

# DESIGN AND IMPLEMENTATION OF A TENSILE TESTING MACHINE

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## Abstract

The aim of this paper is to present the design and manufacturing process of a tensile testing machine capable of measuring the tensile strength of polymeric materials. The structure of the instrument is similar to that used in the industry; however, it is budget friendly. The instrument consists of a frame, and two screws which are driven by two stepper motors. An Arduino is used to control the mechanical part of the instrument and to connect it to the software.

**Keywords:** *tensile properties, elongation, design, polymer, control.*

## 1. Introduction

Leonardo Da Vinci was one of first to use tensile testing measurement to determine the tensile properties of a string. The procedure involved pouring sand into a basket that was attached to one end of the string until the string broke. The working principle of the tensile instruments used today is the same: the specimen is loaded until it breaks. [1, 2]

The aim of tensile testing is to determine the ultimate tensile strength, elongation at break, the energy needed to break the specimen in order to determine the limit of reversible deformation, the yield stress and more. All these material properties and characteristics are necessary for engineers to design new products. [2]

Tensile testing provides information about the materials response to static loads; however, the same material bears much less load under dynamic conditions. The tensile properties of any material are dependent on the temperature. Typically, as temperature increases the tensile properties decrease. On the other hand, when the temperature decreases the material become brittle. Tensile testing is performed on standardized specimens, that are specified in standards according to the type of tested material. During

quasi static tensile testing the elongation rate is specified, and the instrument measures the load, recording the stress vs. elongation curve. The diagram illustrates two main stresses: [3]

- the yield stress ( $R_e$ ) – below which the deformation is reversible,
- the ultimate tensile stress ( $R_m$ ) – that is the largest stress that the specimen can bear.

The accuracy and the precision of tensile testing is determined by the instrument. In general, the industry uses instruments that are capable of uniaxial loading. The instrument that we have designed is also a uniaxial tensile instrument. The device consists of the following components: a frame that provides the stability, clamping units to hold the specimen, a load cell and amplifier, the electro-mechanic drivetrain providing the required load, elongation rate and the control unit. In the following each of the components will be presented.

## 2. The designed instrument

### 2.1. Input parameters

One of the major requirements was to design a budget friendly device that can be to used in laboratory experiments. This instrument is intended

to be used in the Polymer Lab at the Department of Mechanical Engineering of the Sapientia University.

We have used the ultimate tensile stress value of poly(ethylene terephthalate) (PET) as the upper limit of the measurable stress. [4] The ultimate tensile strength of PET based on the specimen specified by ISO-527-1, 40 mm<sup>2</sup> cross-section area, is 132 MPa. The required force to break the specimen, then can be calculated to be 5280 N. Using a 1.2 security factor the force is 6336 N, that was rounded to 6500 N. The drivetrain of the instrument consists of two stepper motors and two screws, thus only half of the final force is applied to one of the motors and the screws.

The maximum elongation of the A2 specimen from ISO 527-1 was set to ~ 300 %, thus the length of the screws could be determined to be 720 mm each.

**2.2. The structure of the instrument**

**2.2.1. Frame**

The base plate of the device is 15 mm thick and made of OL50 material, that is connected to two stainless steel supporting rods of 20 mm diameter. Linear bearings are connected to the rods in order to provide the uniaxial translational motion. The supporting rods have double functionality: they hold the motors, thus bearing load and they guide the crosshead during the translational motion. In the top of the instrument a crossbar is situated, onto which the motors are mounted as well as the bearings of the screws. This piece is made of aluminum 6061.

**2.2.2. Screw**

The inner diameter of the screws is determined for half of the maximum load, 3250 N. The material of the screws is OLC45.

The inner diameter of the screws can be determined by the following equation to be minimum 7.54 mm:

$$d_2 \geq \sqrt{\frac{F}{\pi * \psi_H * \psi_m * \sigma_{meg}}} = 7,54 \text{ mm} \tag{1}$$

where:

- $\sigma_{meg}$  – yield stress in the case of steel-brass,
- $F$  – force,
- $d_2$  – the inner diameter of the screw,
- $\psi_H$  – screw thread profile height coefficient,
- $\psi_m$  – nut height coefficient.

Based on the commercially available screws we have chosen a Tr12x3 trapezoidal screw with 8 mm inner diameter. The nut was chosen to be

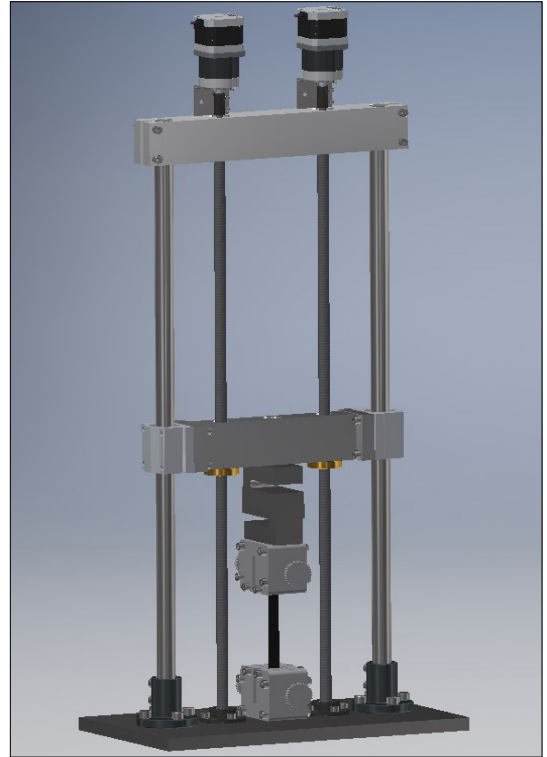


Figure 1. The 3D model of the designed tensile testing instrument.

brass in order to ensure low friction coefficient between the screw and the nut

**2.2.3. Drive train**

Two NEMA 17 stepper motors with speed reducer of  $i = 13.7$  ratio were chosen to provide the necessary torque [5]. Using the required maximum force and the screw dimensions the necessary torque can be calculated with the following equation:

$$M_f = F * \frac{d_2}{2} * \text{tg}(\alpha + \rho) = 2,95 \text{ Nm} \tag{2}$$

where :

- $M_f$  – torque.
- $F$  – force,
- $d_2$  – mid diameter.
- $\alpha$  – thread angle.
- $\rho$  – reeducated friction angle. [6]

The stepper motor can provide 3 N·m torque continuously; however, it can provide an instantaneous torque of 5 N·m for a short period. The elongation of the specimen is determined by the number of steps that is required to break the specimen. The stepper motor with the speed re-

ducer has to turn 913 steps in order to provide 1 mm travel distance between the two clamping units, considering the pitch of the screw, 3 mm, the reduction ration of  $i = 13.7$  and the number of steps, 200, in order for the stepper motor to turn 1 revolution.

#### 2.2.4. Clamping unit

The standardized specimen, A2 ISO 527-1, has a shape that becomes wider at the clamping portion, in our case the width is 20 mm and the thickness is 4 mm. These are the input parameters that the clamping unit design must be based on.

The clamping unit (Figure 2) resembles a vise with two moving faces. 6061 aluminum was used to manufacture the components on CNC milling machines. The vise is comprised of three major parts: the body and the two faces. Both faces can move in the body, which is realized by using M8 screws. The body consists of two parts that are screwed together with M6 screws. The faces of the vise are covered with sandpaper to increase the friction between the faces and the specimen.

Radial-axial bearings are used between the M8 screws and faces of the vise.

#### 2.2.5. Bearings

There are two types of bearings that can be found in the structure of the tensile instrument. On one hand there are the linear bearings that help to guide the crosshead. This is a linear ball bearing that is very ubiquitous in industrial applications due to its simplicity, dependability and low cost. It is also easy to mount, in our case we used M6 screws.

On the other hand, radial-axial bearings (Figure 3), as the second type of bearings, are used to reduce friction and bear loads in the case of the main screws and the frame and in the case of the vice face and the moving screws.

We used SKF bearing with 8 mm inner diameter and 24 mm outer diameter to connect the main screws to the crosshead and the base plate. Due to the small size of the bearing we were not able to find a premade bearing housing, thus the housings were milled into the top crossbar as well as in base plate. SKF bearings with 4 mm inner diameter and 13 mm outer diameters were used in the vise.

#### 2.2.6. Load cell

The force is measured with an STA-3 (LcmSystems) load cell with ~10000 N maximum capacity

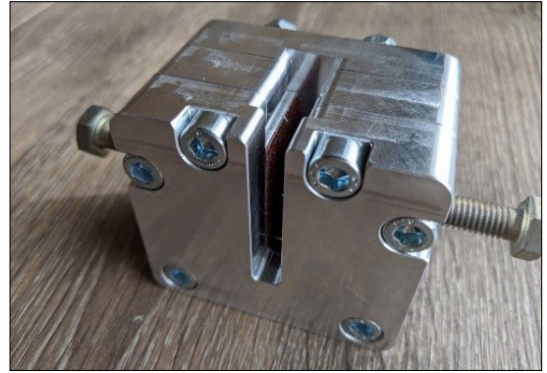


Figure 2. The clamping unit.

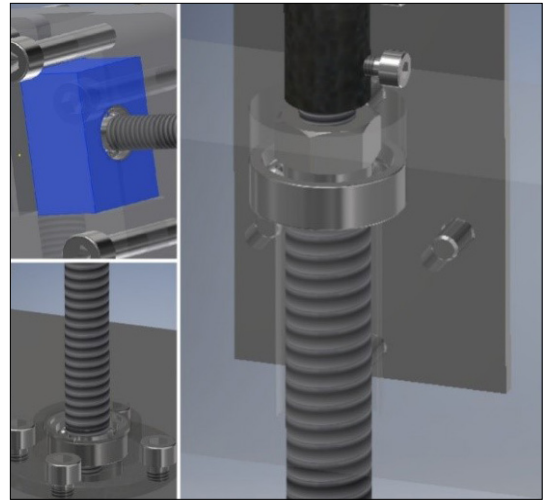


Figure 3. Radial-axial bearings with housing.

for both tension and compression. [7] The load-cell provides an analog voltage signal as the output between 0 – 2 V that is converted to N with the use of the calibration curve. The loadcell is powered by a 12 V DC power supply. M12 screws are employed to mount the loadcell to the crosshead and to the clamping unit. The output signal is processed by a programable Arduino Mega 2560 microcontroller. [8]

#### 2.2.7. Control unit

The stepper motors are controlled by DM33T type stepper-motor control units, that are connected to the above-mentioned Arduino Mega 2560. The programed microcontroller collects the signal from the load cell and provides the direction and number of steps to the stepper motor control units. The Arduino Mega 2560 was designed

for industrial application with a budget friendly mindset.

The PUL pin of the microcontroller is responsible for the number of steps and the DIR pin for the direction, whereas the ENA is the 5 V POWER IN pin.

### 2.2.8. Software

In order to acquire data from the instrument and to have the capability to define different testing conditions, PC software is necessary. The software thus connects the PC to the microcontroller. The software is developed in Java Eclipse environment. As a first step the software allows us to choose which serial port we want to use for communication with the Arduino. The next window allows the user to manually control the instrument, setting zero points, and basically to adopt the measurement protocol to the given size of the specimen. Next the crosshead speed is selected. After setting the zero point, the speed of the measurement and zeroing the load cell we can start the measurement. The measured data will be plotted in real time on a stress-strain diagram. The data can be exported in Excel format for further processing.

## 4. Conclusions

In conclusion, we have designed and partially implemented (Figure 4.) a device that is capable of testing the tensile properties of polymeric materials. The device will be used as a laboratory instrument in the Plastics Laboratory of the Mechanical Engineering Department of the Sapientia EMTE University.

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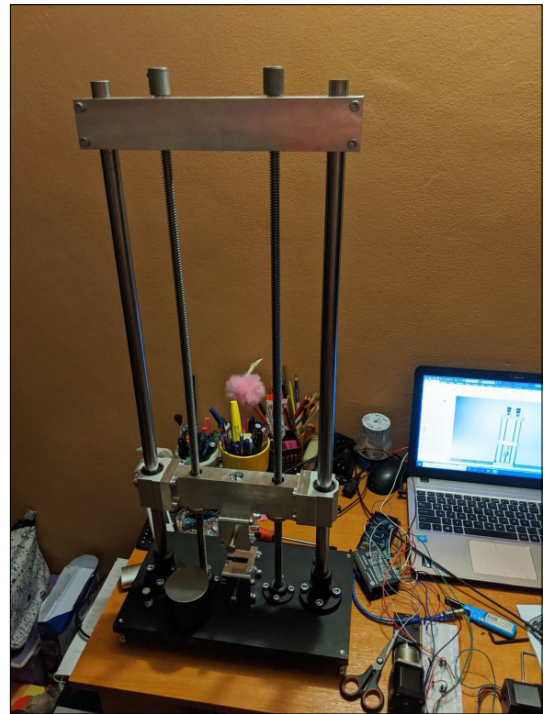


Figure 4. The implemented part of the tensile testing instrument.

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