# Testing Device for Biaxial Loading of Textile Specimens

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**Abstract.** Testing of real properties of textile specimens is needed during the development of new textile structures. One of the basic test is determining the specimen stiffness, it means measurement of the dependence of the force on the textile material stretching. Textile materials are mostly used in technical practice as products in the form of a surface (car seat cover, sail on a boat, etc.). Moreover, textile materials (unlike similar tests of metallic materials, for example) very often exhibit very different properties in different directions due to their structure. The test results depend on the orientation of the loading force against the fibers of the textile structure. For some types of textile materials (eg various nonwovens) this dependence can be very pronounced. For the above reasons, it is clear that the textile material needs to be loaded simultaneously in several directions. So, the biaxial loading device was built because biaxial loading provides more complex information about the structure properties than uniaxial. Perfect load coordination in both axes must be observed in these tests. The test device control system design is described in this paper.

**Keywords:** Textile structures · Biaxial loading · Testing device · Control system · Labview

## 1 Introduction

Textile materials are mostly used in technical practice as products in the form of a surface (car seat cover, sail on a boat, etc.). Textile materials very often exhibit very different properties in different directions due to their structure and for some types of textile materials (eg various nonwovens), this dependence can be very pronounced. The properties of such materials must be tested under biaxial loading [1]. A typical example of a textile structure biaxial loading is shown in Fig. 1.

The specimen is anchored between the four jaws. Two opposing jaws always form one load axis. Jaws in the one axis always move in the opposite direction at the same time, so the sample is in this axis loaded symmetrically according to the imaginary centre. The specimen is thus loaded in two mutually perpendicular directions. The two axes are independent of one another, so that the specimen can be subjected to different loading in each direction.


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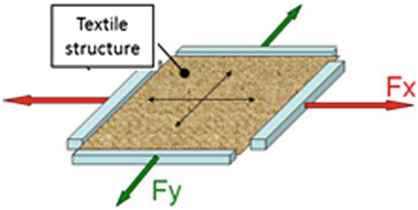


**Fig. 1.** Typical arrangement of a textile structure biaxial test.

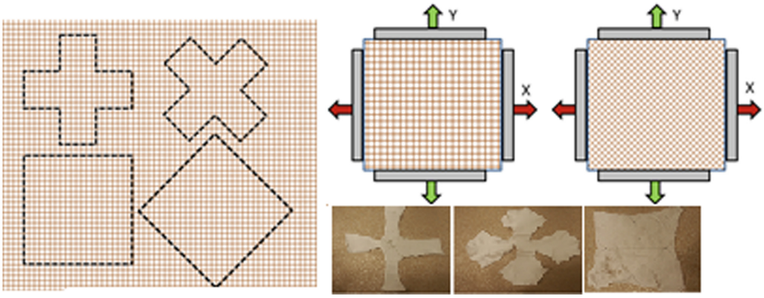


**Fig. 2.** The principle of specimen creation and real test specimens.

Specimens for testing are cut from the base material in the shape of a square or a cross. These shapes may be orientated in the direction of fibres or rotated relative thereto, so that the directions of loading are then identical to or rotated (typically 45 degrees) with respect to the tested material fibres. The machine anchor jaws must therefore be designed so that the specimen can be anchored independently of the direction its fibers. The principle of a specimen creation and real test specimens from different textile structures are shown in Fig. 2.

The described tests are done at the Department of Technologies and Structures at the Faculty of Textile Engineering at the Technical University in Liberec. Therefore, in 2011, the first type of testing device for biaxial loading of textile structures [2] was built in cooperation with the Department of Design of Mechanical Elements and Mechanism at the Faculty of Mechanical Engineering.

## 2 Materials and Methods

The first type of the test device was built according to the requirements for testing textile specimens at the time of its creation. Parameter definition was based on previously performed one-axis stress tests. Basic parameters are summarized in the Table 1.

### 2.1 The Biaxial Testing Device Design

The linear movement of the jaw is most easily realized with a motion bolt with an electric motor. In doing so, it is essential that the movement of both jaws in one axis is fully

**Table 1.** The first type biaxial testing device parameters.

| Parameter | Value |
|---|---|
| Maximum force | 500 N |
| Maximum jaw displacement | 100 mm |
| Maximum jaw speed | 2 mm/s |

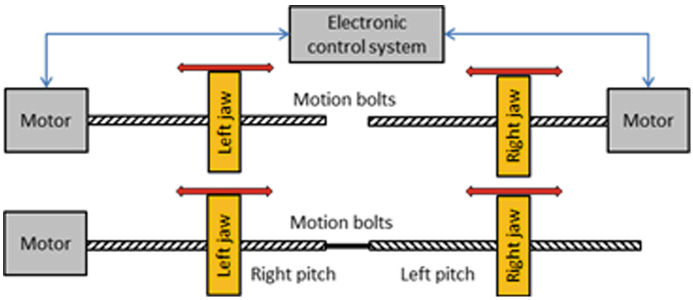


**Fig. 3.** The principle of the jaws movement synchronization.

synchronized for proper test performance. The jaws must move at the same speed to the same stroke for the still symmetrical loading of the specimen around the imaginary center. Two different paths lead to this goal. The first possibility is that each jaw is moved by a separate motor. Motion synchronization is realized electronically by both motors controlling. The other option is to use only one motor and two mechanically coupled motion bolts. One bolt has left and second right pitch. The jaws motion synchronization is ensured mechanically here and the inverted pitch of the bolts ensures the opposite direction of movement of the two jaws in the same direction of bolts rotation. The principle of both options is shown in Fig. 3.

## 2.2 The Biaxial Testing Device Practical Realization

The second method with mechanical motion synchronization was chosen to design this test device. Thus, only one sensor per axis is sufficient to measure the position of the jaws. One of the jaws in each axis is then fitted with a force sensor. Because the required forces and velocities are not large, the jaws are mounted only on a simple sliding guide on the rigid frame. The testing device is shown in Fig. 4.

The base frame was welded from steel profiles, sliding guides and moving screws were purchased from normal production. Two Maxon DC motors were used to control the motion bolts. Linear potentiometric sensors have been used to measure jaws displacement, the force was measured by strain gauge force sensors.

## 2.3 The Biaxial Testing Device Control System

National Instruments DAQ unit NI USB 6009 is the foundation of the control system. It is equipped with 14-bit A/D and D/A converters. Jaw position sensors are directly connected to the unit's analog inputs, force sensors are connected via differential amplifiers because their signal is too small for direct connection. Maxon engine control units are connected to the DAQ unit analogue outputs, the motors speed and direction of rotation can be controlled by them. All components are powered by the 24 V switching power supply (see Fig. 5).

The control application was created in Labview 2009. The application is based on two PI controllers for jaw control in both axes. Controllers allow position or force feedback to be used. The X-axis control is always independent, the Y-axis can also be independent, or can be controlled based on the evolution of the X-axis response using drag control. The user interface is the next layer of this application. It allows manual control of the jaw feed, approach to the specified position or force. Sequences of such commands can

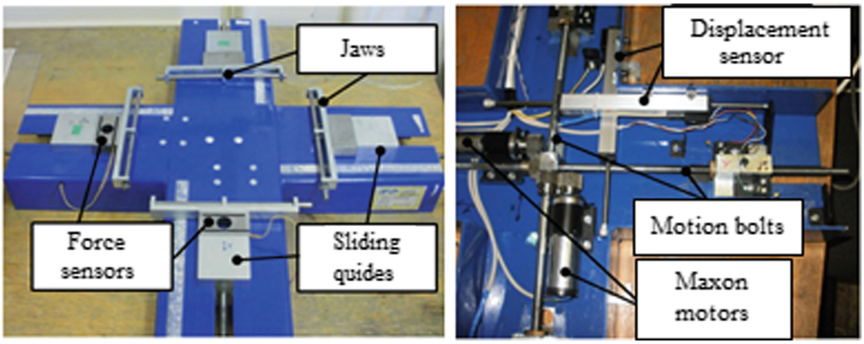


**Fig. 4.** The first type of biaxial testing device.

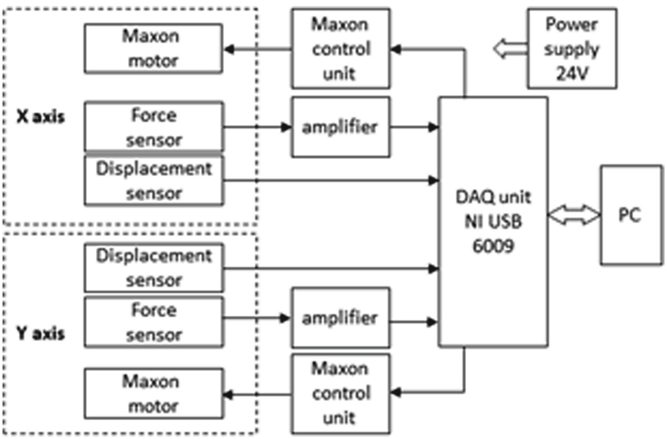


**Fig. 5.** The control system block scheme.

also be programmed in the application and stored as a test prescription. The test can then be performed in automatic mode and can be accurately repeated for multiple samples.

## 3 The Biaxial Testing Device, New Solution

The testing device described in Chapter 2 is still in use. However, since 2011, there has been a great deal of development in the field of tested textile structures and the parameters of the equipment have ceased to meet the needs of the tests. For some textile structures, the required test force is many times greater than the 500N maximum of the test device or the tests must be performed under non-standard conditions [3]. Changes in sample structure during loading are mostly monitored by the camera. For simpler structures, one camera from above is sufficient, but for more complex ones, it is often necessary to place two cameras on either side of the specimen or to place a light source against the camera to light the structure. The original device does not allow this, from the underside of the sample is the surface of the supporting frame.

These shortcomings led to the decision to build a new biaxial testing facility. The first new requirement was free space from both sides of the test sample to allow two opposing cameras to be used. In addition, other parameters of the device, which are summarized in Table 2, were increased.

### 3.1 New Biaxial Testing Device Design and Realization

Creating free space in the middle of the test device was the biggest change in the design of the new solution. The required free space does not allow the motion bolts to be placed in the jaw axis. Again, the question of whether to use two separate units in each load axis and to synchronize them electronically, or to use a mechanical connection as in the previous solution, was solved. A complete change of control application would be needed in the case of the first option, since four engines would have to be controlled instead of two. When using the second variant, the much higher required forces cause complications in the design of the sliding jaws because the moving bolts must be located outside the jaw axis. It was a great dilemma to decide for one of the variants. Finally, a solution identical to the previous device was chosen, ie the mechanical connection of the jaws with one motor in each axis. This makes it possible to use the original control software practically unchanged.

**Table 2.** The new biaxial testing device parameters.

| Parameter | Value |
|---|---|
| Maximum force | 5 kN |
| Maximum jaw displacement | 250 mm |
| Maximum jaw speed | 10 mm/s |
| Window in the center of the device | 100 x 100 mm |

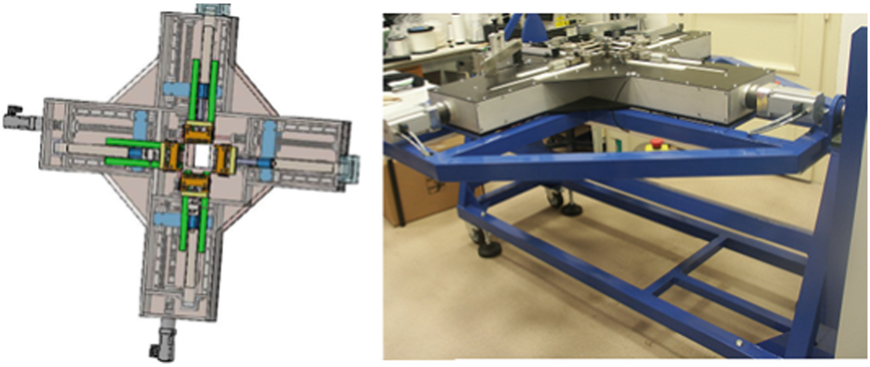

**Fig. 6.** New biaxial device design (left) and its final realization (right).

Since the production of the test equipment with the required parameters is already very demanding, it could not be implemented directly on the university. The final design and manufacture of mechanical part of the testing device was therefore entrusted to the Festo company. A new solution design and final realization are shown in Fig. 6.

The base is an inclined welded frame on which a biaxial loading device is mounted. Folding the frame makes it easy to install the camera from the bottom of the sample. Each axis of the biaxial device is equipped with a single Festo stepper motor, which moves both opposing jaws simultaneously via ball moving bolts with opposite pitch. The moving bolts are located outside the central window.

The linear potentiometric displacement sensor measures the position of the jaws in each load axis. One jaw in the axis is again equipped with a strain gauge force sensor. The sensor equipment is therefore exactly the same as at the first device and the sensors layout is shown in Fig. 7.

### 3.2 The Control Cystem Innovation

The control system hardware is essentially the same as at the first biaxial device. However, its individual elements have been upgraded so that the equipment follows the current technical level. The first upgrade involved the National Instruments measuring unit. The device uses the NI USB 6002, which is part of the latest product line. This unit includes fast 16-bit A / D and D / A converters, as well as a set of logic inputs and outputs. Linear potentiometer jaw position sensors are connected directly to this unit. The strain gauge force sensor signals are amplified before being connected to the unit. The amplifiers are again selected from the latest product range from Orbit Merret company. These amplifiers are programmable and allow you to set parameters very efficiently so that the input range of A / D converters is fully utilized. Using 16-bit converters and optimizing the force sensor amplifiers, it was possible to maintain very good positioning and force measurement accuracy even though their ranges are greater than in the previous device. Of course, the control system also includes engine control units that correspond to the stepper motors used. The 24 V power supply had to be newly dimensioned as the power input of the motors is of course much higher than in the previous device. The high power

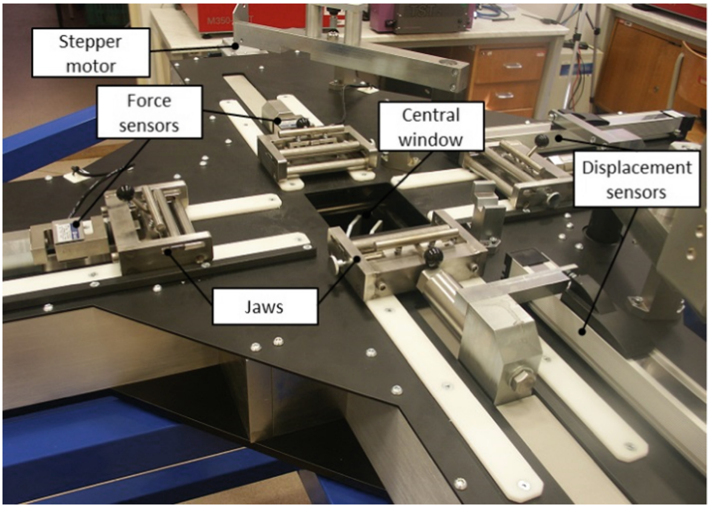


**Fig. 7.** Sensors arrangements

of the engines and the high forces required a safety solution, so the device is equipped with safety relays and a total stop button set. It is also necessary to activate the start of the motors with the hardware button directly on the device. This prevents unexpected engine starting, for example, after accidental clicking in the control application. The whole solution of this power and safety part of the control system was designed and supplied by Festo to be fully in line with the stepper motors used. The NI USB 6002 controls motor controllers by analog channels. Voltage and polarity of the voltage control the speed and direction of motors rotation. Signals from motor enable button and total stop buttons are connected to the unit's logic inputs so that their status can be signaled directly in the control application. The level converter from 24 V logic to TTL is used for their connection (see Fig. 8).

### 3.3 The Control System Sftware Application

Running on a standard PC with Windows operating system was a basic requirement for application development. At the same time, users wanted the application's user interface to be as consistent as possible with that of the previous device, as this environment was user-friendly and easy to use. Since the configuration of the new device and the control system hardware is virtually identical to the original solution, these requirements were easy to implement. Labview was reused to create the application. Only the newer version 2010 had to be used because drivers for the new generation of DAQ NI-USB units were no longer available in Labview 2009. Because the compatibility of newer versions of Labview with older applications is ensured, there was no problem transferring the original application to the new environment. Thus, the user control layer could be retained, the application window design and the method of its control remained the same. Of course, the core of the application had to be modified because the DAQ drivers had to be replaced. Also, it was now necessary to process the logical inputs of the hardware button state.

The running of an application created in Labview is controlled by the bitrate as opposed to sequentially executed commands in other programming languages. This makes it easy to create parallel program blocks with different priorities. In addition, hardware timed loops can be used in the application and run very accurately and independently of the operating system. This makes it possible to create a very precise control application on a regular PC. The only limitation is the lower loop timing speed, here it is a maximum of 1 kHz compared to 1 MHz in real-time systems. Since the speed of the test device jaws is not high, this limitation is insignificant.

These options were used when designing the control application. The block diagram is shown in Fig. 9.

Two parallel independent loops are its basis. The first, time-critical loop, uses hardware timing with a 10ms period. Two feedback PI controllers for motors in both axes

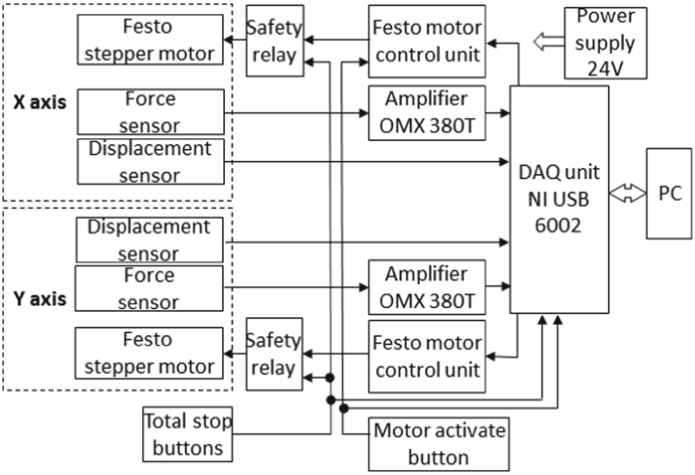


**Fig. 8.** The control system block scheme.

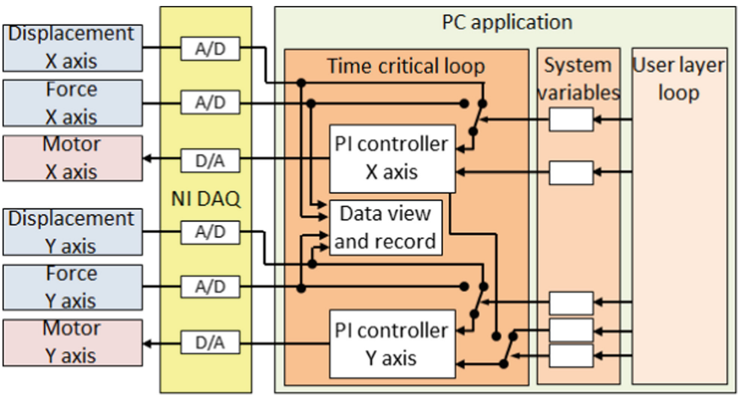


**Fig. 9.** New control application block scheme.

are its main elements. This loop is also used for measuring, displaying and storing data. The second loop serves the user interface layer. Timing is not critical here, the loop runs with a software-specified period of approximately 200 ms. Due to the human reaction time, this speed is quite sufficient. If the two loops are to be truly time-independent, the data transfer between them must be resolved correctly. Otherwise, a faster loop could wait for data from a slower loop and its timing would be broken. To prevent this, data is passed through a block of system variables. Both loops can write and read data into it at any time, and timing cannot be violated.

The X-axis is the main axis of the test device and is always independent. It can be controlled in position or force feedback, the user selects the feedback type in the control application. The Y-axis may also be independent of the same feedback control options, or may be coupled to the control of the X-axis. Then the Y-axis can copy the X-axis variables in the chosen way. For example, the sample is stretched in the X-axis by a constant position change. The force in X-axis varies according to the sample parameters. The Y-axis control can be set so that the Y-axis automatically maintains the same value of force according to the X-axis force value.

The user interface window controls the entire device. There are buttons for manual control and automatic movement to the set position or force. An integral part of this window is also the time chart of all quantities. The application user window is shown in Fig. 10 (the application is localized in the Czech language, so the description of the elements corresponds to it).

The application also allows to program the sequence of desired steps and save it to a file. The test can then be run in automatic mode and can be repeated as many times as you like. Thus, the properties of the various textile structures can be compared very well, as the test conditions are always exactly the same. The user interface of the newly

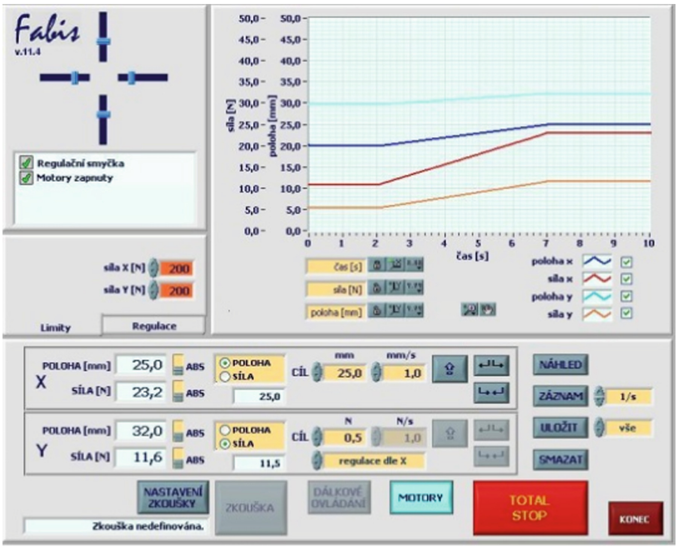


**Fig. 10.** The control application user window.

created application, the direct device control system and the test programming remained very similar to the previous solution. This allows users to use a familiar environment to control a new test device and not learn any new procedures.

## 4 Conclusion

The new biaxial testing facility was built to test modern textile structures. Two departments of the Technical University and Festo company cooperated on its design, construction and commissioning. The device is designed for high forces and displacements so that very strong or very flexible materials can be tested. The center window allows the use of modern optical methods for measuring the deformation of the textile structure during loading. A light source positioned opposite the camera may highlight the specimen structure being tested, or two opposing cameras may be used for complexly shaped textile structures. The control application remained very similar to the original solution. So, users can use the new device without having to learn new procedures and methods to its control and can continue to use the established testing methodology.

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