of a single ski (1-2 kg) with the mass of the body (1 ski boot + 1 leg + $\frac{1}{2}$ of body weight of typically 30-50 kg) and the estimating energy of vibration of the ski with an amplitude of 5 cm at 10 Hz will give an amplitude of ski + skier (close to eigen value for almost every ski) of 1 cm, if all energy of vibrating the ski is transferred to skiers' body.

(2) Only vibration of ski underfoot is felt by the skier.

Skiing is a combination of gliding along the longitudinal axis of a ski and perpendicular to the longitudinal axis. Gliding in direction perpendicular to the longitudinal axis is usually called skidding. No skidding is possible only and only if the whole length of the ski-snow contact (ski edge) is of the same shape (turn radius) as the path of a ski, see Fig. 1. In all other cases skidding is mandatory. A ski is either flat on snow or set at an angle, where the edge in contact with the snow is commonly called 'inner edge' and the edge without contact is called 'outer edge'. Usually, the angle between snow surface and ski base is changing during skiing, but over a single turn, inner and outer edges are not changed. A skier can manipulate the shape of a ski edge by changing the angle between snow surface and ski base (angulation) and therefore exploiting the geometrical property of a ski called 'side cut' and perform carving turns with different radiuses. Therefore, we can define skidding as movement of the ski from inner edge to the projection of outer edge on the snow surface.

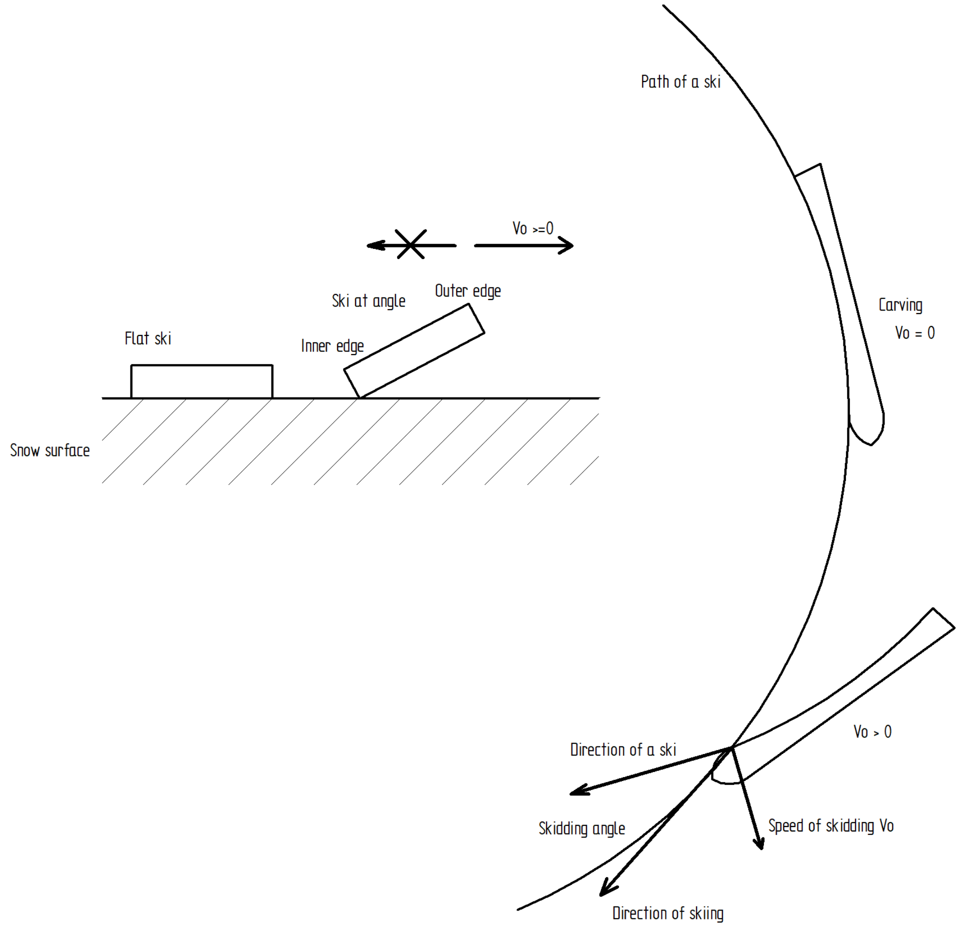

Figure 1: General setup.

(3) Skidding is only possible in one direction over the whole length of a ski.

And,

(4) no skidding is possible in the direction from outer to inner edge.

An additional parameter, we must consider, is the speed of skidding. We can derive the speed of skidding by estimating the speed of skiing with a combination of the angle between the longitudinal axis of the ski and the direction of movement of the ski. Angle of skidding can be estimated but setting limits. Angles between 0° and 90° (pure carving and pure skidding) can be considered reasonable. We also assume the snow surface as flat and even in consistency and no vibrations as result of snow irregularities are considered.

Model

Usually stip-slip mechanisms are modeled as mass, suspended by horizontal spring, set on conveyor belt, see Fig. 2.

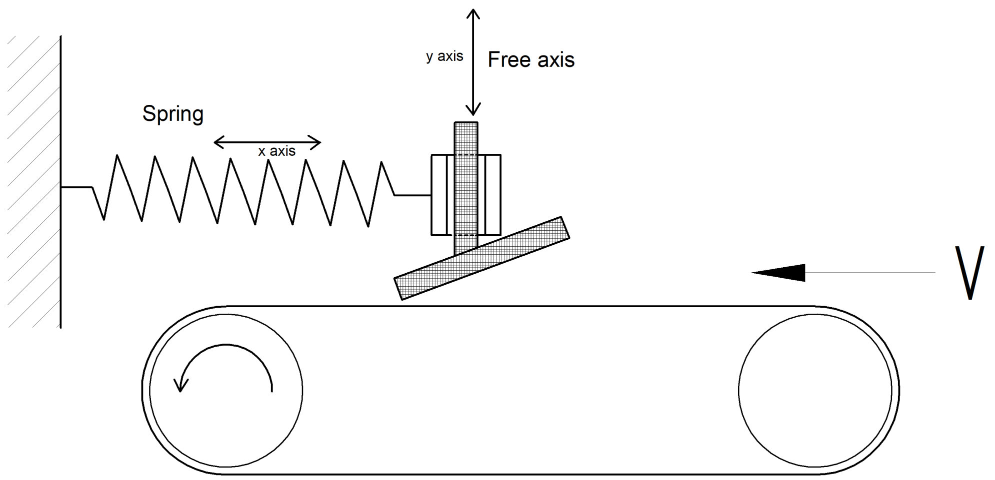

Figure 2: Model setup, redrawn from [2].

This is a useful simulation for certain kind of vibrations, but in skiing there must be an additional condition set, because of (4). In other words:

(5) The friction coefficient in one direction of movement should be considered as infinite.

In this thought experiment, we replace the spring by a simple harmonic oscillator, see Fig. 3. A simple harmonic oscillator is a device that introduces sinusoidal motion over x, in our case it moves a ski left and right with amplitude A with given frequency. We examine the envelope inside which vibrations of the system are possible and determine which frequencies and amplitudes develop at given skidding speed considering condition (5).

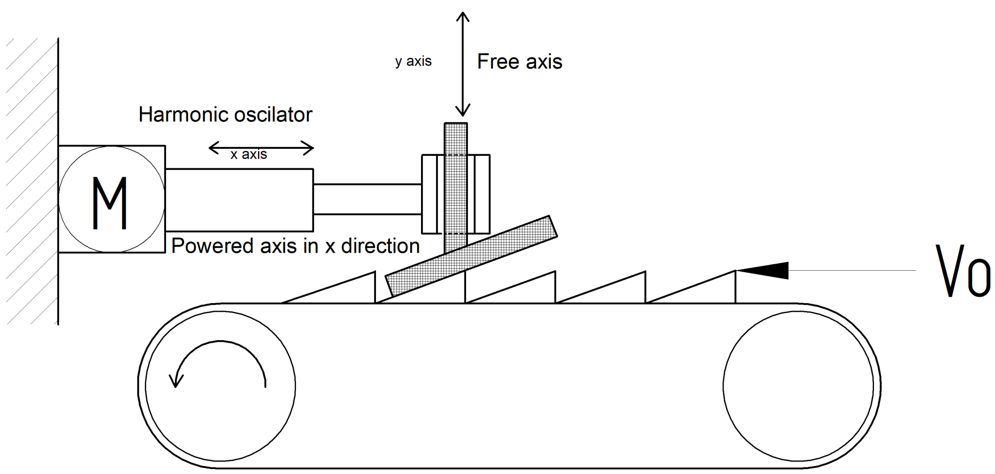

Figure 3: Extended model setup.

Definitions

- v - speed of a skier
- v_0 - maximal velocity of harmonic oscillator
- γ - oscillator frequency
- A - amplitude of harmonic oscillator
- δ - skidding angle. Angle between direction of skiing and orientation of longitudinal axis of the ski.

Results

The jagged surface is moving under the mass of the harmonic oscillator with given velocity v_0. The mass of the harmonic oscillator can oscillate in x-direction only if the maximum speed of the oscillator is less than the speed of the surface v_0. As soon as the speed of mass is larger than v_0, amplitude is decreased to follows rule (5) as the 'ski' jams into the belt, i.e., the ski is not able to skid against snow.

We can calculate the harmonic oscillator on the basis of the given skidding speed as limiting factor (5):

$$(7)\ v_0 = \omega A = 2\pi\gamma A \qquad (1)$$

and calculate the frequency of this vibration as function of amplitude:

$$(8)\ \gamma = \frac{v_0}{2\pi\, A} \qquad (2)$$

Appling rule (5) as:

$$(9)\ v_0 \leq v \sin\delta \qquad (3)$$

Where $v \sin\delta$ is the speed of skidding as function of speed of skiing and skidding angle. The frequency possible at given amplitude is:

$$(10)\ \gamma = \frac{v \sin\delta}{2\pi\, A}. \qquad (4)$$

Discussion

With the calculation above, we can now input different realistic data of speed, skidding angle and amplitude. As not all amplitudes are realistic or problematic, we can limit our input data to realistic values, since an amplitude of 1 m or 0,0001 m have no practical sense. By (10) we get limits for possible vibration frequency – amplitude combinations. The following example is for an amplitude of 10 mm at skidding angles of 5°, 15°, 30° and 45°, shown in Fig. 4.

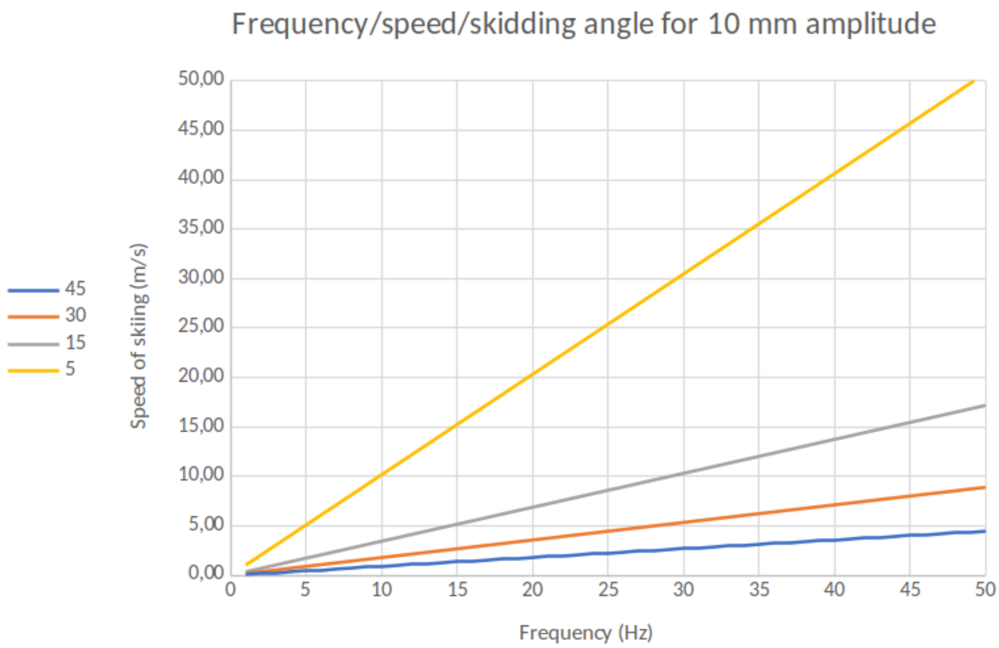

Figure 4: Speed of skiing as function of frequency.

For example, to initiate vibrations with an amplitude 10 mm and a frequency of 20 Hz, for a skidding angle of 5 degrees, the speed must be at least 20 m/s, but for a skidding angle of 45 degrees, a speed of 3 m/s is enough. Similar graphs can be plotted for other amplitudes and skidding angles.

Conclusions

This oversimplified model shows that there is a limit of the amplitude for the given regime of skiing, for which vibration of a ski under foot at a given frequency is possible. Presented results might even correspond to general experience, but this model is far from being scientifically proven.

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About the Author

Jurij Franko, graduated from the University of Ljubljana, worked in different fields including position as R&D manager at Elan, Slovenia and Elan snowboards, Austria. He is author of several patents including: SI9200121A SKI FOR ALPINE SKIING, SI9800003A PLATFORM FOR FIXING SKI OR SIMILAR SKATING DEVICE, WO02053239A2 SKIING BOOT AND SAFETY BINDING ASSEMBLY FOR ALPINE SKIING. He is currently self-employed and works on Smart Ski project (https://lusst-ski.com/)

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