Contents

Introduction

Padua's Mechanical University collaborates with different manufacturing companies to improve ski and snowboard equipment in order to enhance the security and the performance of skiing.

The part of the equipment that influences the most with its effects the quality of skiing is the ski boots.

There are numerous types of ski boots in the global market with different shapes, number of buckles, nominal Flex Index and other objective characteristics.

The principal feature of the ski boots is the Flex Index. It is the most commonly known value explicited by ski boots brands, which allows the costumer to recognize the stiffness of the boot.

Thanks to the ski boots the skier is able to control his/her movements while skiing, because his/her weight is gradually unloaded to feet and legs, and finally to the boots.

Aim of the Work

The work described in this thesis focuses on the main factors influencing the ski boot's behaviour. In this regards, I have analysed and described a set of ten ski boots characterized by different features. As far as this description is concerned, the independent variables considered are:

- the number of the buckles;
- the material;
- **the prosthesis**;
- **the work bench**;
- **the axial load**;
- **the test's velocity**;
- the extremes of the hysteresis cycle in terms of the bending moment and angle;
- **the temperature**.

The abovementioned-underlined factors are taken into consideration in order to define and characterize the behaviour of the ski boot.
As far as the previous thesis dealing with this kind of work are concerned, the test on the ski boots was made by positioning the angle sensors between the shell and the cuff and between the shell and the tibia, and they were employed on field tests. The analysed data and the angular extremes of the ski boot are taken as reference. In the flexion forward the displacement is bigger than the displacement according to the opposite way. Therefore, the angle's range is defined between 15 and -5 [°] in respect to the neutral position.
The velocities recorded in the field tests have different nominal values: the maximum flexion value is 160 [°/s], whereas along the extension the maximum is 190 [°/s].
In the field data only the angles, rather than the moment supported by the ski boot, are considered.
The work of my thesis focuses on the use of work benches and on the development of different systems' analyses. The systems' analyses include hydraulic actuators like the torsion machine with swinging lever and the linear actuators. In the following steps, the bending moments are measured in respect to the angles, whereas the hysteresis cycles are defined by employing the available instrumentation.
From a vivo test point of view, the ski boots are tested on a human tester in Padua's Bio-Mechanics Laboratory. In this regards, the aim of this working section focuses on the attention on the standardization of a univocal protocol, which could be employed in field and in other laboratories.

Chapter 1 : Flex Index

1.1. Definition

Flex Index [4] is a value whose goal is to quantify the applicable force that is requested to bend to a certain degree a definite ski boot. The force is applied to a lever simulating a leg inserted into a ski boot. The structural features of the boot should be able to modulate the stress impressed on the ski with its gambit bending flexion. In this way the boot is allowed to exercise an adequate control on the ski, and subsequently on the skier in every phase of his/her activity.

The binomial ski boot and ski should be taken as an elastic unit, and therefore the action exercised by the skier is the force simultaneously applied on this unit. This elastic behaviour, controlled by the elastic features of ski boot, lies at the base of the dynamic actions exercised while skiing.

Flex Index is to be valued by taking into account the technical level of skier. It is wrong to associate the Flex Index to the weight and the height of the skier. Indeed, given a skier's average body conditions (weight, height, training level), the higher his/her technical level is, the greatest is the dynamic stress affecting the skier's activity. Accordingly, a great technical level leads the skier in the search for an almost "exasperated" ski-limit and dynamic gesture, that a beginner would not be able to practice.

What happens if a skier wears a typology of ski boot whose Flex Index is inferior to its technical features? In this case, the skier feels little support by the ski boot, which does not allow him/her to drive the ski in a proper way. Conversely, if the Flex Index is higher, the skier feels like its foot is somehow blocked. Indeed, in this case the skier is

not able to properly move the ankle, which enables the skier to do as many configurations as the different curve types. Besides, if the skier chooses a ski boot typology whose Flex Index is higher than his/her technical capacity, she/he would not be able to correctly manage the damping needed on a disconnected slope.
There is another independent variable that influences the Flex Index, that is stiffness. The material building up the ski boot has its stiffness, which is inconstant as regards the temperature variation. The stiffness of the plastic material is given by the elastic modulus, which is the result of the relation between a tension imprinted on the material and the deformation of the same material [1], [4].

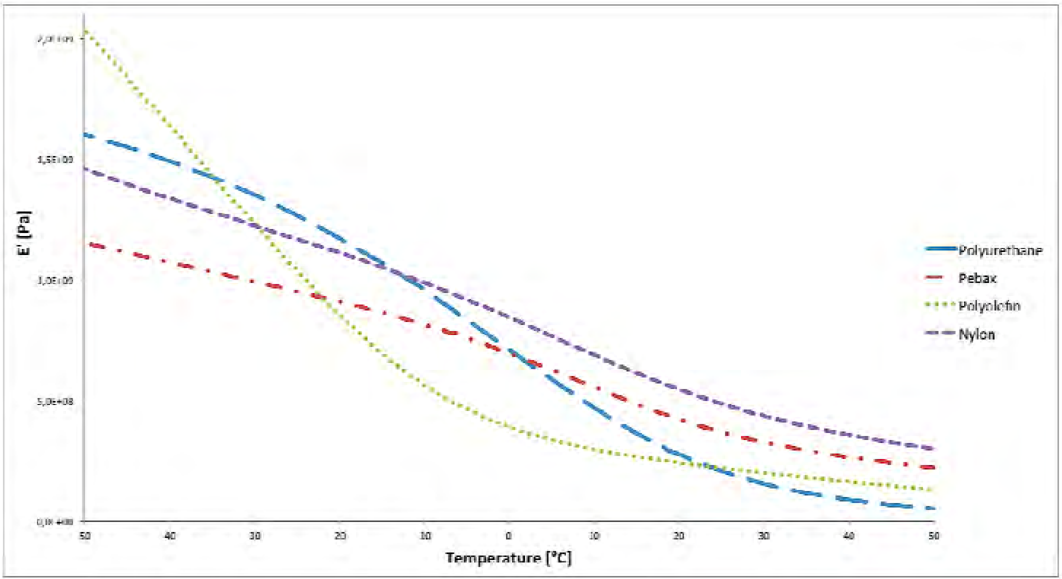


Figure 1.1 Storage modulus of plastic employed for ski boots' shell and cuff, measured at 1 Hz [3].

As the above *Figure 1.1* shows, the value of the elastic modulus varies according to the different climate conditions. This is the reason why sometimes the skier feels disillusioned when trying for the first time a pair of ski boots on the slope and feeling they are too rigid; whereas in the shop she/he thought they suited okay. Anyway, a ski boot is composed by many materials according to its different parts.
The elastic behaviour of a ski boot depend on many other parameters, such as the structure of the boot and the thickness of its parts. Besides, the test method employed to measure the Flex Index is an important parameter as it determines the Flex Index value.

Every brand of ski boot has its method for evaluating the Flex Index, and even nowadays it does not exist a standardised method to measure it. This value depends on a great numbers of variables and for this reason the Flex Index should be considered only as a data. In this way, the Flex Index of a specific branded ski boot cannot be compared to that of other brands. In this regards, a brand "arbitrary" Flex Index coefficient is continually exploited on a commercial level to make a branded boot to look more attractive than its competitors.

From a engineering point of view, the main goal is to find the true value of the Flex Index (eFI) as to correctly determine the value of a given ski boot. The Flex Index is the value of the bending moment applied to the boot hinge when a specific prosthetic leg is 10 degrees bent forward with respect to its neutral axis (where bending moment is null).

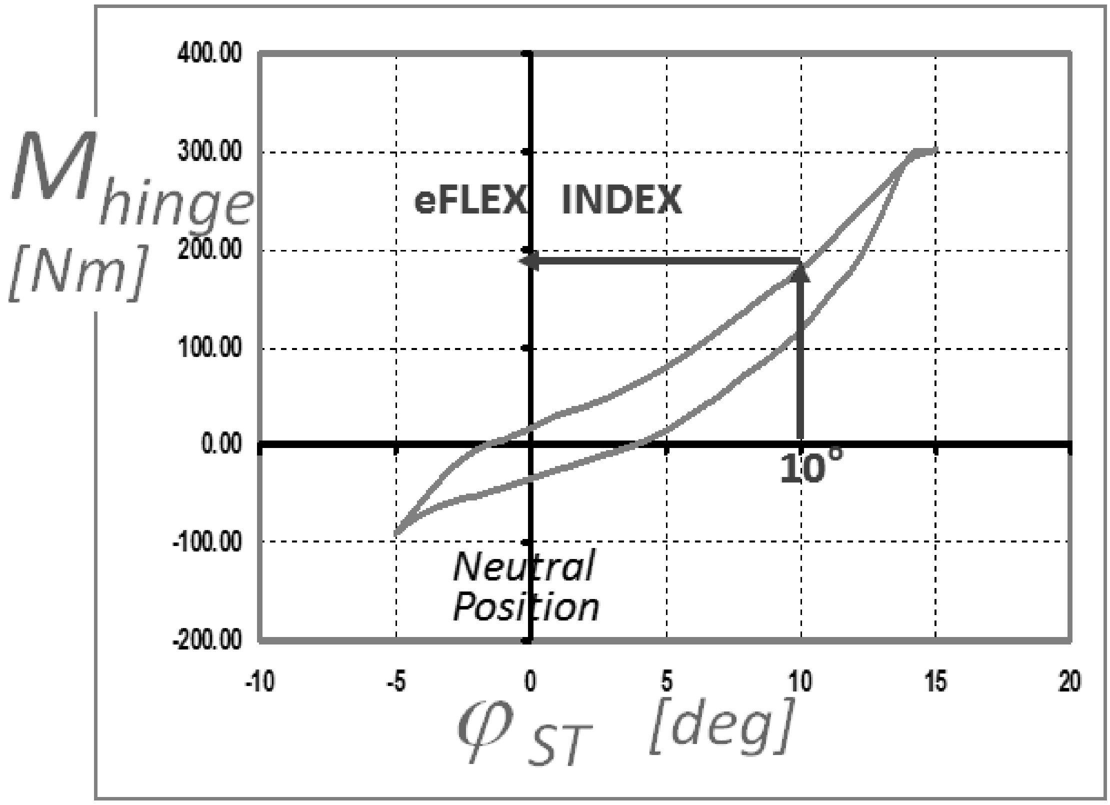


Figure 1.2 **Hysteresis loop and Flex Index relative to forward bending moment.**

The *Figure 1.3* below shows the subdivision of the ski boots typologies in different categories based on their Flex Index:

Ability	Beginner – Intermediate	Intermediate - Advanced	Advanced - Expert	Expert - Race
Flex Rating - Men's	60-80	85-100	110-120	130+
Feel	Soft	Medium	Stiff	Very Stiff

Figure 1.3 Indicative Flex Index of the ski boot.

There are different methods to analyse the Flex Index, however, this thesis is based on the work made employing a torsion machine and another work bench that are situated respectively in Padua and in Longarone, Italy.

The torsion machine is made up by two spindles: one generates the torsion moment and the second one remains fixed. The generated torsion moment is converted into the bending moment applied to the prosthetic leg, and finally the strain is transmitted to the ski boot. During this process, the boot is constantly connected to a ski binding that is supported by the second spindle.

Figure 1.4 Torsion machine.

The second and the third work benches are developed in Padua and in DolomitiCert (Longarone), and take its axial force from a MTS machines. Both test benches employed the same working principles. Thanks to a system formed be a mechanical rod it transfers the axial force to the prosthesis inserted into the ski boot.

Figure 1.5 Work bench in DolomitiCert (Longarone).

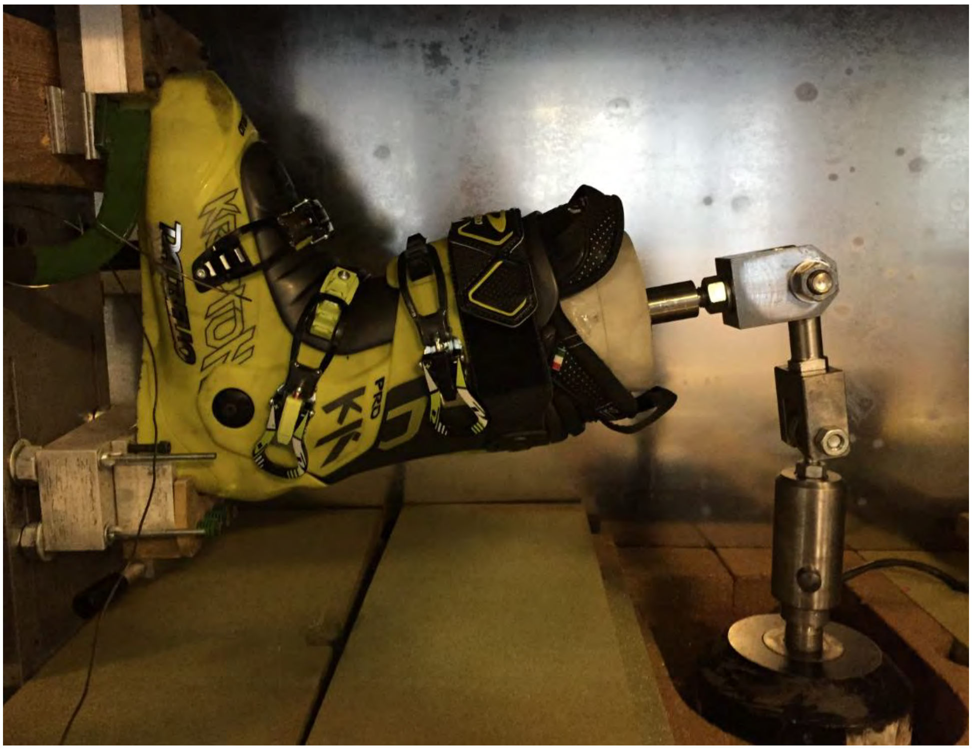


Figure 1.6 Work bench in DolomitiCert (Longarone).

The method of testing applied in both work benches session can be divided into two moments:

- in the first part, the focus is on the behaviour of the ski boot in a given environmental temperature (T ≈ 20°C);
- in the second moment a booth refrigerator is employed, and it is positioned above the test bench. In this way, the temperature drops to the temperature of use of the boot (T ≈ -10 ÷ -20°C).

Given the results obtained from testing different types of ski boots, the curve of forward/backward bending moment-angle is obtained. The curve is characterized by the loading and unloading phases: a complete cycle of loading and unloading defines the hysteresis loop.

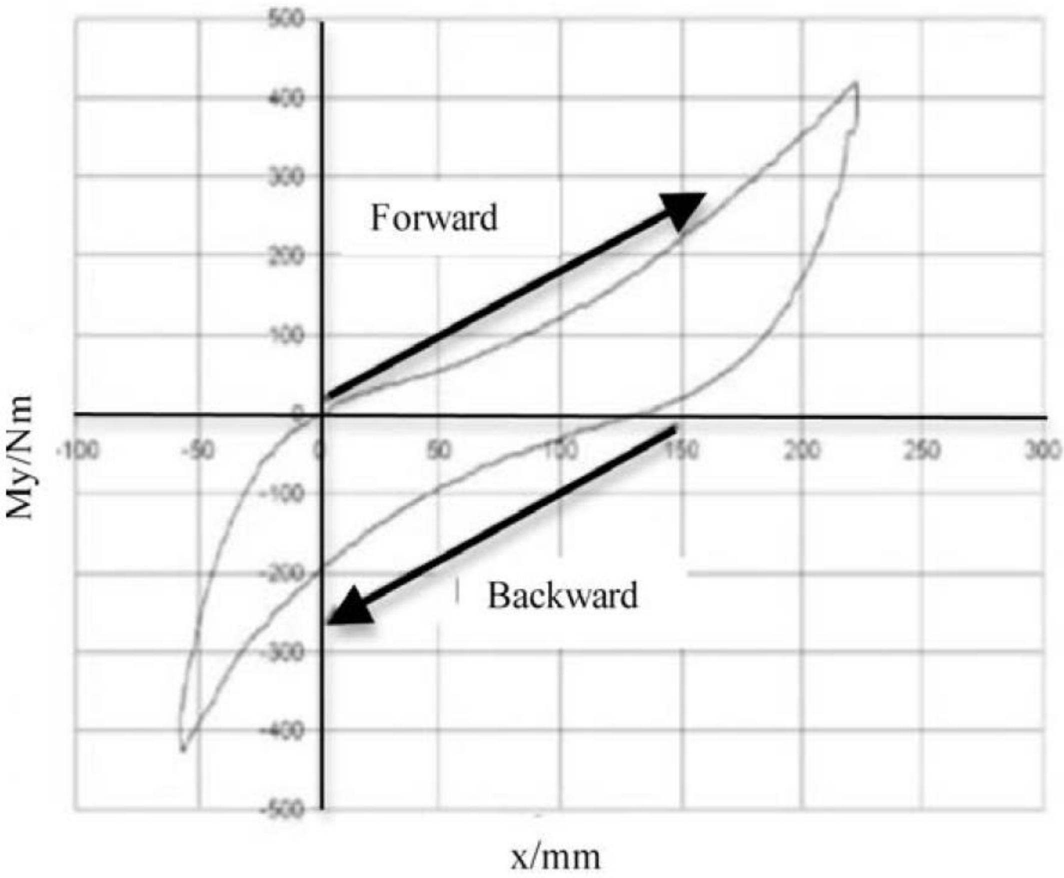


Figure 1.7 Loading phase (forward) and unloading phase (backward)

In the light of the above-mentioned, it is clear that the use the Flex Index as the only parameter of analysis is not sufficient in order to determine the stiffness behaviour of a determined ski boot.

From the hysteresis loop two different values of bending moment relative to 10° can be singled out: one refers to the forward bending moment (flexion direction) and second one to the backward moment (extension direction). This being said, it is possible to characterise the ski boot according to two Flex Index coefficients.
The conventional test procedure that is currently employed in the boot manufacturer laboratories accounted in this study consists in the cyclical application of flexion angles from +15° (forward) to -15° (backward) in respect to a neutral position of the boot.
One of the aims of this work is to understand which method of testing is more correct in simulating the real motion of the skier. Accordingly, in order to analyse the behaviour of the ski boot in my tests I have employed the range test from +15° to -5° in respect to a neutral axis.

1.2. Parts of the Ski Boot

In recent years, ski boots have been significantly improving thanks to the new materials and the new designed forms.
Ski boots are designed to transfer your movements into your skis, while supporting and protecting your feet, ankles, and lower legs. In order to correctly transfer the force, the boots have to be stiff so as to limit the movement of the ankles. Ski boots are pivotal parts of skiing equipment for two main reasons [2]:

- they protect the tibia and the foot from the solicitations occurring while skiing on the slope;
- they transfer to the skis the loads applied by the skier's body, thus enabling the skis to carve the snow and consequently to obtain the desired trajectory.

Besides, the ski boots should satisfy minimum requirements, for instance:

- they should be resistant to impacts at low temperature;
- they should have a long-term stability as regards temperature, UV aging and hydrolysis;
- they should return to their original positions after being flexed;

- they should have optimal viscous-elastic properties in order to obtain a progressive flex and an optimized rebound;
- they should not become too stiff at low temperature.

From a engineering point of view, each part of a ski boot is constructed so as to make it effectively work in consonance to the overall structure. Ski boots are composed by many parts, as shown in the *Figure 1.8* :

Figure 1.8 Parts of a ski boot.

1.2.1.Shell and Cuff

As far as the structural parts of the ski boot are concerned, shell and cuff are two essential elements [2], [3].

The shell is the solid outer layer of the ski boot, and it is made of two parts, the lower shell and the cuff. The lower shell is where your foot is contained, and the cuff is the part that wraps up your shin and lower leg. Shells are made of polymer plastics, often Polyurethane or Polyether. The function of the shell is to form the outer exoskeleton of

the ski boot, that is to hold everything together, to keep the ski boot attached to the ski binding and to provide the strength and stiffness of the boot.
The cuff is connected to the shell through two connective elements positioned near the two malleoli, in lateral and medial positions.

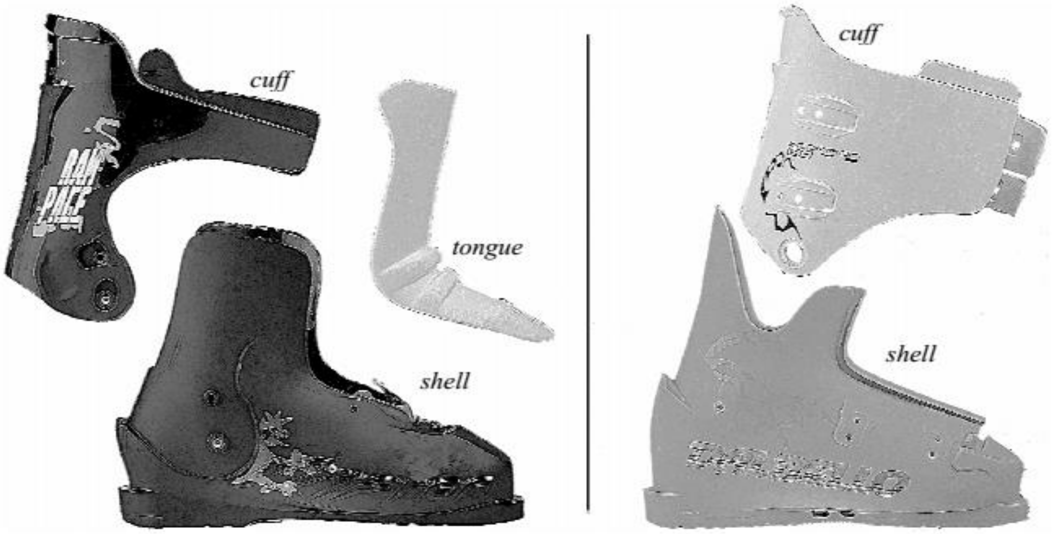


Figure 1.9 Structural elements: cuff and shell.

1.2.2.Liner

The soft part is made of the "liner" [2] [3], which is placed between the rigid part (shell and cuff) and the foot. It is composed of soft material so as to be modelled around the foot. This element varies in accordance to the different typologies of ski boot: for instance, a soft and thick "scarpetta" usually is designed for beginners.
Like the shells, liners can vary a lot. The main features and properties to look for in liners, however, are:

- liner thickness;
- heat mouldable.

The importance of these properties is due to the fact that the boot should be comfortable and able to insulate the foot from the cold, even though the skier will have less sensibility. A liner that is less thick will insure the skier more sensibility, for this reason this type of boot is designed for expert athletes. Nowadays, most of the liners produced contain heat activated materials adapted to the skier's foot profile.

The liner is supported by an element called "zeppa". The principal function of this element is to isolate the ski boot from the external temperature. "Zeppa" is often made of rigid plastic material.

Figure 1.10 "Liner" of the ski boot.

1.2.3.Buckles

The closing clips are made of metal or synthetic materials, in both cases they are valid and resistant [2], [3]. Almost all closing clips feature a micrometric regulation: the arch of the lever that it is attached to the teeth of the rack enables the user close the ski boot in accordance to the size of his/her foot. The closing system that is commonly used involves an extendable arm that can be locked into one of the several hooks reached, and which is eventually pulled tight and latched into the correct position. The length of the buckles in the majority of the boots can be fine-tuned by rotating the buckle arms.

Figure 1.11 Movement of the buckle.

1.2.4.Strap

The Velcro [2], [3] strap surrounding the top of the boot helps tightening the upper part of the ski boot to the skier's leg. This element heightens the level of adjustability and of performance of the ski boot.

Figure 1.12 Strap.

1.2.5.Insole

The insole [2], [3], or footbed, is the platform that lies at the bottom of the ski boot and supports the skier's foot. It is really important to give support to the profile of the foot for the overall comfort and the power of transmission it conveys. Anyway, the insoles that come with the ski boots often do not provide much support.

Figure 1.13 Insole used inside of ski boot

Chapter 2 : Boot Terminology

For describing the analysis of every ski boot on each work bench the same terminology will be used, as shown in the following *Figure 2.1*:

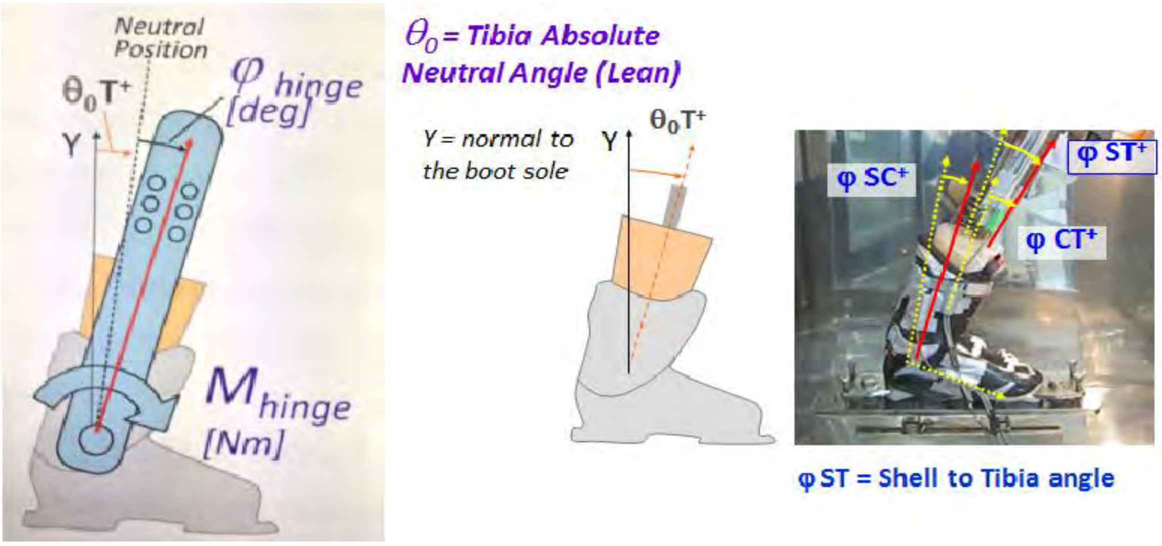


Figure 2.1 Terminology and *angles* used.

Where the angles respectively are:

- φSC the angle between the shell and the cuff;
- φST the angle between the shell and the tibia;
- φCT the angle between the cuff and the tibia.

The cuff in a neutral position can be defined as the natural leg posture obtained from closed buckles and no bending moment applied to the cuff on the hinge.

The neutral position has to be considered as a static absolute angle ϑ_0 between the Y vertical axis normal to the boot sole and a tibia reference axis.

Any change in the inclination of the tibia reference axis from its neutral position is to be intended as the forward or backward flexion angle φ_{HINGE}: this is a relative angle, between two different positioning of the tibia axis, due to the presence of a forward net moment M_{HINGE} applied on the hinge axis, which is able to move the prosthetic leg/tibia from its neutral position

.

Chapter 3 : Ski Boot - Buckles Closure

The aim of the buckles is to guarantee an easier and efficient closure of the shell and the cuff. As far as the quantity of buckles employed on a ski boot is concerned, it can vary, especially in accordance to its geometry.

The ski boots with high performance characteristics are usually composed by four buckles. Two of them are positioned on the shell and the other two on the cuff.

The ski boot with a Cabrio design has three buckles and a Micrometric adjustment system of the levers that is used to guarantee a more precise fit.

The closure system of every ski boot is based on a mechanism in which an extremity of the hook clutches to the teeth of a rack. Accordingly, this mechanism is made out of metallic material (e.g. Aluminum or Aluminum alloys).

Even tough there are different types of buckles' and ranks' structures, the closure system always works in the same way. When the hook clutches to the space between two adjacent teeth of the rack, it generates the necessary force of closing.

Figure 3.1 Buckle-closure.

3.1. Ski Boot - Strap Closing

The strap closing system is employed in different types of ski boots; its mechanism is placed in the upper part of the ski boot. It guarantees a precise closing and enables a good contact between the tibia and the gambit so as to permit a gradual flexion of the shank.

The strap system is made up by a clasp that is fixed to the upper and medial part of the ski boot. The strap has two extremities: one is fixed opposite to the clasp whereas the other passes through the hole of the clasp. The latter passing through the clasp is reunited to the former thus building up the strap closing system.

Figure 3.2 Strap-closure.

3.2. Forces in the Closing System

The regulation and the degree of closure of the ski boot is a personal factor depending on the skier.

The user chooses his/her degree of closure basing his/her research on the comfort, the security and the sensitivity of the ski boot.

From an engineering point of view, the closure system represents an important parameter as it can influence the behaviour and characterization of the ski boot, in particular the definition of the Flex Index.

The measuring values of the closing forces, which are involved and developed in the buckles closing system, are useful in the analysis of their correlation with the Flex Index.

Several systems of analysis can be employed in order to measure the abovementioned forces. This being said, in the work leading to this thesis, the chosen method of analysis takes into consideration the different types and brands of ski boot, and therefore varying geometries, structures and designs of buckles. Conversely, as far as the velcro is

concerned, it usually has a similar geometry so that there are little to no differences between the velcros of different brands.
In order to understand the evolution and the subdivision of the force into the buckles, an universal measuring system for different types of buckles should be employed. The two types of measuring systems enhancing this kind of analysis are:

- The application of a set of strain gauges on the single buckle;
- The building of a load cell and its insertion between the rank and the buckle.

The first case, that is the process of installation of the strain gauges on the buckle, requires lots of time and is very expensive, due mainly to the cost of the strain gauges. The second case is about building a load cell, as shown in the following *Figure 3.3*:

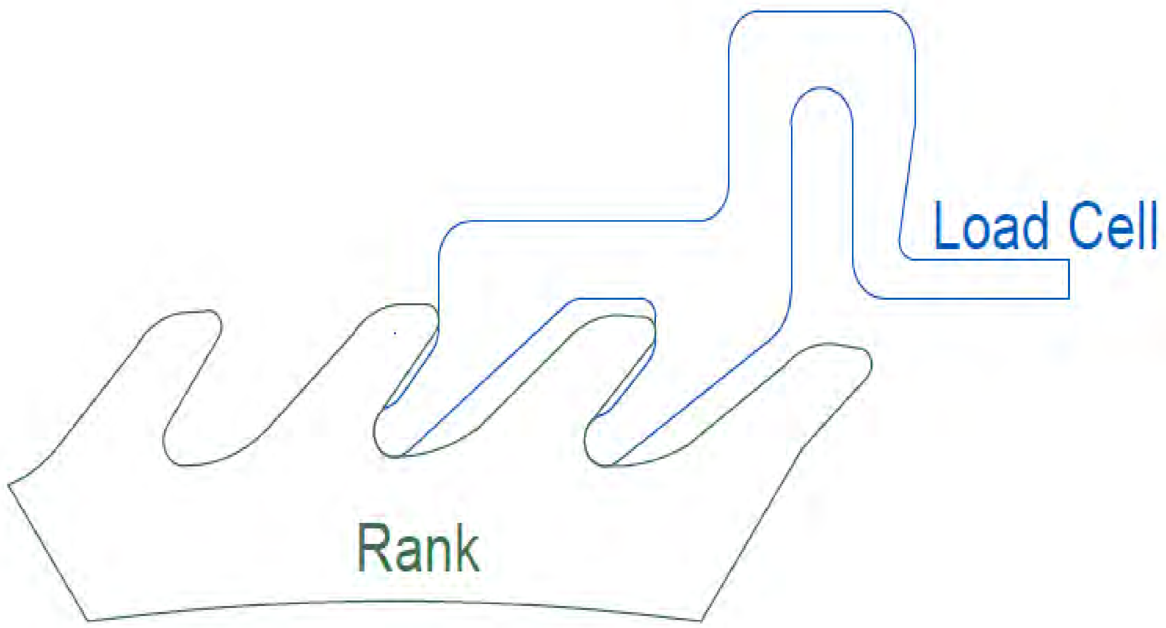


Figure 3.3 Load cell and rank of the ski boot.

3.3. Dimensioning and Verifying

In the dimensioning and verifying analysis the maximum value of the buckle's closing force is estimated at about 200 [N].

According to the previous *Figure 3.3*, the sketched load cell is positioned on the rack of the ski boot: the buckle passes over the rack and hooks the load cell. The closing force developed is transmitted to the load cell (clasp) that works in compression.
Now, taking into analysis the clasp, it can be said that it is divided into two parts:

- the stress analysis;
- the contact analysis.

3.3.1.Ansys Analysis

In this chapter, I am going to consider only the clasp (load cell) and the force, which is inclined of 20° ÷ 45° from the tangential line, passing through the rack. The force is applied in the approximated point, where the hook of the ski boot clutches to the load cell; this force is divided into two components, the horizontal and the vertical. Considering only the horizontal force thus overlooking the vertical one, the following values have been chosen:

- horizontal component of the force: F_x=200 [N];
- vertical component of the force: F_y = 0 [N].

The other data of the analysis are:

- the material of the load cell: Aluminium;
- the behaviour of the material: isotropous, elastic and linear.

In the following *Figure 3.4*, the point of application of the force and the restricted displacement can be seen.

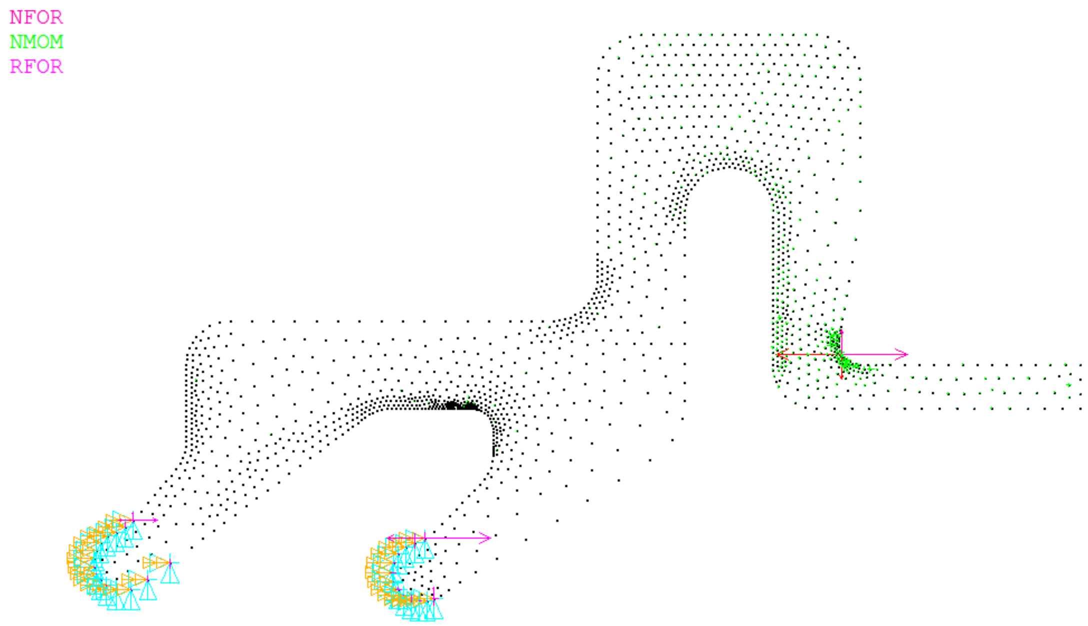


Figure 3.4 Application point of the forces F_y and F_x.

Besides, Ansys analysis enables to plot the deformed shape of the load cell and to valuatedthe hypothetical displacements along the principal directions (x and y axis).

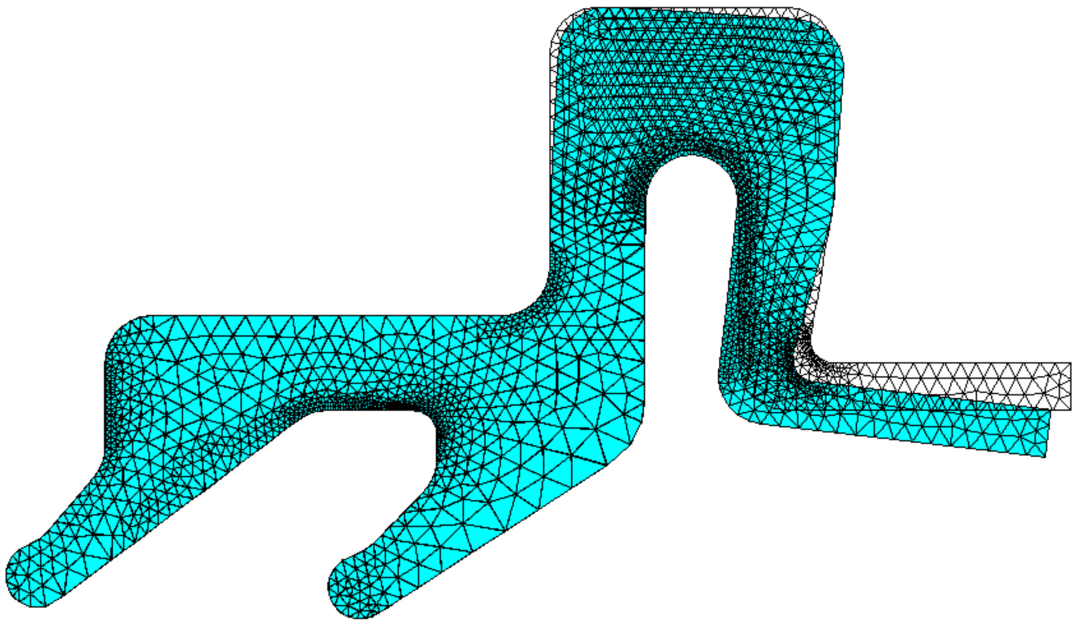


Figure 3.5 Deformed shape.

The simulation has given the following maximum values of displacement in the x and y directions:

- u_x = 0.034 [mm]
- u_y = 0.035 [mm]

As far as the static dimensioning of the load cell is concerned, it is performed using a constant value of the load, whose estimation is about 200 [N] (20 [kg].
The geometry of the clasp has a thickness of 10 [mm]. The complete quota of the load cell system is shown in the second *Figure 3.7* below. The thickness value is assumed to be 10 [mm], since the dimensions of the rack and of the buckles depend on the different brands of the ski boots.

Figure 3.6 Dalbello Krypton's rank and buckle forms (A), Tecnica Phnx 100 (B), Nordica Fire Arrows and Nordica Hell&Back (C).

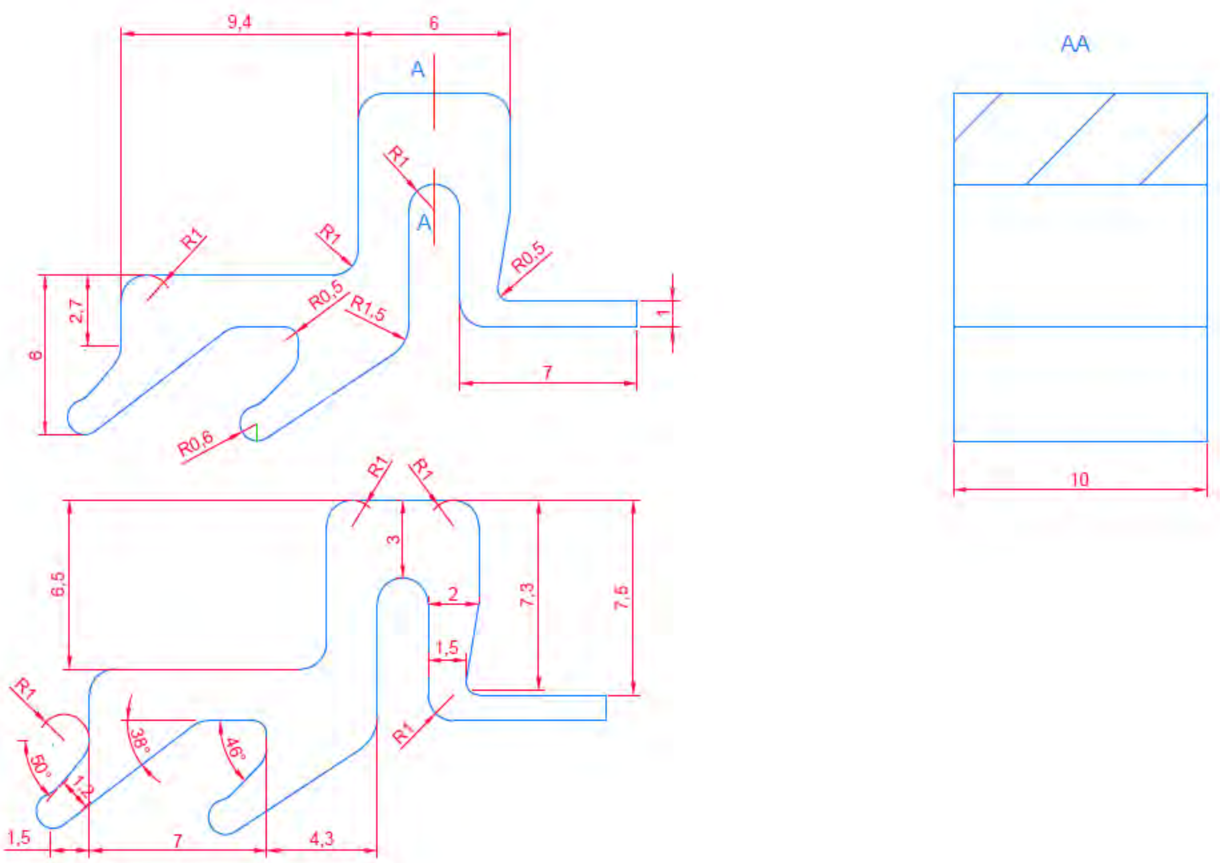


Figure 3.7 Dimensions of the load cell.

In Ansys analysis the finite elements modelling, the data for the load and the material of the clasp are employed:

- Load:
    - $F_y = 0$ [N];
    - $F_x = 200$ [N];
    - total closing force: 200 [N];
    - inclination in respect to the horizontal line: $\vartheta = 0°$.
- Material of the clasp:
    - $\sigma_{adm} = 480$ [MPa];

- E = 70 000 [MPa];
- $\nu = 0.33$;
- security coefficient: $\varphi_{s\ IP} = 3$.

o Critique section closed to the carving:

- b = 10 [mm] (along z-axis);
- h = 3 [mm] (along y-axis);
- Izz = 22.5 [mm^4].

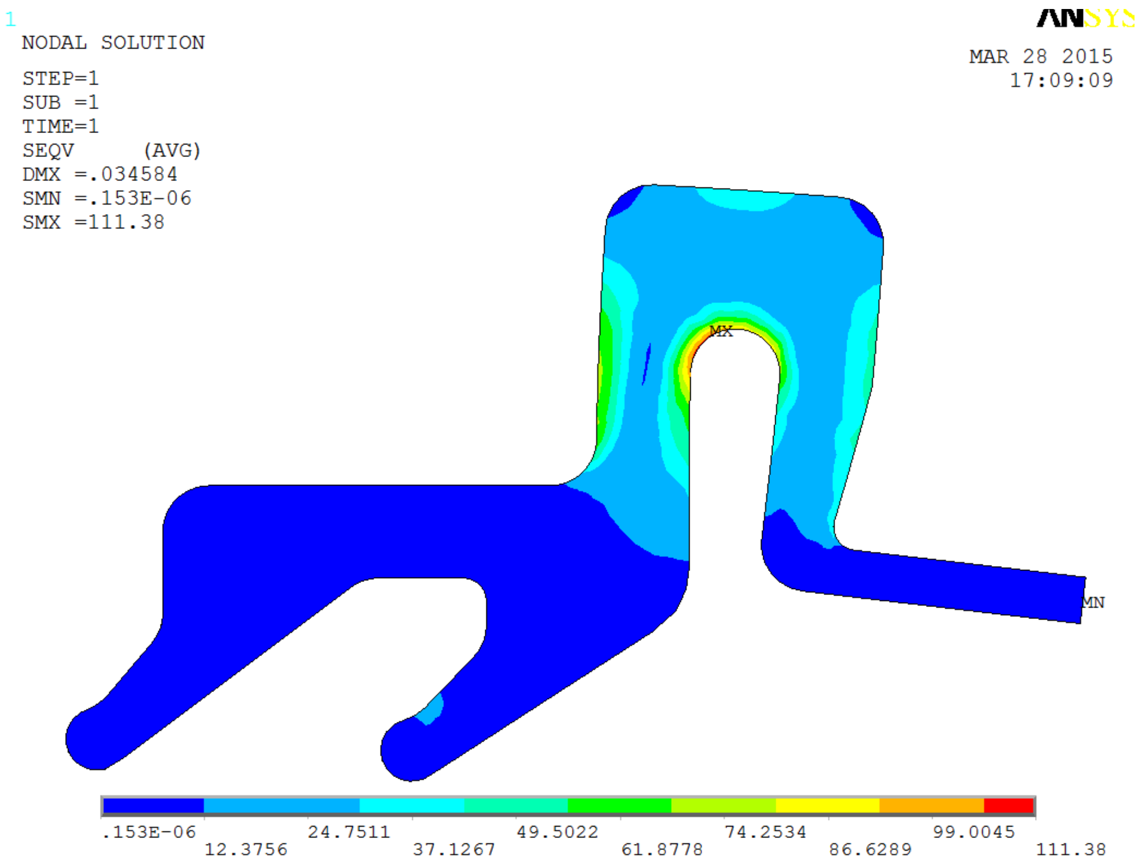


Figure 3.8 Von Mises stress in Ansys analysis.

The lines of the force always take the shortest ways. In the proximity of the carving, the typical effect of the "carving effect" can be seen, especially where the lines of the force tend to get close. In this regard, the "carving effect" involves in the stressing material a little portion of the very material. Whereas the opposite side of the material is subjected to an inferior tension.

In the following *Figure 3.9*, two extremity nodes of the critical section are marked with two red circles. Between these two nodes, a "path operation" that shows the progression of the Von Mises stress has been done.

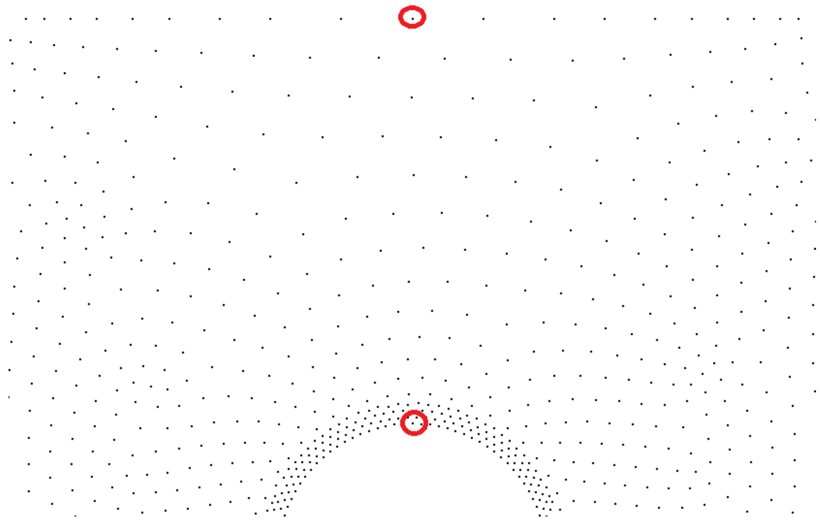


Figure 3.9 Extremity nodes of the path operation.

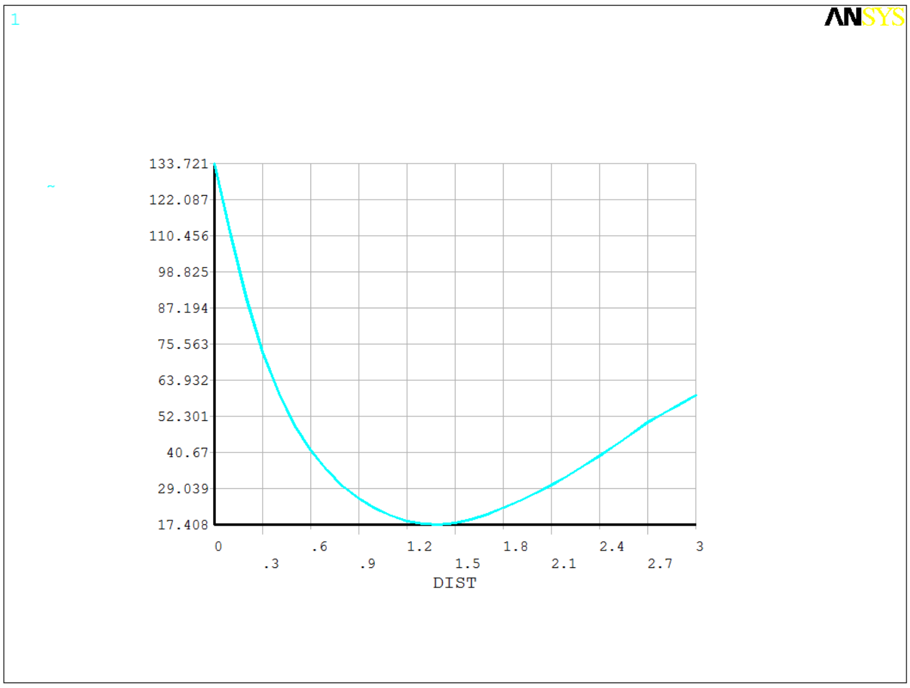


Figure 3.10 Tendency of the Von Mises stress.

The admissible tension is 480 [MPa], and, by considering the contacts between the hook and the load cell, the stressing value inferred is equal to 133,7 [MPa]. As a result, the load cell is finally verified according to the static dimensioning.
The following paragraph displays another examination, which is complementary to the last one. As we will see, an analytic approach will be used instead of the Ansys analysis, because even if Anasys is a good instrument, it is not perfect.

3.3.2.Analytic analysis

This chapter explains and analyses only the critical part of the load cell.
Accordingly, in the analytic analysis a simple studying model with its lever arms has been employed. Then the stresses of the bending moment, the axial force and the shear force are analysed. Finally, the resulting values of each stress are combined by using the Von Mises formula. The analytic verification is completed when the Von Mises tension is combined to the admissible tension employed.

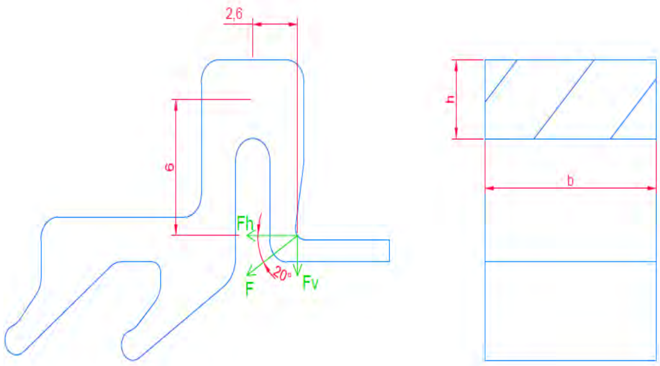


Figure 3.11 The forces F_h and F_v and the lever arms between the application point of the forces and the middle of the critique section.

Data of the analytic analysis:

- Fv = 0 [N];
- Fh = 200 [N];
- b_V = 6 [mm].

The inferred calculation is:

$$M_z = F_h * b_V = 1269 \ [N \ mm]$$

$$\sigma_{Mf} = \frac{M_f}{(\frac{b * h^3}{12})} * \frac{h}{2} = 84{,}6 \ [MPa]$$

The axial and shear forces and their respectively tensions are:

$$\sigma_N = \frac{N}{A} = \frac{F_h}{b * h} = 6{,}7 \ [MPa]$$
$$\tau_T = \frac{3}{2} * \frac{T}{b * h} = \frac{3}{2} * \frac{V_B}{b * h} = 4{,}7 \ [MPa]$$

The material employed in the analytic analysis is Aluminium and its admissible tension is 480 [MPa]. Again the security coefficient is to be found by correlating the admissible tension and the result of the Von Mises stress.

In the critical section of the material, two points are to be found: in the first one the stress of the bending moment has the same verse of the axial stress; whereas, in the second one, the contributions of the bending moment and axial stress have reverse directions.

In the first case, the Von Mises tension results in:

$$\sigma_{VM} = \sqrt{\left(\sigma_{Mf} + \sigma_N\right)^2 + 3 * \tau_T{}^2} = 91{,}6 \ [MPa]$$

The resulting security coefficient is bigger than the coefficient founded into Ansys analysis:

$$\varphi_s = \frac{\sigma_{Adm}}{\sigma_{VM}} = 5{,}2 > \varphi_{s\,IP} = 3$$

Chapter 4 : Instrumentation

The characterization of the ski boot, different instrumentation are employed. In this way, the study are involved:

- the prosthetic leg of the Department of the Mechanical Engineering of the University of Padua (PPS);
- the prosthetic leg of the DolomitiCert with a rigid "gambit" (PLR);
- the prosthetic leg of the DolomitiCert with a soft "gambit" (PLS);
- the prosthetic leg of the University of Innsbruck;

- the different type of the ski boots;

- work bench UTP: Unit Torsion Padua (MTS locates in Padua);
- work bench UFP: Unit Fixed Padua(MTS locates in Padua);
- work bench UFL: Unit Fixed Longarone (MTS locates in Longarone);

4.1. Prosthetic Leg

In order to simulate the mechanical behaviour of the skiing movements of the ski boot, four types of the prosthetic leg are employed in this analysis.

4.1.1.Prosthetic Leg Padua Silicon: PPS

The PPS prosthetic leg is realized in Department of Mechanical Engineering of the University in Padua.

It is made up by an internal structure and an external cover. The structure is build up by a hinge which it has the function of the human ankle.

The cover is made of the silicon material which it bestows the flexibility on the foot.

Accordingly, in the upper art of the foot, there is a screw that it can screwed on a tube. The principal function of the tube is to allow the use of the prosthetic leg in the Unit Torsion Padua. This tube is interchangeable and it can used for the prosthetic legs PLR and PLS.

Figure 4.1 Prosthetic leg.

The hardness of the material of the prosthesis is measured with two instrumentations: "Durometro Shore A" and the "Durometro Shore D".
The Durometro type A is a tool for the hardness testing of the rubbers products. The Durometro type D is employed for the hard/moderately hard plastic.

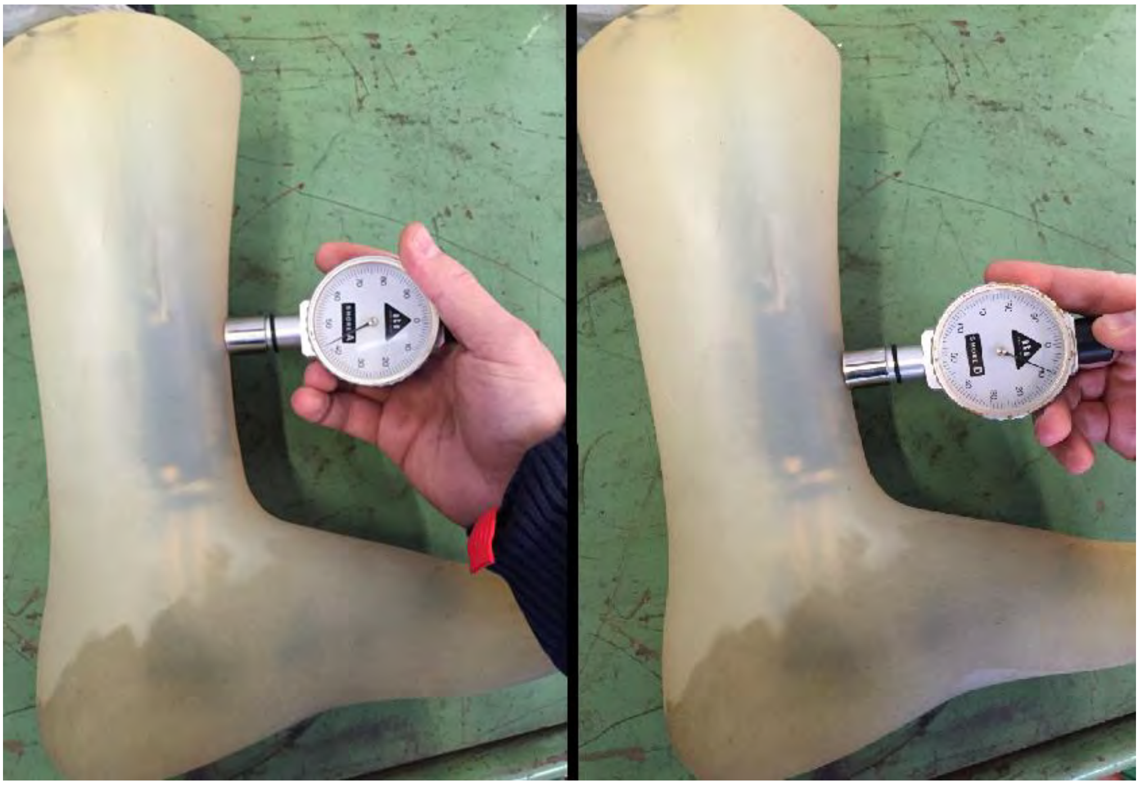


Figure 4.2 From the left to the right: the hardness measured with a Duromentro type A and with a Durometro type D.

They are different mechanical sensor, and their forms and dimension are shown in the *Figure 4.3* below.

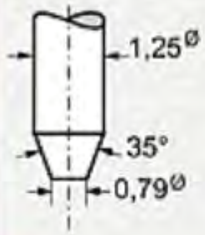
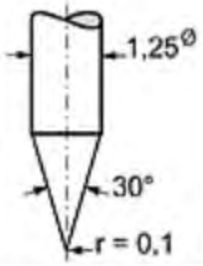
Process	Shore A	Shore D
Standards	ISO 868 DIN 53 505	ISO 868 DIN 53 505
Indenter	Truncated cone  	Cone 
Test load	9,81 N	49,05 N
Holding time	15 s	15 s
Uses	Soft elastomers, very soft thermoplastics	Hard elastomer, soft thermoplastics

Figure 4.3 The Durometro Shore A and Shore D.

The hardness is valuated in different point of the prosthesis (more than six) and the average of the results is taken. Anyway, the result of the average defines the typology of the material which it can be inferred in the Tab below.

Comparative hardness scales for soft materials

	Hardness scale						
		Rockwell		Shore			
Mohs	Brinell	M	α (≈R)	D	C	A (≈IRHD)	Types of product
2	25	100					Hard plastics
	16	80					
	12	70	100	90			
	10	65	97	86			
	9	63	96	83			Moderately hard plastics
	8	60	93	80			
	7	57	90	77			
	6	54	88	74			
1	5	50	85	70			
	4	45		65	95		
	3	40	(50)	60	93	98	Soft plastics
	2	32		55	89	96	
	1.5	28		50	80	94	
	1	23		42	70	90	
	0.8	20		38	65	88	Rubbers
	0.6	17		35	57	85	
	0.5	15		30	50	80	
				25	43	75	
				20	36	70	
				15	27	60	
				12	21	50	
				10	18	40	
				8	15	30	
				6.5	11	20	
				4	8	10	

Table 4.1 The Hardness tab for the Shore A and D.

The hardness of the PPS prosthetic leg is:

PPS		
point	Shore A	Shore D
1	46	8
2	49	8
3	48	9
4	47	9
5	47	9
6	47	7
7	47	8
8	46	8
9	48	7
10	47	9
11	49	9
12	47	10
13	48	9
14	49	8
15	46	7
16	47	6
17	47	7
18	47	7
19	47	8
20	47	8
Average	47,3	8,05

Figure 4.4 The hardness of the PPS.

4.1.2.Prosthetic Leg Longarone (PLR - PLS)

The second prosthetic leg is realized by DolomitiCert in Longarone.
It is made up by two parts: the foot and the leg.
The parts' material is different. A ankle-junction, placed between the parts, makes possible the relative movements between the two parts.

Figure 4.5 The foot, the ankle-junction and the leg.

As far as the dimensions are concerned, this prosthetic leg is short than PPS.
In order to use the prosthesis in the all work-benches, a cylindrical connecting element is built: an extremity is inserted into the leg and is jointed with the ankle junction. The other extremity is a screw. This element can be covered with a blunt conic-rubber: one is rigid and the other one is soft.

Figure 4.6 Prosthetic leg with rigid gambit: PLR.

Figure 4.7 Prosthetic leg with soft gambit: PLS.

Figure 4.8 The cylindrical connecting element.

The blunt conic-rubbers has different hardness and they have (circa) the same dimensions of the PPS prosthesis: the ellipses in three/four points along the central axis of the leg.

Another grasping system is used for the prosthesis of Longarone. The mentioned grasp is built by DolomitiCert and it is made out of a cylindrical element which it has an "eyelet". The eyelet enables the coupling between the prosthetic leg and a extensor element of the actuator. In this case the connecting rod is not employed, but a lot of the lubricant is used to prevent the friction action in the junction.

In figures below, the hardness of the two parts of the prosthesis (foot and leg) and of the two rubbers (rigid and soft).

PLR/S - LEG		
point	Shore A	Shore D
1	/	64
2	/	59
3	/	60
4	/	58
5	/	54
6	/	56
7	/	57
8	/	56
9	/	62
10	/	63
11	/	60
12	/	60
13	/	57
14	/	54
15	/	56
16	/	56
17	/	58
18	/	56
19	/	59
20	/	60
Average		64

Figure 4.9 The hardness of the prosthesis's leg.

PLR/S - FOOT		
point	Shore A	Shore D
1	58	16
2	59	16
3	61	15
4	57	15
5	57	15
6	59	15
7	6	15
8	59	16
9	59	18
10	58	17
11	57	16
12	58	14
13	59	15
14	56	16
15	61	17
16	61	17
17	59	14
18	59	15
19	58	15
20	59	14
Average	56	15,55

Figure 4.10 The hardness of the prosthesis's foot.

RIGID RUBBER		
point	Shore A	Shore D
1	51	9
2	51	9
3	49	12
4	47	11
5	57	13
6	55	12
7	55	10
8	56	10
9	53	11
10	54	11
11	55	12
12	58	13
13	55	9
14	56	13
15	59	12
16	54	12
17	56	11
18	58	10
19	58	12
20	59	12
Average	54,8	11,2

Figure 4.11 The hardness of the rigid rubber.

SOFT RUBBER		
point	Shore A	Shore D
1	31	5
2	36	4
3	25	6
4	37	5
5	35	5
6	25	4
7	26	6
8	35	6
9	34	6
10	36	6
11	33	5
12	37	5
13	35	4
14	35	5
15	38	4
16	38	5
17	37	6
18	37	4
19	38	3
20	38	5
Average	34,3	4,95

Figure 4.12 The hardness of the soft rubber.

4.1.3.Prosthetic Leg Innsbruck (PIR - PIS)

The third prosthetic leg is realized by the University of Innsbruck.

It is a prototype and it represents a mould of a real human right leg.

The prosthesis has a metal foot which can flex the sole of the foot in prone and supine directions.

The ankle is connected with the foot by a cylindrical joint and with the leg by another joint that it releases one degree of freedom: the flexion and the extension of the leg.

The leg is made up by an anterior and a posterior parts. The anterior part is fixed on the leg, whereas the posterior one is interchangeable: there are two posterior part, one is built up with a rigid material, the other with a soft material.

Figure 4.13 The prosthesis with a rigid posterior part.

Figure 4.14 The prosthesis with a soft posterior part.

Anyhow, there three "red" pieces, that they are filled up the space inside the shoe of the ski boot.

4.2. Ski Boot

In order to conduct the research, different types of the ski boot are employed. The ski boot used have different nominal Flex Index and are dedicated to diverse disciplines.

4.2.1.Dalbello Vantage 4L.

The Dalbello Vantage ski boot is for beginner to intermediate skiers. This boot has ratchet leg buckles which are easier to close than traditional buckles.
It also gives a larger adjustment range around the calf. The Dalbello Vantage is designed for the rental market that makes them tough and durable.
The nominal Flex Index is 60 [N m/°].

Figure 4.15 Dalbello Vantage 4L.

4.2.2.Dalbello Krypton PRO

The Dalbello Krypton PRO ski boot is for expert and complete skiers. It is versatile and precise.
The ski boot has a modular insert element (between the shell and the gambit) that is employed while the flexion regulation.
The closing system has three buckles and a strap in the upper part. The buckle on the point of the boot has an inverted closing movement. This characteristic wards off the damage of the buckle while the downhill and the evolution movements.

Other characteristic of this ski boot is the hinge between the cuff and the shell: the hinge is placed in a lower position than the traditional ski boots (it is shifted about 50÷70 [mm] downwards).
The nominal Flex Index is 130 [N m/°].

Figure 4.16 Dalbello Krypton PRO.

4.2.3.Nordica Fire Arrow F2.

The ski boot is oriented towards the expert skiers. Its performances and its technologies are higher than a traditional ski boot.
The closing system is composed by a strap and three buckles with relative micrometric screw for a precise regolation. The nominal Flex Index is 120 [N m/°]

Figure 4.17 Nordica Fire Arrow F2.

4.2.4.Nordica Hell and Back Hike Pro.

The Nordica Hell and Back ski boot is similar to the Nordica Fire Arrow. It is a lightweight ski boot thanks to the its material: a polymer with high density.

It has three buckles and a strap. A characteristic of this ski boot is the hinge between the shell and cuff. Anyhow, the hinge coincides with the closure of the second buckle. This feature enables that the flexion of the gambit is the same with the flexion of the leg.

The flex Index is 110 [N m/°].

Figure 4.18 Nordica Hell and Back Hike PRO.

4.2.5.Tecnica Phoenix 100

The Tecnica Phoenix 100 is for the intermediate skiers. The ski boot is made up by four buckles with their micrometric screws and a strap. The Air Shell technology enables the fitting regulation in the near of the heel. It is composed by two independent inflatable structures which are adjustable with a mechanism. The nominal Flex Index is 100.

Figure 4.19 Tecnica Phoenix 100.

4.2.6.Head Vector 120

The Head Vector 120 is for expert level skiers. It is designed especially for piste and off-piste. The ski boot is comfortable and easy to regulate.

The buckles are four and there is the double velcro. The function of the double velcro is to be the fifth and the sixth buckles improving the closure.

The Flex Index is 120 [N m/°].

Figure 4.20 Head Vector 120.

4.2.7.Head Next Edge

The Head Next Edge ski boot is for beginner skiers. This boot has four buckles and a strap in the upper.
It is easy to wear and has a double canting.
It is designed for the rental market that makes them tough and durable.
The nominal Flex Index is 70 [N m/°].

Figure 4.21 Head Next Edge.

4.2.8. The Prototypes

For the prosthetic legs comparison, two prototype of the ski boots are employed. In this regards, they have not yet a definitive name. One is designed for the expert skiers, whereas the other one is for the expert/intermediate.
In the analysis, they are called:

- Tecnica "Orange" 120;
- Nordica "Black" 100.

Figure 4.22 Tecnica "Orange" 120.

Figure 4.23 Nordica "Black" 100.

4.3. Work benches

4.3.1.Torsion Unit Padua (UPT)

In the University of Padua labs, a servo-hydraulic torsion bench is equipped for the execution of the felxion test on the ski boots.

The first work bench used is a servo-hydraulic torsion bench. This bench is adapted to be used for the execution of flexion test on ski-boots. In order to adapt this torsion bench to simulate a skiing session, it is used an mechanical-arm, that has empty rectangular section, which has two extremities: one is jointed with a "motor spindle" of torsion machine and the other one is free. On last one, find four bearings and their function is to allow to hook up the prosthetic leg with the mechanical-arm, like in next *Figure 4.24*.

Figure 4.24 Mechanical arm connects with motor-spindle of torsion machine

The bearings drive the pole of prosthetic leg and allow small relative displacements during the test along pole axis.
Therefore, torsion is converted in bending moment that is applied to the ski boot. It is possible to rotate together motor spindle of torsion machine and so also the mechanical arm using the MTS software.
A special ski binding, realized by the University of Padua, is used to anchor a ski boot to the bench ground in a rigid way. It is adjustable for different size of boots and can be calibrated between until 30 Din. It is regulated to the maximum value available (30 Din) so to block all degree of freedom of the plant of the boot.

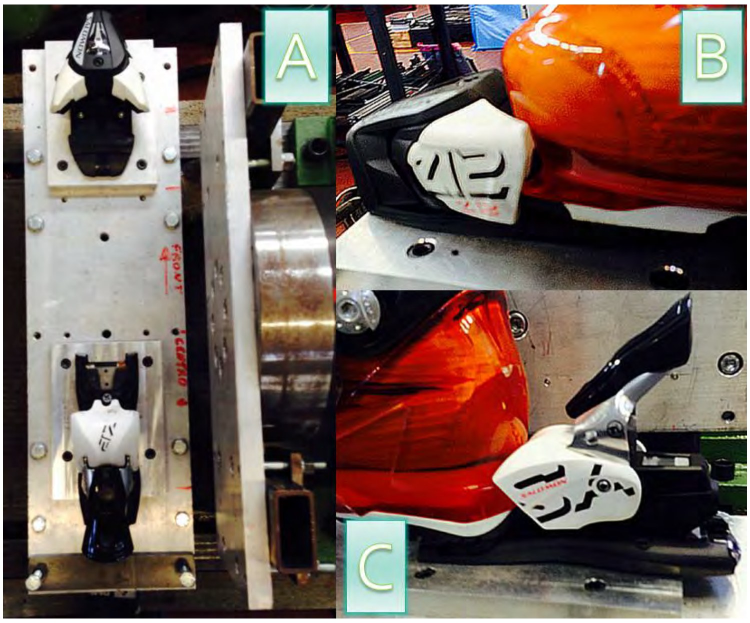


Figure 4.25 Ski binding (A); Anterior part (B); Posterior part(C)

4.3.2.Fixed Unit in Padua (UPF)

The second test bench employed is the Fixed Unit of the University of Padua. The term "Fixed" is defined the configuration of the work bench where an extremity of the hydraulic actuator is fixed. Therefore, the weight of the actuator does not lie on the prosthesis.
As far as this mechanical system is concerned, an analytic model is employed to study the relationship between the horizontal displacements and the angle of the prosthetic leg. Accordingly, the analytic study is applied to the crank mechanism, the measuring of

the lever arm (from the level of the actuator until the hinge of the ski boot) is measured and then the test is gone ahead.
The actuator is positioned at the fixing height to the bench and it can moved in horizontal direction.

Figure 4.26 The actuator of the Fixed Unit in Padua.

The ski binding employed to joint the ski boot on the bench is the same used in the precedent test bench, the Torsion Machine.

Figure 4.27 The ski binding employed in the UPF and in UPT.

The crank mechanism is made up by a connecting rod that its extremities are jointed with the actuator and one with the prosthesis.
In order to impart the forces and the displacements, the rod is composed by two spherical joints. In this regards the plane flexion of the prosthesis is enabled and the possible movements in other plane are allowed. The study is based on the plane flexion but the ski boot's form is not perfect and its flexion can be directed even only for a bit part in other directions.

Figure 4.28 The connecting rod and its spherical joints.

In the second part of this analysis, a freezer room is installed on the work bench. The freezer employed is enabled to amount to a constant temperature T = -20 [°C].

Figure 4.29 The Fixed Unit of Padua into the freezer room.

Taken into consideration the test's obstructions, an extension of the hydraulic ram is employed. In this way, the load cell is remained outside of the freezer and the measurements are not distorted.

Figure 4.30 The extension of the hydraulic ram.

The axial kinematic system has to operate into the freezer cabin. The refrigerator does not carry out a structural role because its material (plastic and insulation materials) could not support the loads inferred by the cold-tests. At the low temperature, the ski boot is inclined to increase its stiffness and the necessary loads for the execution of the test. In this regards, four cylindrical support-elements are fixed with the bench and pushed through the base of the cabin. Into the freezer, a structure is placed and jointed with the four supports. In this way, the loads are unloaded to the four support and not to the cabin of the freezer.
The functions of the structure into the freezer and on the lock plate, are:

- support the extension of the hydraulic ram;
- keep an axial movement of the hydraulic ram as much as along a horizontal line;
- escape the contact between the extension of the ram and the freezer. In particular on the wall of the cabin, a hole (about 20 [mm]) is made for the passage of the ram. The dimension of the hole is smaller for minimize the temperature loss.

4.3.2.1. Model of the Fixed Unit in Padua

In order to analyse the ski boots with the UPF work bench, a analytic model is employed. The independent variable of the this axial mechanism is the stroke of the actuator x. In this regards the horizontal displacements are converted into angles between the tibia and ski boot's shell θ_1. The last variables are the angle of the rod in respect to the actuator θ_2, the length of the rod a and the distance between the ski boot's hinge and the prosthesis's joint b

The model is shown in *Figure 4.31* below.

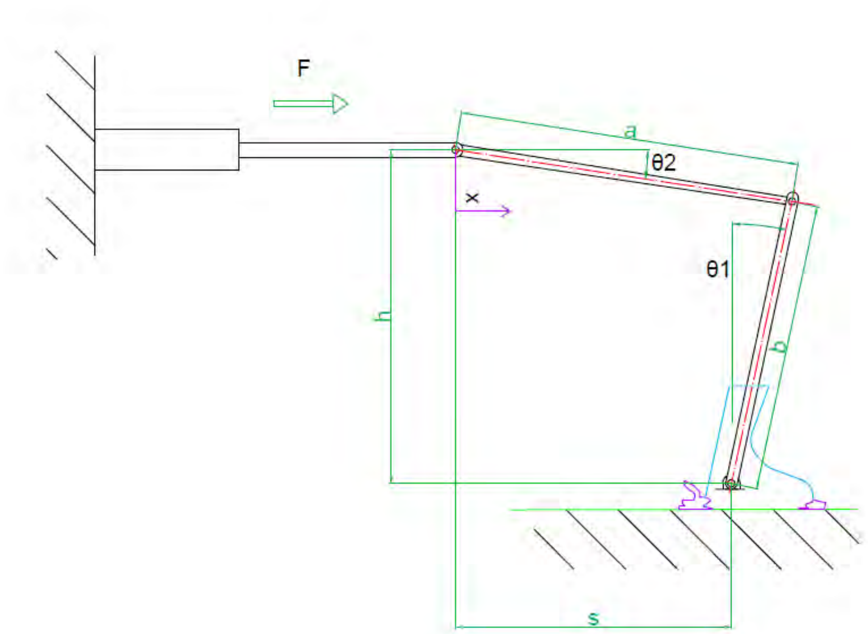


Figure 4.31 The model of the work bench UPF and the variables: X, ϑ_1 and ϑ_2.

The inferred calculation is:

$$\begin{cases} a\ \cos\theta_1 + b\ \cos\theta_2 = s \\ a\ \sin\theta_1 + b\ \sin\theta_2 = h \end{cases}$$

With the derivation of the equations in respect to the time, it is obtained the velocities:

$$\begin{cases} -\dot{\theta_1}\ a\ \sin\theta_1 - \theta_2\ b\ \sin\theta_2 = \dot{s} \\ \dot{\theta_1}\ a\ \cos\theta_1 + \dot{\theta_2}\ b\ \cos\theta_2 = 0 \end{cases}$$

$$\dot{x} = \dot{s} = -\dot{\theta}_1 \, a \, (\sin\theta_1 - \cos\theta_1 \tan\theta_2)$$

The choice of the axial range has been made taking into consideration the inclination of the prosthesis's tibia. The system is not composed by the real axles like in the model, therefore the angle of the prosthetic leg (and so the vertical range of the actuator) is measured with a digital lever.

4.3.3.Fixed Unit Longarone (UPL)

The third work bench employed for the flexion test of the ski boots is the DolomitiCert's Fixed Unit.

This test unit is composed by an axial MTS machine, a ski binding and a connecting rod shorted than the rod employed in the Fixed Unit in Padua.

The actuator of the axial machine is putted in vertical position and on the top of the actuator is installed a load cell which it measures the axial force.

The machine can be moved along the longitudinal axis, but for the test it is clasped in a fixed position.

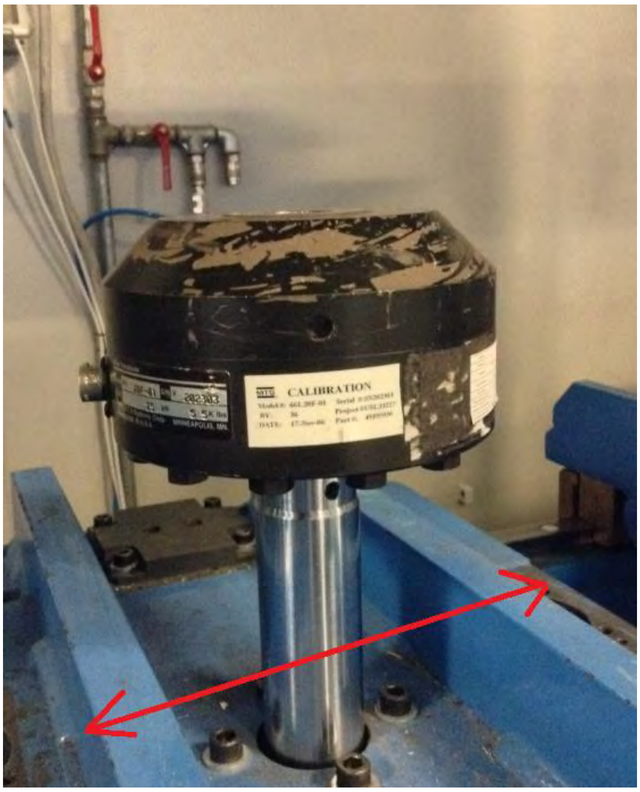


Figure 4.32 The actuator of the Fixed Unit

The ski binding is made out of the metal material: steel and copper's alloy. It is composed by two blocks, one is anterior and the other one is the posterior part. The posterior block has a lever arm: this system simplifies the insertion of the ski boot into the ski binding and clamps it. The distance between the two blocks is not unmovable and it can be regulated it on the strength of the ski boot's size. The regulation is adjustable with four screws that can move upwards or downwards the above block
The blocks are fixed with a structure which is jointed on the bench.

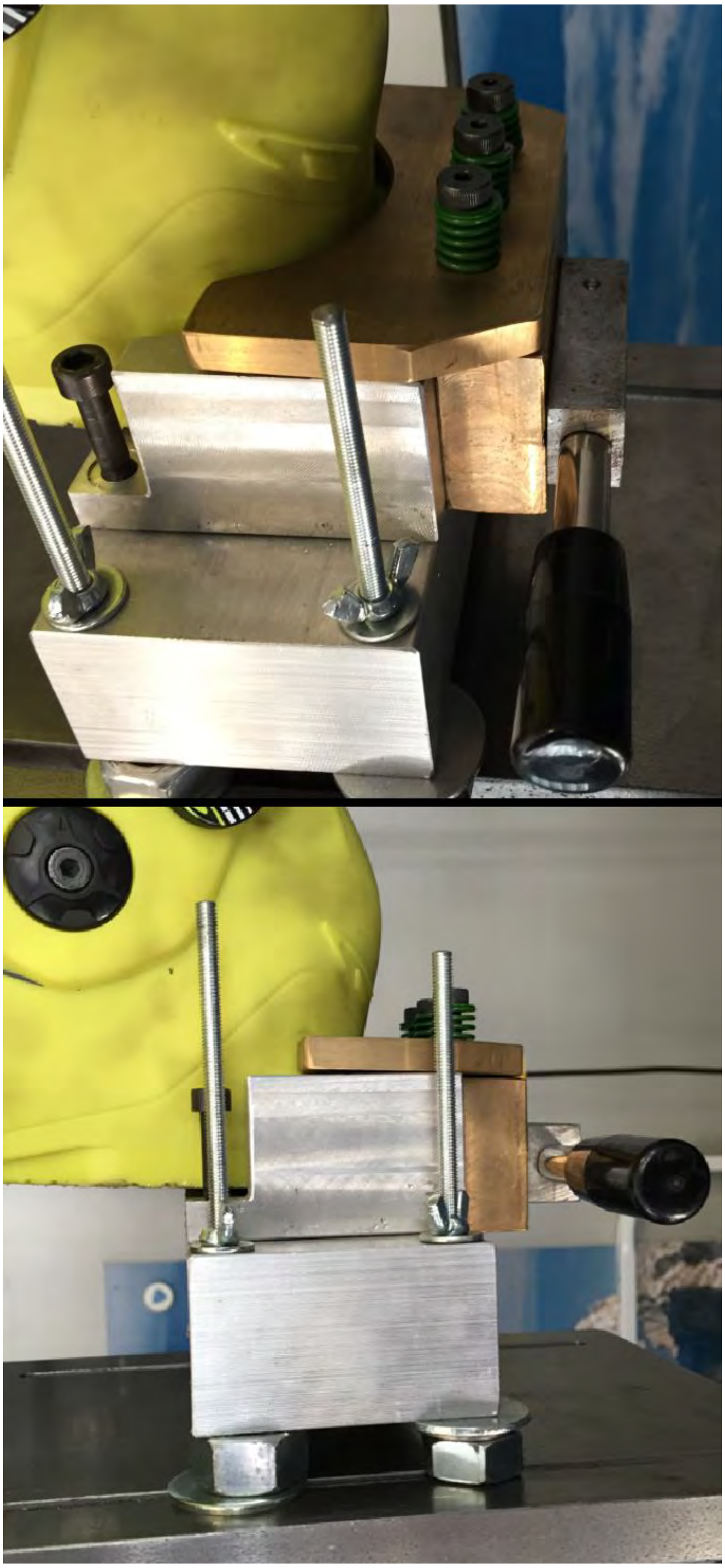


Figure 4.33 The posterior block with its closing lever arm and the screws for the vertical regulation.

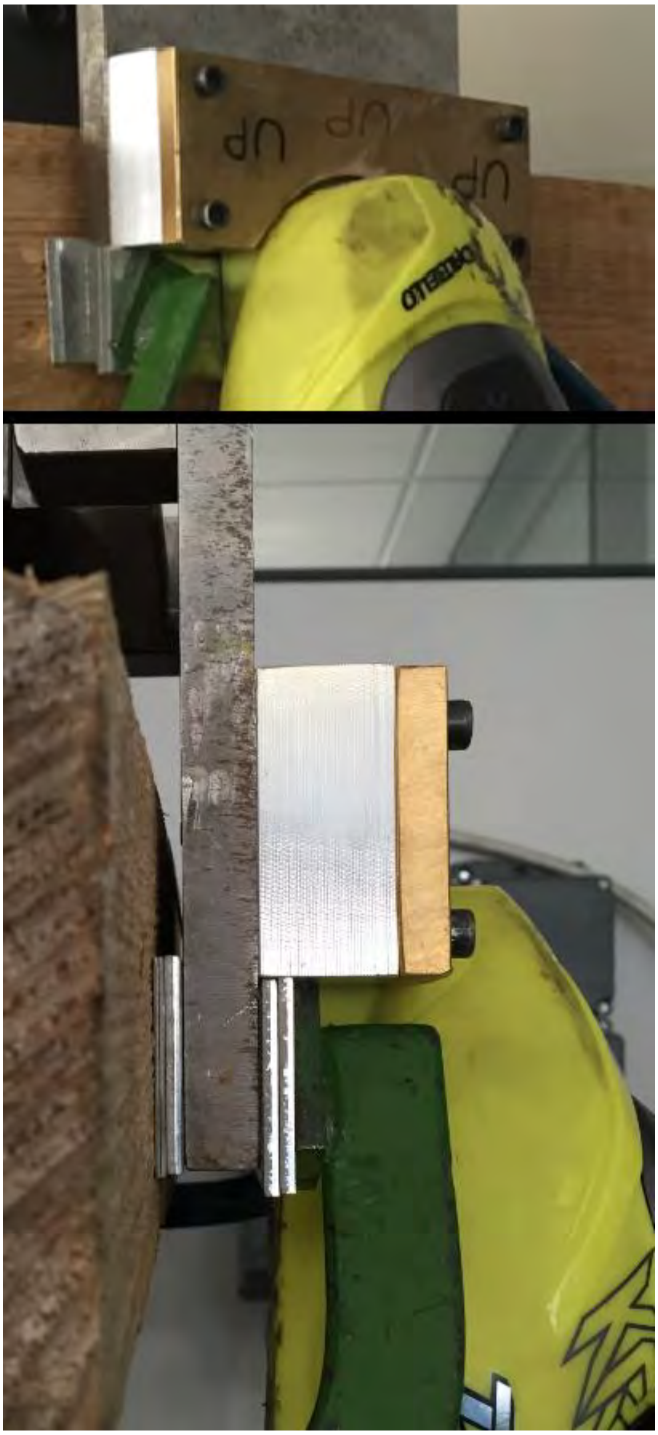


Figure 4.34 The anterior block.

The extremity of the actuator is grasped with the prosthetic leg with a short connecting rod. The connecting rod is shorter than the rod employed in the Fixed Unit in Padua, because the vertical range of the axial machine is restricted.

Figure 4.35 The connecting rod with the two joint: one with the prosthesis (above) and the second with the actuator (below).

In the second part of this analysis, a freezer room is employed. The freezer cabin is not static and it can be moved on the work bench.

With the insulating panels, the volume around the ski boot and the axial is circumscribed and the temperature is measured with a thermocouple. The thermocouple's sensor is positioned in the near of the ski boot.

Figure 4.36 The ski boot into the freezer room, the insulating panels and the sensor of the thermocouple.

4.3.3.1. Model of the Fixed Unit in Longarone

In order to analyse the ski boots with the test bench in question, an analytic model is employed. In this regards, the crank mechanism is simplified with a model so as to study the relationship between the independent variables. The independent variables are the vertical moving of the actuator x, the angle between the ski boot's shell and the tibia of the prosthesis θ_1 and the angle between the axias of the actuator and the connecting rod θ_2.

The other data are: the length of the prosthetic leg a (from the ski boot's hinge until the joint between the rod and the prosthesis) and the length of the connecting rod b.

The model is shown in *Figure 4.37* below.

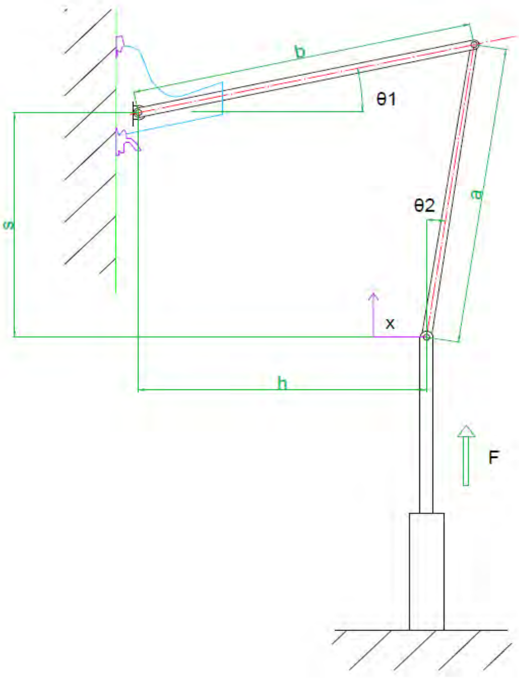


Figure 4.37 The model of the work bench and the variables: X, ϑ_1 and ϑ_2.

The inferred calculation is:

$$\begin{cases} a\ \cos\theta_1 + b\ \cos\theta_2 = s \\ a\ \sin\theta_1 + b\ \sin\theta_2 = h \end{cases}$$

With the derivation of the equations in respect to the time, it is obtained the velocities:

$$\begin{cases} -\dot{\theta}_1\ a\ \sin\theta_1 - \theta_2\ b\ \sin\theta_2 = \dot{s} \\ \dot{\theta}_1\ a\ \cos\theta_1 + \dot{\theta}_2\ b\ \cos\theta_2 = 0 \end{cases}$$

$$\dot{x} = \dot{s} = -\dot{\theta}_1\ a\ (\sin\theta_1 - \cos\theta_1 \tan\theta_2)$$

The choice of the axial range has been made taking into consideration the inclination of the prosthesis's tibia. The system is not composed by the real axles like in the model, therefore the angle of the prosthetic leg (and so the vertical range of the actuator) is measured with a digital lever.

Chapter 5 : Dynamics Test in Vivo

For the experiments in both the Torsion and axial units, the same brand of ski boots used for the Vivo test have been used Dalbello Krypton, Nordica Fire Arrow, Nordica Hell&Back and Tecnica Phnx 100.
Accordingly, this type of test enables to scrutinize the behaviour of the abovementioned ski boots when a human person performs forward flexion and backward extension movements.
The focus is to simulate the flexion and the extension movements through the machines.
The velocity of the motion is maintained at about 20 [°/sec] circa.

5.1. Aim of the Test

The data resulting from this section of the analysis of the ski boots are useful as they make it possible to compare them with the data obtained in the other type of the tests (test in vitrio and test in field).
Accordingly, the test in vivo is takes place in Padua's laboratory of Bio-Mechanics in Padua.
The four type of ski boots are the subject matter of the research, which are tested through the machine: on each type of ski boot a procedure involving a great degree of repeatability is performed. It is pivotal to notice the importance of the repeatability, as it enables the comparison of the results between tests.

This was done by using dynamometric platform to measure the behaviour of the vertical force during the test, markers and optoelectronics system able to import the human movements during the ski-simulation, electrogoniometers to measure the angles between tibia-shell and shell-cuff.

5.2. Instrumentation

The Bio-Mechanics in Padua was fundamental in order to carry out the test in vivo as it provided the perfect place and the necessary tools for the experimentations to take place.
Accordingly, the following tools have been used:

- Optoelectronic system;
- Electro-goniometers;
- Dynamometric platform;
- Ski;
- Ski boots.

5.2.1.The Optoelectronics System

This system of measurement is based on infrared cameras, infrared illuminators and passive reflective markers.
The passive markers are to be recognized on the basis of an initial static positioning and a model of anatomic arrangement.

Figure 5.1 Marker.

It is an invasive application because markers need to be applied on the subject's skin, besides this application can be done on a restricted volume.

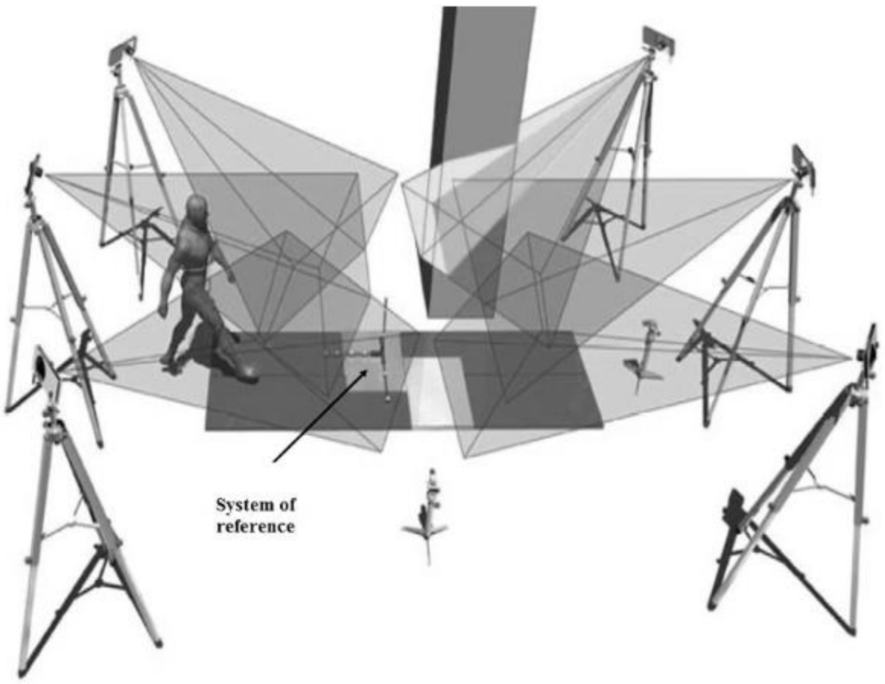


Figure 5.2 Infrared Cameras and BTS program (SmartCapture)

With this technology to be able to calculate the three dimensional position of a marker, but only if the marker is captured by at least two cameras.
For each camera it is possible to draw the straight line passing that passes optical centre of the lens and the sensor point where the marker is projected.
The marker is located at the intersection of the two straight lines.
Before carrying performing, it is however necessary to carry out adjust with calibration of the system.
During the calibration procedure, cameras detect a set of axes which is the build up reference system. For each chamber, the position and orientation, as well as the focal length, the position of the optical center and distortion parameters are then calculated. With the resulting it is possible to perform three dimensional reconstruction

5.2.2.Electrogoniometer

Electrogoniometers are among the first systems used for the analysis of human movement. These are special sensors capable of measuring the angle between two segments.

The main limitations of these tools are the limited accuracy and the disturbance on the subject due to the impediment caused by the wires or the very presence of electrogoniometer's part on the body.

Figure 5.3 Electrogoniometer.

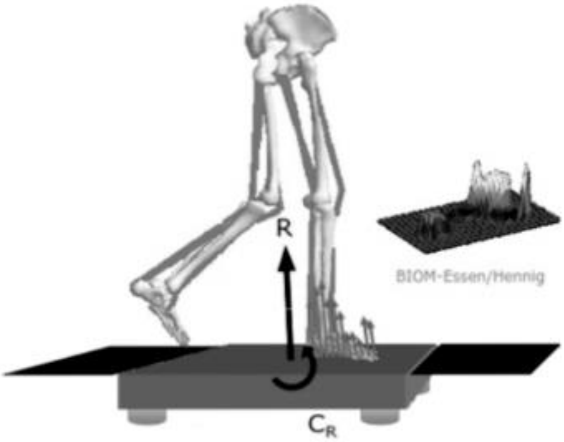
5.2.3.The Dynamometric Platform

The dynamometric platform measures the force that is applied on it. In detail, the aim of this system is to supply an electric signal that is proportional to the force applied.

The principle works always as follows a force causes a deformation of the platform and four load cells positioned in four angles measure the three components along the X-Y-Z axis.

The system allows the analysis of the static and dynamic characteristics.

As far as the static characteristic is regarded, it can measure static stability; whereas the dynamic characteristic focuses on three reactions with the ground, the COP position (centre of pressure) and the bending moment generated by a friction coefficient of ground too.



Scheme of a dynamometric platform.

5.2.4.Ski and ski boot

Given a ski, it is positioned and eventually fixed on the dynamics platform with the help of two clamps. The ski taken into consideration are the same that have been tested in both the Padua's and Longarone's work benches.

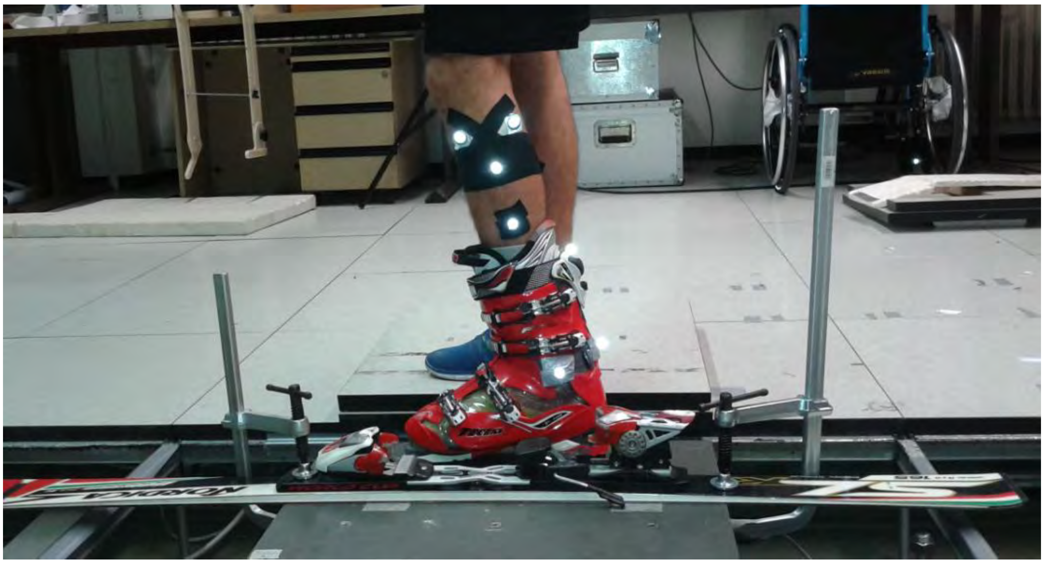


Figure 5.4 The ski boot wore by a tester and jointed to the ski.

5.3. Procedure

The analysis of the bending moment between the tibia and the shell, is one of the principal parameters measured in the work this thesis focused on.
The measurement of the moment at the human body's ankle took placed in the Bio Mechanics Laboratory, where a human tester has simulated a ski movements.
Besides, considering that the optoelectronics system enables record straight the trajectories of the malleolus while the tester wears the ski boot. In this regards, it was necessary to introduce a procedure which mede possible to find the position of the malleolus on the software. As a result, it is applied a cluster of the markers on the tester's tibia was applied (three markers which are fixed on a “T” shaped Aluminium element, which is jointed on the tibia with some adhesive tape).
The first step of the test are essential in order to determine the ideal dimensions of the Aluminium element and if its application point enable lesser movements compared with tibia.
The following *Figure 5.5* shows three different positioning on the “T” element.

Figure 5.5 The three positions tested in my analysis.

The results of this trial test demonstrate how the first position is better than the others and therefore it has been selected as the configuration to employ.

5.4. The Foot's Static Analysis

By employing the first configuration of the cluster, the recording of the signals of the optoelectronics system were possible. In addition to this configuration, two more markers were added one in correspondence to the medial and lateral malleulus. and one along the cross between the head of the fibula and the lateral malleolus. To human tester, it is asked to stand into a calibration volume, thus the recording of the signal starts.

Before the application of the sensor, the human tester's leg is prepared

. Accordingly, the markers on the malleolus are fixed on the skin with some double adhesive tape, while the "T" element is fixed on it with additional "kinesiotape" (the "kinesiotape" has high perspiration resistance and is comfortable when moving).

Figure 5.6 The executive protocol for the foot's static analysis.

The aim of this data acquisition is worked up to obtain with high precision the coordinates of the malleulos, body of the tibia and the element "T".

This method is allowed to obtain the same coordinates in the dynamics test.

5.5. Dynamics Analysis

As far as the simulation of the ski is concerned, the markers are placed on the external surface of the ski boot. The application points are the posterior surface, the inferior surface of the gambit and between the tibia and the shell. This arrangement of the markers allows to calculate two angles:

- the angle between the gambit and the shell;
- the angle between the tibia and the shell.

The pictures below show the application points of the marker of the four ski selected boots.

Figure 5.7 (A)Tecnica, Phnx 100; (B) Nordica, Hell and Back; (C) Nordica, Firearrow; (D) Dalbello, Krypton. Illustration of the application points of the markers.

Other two markers are positioned on the dynamometric platform on a posterior and an anterior points along the flexion/extension direction.
The ski is in-built only with the dynamometric platform rather than with the ground of the laboratory.

Figure 5.8 The ski fixed on the dynamometric platform

The same procedure is employed in every test. The procedure starts when the human tester picks up his/her ski boot for 5 seconds. Then he/she joints the ski boot with the ski binding and after that remains in a in neutral position (with the his/her weight on the other leg). In this regards, the tester can simulate the ski movements, with 5 "soft" flexions of the leg, a pause of 5 second and finally 5 "strong" flexions.

Chapter 6 : Test Protocols

In order to be able to characterize the ski boots according to the given parameters (Flex Index, K_5,K_{15} and Progression) different tests have been performed using the following definite protocols in accordance with the correspondent work bench.
Accordingly, the test are:

- test in Padua's work bench (Padua Torsion Unit);
- test in Padua's work bench (Padua Fixed Unit);
- test in Padua's laboratory of Bio mechanics;
- test in Longarone's workbench (Longarone Fixed Unit).

6.1. Torsion Unit's Protocol

In this part of the analysis, the test consists of many differentiated steps for each ski boot.
The analysis is divided in two main sections. The first section takes into account the action of variations the weight, whereas the second one neglects this variable.
Starting with the latter section, that ignores the weight factor, the procedure follows these passages:

- the prosthetic leg is inserted into the ski boot;
- the closure of the buckles is defined by a "closing code", which is kept constant, and a sequence of the four numbers: (1)-(2)-(3)-(4).

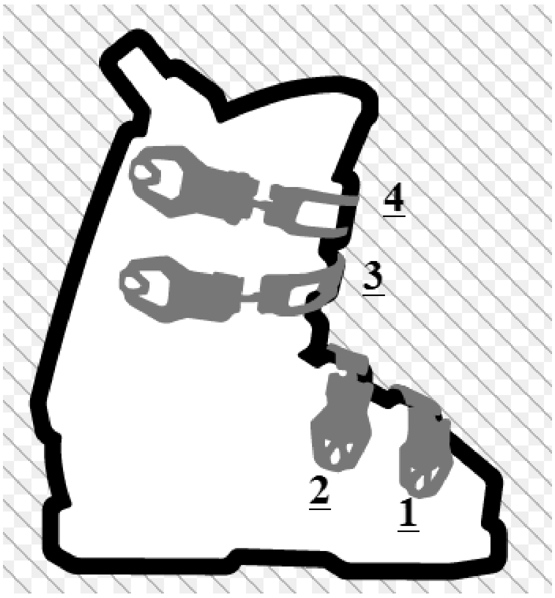


Figure 6.1 Sequence of the four numbers used for the definition of the "closing code"

- the closing code depends on the regulation of the "micrometric-screw" (the closing code, mentioned below, has been employed in every work bench).
- The "closing codes" of the six analysed ski boots are:

  - Dalbello Krypton: 2-3-2;
  - Nordica Fire Arrow: 2-2-3;
  - Nordica Hire&Back: 2-4-2
  - Tecnica PHNX 100: 2-2-3-2;
  - Head Vector: 2-2-4-3;
  - Head Edge: 2-3-2-1;
  - Tecnica Orange: 2-3-4-3;
  - Nordica “Black”: 2-3-5-5.

The values of the abovementioned codes are equivalent to a closing force of about 10÷12 [kg] (circa).

In order to obtain this closing force and these closing codes, the number of the turns of the micrometric-screw (starting from the position where it is totally screwed in) are counted for each buckle:

- Dalbello Krypton: 2-3-2
    - buckle-1: +4 turns
    - buckle-2: +1 turns
    - buckle-3: +4 turns

- Nordica Fire Arrow: 2-2-3
    - buckle-1: +1 turns
    - buckle-2: +0 turns
    - buckle-3: +4 turns

- Nordica Hire&Back: 2-4-2
    - buckle-1: +1 turns
    - buckle-2: +0 turns
    - buckle-3: +5 turns

- Tecnica PHNX 100: 2-2-3-2
    - buckle-1: +0 turns
    - buckle-2: +1 turns
    - buckle-3: +2 turns
    - buckle-4: +0 turns

- Head Vector: 2-2-4-3
    - buckle-1: +4 turns
    - buckle-2: +4 turns
    - buckle-3: +4 turns
    - buckle-4: +3 turns

- Head Edge: 2-3-2-1
    - buckle-1: +0 turns

        - buckle-2: + 0 turns
        - buckle-3: +0 turns
        - buckle-4: +0 turns

    - Tecnica “Orange”: 2-3-4-4
        - buckle-1: +0 turns
        - buckle-2: +0 turns
        - buckle-3: +0 turns
        - buckle-4: + 0turns

    - Nordica “Black” 2-3-5-5
        - buckle-1: +0 turns
        - buckle-2: + 0turns
        - buckle-3: + 0turns
        - buckle-4: + 0turns

- the lever arm of the prosthetic leg is fixed with the metal arm, which is attached to the motor spindle of the torsion machine;
- the ski boot is jointed to the ski binding, which is attached to the second spindle (the second motor spindle works like a load cell);
- the prosthetic leg is ran to the neutral position;
- with a function of the torsion machine ("Function Generator"), the setup of the artificial foot inside the ski boot is searched, thus generating a displacement cycle (usually a cycle with an amplitude of the 7÷8 [°] around the initial neutral position and with a frequency of the 1÷2 [Hz]);
- the prosthetic leg is ran to the definitive neutral position, or rather the position according to which the measuring of the bending moment on the ski boot is null;
- the application of the procedure, with a forward flexion of 15[°] and a backward extension of 5[°] in respect to the neutral position, with different angular velocities:

    - $\omega = 20\ {}^{\circ}/_{sec}$
    - $\omega = 50\ {}^{\circ}/_{sec}$

- $\omega = 80\ {}^{\circ}/_{sec}$

- the acquisition of the data;
- the elaboration of the data.

Now turning to the former section of the abovementioned analysis, the one taking into account the weight variable, it can be noticed how different loading conditions are employed. The conditions are chosen considering also the Ski-Tester's test, which are carried out with a variation of loads oscillating from 50 [kg] to 140 [kg]. Having assumed this one vertical force of 40 [kg], one of 80 [kg] and one of 115 [kg] are chosen.

Figure 6.2 The connection of the compressing air system (A), the connection of the pneumatic actuator with the prosthetic leg (B) and a picture of the profile of the system (C).

The actuator SMC SDB 63-80 has a maximum value of the pressure of 10 [bar] (1 [MPa]), a bore of 63 [mm] and the stroke is 80 [mm].
Accordingly, the force and the section have been written as follows:

$$F_1 = 40 * g = 400\ [N]$$
$$F_2 = 80 * g = 800\ [N]$$
$$F_3 = 120 * g = 1200\ [N]$$

$$F_1 = S * p = 400\ [N]$$
$$F_2 = S * p = 800\ [N]$$
$$F_3 = S * p = 1200\ [N]$$

$$S = \frac{\pi * d^2}{4} = 3{,}116 * 10^{-3}\ [m^2]$$

Where g is the gravity coefficient ($g = 9.806\ [{}^{m}/_{s^2}]$), S is the section of the actuator, d is the diameter of the actuator and F is the force that the actuator has to apply on the prosthetic leg.
Respectively, the values of the pressure can be inferred:

$$p_1 = \frac{F_1}{S} = 128370\ [Pa] = 1{,}3[bar]$$
$$p_2 = \frac{F_2}{S} = 256740\ [Pa] = 2{,}6\ [bar]$$
$$p_3 = \frac{F_3}{S} = 385109\ [Pa] = 3{,}8\ [bar]$$

As far as the section with weight is concerned, the protocol procedes according to the following steps:

- the prosthetic leg is inserted into the ski boot;
- the buckles and the strap are closed according to the same "closing-code" and therefore with an equal closing force;
- the lever arm of the prosthetic leg is fixed to the metal arm which is attached to the motor spindle of the torsion machine;
- the ski boot is jointed to the ski binding that is attached to the second spindle (the second motor spindle works like a load cell);
- the compressed air system is connected to the pneumatic actuator with a specific value of the pressure;
- the prosthetic leg is ran to the neutral position;
- with a function of the torsion machine ("Function Generator"), the setup of the artificial foot inside the ski boot is searched, generating a displacement cycle (usually a cycle with an amplitude of 7÷8 [°] around the initial neutral position with a frequency of 1÷2 [Hz]);
- the prosthetic leg is ran to the definitive neutral position, or rather the position when the measuring of the bending moment on the ski boot is null;

- application of the procedure, with a forward flexion of the 15[°] and a backward extension of 5[°] in respect to the neutral position, and with different angular velocities:

    - $\omega = 20\ {}^{\circ}/_{sec}$
    - $\omega = 50\ {}^{\circ}/_{sec}$
    - $\omega = 80\ {}^{\circ}/_{sec}$

- the acquisition of the data;
- the elaboration of the data.

6.2. Vivo Test's Protocol

The procedure has to be the same for each ski boot in order to obtain results that can be compared.
The procedure of the test in vivo is defined in next list:

- the IR cameras are arranged in the lab according to an "hexagon" disposition;
- the three axis of the reference are positioned in the middle of the "hexagon" space which is formed by the cameras;
- the volume of the space enclosed by the cameras is calibrated with a specific gesture of a wand axis;
- employing some clamps, a ski is attached to a dynamometric platform;
- the human tester wears the ski boot, closes the buckles and joints the ski boot with the ski binding of the ski;
- following a specific software protocol, the markers are applied on the subjecting point of the human tester;

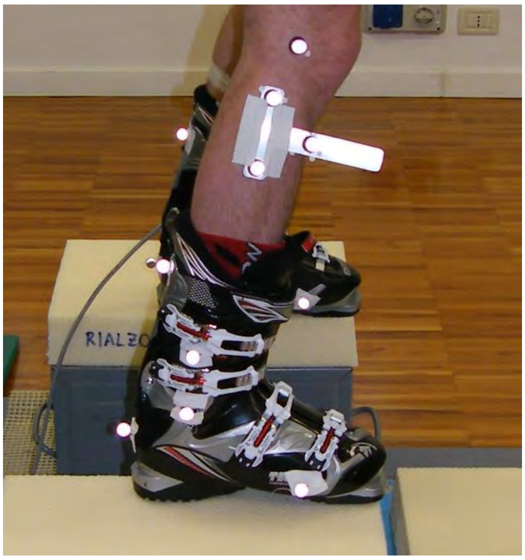


Figure 6.3 The human leg in the ski boot and the application points of the markers

- the electrogoniometers are inserted in order to measure two angles: one between the shell and the cuff, the other between the tibia and the cuff;

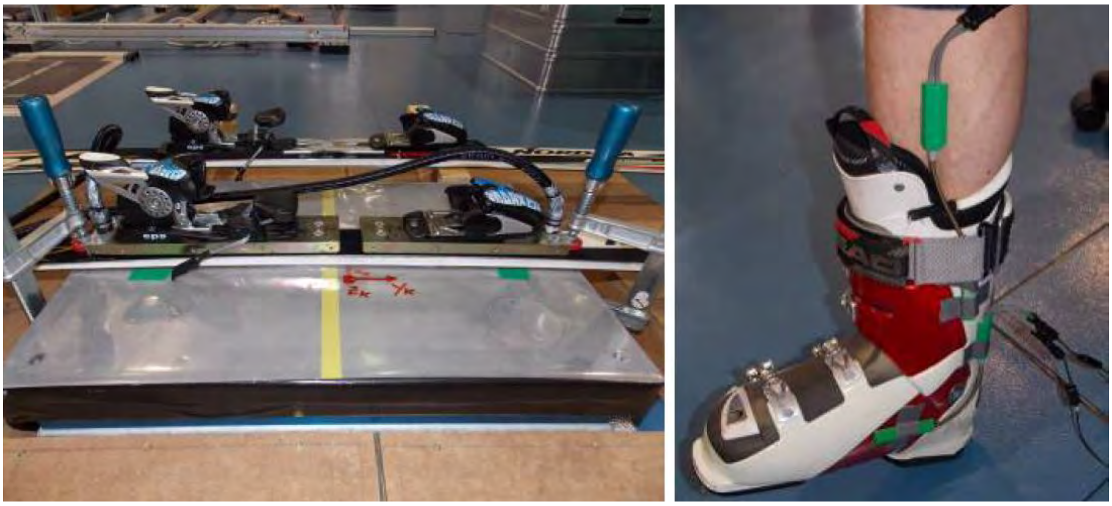


Figure 6.4 The ski binding placed on the dynamometric platform and the application points of the elettrogoniometers

- the movements of the tester are recorded (flexion and extension);
- the software simultaneously tracks the moving trajectories with the movements of the tester (the 3D reconstruction of the trajectories of the markers and the correct association of the markers with the anatomical landmarks of the model).
- Analysis of the acquisition data (filtering, correction and interpolation).
- Processing data (evaluation of the kinematic / dynamics/ muscle)

6.3. Padua Fixed Unit's Protocol

The protocol of Padua Fixed Unit test bench follows a procedure which is similar to the one used with Longarone's axial machine.
However, this analysis only revolves around tests that do not taken into account the application of the "weight" on the prosthetic leg.
The tests are divided into two parts:

- in the first part, the analysis are performed at room-temperature (T≈20 [°C]);
- in the second part, a freezer box is installed on the work bench, therefore the work-temperature is maintained under the threshold of 0 [°C], precisely T≈-20 [°C].

In every section, the values of the axial velocity of the hydraulic ram are calculated so as to guarantee the angular velocity employied in other test benches: 20, 50 and 80 [°/sec].
The protocol can be described as follows:

- the prosthetic leg is inserted into the ski boot;
- the closure of the buckles is defined according to the abovementioned "closing code" (the closing force of the buckles is 10 ÷12 [kg]);
- the "closing code" of the six ski boot analyzed are:
    - Dalbello Krypton: 2-3-2;
    - Nordica Fire Arrow: 2-2-3;
    - Nordica Hire&Back: 2-4-2
    - Tecnica PHNX 100: 2-2-3-2;
    - Head Vector: 2-2-4-3;
    - Head Edge: 2-3-2-1;
    - Tecnica Orange: 2-3-4-3;
    - Nordica "Black": 2-3-5-5.
- the ski boot is attached to the ski binding (the ski binding used in the torsion test bench);

Figure 6.5 The "Ski binding" employed in Padua's axial work bench

- the position of the ski binding can vary for each ski boot. And can therefore be modified according the regulation of the support of the ski binding. The support is clutched with the bench through four "mobile constrains".

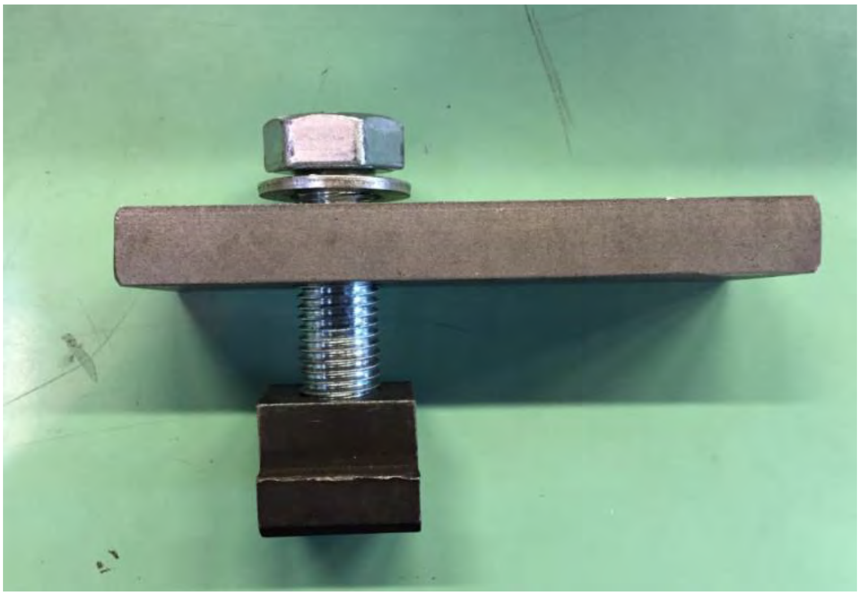


Figure 6.6 The mobile constrains" used for fixing the "Ski binding".

- the hydraulic ram is connected to the connecting rod;

Figure 6.7 The connecting rod, which is attached to the hydraulic actuator (the extremity on the left) and to the prosthetic leg (the extremity on the right).

- the connecting rod is connected to the prosthetic leg;

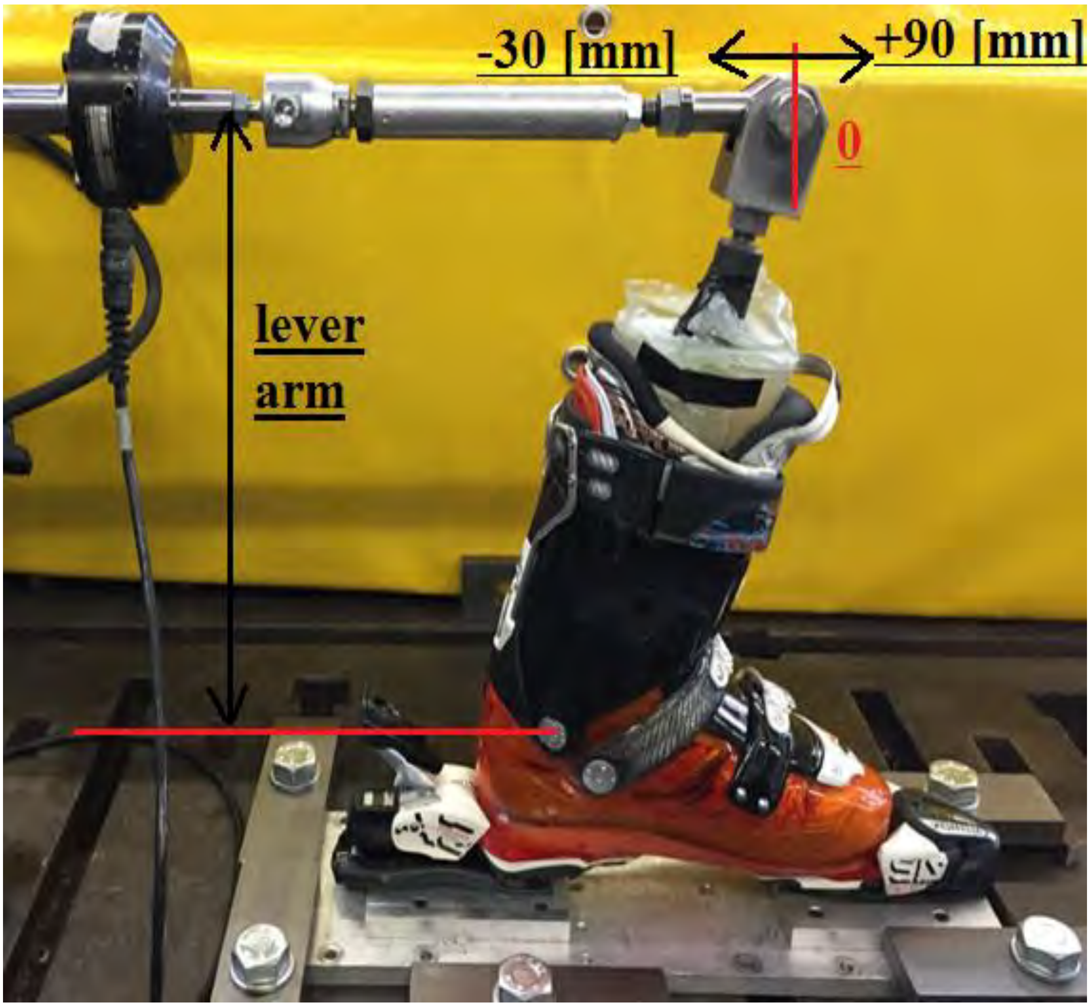


Figure 6.8 From the left to the right: hydraulic ram, the rod and the prosthetic leg into the ski boot.

- with the function of the MTS axial machine called "Manual-Command: Force-control", the actuator is brought the position where the force is null (this neutral position is not definitive);
- with the function of the MTS machine called "Function Generator", the setup of the artificial foot inside the ski boot is looked for a displacement cycle (usually 10 cycles with an amplitude of ±20 mm [°] around the initial neutral position with a frequency of 1÷2 [Hz]);
- with the "Manual Command: Force-control" the actuator is brought to the definitive neutral position;
- the procedure used is defined by a flexion of +15 [°] and an extension of -5 [°] in respect to the neutral position. The angular velocities and the angles are

translated in the axial machine's strake and they are calculated for the different conditions (the conditions are normalized to the neutral position):

1. with the prosthetic leg PPS, the parameters are:

$$x_0 = 0\ [mm];$$
$$x_{+\ flexion} = +88\ [mm];$$
$$x_{-\ extension} = -30\ [mm];$$

$$\omega_A = 20\ {}^{\circ}/_{sec} \rightarrow x_1 = 138[mm/s];$$
$$\omega_B = 50\ {}^{\circ}/_{sec} \rightarrow x_2 = 330\ [mm/s];$$
$$\omega_C = 80\ {}^{\circ}/_{sec} \rightarrow x_2 = 526\ [mm/s];$$

2. with the prosthetic legs PLR and PLS, the parameters are

$$x_0 = 0\ [mm];$$
$$x_{+\ flexion} = +88\ [mm];$$
$$x_{-\ extension} = -30\ [mm];$$

$$\omega_A = 20\ {}^{\circ}/_{sec} \rightarrow x_1 = 138\ [mm/s];$$
$$\omega_B = 50\ {}^{\circ}/_{sec} \rightarrow x_2 = 330\ [mm/s];$$
$$\omega_C = 80\ {}^{\circ}/_{sec} \rightarrow x_2 = 526\ [mm/s];$$

- the acquisition of the data (with a sample-frequency: 1 [kHz];
- the elaboration of the data.

In the second part of this analysis, a freezer room is installed on the work bench. the freezer employed is set to amount to a constant temperature T = -20 [°C].
The procedure performances in this section is the same, other than the conditioning of the ski boot. In this analysis, the principal parameter is the temperature and the conditioning process has needed to a specific time. Accordingly, the ski boot is placed into the freezer room for the whole night and in the morning it is tested. The

temperature of the ski boot's parts has to be constant and the thermal gradient between the external surfaces and the prosthetic leg has to be null The thermocouple is inserted into the ski boot, between the prosthetic leg and the boot, thus the temperature is measured.
The procedure of this protocol can be described as follows:

- the prosthetic leg is inserted into the ski boot;
- the closure of the buckles is defined according to the abovementioned "closing code" (the closing force of the buckles is closed to 10 ÷12 [kg]);
- the "closing code" of the six analysed ski boots are:
    - Dalbello Krypton: 2-3-2;
    - Nordica Fire Arrow: 2-2-3;
    - Nordica Hire&Back: 2-4-2
    - Tecnica PHNX 100: 2-2-3-2;
    - Head Vector: 2-2-4-3;
    - Head Edge: 2-3-2-1;
    - Tecnica Orange: 2-3-4-3;
    - Nordica “Black”: 2-3-5-5.

- the ski boot is attached to the ski binding (the ski binding used in the torsion test bench);
- the position of the ski binding can vary for each ski boot, and can therefore be modified according the regulation of the support of the ski binding. The support is clutched with the bench four "mobile constrains".
- the hydraulic ram has a cylindrical-extension which goes through the cabin of the freezer. The extension element is connected to the connecting rod;
- the connecting rod is connected to the prosthetic leg;

Figure 6.9 The extension of the hydraulic ram, the connecting rod and the ski boot in the freezer room.

- the filament of the thermocouple is inserted into the freezer room and its sensor is positioned between the prosthetic leg and the ski boot;

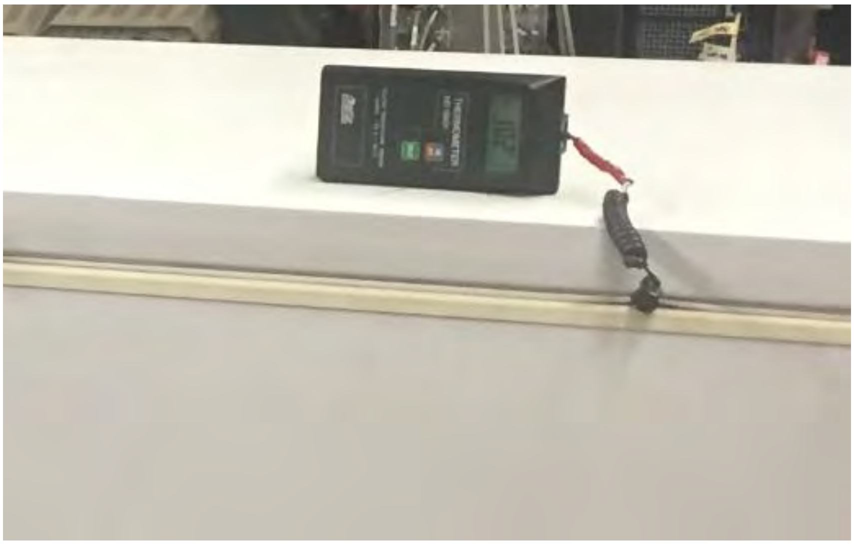


Figure 6.10 The thermocouple.

- the freezer is closed and it is necessary to wait for the conditioning process of the ski boot (approximatively the whole night);
- with the function of the MTS axial machine called "Manual-Command: Force-control", the actuator is brought to the position where the force is null (this neutral position is not definitive);
- with the function of the MTS machine called "Function Generator", the setup of the artificial foot inside the ski boot is looked for a displacement cycle (usually 10 cycles with an amplitude of ±20 mm [°] around the initial neutral position with a frequency of 1÷2 [Hz]);
- with the "Manual Command: Force-control" the actuator is brought to the definitive neutral position;
- the procedure performed on the other work bench is defined by a flexion of +15 [°] and an extension of -5 [°] in respect to the neutral position. The angles are translated into strake of the axial machine:

    - the flexion of +15 [°] corresponds to +88 [mm] in respect to the neutral position;
    - the extension of -5 [°]corresponds to -30 [mm] in respect to the neutral position;

- The axial velocity $\dot{x}$ is defined in [Hz] and for tests, the results of the angular velocities of the prosthetic leg are:

$$\begin{cases} \omega_1 = \dot{\theta}_1 = 17{,}4\ [°/\sec] \\ \dot{x}_1 = 0{,}5\ [Hz] \end{cases}$$

$$\begin{cases} \omega_2 = \dot{\theta}_2 = 34{,}8\ [°/\sec] \\ \dot{x}_2 = 1\ [Hz] \end{cases}$$

$$\begin{cases} \omega_3 = \dot{\theta}_3 = 69{,}8\ [°/\sec] \\ \dot{x}_3 = 2\ [Hz] \end{cases}$$

- Acquisition of the data (with a sample-frequency: 1 [kHz]);
- Elaboration of the data.

6.4. Longarone Fixed Unit's Protocol

The behaviour of the ski boots is valued according to another type of analysis. This system concerns in an axial machine (MTS).
The procedure develops according the following steps:

- the "ski binding", which is composed by two blocks characterized by a high stiffness (the two block are made up by Aluminium and Aluminium's alloy), is fixed on the principal structure. The anterior block is kept in stationary position with two clamps and a thickness piece that is made up by wood, and two clamps;

Figure 6.11 The anterior block (in the first picture) and backward block (second picture).

- the prosthetic leg is inserted into the ski boot;
- the ski boot is attached with the "ski binding";
- the closure of the buckles is defined according to the abovementioned "closing code" (the closing force of the buckles is closed to 10 ÷12 [kg].);
  The "closing code" of the six analysed ski boots are:

  - Dalbello Krypton: 2-3-2;
  - Dalbello Vantage: 4-5-12-10;
  - Head Vector: 2-2-4-3;

  The closing force of any buckle is measured through a manual load cell.

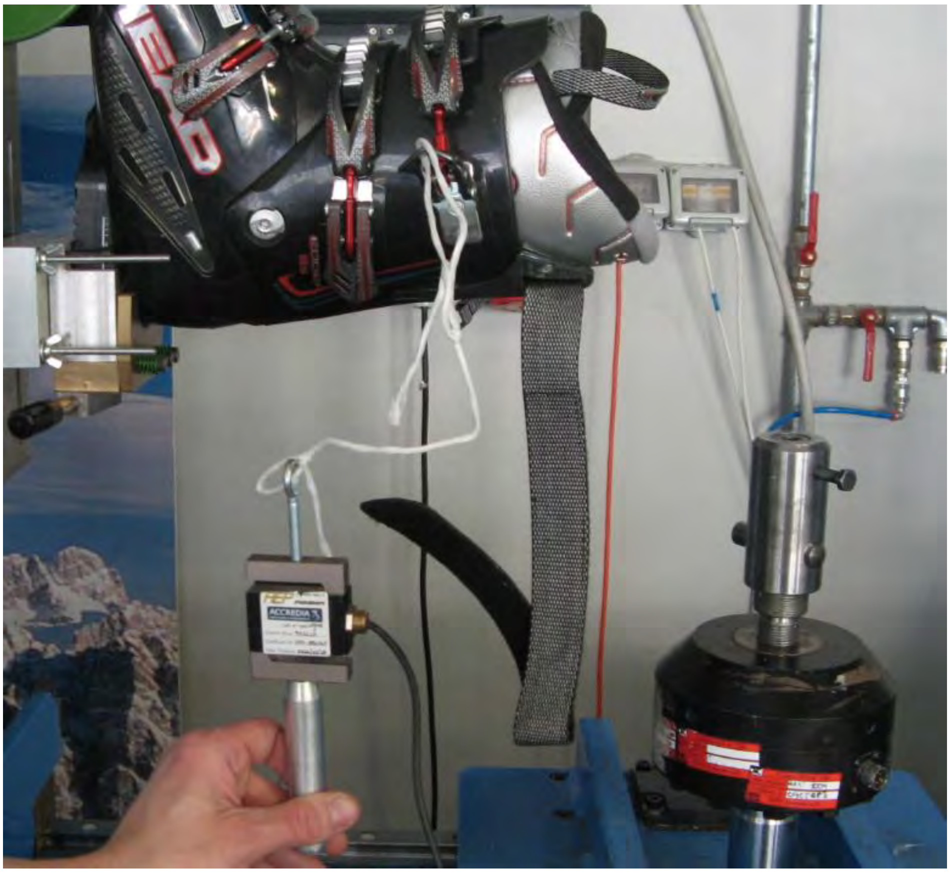


Figure 6.12 The manual load cell employed in measuring of the closing force of single buckle.

- an extremity of the rod is attached with an extremity of the axial machine (MTS);

Figure 6.13 In the part below of the figure the extremity of the axial machine that is jointed with the rod through a junction.

- the other extremity is connected to the extremity of the prosthetic leg;

Figure 6.14 The other extremity of the rod is jointed with the prosthetic leg by another junction.

- the bench of the axial machine is on fixed and the gap between the centre of the axial machine and the hinge of the ski boot can be measured;

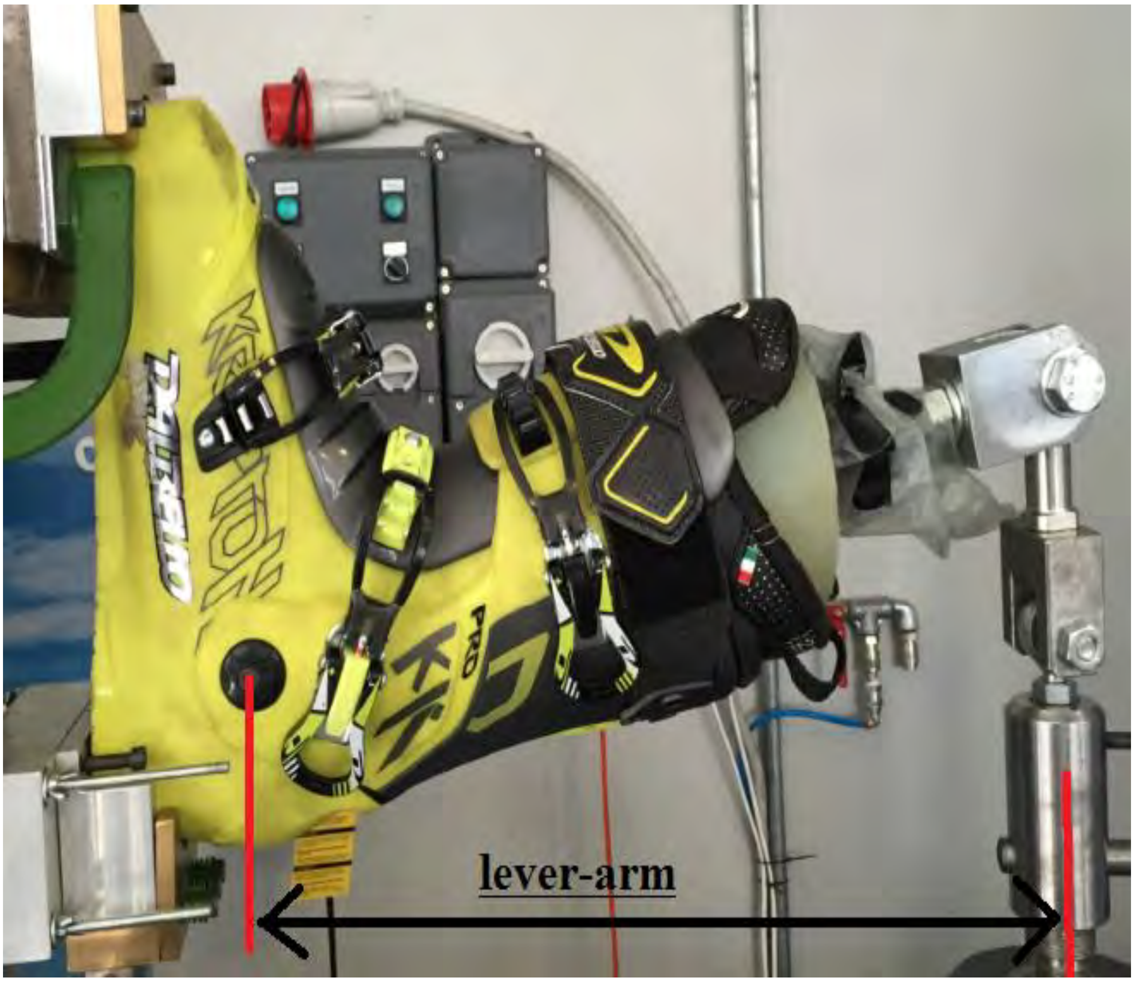


Figure 6.15 The lever arm between the centre of the axial machine and the hinge of the ski boot.

- with the function of the MTS axial machine called "Manual-Command: Force-control", the actuator is brought in the position where the force is null (this neutral position is not definitive);
- with the function of the MTS machine called "Function Generator", the setup of the artificial foot inside the ski boot is looked for a displacement cycle (usually 10 cycles with an amplitude of ±20 mm [°] around the initial neutral position with a frequency of 1÷2 [Hz]);
- with the "Manual Command: Force-control" the actuator is brought to the definitive neutral position;
- the procedure used is defined by a flexion of +15 [°] and an extension of -5 [°] in respect to the neutral position. The angular velocities and the angles are

translated in the axial machine's strake and they are calculated for the different conditions (the conditions are normalized to the neutral position):

1. with the prosthetic leg PPS, the parameters are:

$$x_0 = 0\ [mm];$$
$$x_{+\ flexion} = +88\ [mm];$$
$$x_{-\ extension} = -30\ [mm];$$

$$\omega_A = 20\ {}^{\circ}/_{sec} \rightarrow x_1 = 138[mm/s];$$
$$\omega_B = 50\ {}^{\circ}/_{sec} \rightarrow x_2 = 330\ [mm/s];$$

$$lever\ arm = 385\ [mm];$$

2. with the prosthetic legs PLR and PLS, the parameters are

$$x_0 = 0\ [mm];$$
$$x_{+\ flexion} = +88\ [mm];$$
$$x_{-\ extension} = -30\ [mm];$$

$$\omega_A = 20\ {}^{\circ}/_{sec} \rightarrow x_1 = 138\ [mm/s];$$
$$\omega_B = 50\ {}^{\circ}/_{sec} \rightarrow x_2 = 330\ [mm/s];$$

$$lever\ arm = 385\ [mm];$$

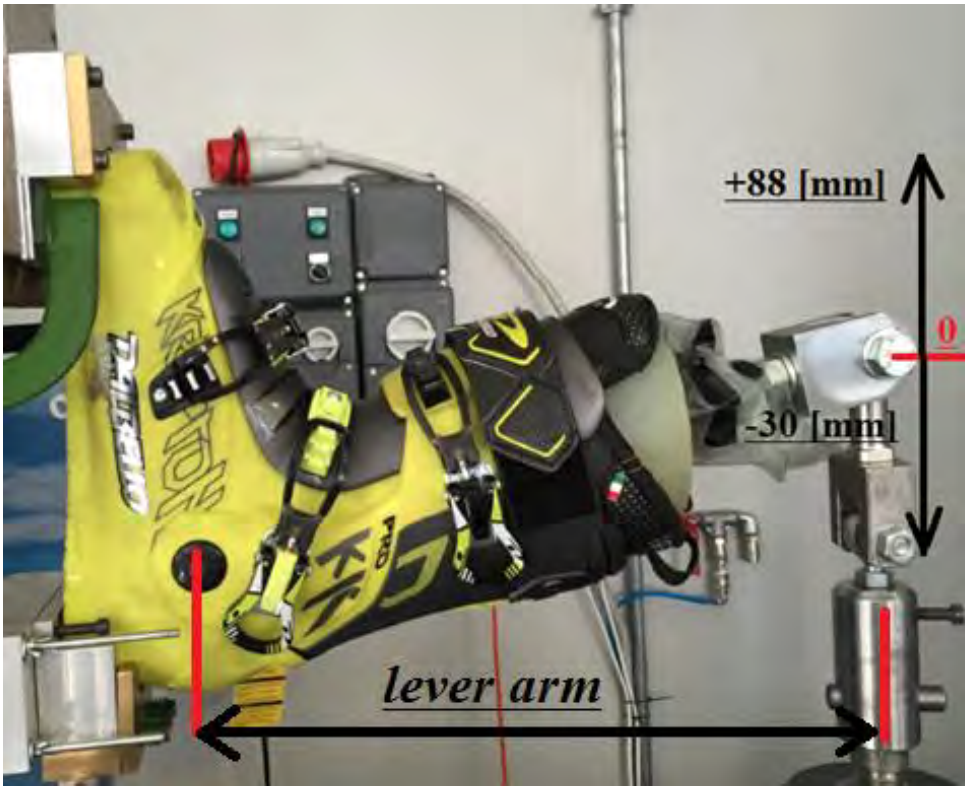


Figure 6.16 The Neutral position (F=0), the boundary values of the maximum flexion (+88 [mm]) and maximum extension (-30 [mm]);

1. with the prosthetic legs PIR and PIS, the absolute neutral position x_0, the absolute maximum and minimum values which they correspond to the maximum flexion and extension (+15 [°] and -5 [°] in respect to the neutral position) are:

$$x_0 = 0\ [mm];$$
$$x_{+\,flexion} = 148\ [mm];$$
$$x_{-\,extension} = -50\ [mm];$$

$$\omega_A = 20\ {}^{\circ}/_{sec} \rightarrow x_1 = 224\ [mm/s];$$
$$\omega_B = 50\ {}^{\circ}/_{sec} \rightarrow x_2 = 500\ [mm/s];$$

$$lever\ arm = 630\ [mm];$$

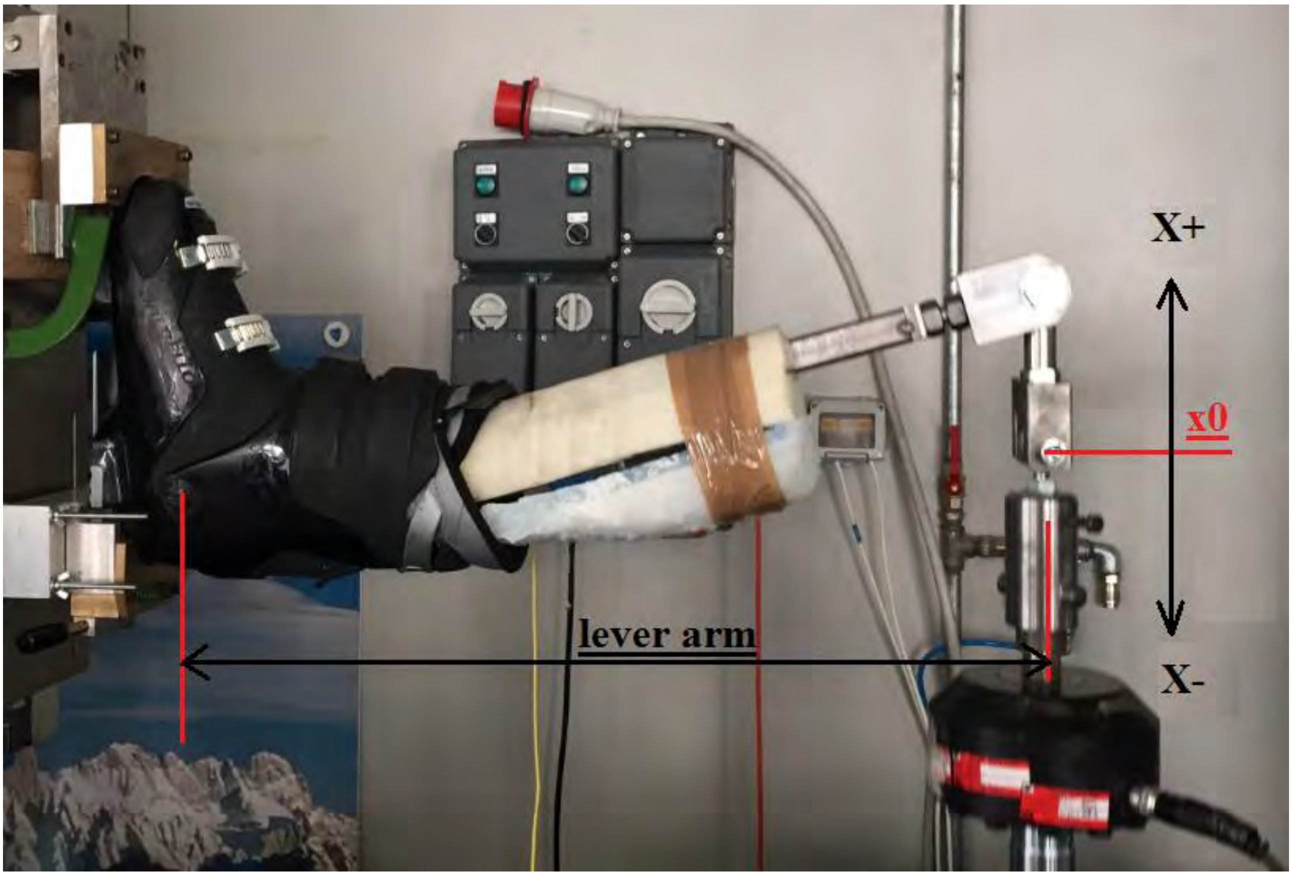


Figure 6.17 The lever arm between the centre of the axial machine and the hinge of the ski boot.

- the test of any ski boot are repeated three times and for each angular velocity (for the repeatability);
- the acquisition of the data (with a sample-frequency: 1 [kHz]);
- the elaboration of the data.

In the second part of this test, the ski boot and the axial MTS system are placed into a freezer room.

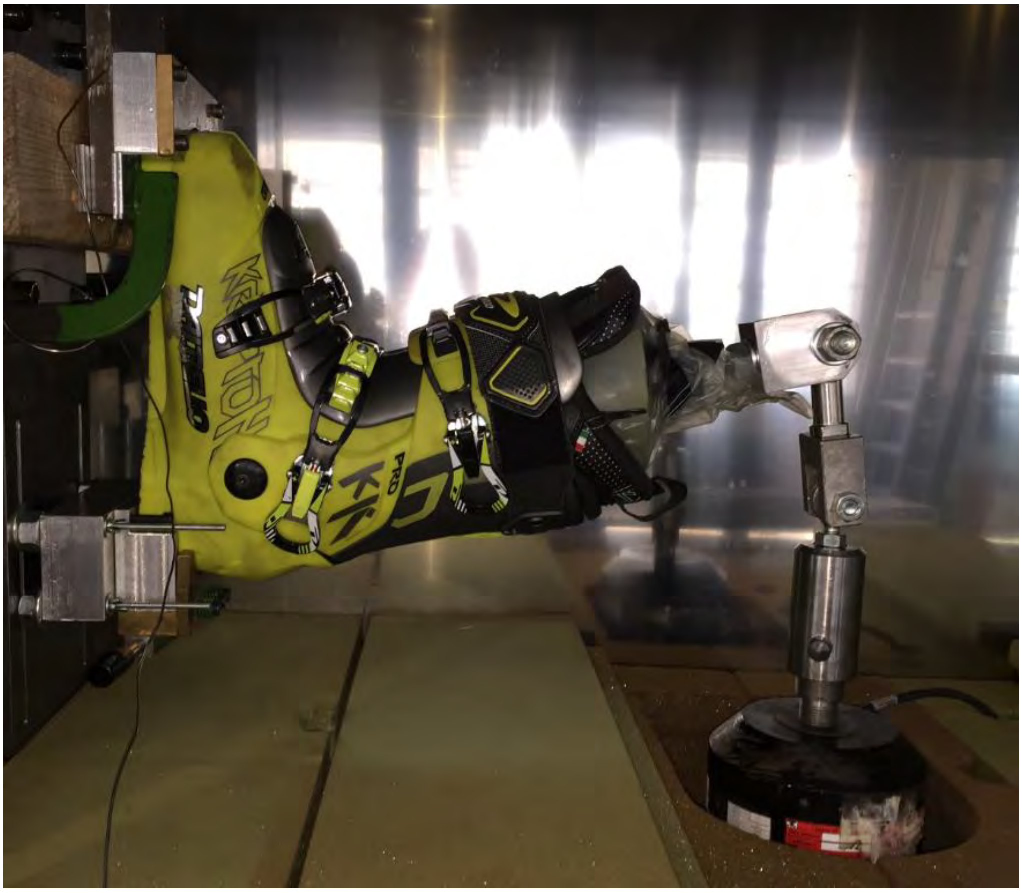


Figure 6.18 The ski boot inside the freezer room and the filament of the thermocouple

The freezer has a digital thermostat which make it possible to regulate the temperature inside the cabin. In this regards, a thermocouple is employed for a accurate measurement of the temperature and its sensor is placed near of the ski boot.
The tests are repeated for two temperature's steps by putting inside the freezer-room:

- T_A = ambient temperature (≈ 22 ÷ 25 [°C]);
- T_C = -20 [°C].

- the acquisition of the data (with a sample-frequency: 1 [kHz]);
- the elaboration of the data.

Chapter 7 : Result's Reading

In order to simplify the reading of the diagrams, the lettering is agreed upon as it can be seen in the following list:

I. **The typology of the ski boot:**

- Dalbello Vantage: DLB-V.

II. **The test bench:**

- Longarone's Fixed Unit: UFL.

III. **The prosthetic leg:**

- the prosthetic leg of Padua's University of Mechanical Engineering:PPS;
- the prosthetic leg with rigid rubber of Longarone's DolomitiCert:PLR;
- the prosthetic leg with soft rubber of Longarone's DolomitiCert:PLS;
- the prosthetic leg with rigid calf of Innsbruck University:PIR;
- the prosthetic leg with rigid calf of Innsbruck University:PIS.

IV. **The closing code:**

- the closing code $S1\ and\ S2$ of the each buckle is:

    - buckle 1: maximum value of closure;

- buckle 2: maximum value of closure;
- buckle 3: a closing force value of 10÷11 [kg];
- buckle 4: a closing force value of 10÷11 [kg].

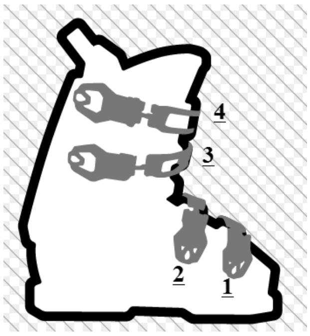


Figure 7.1 Index of each buckle.

V. The angular velocity:

- $\omega = 20\ [°/s]$: $20°sec$;
- $\omega = 50\ [°/s]$: $50°sec$;
- $\omega = 80\ [°/s]$: $80°sec$.

VI. The range of the angles:

- +15 [°] and -5 [°] from the neutral angle: $+15° - 5°$.

VII. The temperature of the test:

- the temperature between 20 and 24 [°C]: TA

VIII. The vertical load applied to the prosthetic leg (to simulate the human weight):

- the zero value of the load: $L0$

Chapter 8 : Elaboration Data

The elaboration of the data is an important phase of the protocol because it is the step where the results are defined.
The output data of the different test benches are:

- in the Torsion MTS machine, the data are the angle between the Tibia and the Shell ($\vartheta_{Tibia/Shell}$ [°]) and the torque measured by the load cell ($Moment$ $[N\ m]$);
- in the axial MTS machine in Longarone, the data are the stroke of the hydraulic ram (S $[mm]$) and the axial force meausred by the load cell along the actuator (F $[N]$);
- in the axial MTS machine in Padua, the data are the stroke of the hydraulic ram (S $[mm]$) and the axial force meausred by the load cell along the actuator (F $[N]$).

8.1. Elaboration Data in UPT

The measuring values of the $\vartheta_{Tibia/Shell}$ are the absolute angles. They are normalized to the "neutral" angle.
The measuring of the torque moment is the bending moment that is applied to the prosthetic leg and so therefore the ski boot.

The diagram between these two parameters that can be inferred is shown in the *Figure 8.1* below.

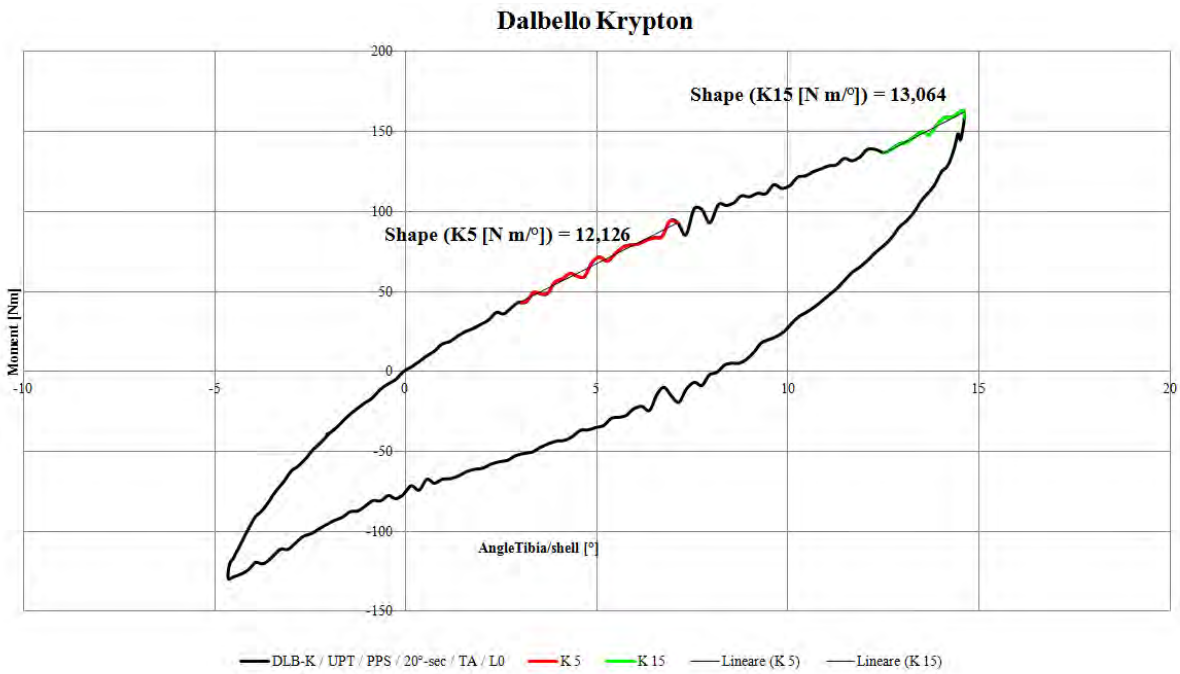


Figure 8.1 The hysteresis cycle obtained in the Torsion MTS machine.

By assuming an error value of ± 2 [°], the average of all the values of the bending moment between 12 [°] and 8 [°] defines the engineering Flex Index (from neutral position: 10 [°] + 2 [°] and 10 [°] - 2 [°]).

With equal criteria (an error value of ± 2 [°]) the parameters K_5 and K_{15} are defined. The K_5 and the K_{15} define the shape of the curve in the loading segment (these values are shown in the *Figure 8.1* above through "red" and "green" segments).

The relationship between the K_{15} and the K_5 is the Progression.

The hysteresis area included between the loading and unloading segment of the cycle, is implemented in the Matlab-Program. The program makes a subtraction between the area below the "loading segment" and the area below the "unloading segment".

8.2. Elaboration Data in UPF

The elaboration of the data is an important phase of the protocol because it is the stage where the results are defined and compared.
The output data of the Fixed Unit in Padua :

- the stroke of the hydraulic ram ($S\ [mm]$);
- the axial force measured with the load cell along the actuator ($F\ [N]$);

The measuring of the hydraulic ram's stroke is converted into the prosthesis's angle $\vartheta_{Tibia/Shell}$ with a conversion factor (CF). For instance, the inferred conversion factor can be:

I. neutral position (absolute stroke and absolute angle):

- $x_0 = 0\ [mm]$;
- $\theta_0 = 17\ [°]$;

II. maximum flexion's position (+15 [°] from neutral position):

- $x_+ = -89\ [mm]$;
- $\theta_+ = 32\ [°]$;

III. minimum extension position (-5 [°] from neutral position):

- $x_- = +29\ [mm]$;
- $\theta_- = 12\ [°]$;

$$\boldsymbol{Conversion\ Factor\ (CF)} = \frac{|\theta_+| - |\theta_0|}{|x_+| - |x_0|} = \frac{|\theta_0| - |\theta_-|}{|x_-| - |x_0|} = 6{,}1$$

$$\boldsymbol{\theta_{Tibia/Shell_i}} = CF * x_i$$

where the x_i is the instantaneous measuring of the actuator's stroke and $\theta_{Tibia/Shell_i}$ is the instantaneous measuring of the angle between the tibia and the shell.
Taking into consideration the measuring of the moment applied to the ski, the distance between the ski boot's hinge and the actuator's vertical axis are measured. This parameter is the lever arm of the force measured with the actuator's load cell.
For the different prosthetic legs, the lever arms are:

1. with the prosthetic leg PPS the lever arm is:

    - $l_{PPS} = 385\ [mm]$;

2. with the prosthetic legs PLR and PLS the lever arm is:

    - $l_{PLR/PLS} = 385\ [mm]$;

In order to compare the different diagrams, all the moments are normalized. The hysteresis cycle is pushed through the zero (the centre of the diagram between the moment and the angle).
The diagram that can be inferred from these two parameters in shown in the following *Figure 8.2*:

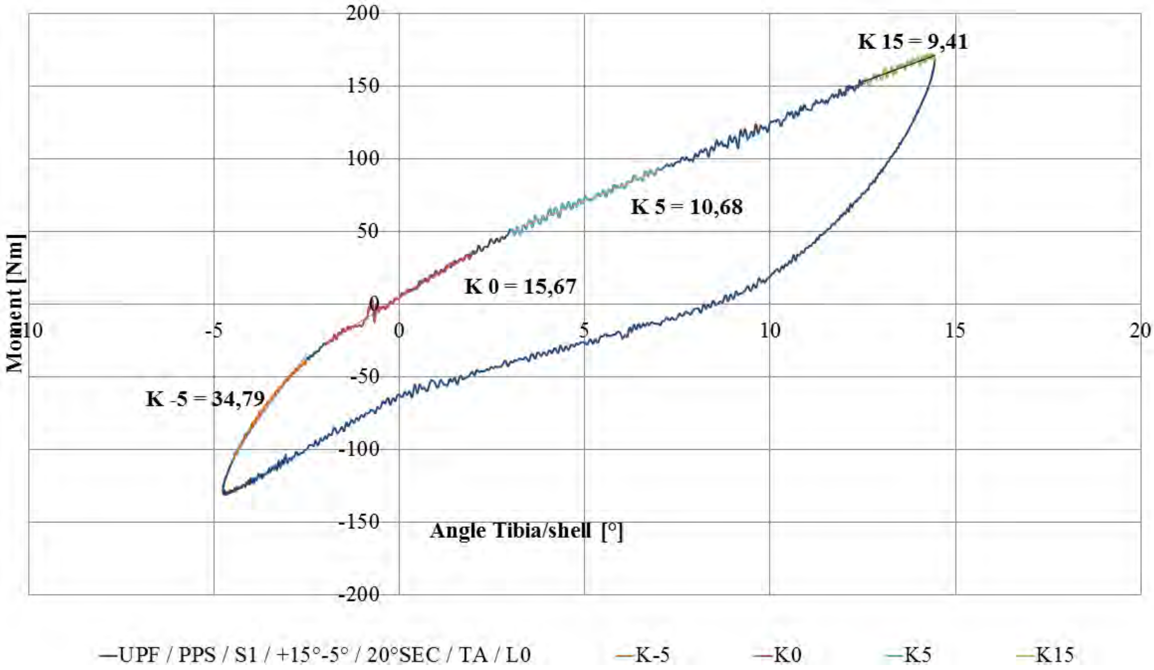


Figure 8.2 The hysteresis cycle obtained in Fixed Unit in Padua.

By assuming an error value of ± 2 [°], the average of all the values of the moment measured between 12 [°] and 8 [°] defines the engineering Flex Index (from a neutral position: 10+2 [°] and 10 - 2 [°]).

With an equal criteria (an error value of ± 2 [°]) the parameters K_{-5}, K_0, K_5 and K_{15} are defined. The K_i coefficients define the shape of the curve in the loading segment of the cycle and in the proximity of a prearranged angle (these values are shown in the *Figure 8.2* above according to the "light blue-segment" (K_{-5}), the "green-segment" (K_{-0}), the "orange-segment" (K_5) the "red" and the "red-segment" (K_{15})).

The relationship between the K_{15} and the K_5 is the Progression:

$$Progression = \frac{K_{15°}}{K_{5°}}$$

The relationship between the K_0 and the K-5 is the Progression $Prog_{0°/-5°}$:

$$Prog_{0°/-5°} = \frac{K_{0°}}{K_{-5°}}$$

The relationship between the K_5 and the K_0 is tre Progression $Prog_{5°/0°}$.

$$Prog_{5°/0°} = \frac{K_{5°}}{K_{0°}}$$

The hysteresis area included between the loading and unloading segments of the cycle, is implemented through Matlab-Program. The program makes a subtraction between the area under the "loading segment" and the area under the "unloading segment". Accordingly, the result of the subtraction is the energy which is absorbed by the ski boot during the test.

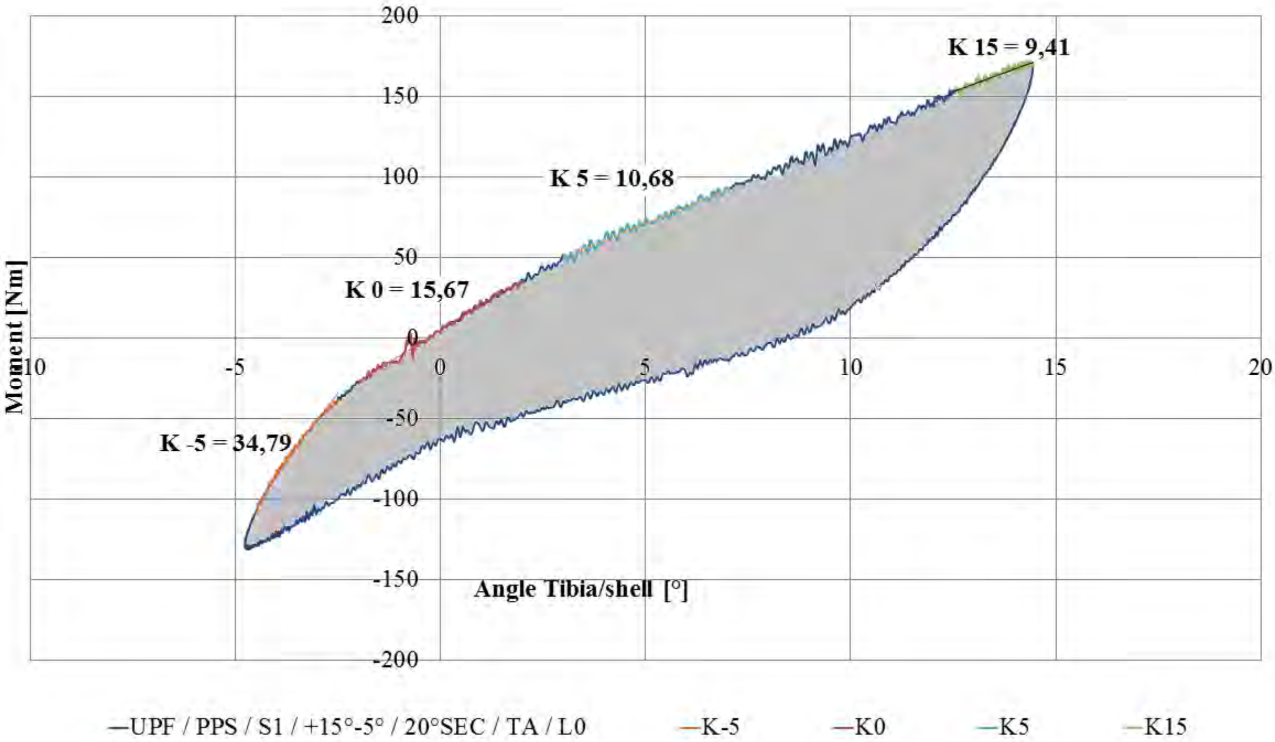


Figure 8.3 The hysteresis area.

8.3. Elaboration Data in ULF

The output data of the Fixed Unit in Longarone :

- the stroke of the hydraulic ram ($S\ [mm]$);
- the axial force measured with the load cell along the actuator ($F\ [N]$);

The measuring of the hydraulic ram's stroke is converted into the prosthesis's angle $\vartheta_{Tibia/Shell}$ with a conversion factor (CF). For instance, the inferred conversion factor can be:

IV. neutral position (absolute stroke and absolute angle):

- $x_0 = 0\ [mm]$;
- $\theta_0 = 17\ [°]$;

V. maximum flexion's position (+15 [°] from neutral position):

- $x_+ = -90\ [mm]$;
- $\theta_+ = 32\ [°]$;

VI. minimum extension position (-5 [°] from neutral position):

- $x_- = +30\ [mm]$;
- $\theta_- = 12\ [°]$;

$$\boldsymbol{Conversion\ Factor\ (CF)} = \frac{|\theta_+| - |\theta_0|}{|x_+| - |x_0|} = \frac{|\theta_0| - |\theta_-|}{|x_-| - |x_0|} = 6$$

$$\boldsymbol{\theta_{Tibia/Shell_i}} = CF * x_i$$

where the x_i is the instantaneous measuring of the actuator's stroke and $\theta_{Tibia/Shell_i}$ is the instantaneous measuring of the angle between the tibia and the shell.
Taking into consideration the measuring of the moment applied to the ski, the distance between the ski boot's hinge and the actuator's vertical axis are measured. This parameter is the lever arm of the force measured with the actuator's load cell.
For the different prosthetic legs, the lever arms are:

3. with the prosthetic legs PIR and PIS the lever arm is:

    - $l_{PIR/PIS} = 630\ [mm]$;

4. with the prosthetic leg PPS the lever arm is:

    - $l_{PPS} = 385\ [mm]$;

5. with the prosthetic legs PLR and PLS the lever arm is:

    - $l_{PLR/PLS} = 385\ [mm]$;

6. with the prosthetic legs PLR and PLS and the Longarone's grasping, the lever arm is:

    - $l_{PLR/PLS\_LOgrasp} = 360\ [mm]$;

The procedure of the comparison, the normalization of the bending moment and the calculation of the dependent variables follows the same step employed in the elaboration data of the UPF.

Chapter 9 : Statistical Analysis

As far as the statistical analysis is concerned, the parameters of the characterization of the ski boot and the prosthesis are studied from a different point of view. The statistical analysis evaluates a single test which is composed by 25 consecutive cycles. For every cycle applied to the ski boot, the analysis evaluates:

- the engineering Flex Index;
- the K_5 coefficient;
- the K_{15} coefficient;
- the Progression;
- the maximum value of the moment;
- the minimum value of the moment.

The aim of this analysis is to find the average value and the standard deviation of every parameter. Furthermore, the Chauvenet criterion is applied to find if a given data can be eliminated from the analysis.

The analysis below is concerned with the PPS prosthetic test.

	Nr cycle	eFI	dev eFI	M max	dev M max	M min	dev M min
	1	79,442	4,231	101,259	29,767	-133,739	15,288
	2	80,283	1,480	104,763	3,809	-131,313	2,201
	3	83,947	5,992	108,483	3,125	-127,352	6,135
	4	83,340	3,389	108,515	3,238	-127,857	3,888
	5	82,845	1,810	109,372	7,061	-129,073	0,571
	6	82,409	0,828	107,234	0,269	-128,884	0,893
	7	82,133	0,401	107,441	0,526	-129,418	0,169
	8	81,887	0,150	107,002	0,082	-129,755	0,005
	9	80,930	0,324	106,284	0,186	-129,731	0,010
	10	80,930	0,324	106,603	0,013	-129,975	0,021
	11	81,604	0,011	106,615	0,010	-129,907	0,006
	12	81,508	0,000	106,999	0,081	-129,418	0,169
	13	81,396	0,011	106,412	0,092	-129,589	0,057
	14	81,337	0,026	106,355	0,130	-129,626	0,041
	15	81,302	0,039	107,229	0,265	-129,808	0,000
	16	81,072	0,182	107,424	0,503	-129,775	0,003
	17	81,125	0,140	106,434	0,079	-129,850	0,000
	18	81,092	0,166	106,425	0,084	-130,070	0,058
	19	81,053	0,199	106,151	0,319	-130,516	0,472
	20	80,920	0,336	107,194	0,229	-130,488	0,434
	21	80,930	0,324	106,823	0,012	-130,264	0,189
Total		1711,485	20,363	2241,018	49,878	-2726,408	30,612
Average		81,499		106,715		-129,829	
Standard Deviation		1,009		1,579		1,237	
Error		0,220		0,345		0,270	

Table 9.1 The result's tab of the eFI, the maximum and minimum of the moment.

	Nr cycle	K5	dev K5	K15	dev K15		Progression	dev Progr
	1	7,434	0,176	2,275	0,360		0,306	0,003582
	2	7,971	0,014	2,999	0,015		0,376	0,000108
	3	7,944	0,008	2,909	0,001		0,366	0,000000
	4	7,925	0,005	3,029	0,024		0,382	0,000267
	5	7,791	0,004	3,069	0,038		0,394	0,000790
	6	7,919	0,004	2,884	0,000		0,364	0,000003
	7	7,980	0,016	2,931	0,003		0,367	0,000002
	8	7,637	0,047	2,807	0,005		0,368	0,000003
	9	7,978	0,015	2,893	0,000		0,363	0,000010
	10	7,874	0,000	2,803	0,005		0,356	0,000099
	11	7,747	0,012	2,947	0,005		0,380	0,000213
	12	7,722	0,017	2,718	0,024		0,352	0,000192
	13	7,851	0,000	3,018	0,021		0,384	0,000345
	14	7,923	0,005	2,813	0,004		0,355	0,000117
	15	7,983	0,016	2,893	0,000		0,362	0,000012
	16	7,787	0,005	2,803	0,005		0,360	0,000035
	17	7,988	0,018	2,904	0,001		0,364	0,000005
	18	8,206	0,124	2,998	0,015		0,365	0,000000
	19	7,987	0,018	3,008	0,018		0,377	0,000116
	20	7,726	0,016	2,893	0,000		0,374	0,000074
	21	7,568	0,082	2,774	0,010		0,367	0,000000
Total		164,940	0,603	60,370	0,555		7,683	0,005972
Average		7,854		2,875			0,366	
Standard Deviation		0,174		0,167			0,017281	
Error		0,038		0,036			0,003771	

Table 9.2 The result's tab of the K_5, the K_{15} and Progrssion.

In the next tab, the Chauvenet criterion is employed for the n experimental data. Taken a series of n experimental data, the values that show a distancing from the average value are to be eliminated from the analysis. The probability of a distancing from the average value is less than $\frac{1}{2\,n}$.

The procedure is concerned with the calculation of:

- the parameter average;
- the standard deviation;
- the parameter deviation s_i.

Taken into a probability $p = 1 - \frac{1}{2*n}$, z is found from the $F(z) = \frac{p+1}{2}$ *Table 9.3*.

When $|s_i| > z_{lim}$ the data can be rejected.

n	p	F(z)	Z_{lim}
5	0.9000	0.950	1.65
6	0.9167	0.958	1.73
8	0.9375	0.969	1.86
10	0.9500	0.975	1.96
20	0.9750	0.9872	2.24
50	0.9900	0.9950	2.58
100	0.9950	0.9972	3.02
500	0.9990	0.9995	3.28
1000	0.9995	0.99972	3.46

Table 9.3 The $F(z)$ table (confidence: 95 [%]).

Nr cycle	eFI	si	Chauvenet	M max	si	Chauvenet	M min	si	Chauvenet
1	79,442	-2,038	Ok	101,259	-3,455	No	-133,739	-3,160	No
2	80,283	-1,206	Ok	104,763	-1,236	Ok	-131,313	-1,199	Ok
3	83,947	2,426	No	108,483	1,119	Ok	-127,352	2,002	Ok
4	83,340	1,824	Ok	108,515	1,140	Ok	-127,857	1,594	Ok
5	82,845	1,333	Ok	109,372	1,683	Ok	-129,073	0,611	Ok
6	82,409	0,902	Ok	107,234	0,329	Ok	-128,884	0,764	Ok
7	82,133	0,628	Ok	107,441	0,459	Ok	-129,418	0,332	Ok
8	81,887	0,384	Ok	107,002	0,182	Ok	-129,755	0,060	Ok
9	80,930	-0,564	Ok	106,284	-0,273	Ok	-129,731	0,079	Ok
10	80,930	-0,564	Ok	106,603	-0,071	Ok	-129,975	-0,118	Ok
11	81,604	0,103	Ok	106,615	-0,063	Ok	-129,907	-0,063	Ok
12	81,508	0,009	Ok	106,999	0,180	Ok	-129,418	0,332	Ok
13	81,396	-0,102	Ok	106,412	-0,192	Ok	-129,589	0,194	Ok
14	81,337	-0,161	Ok	106,355	-0,228	Ok	-129,626	0,164	Ok
15	81,302	-0,196	Ok	107,229	0,326	Ok	-129,808	0,017	Ok
16	81,072	-0,423	Ok	107,424	0,449	Ok	-129,775	0,044	Ok
17	81,125	-0,371	Ok	106,434	-0,178	Ok	-129,850	-0,017	Ok
18	81,092	-0,404	Ok	106,425	-0,184	Ok	-130,070	-0,195	Ok
19	81,053	-0,442	Ok	106,151	-0,357	Ok	-130,516	-0,555	Ok
20	80,920	-0,574	Ok	107,194	0,303	Ok	-130,488	-0,533	Ok
21	80,930	-0,564	Ok	106,823	0,069	Ok	-130,264	-0,352	Ok
	pi	0,9761905		pi	0,9761905		pi	0,9761905	
	Fz	0,9880952		Fz	0,9880952		Fz	0,9880952	
	zlim	2,24		zlim	2,24		zlim	2,24	

Nr cycle	K5	si	Chauvenet	K15	si	Chauvenet	Progression	si	Chauvenet
1	7,434	-2,420	No	2,275	-3,600	No	0,306018	-3,463146	No
2	7,971	0,672	Ok	2,999	0,746	Ok	0,376244	0,600656	Ok
3	7,944	0,517	Ok	2,909	0,203	Ok	0,366125	0,015136	Ok
4	7,925	0,409	Ok	3,029	0,926	Ok	0,382199	0,945257	Ok
5	7,791	-0,366	Ok	3,069	1,168	Ok	0,393978	1,626881	Ok
6	7,919	0,372	Ok	2,884	0,057	Ok	0,364234	-0,094287	Ok
7	7,980	0,722	Ok	2,931	0,337	Ok	0,367299	0,083057	Ok
8	7,637	-1,251	Ok	2,807	-0,404	Ok	0,367600	0,100485	Ok
9	7,978	0,710	Ok	2,893	0,110	Ok	0,362640	-0,186533	Ok
10	7,874	0,115	Ok	2,803	-0,432	Ok	0,355935	-0,574585	Ok
11	7,747	-0,619	Ok	2,947	0,436	Ok	0,380449	0,844012	Ok
12	7,722	-0,760	Ok	2,718	-0,939	Ok	0,352007	-0,801893	Ok
13	7,851	-0,020	Ok	3,018	0,860	Ok	0,384427	1,074228	Ok
14	7,923	0,398	Ok	2,813	-0,369	Ok	0,355054	-0,625537	Ok
15	7,983	0,739	Ok	2,893	0,110	Ok	0,362413	-0,199677	Ok
16	7,787	-0,387	Ok	2,803	-0,431	Ok	0,359950	-0,342240	Ok
17	7,988	0,771	Ok	2,904	0,177	Ok	0,363566	-0,132981	Ok
18	8,206	2,028	Ok	2,998	0,740	Ok	0,365341	-0,030239	Ok
19	7,987	0,762	Ok	3,008	0,799	Ok	0,376618	0,622342	Ok
20	7,726	-0,740	Ok	2,893	0,111	Ok	0,374494	0,499387	Ok
21	7,568	-1,652	Ok	2,774	-0,605	Ok	0,366550	0,039679	Ok
	pi	0,9761905		pi	0,9761905		pi	0,9761905	
	Fz	0,9880952		Fz	0,9880952		Fz	0,9880952	
	zlim	2,24		zlim	2,24		zlim	2,24	

Table 9.4 The Chauvenet's criteria.

In the Chauvenet *Table 9.4*, the first cycle cannot be considered, whereas the other cycles are very similar and their deviation is little.

The frequency diagram evidences a Gauss' trend of the data, with a high frequency of the data in the middle of the curve.

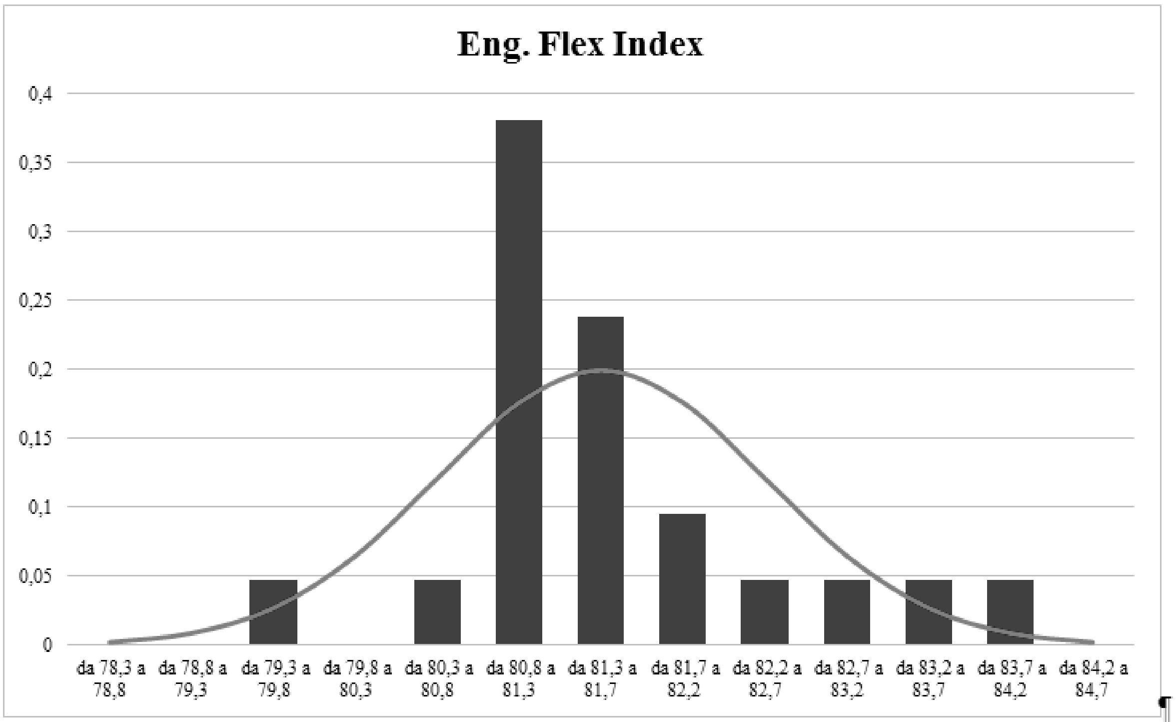


Diagram 9.1 The frequency's diagram of the engineering Flex Index.

The measurement of the eFI is:

$$Standard\ Deviation = 0{,}9$$

$$error = 0{,}192\ [N\ m] \rightarrow 0{,}2\ [N\ m]$$

$$eFI = 81{,}4 \pm 0{,}2\ [N\ m]$$

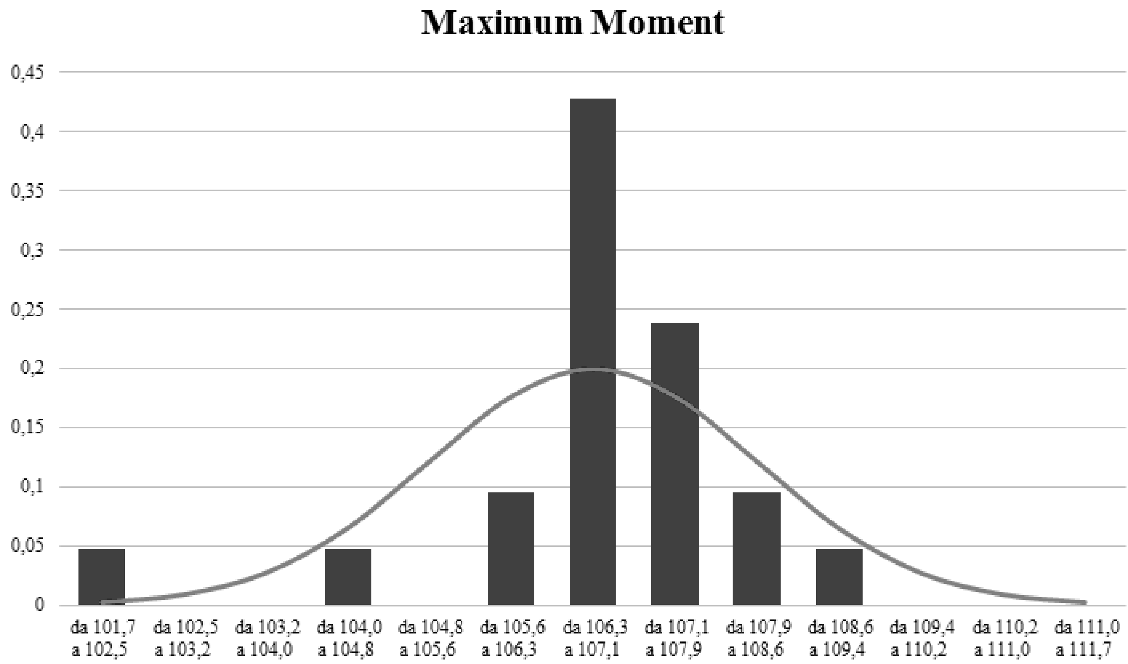


Diagram 9.2 The frequency's diagram of the maximum moment.

The measurement of the maximum of the moment is:

$$Standard\ Deviation = 0{,}99\ [N\ m]$$

$$error = 0{,}221\ [N\ m] \rightarrow 0{,}2\ [N\ m]$$

$$M_{max} = 107{,}0 \pm 0{,}2\ [N\ m]$$

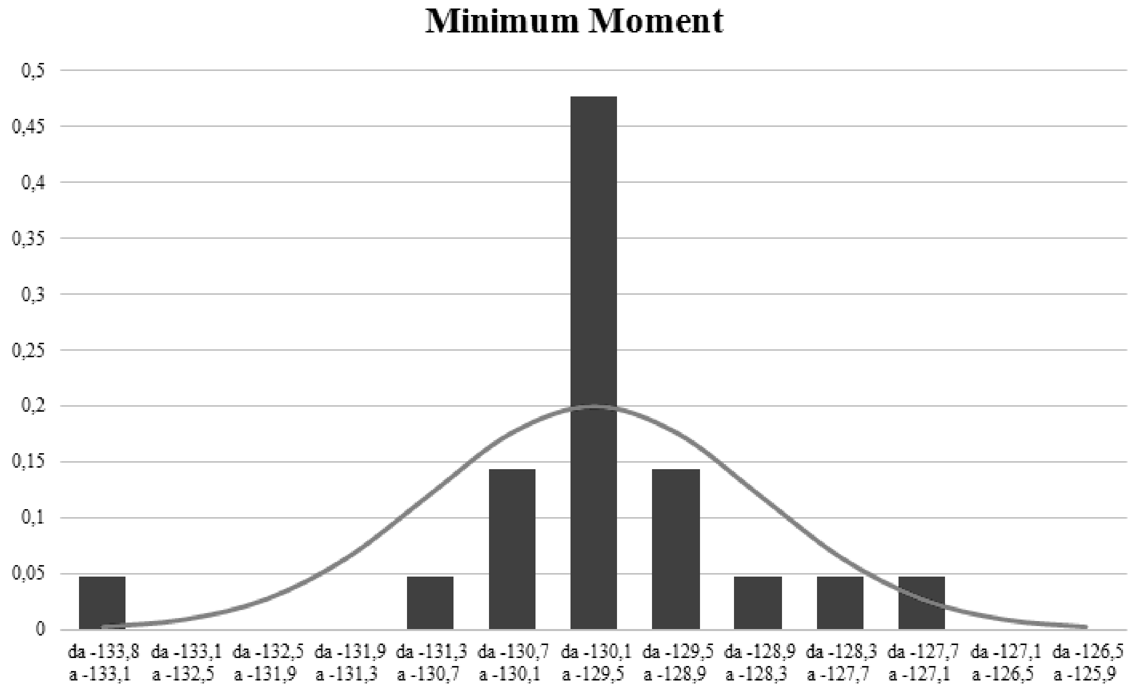


Diagram 9.3 The frequency's diagram of the minimum moment.

The measurement of the minimum moment is:

$$Standard\ Deviation = 0{,}87\ [N\ m]$$

$$error = 0{,}196\ [N\ m] \rightarrow 0{,}2\ [N\ m]$$

$$M_{min} = -129{,}8 \pm 0{,}2\ [N\ m]$$

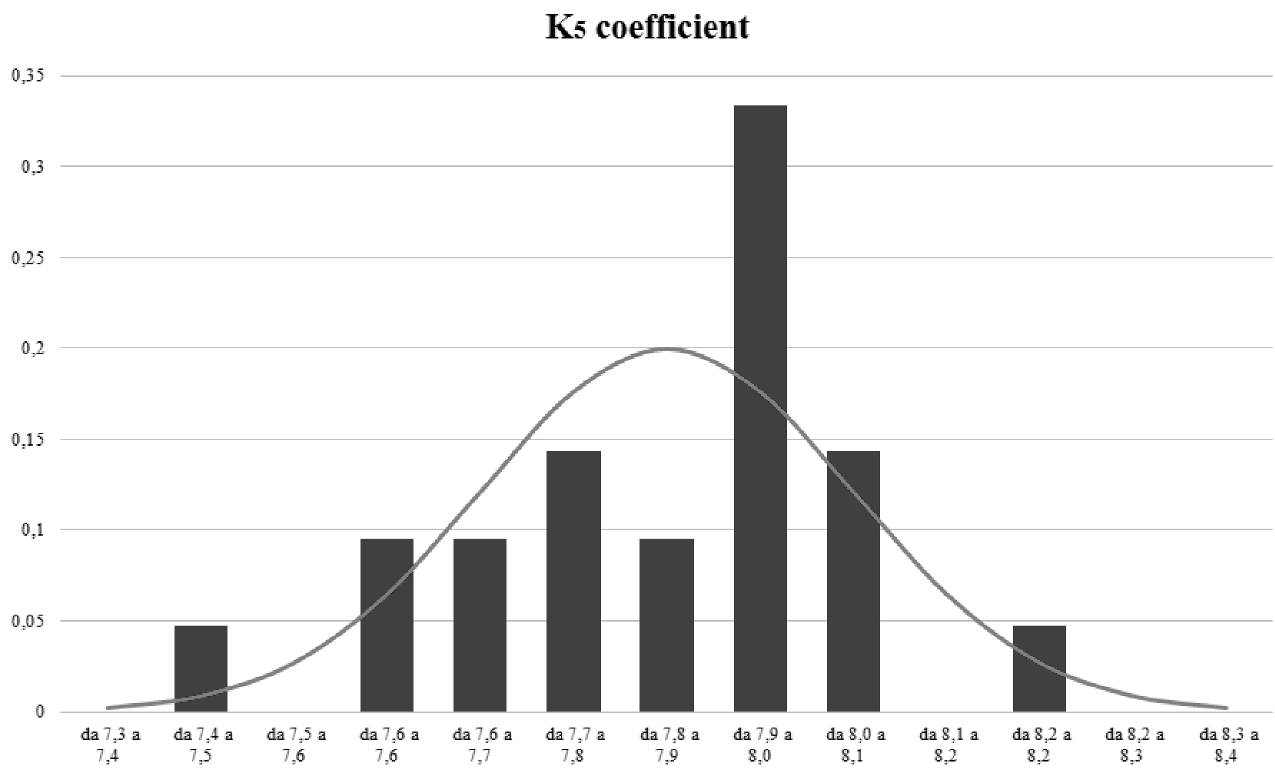


Diagram 9.4 The frequency's diagram of the K_5 coefficient.

The measurement of the K_5 coefficient is:

$$Standard\ Deviation = 0{,}15\ [N\ m/°]$$

$$error = 0{,}104\ [N\ m] \rightarrow 0{,}1\ [N\ m]$$

$$K_5 = 7{,}8 \pm 0{,}1\ [N\ m]$$

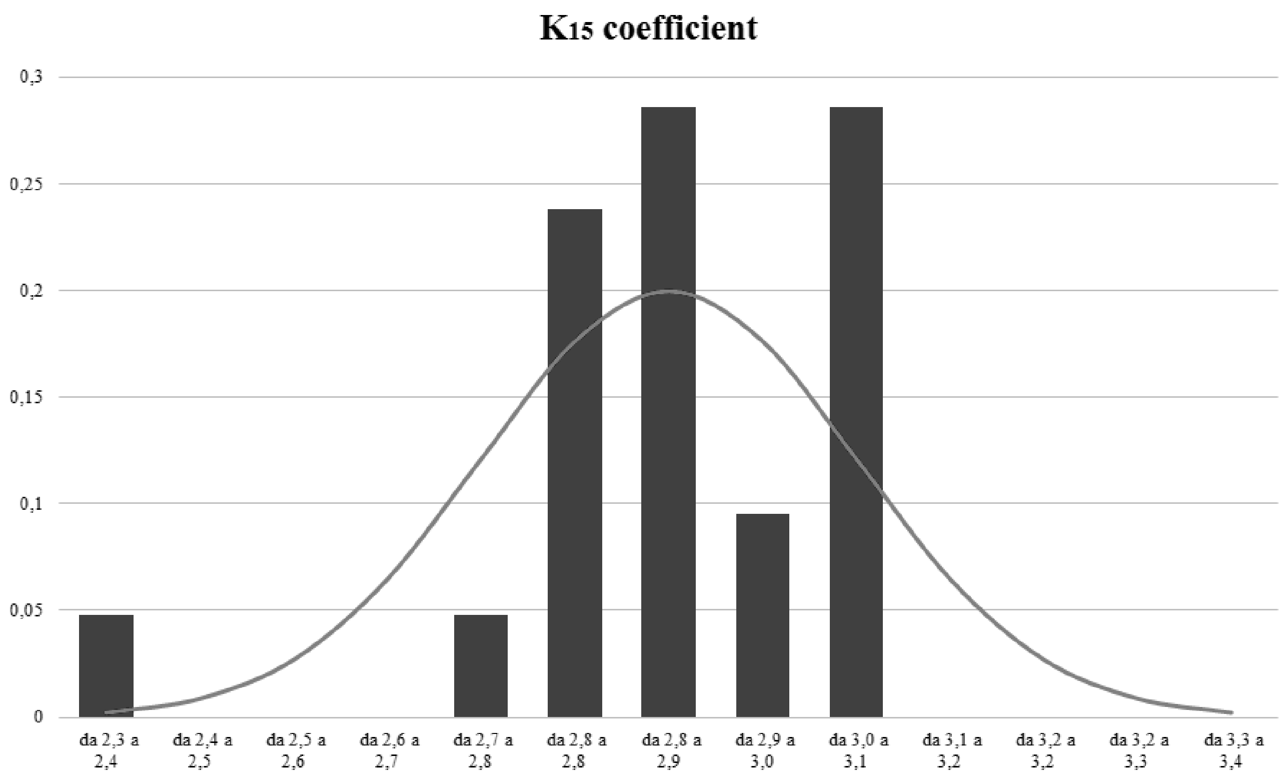


Diagram 9.5 The frequency's diagram of the K_{15} coefficient.

The measurement of the K_{15} coefficient is:

$$Standard\ Deviation = 0{,}09\ [N\ m/°]$$

$$error = 0{,}022\ [N\ m] \rightarrow 0{,}1\ [N\ m]$$

$$K_{15} = 2{,}9 \pm 0{,}1\ [N\ m]$$

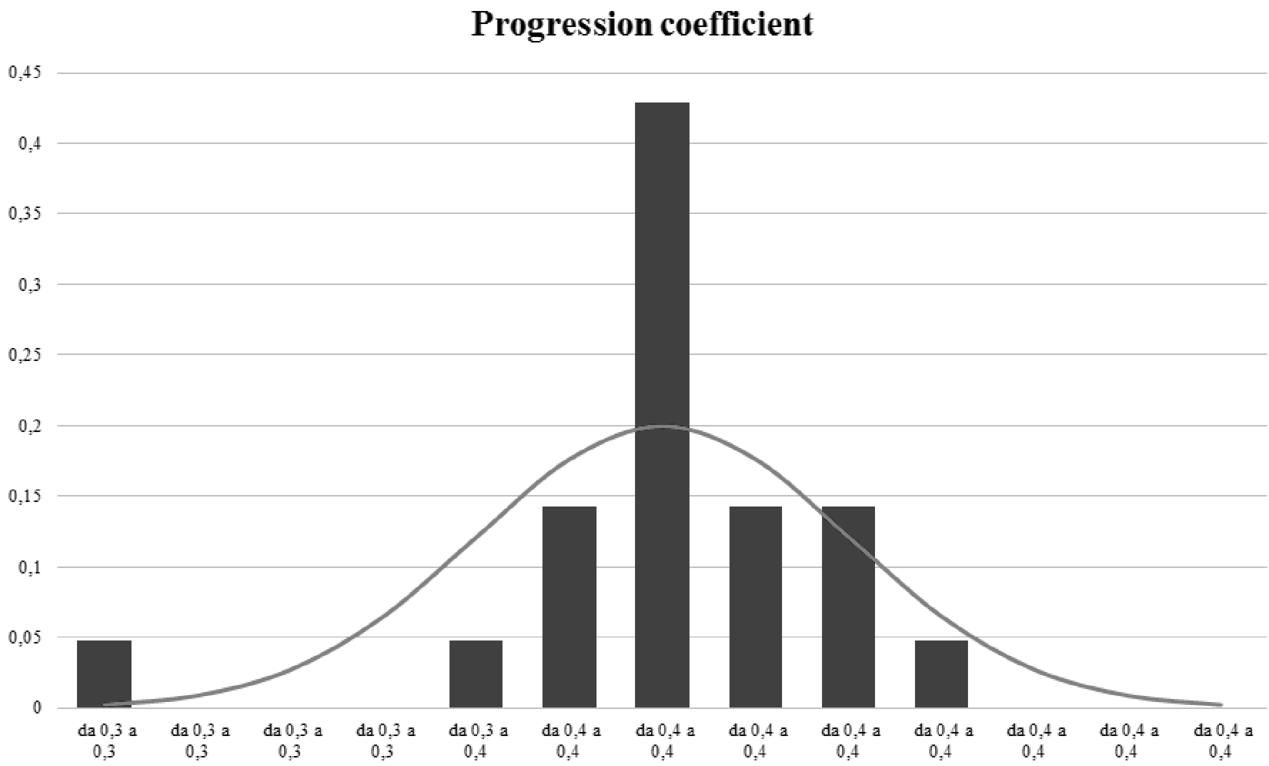


Diagram 9.6 The frequency's diagram of the Progression coefficient.

The measurement of the Progression coefficient is:

$$Standard\ Deviation = 0{,}01$$

$$error = 0{,}002 \ \rightarrow 0{,}1$$

$$Progression = 0{,}37 \pm 0{,}1$$

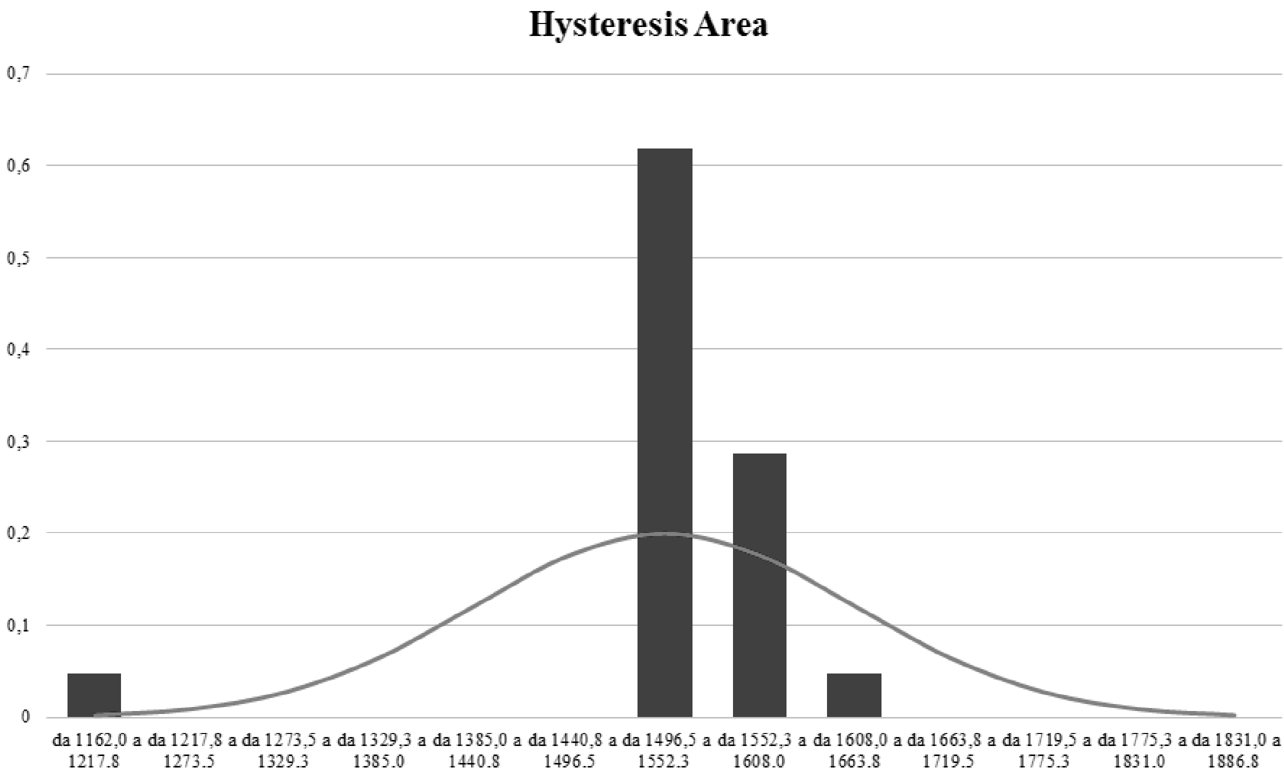


Diagram 9.7 The frequency's diagram of the Hysteresis Area.

The measurement of the Hysteresis Area is:

$$Standard\ Deviation = 1457{,}18$$

$$error = 318\ [N\ m°] \rightarrow 320\ [N\ m°]$$

$$Progression = 1524 \pm 320\ [\ N\ m\ °]$$

Chapter 10 : Results

The ski boots are tested according to different independent variables:

- the work bench;
- the temperature;
- the prosthesis;
- the angular velocity;
- the vertical load (to simulate the weight of a given person).

In order to understand the influence of these parameters, the hysteresis cycle of each ski boot is analysed and the different coefficients are extrapolated.
The analysis of each cycle concerns the following comparisons:

- the engineering Flex Index;

- the maximum value of the bending moment M_{max};
- the minimum value of the bending moment M_{min};
- the relationship of the minimum and maximum moments R;

- the shape of the "loading-segment" of the hysteresis cycle in the proximity of the angle $\theta = -5$ [°]: K_{-5};
- the shape of the "loading-segment" of the hysteresis cycle in the proximity of the angle $\theta = 0$ [°]: K_0;

- the shape of the "loading-segment" of the hysteresis cycle in the proximity of the angle $\theta = +5$ [°]: K_{+5};
- the shape of the "loading-segment" of the hysteresis cycle in the proximity of the angle $\theta = +15$ [°]: K_{+15};

- the progression between the angles $\theta = -5$ [°] and $\theta = 0$ [°] : $Progr_{0/-5}$;
- the progression between the angles $\theta = 0$ [°] and $\theta = +5$ [°] : $Progr_{5/0}$;
- the progression between the angles $\theta = +5$ [°] and $\theta = +15$ [°] : $Progression$;
- the progression between the angles $\theta = -5$ [°] and $\theta = +5$ [°] : $Progr_{5/-5}$;
- the progression between the angles $\theta = -5$ [°] and $\theta = +15$ [°] : $Progr_{15/-5}$;
- the progression comparison between the angles $\theta = 0$ [°] and $\theta = +15$ [°] : $Progr_{15/0}$;

- the hysteresis area.

In addition to the ski boot's analysis, this work is concerned with the influence of the different independent variables.
Firstly, a principal *Table 10.1* featuring a vertical and a horizontal axis is defined. On the vertical axis there are all the ski boots taken into consideration, whereas on the horizontal one the independent variables with their variations are displayed.

Type of Ski Boot	*Work Bench*			*Temperature*		*Prosthetic Leg*					*ω*			*Load*			
	UPT	*UPF*	*ULF*	*T0*	*T1*	*PPS*	*PLR*	*PLS*	*PIR*	*PIS*	*20*	*50*	*80*	*0*	*40*	*80*	*110*
Dalbello Krypton	x	x	x	x	x	x	x	x			x	x	x	x	x	x	x
Dalbello Vantage			x	x		x	x	x	x	x	x	x					
Nordica FireArrow	x	x		x		x	x	x			x	x	x	x	x	x	x
Nordica Hell&Back	x	x		x		x	x	x			x	x	x	x	x	x	x
Nordica "Black"	x	x		x	x	x	x	x			x	x		x	x	x	x
Tecnica phnx	x	x		x		x	x	x			x	x	x	x	x	x	x
Tecnica "Orange"	x	x		x	x	x	x	x			x	x		x	x	x	x
Head Vector	x	x	x	x	x	x	x	x			x	x	x	x	x	x	x
Head Edge	x	x		x		x	x	x			x	x	x	x	x	x	x

Table 10.1 Indicative table.

	UPT																																																																						
	TA																																				T1																																			
	PPS												PLR												PLS												PPS												PLR												PLR											
	L0			L40			L80			L110			L0			L40			L80			L110			L0			L40			L80			L110			L0			L40			L80			L110			L0			L40			L80			L110			L0			L40			L80			L110		
	20	50	80	20	50	80	20	50	80	20	50	80	20	50	80	20	50	80	20	50	80	20	50	80	20	50	80	20	50	80	20	50	80	20	50	80	20	50	80	20	50	80	20	50	80	20	50	80	20	50	80	20	50	80	20	50	80	20	50	80	20	50	80	20	50	80	20	50	80	20	50	80
DALBELLO KRYPTON	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X																																																
DALBELLO VANTAGE																																																																								
NORDICA FIREARROW	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X																																																
NORDICA HELL AND BACK	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X																																																
NORDICA BLACK	X	X		X	X		X	X		X	X		X	X		X	X																																																									
TECNICA PHNX	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X																																															
TECNICA "ORANGE"	X	X		X	X		X	X		X	X		X	X		X	X																																																									
HEAD VECTOR	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X																																																
HEAD EDGE	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X																																																

	UPF																																																																							
	TA																																				T1																																			
	PPS												PLR												PLS												PPS												PLR												PLR											
	L0			L40			L80			L110			L0			L40			L80			L110			L0			L40			L80			L110			L0			L40			L80			L110			L0			L40			L80			L110			L0			L40			L80			L110		
	20	50	80	20	50	80	20	50	80	20	50	80	20	50	80	20	50	80	20	50	80	20	50	80	20	50	80	20	50	80	20	50	80	20	50	80	20	50	80	20	50	80	20	50	80	20	50	80	20	50	80	20	50	80	20	50	80	20	50	80	20	50	80	20	50	80	20	50	80	20	50	80
DALBELLO KRYPTON	X	X											X	X																							X	X																																				
DALBELLO VANTAGE																																																																								
NORDICA FIREARROW	X	X											X	X																																																												
NORDICA HELL AND BACK													X	X																							X	X																																				
NORDICA BLACK	X	X																																			X	X																																				
TECNICA PHNX	X	X											X	X																																																												
TECNICA "ORANGE"	X	X																																			X																																					
HEAD VECTOR	X	X											X	X																							X	X																																				
HEAD EDGE	X	X											X	X																																																												

	ULF																																																																							
	TA																																				T1																																			
	PPS												PLR												PLS												PPS												PLR												PLR											
	L0			L40			L80			L110			L0			L40			L80			L110			L0			L40			L80			L110			L0			L40			L80			L110			L0			L40			L80			L110			L0			L40			L80			L110		
	20	50	80	20	50	80	20	50	80	20	50	80	20	50	80	20	50	80	20	50	80	20	50	80	20	50	80	20	50	80	20	50	80	20	50	80	20	50	80	20	50	80	20	50	80	20	50	80	20	50	80	20	50	80	20	50	80	20	50	80	20	50	80	20	50	80	20	50	80	20	50	80
DALBELLO KRYPTON	X	X											X	X											X	X											X	X											X	X											X	X										
DALBELLO VANTAGE	X	X											X	X											X	X																																														
NORDICA FIREARROW																																																																								
NORDICA HELL AND BACK																																																																								
NORDICA BLACK																																																																								
TECNICA PHNX																																																																								
TECNICA "ORANGE"																																																																								
HEAD VECTOR	X	X											X	X											X	X											X	X											X	X											X	X										
HEAD EDGE																																																																									

Table 10.2 The work benches' table: UPT, UPF and ULF.

It is interested to notice that there are infinite combinations between the principal independent variables and the underneath categories. For instance, taking into consideration the work bench principal variable, the different loads (L0, L40, L80, L110), prosthesis (PPS, PLR, PLS, PIR and PIS), temperature (T0 and T1) and angular velocities (are employed for each work unit , 50 and 80 [°/s) are employed.

In this regards, initially the *Table 10.2* has been carefully observed and the focus was shifted on the statistical analysis. For instance, carry on with the last example of the work bench, only the ski boots analysed in all the work benches are taken into account: in this case, the statistical analysis includes the ski boots tested without load, at the ambient conditions, using two angular velocities (20 and 50 [°/s]) and with PPS and PLR prosthesis.

Therefore, a configuration is chosen as reference, whereas the others are normalized in accordance with the reference. As a result, a distancing percentage between the different configurations can be noticed.

10.1. Prosthesis's Influence

In order to study the effects of the five prosthetic legs, the Prosthesis's *Table 10.3* below shows that all the prosthesis are analysed only through the ULF work bench, at ambient temperature and without the vertical load's application.

The angular velocities employed are only 20 [°/s]. Both Innsbruck's prosthesis have a bigger lever arm and their hysteresis cycles in the test with 50 [°/s] evidence a "loud" signal. For the other prosthesis both velocities are employed.

Accordingly, by maintaining a constant work bench (that is, its load and its temperature), the analysis can be divided into two sections:

1. the first section takes into account the 20 [°/s] and the analysed prosthesis (PPS, PLR, PLS, PIR and PIS);
2. the second section takes into consideration the 50 [°/s] and the analysed prosthesis with this value of the velocity.

Each section has its reference configuration and the results are finally included into a final total comparison between the reference prosthesis and the others.

In this last comparison, the distancing percentage with the reference configuration is valued, and the influence of every independent variables are always defined with average value percentage with their errors.

	PPS		PLR		PLS		PIR		PIS	
	Main	*S.d. PPS*	*Main*	*S.d. PLR*	*Main*	*S.d. PLS*	*Main*	*S.d. PIR*	*Main*	*S.d. PIS*
	[%]	*[%]*	*[%]*	*[%]*	*[%]*	*[%]*	*[%]*	*[%]*	*[%]*	*[%]*
eFi	100	6,34	2,64	8,27	11,85	12,3	-22,6	20	-25,5	20
R	100	8,89	4,38	23,28	- 2,63	21,38	-23,3	20	-39,2	20
K5	100	21,12	2,63	15,84	10,14	12,73	-32,5	20	-62,3	20
K15	100	15,25	33,39	79,22	36,4	91,86	231	20	166,5	20
Progr.	100	23,39	40,09	71,81	22,75	79,07	151	20	141,2	20
A hyst.	100	3,12	17,51	44,71	23,6	43,59	15,2	50	11,8	50

Table 10.3 The distancing percentage between the PPS and the other prosthesis.

	UPT					UPF					ULF				
	TA					TA					TA				
	L0					L0					L0				
	20					20					20				
	PPS	**PLR**	**PLS**	**PIR**	**PIS**	**PPS**	**PLR**	**PLS**	**PIR**	**PIS**	**PPS**	**PLR**	**PLS**	**PIR**	**PIS**
DALBELLO KRYPTON	X	X				X	X	X			X	X	X		
DALBELLO VANTAGE											X	X	X	X	X
NORDICA FIREARROW	X					X	X	X							
NORDICA HELL AND BACK	X	X													
NORDICA BLACK	X					X									
TECNICA PHNX	X					X	X	X							
TECNICA "ORANGE"	X					X									
HEAD VECTOR	X					X	X	X			X	X	X		
HEAD EDGE	X					X	X	X							

	UPT					UPF					ULF				
	TA					TA					TA				
	L0					L0					L0				
	50					50					50				
	PPS	**PLR**	**PLS**	**PIR**	**PIS**	**PPS**	**PLR**	**PLS**	**PIR**	**PIS**	**PPS**	**PLR**	**PLS**	**PIR**	**PIS**
DALBELLO KRYPTON	X	X				X	X	X			X	X	X		
DALBELLO VANTAGE											X	X	X	X	X
NORDICA FIREARROW	X					X	X	X							
NORDICA HELL AND BACK	X	X													
NORDICA BLACK	X					X									
TECNICA PHNX	X					X	X	X							
TECNICA "ORANGE"	X					X									
HEAD VECTOR	X					X	X	X			X	X	X		
HEAD EDGE	X					X	X	X							

Table 10.4 Prosthesis' Table.

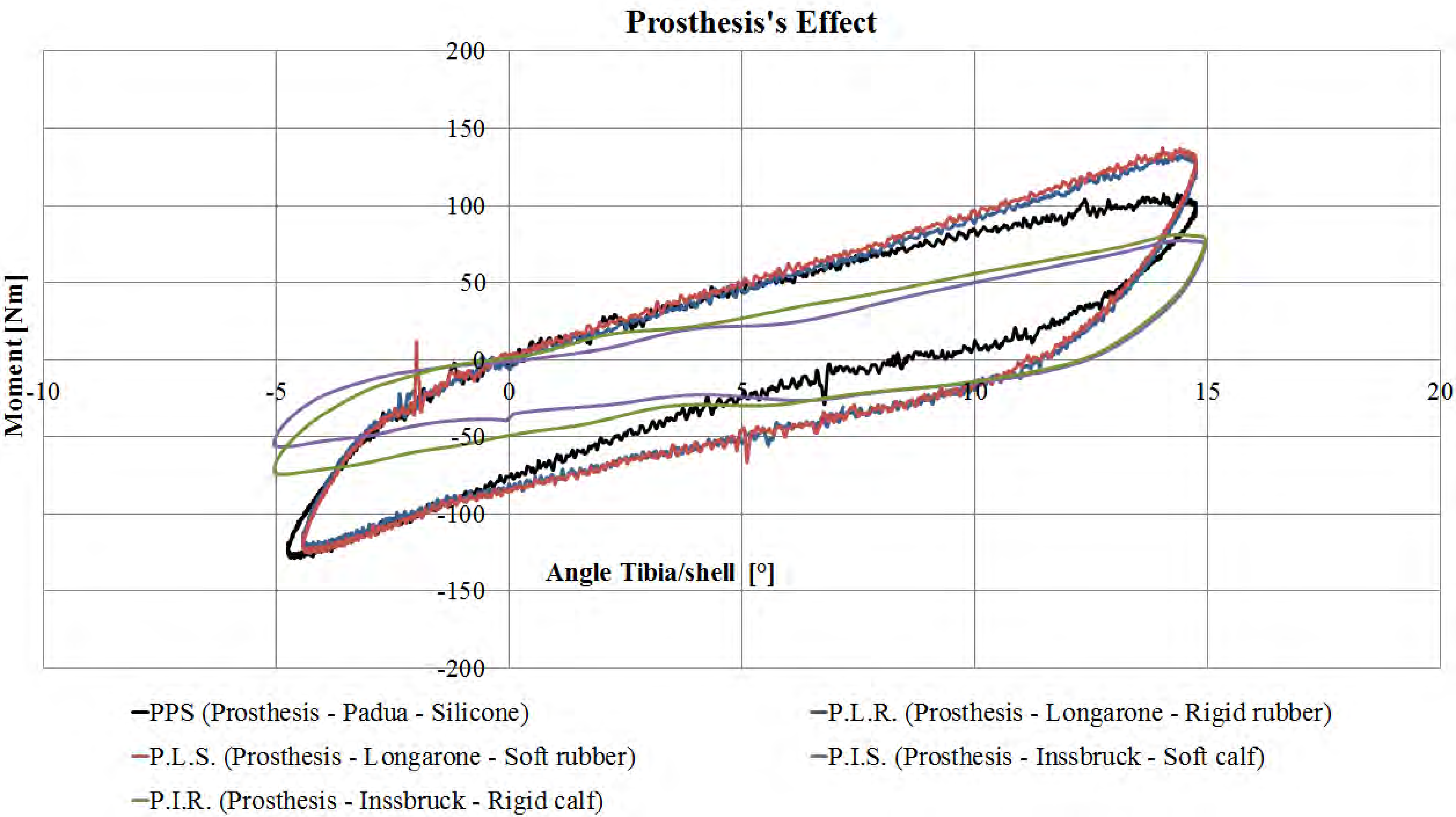
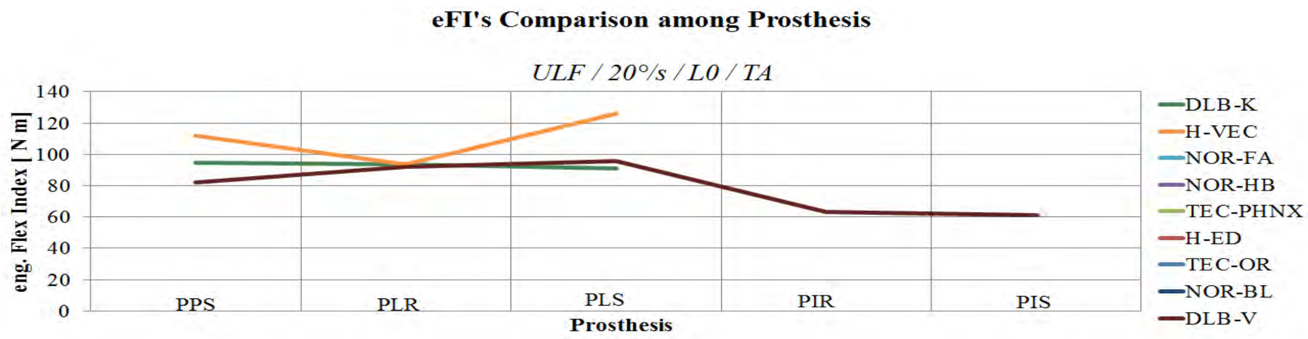
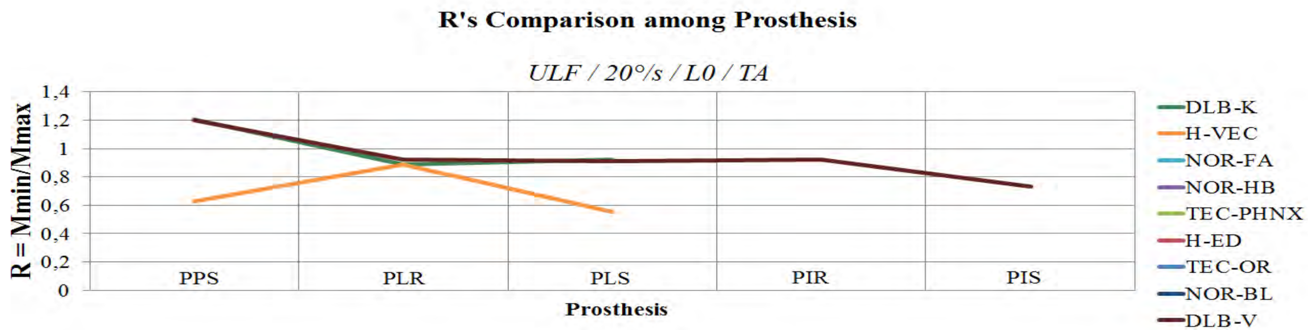


Table 10.5 Hysteresis cycles of every prosthesis.

In the above *Figure 10.5* the hysteresis cycles of the each prosthesis employed are shown. The reference cycle is the one close to the PPS (black cycle).

In the figures below, the absolute values and the influence of the prosthetic leg for each parameter can be seen.





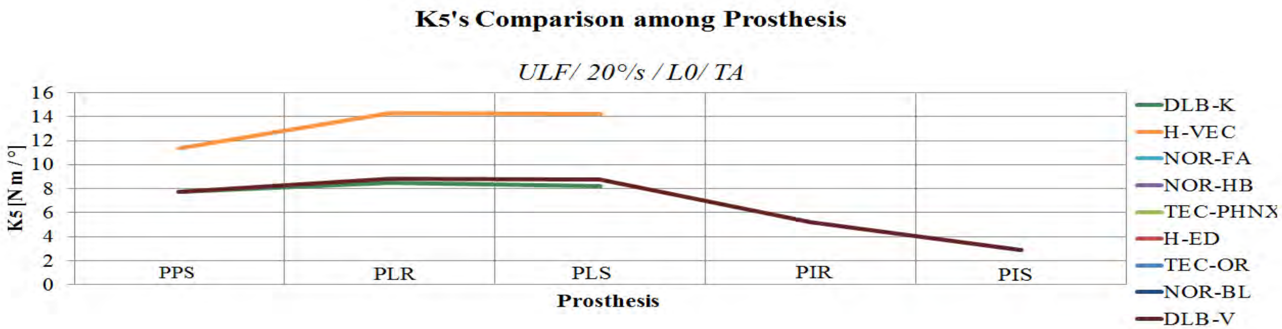
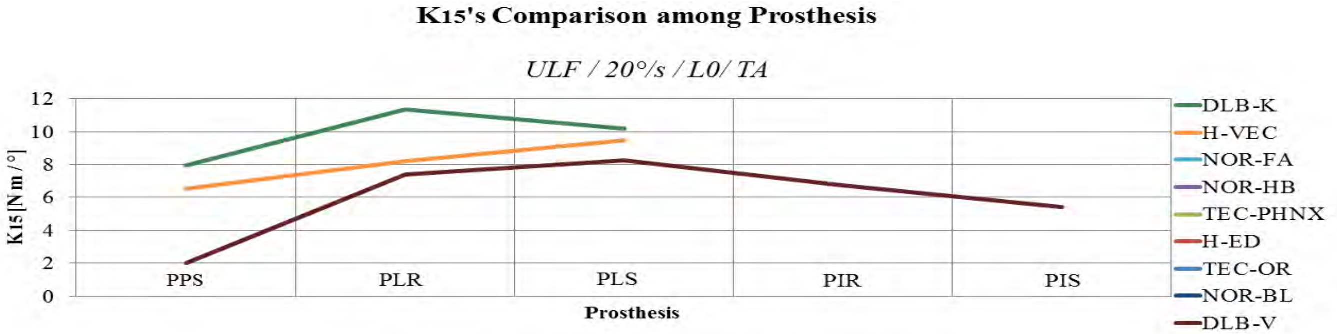
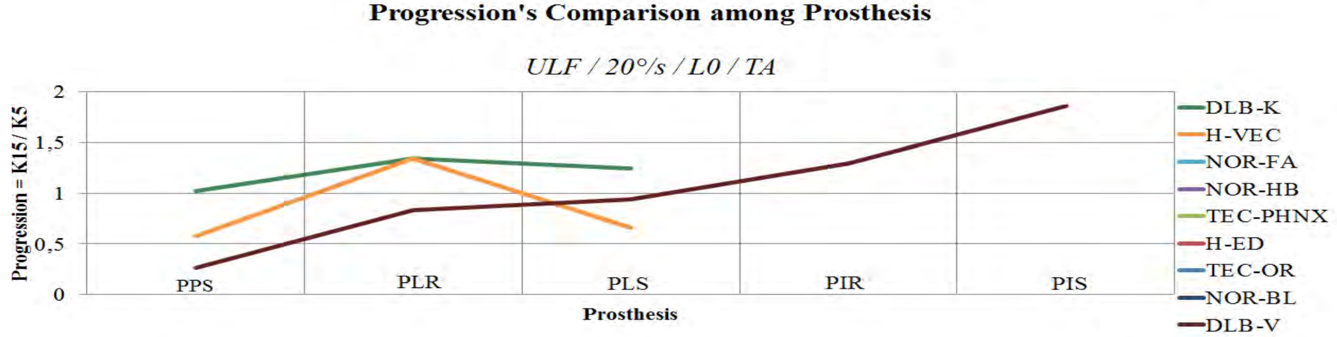


Table 10.6 Total absolute results.





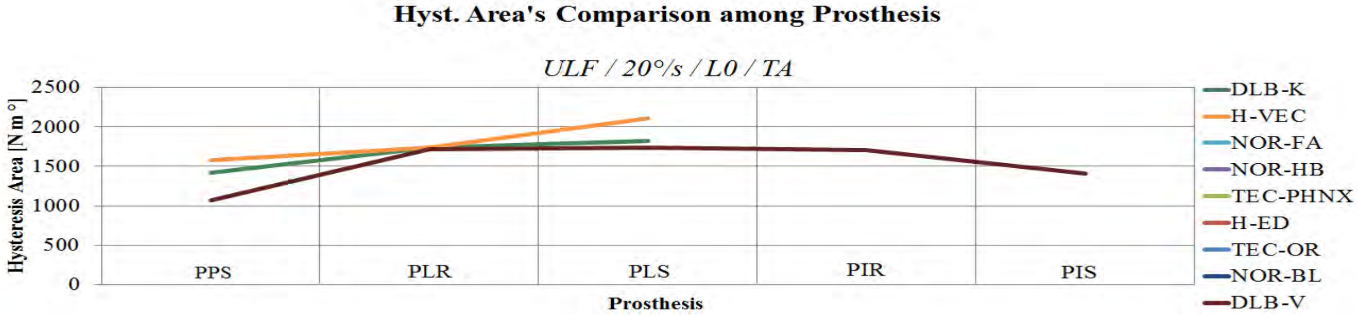


Diagram 10.1 Total absolute results.

10.1.1. P.L.R.'s Influence

The reference configuration has been defined as follows:

- the reference work bench: ULF;
- the reference temperature: TA;
- the reference load: L0;
- the reference velocity: 20 and 50 [°/s];
- the reference prosthesis: PPS.

In this regards, the influence of the PLR in respect to the PPS involves different trends for every parameter. Here, as follows, the inferred results:

	n	eFI	$d.^2$ eFI
	1	-0,99	13,27
	2	12,05	88,4
	3	-16,43	363,79
	4	2,95	0,1
	5	1,36	1,66
	6	2,19	0,21
	7	- 0,91	12,64
	8	15,56	166,84
	9	1,92	0,52
	10	8,75	37,28
n	10		
Tot.	=	26,44	684,7
Main	=	2,64	
S. d.	=	8,72	
Err.	±	2,76	

eFI = 2,64 ± 2,76 [%]

	n	R	$d.^2$ R
	1	-26	922,97
	2	-23,33	768,3
	3	41,34	1365,96
	4	-15,59	398,97
	5	13,36	80,46
	6	43,16	1503,35
	7	10,91	42,62
	8	-12,92	299,56
	9	10,34	35,46
	10	2,58	3,26
n	10		
Tot.	=	43,85	5420,92
Main	=	4,38	
S. d.	=	24,54	
Err.	±	7,76	

R = 4,38 ± 7,76 [%]

Table 10.7 eFI's and R's results.

	n	K5	d.^{2} K5
	1	9,65	49,28
	2	14,51	141,
	3	25,44	519,92
	4	- 8,99	135,07
	5	-14,3	286,62
	6	6,58	15,57
	7	-22,83	648,34
	8	26,83	585,48
	9	- 4,13	45,74
	10	- 6,43	82,11
n	10		
Tot.	=	26,34	2509,14
Main	=	2,63	
S. d.	=	16,7	
Err.	±	5,28	

K 5 = 2,63 ± 5,28 [%]

	n	K15	d.^{2} K15
	1	43,3	98,11
	2	263,05	52744,7
	3	25,15	68,01
	4	28,84	20,76
	5	- 0,76	1166,21
	6	3,61	886,7
	7	-30,19	4042,66
	8	14,93	340,99
	9	0,72	1067,65
	10	-14,72	2314,96
n	10		
Tot.	=	333,92	62750,74
Main	=	33,39	
S. d.	=	83,5	
Err.	±	26,41	

K 15 = 33,39 ± 26,41 [%]

Table 10.8 K5's and K15's results.

	n	Progr	d.^{2} Progr
	1	30,6	90,1
	2	217,11	31334,49
	3	132,21	8485,38
	4	41,51	2,
	5	6,79	1109,28
	6	- 3,12	1867,95
	7	- 9,55	2464,67
	8	-10,16	2525,16
	9	5,02	1229,96
	10	- 9,47	2456,23
n	10		
Tot.	=	400,95	51565,22
Main	=	40,09	
S. d.	=	75,69	
Err.	±	23,94	

Progr. = 40,09 ± 23,94 [%]

	n	A hyst.	d.^{2} A hyst
	1	22,41	24,05
	2	61,06	1896,56
	3	9,76	60,06
	4	-30,27	2283,14
	5	77,39	3585,05
	6	- 5,73	540,11
	7	-51,63	4780,29
	8	-15,98	1121,91
	9	92,99	5696,91
	10	15,11	5,76
n	10		
Tot.	=	175,11	19993,84
Main	=	17,51	
S. d.	=	47,13	
Err.	±	14,9	

A hyst. = 17,51 ± 14,90 [%]

Table 10.9 Progression's and Hysteresis Area's results.

10.1.2. P.L.S.'s Influence

The reference configuration has been defined as follows:

- the reference work bench: ULF;
- the reference temperature: TA;
- the reference load: L0;
- the reference velocity: 20 and 50 [°/s];
- the reference prosthesis: PPS.

In this regards, the influence of the PLS in respect to the PPS involves different trends for every parameter. Here, as follows, the inferred results:.

	n	eFI	$d.^2$ eFI
	1	- 3,44	233,93
	2	16,65	23
	3	12,49	0,4
	4	10,23	2,63
	5	- 0,66	156,58
	6	0,64	125,8
	7	10,07	3,18
	8	28,1	263,93
	9	6,63	27,31
	10	37,84	675,09
n	10		
Tot.	=	118,55	1511,85
Main	=	11,85	
S. d.	=	12,96	
Err.	±	4,1	

eFI = 11,85 ± 4,10 [%]

	n	R	$d.^2$ R
	1	-23,5	435,43
	2	-24,17	463,65
	3	-12,65	100,37
	4	- 0,72	3,65
	5	17,58	408,8
	6	49,26	2693,33
	7	-16,96	205,13
	8	-15,38	162,58
	9	6,49	83,29
	10	- 6,3	13,41
n	10		
Tot.	=	-26,34	4569,64
Main	=	- 2,63	
S. d.	=	22,53	
Err.	±	7,13	

R = -2,63 ± 7,13 [%]

Table 10.10 eFI's and R's results.

	n	K5	d.[2] K5
	1	5,87	18,28
	2	13,86	13,82
	3	25,24	227,97
	4	- 7,23	301,67
	5	- 9,85	399,64
	6	- 0,06	104,2
	7	11,61	2,15
	8	29,22	363,93
	9	8,92	1,5
	10	23,85	187,9
n	10		
Tot.	=	101,43	1621,06
Main	=	10,14	
S. d.	=	13,42	
Err.	±	4,24	

K 5 = 10,14 ± 4,24 [%]

	n	K15	d.[2] K15
	1	28,37	64,53
	2	306,4	72900,23
	3	44,27	61,96
	4	-25,59	3842,89
	5	-11,08	2255,13
	6	- 0,41	1355,4
	7	- 1,45	1433,04
	8	10,98	646,19
	9	6,88	871,48
	10	5,66	945,39
n	10		
Tot.	=	364,04	84376,23
Main	=	36,4	
S. d.	=	96,83	
Err.	±	30,62	

K 15 = 36,40 ± 30,62 [%]

Table 10.11 K5's and K15's results.

	n	Progr	d.[2] Progr
	1	21,04	2,93
	2	257,03	54889,6
	3	14,54	67,33
	4	-19,81	1811,42
	5	- 1,72	598,89
	6	- 0,31	531,83
	7	-11,79	1192,98
	8	-14,22	1366,61
	9	- 1,96	610,62
	10	-15,31	1448,22
n	10		
Tot.	=	227,49	62520,42
Main	=	22,75	
S. d.	=	83,35	
Err.	±	26,36	

Progr.= 22,75 ± 26,36 [%]

	n	A hyst.	d.[2] A hyst
	1	28,48	114,35
	2	22,52	545,29
	3	13,69	30,08
	4	- 2,87	1767,47
	5	25,4	6680,45
	6	- 5,93	2034,
	7	92,42	2835,25
	8	-25,24	4149,38
	9	63,89	610,83
	10	23,86	234,49
n	10		
Tot.	=	236,21	19001,58
Main	=	23,62	
S. d.	=	34,07	
Err.	±	10,77	

A hyst. = 23,60 ± 14,53 [%]

Table 10.12 Progression's and Hysteresis Area's results.

For the two prosthetic legs of University of Innsbruck, the data of the 25 consecutive cycles applied for every test are assumed. According to the statistical analysis of Chapter 8, the error of every parameter results at about 1 [%]. In this cases, the error is increased to 10 [%]. and to 50 [%] for the hysteresis area.

10.1.3. P.I.R.'s and P.I.S.' Influence

The reference configuration has been defined as follows:

- the reference work bench: ULF;
- the reference temperature: TA;
- the reference load: L0;
- the reference velocity: 20 [°/s];
- the reference prosthesis: PPS.

In this regards, the influence of the PIR in respect to the PPS involves different trends for every parameter.

eFI =	-22,66	±	20,00	[%]
R =	-23,33	±	20,00	[%]
K 5 =	-32,51	±	20,00	[%]
K 15 =	231,53	±	20,00	[%]
Progression =	391,25	±	20,00	[%]
Hysteresis Area =	15,20	±	50,00	[%]

Table 10.13 PIR's results.

eFI =	-25,49	±	20,00	[%]
R =	-39,17	±	20,00	[%]
K 5 =	-62,31	±	20,00	[%]
K 15 =	166,50	±	20,00	[%]
Progression =	606,46	±	20,00	[%]
Hysteresis Area =	11,80	±	50,00	[%]

Table 10.14 PIS's results.

10.1.4. Commenting in Results

It is possible to notice that the repeatability of the effective Flex Index, R and K_5 is less than 20 [%], whereas the other variables are included between 40 and 80 [%].

Taking into account both the Longarone's prosthesis, the Flex Index, the relationship between the moments and the K_5 are increase of 5 ÷10 [%]. The Innsbruck's prosthesis tend to decrease these variables.

The K_{15}, the Progression and the Area are always bigger than the reference prosthetic leg, and their distancing percentages are over the 80 [%]

The hysteresis cycles of the PLR and PLS do not present any pronounced difference. The hardness of the rubber has no influence.

The cycles of PIR and PIS have an equal flexion, whereas, in the extension, the PIR is further stressed. This effect can be associated to the hardness of the calf.

10.2. Work Bench's Influence

Taken into consideration the work bench factor, the work benches' *Table 10.16* for this parameter is defined. In this regards, confronting the table and the available data, a configuration was designed as a reference for evidencing the work bench effect.

The *Table 10.16* below shows that the PPS and the PLR are tested at room temperature in every work bench, while always employing two values of angular velocity (20 and 50 [°/s]).

The analysis is kept constant at room temperature (TA) and without any vertical weight (L0).

In particular, the analysis is divided into two underneath categories: the PPS use and the PLR use.

For both categories, the two values of velocity are considered for every combination the tests in every work bench.

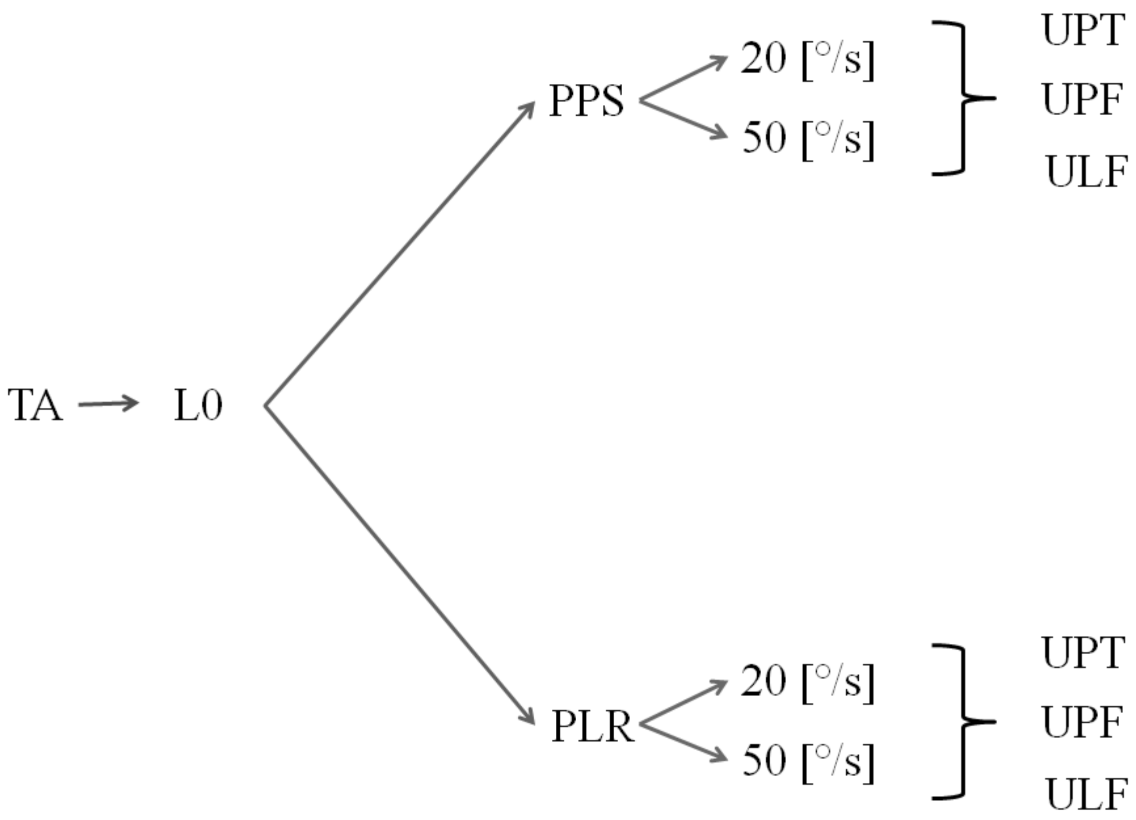


Figure 10.1 Sketch of the scheme employed for the work bench's analysis.

Every combination has the UPT as the reference. For instance, the comparison between the ski boots tested with all work benches, with 20 [°/s] and the PPS, has the following reference:

- respectively, ski boot analysed with the PPS, 20 [°/s] and with the UPT work bench.

The comparison between the ski boots tested with all work benches, with 50 [°/s] and with PPS has the following references:

- respectively, ski boot analysed with the PPS, 50 [°/s] and with the UPT work bench.

The comparison between the ski boots tested with all work benches, with 20 [°/s] and with the PLR has the following reference:

- respectively, ski boot analysed with the PLR, 20 [°/s] and with the UPT work bench.

The comparison between the ski boots tested with all work benches, with 50 [°/s] and the PLR has the following reference:

- respectively, ski boot analysed with the PLR, 50 [°/s] and with the UPT work bench.

The results of every comparison are collected into an single comparison that evidences the distancing percentage between the reference condition and the work bench's effects. In the next *Table 10.15* the total results **with** the UPT, as the reference work bench, are shown.

	UPT		UPF		ULF	
	Main	*S. d. UPT*	*Main*	*S. d. UPF*	*Main*	*S. d. ULF*
	[%]	*[%]*	*[%]*	*[%]*	*[%]*	*[%]*
eFi	100	12,07	- 0,32	10,83	-17,46	15,39
R	100	19,14	15,82	21,36	26,73	30,42
K5	100	15,69	2,04	14,62	-13,74	25,69
K15	100	16,43	14,19	37,89	-38,06	12,25
Progr.	100	22,85	14,65	28,98	-29,29	16,32
A hyst.	100	25,3	12,1	12,15	28,2	17,39

Table 10.15 The distancing percentage between the UPT and the other work benches.

	UPT					UPF					ULF				
	TA					TA					TA				
	L0					L0					L0				
	20					20					20				
	PPS	PLR	PLS	PIR	PIS	PPS	PLR	PLS	PIR	PIS	PPS	PLR	PLS	PIR	PIS
DALBELLO KRYPTON	X	X				X	X	X			X	X	X		
DALBELLO VANTAGE											X	X	X	X	X
NORDICA FIREARROW	X					X	X	X							
NORDICA HELL AND BACK	X	X													
NORDICA BLACK	X					X									
TECNICA PHNX	X					X	X	X							
TECNICA "ORANGE"	X					X									
HEAD VECTOR	X					X	X	X			X	X	X		
HEAD EDGE	X					X	X	X							

	UPT					UPF					ULF				
	TA					TA					TA				
	L0					L0					L0				
	50					50					50				
	PPS	PLR	PLS	PIR	PIS	PPS	PLR	PLS	PIR	PIS	PPS	PLR	PLS	PIR	PIS
DALBELLO KRYPTON	X	X				X	X	X			X	X	X		
DALBELLO VANTAGE											X	X	X	X	X
NORDICA FIREARROW	X					X	X	X							
NORDICA HELL AND BACK	X	X													
NORDICA BLACK	X					X									
TECNICA PHNX	X					X	X	X							
TECNICA "ORANGE"	X					X									
HEAD VECTOR	X					X	X	X			X	X	X		
HEAD EDGE	X					X	X	X							

Table 10.16 Work benches's table.

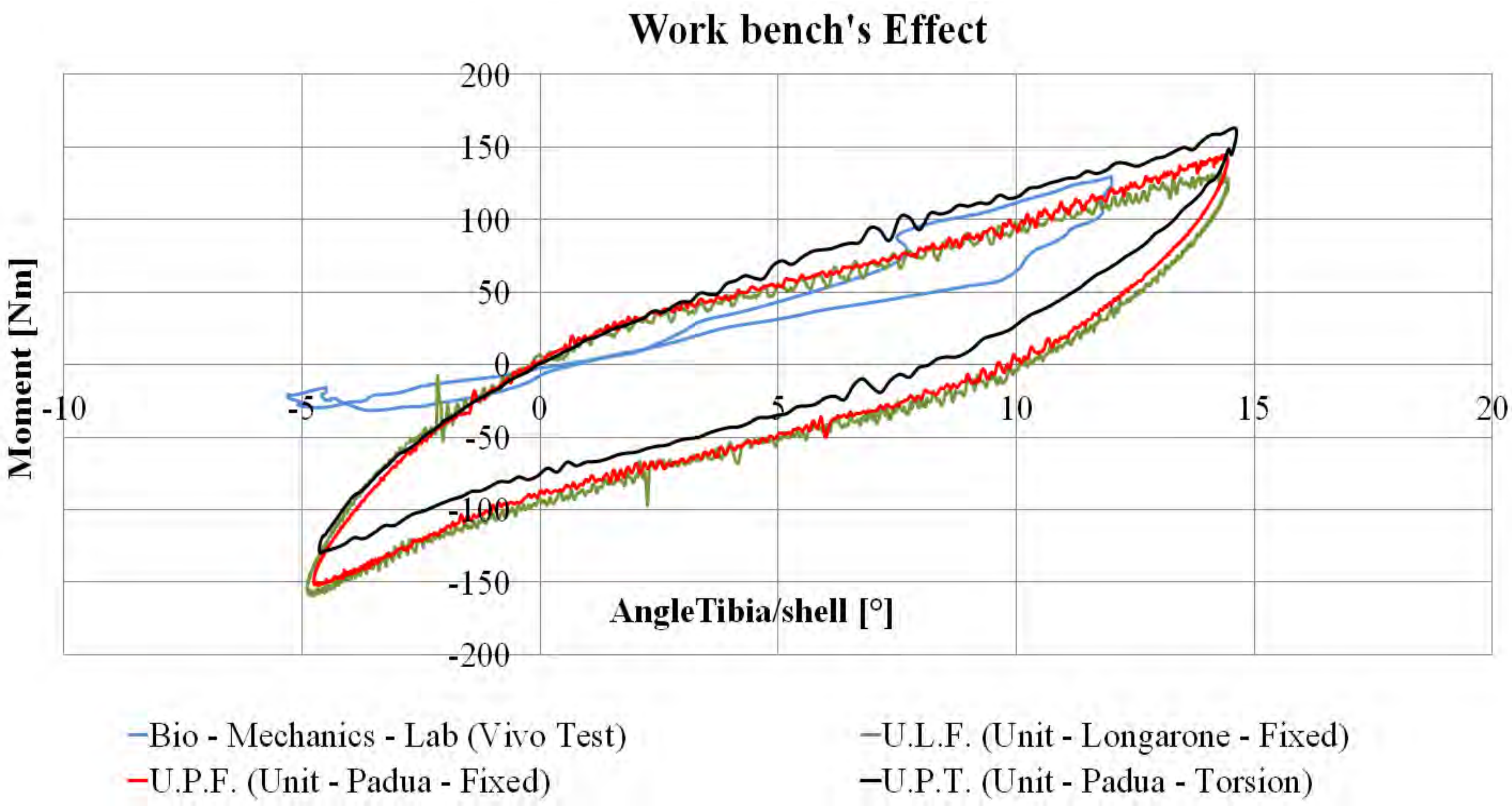


Figure 10.2 Hysteresis cycles in every work bench.

In the *Figure 10.2* above are shown an example of the hysteresis cycles employing the different work benches. The reference cycle is that about the UPT (black cycle).
In the figures below, for each parameter the absolute values and the influence of the work bench are shown.

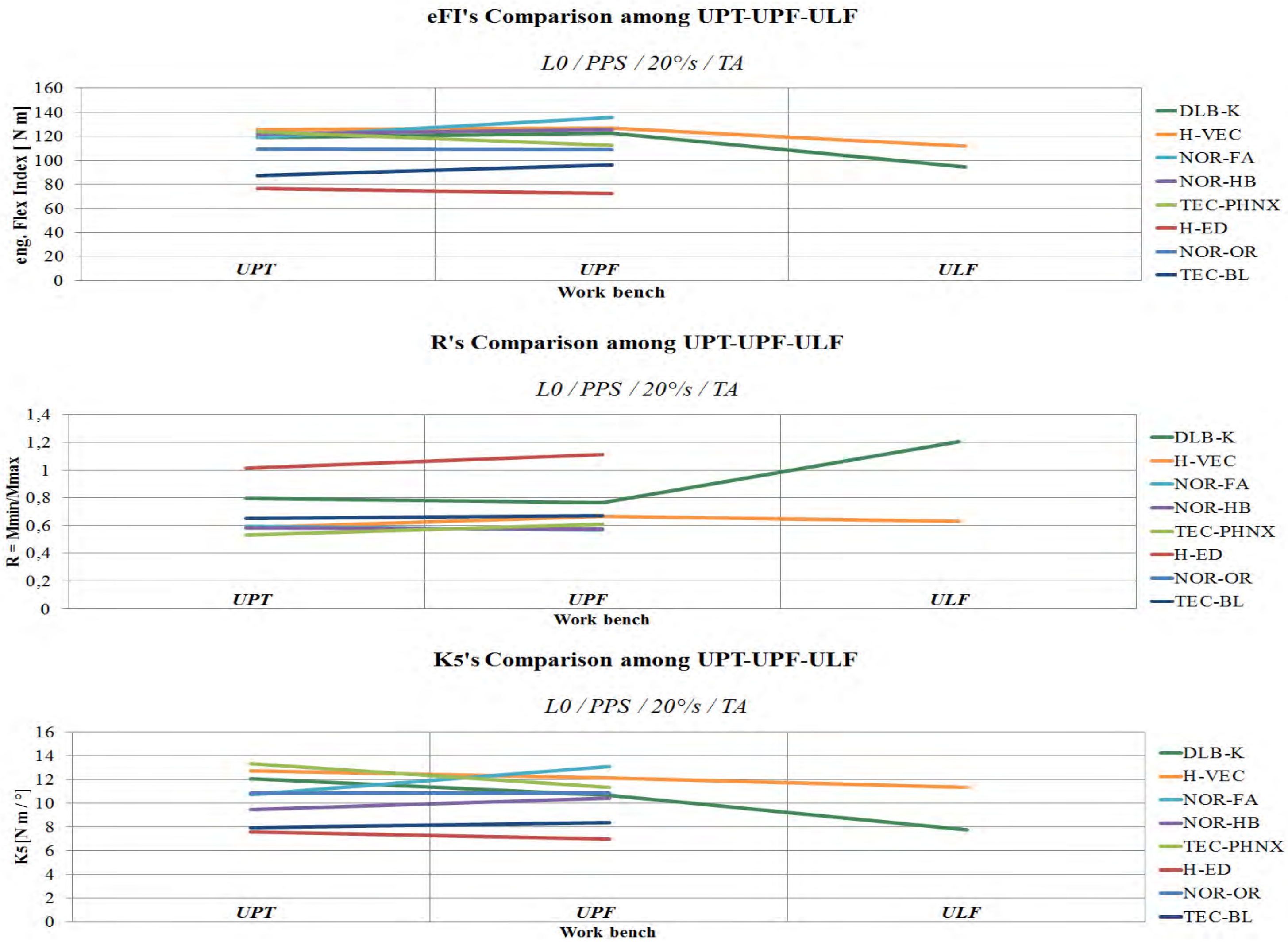


Figure 10.3 Total absolute results.

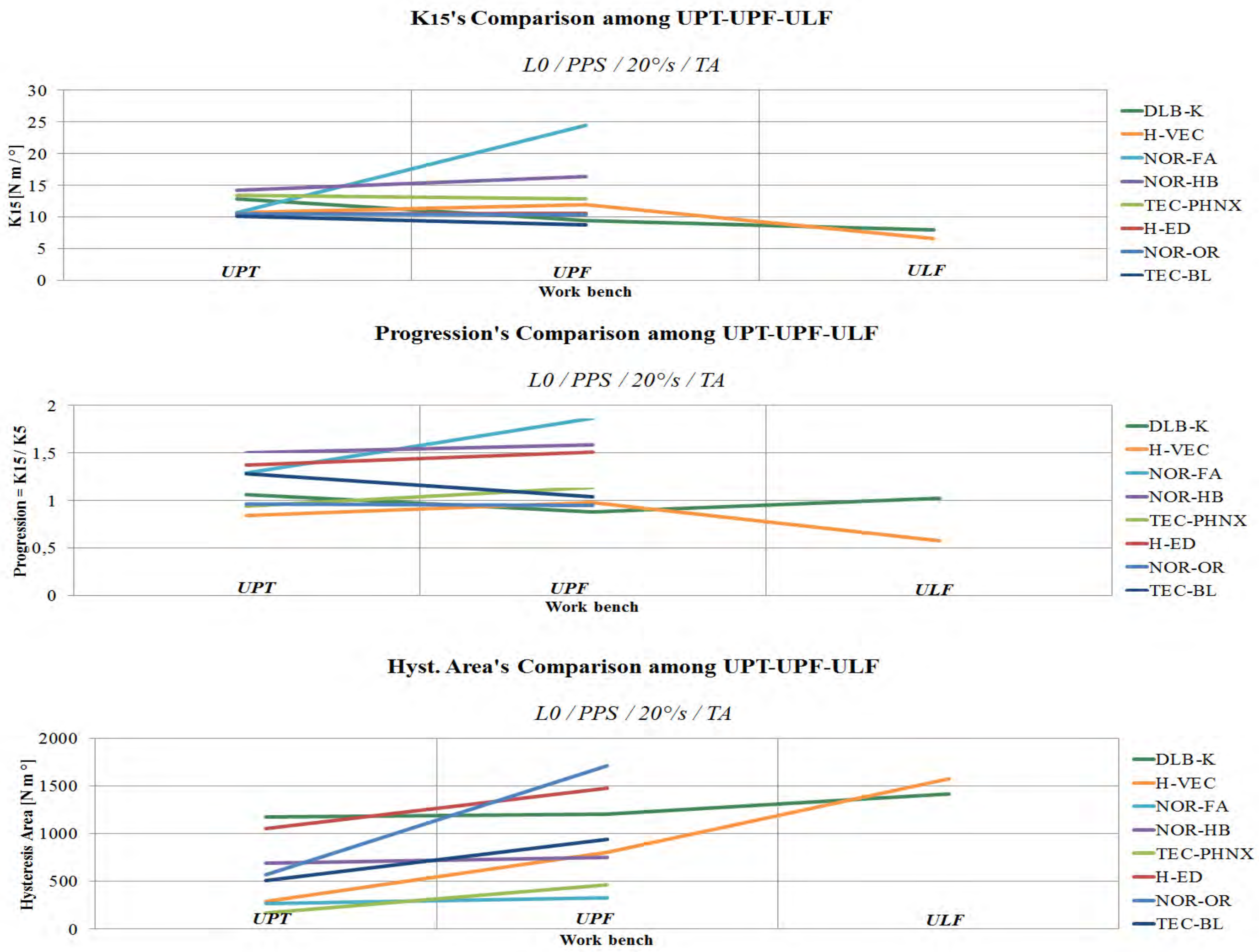


Figure 10.4 Total absolute results.

10.2.1. U.P.F.'s Influence

The reference configuration is defined as follows:

- the reference work bench: UPT;
- the reference temperature: TA;
- the reference load: L0;
- the reference velocity: 20 and 50 [°/s];

	n	eFI	$d.^2$ eFI
	1	3,46	14,28
	2	13,83	200,06
	3	2,74	9,34
	4	- 1,	0,47
	5	- 9,04	76,15
	6	9,84	103,14
	7	1,2	2,3
	8	- 5,37	25,57
	9	- 7,28	48,46
	10	12,67	168,54
	11	6,81	50,79
	12	-10,6	105,78
	13	-13,33	169,46
	14	5,22	30,68
	15	6,23	42,84
	16	-19,21	356,96
	17	-20,69	414,96
	18	6,46	45,88
	19	5,57	34,69
	20	- 8,67	69,74
	21	9,97	105,76
	22	5,26	31,12
	23	-16,98	277,68
	24	14,31	213,86
	25	8,6	79,54
	26	- 0,08	0,06
	27	12,55	165,45
	28	-21,32	441,05
n	28		
Tot.	=	- 8,84	3284,6
Main	=	- 0,32	
S. d.	=	11,03	
Err.	±	2,08	

eFI = -0,3 ± 2,1 [%]

	n	R	$d.^2$ R
	1	- 3,89	388,81
	2	- 4,37	407,91
	3	- 1,81	310,95
	4	53,68	1433,34
	5	14,87	0,91
	6	3,08	162,51
	7	14,73	1,2
	8	9,6	38,76
	9	34,28	340,64
	10	- 4,84	426,98
	11	- 5,22	443,05
	12	60,	1951,45
	13	38,36	508,05
	14	30,74	222,4
	15	13,56	5,13
	16	36,44	425,17
	17	40,96	631,59
	18	- 7,34	536,78
	19	4,92	118,96
	20	4,84	120,69
	21	10,5	28,32
	22	21,57	32,99
	23	11,49	18,75
	24	- 7,58	547,58
	25	4,41	130,26
	26	-11,86	766,69
	27	13,56	5,13
	28	68,42	2766,37
n	28		
Tot.	=	443,09	12771,38
Main	=	15,82	
S. d.	=	21,75	
Err.	±	4,11	

R= 15,8 ± 4,1 [%]

Table 10.17 eFI's and R's results.

	n	K5	d.² K5
	1	-11,56	184,93
	2	22,17	405,26
	3	10,28	68,04
	4	- 0,06	4,41
	5	-15,26	299,13
	6	5,52	12,17
	7	- 4,46	42,2
	8	- 8,1	102,71
	9	0,51	2,32
	10	32,42	923,33
	11	16,54	210,49
	12	-24,87	723,7
	13	-15,82	318,91
	14	-10,22	150,33
	15	2,84	0,65
	16	- 1,59	13,13
	17	-14,14	261,55
	18	29,55	757,22
	19	10,	63,42
	20	-18,05	403,35
	21	4,68	6,99
	22	7,72	32,28
	23	7,04	25,06
	24	23,34	454,01
	25	11,49	89,32
	26	-13,63	245,53
	27	14,44	153,94
	28	- 3,79	33,93
n	28		
Tot.	=	57,02	5988,33
Main	=	2,04	
S. d.	=	14,89	
Err.	±	2,81	

K 5 = 2,0 ± 2,8 [%]

	n	K15	d.² K15
	1	-26,52	1657,26
	2	76,32	3860,4
	3	15,53	1,8
	4	- 0,95	229,2
	5	2,55	135,43
	6	-13,91	789,82
	7	10,98	10,3
	8	1,37	164,28
	9	-14,64	830,97
	10	84,83	4990,43
	11	8,77	29,4
	12	0,82	178,86
	13	-12,01	686,25
	14	-18,85	1091,63
	15	-28,58	1829,68
	16	-16,06	914,93
	17	-33,42	2266,94
	18	65,77	2660,25
	19	17,7	12,32
	20	4,15	100,86
	21	62,22	2307,24
	22	7,28	47,82
	23	-17,01	973,67
	24	94,1	6385,28
	25	9,89	18,53
	26	42,13	780,56
	27	92,98	6207,25
	28	-18,1	1042,89
n	28		
Tot.	=	397,33	40204,24
Main	=	14,19	
S. d.	=	38,59	
Err.	±	7,29	

K 15 = 14,2 ± 7,3 [%]

Table 10.18 K5's and K15's results.

	n	Progr	d.^{2} Progr
	1	-16,91	995,89
	2	44,33	881,07
	3	5,81	78,14
	4	- 1,04	246,1
	5	21,02	40,63
	6	-18,75	1115,29
	7	16,16	2,3
	8	10,31	18,83
	9	-15,45	906,04
	10	39,57	621,13
	11	25,8	124,33
	12	33,33	349,22
	13	5,	93,04
	14	- 9,71	593,15
	15	-30,66	2052,7
	16	-14,81	867,93
	17	-22,54	1383,02
	18	47,73	1094,38
	19	9,27	28,88
	20	14,29	0,13
	21	54,98	1627,21
	22	6,08	73,36
	23	-22,66	1391,74
	24	60,94	2142,81
	25	19,62	24,74
	26	75,24	3671,42
	27	69,22	2978,15
	28	3,95	114,46
n	28		
Tot.	=	410,08	23516,07
Main	=	14,65	
S. d.	=	29,51	
Err.	±	5,58	

Progr = 14,6 ± 5,6 [%]

	n	A hyst.	d.^{2} A hyst
	1	2,28	78,67
	2	3,32	61,23
	3	8,84	5,33
	4	0,68	109,44
	5	16,62	30,03
	6	12,85	2,89
	7	22,94	139,15
	8	9,8	1,8
	9	10,57	0,33
	10	9,31	3,36
	11	13,56	5,85
	12	11,29	0,02
	13	33,57	502,99
	14	23,16	144,28
	15	14,82	13,53
	16	-23,69	1213,71
	17	12,23	1,17
	18	17,89	45,51
	19	8,51	6,96
	20	0,76	107,87
	21	0,37	116,
	22	34,	522,29
	23	30,07	358,17
	24	4,21	48,14
	25	11,48	0,11
	26	11,2	0,
	27	1,73	88,6
	28	9,69	2,13
n	28		
Tot.	=	312,05	3609,57
Main	=	11,14	
S. d.	=	11,56	
Err.	±	2,19	

A hyst. 11,1 ± 2,2 [%]

Table 10.19 Progression's and Hysteresis Area's results.

10.2.2. U.L.F.'s Influence

The reference configuration is defined as follows:

- the reference work bench: UPT;
- the reference temperature: TA;
- the reference load: L0;
- the reference velocity: 20 and 50 [°/s];

	n	eFI	d.² eFI
	1	-20,4	8,63
	2	-10,74	45,22
	3	-41,94	599,17
	4	-13,71	14,06
	5	-27,47	100,13
	6	1,83	372,37
	7	-32,68	231,54
	8	5,41	522,95
n	8		
Tot.	=	-139,7	1894,06
Main	=	-17,46	
S. d.	=	16,45	
Err.	±	5,82	

eFI = -17,5 ± 5,8 [%]

	n	R	d.² R
	1	51,51	614,45
	2	8,15	344,97
	3	94,31	4567,92
	4	15,25	131,61
	5	30,14	11,63
	6	- 4,8	993,76
	7	18,39	69,48
	8	0,85	669,72
n	8		
Tot.	=	213,81	7403,53
Main	=	26,73	
S. d.	=	32,52	
Err.	±	11,5	

R = 26,7 ± 11,5 [%]

Table 10.20 eFI's and R's results.

	n	K5	d.² K5
	1	-35,97	494,02
	2	-10,56	10,11
	3	-66,06	2737,08
	4	- 9,18	20,8
	5	-20,74	48,99
	6	12,18	672,26
	7	1,54	233,48
	8	18,85	1062,37
n	8		
Tot.	=	-109,95	5279,11
Main	=	-13,74	
S. d.	=	27,46	
Err.	±	9,71	

K 5 = -13,7 ± 9,7 [%]

	n	K15	d.² K15
	1	-38,12	0,
	2	-39,	0,88
	3	-51,69	185,9
	4	-47,01	80,07
	5	-34,25	14,5
	6	-23,66	207,39
	7	-54,05	255,66
	8	-16,7	456,27
n	8		
Tot.	=	-304,46	1200,67
Main	=	-38,06	
S. d.	=	13,1	
Err.	±	4,63	

K 15 = -38,1 ± 4,6 [%]

Table 10.21 K5's and K15's results.

	n	Progr	d.^{2} Progr
	1	- 3,35	672,8
	2	-31,78	6,18
	3	-14,64	214,72
	4	-51,25	482,08
	5	-17,09	148,83
	6	-32,04	7,56
	7	-53,74	598,01
	8	-30,43	1,31
n	8		
Tot.	=	-234,32	2131,48
Main	=	-29,29	
S. d.	=	17,45	
Err.	±	6,17	

Progr = -29,3 ± 6,2 [%]

	n	A hyst.	d.^{2} A hyst
	1	20,25	72,67
	2	7,71	443,45
	3	32,71	15,53
	4	11,16	310,15
	5	43,1	205,45
	6	26,72	4,22
	7	34,73	35,53
	8	53,78	625,58
n	8		
Tot.	=	230,17	1712,58
Main	=	28,77	
S. d.	=	15,64	
Err.	±	5,53	

A hyst. = 28,8 ± 5,5 [%]

Table 10.22 Progression's and Hysteresis Area's results.

10.2.3. Bio–Mechanics-Lab

In the vivo analysis, four ski boots (Dalbello Krypton, Nordica FireArrow, Nordica Hell and Back, Tecnica Phnx) are tested through a human tester. These boots are analysed by using both Padua's Units, UPT and UPF. Therefore, in the following comparison the absolute tendency of the dependent variables of only the UPT, the UPF and the Biomechanics laboratory is shown.

The *Table 10.23* below explains the correlations between the singular ski boot and the independent variables.

The comparison between the ski boots tested with all work benches, at the room temperature, has the following reference:

- respectively, ski boot analysed with PPS, 20 [°/s] and with UPT work bench.

The results of each comparison are collected into an unvocal comparison that evidences the distancing percentage between the reference condition and the work bench's effects.

	UPT					UPF					BIO - MECH. - LAB
	TA					TA					TA
	L80					L80					70 [Kg]
	20					20					
	PPS	PLR	PLS	PIR	PIS	PPS	PLR	PLS	PIR	PIS	
DALBELLO KRYPTON	X	X				X	X	X			X
DALBELLO VANTAGE											
NORDICA FIREARROW	X					X	X	X			X
NORDICA HELL AND BACK	X	X									X
NORDICA BLACK	X					X					
TECNICA PHNX	X					X	X	X			X
TECNICA "ORANGE"	X					X					
HEAD VECTOR	X					X	X	X			
HEAD EDGE	X					X	X	X			

Table 10.23 Work benches' table.

In the figures below, for each parameter the absolute values and the influence of the work bench are shown.

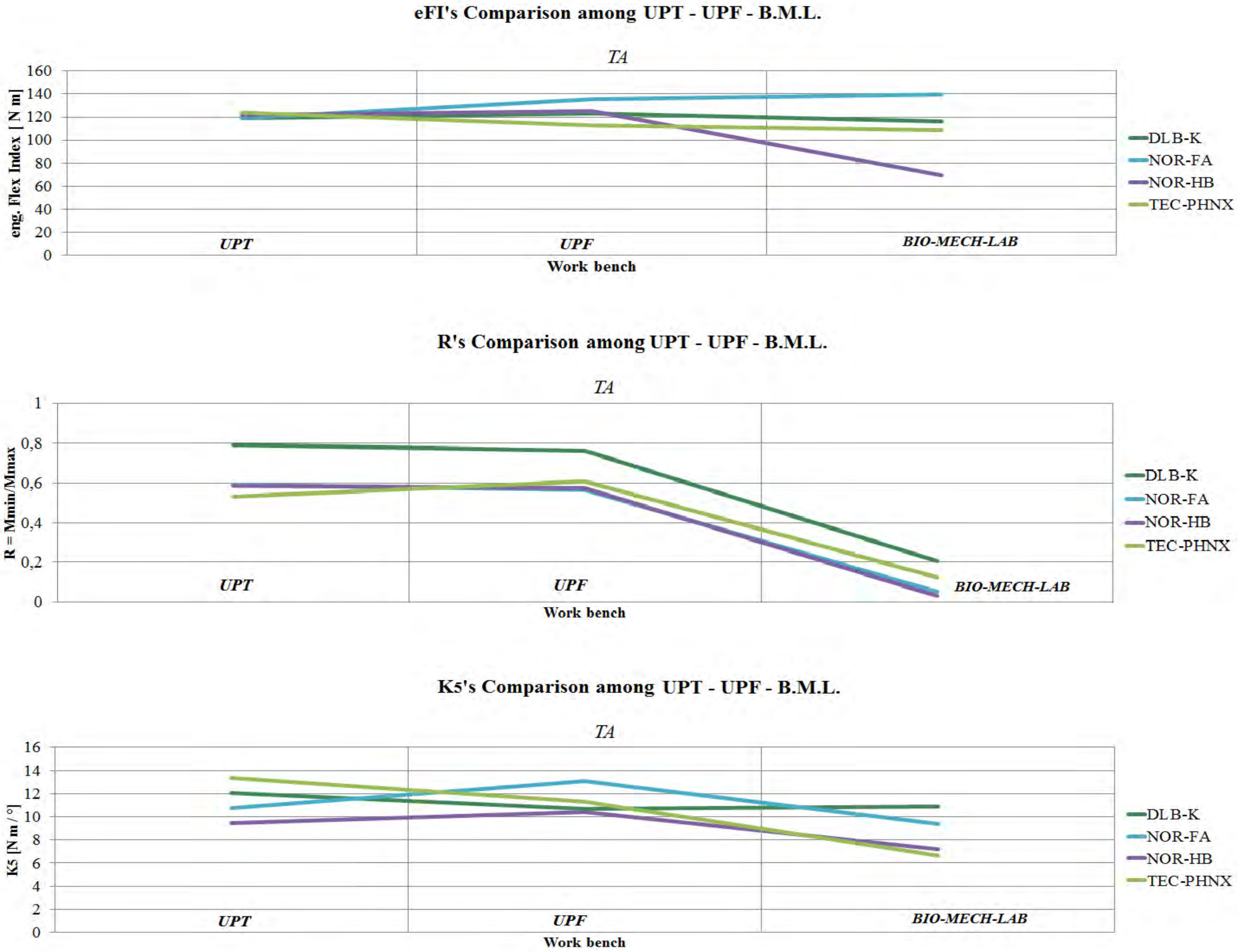


Figure 10.5 Total absolute results.

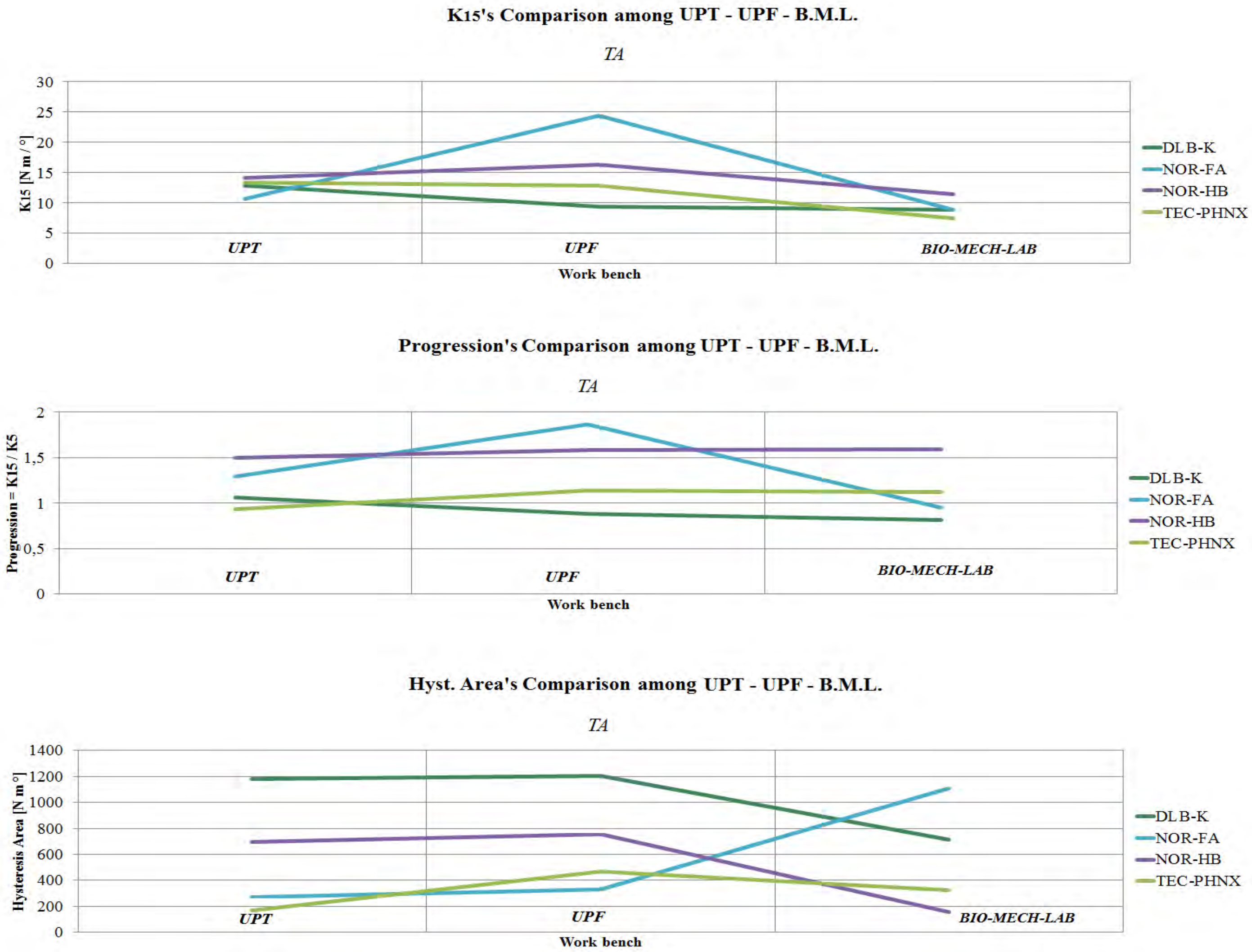


Figure 10.6 Total absolute results.

10.2.3.1. Bio – Mechanics - Lab's Influence

The reference configuration is defined as follows:

- the reference work bench: UPT;
- the reference temperature: TA;
- the reference load: L80;
- the reference velocity: 20 [°/s];

	n	eFI	d.² eFI
	1	- 2,14	64,44
	2	17,23	750,63
	3	-43,24	1093,2
	4	-12,53	5,58
n	4		
Tot.	=	-40,69	1913,85
Main	=	-10,17	
S. d.	=	25,26	
Err.	±	12,63	

eFI = -10,2 ± 12,6 [%]

	n	R	d.² R
	1	-74,07	99,28
	2	-90,92	47,37
	3	-94,71	114,06
	4	-76,44	57,73
n	4		
Tot.	=	-336,14	318,44
Main	=	-84,04	
S. d.	=	10,3	
Err.	±	5,15	

R = -84,0 ± 5,2 [%]

Table 10.24 eFI's and R's results.

	n	K5	d.² K5
	1	-10,11	200,33
	2	-12,77	132,32
	3	-23,91	0,13
	4	-50,28	676,77
n	4		
Tot.	=	-97,07	1009,54
Main	=	-24,27	
S. d.	=	18,34	
Err.	±	9,17	

K5 = -24,3 ± 9,2 [%]

	n	K15	d.² K15
	1	-31,05	0,35
	2	-35,84	17,6
	3	-19,39	150,32
	4	-40,31	75,01
n	4		
Tot.	=	-126,6	243,29
Main	=	-31,65	
S. d.	=	9,01	
Err.	±	4,5	

K15 = -31,6 ± 4,5 [%]

Table 10.25 K5's and K15's results.

	n	Progr	d.^{2} Progr
	1	-23,59	309,01
	2	-26,44	417,5
	3	5,94	142,71
	4	20,06	679,4
n	4		
Tot.	=	-24,03	1548,62
Main	=	- 6,01	
S. d.	=	22,72	
Err.	±	11,36	

Progr = -6,0 ± 11,4 [%]

	n	A hyst.	d.^{2} A hyst
	1	-39,25	12395,73
	2	311,13	57140,98
	3	-77,03	22237,4
	4	93,51	458,66
n	4		
Tot.	=	288,36	92232,77
Main	=	72,09	
S. d.	=	175,34	
Err.	±	87,67	

A hyst. = 72,1 ± 87,7 [%]

Table 10.26 Progression’s and Hysteresis Area’s results.

10.2.4. Commenting in Results

It is possible to notice that the repeatabilities of respectively the effective Flex Index, R, K_5, K_{15} and of the Progression are lesser than 35 [%], also the hysteresis area is included between 10 and 25 [%].

By taking into account both the Fixed Units in Padua, their distancing percentages from the reference are not excessive (30 [%]) except for the variable Area.

It can be noticed how the work benches' cycles are more different than the cycle of the test in vivo. The form of the latter is not similar, but considering the values of the dependent variable, the distancing is not so different (5 ÷20 [%]). A principal difference between the tests made by using the machines and those made by using the tester is the moment's application, which is always constant in the units, whereas the human tester does not allow the application of a constant value of the stress.

10.3. Load's Influence

As far as the study of the effects of the vertical weight is concerned, the loads' *Table 10.28* of this comparison is defined. The *Table 10.28* shows how the "weight" load is employed only in the Unit Padua Torsion (UPT) work bench. The other axial benches are not predisposed to this application.

Therefore, the UPT is taken into account as the reference test bench as a consequence of the room temperature (TA).

As far as the prosthesis and the angular velocity are concerned, respectively the prosthesis are two (PPS and PLR), whereas the velocity employed are 20, 50 and 80 [°/s].

The configurations of the loads applied are:

- without the load: L0;
- with 40 [N]: L40;
- with 80 [N]: L80;
- with 110 [N].

In particular, the analysis is divided into two subcategories: the use of the PPS and the use of the PLR. The PPS is tried on all the ski boots, whereas the other prosthesis on only two ski boots. The first category is chosen as the principal.

Two values of velocity are considered and four load's combinations are analysed.

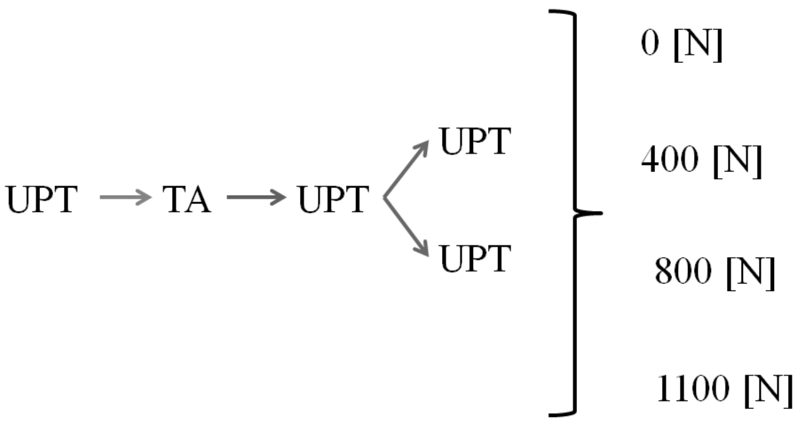


Figure 10.7 Sketch of the scheme employed for the load's analysis.

Every combination has the UPT as the reference. For instance, the comparison between the ski boots tested with UPT work benches, with 20 [°/s] and with PPS has the following reference:

- respectively, ski boot analysed with PPS, 20 [°/s] and without load (L0).

The comparison between the ski boots tested with the UPT work benches, with 50 [°/s] and with PPS has the following reference:

- respectively, ski boot analysed with PPS, 50 [°/s] and without load (L0).

The results of every comparison are collected into an unvocal comparison that evidences the distancing percentage between the reference condition and the vertical load's effects.
In the next *Table 10.27* are shown the total results with the L0 configuration as the reference load condition.

	L0		L40		L80		70 [kg]		L110	
	Main	S.d. L0	Main	S.d. L40	Main	S.d. L80	Main	S.d. Human's weight	Main	S.d. L110
	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]
eFi	100	14,79	3,63	6,12	8,74	10,99	-10,17	21,87	16,79	24,66
R	100	20,48	9,95	25,07	13,69	26,28	-84,04	8,92	- 2,9	33,08
K5	100	18,58	0,84	14,63	4,61	12,43	-24,27	15,89	11,65	26,55
K15	100	16,37	2,65	15,3	0,79	11,38	-31,65	7,8	3,66	13,27
Progr.	100	15,1	3,27	15,03	- 1,42	15,1	- 6,01	19,68	- 5,73	15,94
A hyst.	100	15,1	17,9	23,2	25,3	32,1	72,09	31,85	23,2	23,89

Table 10.27 The distancing percentage between the L0 and the other load's conditions.

	UPT												UPT												UPT											
	TA												TA												TA											
	PPS				PLR				PLS				PPS				PLR				PLS				PPS				PLR				PLS			
	20												20												20											
	L0	L40	L80	L110	L0	L40	L80	L110	L0	L40	L80	L110	L0	L40	L80	L110	L0	L40	L80	L110	L0	L40	L80	L110	L0	L40	L80	L110	L0	L40	L80	L110	L0	L40	L80	L110
DALBELLO KRYPTON	X	X	X	X	X	X	X	X																																								
DALBELLO VANTAGE																																																
NORDICA FIREARROW	X	X	X	X																																												
NORDICA HELL AND BACK	X	X	X	X																																												
NORDICA BLACK	X	X	X	X																																												
TECNICA PHNX	X	X	X	X																																												
TECNICA "ORANGE"	X	X	X	X																																												
HEAD VECTOR	X	X	X	X	X	X	X	X																																								
HEAD EDGE	X	X	X	X																																												

	UPT												UPT												UPT											
	TA												TA												TA											
	PPS				PLR				PLS				PPS				PLR				PLS				PPS				PLR				PLS			
	50												50												50											
	L0	L40	L80	L110	L0	L40	L80	L110	L0	L40	L80	L110	L0	L40	L80	L110	L0	L40	L80	L110	L0	L40	L80	L110	L0	L40	L80	L110	L0	L40	L80	L110	L0	L40	L80	L110
DALBELLO KRYPTON	X	X	X	X	X	X	X	X																																								
DALBELLO VANTAGE																																																
NORDICA FIREARROW	X	X	X	X																																												
NORDICA HELL AND BACK	X	X	X	X																																												
NORDICA BLACK	X	X	X	X																																												
TECNICA PHNX	X	X	X	X																																												
TECNICA "ORANGE"	X	X	X	X																																												
HEAD VECTOR	X	X	X	X	X	X	X	X																																								
HEAD EDGE	X	X	X	X																																												

Table 10.28 Loads' table.

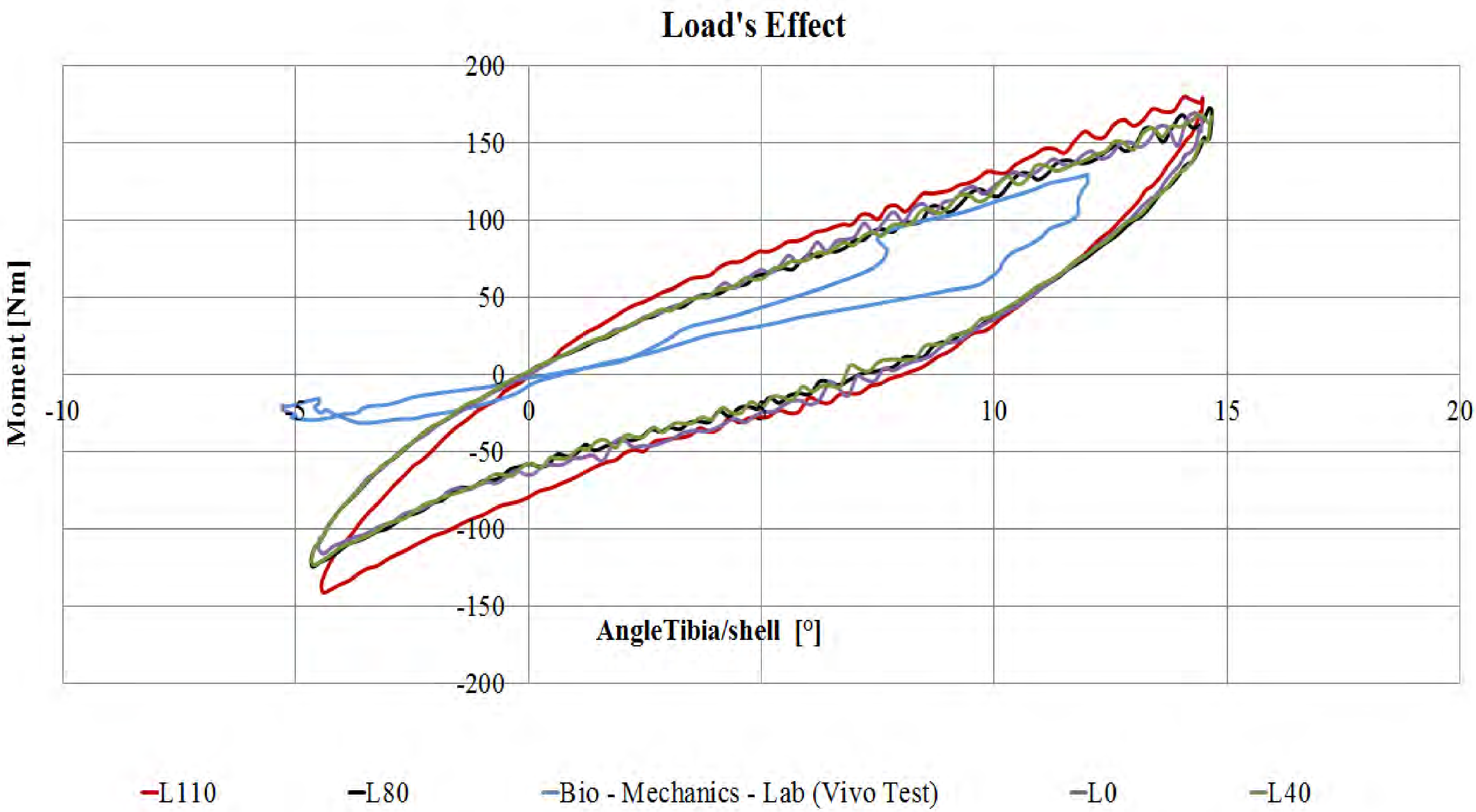


Figure 10.8 Hysteresis cycles with the different loading conditions.

In the *Figure 10.8* above the hysteresis cycles of the each load employed are shown. The reference cycle is the one about the L0 condition (black cycle).

In the figures below, for each parameter the absolute values and the influence of the "weight load" are shown.

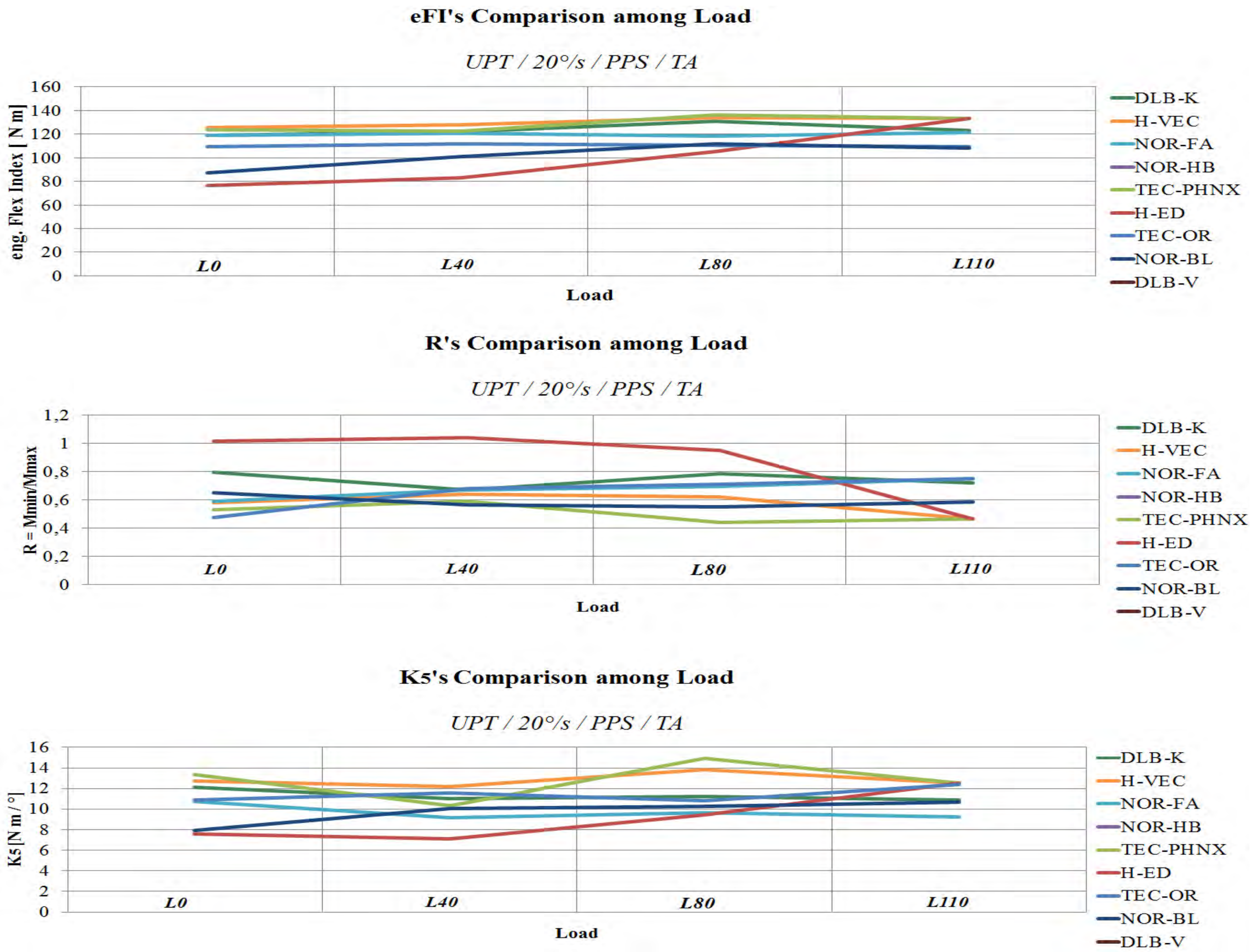


Figure 10.9 Total absolute results.

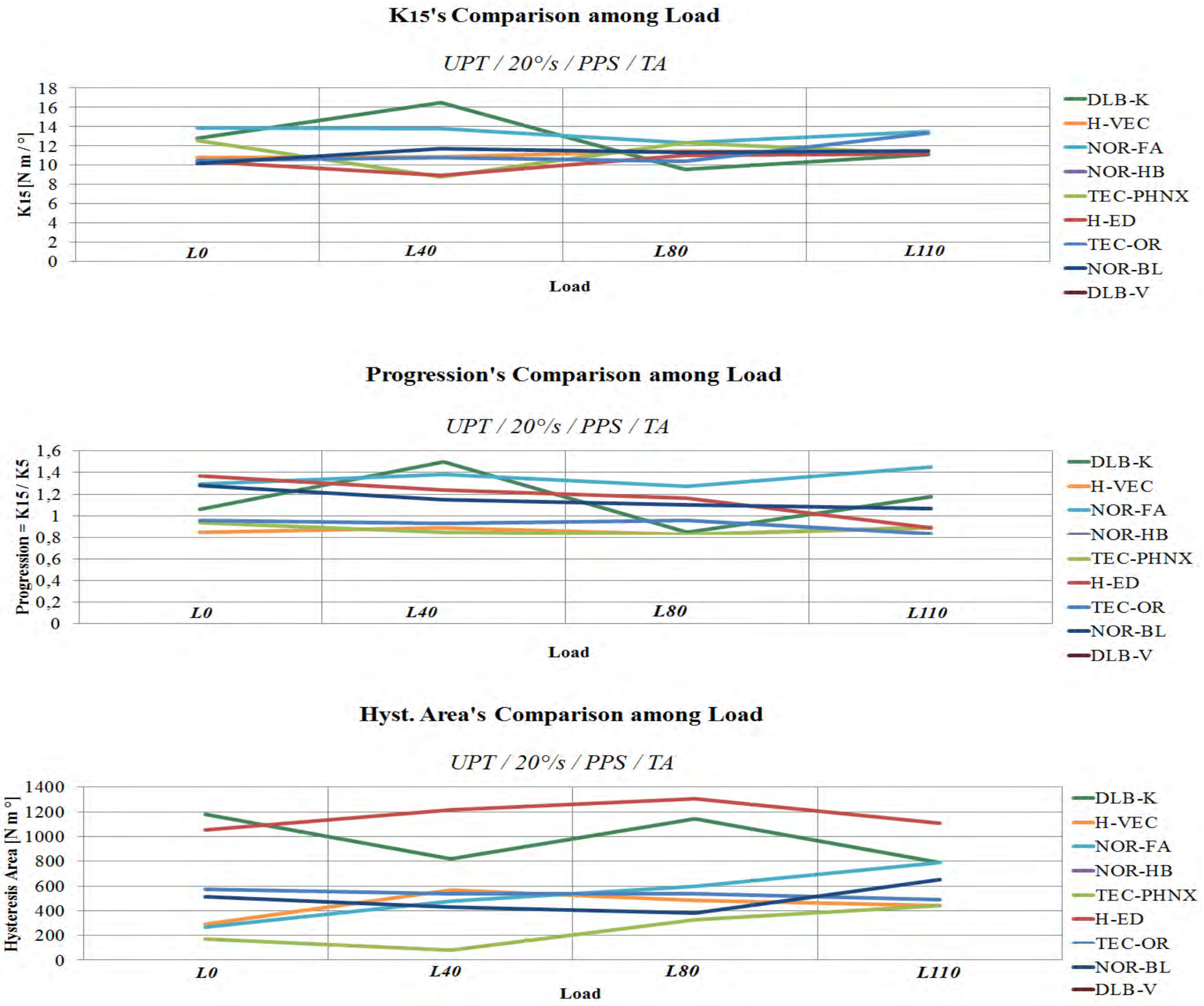


Figure 10.10 Total absolute results.

10.3.1. L 40's Influence

The reference configuration is defined as follows:

- the reference work bench: UPT;
- the reference temperature: TA;
- the reference load: L0;
- the reference velocity: 20 and 50 [°/s];
- the reference prosthesis: PPS.

In this regards, the influence of the L40 condition in respect to the L0 involves different trends for every parameters. Here, as follows, the inferred results:

	n	eFI	$d.^2$ eFI
	1	2,95	0,46
	2	1,36	5,17
	3	2,19	2,08
	4	- 0,91	20,63
	5	15,56	142,31
	6	1,92	2,92
	7	8,75	26,2
	8	- 3,29	47,85
	9	2,06	2,47
	10	8,16	20,52
	11	7,61	15,81
	12	- 2,33	35,58
	13	13,44	96,26
	14	- 6,64	105,42
n	14		
Tot.	=	50,84	523,7
Main	=	3,63	
S. d.	=	6,35	
Err.	±	1,7	

eFI = 3,63 ± 1,70 [%]

	n	R	$d.^2$ R
	1	-15,59	652,45
	2	13,36	11,57
	3	43,16	1102,52
	4	10,91	0,92
	5	-12,92	523,35
	6	10,34	0,15
	7	2,58	54,36
	8	-16,27	687,77
	9	3,23	45,26
	10	31,11	447,64
	11	-13,84	565,97
	12	10,25	0,09
	13	- 4,07	196,6
	14	77,11	4510,12
n	14		
Tot.	=	139,35	8798,77
Main	=	9,95	
S. d.	=	26,02	
Err.	±	6,95	

R = 9,95 ± 6,95 [%]

Figure 10.11 eFI's and R's results.

n	K5	d.^{2} K5
1	- 8,99	96,6
2	-14,3	229,12
3	6,58	32,95
4	-22,83	560,23
5	26,83	675,48
6	- 4,13	24,7
7	- 6,43	52,83
8	11,54	114,55
9	- 0,71	2,4
10	-12,12	168,08
11	20,72	395,22
12	- 1,79	6,92
13	24,74	571,21
14	- 7,36	67,2

n	14		
Tot.	=	11,76	2997,49
Main	=	0,84	
S. d.	=	15,18	
Err.	±	4,06	

K 5 = 0,84 ± 4,06 [%]

n	K15	d.^{2} K15
1	28,84	685,79
2	- 0,76	11,6
3	3,61	0,93
4	-30,19	1078,34
5	14,93	150,75
6	0,72	3,73
7	-14,72	301,72
8	11,01	69,87
9	14,23	134,07
10	1,18	2,16
11	16,95	204,59
12	3,85	1,43
13	9,08	41,41
14	-21,64	590,02

n	14		
Tot.	=	37,07	3276,43
Main	=	2,65	
S. d.	=	15,88	
Err.	±	4,24	

K 15 = 2,65 ± 4,24 [%]

Figure 10.12 K5's and K15's results.

n	Progr	d.^{2} Progr
1	41,51	1461,94
2	6,79	12,36
3	- 3,12	40,94
4	- 9,55	164,45
5	-10,16	180,35
6	5,02	3,07
7	- 9,47	162,28
8	- 0,91	17,49
9	15,11	140,06
10	13,98	114,6
11	18,87	243,2
12	6,21	8,65
13	-13,33	275,54
14	-15,13	338,76

n	14		
Tot.	=	45,82	3163,68
Main	=	3,27	
S. d.	=	15,6	
Err.	±	4,17	

Progr.= 3,27 ± 4,17 [%]

n	A hyst.	d.^{2} A hyst
1	- 6,27	588,8
2	47,39	863,91
3	- 5,73	562,79
4	- 1,63	385,05
5	- 5,98	574,94
6	29,99	143,88
7	35,11	293,
8	29,23	126,3
9	38,67	427,65
10	- 5,71	561,64
11	2,17	250,39
12	- 2,06	402,34
13	45,22	741,23
14	51,52	1123,7

n	14		
Tot.	=	251,91	7045,61
Main	=	17,99	
S. d.	=	23,28	
Err.	±	6,22	

A hyst. = 17,99 ± 6,22 [%]

Figure 10.13 Progression's and Hysteresis Area's results.

10.3.2. L 80’s Influence

The reference configuration is defined as follows:

- the reference work bench: UPT;
- the reference temperature: TA;
- the reference load: L0;
- the reference velocity: 20 and 50 [°/s];
- the reference prosthesis: PPS.

In this regards, the influence of the L80 condition in respect to the L0 involves different trends for every parameters. Here, as follows, the inferred results:

	n	eFI	$d.^2$ eFI
	1	10,23	2,21
	2	- 0,66	88,41
	3	0,64	65,7
	4	10,07	1,76
	5	28,1	374,67
	6	6,63	4,48
	7	37,84	846,4
	8	10,25	2,27
	9	2,08	44,37
	10	5,29	11,92
	11	- 3,06	139,32
	12	8,19	0,31
	13	8,52	0,05
	14	- 1,71	109,28
n	14		
Tot.	=	122,42	1691,14
Main	=	8,74	
S. d.	=	11,41	
Err.	±	3,05	

eFI = 8,74 ± 3,05 [%]

	n	R	$d.^2$ R
	1	- 0,72	207,73
	2	17,58	15,17
	3	49,26	1265,48
	4	-16,96	939,18
	5	-15,38	845,31
	6	6,49	51,8
	7	- 6,3	399,45
	8	7,42	39,25
	9	4,68	81,22
	10	36,89	538,21
	11	12,58	1,23
	12	10,66	9,2
	13	0,34	178,24
	14	85,11	5101,03
n	14		
Tot.	=	191,65	9672,5
Main	=	13,69	
S. d.	=	27,28	
Err.	±	7,29	

R = 13,69 ± 7,29 [%]

Figure 10.14 eFI’s and R’s results.

	n	K5	d.² K5
	1	- 7,23	140,18
	2	- 9,85	209,16
	3	- 0,06	21,89
	4	11,61	48,93
	5	29,22	605,45
	6	8,92	18,54
	7	23,85	370,04
	8	7,52	8,47
	9	- 4,18	77,28
	10	0,79	14,64
	11	-11,35	254,72
	12	- 0,94	30,86
	13	- 4,85	89,59
	14	21,14	273,08
n	14		
Tot.	=	64,6	2162,83
Main	=	4,61	
S. d.	=	12,9	
Err.	±	3,45	

K 5 = 4,61 ± 3,45 [%]

	n	K15	d.² K15
	1	-25,59	695,87
	2	-11,08	141,05
	3	- 0,41	1,45
	4	- 1,45	5,04
	5	10,98	103,87
	6	6,88	37,1
	7	5,66	23,66
	8	- 4,75	30,76
	9	10,42	92,69
	10	3,84	9,28
	11	- 8,73	90,66
	12	11,5	114,76
	13	20,93	405,73
	14	- 7,11	62,47
n	14		
Tot.	=	11,09	1814,39
Main	=	0,79	
S. d.	=	11,81	
Err.	±	3,16	

K 15 = 0,79 ± 3,16 [%]

Figure 10.15 K5's and K15's results.

	n	Progr	d.² Progr
	1	-19,81	338,31
	2	- 1,72	0,09
	3	- 0,31	1,22
	4	-11,79	107,58
	5	-14,22	163,85
	6	- 1,96	0,3
	7	-15,31	192,88
	8	-11,27	97,11
	9	15,32	280,3
	10	21,51	525,51
	11	3,4	23,18
	12	12,62	197,12
	13	26,76	794,06
	14	-23,07	468,73
n	14		
Tot.	=	-19,86	3190,24
Main	=	- 1,42	
S. d.	=	15,67	
Err.	±	4,19	

Progr. = -1,42 ± 4,19 [%]

	n	A hyst.	d.² A hyst
	1	- 2,87	793,23
	2	10,91	207,04
	3	- 5,93	974,87
	4	92,42	4505,64
	5	-25,24	2554,17
	6	63,89	1489,34
	7	23,86	2,06
	8	29,47	17,41
	9	41,6	266,01
	10	-12,18	1404,26
	11	29,65	19,01
	12	11,95	178,17
	13	39,85	211,91
	14	56,75	989,58
n	14		
Tot.	=	354,13	13612,69
Main	=	25,3	
S. d.	=	32,36	
Err.	±	8,65	

A hyst. = 25,30 ± 8,65 [%]

Figure 10.16 Progression's and Hysteresis Area's results.

10.3.3. L 110's Influence

The reference configuration is defined as follows:

- the reference work bench: UPT;
- the reference temperature: TA;
- the reference load: L0;
- the reference velocity: 20 and 50 [°/s];
- the reference prosthesis: PPS.

In this regards, the influence of the L110 condition in respect to the L0 involves different trends for every parameters. Here, as follows, the inferred results:

	n	eFI	$d.^2$ eFI
	1	3,5	176,49
	2	2,03	217,87
	3	0	281,89
	4	7,49	86,52
	5	23,8	49,13
	6	6,18	112,52
	7	74,52	3333,29
n	7		
Tot.	=	117,53	4257,7
Main	=	16,79	
S. d.	=	26,64	
Err.	±	10,07	

eFI = 16,79 ± 10,07 [%]

	n	R	$d.^2$ R
	1	- 9,29	40,86
	2	26,89	887,34
	3	57,89	3695,79
	4	-12,25	87,43
	5	- 9,54	44,09
	6	-19,96	291,07
	7	-54,04	2615,07
n	7		
Tot.	=	-20,29	7661,65
Main	=	- 2,9	
S. d.	=	35,73	
Err.	±	13,51	

R = -2,90 ± 13,51 [%]

Figure 10.17 eFI's and R's results.

	n	K_5	d.^{2} K_5
	1	- 9,99	468,25
	2	-13,64	639,71
	3	14,34	7,24
	4	- 6,52	329,93
	5	34,65	529,24
	6	- 1,69	177,96
	7	64,39	2781,51
n	7		
Tot.	=	81,54	4933,84
Main	=	11,65	
S. d.	=	28,68	
Err.	±	10,84	

K 5 = 11,65 ± 10,84 [%]

	n	K_{15}	d.^{2} K_{15}
	1	-13,52	295,18
	2	- 2,75	41,04
	3	27,84	584,96
	4	-10,73	207
	5	13,1	89,12
	6	4,21	0,31
	7	7,45	14,4
n	7		
Tot.	=	25,6	1232,01
Main	=	3,66	
S. d.	=	14,33	
Err.	±	5,42	

K 15 = 3,66 ± 5,42 [%]

Figure 10.18 K5's and K15's results.

	n	Progr	d.^{2} Progr
	1	11,32	290,57
	2	12,52	332,75
	3	-13,33	57,87
	4	- 4,54	1,41
	5	-16,41	114,07
	6	5,38	123,33
	7	-35,02	858,12
n	7		
Tot.	=	-40,08	1778,11
Main	=	- 5,73	
S. d.	=	17,21	
Err.	±	6,51	

Progr.= -5,73 ± 6,51 [%]

	n	A hyst.	d.^{2} A hyst
	1	-13,22	1318,98
	2	32,46	87,64
	3	- 4,81	778,79
	4	41,3	331,37
	5	36,51	179,84
	6	49,83	714,46
	7	19,62	12,11
n	7		
Tot.	=	161,7	3423,18
Main	=	23,1	
S. d.	=	23,89	
Err.	±	9,03	

A hyst. = 23,10 ± 9,03 [%]

Figure 10.19 Progression's and Hysteresis Area's results.

10.3.4. Human weight

In order to study the effect of the tester's weight in respect to the loads applied in the torsion unit in Padua, an indicative *Table 10.29* is defined and observed. Accordingly, the aim is to find the trends percentage of each dependent variable.

Starting from the *Table 10.29*, this one explains the correlations between the single ski boot and the independent variables.

The comparison between the ski boots tested with the UPT work bench, at the room temperature, has the following reference:

- respectively, ski boot analysed with PPS, 20 [°/s] and with L0 load condition.

The results of every comparison are collected into an unvocal comparison that evidences the distancing percentage between the reference condition and the load's effects.

	UPT					BIO - MECH. - LAB				
	TA					TA				
	L0	L40	L80	70 [kg]	L110	L0	L40	L80	70 [kg]	L110
DALBELLO KRYPTON	X	X	X		X				X	
DALBELLO VANTAGE										
NORDICA FIREARROW	X	X	X		X				X	
NORDICA HELL AND BACK	X	X	X		X				X	
NORDICA BLACK	X	X	X		X					
TECNICA PHNX	X	X	X		X				X	
TECNICA "ORANGE"	X	X	X		X					
HEAD VECTOR	X	X	X		X					
HEAD EDGE	X	X	X		X					

Table 10.29 Work benches' table.

In the figures below, for each parameter the absolute values and the influence of the human's weight are shown.

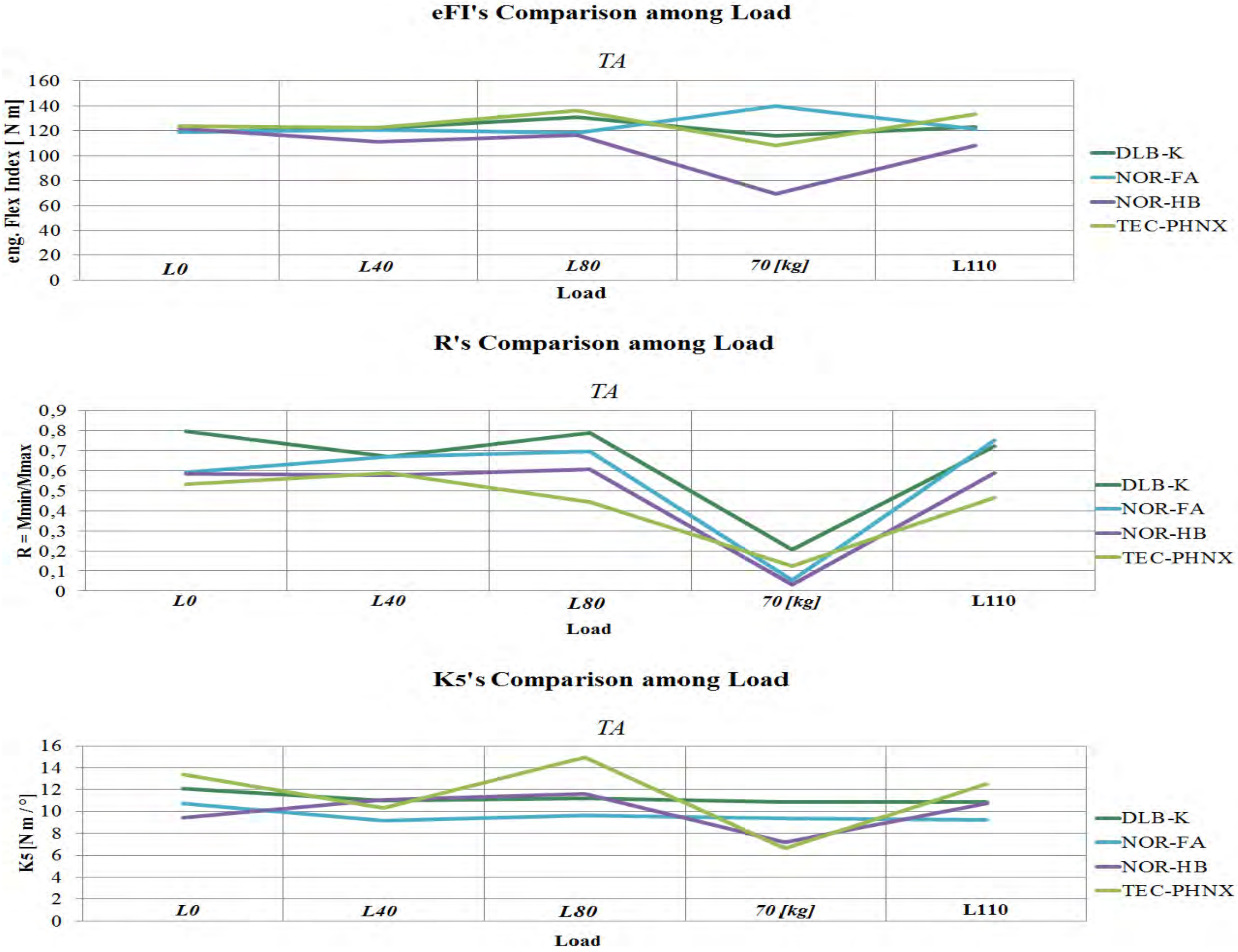


Figure 10.20 Total absolute results.

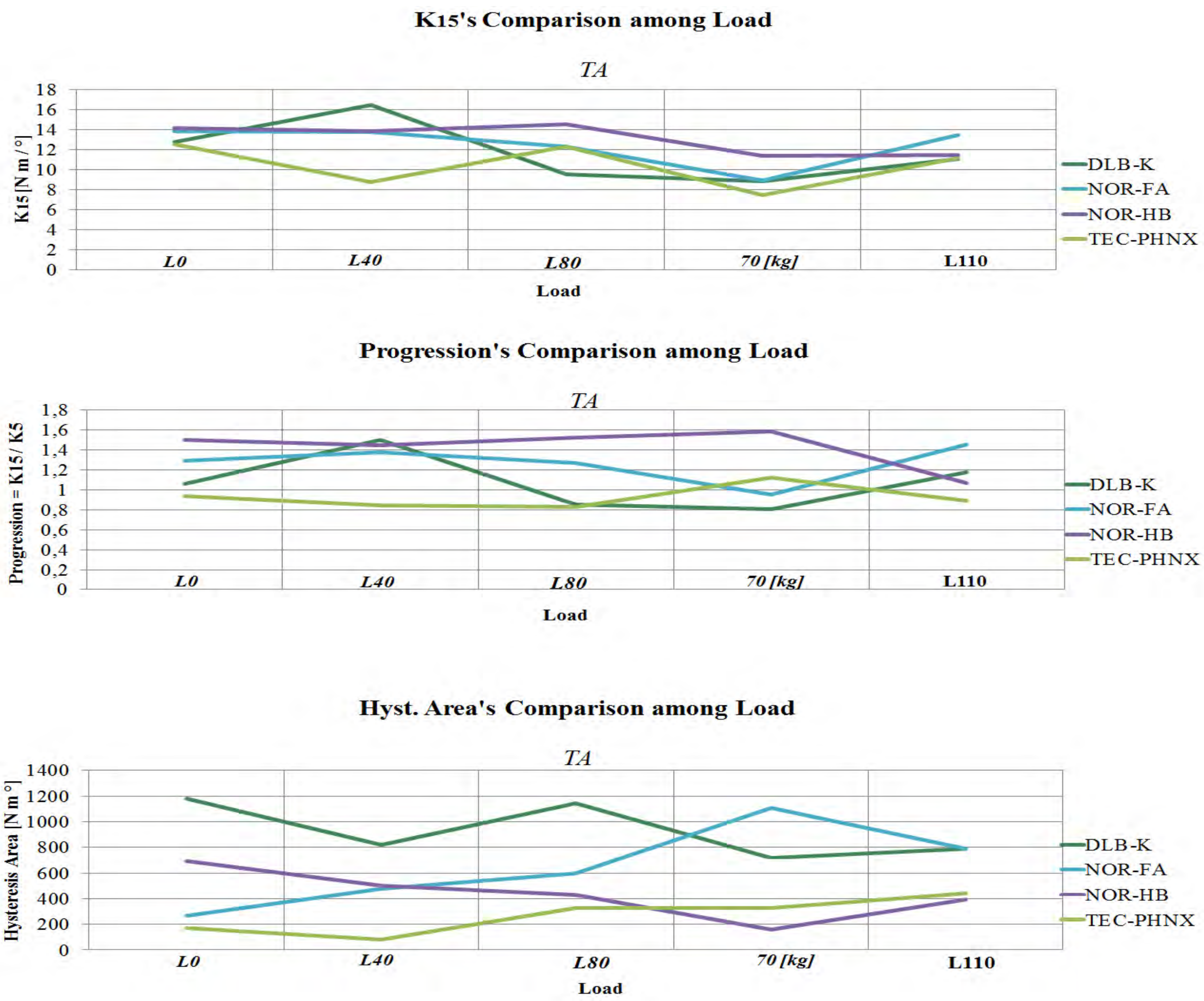


Figure 10.21 Total absolute results.

10.3.4.1. Human weight's Influence

The reference configuration is defined as follows:

- the reference work bench: UPT;
- the reference temperature: TA;
- the reference load: L0;
- the reference velocity: 20 [°/s];
- the reference prosthesis: PPS.

In this regards, the influence of the tester's weight condition in respect to the L0 involves different trends of every parameters. Here, as follows, the inferred results:

	n	eFI	d.² eFI
	1	- 2,14	64,44
	2	17,23	750,63
	3	-43,24	1093,2
	4	-12,53	5,58
n	4		
Tot.	=	-40,69	1913,85
Main	=	-10,17	
S. d.	=	25,26	
Err.	±	12,63	

eFI = -10,2 ± 12,6 [%]

	n	R	d.² R
	1	-74,07	99,28
	2	-90,92	47,37
	3	-94,71	114,06
	4	-76,44	57,73
n	4		
Tot.	=	-336,14	318,44
Main	=	-84,04	
S. d.	=	10,3	
Err.	±	5,15	

R = -84,0 ± 5,2 [%]

Figure 10.22 eFI's and R's results.

	n	K5	d.² K5
	1	-10,11	200,33
	2	-12,77	132,32
	3	-23,91	0,13
	4	-50,28	676,77
n	4		
Tot.	=	-97,07	1009,54
Main	=	-24,27	
S. d.	=	18,34	
Err.	±	9,17	

K5 = -24,3 ± 9,2 [%]

	n	K15	d.² K15
	1	-31,05	0,35
	2	-35,84	17,6
	3	-19,39	150,32
	4	-40,31	75,01
n	4		
Tot.	=	-126,6	243,29
Main	=	-31,65	
S. d.	=	9,01	
Err.	±	4,5	

K15 = -31,6 ± 4,5 [%]

Figure 10.23 K5's and K15's results.

	n	Progr	d.² Progr
	1	-23,59	309,01
	2	-26,44	417,5
	3	5,94	142,71
	4	20,06	679,4
n	4		
Tot.	=	-24,03	1548,62
Main	=	- 6,01	
S. d.	=	22,72	
Err.	±	11,36	

Progr = -6,0 ± 11,4 [%]

	n	A hyst.	d.² A hyst
	1	-39,25	12395,73
	2	311,13	57140,98
	3	-77,03	22237,4
	4	93,51	458,66
n	4		
Tot.	=	288,36	92232,77
Main	=	72,09	
S. d.	=	175,34	
Err.	±	87,67	

A hyst. = 72,1 ± 87,7 [%]

Figure 10.24 Progression's and Hysteresis Area's results.

10.3.5. Commenting in Results

It is possible to notice that the repeatabilities of respectively the effective Flex Index, R, K_5, K_{15} and Progression are lesser than 30 [%]. The hysteresis area is included between 15 and 30 [%].

The abovementioned analysis shows that there are not particular differences between the reference variable and the others.

In the vivo test, a tester having a weight of 70 [kg] (700 [N]) is employed. The flexion is characterized by a portion of the cycle that is parallel to the others cycles. In the opposite direction, the distancing is clearly noticeable. This divergence can be associated to the different procedures employed: one by using of the prosthesis and one by using the real foot. The latter is covered by the muscles that have a notable influence on the forces and therefore on the bending moments.

10.4. Temperature's Influence

The study of the temperature's effect is based on the relative temperature's *Table 10.31*. As far as the TA temperature's condition is concerned, all the ski boots are tested on all the work benches; whereas the TC temperature's condition was possible only on the axial benches.
The prosthesis tested with two temperature's steps, are the PPS, PLR and PLS as a consequence of the load condition: the axial units have the L0 configuration in common.
The analysis is divided in three subcategories depending on three prosthesis and on the work bench employed.

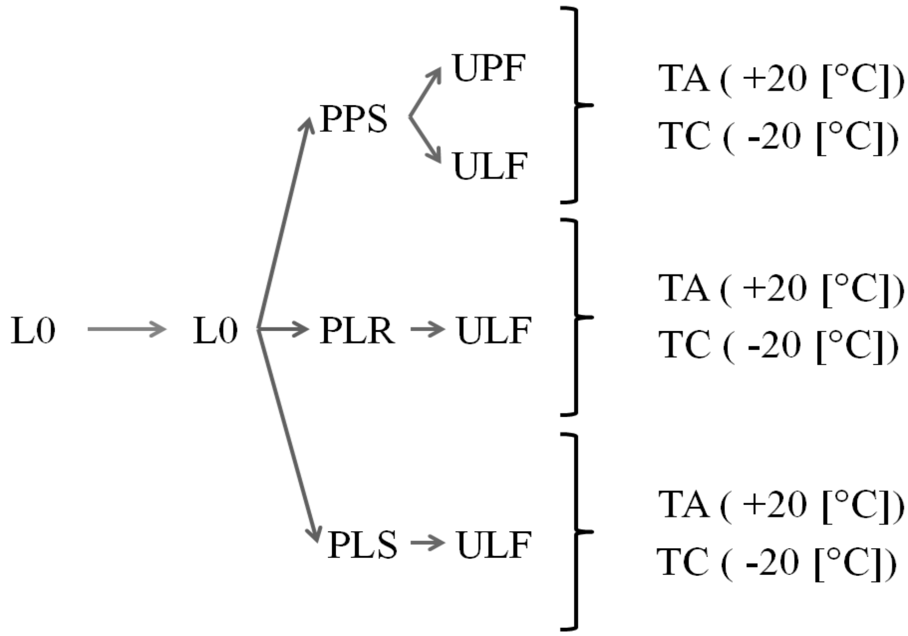


Figure 10.25 Sketch of the scheme employed for the load's analysis.

Every prosthesis's combination has the L0 and the 20 [°/s] as the references. For instance, the comparison between the ski boots tested without load (L0), with the prosthesis PPS and with the UPF has the following reference:

- respectively, ski boot analysed with the PPS, the same work bench (UPF) and the room temperature TA.

The comparison between the ski boots tested without load (L0), with the prosthesis PPS and with the ULF has the following reference:

- respectively, ski boot analysed with the PPS, the same work bench (ULF) and the room temperature TA.

The comparison between the ski boots tested without load (L0), with the prosthesis PLR and with the ULF has the following reference:

- respectively, ski boot analysed with the PLR, the same work bench (ULF) and the room temperature TA.

The comparison between the ski boots tested without load (L0), with the prosthesis PLS and with the ULF has the following reference:

- respectively, ski boot analysed with the PLS, the same work bench (ULF) and the room temperature TA.

The results of every comparison are collected into an univocal comparison that evidences the distancing percentage between the reference condition and the temperature's effect.

	TA (+20 [°C])		TC (-20 [°C])	
	Main	S.d. TA	Main	S.d. T1
	[%]	[%]	[%]	[%]
eFi	100	9,32	67,11	45,81
R	100	24,65	-10,25	28,29
K5	100	18,66	81,22	34,51
K15	100	23,31	127,01	63,88
Progr.	100	16,22	14,79	36,28
A hyst.	100	29,29	70,05	49,64

Table 10.30 The distancing percentage between the TA and the TC conditions.

	L0											
	20 [°/s]											
	TA						TC					
	PPS		PLR		PLS		PPS		PLR		PLS	
	UPF	ULF	UPF	ULF	UPF	ULF	UPF	ULF	UPF	ULF	UPF	ULF
DALBELLO KRYPTON	X	X	X	X		X	X	X		X		X
DALBELLO VANTAGE		X		X		X						
NORDICA FIREARROW	X		X									
NORDICA HELL AND BACK	X		X				X					
NORDICA BLACK	X		X				X					
TECNICA PHNX	X		X									
TECNICA "ORANGE"	X		X				X					
HEAD VECTOR	X	X	X	X		X	X	X		X		X
HEAD EDGE	X		X									

Table 10.31 Temperature's Table.

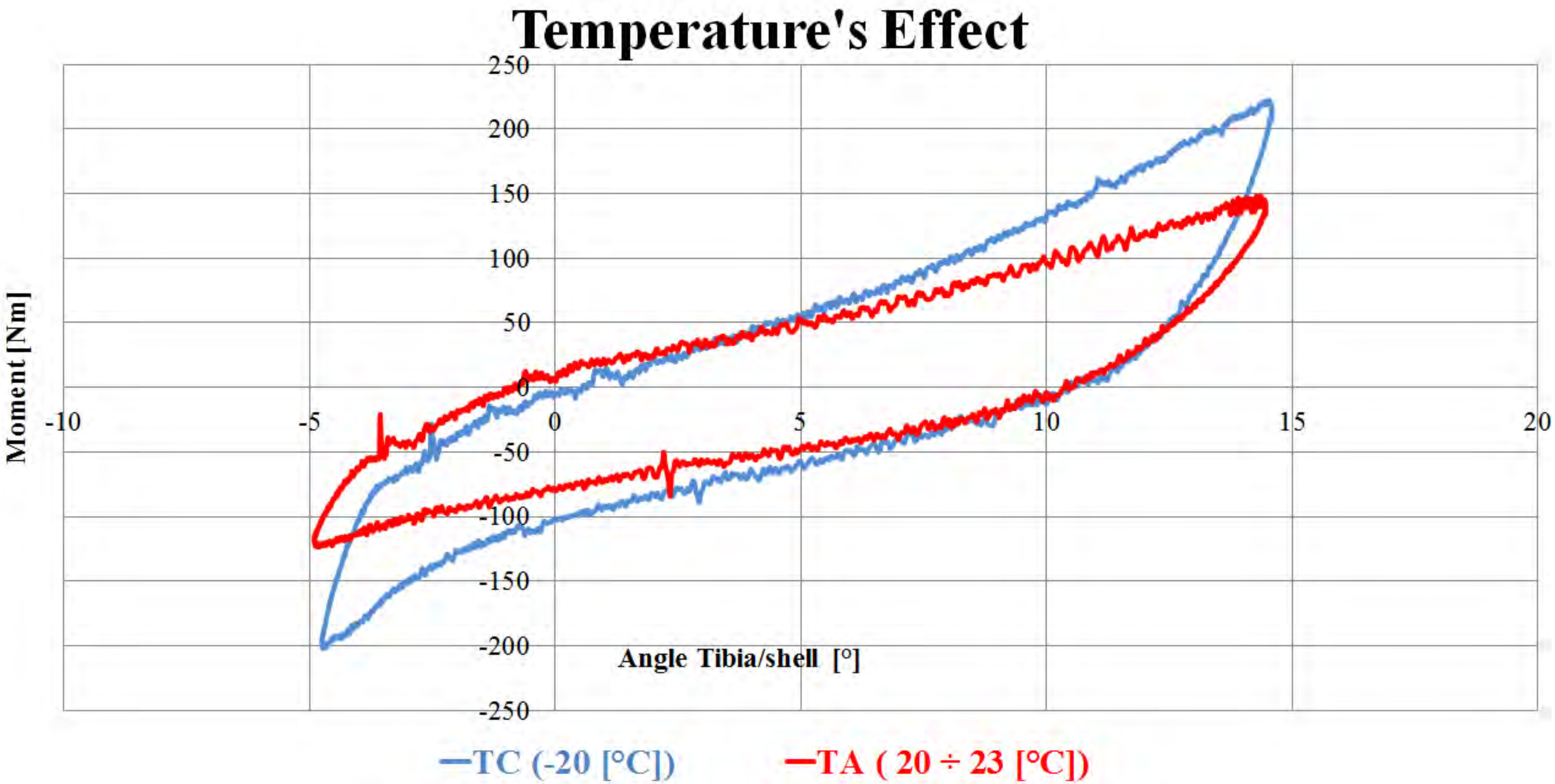


Figure 10.26 Hysteresis cycles of the TA and TC temperature.

In the *Figure 10.26* above the hysteresis cycles of the each step of the temperature employed are shown. The reference cycle is that about the TA (black cycle).

In the figures below, for each parameter the absolute values and the influence of the prosthetic leg are shown.

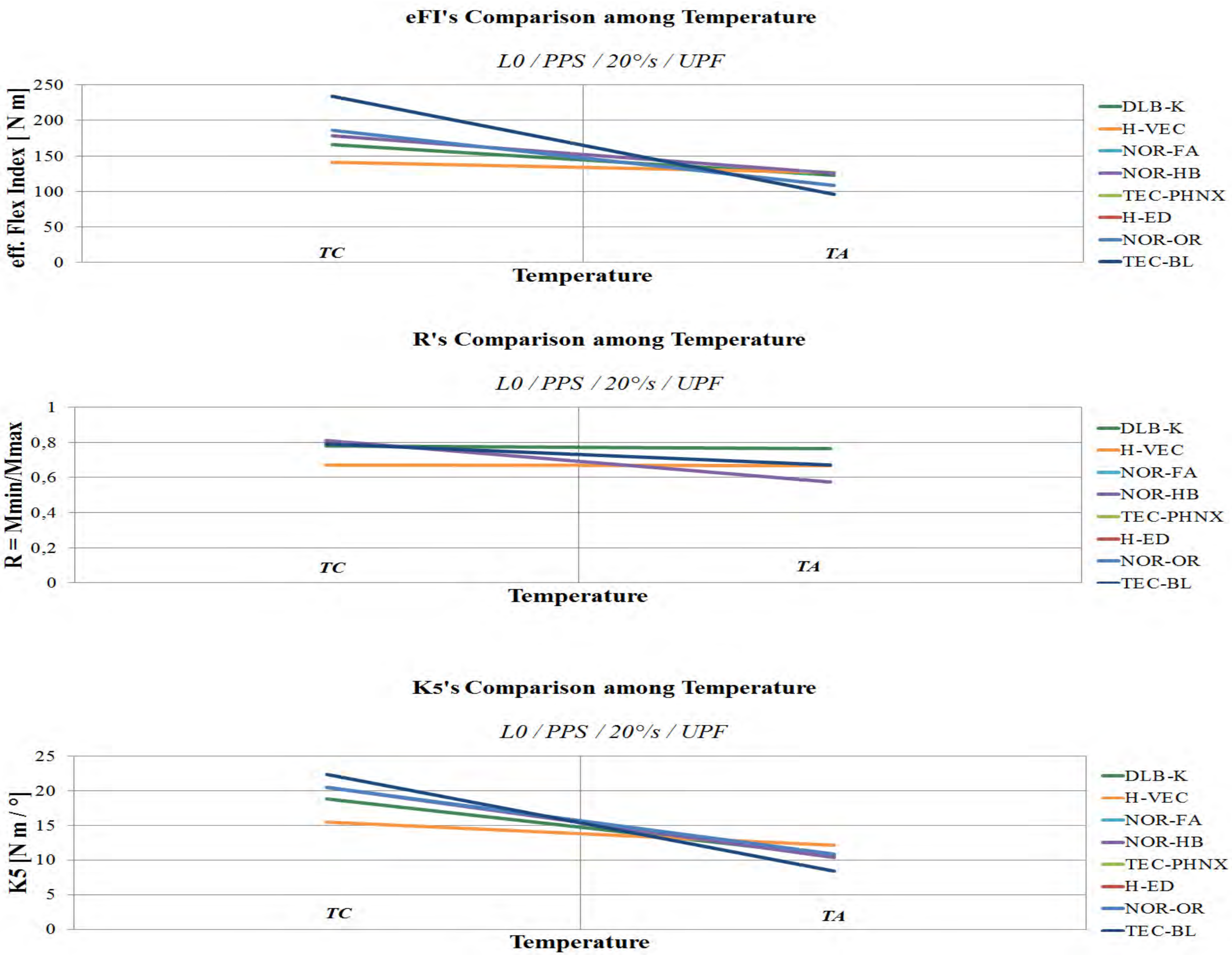


Figure 10.27 Total absolute results.

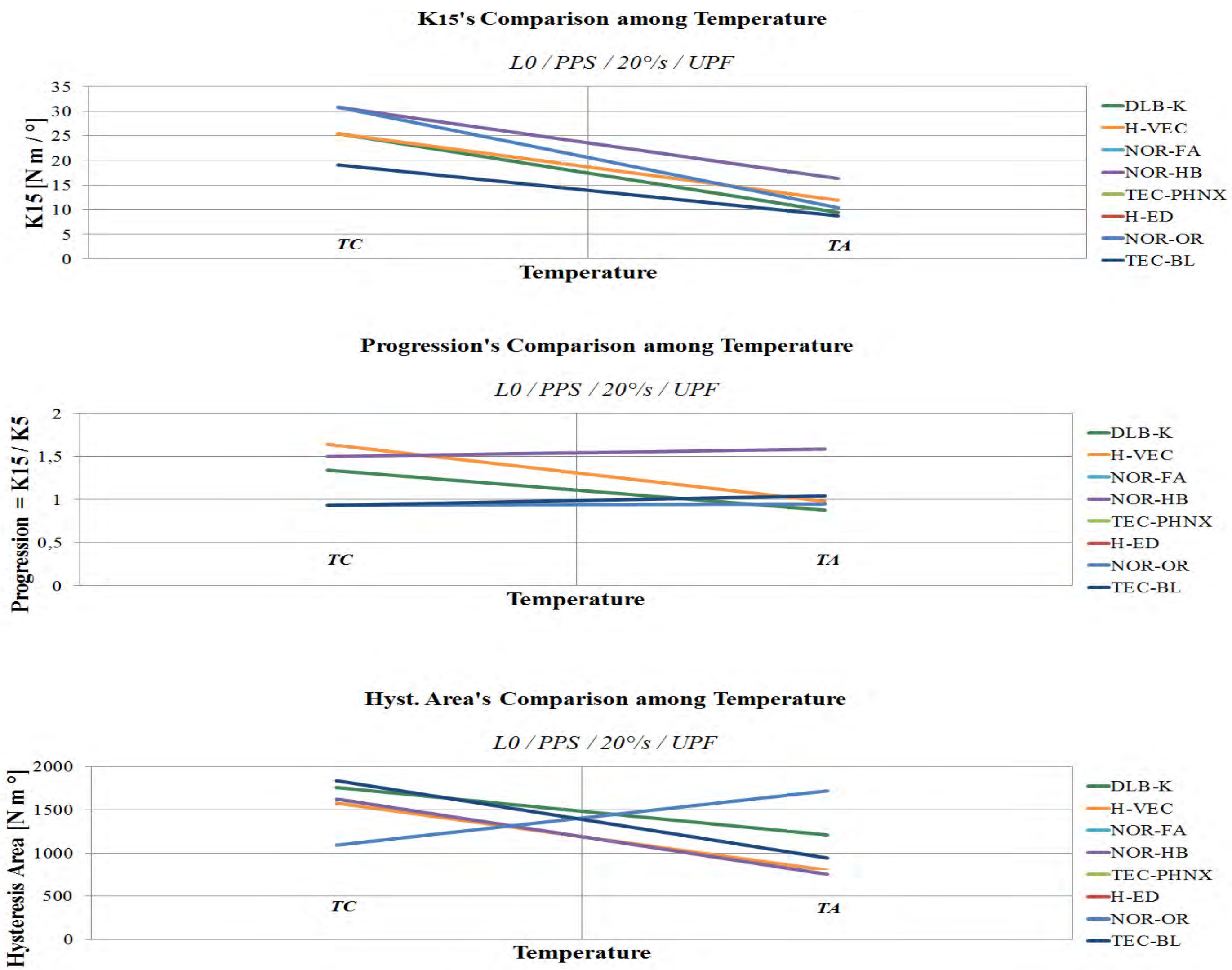


Figure 10.28 Total absolute results.

10.4.1. Temperature TC's Influence

The reference configuration is defined as follows:

- the reference work bench: UPF;
- the reference temperature: TA;
- the reference load: L0;
- the reference velocity: 20;
- the reference prosthesis: PPS.

In this regards, the influence of the TC condition in respect to the TA involves different trends for every parameter. Here, as follows, the inferred results:

	n	K_5	$d.^2\ K_5$
	1	75,89	28,41
	2	96,76	241,52
	3	88,89	58,77
	4	166,1	7204,98
	5	27,45	2891,48
	6	93,08	140,66
	7	99,47	332,94
	8	50,3	956,02
	9	82,21	0,98
	10	52,19	843,11
	11	61,1	405,07
n	11		
Tot.	=	893,44	13103,93
Main	=	81,22	
S. d.	=	36,2	
Err.	±	10,91	

K 5 = 81,222 ± 10,915 [%]

	n	K_{15}	$d.^2\ K_{15}$
	1	169,37	1794,77
	2	88,3	1498,53
	3	198,16	5062,52
	4	118,24	76,89
	5	113,26	189,06
	6	11,54	13333,5
	7	103,71	543,07
	8	70,88	3150,36
	9	243,47	13562,38
	10	88,43	1488,28
	11	191,75	4190,82
n	11		
Tot.	=	1397,1	44890,19
Main	=	127,01	
S. d.	=	67	
Err.	±	20,2	

K 15 = 127,009 ± 20,201 [%]

Figure 10.29 eFI's and R's results.

	n	K5	d.² K5
	1	75,89	28,41
	2	96,76	241,52
	3	88,89	58,77
	4	166,1	7204,98
	5	27,45	2891,48
	6	93,08	140,66
	7	99,47	332,94
	8	50,3	956,02
	9	82,21	0,98
	10	52,19	843,11
	11	61,1	405,07
n	11		
Tot.	=	893,44	13103,93
Main	=	81,22	
S. d.	=	36,2	
Err.	±	10,91	

K 5 = 81,222 ± 10,915 [%]

	n	K15	d.² K15
	1	169,37	1794,77
	2	88,3	1498,53
	3	198,16	5062,52
	4	118,24	76,89
	5	113,26	189,06
	6	11,54	13333,5
	7	103,71	543,07
	8	70,88	3150,36
	9	243,47	13562,38
	10	88,43	1488,28
	11	191,75	4190,82
n	11		
Tot.	=	1397,1	44890,19
Main	=	127,01	
S. d.	=	67	
Err.	±	20,2	

K 15 = 127,009 ± 20,201 [%]

Figure 10.30 K5's and K15's results.

	n	Progr	d.² Progr
	1	52,14	1395,73
	2	- 5,48	410,77
	3	- 1,58	267,79
	4	-10,1	619,09
	5	67,17	2743,67
	6	-41,43	3160,61
	7	2,39	153,52
	8	13,6	1,4
	9	-19,28	1160,62
	10	23,39	73,99
	11	81,82	4493,39
n	11		
Tot.	=	162,64	14480,59
Main	=	14,79	
S. d.	=	38,05	
Err.	±	11,47	

Progr. = 14,785 ± 11,474 [%]

	n	A hyst.	d.² A hyst
	1	45,95	580,96
	2	115,56	2071,14
	3	-36,31	11312,03
	4	95,63	654,15
	5	97,01	726,54
	6	53,55	272,42
	7	105,79	1276,84
	8	36,27	1140,97
	9	154,15	7072,74
	10	25,94	1945,84
	11	77,04	48,77
n	11		
Tot.	=	770,58	27102,4
Main	=	70,05	
S. d.	=	52,06	
Err.	±	15,7	

A hyst. = 70,053 ± 15,697 [%]

Figure 10.31 Progression's and Hysteresis Area's results.

10.4.2. Commenting in Results

It is possible to notice that the repeatabilities of all the dependent variables is included between 10 and 30 [%].

In respect to the reference configuration, the second condition (TC) is characterized by a sensible variation. The low temperature induces the stiffening of the ski boot's material and this is the principal reason of the change of the hysteresis cycle.

As far as the results are concerned, the effective Flex Index, the shapes in the near of 5 and 15 [°] and the area are increased. Only the relationship between the maximum and the minimum bending moment is decreased.

Taken into account the diagrams, the middle portion is characterized by the same tendencies both in the loading segment as in the unloading segment. About this behaviour, in that portion the ski boots are going through the neutral angle (where the bending moment applied is null) and the temperature's effect has not the influence.

The bigger influence is shown in the extremes of the range, where the material is so stressed. As a consequence that other than the neutral interval the shapes are increased.

10.5. Angular Velocity’s Influence

The last independent variable is the test’s velocity. This effect is studied choosing three different values of it.

In order to focus the analysis, the Velocity’s *Table 10.33* is defined and valued.

In the *Table 10.33*, the three values of the velocity is employed for every ski boot, every prosthesis and in every work bench except for the ULF (only 20 and 50 [°/s]) can be observed.

The analysis is divided into three categories relative to the prosthesis. Each prosthesis is again subdivided into three categories that are relative to the three work benches.

The analysis’s model adopted is shown in *Figure 10.32* below.

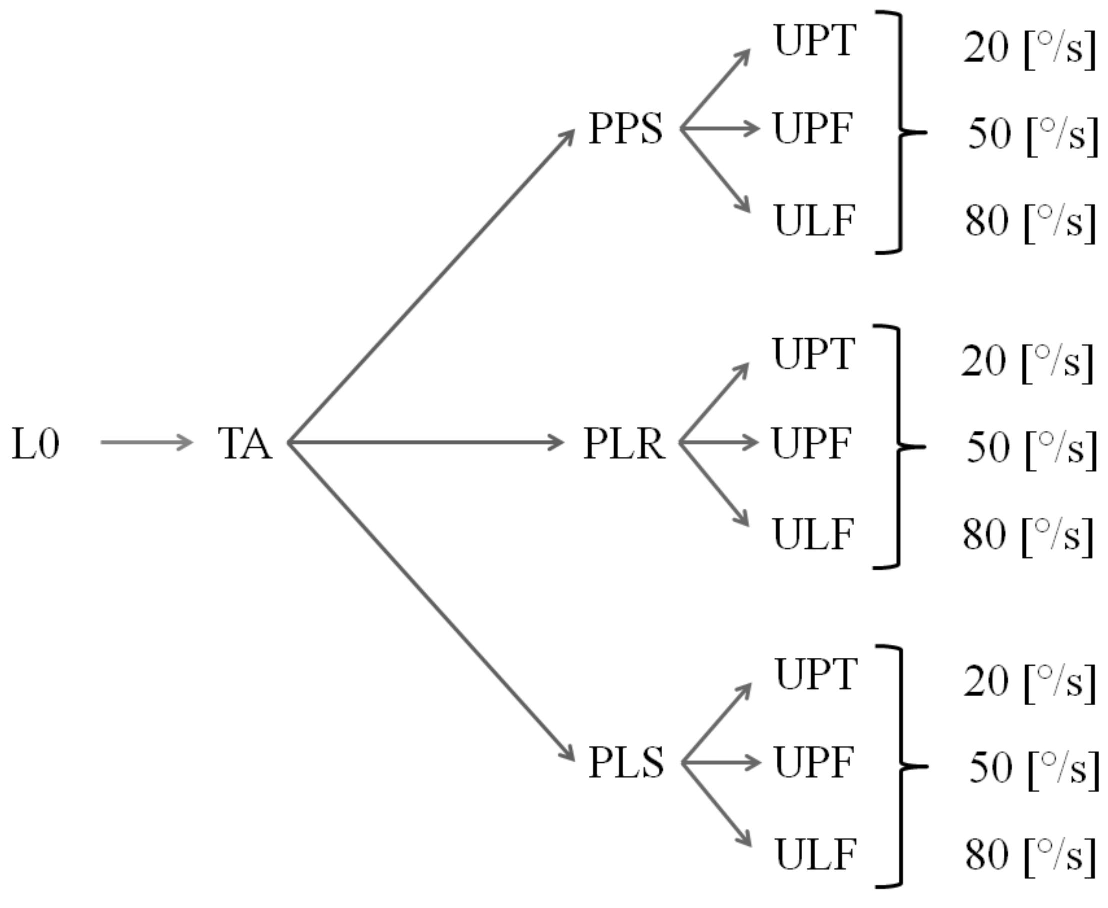


Figure 10.32 Sketch of the scheme employed for the velocity’s analysis.

Every velocity’s combination has the L0 and the TA as the references. For instance, the comparison between the ski boots tested without load (L0), with the prosthesis PPS and with the UPT has the following reference:

- respectively, ski boot analysed with the PPS, the same work bench (UPT) and 20 [°/s].

The comparison between the ski boots tested without load (L0), with the prosthesis PPS and with the UPF has the following reference:

- respectively, ski boot analysed with the PPS, the same work bench (UPF) and 20 [°/s].

The comparison between the ski boots tested without load (L0), with the prosthesis PPS and with the ULF has the following reference:

- respectively, ski boot analysed with the PPS, the same work bench (ULF) and 20 [°/s].

The same procedure is always adopted for each prosthesis.
The results of every comparison are collected into an univocal comparison that evidences the distancing percentage between the reference condition and the angular velocity's effect.

	20 [°/s]		50 [°/s]		80 [°/s]	
	Main	*D.s. 20 [°/s]*	*Main*	*S.d. 50 [°/s]*	*Main*	*S.d. 80 [°/s]*
	[%]	*[%]*	*[%]*	*[%]*	*[%]*	*[%]*
eFi	100	10,48	1,87	13,17	3,75	14,86
R	100	15,44	- 0,4	17,68	- 9,85	20,25
K5	100	17,74	- 1,03	15,95	1,1	9,68
K15	100	22,8	7,34	19,36	15,08	19,45
Progr.	100	25,42	6,94	17,36	12,33	20,42
A hyst.	100	65,37	15,1	16,8	31,5	53,01

Table 10.32 The distancing percentage between the 20 [°/s] and the other conditions 50 and 80 [°/s].

	L0																										
	TA																										
	PPS									PLR									PLS								
	UPT			UPF			ULF			UPT			UPF			ULF			UPT			UPF			ULF		
	20	50	80	20	50	80	20	50	80	20	50	80	20	50	80	20	50	80	20	50	80	20	50	80	20	50	80
DALBELLO KRYPTON	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X					X	X	X	X	X	
DALBELLO VANTAGE							X	X								X	X								X	X	
NORDICA FIREARROW	X	X	X	X	X	X				X	X	X	X	X	X							X	X	X			
NORDICA HELL AND BACK	X	X	X	X	X	X				X	X	X	X	X	X							X	X	X			
NORDICA BLACK	X	X	X	X	X	X																					
TECNICA PHNX	X	X	X	X	X	X				X	X	X	X	X	X							X	X	X			
TECNICA "ORANGE"	X	X	X	X	X	X																					
HEAD VECTOR	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X					X	X	X	X	X	
HEAD EDGE	X	X	X	X	X					X	X	X	X	X	X							X	X	X			

Table 10.33 The angular velocity's table: 20, 50 and 80 [°/s].

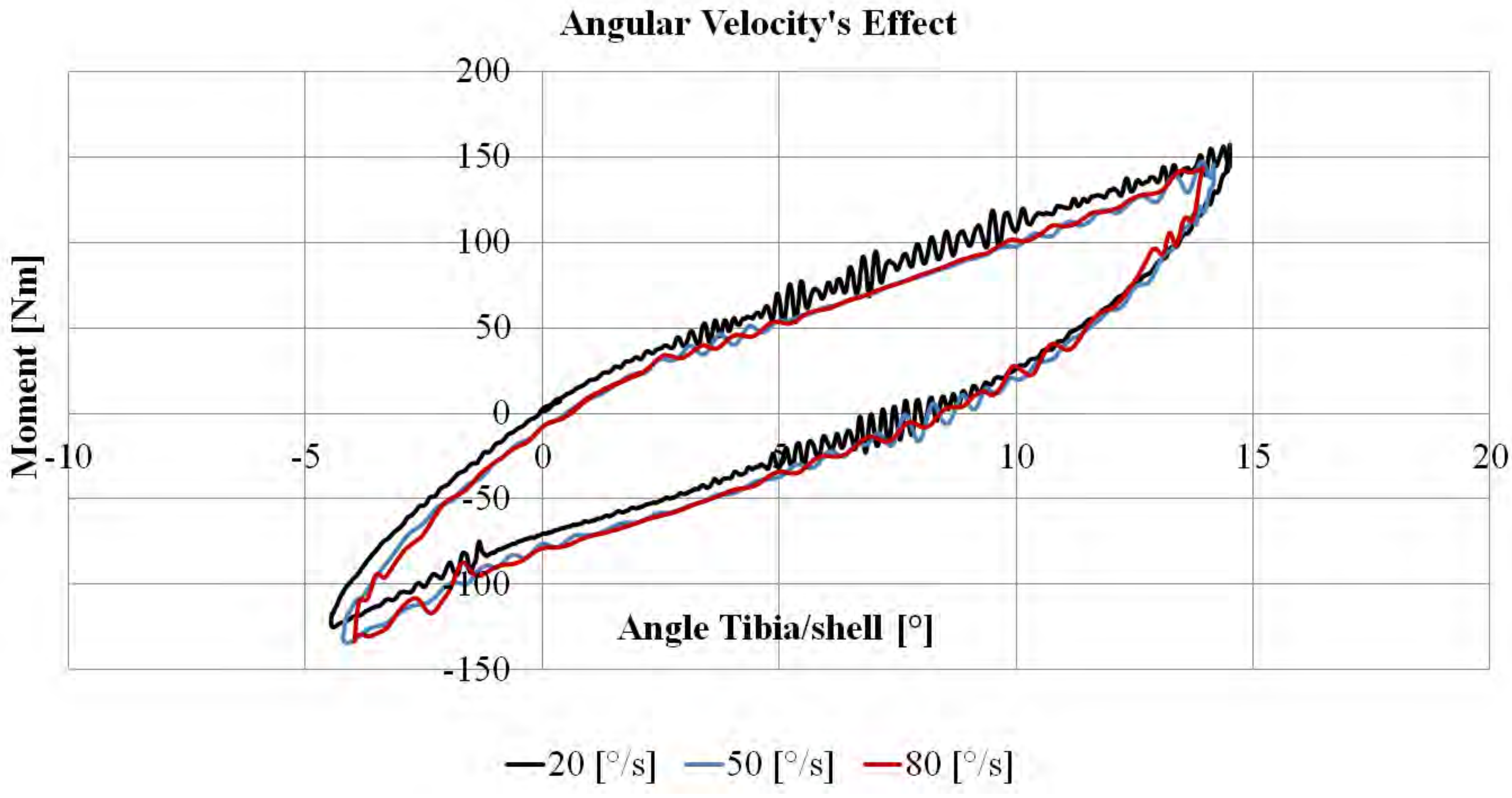


Figure 10.33 Hysteresis cycles of every prosthesis.

In the *Figure 10.32* above the hysteresis cycles of the each value of the velocity employed are shown. The reference cycle is that about the 20 [°/s] (black cycle).
In the figures below, for each parameter the absolute values and the influence of the angular velocity can be saw.

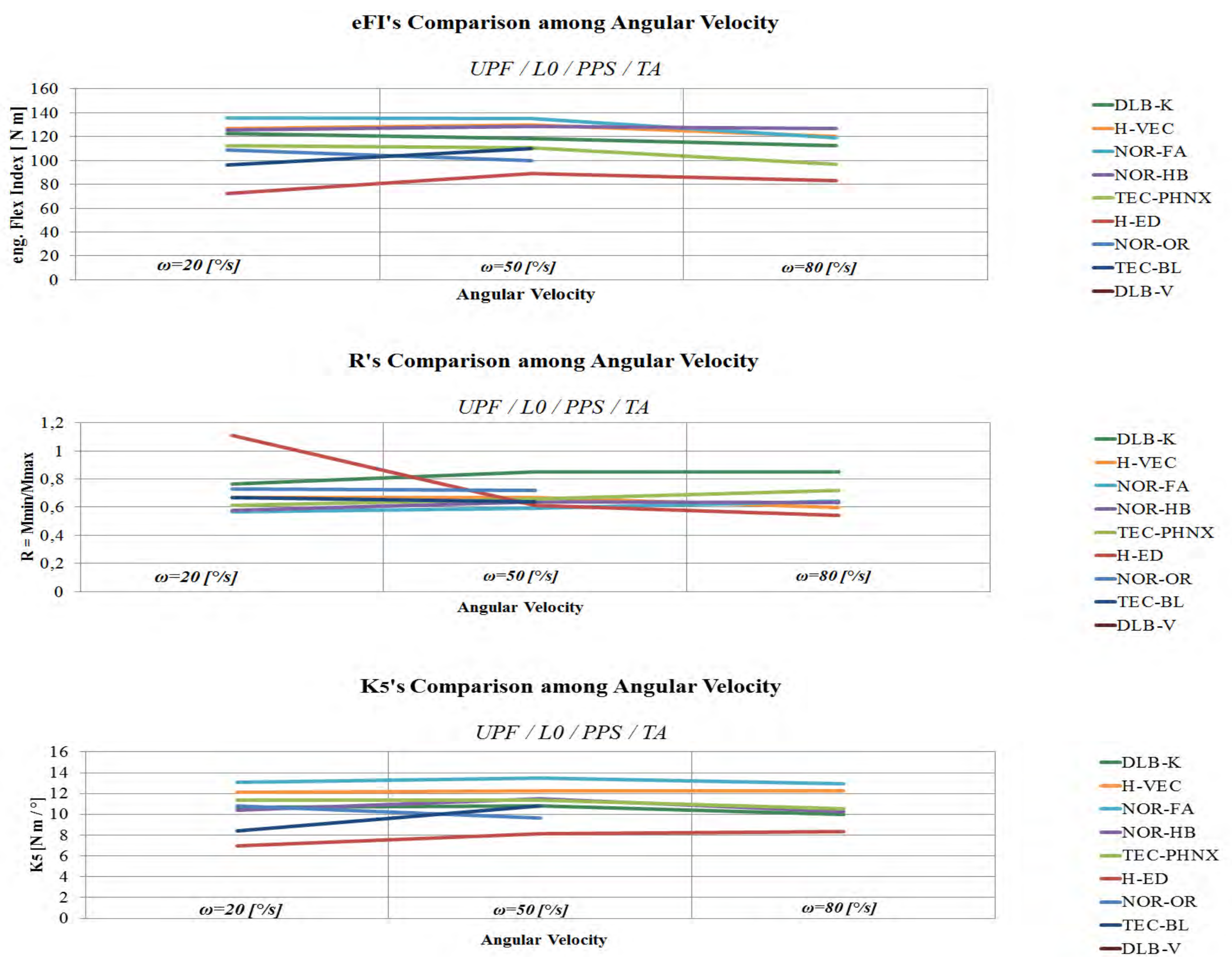


Figure 10.34 Total absolute results.

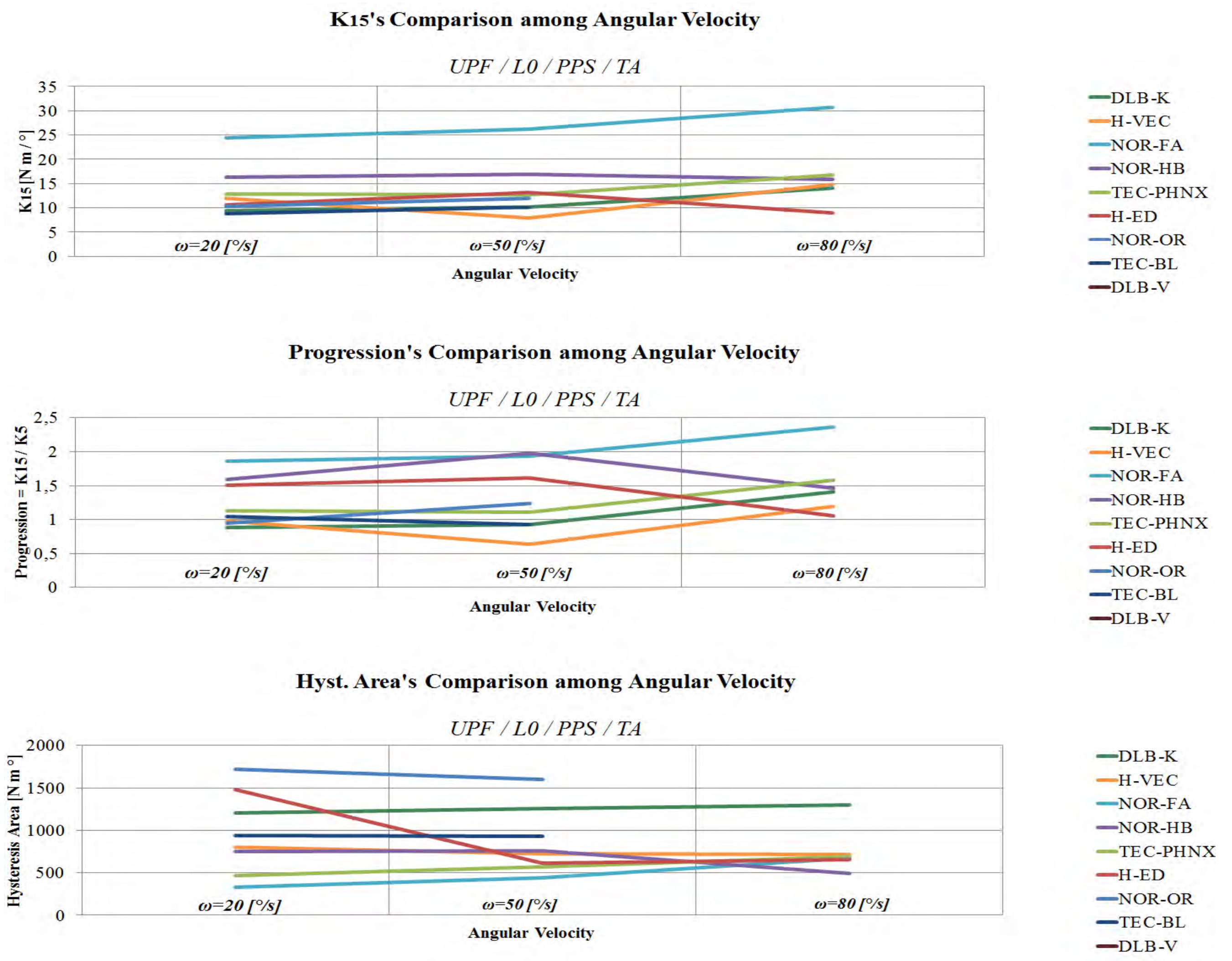


Figure 10.35 Total absolute results.

10.5.1. ω = 50[°/s] - Velocity's Influence

The reference configuration is defined as follows:

- the reference temperature: TA;
- the reference load: L0;
- the reference velocity: 20 [°/s].

In this regards, the influence of 50 [°/s] in respect to 20 [°/s] involves different trends for every parameters. Here, as follows, the inferred results:

	n	eFI	d.² eFI
	1	7,67	33,67
	2	0,77	1,21
	3	- 1,36	10,39
	4	1,73	0,02
	5	2,97	1,2
	6	19,61	314,8
	7	- 2,7	20,89
	8	44,13	1785,76
	9	- 3,51	28,88
	10	- 0,26	4,53
	11	2,55	0,47
	12	- 8,13	99,95
	13	- 1,89	14,14
	14	14,58	161,67
	15	2,13	0,07
	16	23,05	448,76
	17	-21,46	544,44
	18	- 5,95	61,05
	19	-14,09	254,68
	20	- 9,12	120,72
	21	1,61	0,07
	22	- 1,09	8,77
	23	1,98	0,01
	24	- 2,63	20,25
	25	41,2	1547,29
	26	- 4,87	45,43
	27	9,1	52,28
	28	1,75	0,02
	29	11,57	94,21
	30	- 0,35	4,91
	31	5,55	13,55
	32	-15,65	306,8
	33	-14,52	268,44
	34	0,78	1,18
	35	- 9,48	128,76
	36	6,07	17,61
	37	8,58	44,99
	38	- 1,62	12,2
	39	15,75	192,65
	40	-15,46	300,29
	41	-15,53	302,62
	42	5,	9,83
n	42		
Tot.	=	78,47	7279,47
Main	=	1,87	
S. d	=	13,32	
Err.	±	2,06	

eFI = 1,868 ± 2,056 [%]

	n	R	d.² R
	1	-20,25	394,1
	2	4,9	28,03
	3	14,57	224,17
	4	- 5,26	23,66
	5	-10,18	95,62
	6	-24,92	601,43
	7	1,34	3,02
	8	-55,61	3048,73
	9	11,43	139,84
	10	4,38	22,87
	11	10,59	120,73
	12	- 1,37	0,94
	13	8,2	73,87
	14	- 4,78	19,16
	15	0,31	0,5
	16	-44,74	1966,33
	17	2,28	7,15
	18	7,99	70,42
	19	23,38	565,25
	20	27,21	762,34
	21	3,13	12,42
	22	11,48	141
	23	- 4,84	19,71
	24	0,3	0,49
	25	-44,12	1911,33
	26	0,62	1,04
	27	2,87	10,66
	28	10,94	128,51
	29	-20	384,2
	30	3,08	12,08
	31	-22,58	492,03
	32	15,73	260,15
	33	19,18	383,2
	34	6,25	44,21
	35	9,53	98,64
	36	- 4,13	13,93
	37	0	0,16
	38	1,82	4,92
	39	- 3,97	12,74
	40	17,79	330,74
	41	25,27	659,14
	42	5,45	34,26
n	42		
Tot.	=	-16,75	13123,74
Main	=	- 0,4	
S. d	=	17,89	
Err.	±	2,76	

R = -0,399 ± 2,761 [%]

Figure 10.36 eFI's and R's results.

	n	K5	d.² K5
	1	-11,23	104,06
	2	- 5,11	16,65
	3	4,25	27,84
	4	18,12	366,67
	5	0,93	3,86
	6	51,07	2714,37
	7	- 6,11	25,82
	8	8,51	91,1
	9	0,89	3,68
	10	2,85	15,1
	11	10,16	125,3
	12	-11,2	103,32
	13	0,26	1,68
	14	28,52	873,37
	15	1,06	4,38
	16	16,2	296,94
	17	-52,95	2695,42
	18	- 4,66	13,18
	19	-12,77	137,92
	20	-27,03	675,97
	21	- 1,68	0,42
	22	2,63	13,41
	23	0,21	1,55
	24	- 6,11	25,82
	25	2,47	12,26
	26	- 9,03	64,02
	27	- 6,39	28,75
	28	4,02	25,5
	29	5,61	44,13
	30	2,65	13,51
	31	- 8,48	55,43
	32	- 6,52	30,11
	33	- 8,14	50,61
	34	- 0,53	0,25
	35	- 5,04	16,08
	36	4,5	30,59
	37	8,7	94,6
	38	- 3,92	8,35
	39	18,61	385,89
	40	-38,62	1413,2
	41	- 9,57	72,88
	42	- 0,42	0,37
n	42		
Tot.	=	-43,28	10684,34
Main	=	- 1,03	
S. d.	=	16,14	
Err.	±	2,49	

K 5 = -1,030 ± 2,491 [%]

	n	K15	d.² K15
	1	- 7,71	226,49
	2	2,16	26,89
	3	9,55	4,87
	4	13,93	43,4
	5	14,7	54,07
	6	22,22	221,39
	7	2,64	22,16
	8	50,29	1844,7
	9	7,22	0,02
	10	7,09	0,06
	11	3,14	17,7
	12	15,96	74,28
	13	- 1,59	79,74
	14	15,21	61,96
	15	-33,95	1705,46
	16	24,45	292,67
	17	-27,95	1245,88
	18	-10,84	330,61
	19	9,49	4,61
	20	- 8,16	240,25
	21	2,99	18,96
	22	9,27	3,71
	23	20,51	173,29
	24	2,64	22,16
	25	19,59	149,93
	26	14,48	50,91
	27	20,59	175,5
	28	2,01	28,41
	29	64,45	3261,71
	30	22,09	217,54
	31	- 8,7	257,5
	32	-35,81	1862,22
	33	- 2,44	95,75
	34	11,99	21,62
	35	12,83	30,12
	36	22,54	230,9
	37	28,05	428,88
	38	7,6	0,07
	39	28,82	461,11
	40	-28,35	1273,75
	41	-12,36	388,35
	42	- 2,22	91,49
n	42		
Tot.	=	308,4	15741,07
Main	=	7,34	
S. d.	=	19,59	
Err.	±	3,02	

K 15 = 7,343 ± 3,023 [%]

Figure 10.37 K5's and K15's results.

n	Progr	d.² Progr
1	3,77	10,
2	7,56	0,39
3	4,67	5,12
4	- 3,12	101,22
5	13,06	37,53
6	-19,53	700,5
7	9,29	5,53
8	37,99	964,49
9	5,59	1,8
10	4,02	8,53
11	24,45	306,7
12	30,53	556,51
13	- 1,9	78,15
14	-10,58	306,7
15	-34,76	1738,93
16	6,57	0,14
17	- 8,34	233,47
18	-21,9	831,63
19	33,29	694,65
20	25,79	355,48
21	3,56	11,39
22	4,64	5,29
23	0	48,11
24	8,93	3,97
25	2,7	17,92
26	25,6	348,35
27	12,82	34,63
28	14,55	57,91
29	53,33	2152,73
30	18,93	143,89
31	0,64	39,68
32	-29,82	1351,03
33	6,02	0,83
34	11,5	20,82
35	18,81	141,08
36	17,81	118,33
37	17,82	118,38
38	11,97	25,39
39	9,06	4,5
40	-24,27	974,06
41	2,24	22,08
42	- 1,96	79,15

n	42		
Tot.	=	291,3	12657,
Main	=	6,94	
S. d.	=	17,57	
Err.	±	2,71	

Progr. = 6,936 ± 2,711 [%]

n	A hyst.	d.² A hyst
1	34,92	396,13
2	49,94	1219,66
3	- 3,59	346,49
4	- 1,26	265,11
5	10,02	25,01
6	33,92	357,12
7	45,04	901,42
8	24,08	82,02
9	14,08	0,89
10	32,91	320,09
11	30,59	242,53
12	6,64	70,18
13	29,53	210,55
14	- 1,28	265,69
15	- 9,45	598,94
16	18,56	12,53
17	10,04	24,85
18	10,05	24,7
19	16,57	2,39
20	15,9	0,78
21	27,14	146,77
22	- 1,19	262,81
23	-15,38	924,16
24	15,22	0,04
25	-14,96	898,83
26	2,64	153,37
27	14,66	0,13
28	1,52	182,39
29	40,32	640,22
30	30,44	237,79
31	24,04	81,4
32	0	225,62
33	27,05	144,74
34	-10,97	675,71
35	34,39	375,18
36	9,45	31,04
37	36,5	461,31
38	-12,66	766,3
39	15,93	0,83
40	10,05	24,71
41	19,96	24,37
42	9,52	30,29

n	42		
Tot.	=	630,87	11655,08
Main	=	15,02	
S. d.	=	16,86	
Err.	±	2,6	

A hyst. = 15,021 ± 2,602 [%]

Figure 10.38 Progression's and Hysteresis Area's results.

10.5.2. ω = 80[°/s] - Velocity's Influence

The reference configuration is defined as follows:

- the reference temperature: TA;
- the reference load: L0;
- the reference velocity: 20 [°/s].

In this regards, the influence of 80 [°/s] in respect to 20 [°/s] involves different trends for every parameters. Here, as follows, the inferred results:

	n	eFI	$d.^2$ eFI
	1	9,1	28,68
	2	0,94	7,9
	3	- 1,19	24,4
	4	- 0,83	20,96
	5	11,49	59,99
	6	42,55	1505,94
	7	- 8,64	153,35
	8	-12,32	258,2
	9	1,22	6,37
	10	-14,14	320,13
	11	- 5,28	81,42
	12	14,79	121,84
	13	- 8,34	146,21
	14	1,63	4,5
	15	- 0,91	21,69
	16	0,55	10,21
	17	16,35	158,85
	18	56,94	2829,73
	19	- 0,77	20,37
	20	- 1,01	22,65
	21	5,06	1,73
	22	0,58	10,03
	23	1,69	4,24
	24	- 9,69	180,57
	25	- 3,89	58,41
	26	3,56	0,03
	27	- 5,07	77,67
	28	10,55	46,28
n	28		
Tot.	=	104,94	6182,37
Main	=	3,75	
S. d.	=	15,13	
Err.	±	2,86	

eFI = 3,748 ± 2,860 [%]

	n	R	$d.^2$ R
	1	-18,61	76,83
	2	-20,48	113,09
	3	13,55	547,34
	4	-15,26	29,31
	5	-20,13	105,74
	6	-45,75	1289,
	7	11,43	452,6
	8	13,23	532,59
	9	9,72	382,82
	10	18,03	777,29
	11	-10,47	0,39
	12	-51,4	1726,73
	13	18,44	800,12
	14	-31,72	478,33
	15	3,28	172,31
	16	-32,18	498,6
	17	-25,96	259,69
	18	-48,87	1522,91
	19	- 3,53	39,96
	20	9,61	378,7
	21	-21,54	136,67
	22	2	140,38
	23	-28,23	337,74
	24	9,91	390,24
	25	4,99	220,21
	26	- 5,09	22,6
	27	- 6,73	9,74
	28	- 3,97	34,57
n	28		
Tot.	=	-275,74	11476,49
Main	=	- 9,85	
S. d.	=	20,62	
Err.	±	3,9	

R = -9,848 ± 3,896 [%]

Figure 10.39 eFI's and R's results.

	n	K5	d.^{2} K5
	1	- 9,12	104,55
	2	- 2,01	9,72
	3	3,36	5,07
	4	- 1,22	5,4
	5	11,5	108,08
	6	15,59	209,87
	7	- 6,5	57,89
	8	- 1,1	4,85
	9	- 1,6	7,31
	10	- 6,73	61,45
	11	0,75	0,13
	12	19,65	343,99
	13	-13,86	223,79
	14	- 1,72	7,98
	15	7,83	45,19
	16	- 0,53	2,66
	17	16,19	227,73
	18	8,51	54,88
	19	- 6,2	53,38
	20	- 9,95	122,08
	21	2,24	1,3
	22	4,26	9,97
	23	-16,45	308,07
	24	-10,27	129,32
	25	5,01	15,23
	26	6,31	27,15
	27	- 5,09	38,34
	28	22,05	438,8
n	28		
Tot.	=	30,91	2624,16
Main	=	1,1	
S. d.	=	9,86	
Err.	±	1,86	

K 5 = 1,104 ± 1,863 [%]

	n	K15	d.^{2} K15
	1	- 2,53	310,1
	2	14,16	0,85
	3	6,65	71,
	4	- 1,19	264,67
	5	32,63	307,85
	6	47,2	1031,74
	7	49,76	1202,37
	8	25,57	110
	9	- 2,89	322,98
	10	29,92	220,25
	11	24,23	83,69
	12	-15,56	938,5
	13	- 1,35	269,91
	14	10,46	21,32
	15	10,69	19,27
	16	1,15	194,09
	17	37,76	514,26
	18	18,85	14,22
	19	22,43	54,09
	20	8,87	38,54
	21	62,35	2234,7
	22	- 6,49	465,15
	23	-25,03	1608,6
	24	26,38	127,59
	25	15,27	0,04
	26	14,8	0,08
	27	2,23	165,13
	28	15,91	0,68
n	28		
Tot.	=	422,24	10591,69
Main	=	15,08	
S. d.	=	19,81	
Err.	±	3,74	

K 15 = 15,080 ± 3,743 [%]

Figure 10.40 K5's and K15's results.

n	Progr	d.² Progr
1	6,6	32,74
2	16,46	17,11
3	2,67	93,18
4	- 0,8	172,39
5	19,59	52,74
6	27,33	225,21
7	60,09	2281,72
8	26,53	201,88
9	- 7,94	410,67
10	39,25	725,2
11	22,32	99,82
12	-29,84	1777,81
13	14,02	2,86
14	8,84	12,17
15	- 3,25	242,44
16	-16,43	826,79
17	14,14	3,28
18	12,7	0,14
19	30,56	332,5
20	5,64	44,68
21	56,58	1958,77
22	-10,62	526,43
23	- 9,55	478,71
24	40,59	798,75
25	9,72	6,81
26	7,47	23,56
27	7,5	23,25
28	- 5,07	302,68

n	28		
Tot.	=	345,11	11674,29
Main	=	12,33	
S. d.	=	20,79	
Err.	±	3,93	

Progr. = 12,325 ± 3,930 [%]

n	A hyst.	d.² A hyst
1	59,81	796,88
2	44,63	170,3
3	23,68	62,43
4	-46,01	6021,09
5	-46,12	6037,91
6	59,67	788,63
7	28,15	11,79
8	21,75	96,78
9	34,5	8,5
10	48,25	277,65
11	-10,96	1810,13
12	55,7	581,68
13	16,26	234,77
14	31,55	0,
15	29,98	2,59
16	58,32	715,04
17	51,86	411,21
18	-26,32	3352,65
19	- 6,25	1431,72
20	141,68	12121,43
21	- 2,34	1151,09
22	223,58	36860,58
23	22,25	87,15
24	1,81	886,31
25	43,04	131,13
26	15,35	263,71
27	- 4,51	1302,94
28	15,06	273,04

n	28		
Tot.	=	884,358	75889,134
Main	=	31,584	
S. d.	=	53,016	
Err.	±	10,019	

A hyst. = 31,584 ± 10,019 [%]

Figure 10.41 Progression's and Hysteresis Area's results.

10.5.3. Commenting in Results

It is possible to notice that the repeatabilities of respectively the effective Flex Index, R, K_5, K_{15} and Progression are lesser than 20 [%], whereas the hysteresis area is included between 30 and 60 [%].

This independent variable has not a significantly influence, looks like the load.

The Flex Index is almost the same for each condition. The shapes have a slowly increase with the increase of the angular velocity.

Taken into consideration the diagrams, the three cycles have different effective angles' range. this problem is associated to the not perfect working of the unit. The samples' frequency is not sufficient high to measure all the points of the cycle. Therefore with the increase of the velocity, the points measured are always smaller, as a consequence the decreasing of the hysteresis and the increasing of the distancing percentage on the strength of the reference.

In this regards, the cycles are similar.

Chapter 11 : Conclusions

As a conclusion, it can be noticed how different factors can influence the ski boot's behaviour. My study has been applied to different ski boots with different characteristics, brands and nominal Flex Index.

The focus was on the closure of the buckles in order to determine a standard convention for their closure. The force that stresses the buckles during the test is not constant and its trend does not follow a linear function.

Three work benches have been employed: one with swinging arm featuring two spindles (one applying and measuring the angle and the other one the moment); the other test benches feature two axial benches with relative linear hydraulic actuator having an extremity fixed. In these cases, the hysteresis curves depend on the setting of the machines. The conversion stroke/angle is possible only after the analysis of the kinematicism.

On the swing arm test bench it was possible to apply an axial load along the Tibia's axis, which simulated the human body's weight. The system employed was adjusted according to a pressure gauge from 0 [bar] to 3,5 [bar], that is equivalent to 110 [kg]. The axial load does not contribute to the bending moment because the lever arm of the force in respect to the rotation centre is null. The linear work benches are not suitable for this type of effect (Axial-Load). Both axial work benches are composed by a hydraulic actuator connected to a rod that is jointed to the prosthesis. The axial units allow the study of the temperature's effect because they were enclosed by a freezer room.

The main boot characteristics that were studied, are:

- the **effective Flex Index**;

- the tangent **stiffness K_5**;
- the **Progression** (the relationship between two tangents of the stiffness at two different angles to understand the behaviour of the curve between the points considered);
- the **hysteresis area A_{Hyst}**.

The closure of the buckles was controlled and kept constant using the same closing-code (the positions of the buckles) and the same micrometric adjustments. In this regards the influence of this factor is eliminated or at least reduced.
In this regards, to describe the behaviour of the ski boot, the independent variables (influencing factors) I took into consideration are:

- the **Tibia angular velocity**;
- the **temperature**;
- the **axial load**.
- the **prosthesis**;
- the **work bench**;

The velocity was increased starting from 20 [°/s] to 80 [°/s].
By taking into account the temperature, the effect is evidenced in the proximity of the extremities of the cycle.
The prosthetic legs employed are one in fee of the University of Padua (with two ankle degrees of freedom), one in fee of DolomitiCert (1 DOF with two variants depending on the rubber's hardness) and the last one in fee of the University of Innsbruck (an articulate foot 1 DOF with two architectures depending on the calf's hardness).
The other effects regard the work bench and the axial load.
The depending characteristics analysed (eff. Flex Index, K_5, Progression and Area) are chosen as the main useful parameters in order to express the ski boot's behaviour and therefore to support its choice of development. In this regards, the following diagrams report the average results of all ski boots. For instance, by taking into consideration the ski boot, the parameter eFI is set to 100 % both in the cases in which the boot has a high Flex Index or a small one.
Considering the variable's influence, a configuration is taken as reference in order to compare the others. For instance, when the reference work bench is the Torsion unit, the

data of a ski boot tested with this machine have a reference of (100 %). The data of the same ski boot (while maintaining the other variable i.e. the prosthesis, load, temperature and velocity constant) tested with one of the other units is compared with the UPT. Each ski boot has a different behaviour and the singular variable's influence more or less can vary. In this regards, the effect of the factor "work bench" is an average of all the results of each ski boot. The same procedure is employed for each factor.

The effects of the independent factors on the **effective Flex Index** are displayed in the following *Diagram 11.1*.
At the intersection of two principal axis, the reference configuration for the work bench is the UPT, the ambient temperature TA, for the velocity of 20 [°/s], null load L0 for the axial load and PPS for the prosthesis.
As far as the temperature is concerned, the average effect on the eFI is noticeable (the effective Flex Index increases at about 70 [%]). The axial load and the velocity effects are respectively of 20 [%] and 4 [%]. The class of the prosthesis is characterized by a similarity between the two types of prosthetic legs of DolomitiCert and a similar behaviour between the prosthesis of Innsbruck.

The influence of the **K_5** is shown below in *Diagram 11.2*.
The evolution of the K_5 diagram is close to the eFI's. This result indicates that there is a strong correlation (*Diagram 11.5*) between the two factors. *Diagram 11.3* evidences a low sensitivity with respect to the axial load and velocity, whereas the temperature's, work bench's and prosthesis' sensitivities are important.

The same representations are employed for the **Progression** and **Hysteresis Area**.
In *Diagram 11.4* the temperature has a lower effect, whereas the ski boots have high sensitivity with respect to the load and velocity
As far as the last parameter, the hysteresis area, is concerned, the main influencing factors are the temperature, the velocity and the load.

These diagrams can be useful for future developments, as they can set a standard work bench and an univocal protocol.

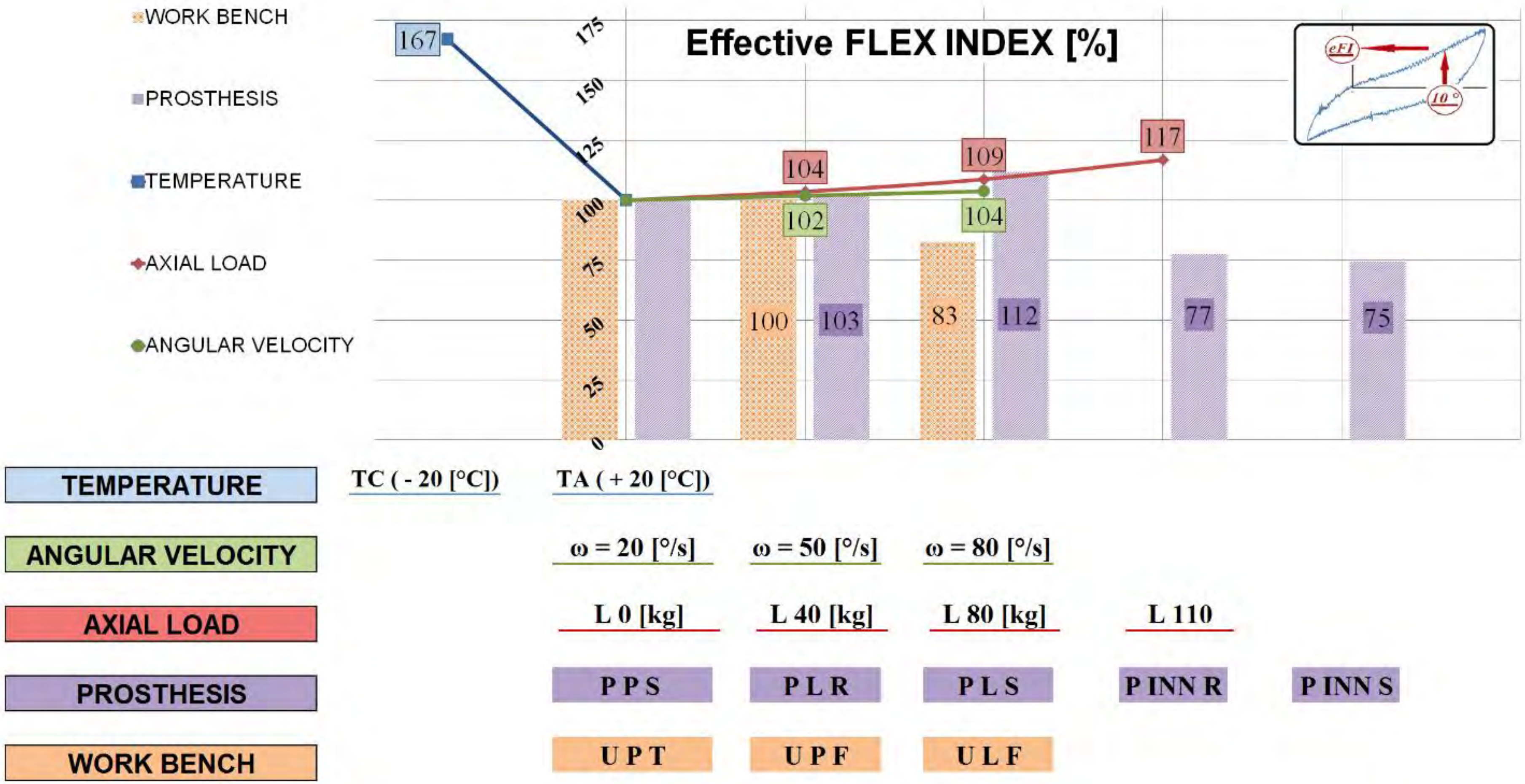


Diagram 11.1 Influence of the Effective Flex Index.

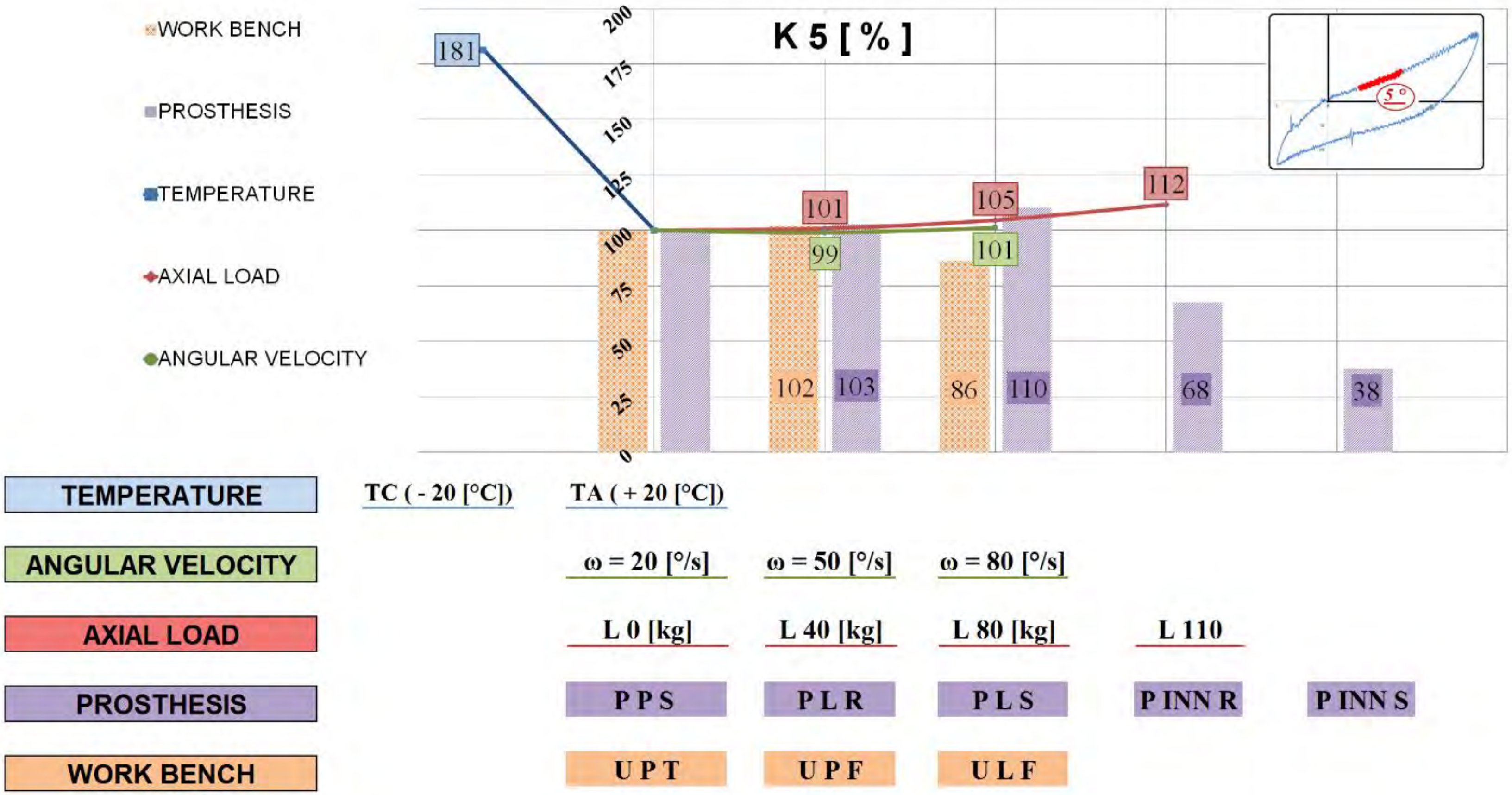


Diagram 11.2 **Influence of the K_5.**

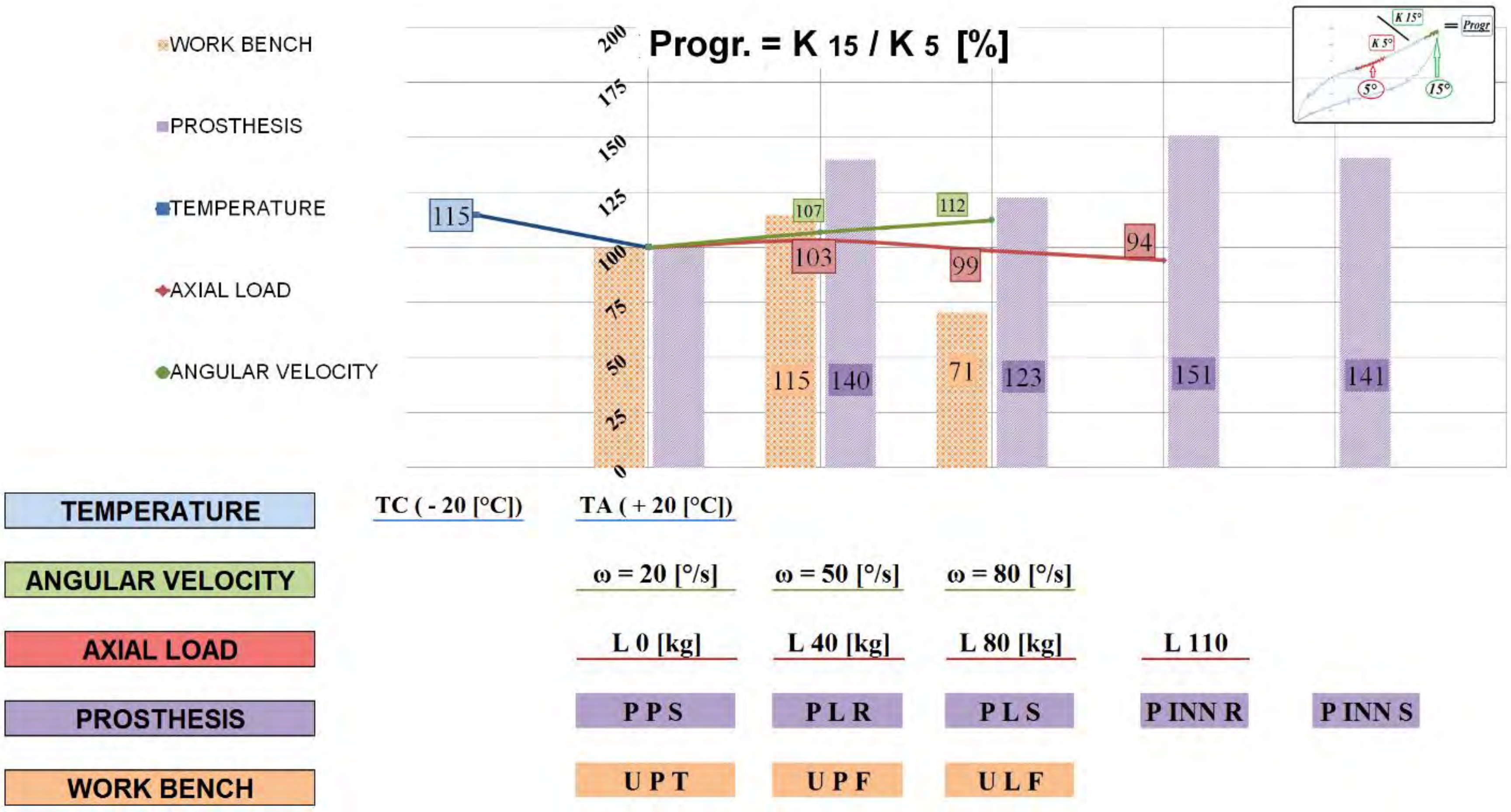


Diagram 11.3 Influence of the Progression.

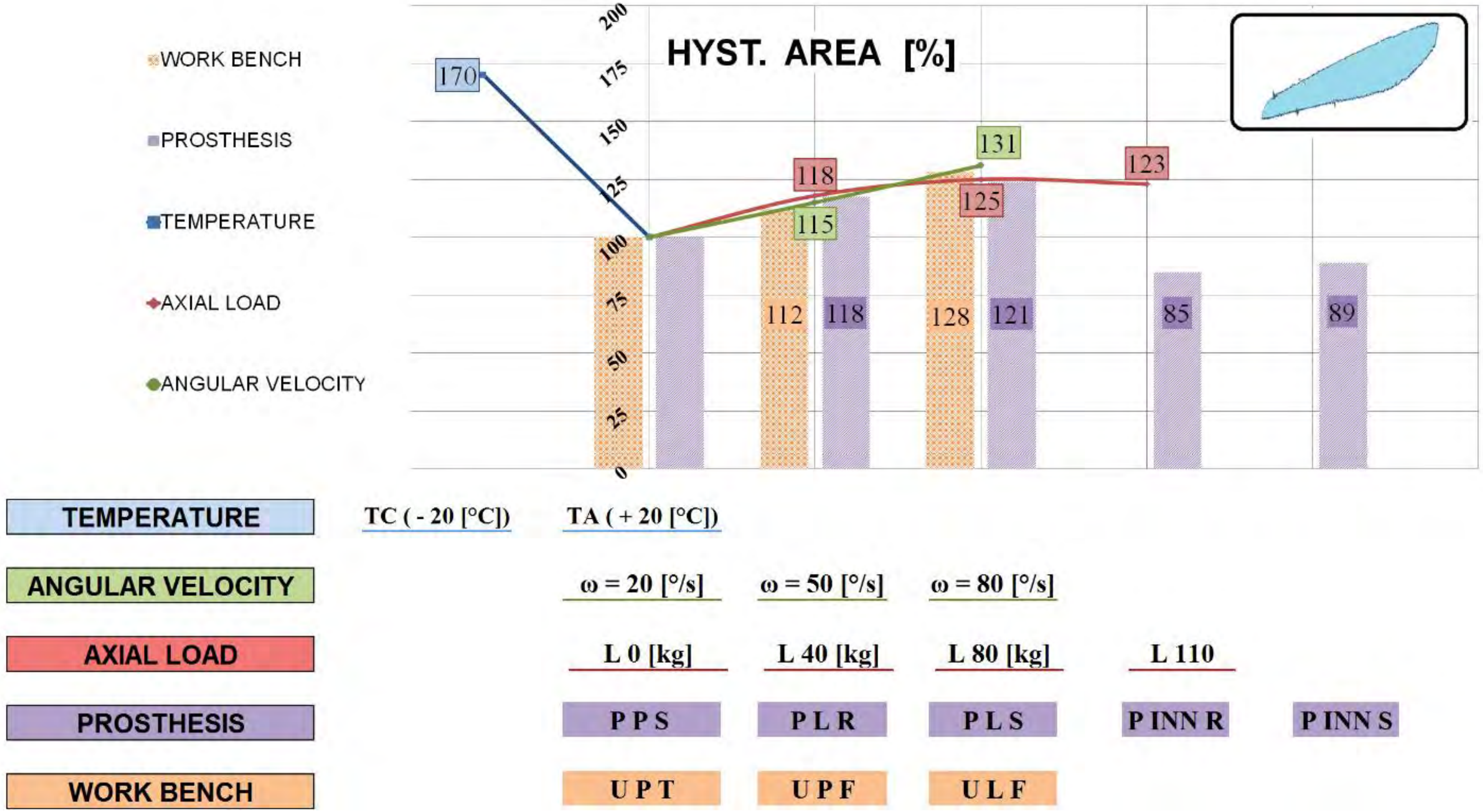


Diagram 11.4 **Influence of the Hysteresis Area.**

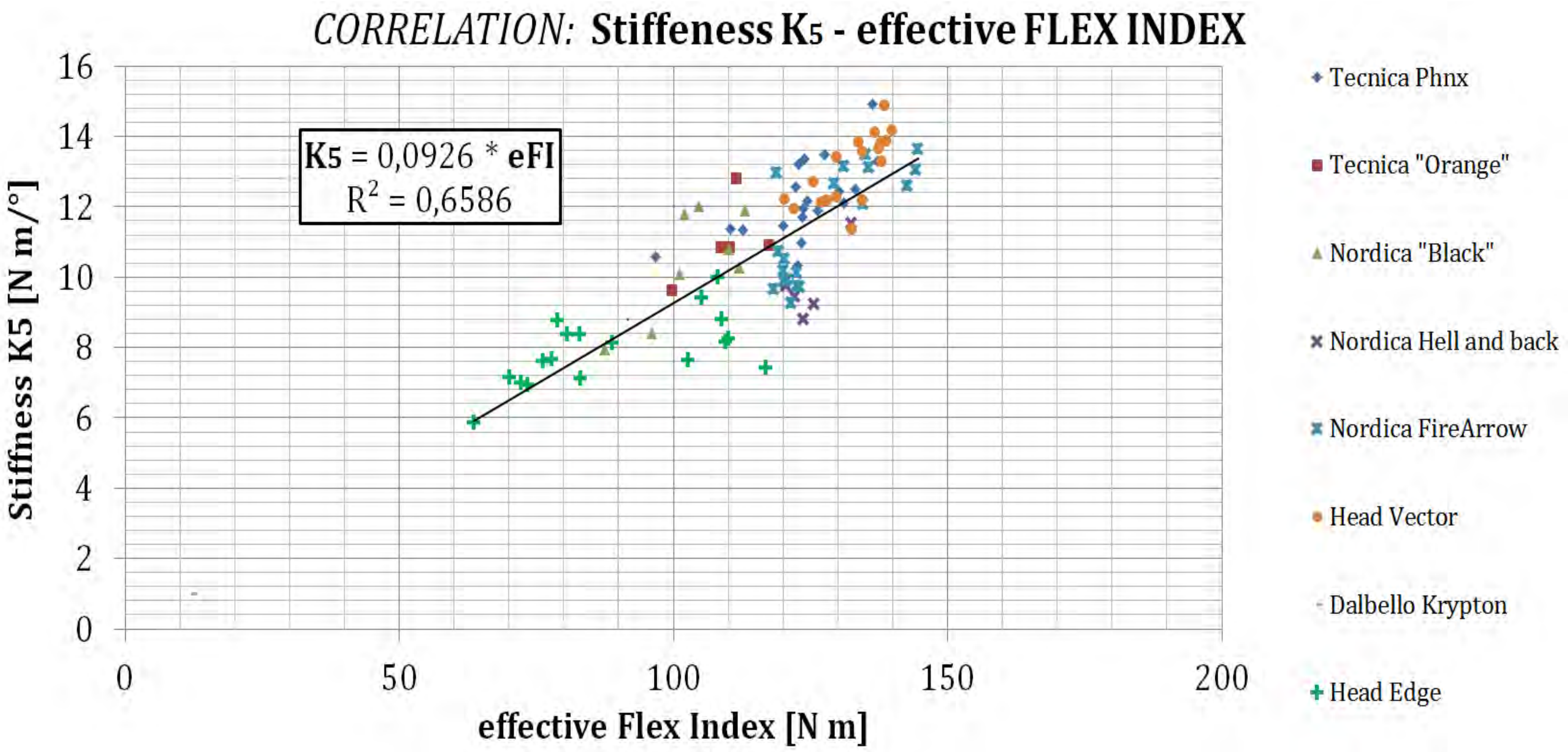


Diagram 11.5 **Correlation between Stiffness K_5 and effective Flex Index.**

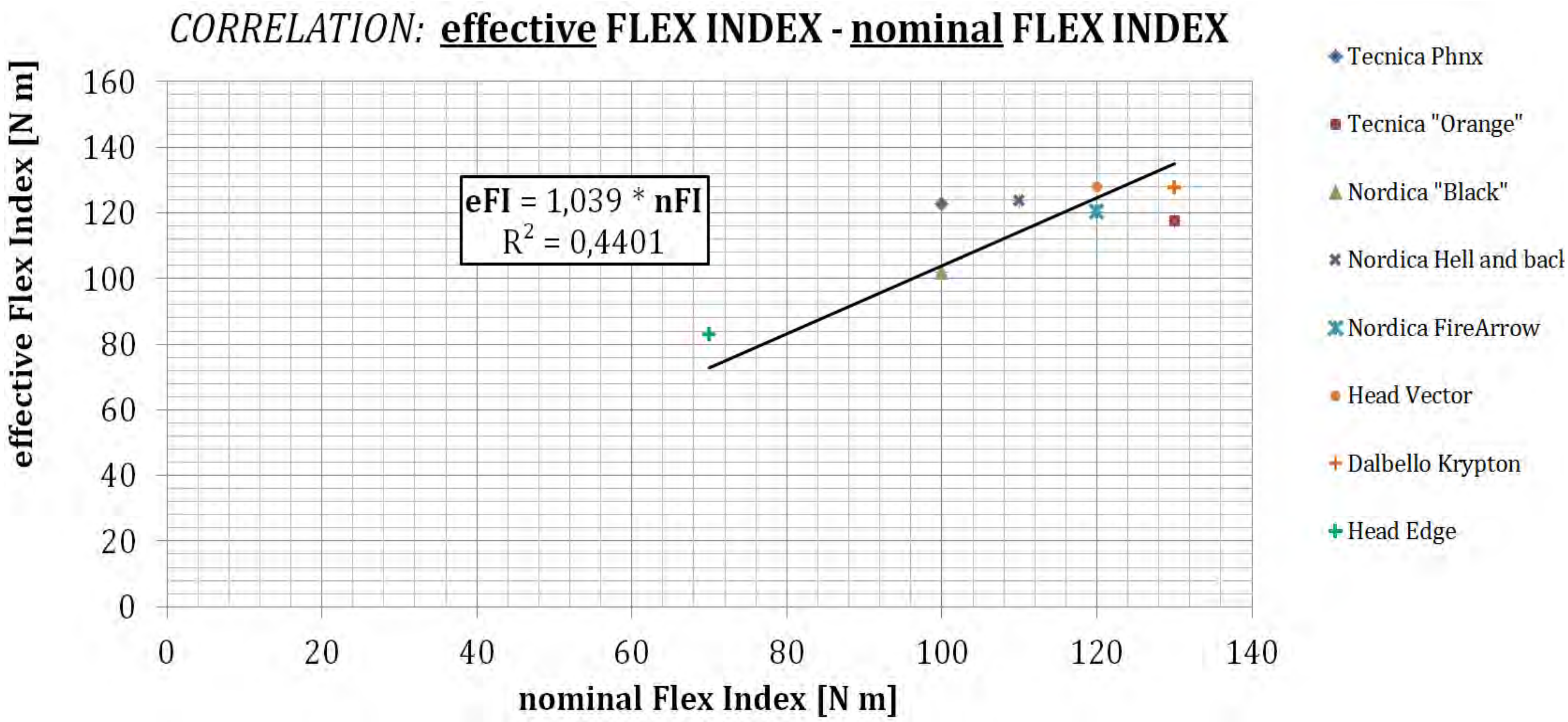


Diagram 11.6 **Correlation between the nominal Flex Index and the effective Flex Index.**

In terms of the possible improvements, to obtain a good quality in the results of the data, the form of the **velocity**'s function has to be changed with a new equation, which has to feature the following requirements:

- a forward linear "ramp" with the flexion velocity measured in field tests (160 [°/s];
- a time interval with the motion is stationary;
- a backward linear "ramp" with the extension velocity measured in field tests (-192 [°/s]).

The **prosthetic** leg has to be composed by a foot in order to obtain an accurate closure of the ski boot, and by at least two degrees of freedom of the ankle. This is due to the fact that the tibia can move in both the sagittal and frontal planes.
The calf has to display similar profile and consistency of diverse human part. The dimension of the prosthesis can be classified according to the strength of the people (with gender distinctions) and to the characteristics of the different sizes. The front part of the leg has to be studied because its hardness is different in respect to the back side.
As far as the **temperature** of the body is concerned, between the external surface of the ski boot and the foot's surface there is a gradient temperature. The temperature has a notable effect on the behaviour of the ski boot and therefore the study of this condition is to be considered very important. As regards the **closure of the buckles** of the ski boot and the micrometric screw, it is necessary to have a standardised and repeatable procedure. The lever of the buckle can vary for each type of ski boot. The forces (the force is not constant but has a non-linear behaviour) can be measured with a small clip that works like a load cell. (***Chapter 3***).
This being said, the axial load is an important factor and its value has to change according to the strength of the size of each individual.
It would be interesting to value the backward **stiffness**. In this work the stiffness is valued at a minimum angle of the range (-5[°]) and at a neutral angle.

When I started the work that lead to the composition of this thesis, in September 2014, my knowledge on ski boots was only limited to their usage.
For this reason, all the experience I have done has been interesting and useful to me in many ways. First and foremost, by taking for granted that ski boots are used during the winter season by loads of people as the principal part of their winter equipment, we still have to face the problem of how to recognize a high-quality boot from another.
My motivation started from this issue, that is, the lack of an objective characterization of the ski boot, which is still to be developed.
Another triggering aspect was the use of different systems of analysis for the characterization of the ski boot. I think that an institution such as the Department of Mechanical Engineering has the necessity to implement its previous studies and move forward in the research, because, in my opinion, only practice can pave the way for the development of important notions in this field.
The work and the analysis at the core of this dissertation took place in the laboratory of the Department of Mechanical Engineering of the University of Padua and in DolomitiCert (LO). The time I spent in DolomitiCert
was useful to me in understanding and adapting to a real working environment and by a cknowledging the differences between such setting and the working atmosphere of
the University.
The work was correlated with an important project, Interreg Project Nr. 6602-21, which focuses on the ski boot's behaviour. The resu
lts acquired from this work has been appraised by the ski boots' companies present at the Montebelluna meeting, which was held on March, 30th 2015.

Bibliography

[1] Martino Colonna, Marco Nicotra and Matteo Moncalero; *Materials, Designs and Standards Used in Ski-Boots for Alpine Skiing*. **2013**. 1-2, 4.

[2] Aldo Pescher, *Come è fatto uno scarpone da sci: Scafo, Gambetto e alter parti*, **2010**.

[3] Article: *Ski Boot Sizing & Buyer's Guide (Size, Fit & Flex).*

[4] www.Ski4people.it ; *3.3-Il flex Index*.

[5] Arturo N Natali, Silvia Todros, Chiara Venturato and Chiara G Fontanella; *Evaluation of the mechanical behaviour of Telemark ski boots: Part I – materials characterization in use conditions*. **2014**.

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