Analysis of equipment for biaxial material testing

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Abstract. This paper aims to analyze the operation of the equipment for biaxial testing. The equipment’s stiffness is one of the main factors influencing the magnitude of reaction forces in the device’s guidance, consequently affecting the measurement accuracy. Based on intensive research on the topic of biaxial testing devices, the present paper deals with the analysis and optimization of the equipment’s current design.

1. Introduction

Various mechanical examinations on different materials and specimens help us understand their mechanical properties or, in other words, their behavior under stress states and strain. It is well known that, in order to accurately characterize the failure properties of materials, to formulate related constitutive and evolutionary damage laws, it is necessary to perform an experimental analysis [1]. One of the most important actions is the biaxial test of butterfly specimens. Planar biaxial testing applies force in two directions, allowing an analysis of the anisotropic behaviors of materials. From this point of view, the issue of ductile failure and biaxial tests are applied to wide areas in mechanical engineering, including, the automotive, aerospace, as well as electrical industry. Therefore, in order to select the suitable material for an application, it is very important to perform a measurement correctly with minimum error or inaccuracy which makes the testing process more difficult than common material testing.

For biaxial loading, there are various measurement methods, distinguished mainly by the type of testing equipment, the shape of a sample, and measurement conditions. They can be generally divided into tensile tests with a special shape of the testing specimen or tests with a simpler specimen geometry but with a complex equipment design which makes the biaxial loading possible. Due to this fact testing equipment is one of the main keys to accomplishing successful biaxial testing of specimens. This paper focuses on specific testing equipment that allows biaxial testing on a butterfly shape sample.

2. The biaxial equipment

The biaxial testing equipment owned by COMTES FHT (Figure 1), was developed in the framework of the project identified as FR-TI2/279, between COMTES FHT, Skoda JS Company, and CVUT University. This Biaxial equipment was designed to apply planar biaxial loading to the specimen during the uniaxial loading of the equipment itself. The equipment (Figure 1) is designed for standard testing machine and it consist of a bottom and an upper welded frame. The welded frames are connected by standard bushings and columns. The bushing were lubricated according to the manufacturer's instructions. The grips are placed on a bottom and upper welded frame and allow the sample to rotate. The rotation is by 5 ° in the range of 0 ° to 90 °, this rotation makes biaxial loading of the specimen possible.
3. Equipment analysis
After several tests on this equipment and comparing the result with numerical simulation, it was found that the equipment has a negative effect on the testing process. The results were not reliable and the testing was not accurate. In this section, the main goal was to find the reason behind the device’s inaccuracy and determine the amount of the device’s deformation and the reaction force which applies during its movement. By analyzing the results, it will be possible to decide whether it is necessary to modify the equipment and which specific parts should be modified in case of necessity. To design the experiment the following subsections must be defined:

3.1. Equivalent specimen
The main shape of the butterfly specimen is problematic from the production point of view. Different curvature in different directions and thickness changes in the center of the sample where the main stress concentration point is realized makes the production difficult. To overcome this problem, equivalent samples were designed with a similar shape to the main specimen, but in a shape that each one has different stiffness in the middle part (Figure 2). Five equivalent samples were designed, with similar main dimensions as thickness, width, and length. The tool steel 1.2842 was chosen as the material of all specimens.

3.2. Loading condition
In the second step for designing the experiment, the loading condition of the specimen during its testing must be defined. The loading condition was chosen, in which the sample causes the greatest reaction force in a radial direction to the guide pillars (columns) of the equipment. FEM analysis has been carried out based on this consideration. A simple FEM analysis was performed by loading a
sample that was loaded at different angles (corresponding to the device). Reaction forces in boundary conditions were monitored in the vertical (along the pillars axis) and transverse (radial to the pillar axis) directions.

Results of the simulation in Figure 3 verified the assumption that the greatest load value in the radial direction was for angles 45° and 60° and the angle 45° was used for following analysis. The higher angles (75° and 90°) are irrelevant based on sample shape and loading condition.

![Figure 3. Relation of reaction force on displacement from FEM simulation [1]](image)

3.3. Measuring instruments

The experiment was performed on an MTS 810 (Material Test System) machine. Basic operating data from the machine which are; the force required to move the working piston and movement of the working piston were recorded. These basic data were supplemented by other methods of measuring the deformation of the equipment. Using the 3D scanner the total deformation of the device was measured and the dial distance indicator measured the lateral deformations in the left side of the device.

![Figure 4. Mounted equipment on the MTS machine and measuring instruments [1]](image)
4. Experiment results

The device’s movement was driven by input force from the MTS machine. The amount of the input force was calculated so that the experiment will occur only in the elastic area. This strategy was chosen because of the linear behavior of materials in the elastic area. Due to the experimental mistakes, it was not possible to apply this strategy for all the specimens. Figure 4 (right) shows the method of the result analysis. The experiment was carried out in the two following main phases.

4.1. Hysteresis analysis (cyclic movement without specimen)

These measurements were applied to analyze the behavior of the equipment in case of repeated measurements or loading. The results of the measurements are defined as the hysteresis curve.

![Figure 5. Cyclic movement results of the equipment [1]](image)

From the graph in Figure 5, can be seen that at the beginning of the experiment, during quasi-static stretching, the equipment forces a resistive force of up to 1000N, then during compressing, its amount reduces to 600N, and finally, it can be seen that a constant reaction force stays around 300N. The main source of this force is the frictional resistance in the sliding because it is the only moving kinematic pair in the equipment.

4.2. With equivalent specimen’s analysis

During the device’s movement, the lateral deformation of the fixture was measured under maximum force and stroke for each sample and it was measured by the dial gauge. The force-displacement dependency was measured from the MTS machine. The testing result from Sample V2 is chosen as a representative result among other samples. V2 was the only specimen that cracked during the experiment due to the large force that was applied to it. Sample V2, as shown in Figure 6, reached a maximum force of 3kN. According to this graph, it can be surely claimed that in the area marked with a red rectangle, the sample was cracked and therefore it stopped applying any force inside the equipment.
Figure 6. Complete experimental results of sample V2 [1]

For analyzing results from a 3D scanner, from the five samples, the data from the measurement of sample V1 was selected as a reference. The sample shape was designed for its maximum stiffness, so it is possible to measure the equipment deformation under loading (the sample has a constant thickness of 3 mm). The first series of scans took place before the loading began when the specimen was clamped to the fixture. The second series was scanned during the experiment when the maximum load was applied to the sample. Comparison of these two states was performed in GOM Inspect software, where Scans of both series were imported and then compared with each other. The overall displacement of the equipment could be evaluated from the comparison (Figure 7). The values obtained show that the equipment’s deformations were relatively small and the device is sufficiently rigid. The only significant displacement was recorded for the parts in the direction of axial displacement, which corresponds to the function of the equipment.

Figure 7. Deformation results based on the 3D scan – comparison unloaded and loaded state of equipment [1]

4.3. Experiment discussion
The results from hysteresis analysis (Figure 5) confirmed that the equipment applies 300N reaction force while cyclic movement without the specimen. Also results from form sample V2 show that the axial force recorded in the red marked region (Figure 6) is the clear resistive force of the equipment and this coincides with the behavior of the device during cyclic movement (Figure 5). Both values are around 300N. The source of this problem is the high value of friction in guide elements of the
equipment which impedes the movement of the headed guide bush. This value is in some cases 10% of
the maximum force value and therefore the influence of this frictional resistance cannot be neglected.
During the experiment, it was also found out that the equipment’s movement in the loading direction
is not stable. This cause that negatively affects the equipment is due to the instability of the upper nut
(Figure 1) and a large clearance between this nut and the ring which holds the nut on the equipment.
Based on this discussion it is necessary to modify the equipment’s parts which caused negative effects
during the experiment.

5. Solution Variants
According to considerations obtained in the previous section, it was attempted to suggest variations
that improve the construction of this product. The main aim of these variants is to eliminate or reduce
frictional forces in the guide elements of the equipment. One variant separately focuses on the upper
nut of the equipment and its method of connection to the test devices.
Two following variants are proposed to minimize frictional forces in guide elements of the equipment.
1st variant focuses on changing the headed guide bush, and 2nd variant aims at changing the design of
the entire fixture by removing the entire guide from the chain. As the second option reduces the
rigidity of the equipment while the first option is easier to operate, the 1st variant is suggested as the
sufficient one.
Also to remove the instability of the equipment, the ring modification is suggested to connect the
equipment with the testing machine instead of using a connection nut. This modification requires
producing a connection ring with the same dimensions and shape as the current ring but with a
threaded hole in the middle of the ring. Drilling the threaded hole according to the linkage part that
COMTES FHT usually uses for connecting to the testing machines, allows the linkage to be directly
connected to the equipment. This direct connection with the upper frame of the equipment without
using any additional nut connection could significantly stabilize the equipment’s movement during
testing and should not apply any additional reaction forces.

6. Conclusion
Biaxial testing equipment for butterfly-shaped specimen’s fixture performs biaxial tests on various
materials, mainly steel types. The special geometry of this sample is very useful for describing the
characterization of the stress states of a material.
Significant friction value in the guide elements of the current equipment, prevents it to be fully
functional and restrain measurement to be sufficiently accurate. This work aimed to find problem
points based on the experiment and analysis of the current state, then to determine its value and verify
the existence of unsuitable reaction forces that may arise during the test. Subsequently, variants were
proposed for solving problematic nodes.
Based on an experiment conducted at COMTES FHT, it has been determined that the guidance of this
device, which allows the clamping plates to move concerning each other, causes an undesirable
reaction force. Another adverse effect was the instability of the upper nut of the device. This instability
mainly affected the continuity and eventual jumps, which were recorded during measurement. By
using a 3D scanner, it was verified that the rigidity of the entire existing fixture is sufficient and there
is no need (contrary to the original assumptions) to change the main concept of design in this fixture.

7. References
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