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UNIVERSAL FORCE CONTROL SYSTEM FOR SMALL STATIC LOADS

Key words

Force measurement, tensile force, compressive force, control system for force adjustment, algorithm.

Abstract

The article is dedicated to a universal model force control system for small static loads. The requirements and the hardware configuration of the control system are presented. The authors also describe basic algorithms for controlling research processes, including issues related to force adjustment such as the automatic force loading and its measurement, the manual force exertion and its measurement, the automatic movement of the object, measuring of the force exerted on the object, as well as archiving and processing the measurement data. The exemplary results of verification tests were presented. Additionally, the possibility to analyse and archive the measurement data of the system is also shown. Finally, the authors describe other examples of applications of the developed control system.

Introduction

Producing a variety of materials and products requires their testing in order to maintain product quality, thereby creating a competitive commercial product. Therefore, the materials and other manufactured item are subject to relevant study and tests. Most of the materials and items made of metal, wood, and ceramics undergo strength tests [1]. The machinery used for the purposes of these tests is usually a universal materials testing machine [2], which can perform tensile and compression tests within a wide exertion range. Thus, using these machines for testing items that are loaded with small forces is inconvenient or even impossible. Such products are usually tested in specialized devices applying loads with high accuracy and small measuring ranges [3].

The article presents a universal force control system for small static loads, which can be used in specialized testing devices that enable force exertions such as the automatic force loading and its measurement, the manual application of force and its measurement, the automatic movement of the test object, and measuring the force exerted on the object. It can be also used for archiving and processing of the measurement data. The loads were determined with the use of methods dedicated to testing complex paper products, since the products of this type require a complex tests structure including nearly all the possible failure modes. The specificity of documents testing is described in the relevant standards [4] and the formal regulations of ICAO (International Civil Aviation Organization) [5].

1. Requirements analysis

Specialized devices performing document testing require continuous loads adjustments; hence, it was decided to develop a universal control system for small load adjustment, enabling three types of objects (documents) testing encompassing the following exertion of force:

- Cyclic combined loads: spherical compressive loads and spherical bending loads within the range of 10 to 350 N;
- Manual compressive loads within the range of 1 to 50 N; and,
- Tensile loads within the range of 0.1 to 100.0 N.

The analysis of the test objects devoted for a cyclic, combined, spherical bending loads and compressive loads involves applying a force that causes the compression and bending of the document on a spherical surface. These loads are exerted on the test object located between the movable metal, stamp-like object in a shape of a segment of a sphere and a flexible base (Fig. 1.)

The procedure of such a test is based on repeated pressing of the document to the flexible base with a programmable force in the range of 10 to 350 N. The applied force is maintained in each cycle of pressing within a programmable time from 1 to 100 s, and then the force is released. The procedure of the entire test involves a number of pressing cycles, within the programmable range from 1 to 99, for each of the two pages of the document.

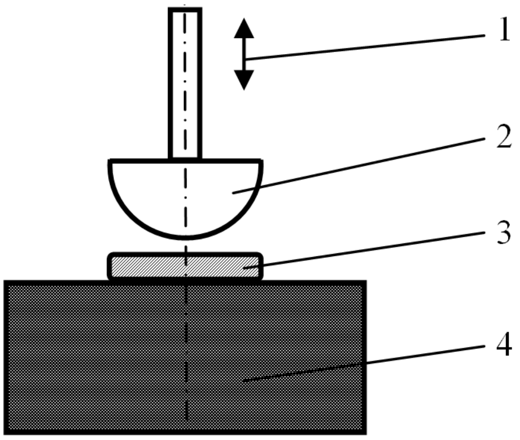


Fig. 1. Schematic diagram of the study of combined loads; 1 – direction of movement of a stamp, 2 – stamp, 3 – test document, 4 – flexible base

Testing objects to which manual tensile loads are applied involves the exertion of force stretching the document's sheets placed in the movable holder (Fig. 2.) To conduct this test, it is necessary to immobilize the entire book where the document is located in one holder, except the card selected for the test, which is fixed in the other, movable holder. Then, a manual sheet tension is applied to a specified value in the range from 1 to 12.5 N.

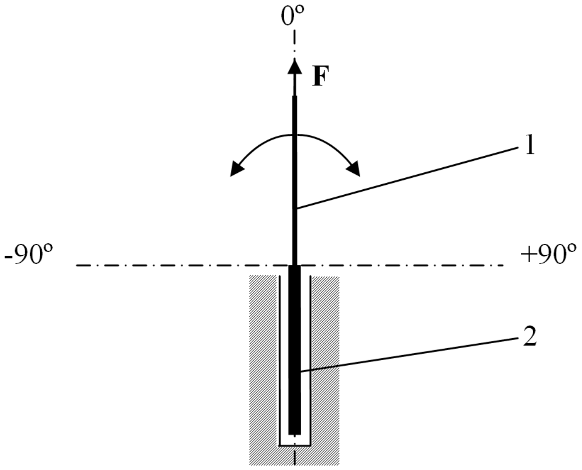


Fig. 2. The method of document testing, in which the tested card is placed in a movable holder; F – tensile force, 1 – test sheet, 2 – test document

Testing objects carrying tensile loads involves placing the document in the movable head and fixing the element of the document under tension into the measurement holder. The process of tearing off the layers of the document is carried out at a speed of 300 mm/min. Simultaneous measurement of the force and the movement of the tearing spot is performed (Fig. 3.) The collected measurement data undergo the analysis and acquisition in order to draw up a graph presenting the dependence of the tearing force on the movement.

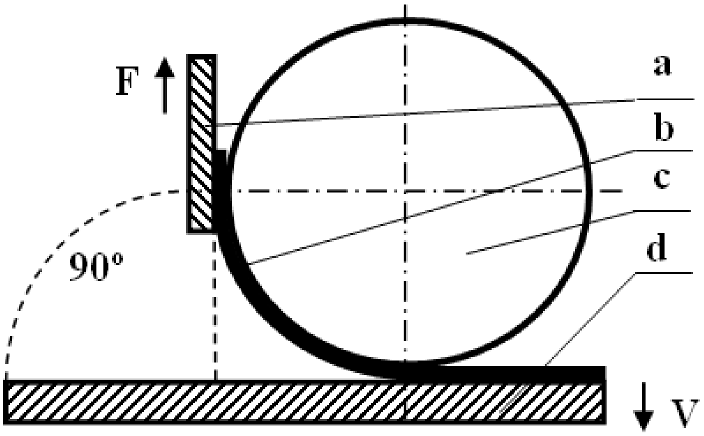


Fig. 3. The method of document testing with a tensile load; a – measuring holder, b – layer of the document being torn off, c – roller, d – core of the document, F – tearing force, v – speed of tearing movement

2. The development of control system

After analysing the various systems of force exertion, a force control system for small loads operating as a closed-loop system was developed (Fig. 4). The developed universal control system enables the exertion and stabilization of force as well as its measurement and filtration. Force exertion can be performed automatically using a stepper motor or manually. The system allows the use of stepper motors controlled with the aid of two types of interfaces: Digital Input/Output and CANopen interface. The developed system enables one to use the direct signal from the force measurement and the filtered signal in the process. Due to the different types and ranges of the test loads, three strain gauge sensors were selected for measurement. Two sensors of CL21ms type performing measurements in two ranges, which are different in sensitivity measurement, are for measuring compressive force, and one sensor of CL17pm type, is for measuring tensile force. The developed control system can use two types of controllers: Twido and M258 family [6]

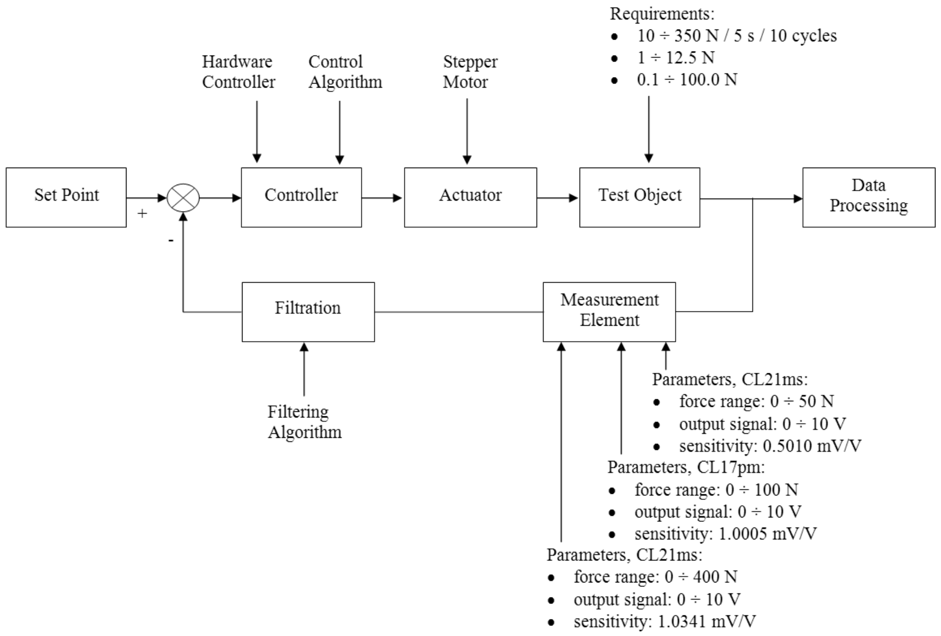


Fig. 4. Block diagram of the universal control system for small loads

There are two types of Magelis operator panels, the keyboard and touchscreen have the role of the setter in the developed system [6]. The data obtained in the process of force adjustment in the developed control system can be analysed and stored on a PC.

3. The development of control algorithms

For this developed hardware structure of the system, algorithms for static and quasi-static force control have been developed. Their examples are shown in Figure 5. Algorithms are presented using UML (Unified Modelling Language) activity diagrams [7, 8]. These algorithms illustrate the adjustment processes of exerting cyclic, compound, compressive and bending loads (Figure 5a), exerting manual, compressive loads (Figure 5b), and exerting tensile force (Fig. 5c).

The functional description of the exemplary process for force control that entails exerting cyclic, automatic, compound force loads and its measurement (Fig. 5a) is presented as follows. The algorithm begins by setting the programmable parameters of the test: the strength, duration of the force exertion and the number of cycles of force exertion. After approval of test parameters, the actuator is automatically moved to the position where the load is removed from the test object (F0 = 0 N). After reaching this position, it is confirmed by the system. Next, the implementation of the set number of cycles of force exertion is checked, n_P. When the set number of cycles of force exertion is not reached, the actuator is automatically moved in order to achieve the desired exertion force F_P. Once it is reached, it is held at the time of t_P. Next, the actuator is automatically moved to the position in which the load is removed from the test object ($F_0 = 0$ N). In this way, the complete cycle of applying force to a test object is performed. Then, the number of performed cycles is compared with a set number of cycles, n_P. When the set number of cycles is reached, the process of force control finishes.

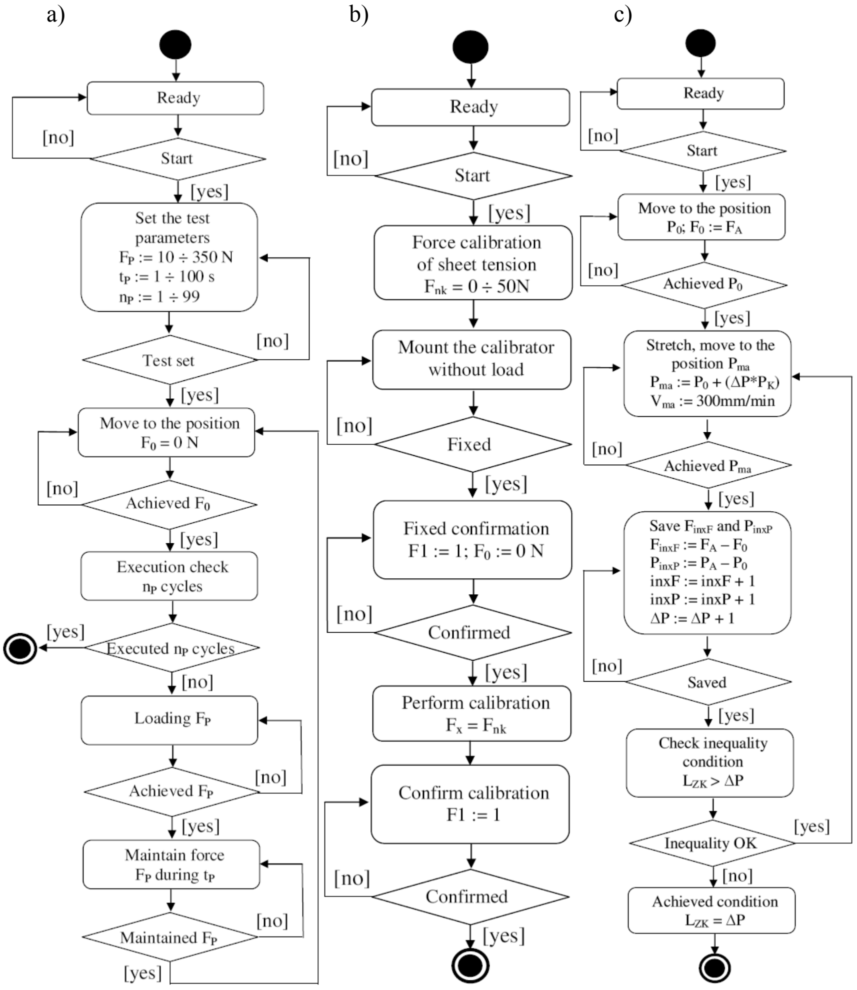


Fig. 5. Specification of the system using UML activity diagrams: a) Performing an automatic, compound force loading and force measurement, b) Performing manual compressive force exertion and its measurement with filtration, c) Performing automatic, step by step movements, measurement of tensile force and archiving measurement data

4. The verification of the control system

The verification of the developed universal control system of small static loads was conducted for three types of test objects: exerting a cyclic compound compressive load and a spherically bending load, as well as with a manual compressive load and a tensile load. The study entailed placing the control system in a mechanical frame enabling the desired force loading. An example of such a system is presented in Figure 6 that shows the stand for testing cyclic, compound compressive and spherically bending force loads. The study of the control system placed at the mentioned stand entailed testing compound, compressive, and spherically bending force exerted on the test object and its stability. In the study, the test object was automatically pressed to a flexible base, and the strength of pressure was subsequently maintained for a certain period of time after which the force was released (Fig. 7). The figure gives an example of an aperiodic process of such a study. In this study, the controlled variable is compared with the applied force of 350 N. The force is stabilized in a five-second period. Based on the process, control parameters were determined, which are as follows: settling time (t_R) equals 19 seconds and the overshoot not exceeding 5% [9].

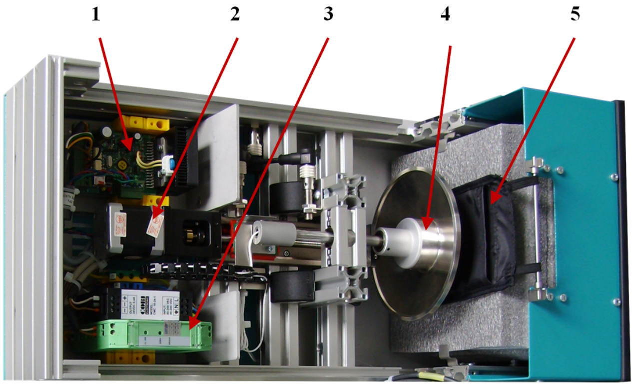


Fig. 6. The view of the stand for automatic, cyclic compound force loading and its measurement; 1 – stepper motor driver, 2 – stepper motor, 3 – measurement amplifier, 4 – stamp with a force sensor, 5 – test object

The developed control system enables the automatic process of force loading and its measurement in a cyclic mode (Fig. 8), with the possibility of setting parameters: strength, the time of the applied load, and the number of cycles of the load exerted on the test object. The value of the force exerted can be taken in the range from 10 to 350 N. The time of the force exerted can be taken in the range from 1 to 100 seconds. The number of performed cycles can be set from 1 to 99.

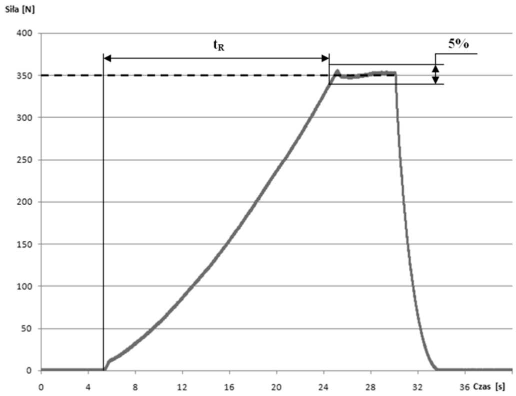


Fig. 7. The process of automatic force control with the set control parameters – The data are compiled based on the oscilloscope recording

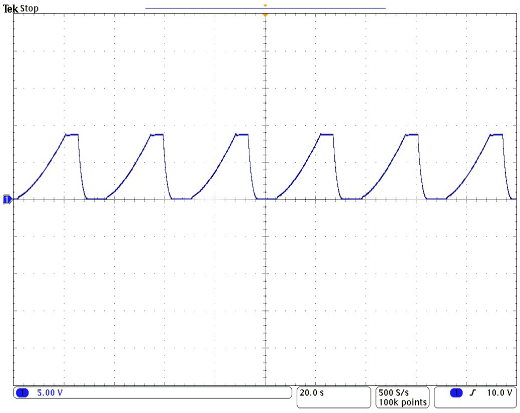


Fig. 8. Sample waveform of the cyclic operation of the control system – Ch1 – the analog output voltage of the measuring amplifier (5V/div) – The measurements were performed with the use of MSO4054 oscilloscope, and the voltage waveform was measured by P6139A voltage probe

The examples of results obtained from additional verification of the developed control system are shown in Figures 9 and 10. The test results from manual compressive force loading and filtration of the measurement signal (Fig. 9) show a comparison of the input – measurement signal (channel Ch1) with the filtered output signal of the control system (channel Ch2). The applied filtration method allows the elimination of rapid impulse interference appearing in the measuring signal.

The test results of the automatic movement control of the test object and measuring the tensile force exerted on the object, archiving and processing of measurement data were presented based on the report on the course of the study (Fig. 10), along with the underlying analysis of the measurement data.

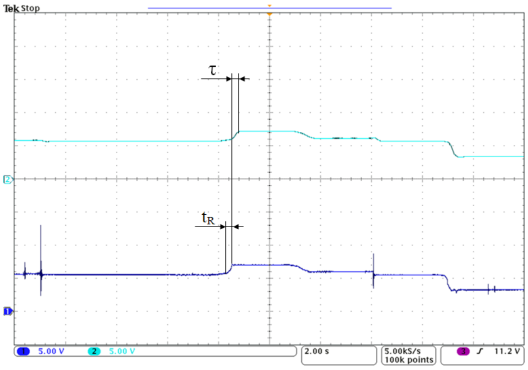
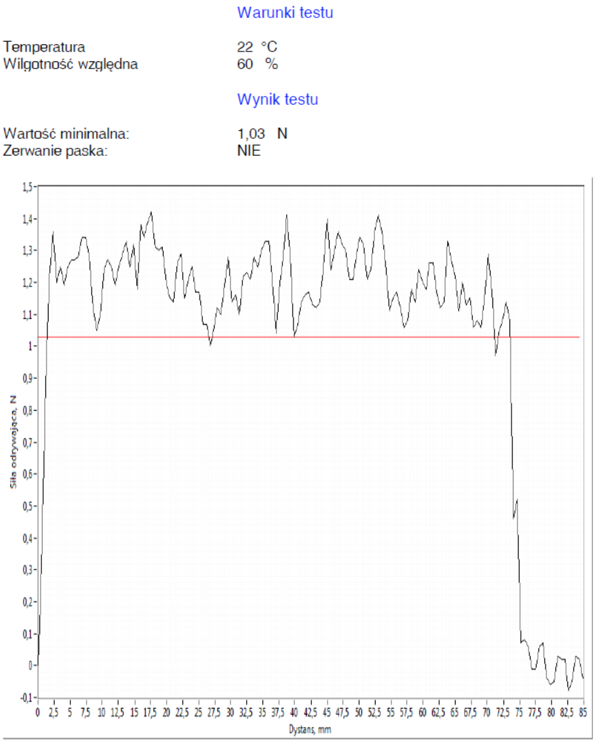


Fig. 9. Waveform presenting measurements and control of forces, with the set control parameters (tR – settling time, τ – the time of the signal delay) – Ch1 – the input voltage waveform of the control system (5V/div), Ch2 – the output voltage waveform of the system (5V/div) – The measurements were performed by MSO4054 oscilloscope, the voltage waveform was measured by P6139A voltage probe



Warunki testu

Temperatura	22 °C
Wilgotność względna	60 %

Wynik testu

Wartość minimalna:	1,03 N
Zerwanie paska:	NIE

Fig. 10. Example of the final report of the study in which the strip No. 2 of the card No. 3 was being torn off

This analysis consists in determining the smallest value of tearing force, continuing over a length of a card, which is longer than 1 mm and not within the range of the extreme measurements at the lengths of 5 mm. The measurement results can be archived as text files, and the final report can be archived as a PDF file.

Summary

A universal force control system for small static loads, dedicated to testing equipment, was developed. It allowed the implementation of programmable tests for small solid and semi-solid loads with the possibility of applying them in a cyclic mode. This system was used in three types of testing devices: a device performing multiple spherical bending of the document, a device for testing the resistance to tearing out the document pages at different angles, and a device for testing the strength of layers' adhesion in a multilayer document.

The developed control system is characterized by the possibility of applying two types of regulators, the possibility of using stepper motors as executing elements that are controlled by the digital I/O and CANopen interface, and the possibility of use as the measuring element two types of strain gauges. This system allows for easy configuration of its hardware implemented according to the requirements and cost of the test. The system is also a universal solution due to the possibility of its application in a variety of test machines, while ensuring good functional and metrological parameters.

The control system enables implementation of various control algorithms executing the following forces: automatic compressive force loading and its measurement in the range of 10 to 350 N, manual compressive force exertion and its measurement in the range of 0 to 50 N, and automatic movement while applying and measuring the tensile force as well as archiving the obtained data.

Another area of application of the developed solution can be systems for applying and testing small loads with a high degree of precision. The examples are devices for testing a variety of materials and plastic components [10], foil, elastic elements, flexible electronic components and systems, pulp, paper and printing products as well as various combinations of the above-mentioned items enriched with personal electronic systems such as RFID systems (Radio Frequency IDenification).

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Uniwersalny układ regulacji siły do małych obciążeń statycznych

Słowa kluczowe

Pomiar siły, siła rozciągająca, siła ściskająca, układ regulacji siły, algorytm

Streszczenie

W artykule opisano modelowy uniwersalny układ regulacji siły do małych obciążeń statycznych. Przedstawiono wymagania oraz konfigurację sprzętową układu regulacji. Podano podstawowe algorytmy sterowania procesami badawczymi obejmujące zagadnienia związane z regulacją siły, takie jak: automatyczne wywieranie siły i jej pomiar, manualne wywieranie siły i jej pomiar, automatyczne przemieszczanie badanego obiektu i pomiar siły wywieranej na obiekt oraz archiwizacja i przetwarzanie danych pomiarowych. Przedstawiono przykładowe wyniki z badań weryfikacyjnych, zaprezentowano możliwość analizy i archiwizacji danych pomiarowych układu oraz podano inne przykłady zastosowań opracowanego układu regulacji.