# INNOVATION OF CAR SEAT TESTING DEVICE WITH THREE AXES OF LOADING

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This work was supported by the Ministry of Education, Youth and Sports of the Czech Republic and the European Union - European Structural and Investment Funds in the frames of Operational Programme Research, Development and Education - project Hybrid Materials for Hierarchical Structures (HyHi, Reg. No.CZ.02.1.01/0.0/0.0/16_019/0000843).

Abstract: The comfort of a car seat depends on many parameters of the seat and the characteristics of the people sitting on it. The paper deals with the innovation of a measuring device for testing car seats in laboratory conditions. The device now makes possibility to realize the vertical movement of the car seat and both the horizontal movement in two directions front-rear and left-right. The vertical movement can realized separately or simultaneously with the horizontal movements. Dependent or independent excitation in all three axes perform laboratory testing automobile seats same as when driving a real car. The advantage of laboratory testing is very good repeatability of tests. Long-term durability tests also should be performed in laboratory conditions in a 24-hour testing mode.

Keywords: car seat, multi-testing, multi-axis loading, measurement methodologies, standards

## 1 Introduction

Testing of car seats in real and laboratory conditions is performed according to relevant standards. These standards are numerous and each corresponds to a specific mode loads a car seat in the car. The comfort of the seat and also the degree of fatigue after driving the car depend on the interaction of the car seat with the human body at the point of contact. Testing of car seats in laboratory conditions requires strict compliance with the prescribed standards, i.e. the subsequent implementation of measured signals in real operation in laboratory conditions, such as simultaneous multi-axis loading.

Therefore, the test equipment must be increasingly sophisticated, allowing load signals to be implemented in all axes independently but also simultaneously. The possibility of performing and comparing tests in the laboratory and in real operation and their uniform evaluation depends on the correct performance of laboratory tests according to the measured signals in the car during real operation. The laboratory equipment, which will enable the loading of the car seat in three axes and will meet the requirements of currently valid standards as [1-4] for the assessment of their properties, will allow their adequate testing in laboratory conditions and also the possibility of comparing measurements from different laboratories.

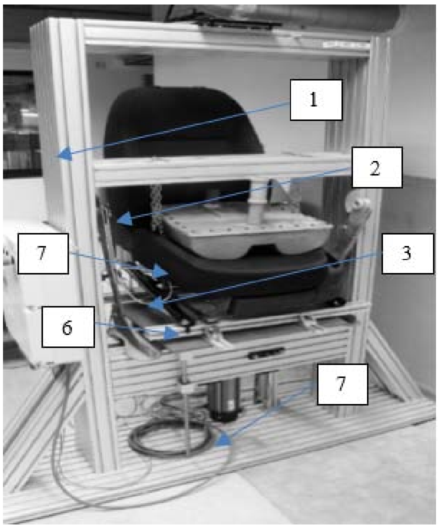


Figure 1 Old testing device

Measurements can be performed in certified laboratories according to a precisely given methodology and the measurement results can be mutually respected. The existing test equipment [5] (Fig. 1, where: Position of fig. 1: 1. Big frame, 2. Small frame, 3. Base frame, 4. Horizontal platform, 5. Vertical actuator, 6. Horizontal actuator, 7. Load) only complied with the standards prescribing the biaxial loading of the car seat, i.e. the vertical load in the “z” axis and the horizontal loading in front of the rear in the “x” axis. Evolution of a dynamic seat test standard proposal for a better protection after rear-end impact describes [6], experimental test-bench development using force control with industrial robots for the analysis of the mechanical response in car seats is described in [7]. Hydraulic stand for testing automatic seats model development [8], laboratory tests of a car seat suspension system equipped with an electrically controlled damper [9], compact system for measuring vibration at different locations of car seat and human driver in dynamic condition [10] provide relevant car seat tests, loading in three axes is demanded.   The aim of this paper is to describe the innovative car seat testing device with three axes of loading.

## 2 Materials and Methods

### 2.1 Hexapod Control

The effect of mechanical vibrations in the car cabin on the driver and passengers is always multiple, therefore it is necessary to reproduce the same load signals during laboratory testing. For the realization of general movement in space, it is suitable to use a device with 6 degrees of freedom, the so-called hexapod [11] (Fig. 2).

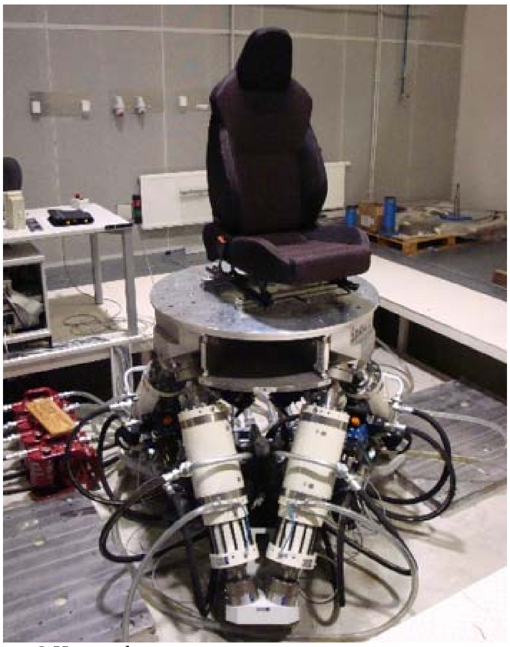

Figure 2 Hexapod

General spatial motion can be realized by means of 6 linear drives, i.e. 3 movements in the x, z, y axes and 3 rotations around these axes. The linear motion of the individual hydraulic motors logically gives the sum the general spatial motion. If we know the course of the movement of at least 2 points in space, it is possible to obtain the necessary linear movements of drives by mathematical transformations, but also based on knowledge of linear movements of drives we can realize the general movement of 2 points in space. The aim of verifying this theory was to measure the general real movements of 2 points in space (in the cab of a car), and their trans-formation into linear movements of drives. Use these linear motions to reproduce back the general real motion of 2 points in space. If this movement can be realized, we can say that laboratory tests fully correspond to real ones and can fully replace them.

The general spatial movement of the hexapod can be realized by means of 6 linear drives, i.e. 3 movements in the x, y, z axes (Fig. 3), equations (1), (2), (3).

$$\overrightarrow{B(t)} = \overrightarrow{A(t)} + \overrightarrow{AB(t)} \tag{1}$$

$$\overrightarrow{\begin{pmatrix} X_B \\ Y_B \\ Z_B \end{pmatrix}(t)} = \overrightarrow{\begin{pmatrix} X_A \\ Y_A \\ Z_A \end{pmatrix}(t)} + \overrightarrow{\begin{pmatrix} X_{AB} \\ Y_{AB} \\ Z_{AB} \end{pmatrix}(t)} \tag{2}$$

$$\overrightarrow{\begin{pmatrix} X_{AB} \\ Y_{AB} \\ Z_{AB} \end{pmatrix}(t)} = \begin{pmatrix} X_{AB} \\ Y_{AB} \\ Z_{AB} \end{pmatrix} . \overrightarrow{\begin{pmatrix} \omega x_{AB} \\ \omega y_{AB} \\ \omega z_{AB} \end{pmatrix}(t)} \tag{3}$$

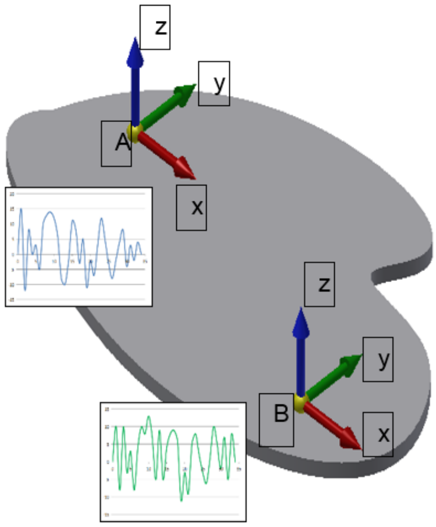


Figure 3 Model of movement

The linear motion of the individual hydraulic motors logically gives the sum the general spatial motion. If we know the course of motion of at least 2 points in space, it is possible to obtain the necessary linear motions of drives by mathematical transformations (1), (2), (3) but also on the basis of knowledge of linear motions of drives we can realize general motion of 2 points in space. The aim of verifying this theory was to measure the general real movements of 2 points in space (in the cab of a car), and their transformation into linear movements of drives. Using these linear motions, reproduce back the general real motion of 2 points in space. If this movement can be realized, we can say that the laboratory tests correspond exactly to the real ones and can fully replace them. In our experience, the repeatability of such laboratory tests is almost 95%. The disadvantage of Hexapod, however, remains the fact that in order to get to a specified point in space, we must use, either a compound movement in the x, z, z axes along a given curve, or gradually realize movements in individual axes, first vertical then horizontal in both directions, result will be the same. The hexapod cannot move abruptly in the x-axis, z-axis and z-axis at the same time. However, this does not completely correspond to the real movement of the car seat during real car operation. It depends on the surface on which the car moves. The measurement results show that the dominant motion is always vertical motion. Additional horizontal front-rear and left-right movements can be added to it. At the same time, all three movements can take place at once, in the given designated axes. Hexapod is not able to realize this. If three independent excitation motors are used, they can be put into operation separately or all three at the same time. In this way, precise movements of the car seat in the car body in real operation can be completely realized. Our innovative device has completely new features and therefore appears to be more suitable than the Hexapod when testing car seats.

**2.2 Triplex Control**

If three independent excitation motors are used, they can be put into operation separately or all three at the same time. Therefore, it can be fully realized precise movements of a car seat in the car body in real traffic. Our innovative device having new properties and therefore appears in the testing of automotive seats more suitable than Hexapod. Unlike the hexapod, operating the Triplex is quite simple. Each linear actuator is controlled separately, i.e. it can be switched on and off separately. The control of linear actuators makes it possible to realize practically any signal, for example a periodic sine, or a signal measured in the cab of a car. All entered movements can be performed simultaneously and independently. This corresponds to the load on the driver in the cab of the car in real traffic. Vibrations in the vertical or horizontal direction can only load the driver, but also simultaneously.

**2.3 Design of new testing device**

We have added another horizontal direction of loading left-right in the "z" axis (Fig. 4, where: 1. Upper mobile platform, 2. Lower mobile platform, 3. Linear actuator of vertical, 4. Linear actuator of horizontal, 5. Linear actuator of horizontal). We now have a vertical motion that realizes the vertical excitation that dominates when driving a car in real traffic. This driver has the highest power. In addition, we have two horizontal exciters that realize horizontal movements, i.e. front-rear movement and left-right movement. We could not place a complete car seat with a load on the existing equipment, so we increased the total height of the test equipment to 2700 mm. It also follows from the requirements of the current standard that the seat must be loaded with a freestanding manikin during the test.

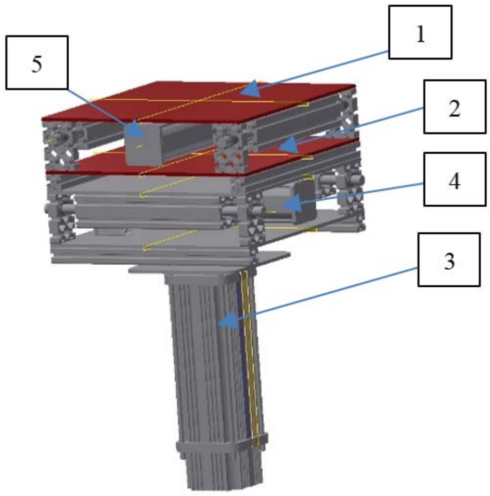


Figure 4 Two horizontal movable platforms

Horizontal movable platform 1 and 2 is on Fig. 5, where: 1. Lower fixed plate, 2. Upper moveable plate, 3. Bearing, 4. Linear guideways.

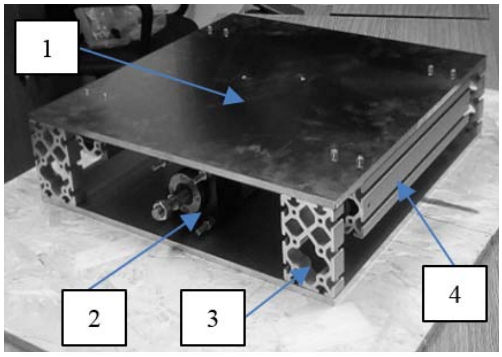


Figure 5 Horizontal movable platform 1 and 2

The concept of horizontal movement was based on the movement of two horizontal plates, which are connected via a linear guide (Fig. 6) and s new linear actuator type GSX40 was chosen for the drive (Fig. 7) where: 1. Corpus linear actuator, 2. Movable shaft, 3. Electrical connection, 4. Control connection, 5. Anchoring. The lower horizontal plate is connected to the vertical actuator, the upper plate is used to anchor the tested seat. The design allows the entire horizontal module to rotate, i.e. rotate in the "z" axis. The device thus becomes universal. We can add two horizontal test signals to the vertical test signal, both front-rear and left-right.

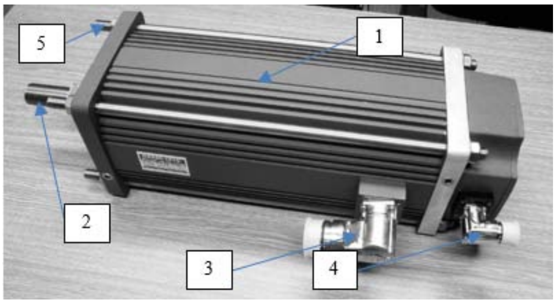


Figure 6 Vertical movement, linear actuator type GSX60

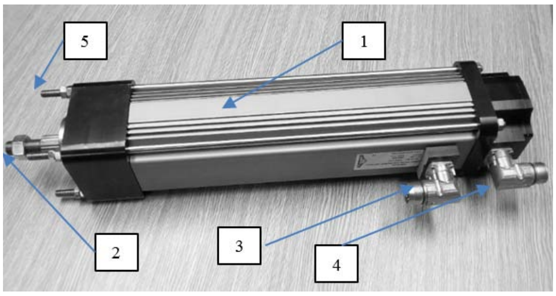


Figure 7 Horizontal movement, linear actuator type GSX40

The overall design concept of the innovated design was based on the assumption of using the Hybrid III test dummy and the H2015 dummy to measure the car seat. Therefore, we had to increase the overall height of the device to 2700 mm. The car seat can now be fully assembled, including the head restraint, and loaded with standard loads. Furthermore, a vertical linear guide has been added to the device, which allows, in case of testing requirements, to keep the load strictly in the vertical axis, i.e. the weight can only move vertically.

**2.4 Principles of control and implementation of excitation signals**

The actuator is basically an electric motor with a gearbox and a motion screw. This converts the rotary motion of the motor into a sliding motion. The actuator is also equipped with a position sensor which is used for position feedback control. An integral part of the actuator is an external control unit that provides power to the electric motor and implements the position feedback control. The control unit communicates with the parent user system via a serial link (RS 232, RS 485) or uses a standard internet connection. A block diagram of the basic actuator wiring is shown in the Fig. 8.

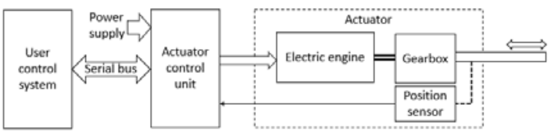


Figure 8 Block diagram of the basic actuator wiring

The user control system is a standard PC with the basic control software installed and included in the actuator delivery. This software is used to set the basic properties of the control unit and the actuator. At the lowest level, it is about setting the basic parameters of the electric motor and position sensor used. This level is handled by the factory settings and does not need to be modified from the user's point of view. The user-modifiable features then at the next level deal mostly with the setting of the starting and braking transient ramps and then the position and speed limit values to make the actuator operation safe in terms of its incorporation into a particular device. Serial line control can also be used for basic positioning, where the actuator linearly travels at the set speed (using the transition ramps) to the desired position and stops there. The final option for serial line control is to program a sequence of positions and speeds that is stored in the control unit and then executed when the start command is sent. However, it is always just a sequence of simple linear position changes at a set speed. Direct position control by the user system in real time is not possible because the serial link is too slow for this type of control. If it is necessary to control the actuator from the user system in real time, an analog control signal is usually used, the magnitude of which is proportional to the desired position value. Only the "start" command is sent over the serial link and the actuator position then follows the analog control signal. A predefined logic input of the controller can also be used instead of the start command. When controlling the actuator's operation, there is no need for basic control software at all and any application that can control the logic input and generate an analogue signal of the desired shape can be used. The actuator control unit can also provide information about its status to the user application using additional logic signals. However, the user system must of course have a unit with an analogue output and logical inputs and outputs. The block diagram of the control is shown in the Fig. 9.

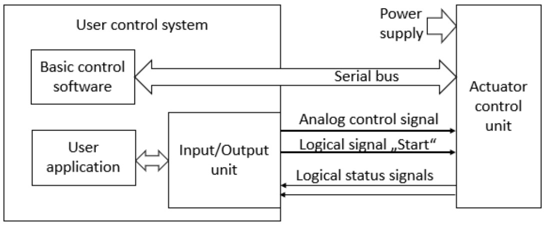


Figure 9 Block diagram of the control

A common PC does not have a basic unit with analogue and logic inputs and outputs and nowadays usually not even a serial RS232 port, but it is not a problem to add these elements to the computer. Nowadays, such units are usually designed as external devices that connect to the PC via a USB port. Thus, no intervention in the computer's HW is needed and even a laptop can be used. A typical example of units with analogue and logic lines are DAQ units from National Instruments. A user application can be created in the Labview programming environment from the same company, which already includes full support for DAQ units. This is also how the control of the actuator control units in the described test setup was solved.

**3 Results and Discussion**

The innovative device (Fig. 10, where: 1. Big frame, 2. Small frame, 3. Base frame, 4. Horizontal platform 1, 5. Horizontal platform 2, 6. Vertical linear guideways, 7. Vertical actuator, 8. Horizontal actuator 1, 9. Horizontal actuator 2) allows to realize the possibility of vertical loading of the car seat up to 100 kg load and movement of the car seat in the interval +/- 90 mm, at the same time allows to realize horizontal movement of the car seat in the interval +/- 25 mm both in front-rear and in left-right directions. This corresponds to the currently valid regulations for laboratory testing of car seats with the prescribed load.

Three types of signals were designed for the basic tests: Stationary periodic signal SPS1.1, Stationary non-periodic signal SNS1.2. Non-stationary non-periodic signal NNS1.3 (Fig. 11).

Since the device is equipped with three actuators, it is of course necessary to control three control units simultaneously. Thus, three separate analogue outputs for the position demand signals and three digital outputs for the "start" signal are required for control. In this device, each control unit gives only one "ready" status signal. Thus, three digital inputs are needed to process these signals. The resulting solution for interfacing the actuator control units to the user PC is shown in the Fig. 12.

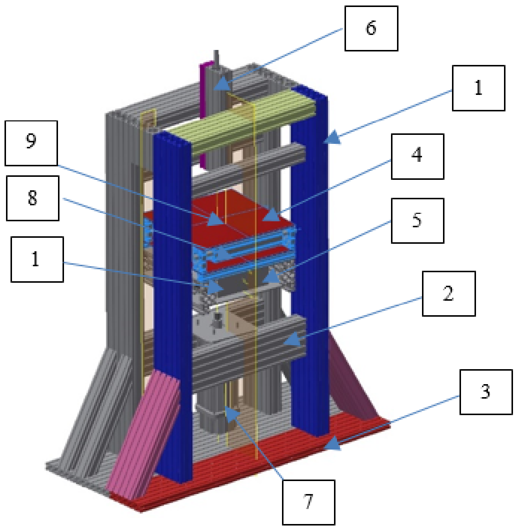

Figure 10 Innovative test equipment

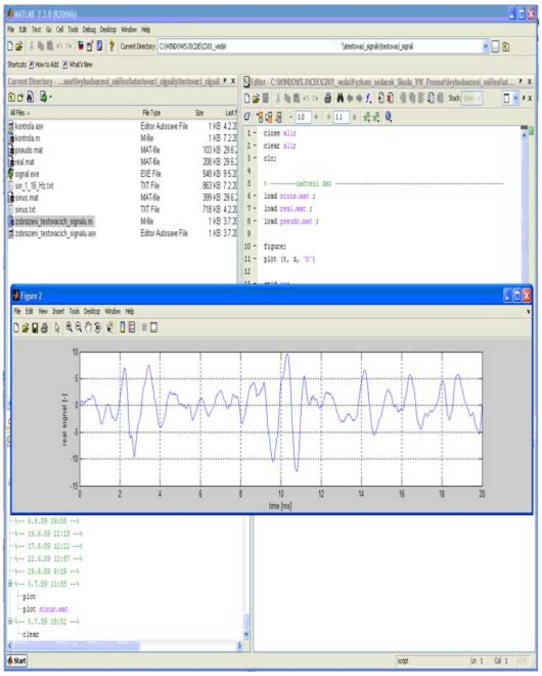
Figure 11 Excitation signal

When controlling positions with analogy signals, it is necessary to maintain a regular sampling frequency of all three control signals so that the synchronization of the three controlled positions is not disturbed. Maintaining accurate sampling is a problem on Windows computers because the operating system does not allow such control. Therefore, the precision hardware timing option of the National Instruments DAQ units is used. The DAQ unit has a precision clock signal that controls the timing of the analogy outputs. Data is taken from buffers which the user application in Labview fills with data in a "batch" manner. So, in essence, you can always just fill the buffers with data before it empties by sending data to the outputs and precise timing is no longer needed. This is already easy to implement even on a Windows application.

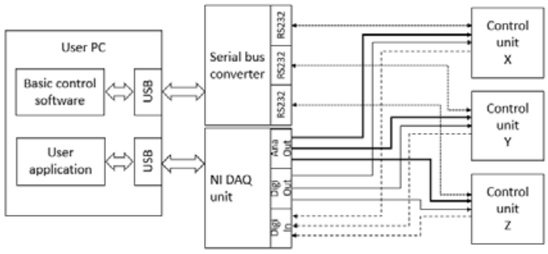

Figure 12 The resulting solution for interfacing the actuator control units to the user PC

The generation of the desired position signals for real-time actuator control is possible in two modes. If harmonic signals are used, the function generator included in Labview can be used. This generator allows the creation of basic periodic signal shapes (sine, triangle, rectangle) with user adjustable values for amplitude, frequency and phase. It can therefore be used to generate any combination of excitation harmonic signals for the three motion axes of the test equipment. The second mode is used when real measured signals are required for control. A data file with a time record of the signals is then used to generate the desired values. The file contains three columns of values defining X, Y and Z axis movements with a fixed time step. During actuator motion control, the user application then reads data from this file and again batch sends it to the NI DAQ unit buffers.

The introduced innovative car seat test device provides three axes of loading thereby exceeding the capabilities of existing device [5] and at the same moment allows independent control of all three axis which is not possible at hexapod [11]. The innovative car seat test device complements and exceeds current patented solutions [12-28].

## 4 Conclusion

The universal equipment for laboratory testing of automobile seats in the three directions of movement, vertical and both horizontal left-right and horizontal front-back was designed. This meets the requirements of current and future standards for determining the comfort properties of car seats. The main advantage of this device is the possibility of realizing completely independent movements in three axes simultaneously and independently, i.e. independent loading in three directions in the "x" axis, "y" axis and "z" axis. This solution makes it possible to test the car seat independently in one direction, but also in several directions at once, by independent signals. The signals will measured in the car at predetermined places specified by the standard and subsequently implemented on our equipment. Measurement and evaluation of car seat testing will already be the subject of further development and another paper**.**

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