INFLUENCE OF THE SKI SIDE CUT ON VIBRATIONS IN ALPINE SKIING

Otmar Kugovnik*
Bojan Nemec**
Matej Supej*
Milan Čoh*

VPLIV STRANSKEGA LOKA SMUČI NA VIBRACIJE PRI ALPSKEM SMUČANJU

(Received: 04. 11. 1999 – Accepted: 13. 11. 2000)

Abstract

In the paper we studied the influence of the ski side cut on vibrations during the ski turn. Vibrations were measured using ground reaction force measuring system. In our tests we found out that the vibrations on skis with emphasized side cut are generally lower comparing to the skis with classical side cut. On the other hand, carving skis can provoke excessive vibration in the case of side skidding. We have explained this phenomena using a heuristic model of side skidding for carving skis. The model was verified with the measurements on the ski slope.

Keywords: measurement, skiing, mathematical model

Izvleček

V članku smo preučevali odvisnost vibracij med izvedbo smučarskega zavoja in geometrijo stranskega loka smuči. Z uporabo sistema za merjenje reakcijskih sil podlage smo pokazali, da smuči s poudarjenim stranskim lokom v splošnem povzročajo manj vibracij med izvedbo zavoja kot smuči s klasičnim stranskim lokom. Med študijem pa smo identificirali situacije, kjer lahko smuči s poudarjenim stranskim lokom povzročijo dodatne vibracije. Fenomen smo razložili s hevrističnim modelom oddrsavanja pri smučeh s poudarjenim stranskim lokom, ki smo ga verificirali z meritvami na terenu.

Ključne besede: merjenje, smučanje, matematični model

*University of Ljubljana - Faculty of Sport, Gortanova 22, SI-1000 Ljubljana, Slovenia
**Jožef Stefan Institute, Jamova 39, SI-1000 Ljubljana, Slovenia

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

INTRODUCTION

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

In our work we have analysed the influence of the side cut of the skis on vibration caused by side skidding. Two categories of skis were compared: skis with classic and extreme side cut. Vibrations were estimated with measuring ground reaction forces. Power spectrum density of the measured force signals determined the amplitude and frequency of the vibrations.

During our analyses, we have noticed that the carving skis act differently if the skidding occurs. We tried to explain the behaviour using mathematical model of the skidding. In the past years several mathematical models of a turning snow ski were 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 (Renshaw and Motte, 1989) developed an empirical formula for icy snow impact model, where the ground reaction force depends on cutting depth and inclination angle. Hirano and Tada (Hirano and Tada, 1996) proposed another model, where they accomplished the material cutting theory. This model is valid for well-packed snow. Another model proposed by Hirano and Tada (Hirano and Tada, 1994) is based on snow pushing, calculated with water jet analogy. This model could be used on soft, powder snow, but with many restrictions, since this model does not produce any ground reaction forces without skidding. However, all proposed models assume turning with skidding, which is reasonable assumption for ski turn on classical skis. With carving skis it is possible to turn the skis without skidding, but experiments have shown that an effect similar to the side skidding can be noticed on certain circumstances on carving skis, too. In the paper we present a model for side skidding on well packed snow, which can be used also on carving skis. Our model was based on some heuristic assumptions, but was verified with the measurements on ski slope.

Similar study was presented in (Niessen, Muller, Raschner and Schwameder, 1996), but focused on vibrations of the skis. On contrary, 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 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 rate of 100 measurements per seconds. The measurement was synchronised with the video image. The block diagram of the ground reaction forces measuring equipment is presented in Fig 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 applying the fast Fourier transform on the measured force signals. We have used MATHALB and Signal processing Toolbox to accomplish this task. Power spectrum density analyses of the captured signals shows frequency and magnitude of the 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 on turns of a typical giant slalom run. The skier was experienced ski instructor. He performed equal ski turns; first using skis with emphasised ski cut (carving skis) with radius of 12 m and next using skis with classical ski cut with radius of 45 m. The snow was well packed, but not icy. The air temperature was +2°C.

RESULTS

Typical response of ground reaction forces and power spectrum density for carving and classical skis is shown in Fig 2,3,4 and 5 respectively. As it can be seen from the force plot, vibrations are smaller on carving skis. A better insight in vibration can be obtained observing power spectrum density plot, which shows the force vibration amplitude related to the frequency (Kugovnik and Nemec, 1998). Vibration at frequencies lower than 2 Hz are manly 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. Side skidding phase in the force plot was identified observing the video image. Over 100 ski runs were analysed and from those we have chosen the turns with the side skidding. In most cases they were correlated with the increased vibrations. Unfortunately, these ski runs were not performed at the same time, same snow condition and with the same skier, therefore statistical analysis was not feasible. Namely, the major part of the vibrations measured during the ski turn is due to the terrain irregularities.

Since carving skis enable to perform ski turn without skidding, vibrations with frequencies over 2 Hz are lower on carving skis. On the other hand, we can notice higher amplitudes on 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.

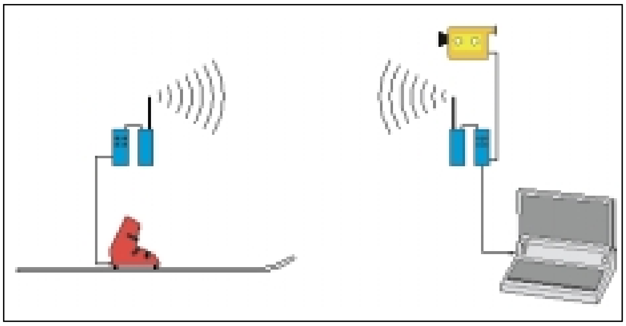

Fig 1: Measuring equipment

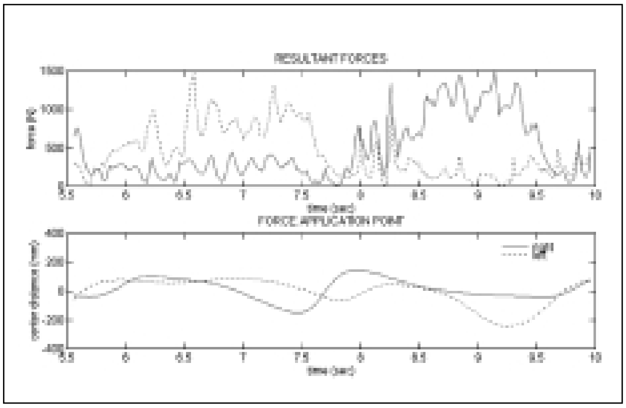

Fig 2. Ground reaction forces and force application point of two turns on carving skis

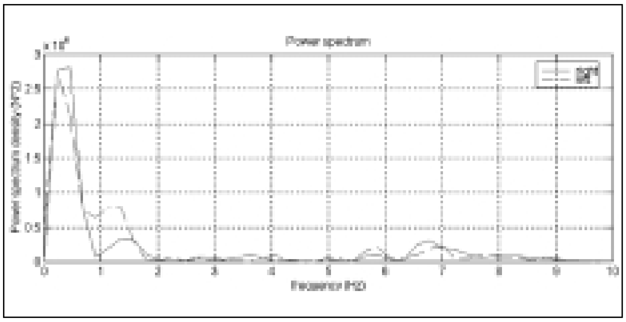

Fig. 3. Power spectrum density of the left turn performed on carving skis

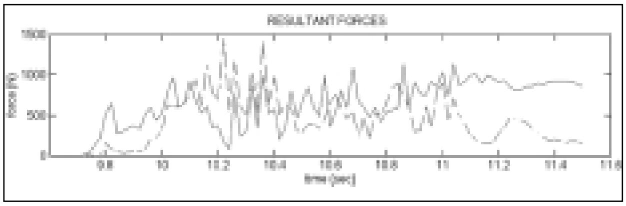

Fig 4:Ground reaction forces of left turn on normal skis

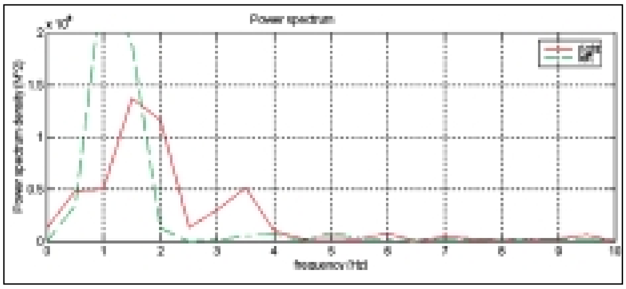

Fig. 5:Power spectrum density of the left turn performed on normal skis

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 comparing 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 6 and 7 respectively. The side skidding on carving skis was explained using a model for side skidding on well packed snow, which can be applied, also on carving skis.

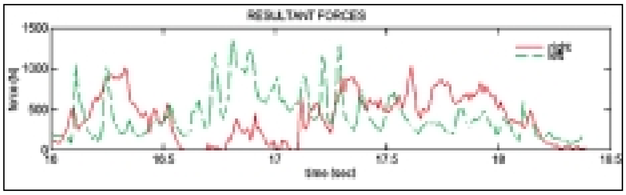

Fig. 6: Ground reaction forces of one ski turn with skidding on carving skis

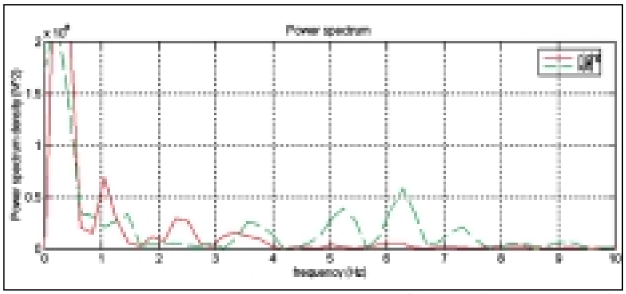

Fig. 7:Power spectrum density of the ski turn with skidding on carving skis

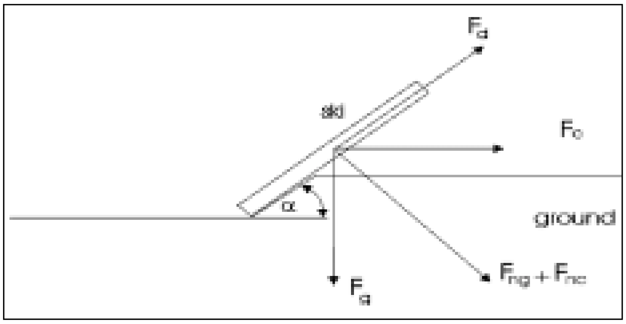

Fig. 8: force balance during the ski turn on well-packed snow.

According with the Fig 8, the force balance equation for a carving ski during the turn are presented with the following equation

$$F_d = F_c \cos\alpha - F_g \sin\alpha - K_{fr}(F_c \sin\alpha + F_g \cos\alpha),$$

where F_c denotes radial forces in ski turn, F_g is gravity force, α is ski inclination angle, K_{fr} is 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 inclination angle is too low, the ski jumps from the groove. Here, we will use a heuristic assumption, that the bent ski is straightened when it jumps from the groove. Since the inclination angle remains the same, the tail and the shoulder of the ski comes first in contact with the snow. The ski then bends until the point under the ski boot sole touches the ground. This is illustrated in Fig. 9.

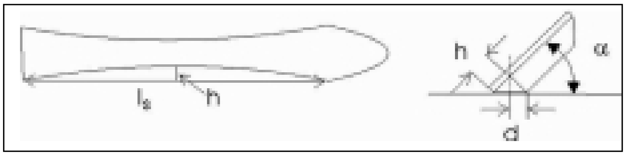

Fig. 9: Bending of the skis in dependence of the side cut and length of the skis.

From Fig. 9 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.

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

Bulge factor h depends on side cut radius r and effective ski length 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, larger bulge factor h causes lower vibration frequencies with larger amplitude, which is less favourable. Although our model is based on heuristic assumption, that the bent ski is straightened when it jumps from the groove, it gives similar results as they were obtained with the simulation of the side skidding using an industrial robot (Nemec and Leonardi, 1999).

CONCLUSIONS

In the paper we have compared vibrations during the ski turn using carving and classical side cut. It was demonstrated that carving skis generally cause fewer vibrations. Namely, carving skis enable to perform the ski turn without the skidding, which can cause undesirable vibrations. On the other hand, it was shown that carving skis could generate greater vibrations on certain snow conditions, if the skidding occurs during the ski turn. We identified the skidding phase of the ski turn by observing the video image of the skiing. Statistical validation of the results was not possible, since we didn't succeed to measure enough ski runs under the same circumstances.

REFERENCES

1. Hirano, Y. (1996). Numerical simulation of a turning alpine ski during recreational skiing. *Int. J. Medicine and Science in Sports and exercise, 28* (9), 1209-1213.
2. Hirano, Y., & Tada, N. (1994). Mechanics of a turning snow ski. *Int. J. Mech. Sci., 5* (36), 421-429.
3. Kugovnik, O., & Nemec, B. (1998). Analyses of vibration and shocks during the parallel turn in alpine skiing. In *Proceedings of ISBS '98* (pp.164-167). Konstanz: UKV – Univesitatsverlag Konstanz.
4. Niessen, W., Muller, E., Raschner, C., & Schwameder, H. (1996). Structural dynamic analysis of alpine skis during turns. In E. Miller, H. Schwameder, E. Kornexl & C. Raschner (Eds.), *Science and Skiing* (pp. 217-225). St Anton: E & FN Spon.
5. Nemec, B. (1997). A system for measuring ground reaction forces in alpine skiing. *Coaching and Sport Science Journal, 2* (3), 46-55.
6. Nemec, B., & Leonardi, M. (1999). Testing alpine skis using industrial robots. In *Proceedings of RAAD '99* (pp. 286-290). Munchen: Technische Universitaet Munchen.
7. Renshaw, A.A., & Mote, C.D. (1989). A model for turning snow ski. *Int. J. Mech. Sci, 31* (10), 721-736.