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The effect of elastic compensation arms on the field and laboratory behavior of alpine skis

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Abstract

An elastic compensation arm hinged at the binding plate and preloaded via a screw was applied to the ski shovel: its effect was to redistribute the pressure applied by the skier on the shovel and to allow the full contact of the edges on the snow during a turn. This enhanced the edge pressure profile at the shovel tip as revealed during bench tests in the lab, thus improving the handling during the turn phase as perceived in the field by expert testers.
Results of the study showed that it is possible to modify the edge pressure profile of a ski by means of the application of elastic compensation arms of suitable stiffness, preload and length. The improvement in the field performance is correlated with the specific engineering parameters that can be evaluated in a laboratory setup.

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Keywords: ski, edge load profile, compensation arm, subjective evaluation

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1. Introduction

The performance of modern skis is more and more related to the correct comprehension of the ski/snow interface behaviour, the effect of binding/plates/boots on the ski structural behaviour, the biomechanics of the skier, in the different types of skiing disciplines and environments [1-3]. Competition among manufacturers is not only based on marketing strategies but still involves the introduction of engineering or technological innovations that can enhance

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the properties of a product, create a new product segment or produce hybrid products that can bridge between different market segments by the introduction of superstructures or the tuning of adjustable components.

The use of elastic super-structures applied to the ski is not new, and almost all main manufacturers developed such solutions in the past or in their recent developments. On the other hand, among other properties, the Edge Load Profile of a carved ski on a flat surface has been studied extensively both by experimental, numerical or combined analysis [5-6]. This curves, at different edge angles, have been recognized as one of the engineering characteristics that can identify the ski properties: so far, the direct effect of an elastic super-structure on the edge load profile of a ski has not be presented, together with the quantification of the internal loads supported by the super-structure during skiing.

The description of the concept, the development and the field and bench evaluation of such a super-structure, covered by International Patents, is the aim of this work.

2. Methods

2.1. Elastic Compensator Arm and skis used

An Elastic Compensation Arm (ECA), as depicted in Figure 1, was applied to the ski shovel in order to enhance the edge pressure profile at the shovel tip. Its intended effect was to improve the edge catching and ski conduction during the turn phase: its function was to redistribute the load applied by the skier on the ski in order to produce a more intense pressure distribution to the shovel, to allow the full contact of the edges on the snow and to raise the anterior peak pressure (Patents EP 1641541 and US 7559571). It is composed by a cantilever arm (11) able to transfer the load to the shovel, hinged at (12) to an aluminium frame (15) to be fixed to the ski plates and preloaded by an adjustable screw (14). The tip of the arm can slide into a low friction slider (6) to transmit flexural and torsional loads (Figure 1).

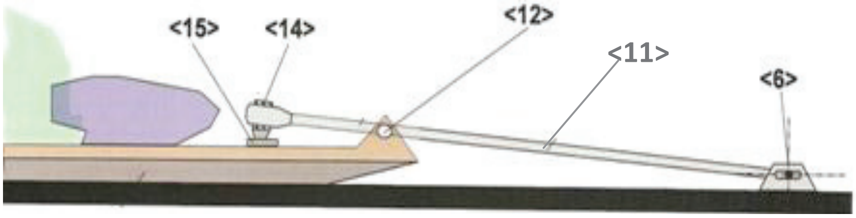


Fig. 1. The compensation arm concept and components. <11> arm, <12> hinge, <15> aluminium plate, <14> adjustable preload screw, <6> slider at the arm tip.

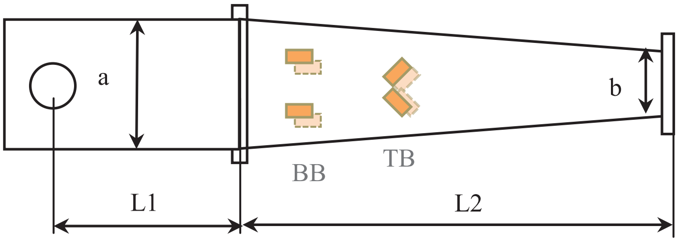


Fig. 2. Sketch of the compensation arm, with parametric dimensions and disposition of bending (BB) and torsion (TB) strain gauge bridges.

The effect of the arm length, thickness and number of preload rotation of the screw on the Edge Load Profile had been prior investigated by means of several laboratory tests [7], while keeping consistent the plate material. As a result, two versions of the elastic compensation arm were here examined: the difference among the two was only in the length of the portion connecting the hinge to the slider. Their effect on the shovel was different due to two reasons: the point of action of the slider (point <6> in Figure 1) and the resulting stiffness of the arm.

Two full strain gauge bridges were applied to arms SST4 and SLT4, in order to measure the Bending and the Torsion actions induced into the arm by the flexion and torsion of the shovel to which the arm is connected by the slider at its tip. The bending bridge was composed by four strain gauges HBM 3 120 LY43, aligned with the ski axis and applied two by two at the opposite faces of the arm, connected in such a way to sense the bending moment acting on the section. The torsion full bridge was obtained after applying two strain gauges HBM 3 120 XY43, with grids oriented at 45° from the ski axis, applied on each side of the arm.

Table 1. Dimensions of the two compensation arms adopted in the study.

	Material	Thickness [mm]	L1 [mm]	L2 [mm]	a [mm]	b [mm]
SST4	Steel	4	100	120	60	30
SLT4	Steel	4	100	250	60	30

Two sets of skis were used for the tests: a standard pair of Nordica GS for Giant Slalom, 182 cm long, R 23m FIS radius, and a modified Nordica ski (named GSM) presenting intentionally a 15% reduction of core thickness along the shovel, having the same side-cut and material layup of the original GS ski.

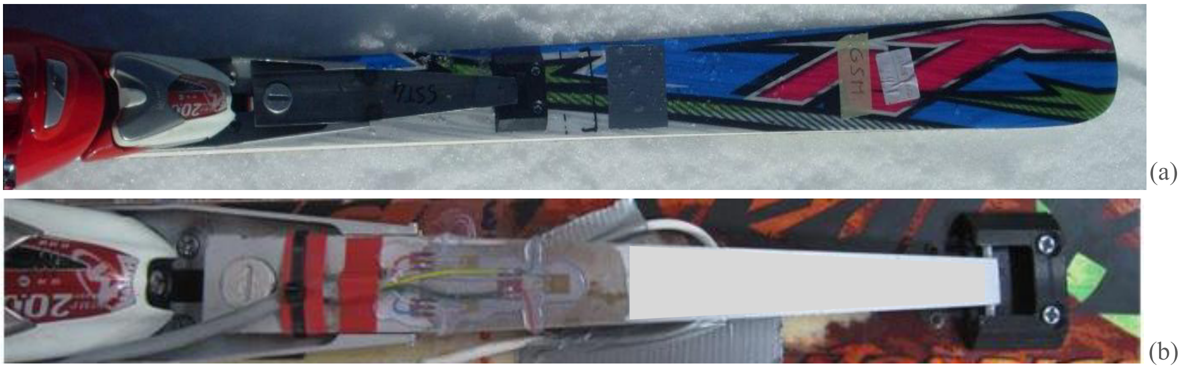


Fig. 3. Compensation arm applied to the skis during field tests. (a) Arm SST4 applied to Nordica GSM during field tests. (b) Arm SLT4 with strain gauge bridges applied for the field tests.

2.2. Laboratory tests

The test bench, developed by the Italian company Slytech™, is equipped with a set of 21 uniaxial vertical load cells disposed horizontally along the ski axis, sustaining each a rocking plate of 100 mm length, with rocking axis perpendicular to the ski axis, covered by a rigid neoprene surface on top.

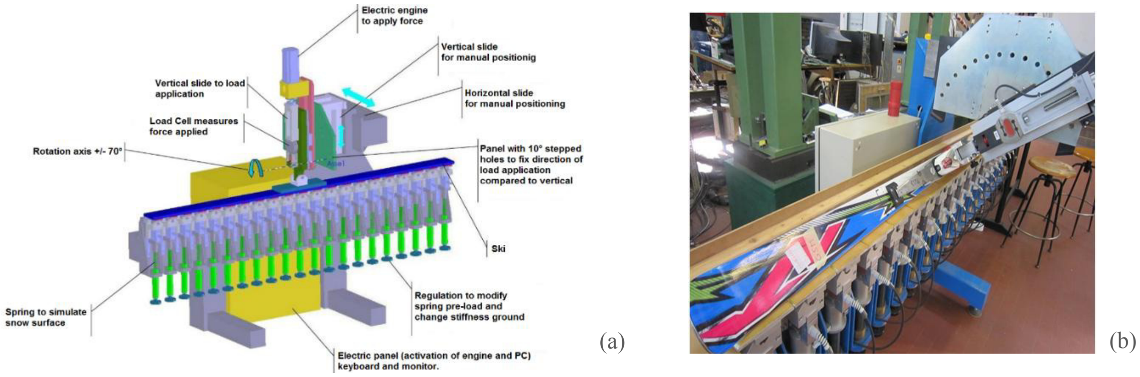


Fig. 4. (a) Sketch of Edge Load Profile test bench used; (b) The ski GSM equipped with SST4 arm during the tests on the ELP test bench.

A linear actuator with axis adjustable in a vertical plane is used to load any type of alpine ski on a bed of load cells: the edging angles can be varied at steps of 10°, ranging from 0° to +/- 70°. On each cell, the contact takes place between the ski sole and the stiff neoprene surface supported by each load cell.

The ski is connected to the actuator by a dummy boot sole made of aluminium, shaped as the ISO boot sole, presenting 5 positions of application of the load spaced of 50 mm from the boot midpoint: position placed at +50 mm from the boot midpoint was used in the tests.

Calibration tests were performed on the strain gauged arms to obtain their calibration constants: bending calibration after applying a known deadweight to the arm tip, torsion after applying a known torque.

2.3. Field Tests

Subsequently, the skis equipped with the arms of Table 1 were instrumented and tested in the slopes.

The normal Nordica GS skis were compared with the modified skis GSM without any arm or equipped with the SST4 arm. A group of 10 expert testers (ski instructors or former racing skiers) was involved in two days of field tests during winter season, with hard packed snow. Testers were required to give their subjective evaluation following the specific questionnaire developed for this purpose and reported in Table 2, similarly to former experiences [5]. The ski shovels were masked and no information were given in advance to testers regarding the modifications to shovels and the effect of the arm.

Each tester performed at least two runs at high speed with each pair of ski (GS, GSM, GSM+SST4): during each run, a portion of short Pole slalom (4m width, 16m step) was followed by a Free field slalom. After the test runs, they had to fill the questionnaire and to give a score to each of the perceived qualities of the two pairs of skis tested.

Table 2. Description of Questionnaire adopted during the field tests.

Q1 – EDGE CATCHING QUICKNESS:	Q3 – REACTIVENESS AT THE END OF THE TURN:
evaluate the readiness of the ski in catching the edge and entering into a turn.	*evaluate the capacity of the ski in "pushing" the athlete out of the turn, helping the edge change*
10 – excellent: very short time for catching the edge and entering into the turn	**10 – excellent:** ski exits the turn with maximum "push".
8 – good: short time for catching the edge and entering into the turn	**8 – good:** ski exits the turn with good "push".
6 – sufficient: long time for catching the edge and entering into the turn	**6 – sufficient:** ski exits the turn with enough "push".
4 – poor: very long time for catching the edge and entering into the turn.	**4 – poor:** ski exits the turn with no "push".
Q2 – CARVING PRECISION:	Q4 – VIBRATION DAMPING:
evaluate the precision of the ski in following the desired turning radius without skidding	*evaluate the capacity of the ski in damping the vibrations during straight skiing or edge change*
10 – excellent: very high precision – no skidding at all	**10 – excellent:** the ski does not present any perceivable vibration.
8 – good: good precision – no evident skidding	**8 – good:** the ski presents some perceivable vibrations.
6 – sufficient: sufficient precision – the skidding can be controlled	**6 – sufficient:** the ski presents evident vibrations.
4 – poor: poor precision – the skidding is evident and can hardly be controlled	**4 – poor:** the ski presents high vibrations affecting his performances.

3. Results

The results of the laboratory tests on GS, GSM, GSM+SST4 and GSM+SST4 skis at 40° edging angle are reported in Figure 5.a in terms of Edge Load Profile, measured at each load cell along the ski edge. As it can be appreciated from the analysis of the profiles, the shovel presents a wide unloaded portion on the GSM ski even at 40° edging angle, that the original GS ski (of good construction) did not presented.

On the other hand, the application of the SST4 arm on a GSM ski produces a "filling" of the unloaded portion of the shovel and induces loads peaks at the shovel larger than the GSM version. Both arms present a more uniform pressure distribution at the shovel, with a more advanced and pronounced peak than the original GS.

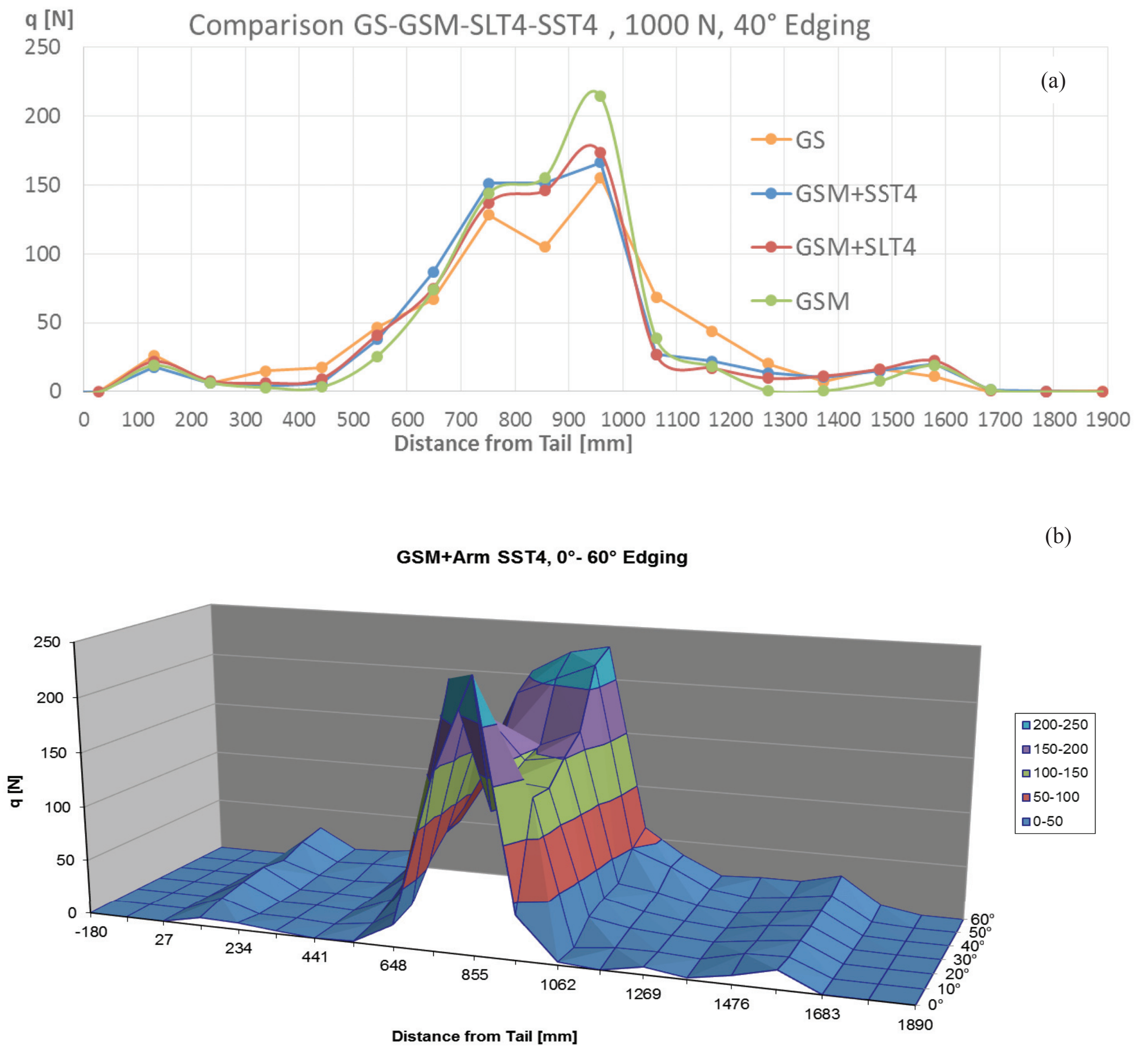
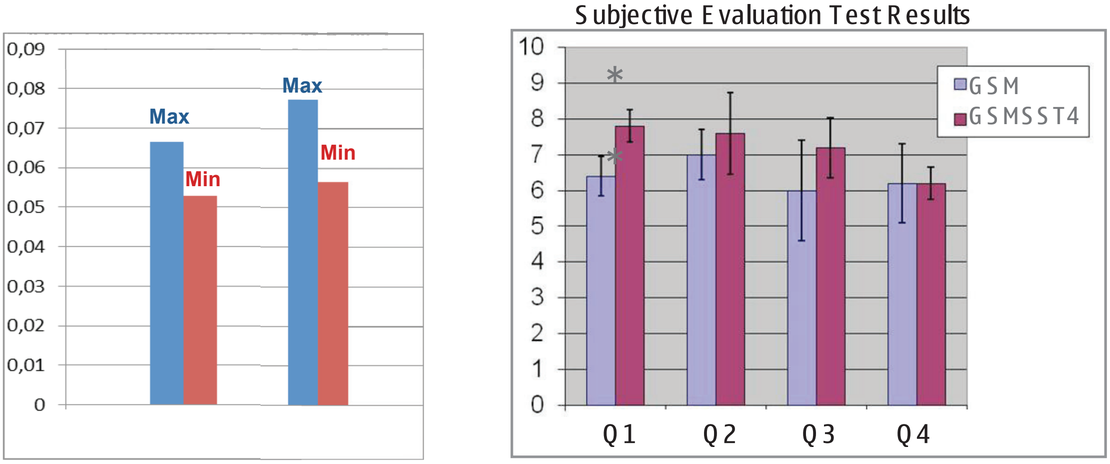


Fig. 5. Results of Edge Load Profile test bench. (a) Comparison of GS and GSM skis and of the effect on GSM of two arms SST4 and SLT4 at 40° edging angle. (b) The overall Edge Load Plot along the ski at varying angle for GSM ski equipped with SST4 arm.

The behaviour of GSM+SST4 at increasing edging angles is reported in Figure 5.b: the "filling" effect of the arm is increasing as the edging angle progresses from 0° to 60°. The secondary peak at the shovel increases accordingly, as well as the tail peak.

The bending forces acting on the arm tip are reported in Figure 6.a: values of the tip forces were normalized to the tester Body Weight. The effect of the skier's skill in loading the skis is expressed by the differences between the maximum (Max) and the minimum (Min) recorded values. These findings are essential for a correct structural design of the arms: with a 1000 N weight subject, bending loads of about 80 N at the arm tip can be estimated. Torsion loads, not reported for brevity, showed the contribution of the arm to the torsional stiffening of the shovel.

The answers to questionnaires of Table 2 are summarized in Figure 6.b as mean values with error bars corresponding to Standard Deviations: out of the three first questions, the modified ski GSM equipped with arm SST4 resulted to perform better than the modified ski GSM on average. Q1 only resulted however to show a significant difference ($p<0.05$) after a paired T-test analysis.



(a) (b)

Fig. 6. (a) Bending forces acting on the arm tip normalized to testers Body Weight (1 B.W.): Max/Min values. (b) Results of subjective evaluation tests to the four questions of Table 1, after the field comparison of GSM skis and the GSM equipped with arm SST4: mean values and SD bars. Q1 is the only presenting a statistically significant difference ($p<0.05$).

4. Discussion and conclusion

Despite the limited number of samples and field tests, results showed that it is possible to modify the edge pressure profile of the GSM ski by means of the application of elastic compensation arms of suitable stiffness and length. On the other hand, the subjective evaluation results show that the GSM+SST4 received significantly better score in the edge catching quickness. Being the only quantitative parameter to be changed, the present results seem to establish a correlation between edge changing quickness and the presence of a good peaked load distribution at the ski shovel. This however is expected to happen mostly on hard packed snow, as in the presence of mid or soft snow the effect of edge grip will be reduced and less perceivable.

These results encouraged however a deeper study of the flexural and torsional structural properties of arms for their implementation in further developments of ski production.

Improvements perceived in the field performance tests need to be systematically correlated to specific engineering parameters that can be evaluated in a laboratory setup, thus enabling the overall improvement of knowledge and ski design process.

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