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THE METHODS OF VALIDATION THE EXPERIMENTAL MEASUREMENT DEVICE FOR GROUND REACTION FORCES DURING ICE HOCKEY SKATING

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SUMMARY

The reliability and validity of measuring device used in human movement research is usually determined by their measurement error. Common practice in recent research is used the equipment much more accurate than is required by practical applications of research. The modern trend is, however, individualization and the creation of specific new measuring devices that can be used in the research. Those devices itself requires their validation (Stergiou 2004). The creation of a new specific equipment can not always ensure such accuracy in prototype that would far exceed the requirements of a desired research. In the Laboratory of Extreme Loading (BEZ) was newly designed a measuring device which has undergone a process of validation by specifying measurement error. This process of validation was based on comparison the newly designed measuring device (measuring skates) with non-specific international standard dynamometer Kistler®. They were applied the basic methodologies for determining measurement errors for the construction of new measuring device. The result is the determination of experimental error of measuring device for two components of reaction force and point of action of the force on skate's blade. Experimental measurement device has a measurement error for F_t ± 8.6%, for F_o ± 10.6% and for point of action of the force x ± 8.4%.

Key words: measuring skates, validation of a measuring device, Kistler®, dynamometric

INTRODUCTION

Common practice in recent research is used the measuring device by several orders of magnitude more accurate than is required by practical applications of research. An example might be the use of Kistler force plates® to determine the difference between an impact force of athletes from various heights. In research plays an important role the order value in units of tens of Newton or more, while the Kistler force plate® is able to measure with an accuracy of 10^{-3} N with error below 1% (Creswell 1998; Hurkmans, Bussmann et al. 2006). The creation new specific equipment can not always ensure such accuracy in prototype that

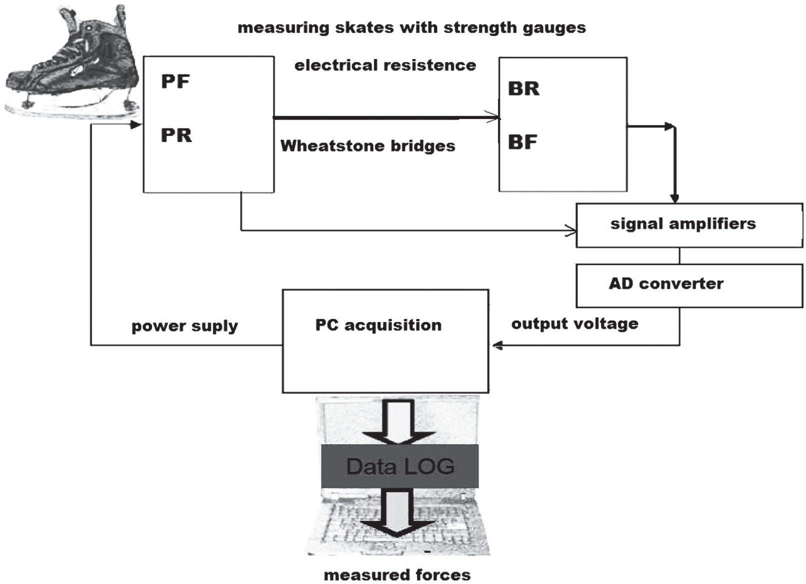

Figure 1. Scheme of measuring device – "measuring skates"

Legend:
PF = front beam load gauges, PR = back beam load gauges, BF = bend on front beam gau ges, BR = bend on rear beam gauges; The top left skate enter the voltage, which "gives" strain gauges in the unloaded state → load change the resistance in strain gauges and the output voltage. From amplifier and AD converter are pure data stored and processed in the acquisition software. The software stores data about the time change and the detected voltage (after conversion) (Šťastný, Kubový et al. 2010).

would far exceed the requirements of a desired research. In the BEZ laboratory it was newly designed a measuring device – "measuring skates" which have undergone a process of calibration (fig. 1). This measuring device was made from the Nike-Bauer Supreme skates 90 (left side only), four sets of gauges (four strain-gauge sensors 6/350DK11E HBM as one set), signal amplifiers (DEWETRON DAQP bridge B 0.1 mV/V), AD converter (NI-USD 6251–18bit) and the PC station with the evaluation software (Dewesoft original-software-DEWETRON). Strain gauges are connected to full bridges (see Figure 2), from which the signal passes through the AD converter to a PC station. Data was collected immediately in acquisition software.

Created measuring device was calibrated by standard dynamometr Kistler® (Šťastný, Kubový et al. 2010). Two components of loading forces were detected that are specifically monitored for a description of the GRF in ice hockey. Detected forces were loading force vector F_t and bending force vector F_o (Pearsall, Turcotte et al. 2000; Dewan 2004). Determination of the two forces also requires clarification of the reference system which is different from the commonly used Cartesian coordinate system.

In the Cartesian coordinate system is defined acting force as vector, which has space appearances and three on the perpendicular component F_x, F_y and F_z. The point of action of the force is defined by three space elements x, y, z, which determine the distance from the reference point 0 in the direction of spatial coordinates. The size of the vector can be computed according to the vector sum of the individual components of those forces (1).

$$\left|\vec{F}\right| = \sqrt{F_x^2 + F_y^2 + F_z^2} \tag{1}$$

Legend: = resultant force vector, F_x = force vector in space direction *x*, F_y = force vector in space direction y, F_z = force vector in space direction *z*

The resulting force vector F is not a practical description of bearing a skates and foot (Jelen 2006). It was therefore chosen a coordinate system, which aptly describes the interaction of foot-skates-surface. In this coordinate system were use the components F_y and F_z, where F_x and is neglected because it is the frictional force acting in the direction of the blade line and become a force to of very small values (coefficient of friction 0.003–0.007 (Bukač 2004)).

The used coordinate system defines the foot with skate as a homogeneous solid operating system to the ground (there is a reduction of interaction points between the foot and skates). The system of foot-skate is considered perfectly rigid body for calculations and neglects the possible distortion. In this system it can be argued that the load of skates matches the load of foot. Liaison axis to describe the load of foot is the sole of a skates. The actual interaction of skates and surface is happening on the skate blade. On the skate blade is well defined reference point 0 to describe the load-bearing force. Point zero is defined as the intersection of the coordinates *y*, *x*, *z* in Fig. 2. It is the intersection on the skate blade along the x axis

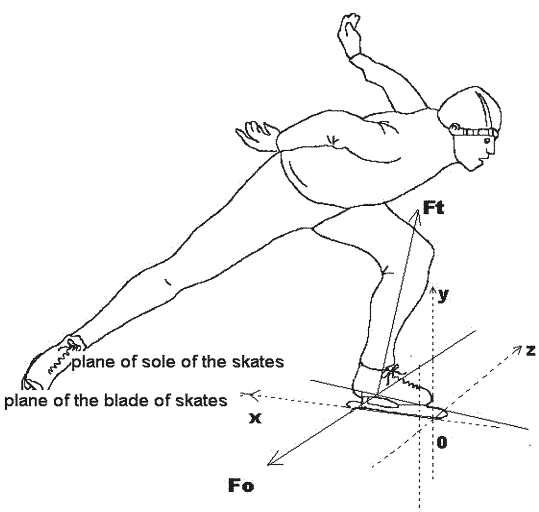

Figure 2. Coordinate system for description of the force components of the experimental measuring device

Legend:
F_t = pressure force component, F_o = bending force component, reference point **0** is on the skates blade bellow the front top of the skates. The shift the point of action of the force from point 0 towards the heel skates has a positive value, *x*, *y*, *z* are spatial coordinates of point.
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starting at the end of the tip of the skate. Taking the thickness of the knife is neglected. (Fig. 2). The z-axis is for reference point 0 defined as the interface of blade and ground (ice).

The task coordinate system does not allow a calculation of the resultant force vector, but finding just two basic components of interactive forces. Basic defined components were calibrated as loading force component F_t and bending force component F_o (Fig 2).

As the loading force F_t (Fig. 2) was defined the force perpendicular to sole of the skates boots. During skating the skates are changing the slope of the blade from "edge to edge" towards the ice. This is one of the reasons why it is necessary to measure the forces of the skates. Naming the loading force component comes from the fact that this component corresponds to the strength of forces that cause plantar pressure (Jelen 2007).

As a bending force F_o is defined a force component acting in the medio-lateral direction towards the sole of skate boots which corresponds to the force that acts perpendicular to the F_t. (see Fig. 2).

The point of action of the force 'x' was defined as the point on the spatial coordinate x, which is in contact with the ground between points 0 and the rear end of skate's blade (reference point 0 has value of 0 and the last point on rear of the blade has a value of 300 mm). The thickness of the blade due to its size (3 mm) was neglected. Point 0 is located under the front tip of the skate. The first well calibrated point is 40 mm from point 0, this is the first point, which is applied in F_t and reflected as pressure deformation, and not pull them under the front beam of skates. Point 260 mm (from 0) is the last item on the skate blade, where the compressive deformation F_t reflected beam skates and not pulling.

METHODS

The validity of measurements using an experimental measuring device – "measuring skates" was intended in the process of validation by identifying measurement errors. Determination of errors of measurement were performed by comparisons of measurement results from measuring skates (F_{skates}) and output from a standard dynamometer Kistler® – 9281 ($F_{kistler}$). It was determined the mean absolute (2) deviation – Δ in measurements and the average relative deviation errors – δ (3). The curves of the two measuring devices were determined by correlation coefficient r_{bk} (4) (Pearson correlation coefficient). Kistler dynamometer® – 9281 is considered as the "gold standard" for measuring GRF, so the data from the dynamometer Kistler® were considered with measurement error of zero (Creswell 1998).

$$\overline{\Delta} = \sqrt{\frac{\Sigma\left(F_{skates} - F_{kistler}\right)^2}{n}} \tag{2}$$

$$\overline{\delta} = \sqrt{\frac{\Sigma \frac{\left|F_{skates} - F_{kistler}\right|}{\left|F_{skates}\right|}}{n}} \cdot 100 \tag{3}$$

$$r_{bk} = \frac{Kov_{bk}}{S_b S_k} \tag{4}$$

Legend:
Δ = average of mean deviation, δ = average of relative deviation, F_{skates} = force measured by measuring skates, later as F_t or F_o, $F_{kistler}$ = force measured by dynamometr Kistler- also as F_z. r_{bk} = correlation coefficient of value from measuring skates and dynamometr Kistler. Kov_{bk} = covariation of inputs measured by measuring skates and dynamometer Kistler. S_b = standard deviation from measuring skates, S_k = standard deviation measured by dynamometer Kistler.
Significant correlation coefficient was considered for validation of the value $\boldsymbol{r_{bk} > 0.9}$ (Stergiou 2004). Kistler dynamometer ® – 9281 was used due to the high accuracy for both calibration and for validation. This type of device has a precision of the order of 10-3 higher than is the requirement for measurement done by constructed skates (Creswell 1998).

RESULTS

Validation was done by dynamometer Kistler® – 9281. Strain gauges were connected to the skate and the recording took place in the software Dewetron®. Measurement was performed while recording both the dynamometer (Kistler®) and measuring skates. For validation F_t and point of action of the force player stepped always on the heel of skate blades and then move the body forward, so that gradually load the entire length of the skate blade. This "swing" was repeated three times for 10 measurements and was repeated with an interval of 14 days.

Sample part of the validation measurement shows the figure 3. The F_t has been validated for measuring range 10–1000 N, a sample graph showing only part of this validation. In quantitative values was find out an absolute deviation average of measurement Δ = 18.6 N and the relative average measurement error δ = 8.6%. The correlation coefficient was r_{bk} = 0.96, indicating a very precise match between the two curves, which is evident from Figure 3. The dependence of F_t on the system Dewetron F_z from dynamometer Kistler ® shows Fig 4.

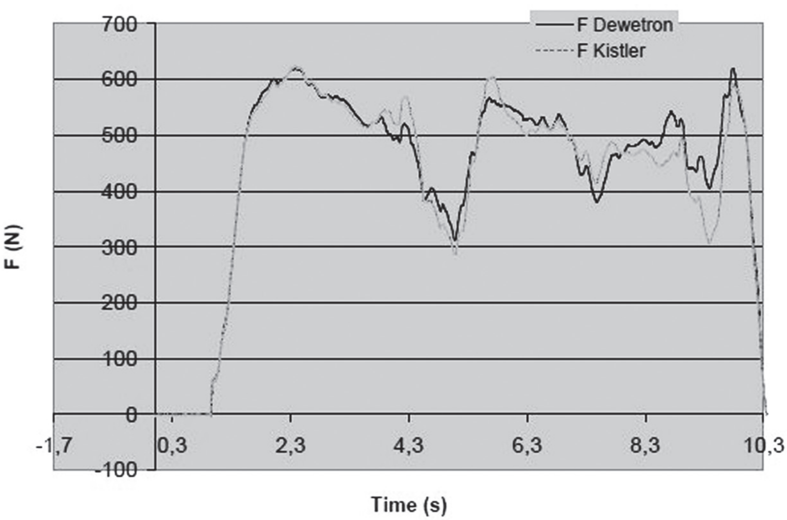

Figure 3. Comparison F_t with a record from force plate

Legend:
Axis y – F_t = force (N), Axis x – time (s)

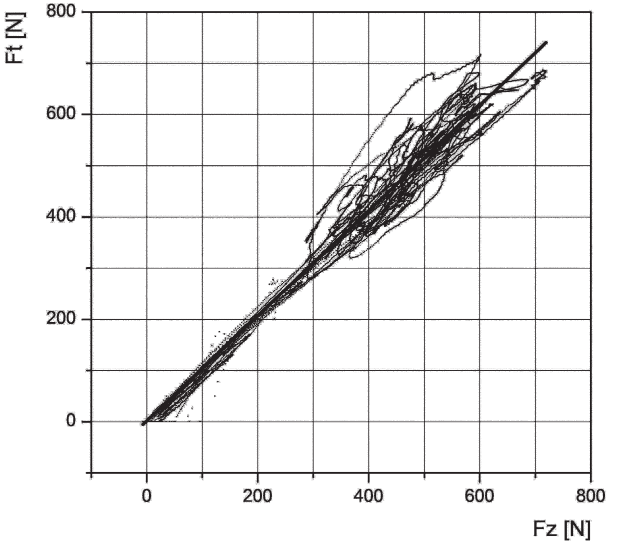

Figure 4. The dependance F_t from mesuring skate to F_z from dynamometer Kistler®

Legend:
The graph shows the dependence of data measured by "measuring skates" and evaluated by system Dewetron on data F_z measured by Kistler dynamometer. F_t = force measured by measuring skates.

The outputs recorded during the validation of F_t were also used to validate the point of action of the force on skate blade x. Figure 5 shows a selected sample of validated curve. Absolute deviation (Δ) was calculated as the difference between the measured values the point of action of the force "x" from measuring skates and point of action of the force measured on the dynamometer at the same time – "$x_{kistler}$" (5). The relative deviation (δ) was calculated as the percentage difference from measuring skates-x and "$x_{kistler}$" from standardized dynamometer (6), while $x_{kistler}$ was regarded as 100%. For orientation was calculated the correlation coefficient (r_{bk}), to quantitatively verify the sameness of the measured curves as recommended by Stergiou (Stergiou 2004).

$$\overline{\Delta} = \sqrt{\frac{\Sigma\left(x - x_{kistler}\right)^2}{n}} \tag{5}$$

$$\overline{\delta} = \frac{\Sigma \frac{\left|x - x_{kistler}\right|}{\left|x\right|}}{n} \cdot 100 \tag{6}$$

Legend:
= absolute measurement deviation, F_t = output from measuring skates, $x_{kistler}$ = output from dynamometer Kistler®, n = number of records = relative deviation.

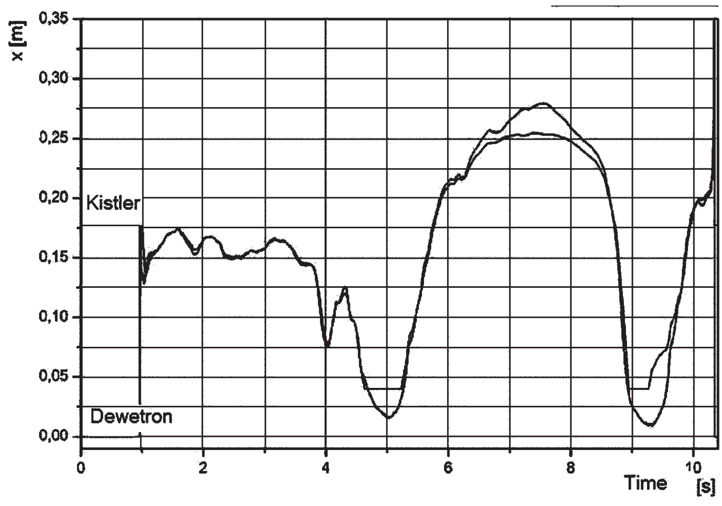

Figure 5. Comparison of record the point of action of the force x with dynamometer Kistler®

Legend:
Axis y – point of action of the force, Axis x – time (s). During loading has been shown, that if loading is out of calibrated device, the measuring skates does not show any output. After loading back into calibrated area is output close to reference measurement from Kistler.

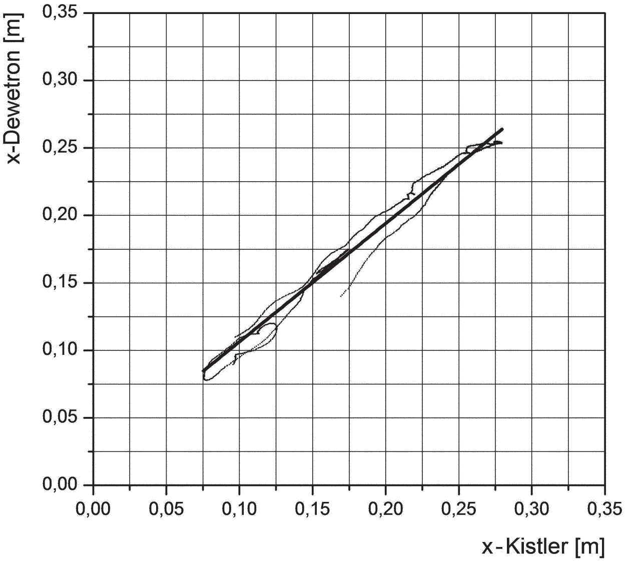

Figure 6. The dependence of point of action of the force x from measuring skate on point of action of the force from dynamometer Kistler®

Legend:
The graph shows the dependence of the measured data by "measuring skates" and evaluated by system Dewetron x to output measured by dynamometer Kistler – *x*. Dewetron = point of action of the force x from "measuring skates". *x* – Kistler = point of action of the force x measured by dynamometer Kistler.

Validation showed an average absolute deviation of measurement = 2.1 mm and average relative measurement error δ = 8.4%. Correlation coefficient of x to "$x_{kistler}$" was $r_{bk} = 0.95$, indicating a very precise match during the two curves, which is evident from Figure 5.

Fig. 5 also shows that if the loading is outside the calibrated region, measuring skates signal is not evaluated. After the "return" to a calibrated area on skate blade is signal output again evaluated by measuring skate. During the validation of x it was necessary to recalculate the values to compare measured on a dynamometer Kistler on the same axis. Dependence of load-x system Dewetron to the load on dynamometer Kistler ® – x is illustrated in Fig. 6.

For validation F_o was conducted a movement "carry weight" from the right inside to left outer side. This corresponds to translating skates from edge to edge during real skating. This "transfer" was repeated three times in ten items, and measurements were repeated with an interval of 14 days. Sample portion of the validation graph shows the Fig. 7, when F_o has been validated for measuring range 2–500N, the sample graph is only part of this validation.

Validation of F_o show an absolute deviation of measurement Δ = 9.3 N and the relative deviation of measurement δ = 10.6%, the correlation coefficient $r_{bk} = 0.98$, indicating a high compliance of measured curves. The dependence of the system Dewetron $\boldsymbol{F_o}$ on the dynamometer Kistler® F_z shows Figure 8. Fig. 7 shows one of Validated measurements. F_o measurement error is relatively higher in value approaching the value of 0.

Based on the precision of measurements are values from "measuring skating" treated as valid within the specified measurement error. Values and the time course of forces correspond to the same record simultaneously scanned with standardized dynamometer.

It has been shown that the validation test detects force acting on skates for F_t, F_o and for point of action of the force on a skate's blade. Measurements and measuring skates are valid within the measurement errors.

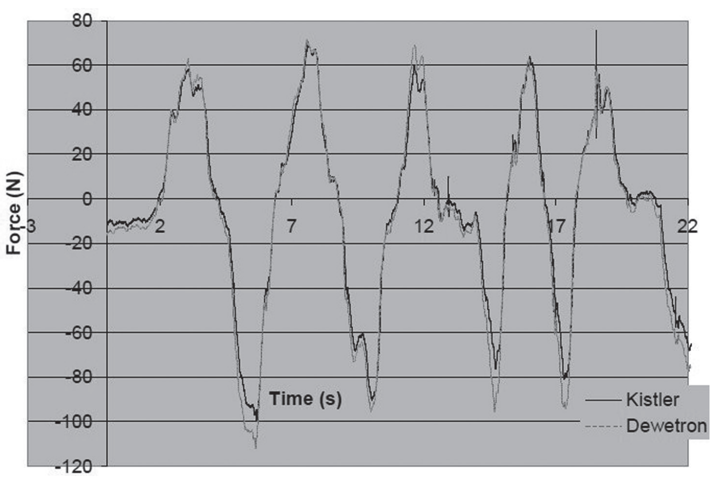

Figure 7. Comparation F_o with record from force plate

Legend:
Axis y – F_o v (N), Axis x – time (s), Measured movement is carry weigth from right to left side on skates blade.

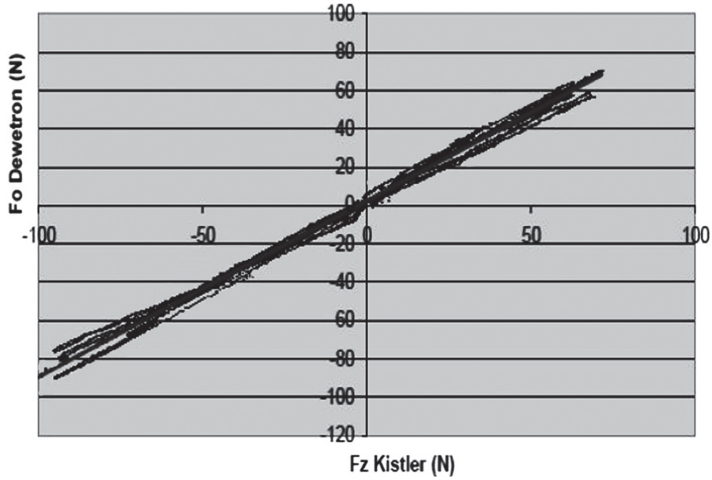

Figure 8. The dependance F_o from measuring skates to F_z from dynamometer Kistler®

Legend:
The graph shows the dependence of data measured by "measuring skates" and evaluated by system Dewetron on data F_z measured by Kistler dynamometer. F_o = force measured by measuring skates. F_z = force measured by Kistler dynamomete

The accuracy of measurement skates is**:**

For $\boldsymbol{F_t}$ **± 8.6%** on the measuring range **10–1000 N**
For ***x*** **± 8.4%** on the measuring range **10–1000 N** in calibrated part of blade
For $\boldsymbol{F_o}$ **± 10.6%** on the measuring range **2–500 N**

This validated measuring device was patented as a utility model of the Industrial Property Office under number 22051 st After successful validation of this device it can be used as an experimental measuring device with regard to measurement error.

DISCUSSION

During the measurement we have to regard the limits within we can consider the outputs of measurement accurate. When measurement error is 8.6%, 8.4% or 10.6% of the specified measurement can not be considered valid results in order of 1N, but rather in the order of 10 N. To measure is necessary to choose studies that require this measurement accuracy. The difference of 10 N could mean in real movement a difference in the evaluation of one kilogram of total GRF at a standstill. Therefore it can be considered accurate enough to detect and evaluate a push off, impact or braking movements in real.

Beside validation is also necessary to mention the deviation of qualitative evaluation of the used elements. In the above-mentioned case, the use of strain gauges brings potential measurement error. The possible errors are:

1 – effect of temperature differences on detection using strain gauges
2 – resolution whether the detection of tension or pressure
3 – calibration method of detection elements

Effect of temperature differences were resolved by using strain gauges with thermal compensation, which is supported by "resetting" the resistor values before each measurement. Resolution, whether the detection of tension or pressure, it is important to select a demonstrative move for validation as well as to calibrate the required components of forces. The validation is necessary to choose the most realistic movement that embraces the extreme values required for the function of skates. In case of skating it was measuring the movement in which we can easily reach the limits of measured loading forces.

Regarding the choice of statistical methods for determining measurement errors, it is necessary to choose the methods that describe the maximum value of the difference between new and already validated device. To determine the timing of measurement of compliance is appropriate to use contrast correlation coefficient, its value must be close to 1. It is also necessary to display a graph on which is possible to see whether the validated device shows values higher or lower to the reference device.

CONCLUSSION

They were applied the basic methodologies for determining a measurement errors for the construction of new measuring equipment. The result is the determination of experimental error of measuring device calibrated for the two components of force and point of action of the force on skate's blade. Experimental measurement device has a measurement error for F_t ± 8.6%, for F_o ± 10.6% and point of action of the force on skate blades x ± 8.4%. The measurement error is poorly presented by this deviation, but for the research is necessary to count with a random error, which is usually expressed in standard deviation of individual measurements.

LIST OF ABBREVIATIONS

$\sum$	sum
$\bar{\delta}$	average of relative deviation
$\bar{\Delta}$	average of absolute deviation
BEZ	Laboratory of Biomechanic of Extreme Loading
BF	bend front, strain gauges detecting the bend force on front beam
BR	bend rear, strain gauges detecting the bend force on rear beam
F	force
F_t	loading force vector
F_o	bending force vector
F_z	vertical force vector
F_x	horizontal force vector
$F_{kistler}$	force detected by dynamometer Kistler – in general

F_{brusle}	force detected by measuring skates – in general
GRF	ground reaction forces
PF	pressure front strain gauges
PR	pressure rear strain gauges
R	reaction force
r	correlation coefficient
r_{bk}	correlation coefficient for output from measuring skates and dynamometer x point of action of the force

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METODY VALIDIZACE EXPERIMENTÁLNÍHO MĚŘÍCÍHO ZAŘÍZENÍ PRO MĚŘENÍ REAKČNÍCH SIL PODLOŽKY BĚHEM BRUSLENÍ V LEDNÍM HOKEJI

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SOUHRN

Reliabilita a validita přístrojových zařízení používaných v kinantropologickém výzkumu je zpravidla určena chybou jejich měření. V současnosti je velmi běžné používat přístrojová zařízení o několik řádů přesnějších, nežli vyžaduje praktická aplikace výzkumu. Moderním trendem je však i individualizace a tvorba nových

specifických měřících zařízeních, které před použitím ve výzkumu vyžadují vlastní proces validace (Stergiou 2004). Pokud jde o tvorbu nových specifických zařízení, nelze vždy hned u prototypů zajistit takovou přesnost měření, která by řádově přesahovala požadavky chtěného výzkumu. V laboratoři BEZ bylo nově konstruováno měřící zařízení, které prošlo procesem validizace určením chyby měření nového zařízení. Tento proces validizace spočíval ve srovnání nově konstruovaného měřícího zařízení (měřící brusle) s nespecifickým mezinárodně standardizovaným zařízením dynamometrem Kistler®. V práci byli uplatněny základní metodické postupy pro určení chyby měření po konstrukci nového měřícího zařízení. Výsledkem je určení chyby měřící experimentálního zařízení pro dvě kalibrované složky síly a působiště síly na noži brusle. Experimentální měřící zařízení má chybu měření $F_t \pm 8{,}6\,\%$, $F_o \pm 10{,}6\,\%$ a působiště síly na noži brusle $x \pm 8{,}4\%$.

Klíčová slova: měřící brusle, Kistler®, validace měřícího zařízení, dynamometrie

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