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A SKIDDING MODEL FOR CARVING SKIS

Otmar Kugovnik[1], Bojan Nemec[2] and Matej Supej[1]

[1]Faculty for Sports, University of Ljubljana,
Ljubljana, Slovenia
[2]Jožef Stefan Institute, Ljubljana, Slovenia

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Abstract:

In the paper a mathematical model of side skidding for carving skis is presented. The authors have demonstrated in their previous work that carving skis generate generally lower vibrations during the parallel ski turn in comparison to the skis with the classical side cut. However, carving skis can provoke excessive vibration in the case of side skidding. This phenomena have been explained by applying a heuristic model of side skidding for carving skis. The model was verified with measurements on the ski slope and with a simulation using an industrial robot.

Keywords: measurement, skiing, mathematical modelling

DAS MODEL DES FLANKENGLEITENS DER CARVINGSCHIER

Zusammenfassung:

Die Arbeit stellt ein mathematisches Modell des Flankengleitens der Carvingschier dar. Vorher haben die Autoren gezeigt, wie die Carvingschier bei den Parallelkurven meistens weniger Vibrationen als die Schier mit dem klasischen Flankenprofil verursachen. Andererseits können die Carvingschier beim Flankengleiten übermäßige Vibrationen erregen. Um dieses Phänomem zu erklären, haben wir ein heuristisches Model des Flankengleitens der Carvingschier benutzt. Das Model ist durch die Messungen auf den Schispuren sowie durch die Simulation mittels eines industriellen Robots verifiziert worden.

Schlüsselwörter: Messung, Skifahren, mathematisches Modell

Introduction

It is well known that vibrations in alpine skiing have a great influence on precise curve tracking, as well as on injuries. Vibrations are mostly due to the terrain irregularities, but can also be generated by the side skidding during imprecise curve tracking (Kugovnik and Nemec, 1998). Ski equipment manufacturers try to reduce the influence of vibrations by using new designs and new materials. One of the important aspects in vibration damping is also the side cut of the skis.

We have analysed in our previous work the influence of the side cut of the skis on vibration caused by side skidding (Nemec, Kugovnik, Gašperšič and Sitar 2000). Two categories of skis were compared: skis with classic and extreme side cut. Vibrations were estimated by measuring ground reaction forces. Power spectrum density of the measured force signals determined the amplitude and frequency of the vibrations. We have demonstrated that carving skis generally generate less vibration during the parallel ski turn in comparison to the skis with the classical side cut. During our analyses, we have noticed that carving skis act differently if skidding occurs. We tried to explain this behaviour by using a mathematical model of skidding. In the past years, several mathematical models of a turning snow ski have been presented. The most critical point in this task is the modelling of the snow impact force. Different snow conditions require different models. Renshaw and Motte (1989) developed an empirical formula for an icy snow impact model, where the ground reaction force depends on cutting depth and inclination angle. Hirano and Tada (1996) proposed another model, where they presented the material cutting theory. This model is valid for well-packed snow. Another model proposed by Hirano and Tada (1994) is based on snow pushing, calculated by using the water jet analogy. This model could be used on soft, powder snow, but with many restrictions, since this model does not include any ground reaction forces without skidding. However, all the proposed models assume turning with skidding, which is a reasonable assumption for the ski turn on classical skis. With carving skis it is possible to turn without skidding, but experiments have shown that an effect similar to the side skidding can be noticed in certain circumstances also with carving skis. In the paper submitted we present a model for side skidding on well-packed snow, which can be used also with carving skis. Our model was based on some heuristic assumptions, but was verified with the measurements on a ski slope.

A similar study was presented by Niessen, Muller, Raschner and Schwameder (1996), but it focused on the vibrations of the skis. In contrast, our study takes into consideration vibrations measured on the ski boots, i.e. vibrations that are transferred to the skier's body.

Methods

Vibrations were measured by using equipment for ground reaction force measurement (Nemec, 1997). Four force transducers per each leg, inserted in the ski boot sole, were used to capture the reactive forces with a rate of 100 measurements per second. The measurement was synchronised with a video image. The block diagram of the ground reaction forces measuring equipment is presented in Figure 1. The computer program enables step-by-step analyses of the ground reaction forces and, simultaneously, analyses of the digitised video movie. Vibrations were obtained by applying the fast Fourier transformation on the measured force signals. We have used MATLAB and Signal Processing Toolbox to accomplish this task. Power spectrum density analyses of the captured signals show the frequency and magnitude of vibrations. With the applied sampling rate of the ground reaction force measuring system (100 Hz), vibrations of frequencies up to 50 Hz can be measured.

Vibrations were studied during turns of a typical giant slalom run. The skier was an experienced ski instructor. He performed equal ski turns using skis with an emphasised ski cut (carving skis) with a radius of 12 m. The snow was well-packed, but not icy. The air temperature was +2 ^{0}C.

Results

A typical response of the ground reaction forces and power spectrum density for carving skis is shown in Figures 2 and 3. A better insight in the vibration can be obtained by observing the power spectrum density plot, which shows the force vibration amplitude related to the frequency (Kugovnik and Nemec, 1998). Vibrations at frequencies lower than 2 Hz are mainly due to the loading and unloading phase during the ski turn, while vibrations of frequencies over 2 Hz represent undesirable vibrations. From the results it can be concluded that side skidding causes vibrations with frequencies over 2 Hz. The side skidding phase in the force plot was identified by observing the video image. Since carving skis allow a ski turn without skidding, vibrations with frequencies over 2 Hz are fewer on carving skis. However, we can notice higher amplitudes on the power spectrum plots for frequencies lower than 2 Hz with carving skis. This is due to the greater radial forces, which are generally obtained during the ski turn using carving skis and performing the turns without skidding.

Figure 1: Measuring equipment

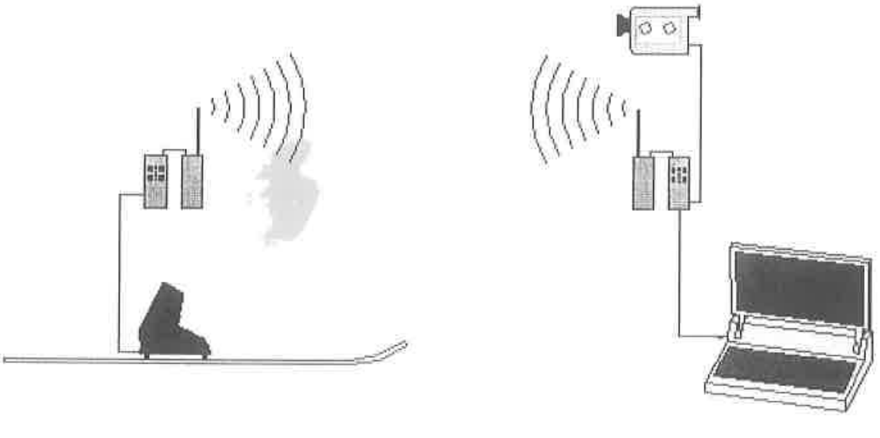


Figure 2: Ground reaction forces and force application point of two turns on carving skis.

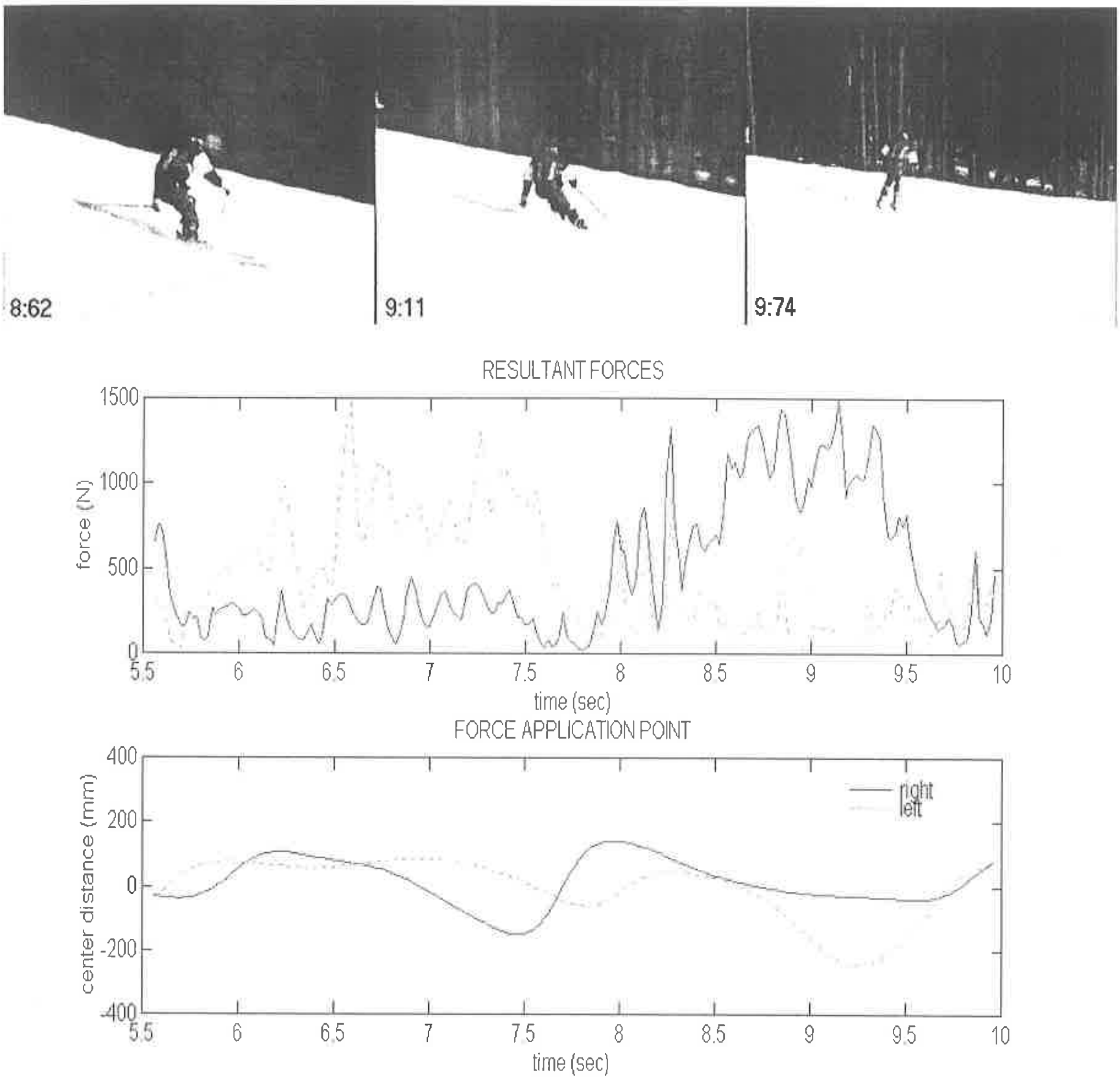


Figure 3: Power spectrum density of the left turn performed on carving skis.

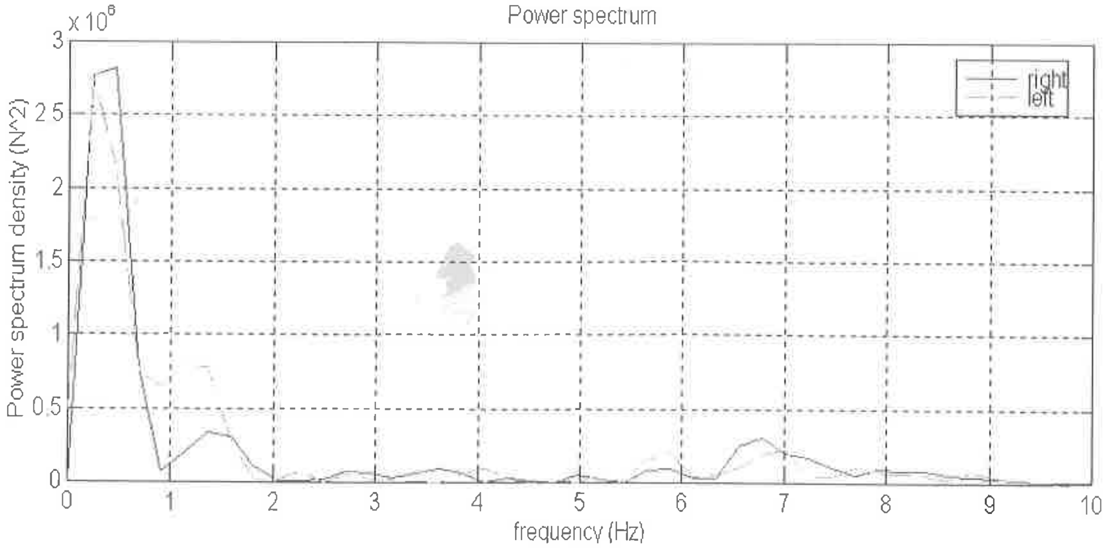


Fig. 4: Ground reaction forces of one ski turn with skidding on carving skis

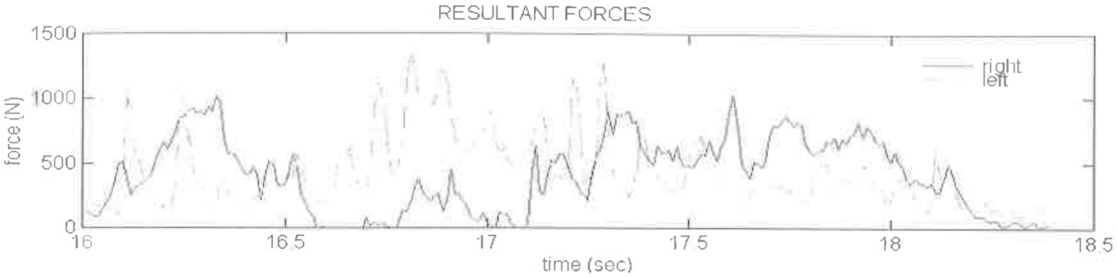


Fig. 5: Power spectrum density of the ski turn with skidding on carving skis

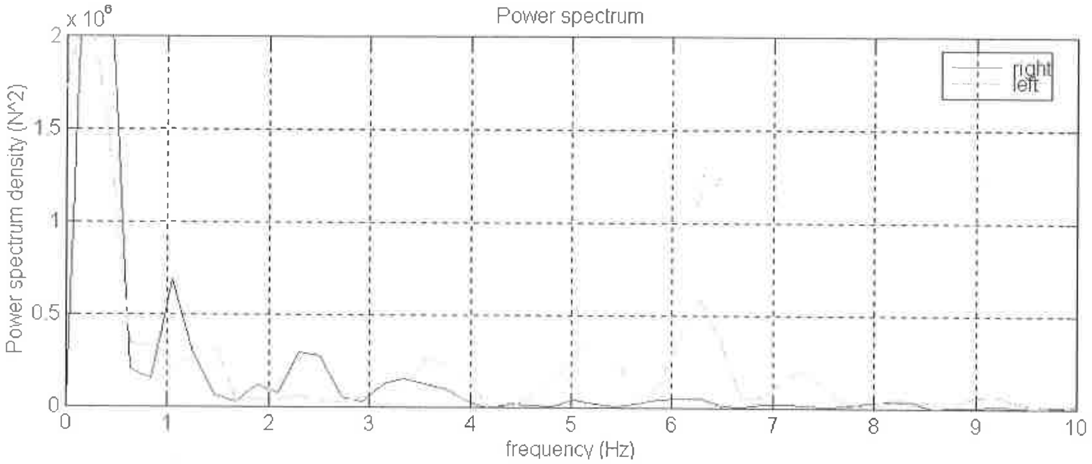
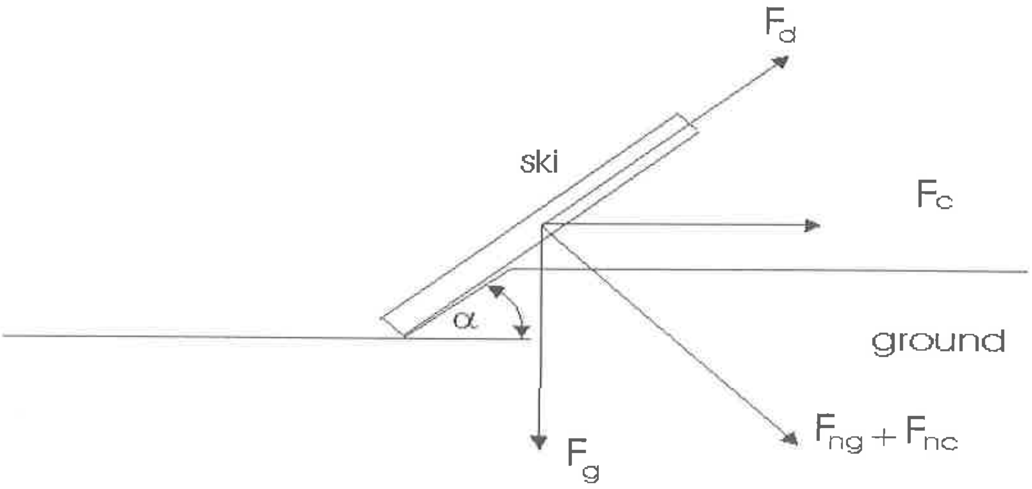


Figure 6: Force balance during the ski turn on well-packed snow.



The above results were obtained if the ski turn on carving skis was performed without the skidding. On the other hand, we have noticed that skidding on carving skis can provoke even greater vibrations compared to the vibrations on the classical skis under the same conditions. This phenomenon was noticed only on well-packed and icy snow. Typical response of ground reaction forces and power spectrum density for skidding on carving skis is shown in Fig 4 and 5 respectively. The side skidding on carving skis was explained using a model for side skidding on well-packed snow.

According to Figure 6, the force balance relation for a carving ski during the turn is presented with the following equation, where F_c denotes radial forces in the ski turn, F_g is gravity force, α is ski inclination angle, K_{fr} is the friction constant, and F_d is dynamic force that causes the ski to jump from the groove in the snow made by the ski. When the dynamic force is positive, i.e. when the radial forces are too large or the inclination angle is too low, the ski jumps from the groove. Here, we will use a heuristic assumption that the bent ski straightens when it jumps from the groove. Since the inclination angle remains the same, the tail and the shoulder of the ski come first into contact with the snow. The ski then bends until the point under the ski boot sole touches the ground. This is illustrated in Figure 7.

Figure 7: Bending of the skis in dependence of the side cut and length of the skis.

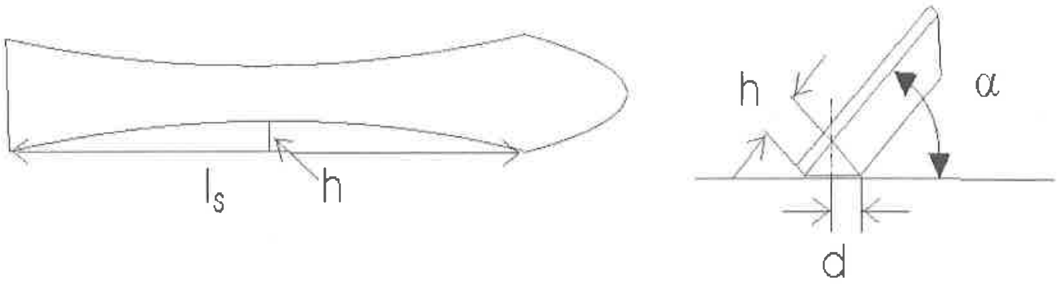
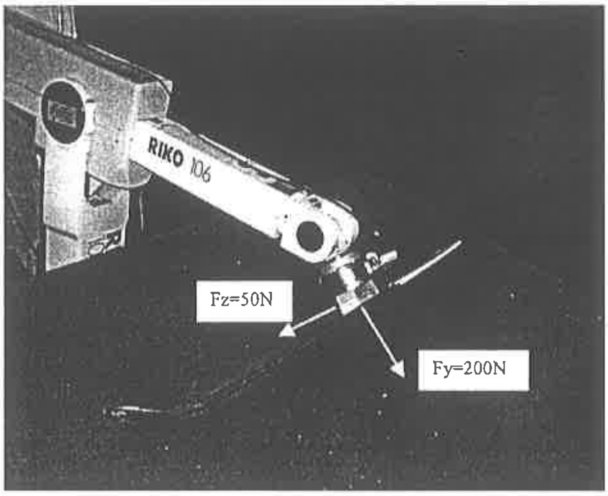


Figure 8: Industrial robot during the simulation of the side skidding



From Figure 9 it is evident that the parallel shift distance d normal to the ski direction l_S depends on side cut radius and length of the ski.

$$d = h\left(\frac{1}{\cos\alpha} - \cos\alpha\right)$$

The bulge factor h depends on the side cut radius r and effective ski lengt l_S and can be expressed as

$$h = r - \sqrt{\left(r^2 - \frac{l_s^2}{2}\right)}.$$

Therefore, longer skis with the same side cut r cause greater sideslip d. Additionally, a larger bulge factor h causes lower vibration frequencies with larger amplitude, which is less favourable.

We tried to verify the model with a simulation. For this purpose we used a force controlled industrial robot, which simulated side skidding (Nemec and Leonardi, 1999). Two skis were compared, one with classical (30m) and one with emphasised side cut (9m). The skis were pushed along a flat surface, covered with a carpet, with 200 N and 50 N in y and z direction respectively, as shown in Figure 8. With the flat surface covered with a carpet, we simulated hard terrain, such as well-packed snow. In order not to exceed the load capacity of the robot, we chose short (child) skis. The length of carving skis was 123 cm and the length of normal skis was 110 cm.

From the measured force-trajectory plot in Figures 9 and 10, we can see that carving skis oscillated with higher amplitude and lower frequency. This is the same result as it can be predicted by using our model.

Conclusions

We have presented in the paper a model for predicting vibrations during side skidding. The model is valid only for well-packed snow. According to our model, increasing the side cut radius and the ski length causes more vibrations during side skidding. We have verified the model with measurements on a ski slope and with a simulation using an industrial robot. The simulation with the robot has shown that the presented model is valid only for well-packed snow. If we changed the ground compliance or diminished the pushing force, there was no significant difference between carving and classical skis.

Figure 9: Results of the simulation of the side skidding, side cut = 30m

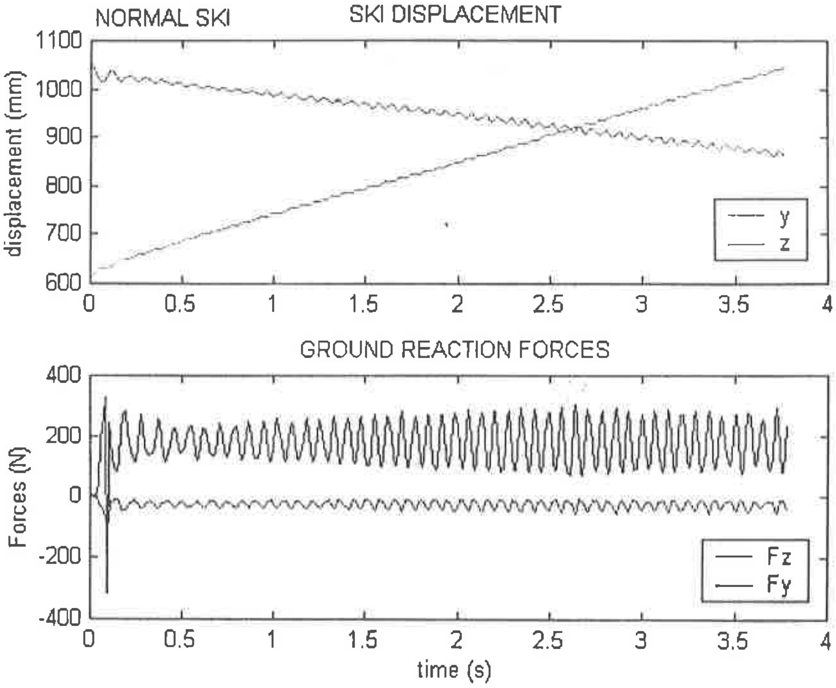
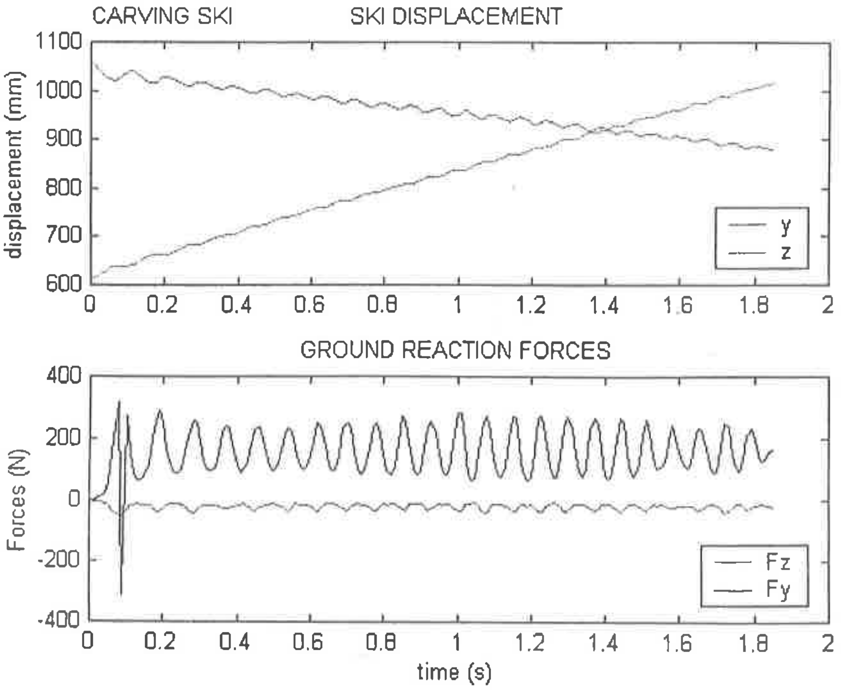


Figure 10: Results of the simulation of the side skidding, side cut = 9m



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Correspondence to:

Bojan Nemec,
Jožef Stefan Institute,
Jamova 39, 1000 Ljubljana, Slovenia
Tel: +386 1 477-36-56
Fax: +386 1 251-93-85
E-mail: bojan.nemec@ijs.si