# Modeling and Control of Testing Device For Carpet Resilience Measurement*

H.İ.Çelik, H.K.Kaynak L.C.Dülger,B.Şahin, E.Gültekin

**Abstract— Abstract: A multifunctional testing device is designed to perform thickness measurement of carpets. Thickness loss is determined for two cases: after short-term static loading and after long-term static loading. Compression and resilience tests and measurements are performed simultaneously on five samples automatically using this testing device. Carpet thickness is measured after different loading conditions. This paper introduces the pneumatic proportional position control system utilized in a testing device. Actuation of the system is performed by using pneumatic actuators. The model is taken as a double acting pneumatic cylinder. PLC used for system automation and control. This testing device has been completed as a result of a research project. A mathematical model is also offered for the actuation system.**

**Keywords— carpet resilience, Matlab/Simulink, Pneumatic cylinder, static loading, position control**

## I. INTRODUCTION

Carpet is a 3D textile structure contains warp, filling and pile yarns. A carpet is under the effect of different forces; axial compression, bending, flattening, and extension can be given as examples. These forces can be concerned either by dynamic loading, or by static loading. The compression behavior of carpet shows time dependent one. The short-term static loading test was performed to determine the percentage thickness loss and thickness recovery for a short interval of time. The experimental variables are found to be pile material, pile density, pile height, and recovery time, on thickness loss and recovery of carpet after short term static loading. The dynamic loading tester has been utilized to simulate the treading action on carpets. For the thickness loss test after long-term and heavy static loading on the carpet, a load of 700 kPa is applied to the carpet sample for 24 hours. The compression behavior of carpet are influenced by the structure and properties of the constituent fibers and yarns, carpet construction parameters. Nature and level of loading and time allowed for both loading conditions and recovery are important. The tests have been performed under two different loading conditions.

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The static loading refers to constant load followed by recovery in common. The dynamic loading is the one with impact load during applications. These loading types definitely lead to deformation in carpet. Thus the influence of different loadings are always to be studied [1].

Many different studies have been performed on compressibility of carpets by applying loading tests. S.A Mirjalili et al [1] have been performed an experimental study on handmade Persian carpets under static force previously. The resiliency of the carpets was measured after applying the static force and the results were compared. N. Özdil et al. [2] have studied on compression behavior different carpets. Seven carpets of wool (Wo), acyclic (PAC) and polypropylene (PP) fibers were experimented in terms of compressibility and thickness recovery properties. The static and dynamic loading tests were performed. The effect of material type, pile height, pile density, yarn count were studied with further conclusions. B. Choibisa et al [3] have studied on compression behavior of hand-tufted carpets. An impact test was performed with a cyclic loading. The action of the machine (ISO 2094:1999) was developed to mimic the main actions of walking, i.e. the compressive effect and shearing effect produced. The experimental variables are taken as pile material, pile density, pile height and number of impacts on thickness loss of carpet in dynamic loading case. H.İ.Çelik et al [4] have then developed a static loading test device capable of doing long-short term loading without automation. This testing device is then taken a national patent [5]. D.Vuruşkan et al. [6] have studied on compression properties of woven carpets under dynamic loading. Carpet compression performances were taken 50, 100, 200, 500, 1000 and 2000 dynamic impacts on carpet samples. Acrylic cut-pile carpets were used as samples. H.İ.Çelik et al. [7] improved a concept design with automation needed for five samples. M. Alsayed et al. [8] produced a testing device for using a single sample. Finally this device has been improved using five test units applying static loads to multiple specimens [9]. In addition to these three different tests, the test device was improved by adapting the software developed for compression and resilience testing to the produced test device.

This study intends to explain modelling and control issues for the actuation system. This testing device is designed and constructed as a result of a research project. Previously it has been used for applying static loads to multiple specimens to measure carpet thickness. Testing device actuation, interface and system operation details are given in Section II. Mathematical model of the pneumatic actuator-load system is derived in simplified manner. Real system model is nonlinear.

Thus some parameters couldn't be measured now. But the device is under operation at the moment. PLC integration details of the pneumatic actuator are given in Section III. Discussions are then included in Section IV. Finally conclusions and findings for this research are presented in Section V.

## II. TESTING DEVICE

### A. *Device Operation and Specifications*

The loading is applied by using pneumatic system elements. Automation of the test device is attained by a PLC (Programmable Logic Controller) and related software. The required loads are applied precisely with PLC and the measurement of carpet thickness is attained automatically. PLC system generates the necessary signals to adjust the amount and duration of air to be sent to the piston. It then sends them to the valve and the proportional regulator. The standard pressures are applied for the required period. The load is lifted at the end of the relevant period. The required loads are given as for; carpet thickness measurement, brief moderate static loading, extended heavy static loading (2 kPa-220 kPa-700 kPa). Testing device includes 5 testing units which is shown in Fig. 1. The specifications for the testing unit were determined. They were given in Table 1.

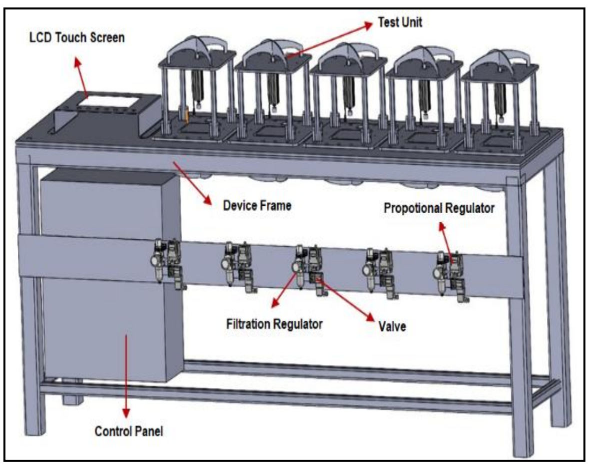


Figure 1. Representation of the device

TABLE I. TESTING DEVICE REQUIREMENTS

| | |
|---|---|
| *Loading-Unloading Unit* | Automatic |
| *Applicable Load Range* | 2 kPa, 220 kPa, 700 kPa |
| *Load Sensitivity* | ±0.2 kPa |
| *Thickness Precision* | ±0.01 kPa |
| *Actuation* | Pneumatic Cylinders (Up-Down) |
| *Applied Area Range* | 300 mm$^2$-1000 mm$^2$ |
| *Control* | PLC |
| *Test Unit Number* | 5 |

A piston cylinder has a diameter of 25 mm is selected with maximum pressure capacity of 1 MPa and a stroke capacity of 100 mm for thickness measurement. This provides a load creating pressure in the specified standards on pressing foot area (300-1000 mm$^2$). The distance between the piston cylinder and the carpet test sample was determined according to the stroke (100 mm) feature of the piston cylinder. An S type load cell has a maximum measurement capacity of 50 kgf with measurement sensitivity of 0.001 kg. Figure 2 represents the carpet test unit schematics.

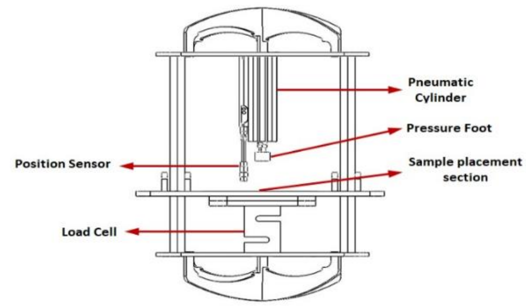


Figure 2. Carpet Test Unit Schematics

Three standard tests performed on the test device which are known as short-term static loading, long-term static loading, compression-return (resilience). Prototype testing device is given in Figure 3.

Figure 3. Prototype Device

### *B Automation with PLC*

Pneumatic cylinders are frequently used in industrial production where compression, pressure application, lifting or linear movement are required. CD55B25-100M SMC Cylinder with is 25mm in diameter. The maximum capacity of pressure is 1 MPa, it has a stroke capacity of 100 mm. D-MP100A SMC, has been selected as a position sensor model. The sensor has a 100 mm measurement capacity and analog output. It is a sensitive sensor that can be adjusted using the touch surface. Position measurement accuracy is 0.01 mm. ITV1030-01F2N3 SMC model proportional regulator; It controls the air pressure in proportion to the electrical signal, can be adjusted to MPa, kgf / cm², bar, PSI and kPa units. It has a pressure range of 0.005 to 0.9 MPa and was preferred due to its ease of installation features. VT307-5D1-02F-Q 3 port valve is used. Manometre-Q40-10Bar is used [10].

In the prototype unit shown in Fig. 4, the carpet sample to be tested can be placed and a load cell measures the load to be pertained to the sample carpet. It is then placed under this platform given in Fig. 3. A system assembly is created using four-sided metal bars for the connection of the upper and lower plates. The positioning is done in the middle of the upper plate. Thus, the load is applied to the center of the carpet sample. The position sensor used to automatically obtain the thickness data is appropriately placed on the cylinder piston. Pneumatic system and PLC hardware are included in Table II. Pneumatic cylinder details and specifications are taken from the data sheet, and given in Table III.

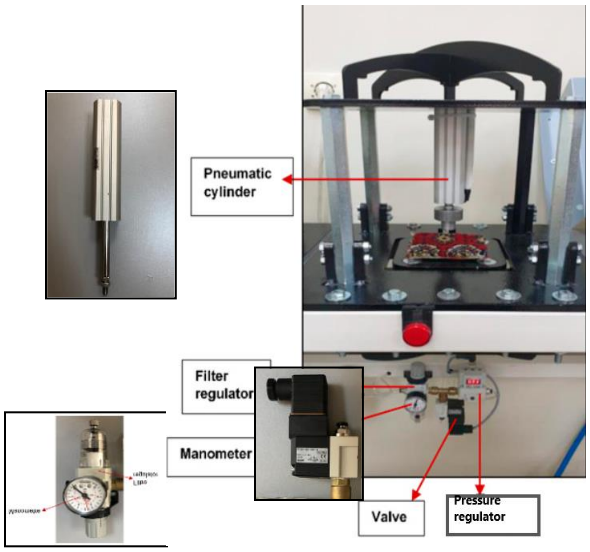


Figure 4 Photograph of the test unit with separated components

TABLE II. PNEUMATIC SYSTEM-PLC HARDWARE

| ***Pneumatic System*** | ***PLC Hardware*** |
|---|---|
| *Cylinder (Q25-100 mm)-5* | *7" Panel-Ethernet-65535 -1 piece* |
| *Position sensor-5* | *PLC CPU-Ethernet Port-5* |
| *Proportional regulator-5* | *Analog module-5* |
| *Valve-5* | *Digital module-5* |
| *Filter regulator-5* | *Load cell-5* |
| *Connection units* | *Panel-1 and Switchgear Materials* |

TABLE III. PNEUMATIC CYLINDER [10]

| ***Type*** | ***Pneumatic*** |
|---|---|
| *Action* | *Double acting-Single Road* |
| *Fluid* | *Air* |
| *Proof Pressure* | *1.5 MPa* |
| $P_{max}$ | *1.0 MPa* |
| $P_{min}$ | *0.05 MPa* |
| *Ambient-Fluid Temp* | *-10 to 60 °C* |
| *Stroke* | *+1 mm* |
| *Piston Speed (Φ20mm-Φ63mm)* | *50-500 mm/s* |

The PLC automation control system software has been completed in accordance with all test scenarios. The interface is completed on the LCD panel. The sensors used in the system are position sensors and load cells. The proportional regulator and valve are the actuators. The signal generated by the control unit with the load values (set load value) entered by the user. The interface is sent to the proportional regulator. Then the appropriate pressure air flow is provided from the valve. The amount of load applied to the carpet sample with the downward movement of the presser foot is measured by the load cell, and it is sent to the control unit as feedback. The control block diagram is given in Fig. 5.

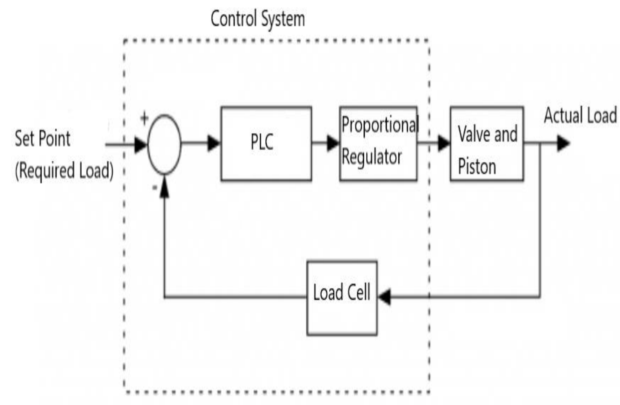


Figure 5. Control Block Diagram

The load applied on the sample remains constant for a period and load assigned. The movement of the presser foot is then measured using the position sensor to be placed on the piston cylinder block (Fig.4). The position sensor has a 100 mm measurement capacity and an analog output, the device can measure the thickness with a sensitivity of 100 mm ± 0.01 mm.

## III. MODELLING DETAILS

Pneumatic actuators are are used in various automation industries providing good force/weight ratio. These actuators show higher accuracy, excellent positioning control and e force control. Here some of the related research on pnematic actuators were dated and utilized in this modelling study.

V.Blagojevic et al. [11] have described a mathematical model and Simulink representation of the pneumatic system-bridging. The system given in the study includes pneumatic double-action cylinder, control manifold, valve for bridging, tubing and sensors. S. Pocari et al [12] have introduced the mathematical model of a pneumatic system with pneumatic cylinder, proportional valve and connecting tubes. Their mathematical model is built with LabView. T.Szakacs [13] has been studied industrial pneumatic cylinder motion with cylinder using a Matlab/Simulink® model *to* control for speed and position. T Dhanya and P.M.Gopal [14] have modelled a pneumatic controller using MATLAB/SIMULINK. System Identification has been used to estimate the mathematical model of a pneumatic actuator system. L. Dvorak et al. [15] performed an experimental study on pneumatic elements using Matlab-Simulink-Simscape. The testing of pneumatic elements mathematical models are given on the base of comparison with experimental data.

*A Pneumatic System Model*

A pneumatic system includes a pneumatic cylinder, a valve, connecting tubes, displacement, pressure and force sensors. The model includes cylinder dynamics, friction, payload and valve characteristics. A simple position control model was developed, The main components are the double acting two chamber linear cylinder which is connected to the load-model. The model building depends on simplifying assumptions. They are taken as ideal gas consideration, constant supply pressure and temperature, homogeneous gas in the cylinder and no leakage. The valve representation is given in Fig. 6.

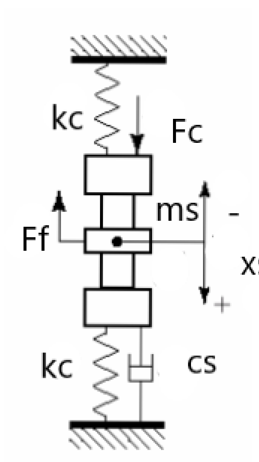


Figure 6. The valve representation proposed

Applying Newton's law here [12], the equation of motion for the piston rod including the mass and friction effects of pneumatic cylinder can be written as

$$m_s\ddot{x}_s + c_s\dot{x}_s - k_s(x_0 - x_s) + k_s(x_0 + x_s) + F_f = F_c \quad (1)$$

In equation (1); $x_s$ is the displacement of the valve element, $x_o$ is the initial compression of the spring in the equilibrium position, $m_s$ refers to the system mass, $c_s$ is the viscosity friction coefficient, $F_f$ is the frictional force, $k_s$ is the stiffness, and Fc is the force produced. Assuming with negligible friction and with no initial deformation, it then becomes as

$$m_s\ddot{x}_s + c_s\dot{x}_s + 2k_s x_s = F_c \quad (2)$$

The Laplace transform is applied to equation (2), the transfer function of the system is then obtained

$$\frac{X_s(s)}{F_c(s)} = \frac{1}{m_s s^2 + c_s s + 2k_s} \quad (3)$$

Here $F_c(s)$ can be replaced by $AP_c(s)$ with given datas for active area ($m^2$), then equation (3) can be rewritten by

$$\frac{X_s(s)}{P_c(s)} = \frac{A/m_s}{s^2 + \frac{c_s}{m_s}s + \frac{2k_s}{m_s}} \quad (4)$$

A- effective area for Φ=25 mm, $m_s$ - mass of the cylinder , ms=0,25 kg , $k_s$- spring stiffness, $k_s$ = 700 N/m , $c_s$ - friction coefficient, $c_s$ = 0,5 Ns /m
By utilizing the actuator data [10, 17], the transfer function of the analysed pneumatic system is then obtained.

*B. Testing Scenarios*

Different loading scenarios are applied during carpet sample tests. An example scenario named as short-term static loading is given in Figure 7. This loading test is performed and the percentage thickness loss and thickness recovery for a short interval of time are determined successfully. According to these scenarios, the loads are applied for the desired duration, thickness measurements are taken at the intervals specified in the standards. The information in the standard of the selected test can be seen on the main screen as the process step, applied load (kPa), load application time (sec) and waiting time. While the test is in progress, the duration of the load applied to the carpet sample can be followed instantly on the main screen in seconds, minutes and in percentage. The user is informed throughout the test with the instant thickness measurement information on the main screen.

The pneumatic system has been simulated using multiple trial runs in Matlab-Control Toolbox. CD55B25-100M SMC Cylinder with is 25mm in diameter [10]. The maximum pressure capacity is 1 Mpa here and its stroke capacity is 100 mm.

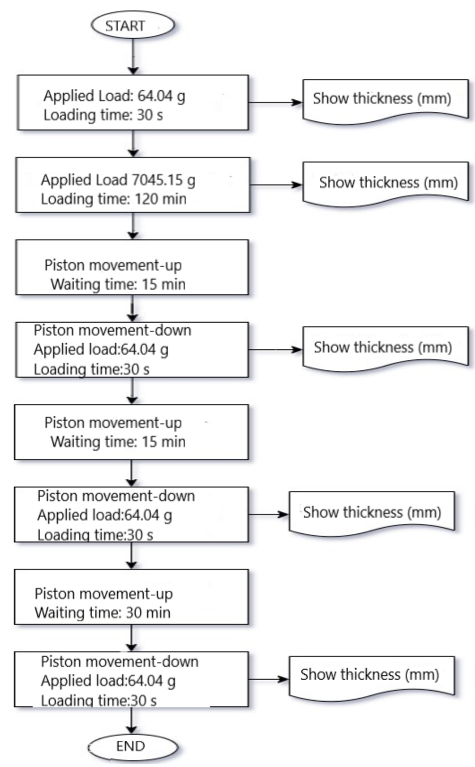


Figure 7 Short term static load testing -Flow chart

## IV. RESULTS AND DISCUSSIONS

Different load application mechanisms and carpet thickness measurement test devices are needed to determine the thickness loss after short-term static loading, thickness loss after long-term static loading, compressibility and resilience properties of the carpet. During the tests carried out using this equipment, the application of loads, monitoring of loading and waiting times, the measurement of thickness, the data acquisition and calculations must be carried out by an operator. In existing carpet thickness measuring devices, the thickness is measured by releasing the presser foot fixed on a shaft moving vertically onto a carpet sample placed on the device table.

According to the relevant national and international standards, it is mandatory to take at least 5 samples from each carpet sample for testing. It is not possible to test 5 samples at the same time with the long-term static loading test device, 5 devices must be purchased to test 5 samples at the same time. Otherwise, carpet testing will take 9-10 days. With this device and related details, the device has been presented, and previously patented. The statistical results are not included for tested specimens.

## V. CONCLUSIONS

Different load application mechanisms and carpet thickness measurement test devices are currently needed to determine the thickness loss after short-term static loading, thickness loss after long-term static loading, compressibility and resilience properties of the carpet. Basically, thickness loss after short-term static loading, thickness loss after long-term static loading, and compression and resilience tests and measurements can be performed simultaneously on five samples automatically with this device. Its control issues with PLC are studied. Here the experimental testing results are not presented. The model can be improved by considering nonlinear details, and piston animation with changing load motion.


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