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FURNITURE IMPACT RESISTANCE TESTING DEVICE

Key words

Prototype testing, furniture testing, horizontal impact, PLC controller.

Summary

The article presents the design of an innovative MU-M/D device for testing furniture horizontal impact resistance. It is a development and adaptation to consumers' needs of the standardised device used for executing horizontal impacts, designed within a Strategic Programme task titled: „Testing and certification devices in furniture and construction materials industries”. During the construction phase of the device, a positively verified author's original concept of designing testing equipment, along with construction modules, was implemented. The designed modules enable the implementation of testing equipment covering approx. 90% of the furniture testing regulations. A concept of designing the measurement-control system using a PLC controller has also been validated. The testing of the prototype was conducted.

Introduction

Furniture impact resistance testing is conducted in accordance with standards [2–7], among others. The procedure consists of an impactor hitting a vertically positioned piece of material or product repeatedly. The materials used may be vertical surfaces of furniture, children cribs' rungs, chairs, gypsum plasterboard, particleboard, framed glass panels in windows or doors etc. The impactor is installed on a pendulum in a bearing mount so that it can move freely and the impact occurs horizontally. It is a modification of a popular impact hammer test method.

The impactor's mass and dimensions are described in relevant standards. Two kinds of impactors are used:

1. 2 kg, 300 mm long – according to standards [2, 4, 5] e.g. to simulate a child kicking the crib's rung,
2. 6.4 kg, 1 m long – according to standards [3, 6, 7].

The standards mentioned describe the following: angle or height of the impactor's elevation, the impact's location, number of impacts, mass, and impactor arm's length. Up to now, the testing has been performed manually and included increasing the angle of fall. The assumption was that, if a piece of furniture can withstand a higher energy impact, it could easily withstand a standardised impact. This testing is tedious, time-consuming and requires substantial strength to lift a bigger impactor.

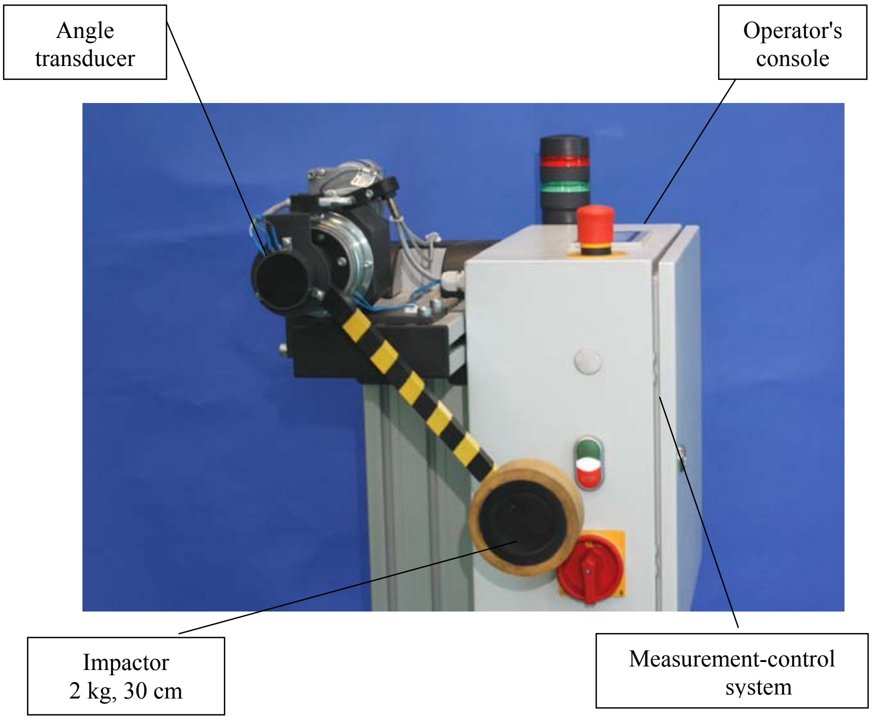

Fig. 1. A model of a device for horizontal impacts with a 2 kg impactor

A standardised device for automation of the testing procedure was designed within the framework of the Strategic Programme (Fig. 1).

1. The design principles of the device for testing furniture impact resistance

A kinematic plan for furniture impact resistance testing device was created (Fig. 2) A motor (M) with an electric clutch (Es) raises the impactor (B.) After achieving the desired angle, the clutch is released. The device therefore consists of an impactor-raising unit and a control-testing unit.

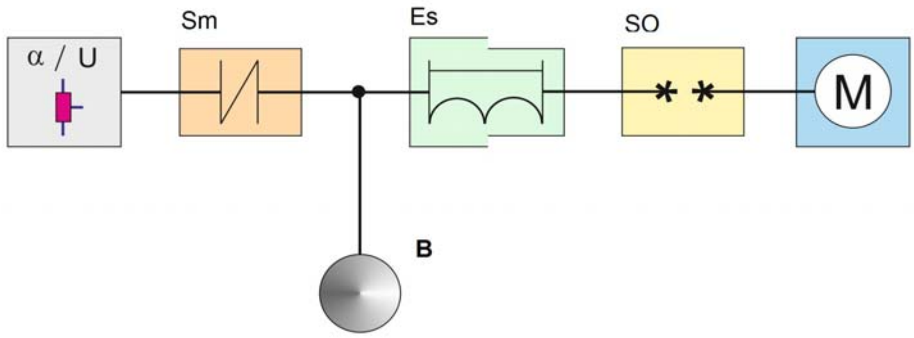

Fig. 2. Kinematic plan of furniture impact resistance testing device B – impactor, α/U – potentiometric sensor of the impactor's rotation angle, Sm – bellow clutch, Es – electric clutch, SO – Oldham clutch, M – DC motor

The following design principles were adopted and implemented in the standardised and newly designed device.

1. The only requirement from the user of the new design was the ability to adjust it to lift two impactors, 100 cm long and weighing 6.4 kg as well as 30 cm long and weighing 2 kg, along with the ability to quickly install it on a 48.3 mm pipe frame (the customer has a support frame to install the device.)
2. An advanced PLC controller with WebServer installed was utilised in the measurement-control system. The basic CPU model is equipped with 4 24VDC transistor outputs and 8 24VDC inputs, as well as with a RJ45 output and USB 2.0. Inputting the testing parameters was done via a touch panel. The goal was to limit the cost of the control system while maintaining its functionality.
3. A 24VDC commutator electric motor with transmission was used to lift the impactor. A 74 Nm, 6.5 rpm motor was selected. The motor is equipped with a set of interference-dampening filters. A PWM controller was equipped to adjust the rotation speed. The speed is controlled by a potentiometer, because of the assumption that, due to the cost of the device, there will be no analogue output in the PLC controller. It was assumed that the motor would

rotate only in one direction that will limit the number of output signal of the PLC controller – one „Start/Stop DC motor" transistor output.

4. The clutch is installed on the DC motor's shaft; its casing rotates once the motor is engaged. A proper 24 VDC clutch was selected with an appropriate holding torque.
5. It was assumed that a potentiometric rotation angle sensor would be utilised to measure the angle. A 0.01°, hysteresis <15 transducer was selected ″ with a linearity <0.5% of the measuring range. An appropriate, 50,000 bit resolution, analogue input module was selected for this transducer.
6. Three separate power supplies were utilised for (1) electric clutch, (2) DC motor and (3) PLC controller, operator's panel and angle transducer. The electric clutch, motor (with the PWM regulator) and PLC controller (CPU with an analogue input module, the operator's panel and angle sensor) cables are galvanically isolated. Such a solution eliminates cross--interference of high-current motor and electric clutch cables witch the PLC controller.
7. Thanks to universal switched-mode power supplies, the device can operate in 100–240 VAC, 50/60 Hz ranges. It is possible to use power supplies operating on AC or DC currents.
8. An induction sensor was installed to prevent the impactor from being raised too high in order to protect the mechanical system.
9. The device is a piece of laboratory equipment; therefore, the impactor's raising module is equipped with sockets allowing easy mounting in different positions.
10. Because only two binary outputs were used, a two-colour signal column was implemented to indicate the device's state. A blinking red light indicates alarm; still green – finished testing or current being present, blinking green - device's operation.
11. An EMC filter was installed on the device's input in addition to the anti-interference DC filters. The device passed the electromagnetic compatibility test performed in the certified ITeE – PIB laboratory.

The MU-M/D (Fig. 3) furniture impact resistance testing device was constructed as a „device designed and constructed specifically for research purposes; for use in laboratories (art. 2h of the Machinery Directive) [1]. That is why the device has no casing and is installed on a pipe scaffold in the place of testing.

Tables 1 and 2 show the impactor's speed and corresponding its kinetic energy. The device is dangerous if it impacts a human body (airsoft guns with projectile kinetic energy under 17 j cause serious injuries [8, 9], and buying an airsoft gun with projectile energy exceeding 17 J requires a permission).

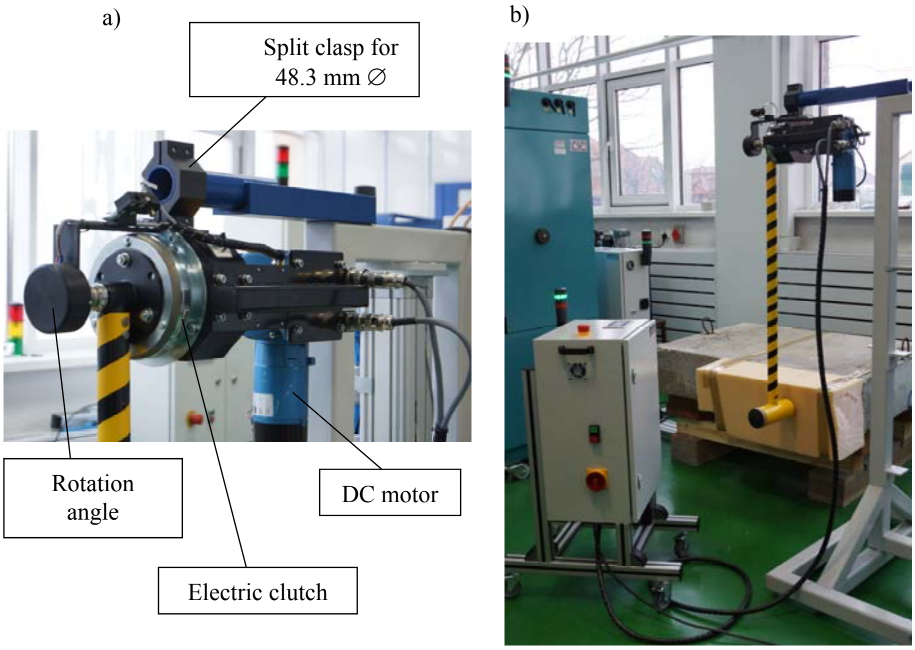

Fig. 3. The MU-M/D furniture impact resistance testing device: a) impactor's raising system with the option to install 30 and 100 cm impactors, b) measurement-control system and impactor's raising system on a prototype testing station

Table 1. 2 kg impactor's speed and kinetic energy

2 kg, 300 mm impactor		
Yaw angle of the impactor [°]	Impact speed of the impactor [m/s]	Kinetic energy of the impactor [J]
30°	0.89	0.79
60°	1.72	2.94
90°	2.43	5.89

Table 2. 6.4 kg impactor's speed and kinetic energy

6.4 kg, 1 m impactor		
Yaw angle of the impactor [°]	Impact speed of the impactor [m/s]	Kinetic energy of the impactor [J]
30°	1.62	8.41
60°	3.13	31.39
90°	4.43	62.78

The design of the furniture impact resistance-testing device ensures repeatability of each impact and automates the testing procedure. It is an innovative device in furniture testing area.

2. Innovative solutions of the measurement-control system

The innovative character of the device is the result of implementing the measurement-control system with a PLC controller and a touch panel. The exchange of information between the device and its operator can be done via the panel or dedicated software.

The following angles were pre-defined to automate the testing procedure (Fig. 4):

1. Neutral position is determined when the impactor hangs freely. Positive angle values are those in the direction of the impactor being raised. Negative angle values are those behind the tested object.
2. Angle α is the current angular position of the impactor.
3. Angle ε determines the precision of the impactor's neutral position.
   For practical purposes, when the impactor touches the tested object, the neutral position is described as $\alpha \in <-\varepsilon, +\varepsilon>$. Software-wise the range check is done using a macro-instruction ICMP>=PLC controller's software [10]. The impactor's neutral position, according to assumed precision, is its starting position while being raised.
4. Angle δ, the angle of destruction, is the negative value angle. Exceeding the angle α below the value of δ is considered as the destruction of the object tested.
5. Angle α_1 and α_2 are the first and second bounce angles from the tested object. This is an additional piece of information that can be read from the measurement-control system. Angles α_1 and α_2 are not defined in relevant regulation.

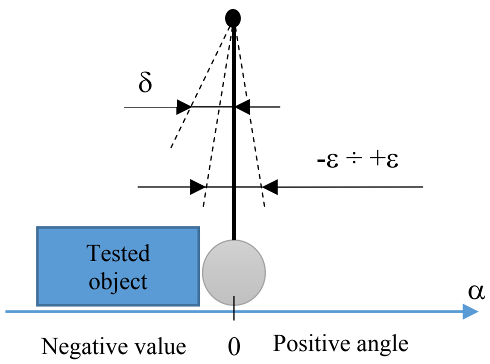

Fig. 4. The method of defining the angles of α – impactor's position, ε precision of neutral position, δ – destruction angle

The angles ε and δ are set using the operator's panel (Fig. 5). The impacts' repetition time T[s] is also set on this screen. An angle reset button was also installed α along with an on/off button for detecting the destruction of the element.

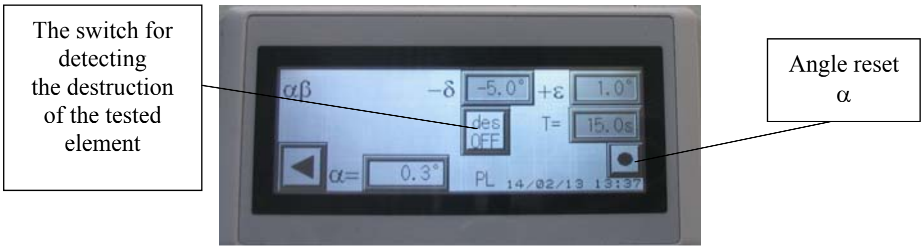

Fig. 5. Operator's panel – angle-defining screen: α – impactor's position, ε – neutral position precision, δ – destruction angle

When the destruction detection switch is on, meeting parameter $\alpha<\delta$ causes the device to stop. The need for resetting neutral position α arises when it is difficult to position the impactor near the tested object (Fig. 4) or if the impactor raising system's mounting is imperfect (Fig. 3a). Upon clicking the reset button, the value $\alpha = 0.3°$ changes into $\alpha = 0.0°$.

Advanced programming options of the PLC controller allow the following:

1. Setting the number of impacts in the range of 1–999, 10 being the default value.
2. Setting the frequency of the impacts by determining the cycle time (Fig. 5).
3. Setting the impactor's lift angle in the range of 0.0°–90.0°.
4. Determining the conditions of aborting the test: e.g. aforementioned destruction of the tested object, i.e. exceeding the default position by a particular value.

The design of the furniture impact resistance-testing machine ensures repeatability of each impact and automates the testing procedure. It is an innovative device in furniture testing area.

3. Calibration method of the impactor position angle measurement track

After assembling the impactor raising system in a new testing location, it is necessary to reset the impactor's angle α, as described in the previous paragraph.

In case of dismounting the impactor rotation angle sensor or bellow clutch or the electromagnetic clutch, it is necessary to calibrate the impactor position angle measurement track. The entire track is calibrated, including the potentiometer sensor's power supply, the potentiometric sensor itself, PLC's analogue-digital converter, and recalculating procedures in the controller.

Fig. 6. Angle measurement track calibration screen α

The calibration procedure is stored as a program in the PLC controller and a screen on the operator's panel (Fig. 6). The calibration is performed for –120°, –90°, 0°, +90° and +120° angles. The impactor's position angle measurement track's calibration procedure α is as follows:

k1. Primary mapping is selected using a button on the right bottom corner of the screen. Then:

$$0\text{–}10V \leftrightarrow \mathbf{Y} = 0.0°\text{–}360.0° \leftrightarrow \alpha = -180.0°\text{–}+180.0°.$$

k2. Click 0° for the impactor's loose position. Install an electronic inclinometer with a resolution ±0.1° and raise the impactor so that it reaches –120°, –90°, +90° and +120° angles. When the reading from the inclinometer stabilises, click corresponding buttons on the operator's panel. The result is the X set with corresponding angles from the set {–120°, –90°, 0°, +90° and 120°} and two fixed points:

$$-180° \leftrightarrow 0.0° \text{ and } +180.0° \leftrightarrow +360°.$$

k3. XYFS macro instruction to define the linear-segment approximation's characteristic in 7 set points (max 32 points):

$$\mathbf{X}\ \{-180°,-120°, -90°, 0°, +90°, +120°\} \leftrightarrow 0.0°\text{–}360.0° = \mathbf{Y}.$$

k4. CYTX macro-instruction, based on that characteristic, allows automatic conversion of measured value **Y**→**X**.

Next graph (Fig. 7) shows primary mapping and the calibration performed. Other inclinations and displacements of the graph are visible in (0, 180) of the calibration procedure performed of the entire angle measurement track α.

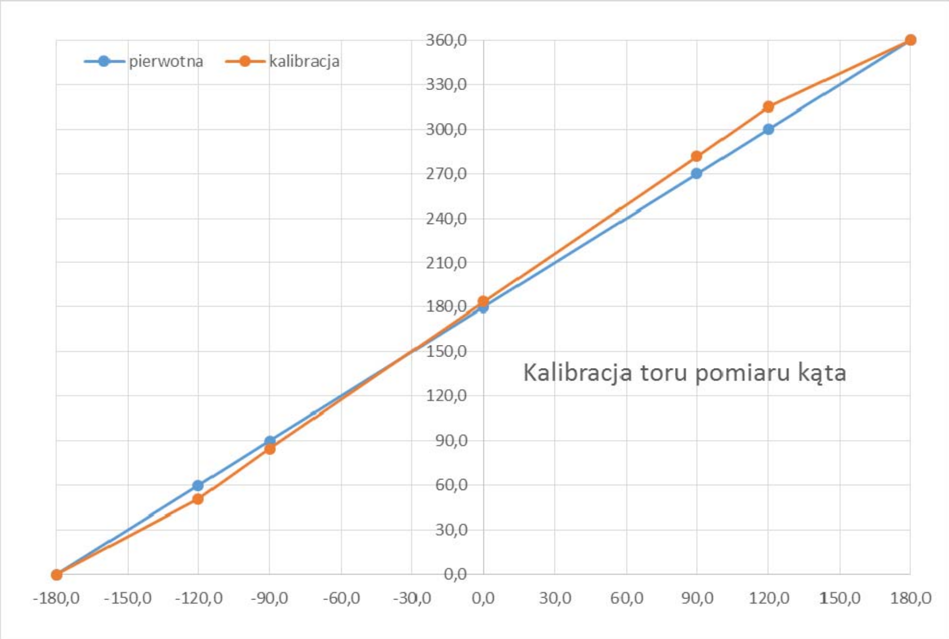

Fig. 7. Angle measurement track calibration graph α for data from Fig. 6

4. Prototype testing of the furniture impact resistance-testing device

Testing was performed of the device's prototype to evaluate mechanical design and the design of the control-measurement system's design along with DC motor and electric clutch's performance an

It was noted that, during the impactor being raised, the clutch slipped and blocked. The holding power of the electric clutch was increased, along with the impactor's mounting on the clutch disk.

During the 100 cm, 6.4 kg impactor's release, it was noted that the board on which the DC motor and electric clutch are installed bends. This is due to the device's reaction to the conservation of angular momentum principle and high moment of force being present. The problem was solved (limited) by decreasing the impactor's raising speed and by reinforcing the board by welding additional square sections (Fig. 3a).

Prolonged testing was conducted consisting of 3000 impactor's hits (Fig. 3b). The impactor's raising module was dismantled. No wear of the device's elements was noted. No overheating of the DC motor or the electric clutch was noted. The DC motor and electric clutch currents were measured while raising the impactor at the beginning and the end of the test, and no increase in current was observed.

As a part of measurement-control system analysis, inerasable counters were implemented (inaccessible to the user) as follows:

- Total operating time (up to approx. 160 years);
- DC motor operating time;
- Electric clutch operating time;
- Number of impactor hits;
- Total alarm count;
- Destruction alarm count;
- Impactor position measurement analogue track alarm count; and,
- Number of instances when the DC motor enables during the impactor's movement, which is undesirable for the device's mechanical system.

The counters implemented are a source of information to the manufacturer about the device's wear and an indication of proper operation and maintenance.

Summary

The furniture impact resistance-testing device ensures repeatability of each impact and automates the testing procedure by setting the impactor's angle, the number of hits, and the time intervals. It is an innovative device in furniture testing. It allows installing two kinds of impactors and determining two parameters not taken into account up to now: the impactor's bounce angle and determining the material's destruction by setting the impactor's penetration angle into the material.

Optional software makes it possible to control the device remotely via USB or RJ45 and receive emails reporting the testing progress.

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Urządzenie do badania udarności mebli

Słowa kluczowe

Badanie prototypu, badanie mebli, uderzenia poziome, sterownik PLC.

Streszczenie

W artykule przedstawiono konstrukcję innowacyjnego urządzenia do badania udarności mebli typ MU-M/D na uderzenia poziome. Jest ono rozwinięciem i dostosowaniem do wymagań odbiorcy modelowego urządzania do realizacji uderzeń poziomych wykonanego w ramach Programu Strategicznego zadania pt. „Urządzenia do badań testowych i certyfikacyjnych w przemyśle meblarskim i materiałów budowlanych”. Podczas wykonywania tego urządzenia poprawnie zweryfikowano przyjętą autorską koncepcję budowy urządzeń do badań testowych z opracowanych modułów konstrukcyjnych. Opracowane moduły konstrukcyjne pozwalają na realizację urządzeń testowych obejmujących ok. 90% norm dotyczących badania mebli. Potwierdziła się również koncepcja budowy systemu pomiarowo-sterującego z zastosowaniem sterownika PLC. Przeprowadzono badanie wykonanego prototypu urządzenia.