Forces Applied on the Ground in Roller Skating

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Walking, running, cycling, skating are just some examples of the many possibilities available to man for his own motion.

Most of these activities have been widely studied both from a physiological as well as biomechanic viewpoint. On the contrary, few researches and experiments are available as regards skating, particularly roller-skating. In this sport the athlete wears a special pair of shoes fitted with four little wheels, each one of which is able to spin freely on a axis of its own.

The analysis of the techniques used in roller-skating (as to how, when and where the propulsive force is applied and of the most appropriate length and frequency of each step) can provide some valuable information for a more thorough development of this sport activity.

In order to have the opportunity to study and evaluate at least some of these parameters, some special force transducers were built and applied to each of the wheel fitted on a pair of skates. Furthermore, front and back weight-force detectors were also installed.

ROLLER-SKATES FORCE
TRANSDUCERS MECHANICS
AND CALIBRATION

In many mechanical systems the relationship between the applied forces and the displacements they cause is not quite linear.

This is due to several reasons, i.e.: frictions between the parts in

motion, non-linearity peculiar to some elements, clearance existing among the contacting parts.

The kind of system used for the measurement of the forces in dynamometric skates is shown in fig. 1a with reference to horizontal transducers. There are some cup-springs located on a fixed axis pushing against a teflon bush and which are bloked by means of an adjusting-nut. The bearings supporting the wheel are fitted on the bush itself.

TO DISPLACEMENT
TRANSCUCER
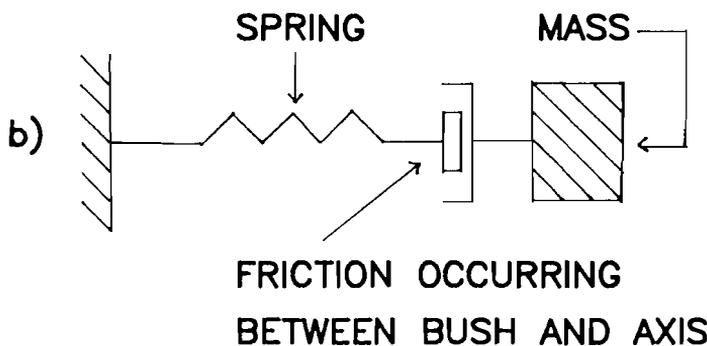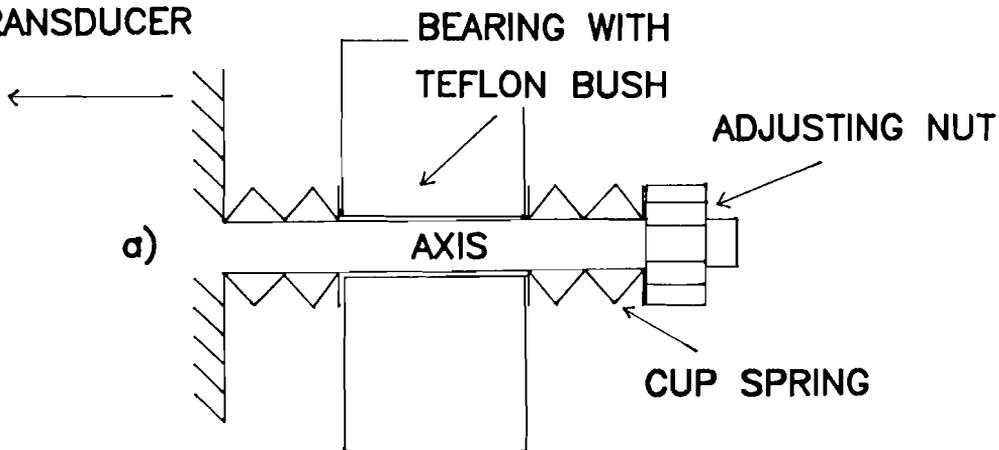
Fig. 1 a) System used for the measurement of the forces acting on the wheels of the dynamometric skates.

b) Scheme of the whole unit spring / damper / mass. The damper represents the frictions occurring between the bush and the axis.

Schematically, the system of measurement may be depicted as a whole unit spring / damper / mass (fig. 1b) where the damper represents the frictions occurring between the bush and the axis.

When carrying out the calibration, known forces were applied to the transducers and the output signal (in millivolts) provided by means of electronic devices was then read.

In order to be able to do this, each force detector was cyclically loaded and unloaded (from −35 kg to +35 kg for horizontal detectors, from 0 to +110 kg for vertical ones), thus achieving diagrams as indicated in fig. 2. The extent to which the presence of frictions prevents the sensor from replying to the load by following one single curve both during the loading as well as the unloading phase, is rather self-evident.

While it is common experience to deal with non-linear calibration curves as mentioned above, when an hysteresis curve occurs it is generally ignored. One way to do this is to find a single regression curve which best interpolates all detected points (best fit curve). In so doing, the two branches, forming a hysteresis curve are squeezed on an average curve

A

VOLT

UNLOADING CURVE

LOADING CURVE

FORCE

LOADING START POINT
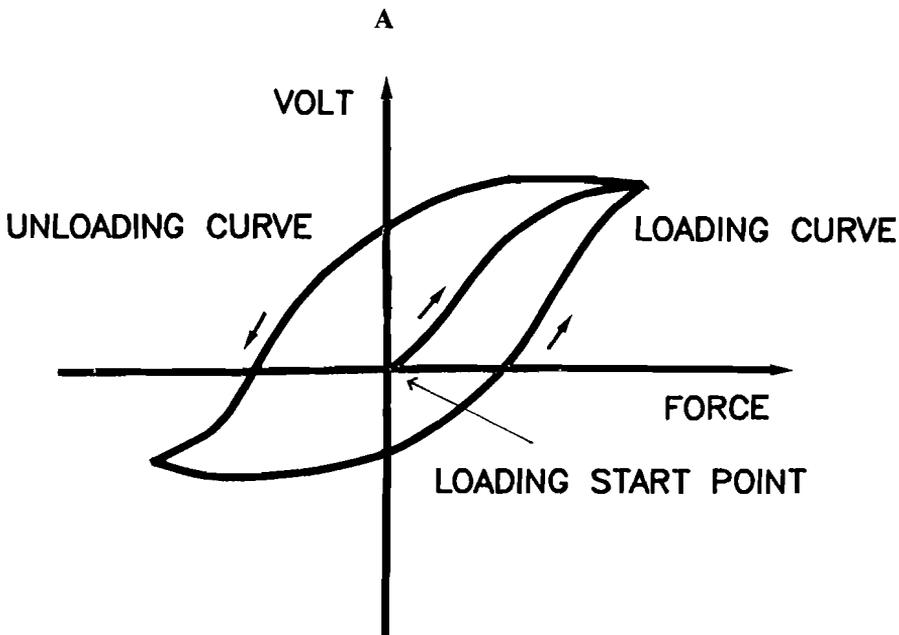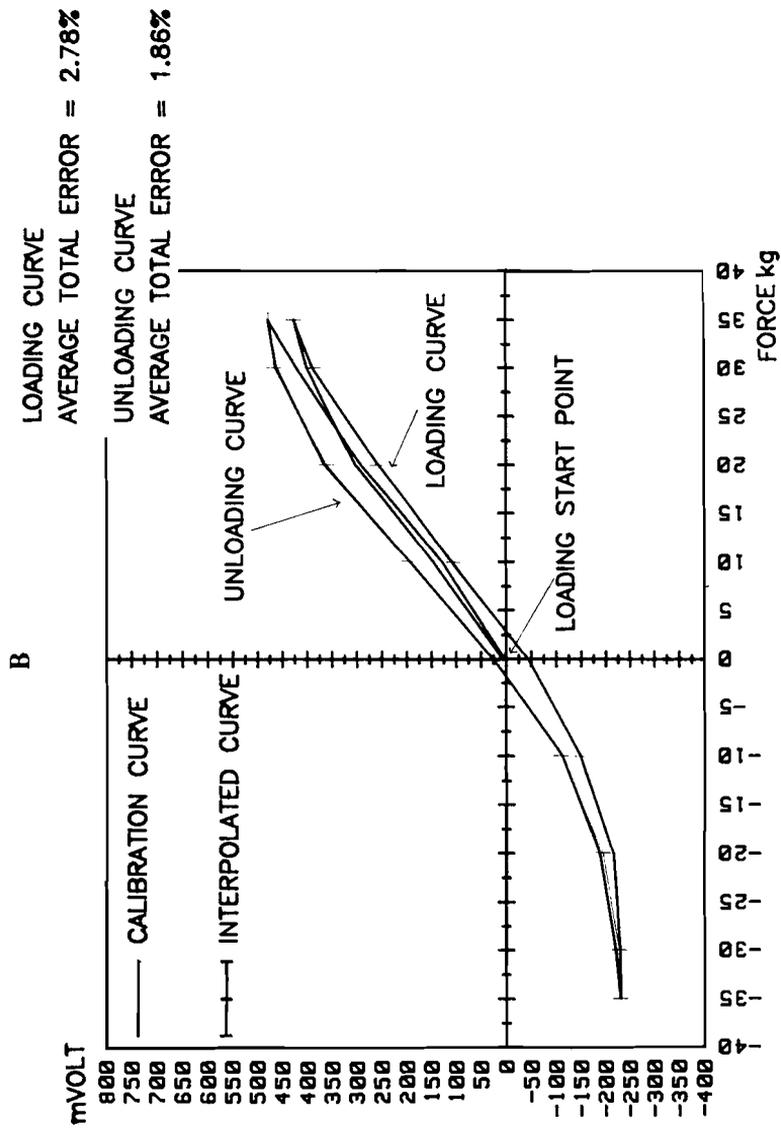
Fig. 2 Signal intensity coming from force transducers in applied load domain.
   a) Scheme of force behaviour.
   b) Real trend.

306

(fig. 3). This kind of procedure is not correct. In fact, the more open is the hysteresis curve, the more serious the error is deemed to be.
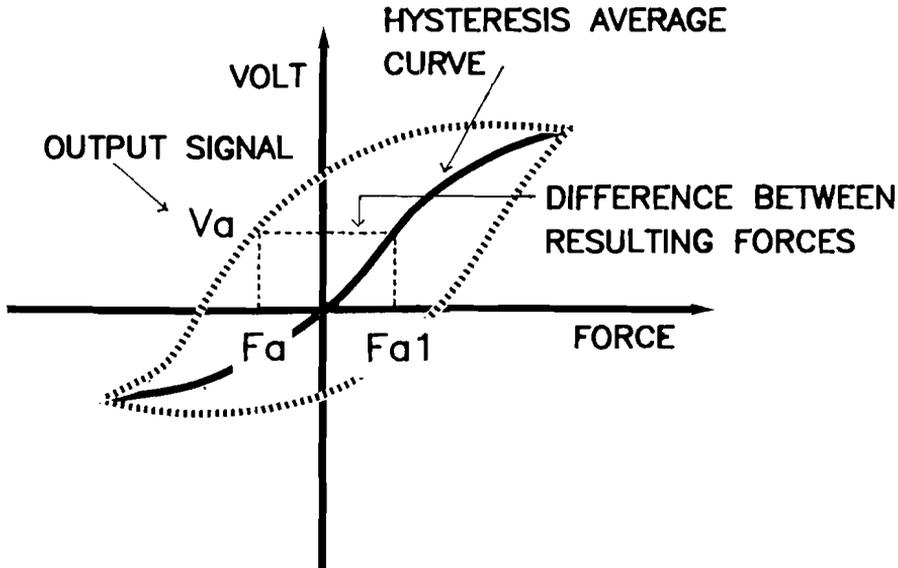
Fig. 3 Hysteresis average curve. The mistake accomplished with an output signal like Va is equal to the difference existing between the forces Fa and Fa1.

In actual facts, the hysteresis conceals the real behaviour of the transducers by reducing the signals amplitude, introducing a delay in the diagrams F(t) and providing trends unreal to a phenomenon (fig. 4a, 4b).

SOLVING METHODS ANALYSIS

The shape of the hysteresis curve of a force detector system depends on the frequency with which the load is applied.

The calibration system we used did not allow this kind of examination as loads could only be applied statically.

Being impossible to identify the variation trend to frequency, the employment of the following hypothesis was thought appropiate: for each

'A FRONT LEFT WHEEL OF THE RIGHT SKATE

WRONG RESULTS

kg 16.672
15.672
14.672
13.672
12.672
11.672
10.672
9.672
8.672
7.672
6.672
5.672
4.672
3.672
2.672
1.672
.672
0—> -.328
-1.328
-2.328
-3.328
-4.328

.096
.596
1.096
1.596
2.096
2.596
3.096
3.596
4.096
4.596
5.096

TIME (sec)
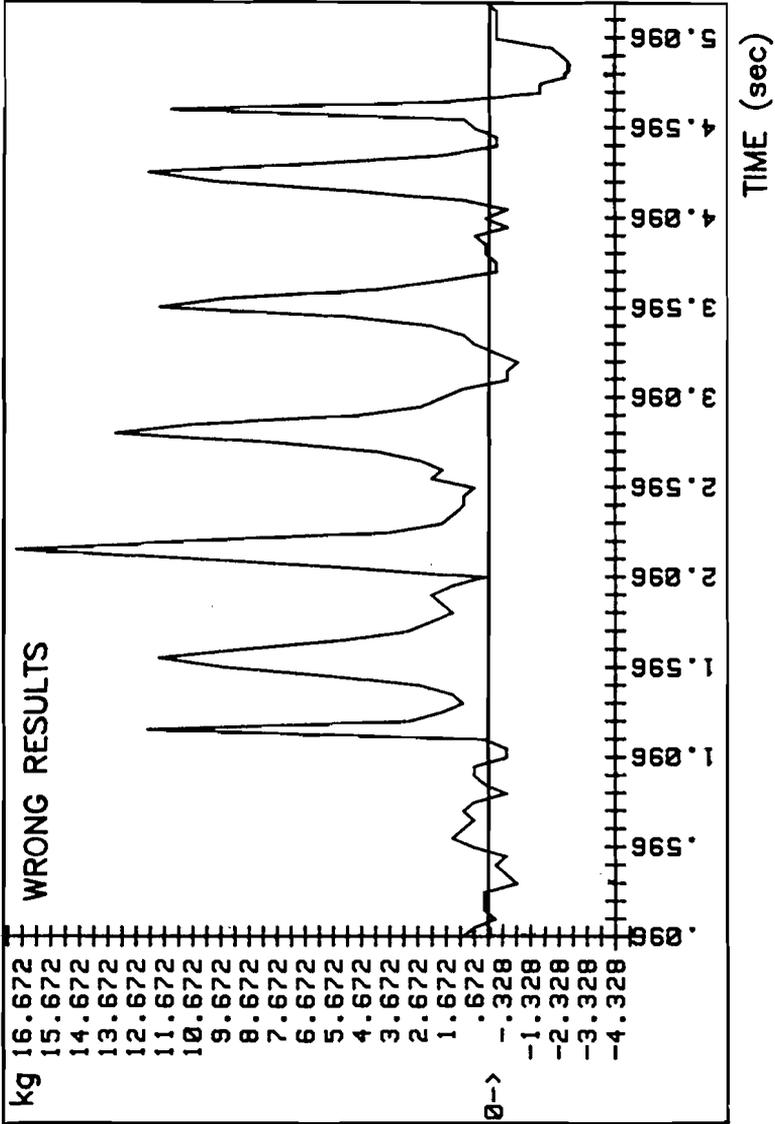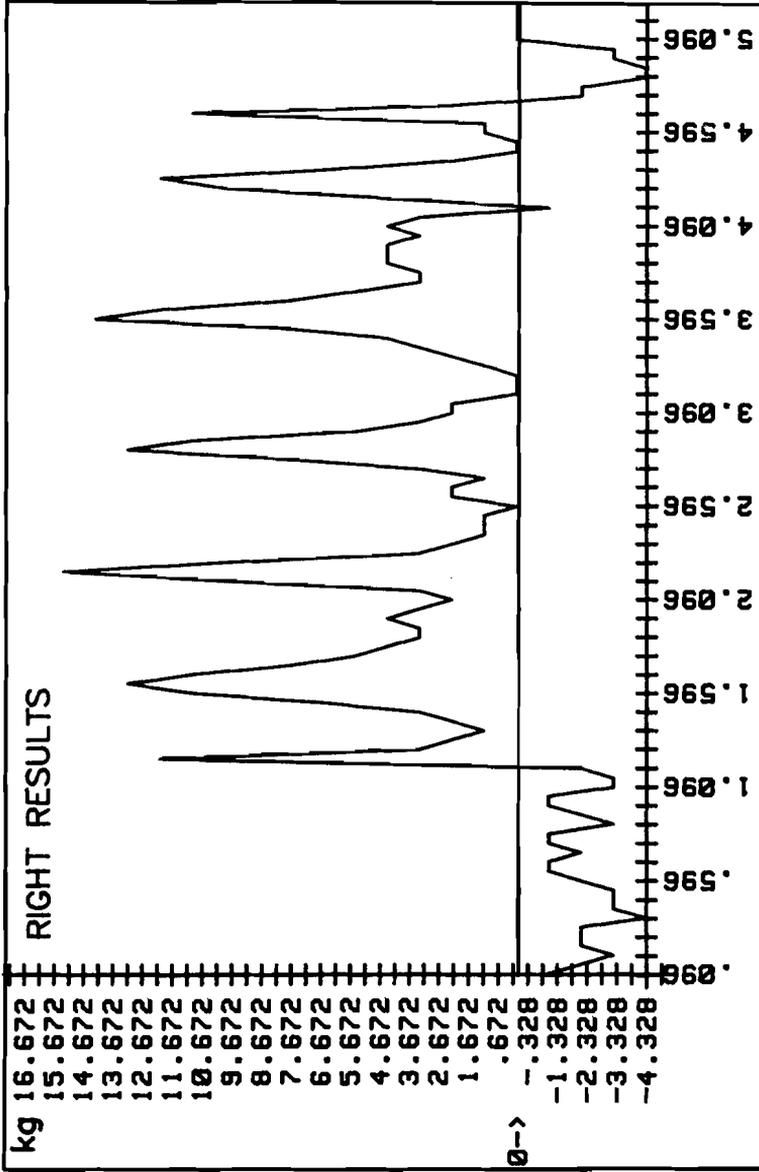
Fig. 4 Force applied on the front left wheel of the right skate.
a) Results using the hysteresis average curve as calibration curve.
b) Right results.

309

detector a couple of curves (loading and unloading ones) is considered. Said curves are obtained, through interpolation, by calibration cycles showing a wider hysteresis; they represent the envelopment of the family of measurable hysteresis.

After selecting the calibration points for each limit curve, interpolation was performed using a polynomial with independent variable F. This allows an univocal V(F) function.

The polynomial degree was selected so as to represent the available points with adequate accuracy (5th degree for horizontal force detectors, 2nd degree for vertical ones).

The most critical zone of the two curves is that next to the ends of the hysteresis cycle. In order to achieve a better depiction of this tract, the terminal points of each limit curve were weighed more than others (4:1).

For each one of the point used in the interpolation the percentage error was evaluated:

$$E\% = \left[1 - \frac{Vcalc}{Vmis} \right] *100$$

whereas for the overall quality of regression the percentage average quadratic error was used:

$$\overline{E\%} = \sqrt{\frac{\sum_{k} E\%_{k}}{n-1}}$$

$$k=1,2,\dots,n$$

READING ALGORITHM OF THE HYSTERESIS CYCLE

We define a «threshold» curve which is one obtained as mean of the limit curves and represents the theoretic behaviour of the force detector in its first loading cycle (upper branch) or unloading cycle (lower branch) (fig. 5).
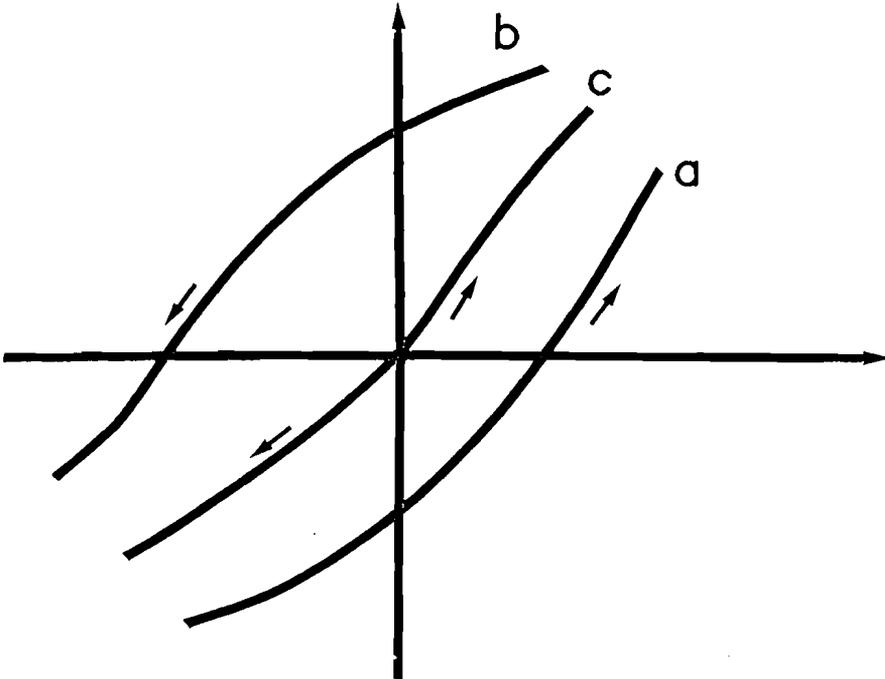
Fig. 5 Threshold curves as mean of the limit curves.
    a) Loading limit curve.
    b) Unloading limit curve.
    c) Threshold curve.

The following hypothesis may be cast: a) the shape of any unloading curve is determined by the limit curve thus, during the sensor's unloading, the $V(F)$ ratio is identified by the unloading curve itself translated so as to pass through the point $F1$, $V1$ where the phenomenon's inversion begins (fig. 6); b) the unloading curves thus obtained are then followed until the threshold curve at the intersection of which the

sensor is deemed to have freed itself from the hysteresis and able to respond to forces applied in the same way as at the beginning of the cycle (fig. 6).
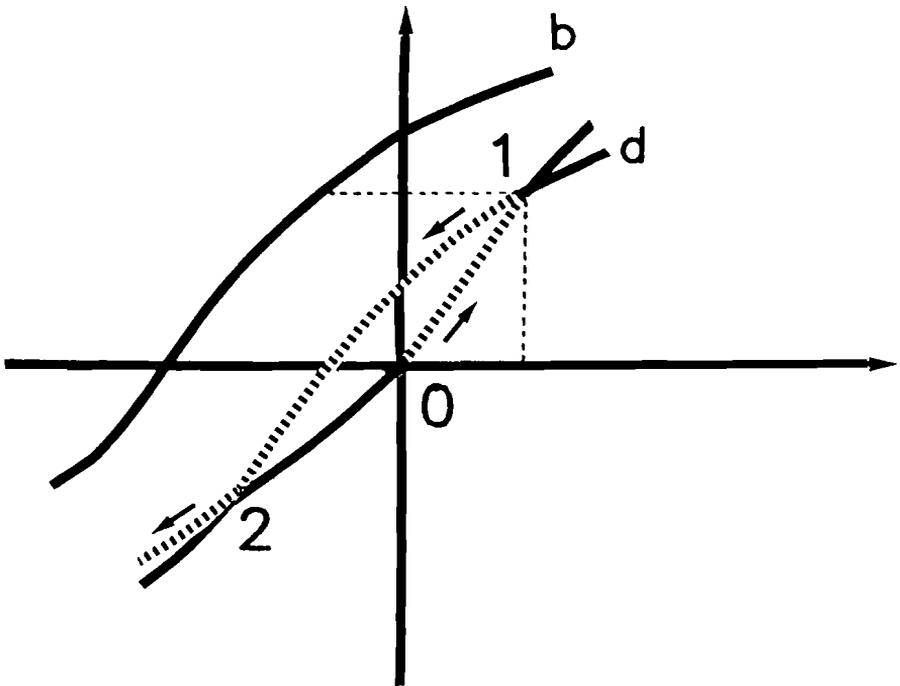
Fig. 6 Methods used to solve the problem of force transducers answer during work.
0) Loading start point.
1) Unloading start point.
2) Intersection point with threshold curve followed from now on.
b) Unloading limit curve.
d) Translated unloading limit curve b).

The phenomenon is given a similar treatment whenever the branch of the curve that has been run belongs to the loading phase.

This algorithm proved to work efficiently except when the two limit curves, in the concerned tract of reading, have two points in common, which never occurred indeed.

CONCLUSIONS

The need to simultaneously record 12 dynamometric signals (6 for each of the two skates) without significantly increase the mass of the skate itself yet keeping its solidity, involved the employment of solutions, mainly mechanical ones, which were fairly complex and featured a non-linear behaviour.

In order not to incur in gross interpretative mistakes of the recorded phenomena, the solution of the problem required a preliminary study which we believe we carried out successfully.

Together with an adequately programmed computer the dynamometric skates are simple to use as they easily fit every athlete and the wheels he prefers without causing any bonds whatsoever.

The possibility of measuring the force applied on each wheel both on the forecarriage as well as on the backcarriage of each skate, allows a detailed study to be carried out on the most critical stages of a competition such as the start (with its several styles) and along track bends.