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Volume 5, Issue 2
January 14, 2016

Journal of Information Sciences and Computing Technologies
www.scitecresearch.com/journals

Computerized Measurement and Control System of the Universal Testing Machine Based On Virtual Instruments

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Abstract

The measurement and control system of the universal testing machine was carried on the data acquisition and processing and realized the closed-loop control of the actuators. This is a complete automated test platform of computer measurement and control technology. The electronic universal testing machine control system was designed and realized basing on the analysis of the related technologies and requirements. The system solves the determination of mechanical properties of materials such as tensile, elongation, force, deformation and displacement of essentially all metallic and non-metallic materials and it assumes good performance. This study has presented test results of six different materials specimens namely: plastic strip (fiber-reinforced polymer), brick masonry, floor tile, chamois leather bag, polyethylene polymer and polystyrene foam. The system uses a user-friendly dialog, it automatically measures material specimen, it compares the results with the standard national values and it can pass or reject unwanted materials. The measurement and control software for the host computer and electronic drive control system of electronic universal testing machine was realized by LabWindows/CVI software development platform. The user-interface provides features for the complete real-time measurement, control, data processing, output results display, report printing and other functions. Practice has proved that, under normal circumstances the system operation is stable and reliable, real-time data acquisition precision has reached the expected requirements as well as making system maintenance to be convenient and flexible.

Keywords: Universal testing machine; Computerized measurement; LabWindows/CVI; Real-time control; Data acquisition; Electronic drive control.

1. Introduction

Tensile and elongation testing is a fundamental material test in which a sample is subjected to uniaxial tension or compression until failure [1]. Testing machines are employed for essentially two reasons; the first is to develop new or better information on known materials or to develop new materials, the second is for maintaining the quality of materials. This is essentially useful to suppliers. For suppliers, the mechanical properties are an important measure of product quality. Occasionally testing is required to certify the product [2]. The test can provide much important information about the material of the sample, such as the amount of force required to break a material, modulus of material, the point of permanent deformation, stress-strain curves, etc. This information can be used to present a better understanding of known materials. A common piece of equipment used for tensile testing is the universal testing machine, which tests materials in tension, compression, or bending. A fundamental trend in the automated test industry is a heavy shift towards software-based test systems. The virtual instrument is trying to integrate all instruments; meter and computer into software. The test level and efficiency is improved when the virtual instrument access network [3, 4, 5].

In the development of new test equipment, improvement in instrumentation sensitivity and the accurate evaluation of basic material properties are important considerations. Better test methods and equipment are required to determine subtle differences in the new alloys and materials currently being developed, as well as to provide improvements in the economy of testing. There are several areas in the present testing procedure that can be improved without requiring extensive development, but by simply combining known techniques and equipment. Current digital and analog instrumentation techniques can be combined to obtain the improved accuracy and sensitivity necessary for modern material testing. These advanced instrumentation techniques would make it possible to preprogram the test strain rate or load rate, to hold it constant, consistent with testing specifications and to increase the number of tests performed per man-hour [6].

With proper data collection procedures, large quantities of information from many tests can be stored, and can then be readily recalled and compared on a statistical basis. Such stored information would be valuable not only to sales personnel requesting specialized properties of products but also to designers requesting statistical evaluation of standard characteristics in particular materials. Improvements in the tension testing techniques provide many additional benefits. Faster testing techniques allow a rapid turnover from test to experimental modification in research, as well as from test to product release in production. In research and development, it is possible to analyze material properties with a higher degree of accuracy so that secondary factors affecting material characteristics can be detectable. In production, when more than one facility is used to make the same product, the automated tension test would provide an excellent basis for quality control. Since the testing is preprogrammed and uniform from installation to installation, a rapid comparison can be made of the statistical material characteristics of products made on different production lines.

Material testing machines were initially manufactured in the 1800s and many older machines are still in use today. Often, the equipment remains functional decades after initial purchase, thereby returning the initial investment back to the owner. However, older machines should be upgraded to benefit from newer innovations and capabilities. The replacement costs for the older mechanical testing machines can be in the tens and hundreds of thousands of dollars. By retrofitting an older machine the owner will gain a clear cost benefits over the purchase of a new system. The reason for this is, since the most expensive and durable part of a new system is the load frame, keeping that old load frame in place and merely adding digital controllers and windows-based software, one expands the functionality with minimum investment. Testing requirements for major organizations such as ASTM, ASME, AASHTO, ISO, DIN, JIS and others undergo regular changes and continuous revisions as materials science and its applications evolve. Machines that were designed many decades ago may not have the correct capabilities to conduct the test and produce the data required by current and future standards.

This study addressed this problem by combining modern transducers, electronics, software and full servo control with an older system. Modern control engineering practice includes the use of control design strategies for improving manufacturing processes and the efficiency of energy use. This enables users to conduct more sophisticated tests using better control of the testing machine and many others through reporting. They are highly reliable, precise and accurate. Also, they are ideal for meeting the robust quality compliance and uptime demands of high-volume manufacturing and product development environments. Along with, precision force and motion control technologies and unrivaled testing expertise are integral to the research and development of materials, components and structures across a diversity of industries and fields. Other features include, high-resolution digital controllers which deliver high speed, closed-loop control and data acquisition for higher fidelity test data acquisition and the possibility for more meaningful analysis.

This gives rise to the need to develop an optimum, effective and inexpensive system that would completely perform the test by using automatically operated servo controlled equipment. In such a system, the machine automatically takes initial measurements, applies the load in a prescribed controlled sequence, records the information, records the final specimen information, reads out the computed results of the tests in visual format (as well as in a format that can be computer processed) and finally, ejects the specimen. The suitability of using this system is based on the following characteristics: fixed voltage sensitivity; low impedance output; high resolution; easy installation; and low cost.

This paper is organized in 6 sections. Section 1 is the introduction, Section 2, necessary related works are presented. In Section 3 the description of the testing equipment and procedure are presented. Section 4, the monitoring software development are indicated. Section 5, presents results and discussion. And section 6 provides conclusions and future insights.

2. Related Works

Several authors reported contributions to the development of measurements and control systems of the testing machines. In order to make a practical application of virtual instrument (VI) technology to material property testing, [7] upgraded a conventional torsion testing machine. The upgraded part of the machine consisted of the hardware and software. The hardware comprised the torque and angular displacement transducers, control instruments and a personal computer (PC). The software was developed by LabVIEW and composed of testing and reporting subsystems. Another technique widely used for local constitutive properties characterization is tensile testing of miniature samples extracted from different weld regions. Reference [8] for example, analyzed the asymmetric mechanical properties of aluminium friction stir welds by testing miniature specimens. In the same way, [9] used micro-mechanical experiments together with digital image correlation (DIC) to quantify the material response within the periodic bands of aluminium friction stir welds. However, since the production and testing of miniature specimens is difficult and expensive, alternative testing techniques are always being proposed.

A non-contact real-time strain measurement and control system based on the digital image correlation method (DICM), has been successfully established for cyclic/fatigue tests of polymer materials by [10]. It allows recording of the evolution of strain during the entire fatigue life of the polymer materials under test. The stress/strain hysteresis loops can also be accurately recorded through synchronizing the stress and strain data. Furthermore, the strain data can be fed back to the control system of the test machine to perform a strain-range controlled fatigue test.

Reference [11] presented descriptions of the structure and functioning of automated test stands for testing static and dynamic contact welding at a high current load, equipped with a computer measurement control system. The authors presented specialist software developed for the stands and there were given exemplary results of contact tests. The developed computer programs ensure complex operation of the stands, including control, measurements, visualization and data acquisition.

The WE300A universal testing machine system was upgraded by using virtual instrument [5]. The software developed was based on PCI bus and runs on the LabWindows/CVI platform. The system can send data which is acquired from the universal testing machine to the Internet/Intranet through the DataSocket server. The users can acquire the data from Internet/Intranet terminal node. However, no test samples were reported in their work.

A measurement and control system was designed according to the requirement of digital transformation to the WJ-10 universal tension and compression testing machine [12]. This system was made up of two parts: The data acquisition system based on C8051F020 and the monitoring system based on the virtual instrument LABVIEW. The physical quantities (such as tension, pressure, deformation, temperature, etc.) of the specimen during the tension and compression experiment were digitally and graphically displayed and stored by using this system. The historical data and curves can be called to be compared to the current experimental data.

This study analyzes several key problems in the design of electronic universal testing machine control system composition and working principle and system. These include how to satisfy the strong real-time requirement of the system, how to test data online processing, how to effectively test analysis, how to draw the curve and how to realize the automatic control requirements. The paper puts forward effective solutions, sums up the general modular structure of electronic universal testing machine control system. The current control system has passed the inspection and testing, and formally puts into use. The system solves the determination of mechanical properties of materials, and gets good performance. Practice has proved, under normal circumstances the system operation is stable and reliable, real-time, data acquisition precision has reached the expected requirements and the system maintenance is convenient and flexible.

3. Description of the Testing Equipment and Procedure

The testing equipment and procedure used is the electromechanical machine which uses a combination of a motor and gear reduction system to move a crosshead up and down to provide force to the sample. The speed of the motor controls the speed of the crosshead. Load cells with different grips are attached to the crosshead. Depending on the material, geometry and strength of test specimens, grips are selected accordingly. In tensile testing, the specimen is held securely in the jaws of the upper and lower grips. The upper grip is attached to the load cell that is mobile in the vertical direction and the lower grip is attached to the fixed base plate of the load frame. In compression testing, an anvil is coupled with the load cell to apply loads to the specimen which is placed on the table. The diameter and loading capacity of the anvil is important in compression testing [3]. The system follows the following sequence of operation:

- Automatically transferring test results from their testing machines into host computer system or database, to eliminate data entry errors.
- Automatically calculating test results, to reduce test times.
- Verifying test results to ensure there were no calculation errors.
- Verifying that a test was performed according to specification to ensure the loading rates or rates of travel were correct.

- Easily comparing old test results to more recent results, simplifying test procedures to reduce test times and improving the accuracy and reliability of their testing machine.

The monitoring and control system hardware design mainly includes an AVR ATmega64 microcontroller (MCU) as a core control system and peripheral circuit design. The control system uses serial peripheral interface (SPI) bus, RS485 bus, IIC bus, RS-232 serial communication interface, pulse counting and other functions. The ATmega64 MCU has enhanced low-power AVR RISC architecture, data throughput up to 1MIPS/MHz, which can alleviate the contradiction between system power consumption and processing speed. The input analog signals from force, displacement and deformation sensors are digitized using analog to digital converter AD7705 chip and fed to the MCU. On one hand, the microcontroller performs computations and transmits the information to the personal computer for data analysis, processing and display. The PC also saves the measured data in the database. It issues commands to control the servo drive unit for testing the specimens. On the other hand, the MCU transmits the information to the electronic drive control system for stand-alone system. The measured results appear on the liquid crystal display (LCD) device. The base of the universal test machine is attached by internal gear system and the servo drive system, the console, a bearing platform and movable components. Built-in monitoring system console is the core of the entire instrument control, mainly by instrumentation amplifier, ADC, signal conditioning circuit, keyboard, etc. The force sensor value detection and measurement is done by the incremental photoelectric encoder pulse counter. Meanwhile, the control system via Modbus protocol precisely controls the servo drive unit to achieve precise testing speed regulation control, displacement distortion control and force control. Figure 1 shows a functional block diagram of the hardware monitoring and control system.

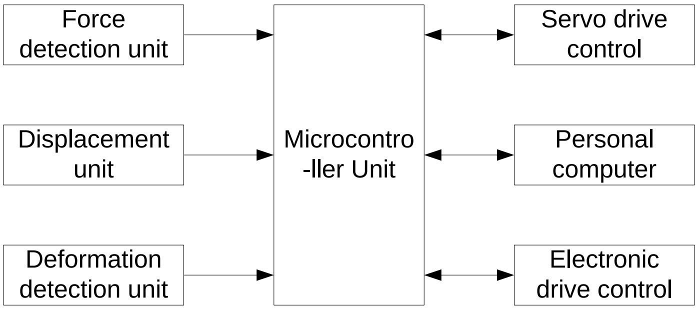

Fig 1: Functional block diagram of the hardware monitoring and control system.

The servo drive is a closed loop control system with variable frequency in order to meet the desired speed and accuracy of the control system. Currently, the servo drive control system operates in three modes: the drive panel setting, analog input settings and bus command set. From the control point of view, the latter is more convenient for setting panel and from the flexibility and precision of operation. The bus command setting mode is much better than the former. Therefore, the measurement and control system for controlling the servo drive unit is used with a bus drive. Typically, the bus servo drive follows MODBUS industrial bus protocol. Modbus is the world's first truly industrial field bus common language protocol used in electronic controller.

4. Monitoring Software

The measurement and control software for the host computer was realized by LabWindows/CVI software development platform whereas the electronic drive control software of electronic universal testing machine was realized by ICCV.7 of AVR. This system can test all kinds of metals and non-metal materials in accordance with the relevant national standards. The user-interface provides features for the complete real time measurement, control, data processing, display result output, report printing and other functions. The main features include real-time measurement and display of test force and peak value, displacement, deformation and other signals, realizes real-time acquisition and control of servo drive system and realizes the precise timing and high speed sampling. The implementation of the test force-time, force-displacement, and test displacement-time should be real-time displayed in a variety of experimental curve display and can always switch observation and zoom, and save operation curve very conveniently. In addition, it supports a variety of control methods including open loop constant displacement and speed, constant stress and a variety of closed loop control modes. Moreover, the system can automatically calculate and generate test report of material test data according to user needs and the corresponding national standard compilation and printing. The implementation of the test force and deformation of the automatic calibration and easy to operate improves greatly the reliability of the machine. For safety use, the system is equipped with an overload protection with automatic shutdown function and automatically determines the specimen fracture.

The LabWindows/CVI software delivers the versatile array of test definition, analysis and reporting capabilities required to address the evolving needs of advanced researchers, as well as the intuitive operator interface needed to establish and sustain standard, industry-compliant manufacturing quality testing. To ensure the function of the majority of the test sample material for testing, the system detects in real time the data sample to be uploaded to a computer. The computer system software supports a large number of test data processing to ensure that the system can detect a large number of data in real-time, secure transmission to the computer, communications interface between the computer system and a USB communication ports.

The virtual instruments, that is, on to the general-purpose computer as the core hardware platform design is defined by the user. The test function is achieved by the test software with a computer system virtual instrument panel. Users can operate this computer via user-friendly graphical interface, as in the operation of their own customized as a traditional instrument. It takes full advantage of the unique computing, storage, playback, call display and intelligent features such as document management, while the traditional instruments of the specialized features and software of the control panel combine to make it blend with the computer. So they constitute a fully functional of computer resources from the exterior to the same traditional instruments, while use fully a new intelligent instrumentation system. LabWindows/CVI software features robust capabilities for interacting numerically and graphically with post-test data. With this operation one can get the most from test results with intuitive displays and flexible, interactive data plots and have full freedom to explore different scenarios by adding variables, calculations, tables or charts. Integrated analysis tools include movable markers, text and construction lines, and the ability to define the region of interest and easily zoom in for closer inspection. Multiple graphs of the same post-test data can even be contrasted simultaneously for deeper insight into test specimen properties.

A computer system is employed to input design specifications for each of the subroutines that make up a software application that is to be the target of a test and the express preconditions and postconditions based on the design specifications. Internal databases are constructed to maintain target type relationships, subroutine declaration syntax and data requirements, condition-subroutine associations, and invariant-type associations. This software equips users with flexible tools for presenting and sharing test data through detailed runtime reports. They can output results directly via a user friendly standard report template Add-In for Microsoft Word and Excel to create custom reports as a process independent from testing itself. Programming tests and monitoring results can be performed through the powerful and intelligent graph work test software, which facilitates comprehensive data management in accordance with national and international test standards.

Based on virtual instrument technology, the system combined with computer technology and instrument technology, sampling the multi input parameter signals and exporting the detailed control signal in the coordination with the hardware. Also, this software monitors and controls the applications process, hardware circuit, real-time sampling, data analysis and signal processing. According to measurement and control requirement, it generates the control signals on the basis of feedback control algorithm, expressing and exporting data, thus achieving a wide range of automatic test requirements and specific function. Software is the key of virtual instrument [13, 14]. Control parameters are auto-tuned in real time based on test force and tensile/strain values measured during testing. This eliminates the need for preliminary testing and makes it easy to perform highly precise stress-controlled or strain-controlled testing. Test force and strain can be measured without having to specify an amplifier range. This means data can be acquired using optimal measurement parameters, even for specimens with unknown strength. In addition, since the analog indicator and output to the data recorder have a virtual range, evaluation is possible in the same manner as before.

Full retrofit is defined as a project where the entire control and data acquisition components are replaced with solid state electronics. In a servomotor that is based on a closed loop system, the current into the motor is continuously updated according to three loops controlling the system. These include a torque (current) loop that controls the amount of the current into the windings, the position loop, and the velocity loop. In most servo-systems, there is direct relationship between the current into the winding and the torque supplied. Optical encoders are used to measure the position, and the velocity data are calculated by real time digital processing of the position data. For each specific control, acquisition, and analysis function provided by the controller card, a library of VIs can be assembled. These VIs can then be used together to create specific testing procedures [15, 16, 17].

When developing these in house systems, several safety precautions must be considered. Various interlock mechanisms for operator protection and fail-safe operation may be employed. The system can be equipped with a visual indicator for the operational status, and a computer controlled stop switch. Two mechanical limiters can mechanically shut the motor off and disengage all torque when exceeded. These may be located at the upper and lower ranges of motion, and activated by the testing arm itself. The third level of safety is provided by the main power switch on the front of the test frame cutting power to release all torque. The fourth level of safety is a built-in limit in the encoder motor. The motor shuts off and disengages all applied torque when a certain error limit is reached. Its internal PID filter (proportional, integral, and derivative) keeps track of exactly where the motor should be and it compares this with the data coming in from the encoder. Any discrepancy is stored as error. This error accumulates while the motor is in servo mode. When the error limit is exceeded the motor is automatically shut off and all torque gets released. If the testing arm tries to move and is unable to do so, it accumulates error and will eventually shut-off. This eliminates concern for a runaway motor crushing up against the top or bottom of the apparatus. The experimental set-up photograph of brick measurement and the electronic drive control system is shown in Figure 2.

Fig 2: The experimental set-up photograph of brick measurement.

5. Results and Discussion

Electronic universal testing machine based on PC has a good test performance, test data, the curve display intuitive and accurate motion control. The system configuration is simple while having strong processing ability of data. Electronic universal testing machine control system has strong real-time performance, scalability, execution of motion control and force control, the exact mechanism of reliable automatic test and multitasking performance requirements. The measurement and control system not only must carry on the data acquisition and processing, but also realize the closed-loop control of the actuator. It is the automated test platform of computer measurement and control technology together. The electronic universal testing machine control system was designed based on the analysis of the related technologies and requirements. The realization of the related functions can solve practical problems for engineering applications and has clear engineering background and application value.

The system main software interface is shown in Figure 3. One can complete the adaptation of national standards. The data show that curve analysis, automatic report, a variety of testing methods, data re-analysis and other functions achieve printing, testing, statistics, sensor channel switch, instrument control and other operations. Personal Computer (PC) software can achieve the instrument's speed and position control, real-time data display, the current value of the force, displacement, deformation data, force and displacement peak values.

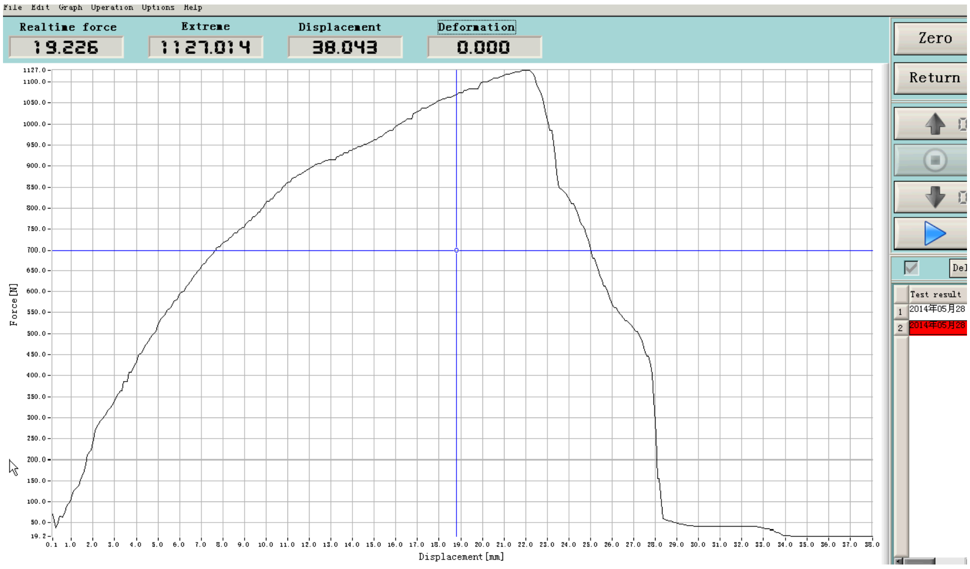

Fig 3: The system main software interface displaying force-displacement curve for the plastic strip specimen.

Two samples of plastic strip (fiber-reinforced polymer) specimens with an area of 55 mm2 and 100 mm length were subjected to tensile and elongation tests. As seen in Table 1, the average maximum force was 11.9019 N, the average deformation was 15.4679 mm, the average tensile was 0.2164 MPa and the average elongation was 15.4679%. Initially, system configuration and parameters settings were performed with standard values. The tensile and elongation values are calculated by the formulas 1 and 2 respectively. The data for this plastic strip shows that as the current input increases, the voltage output demonstrates a linear trend as expected.

$$T = F_{Max} \times A \qquad (1)$$

$$E = \frac{D}{L} \times 100 \qquad (2)$$

Where:
T: Tensile [MPa]
F_{Max}: Maximum force [N]
A: Area [mm^2]
E: Elongation [%]
D: Deformation [mm]
L: Original length [mm]

Table 1. Test results of plastic strip standard no. GB/T11063-2010

S/N	Parameter name	Sample 1	Sample 2	Mean
1	Area [mm*mm]	55.0000	55.0000	55.0000
2	Maximum force [N]	4.5776	19.2261	11.9019
3	Deformation [mm]	9.0234	21.9124	15.4679
4	Original length [mm]	100.0000	100.0000	100.0000
5	Tensile [MPa]	0.0832	0.3496	0.2164
6	Elongation [%]	9.0234	21.9124	15.4679

In a similar manner, the sample of brick masonry specimen with an area of 55 mm2 and 100mm length were subjected to tensile and elongation tests. As depicted in Table 2, the maximum force was 14.0381 N, the deformation was 4.3 mm, the tensile was 0.2552 MPa and the elongation was 4.3%. Tensile strength at the interface is primarily due to chemical bond. This bond depends upon the absorption rate of brick units. High absorption rate decreases the strength of the bond. Thus, brick units are usually wetted before they are laid. Direct tension and bending usually cause the bond to break, and where the break occurs we have separation of brick units and mortar layers. Strong mortars are usually associated with brittle and explosive failure while weak mortars are associated with ductile and slower rate of crack propagation.

Furthermore, the sample of floor tile specimen with an area of 55 mm2 and 100mm length were subjected to tensile and elongation tests. As depicted in Table 3 and the force-time, displacement-time and force-displacement curves for the tests in Fig. 11, 12 and 13 respectively, the maximum force was 0.9155 N, the deformation was 1.2031 mm, the tensile was 0.166 MPa and the elongation was 1.2031%.

Next, the sample of chamois leather bag specimen with an area of 55 mm2 and 100mm length were subjected to tensile and elongation tests. As depicted in Table 4, the maximum force was 48.8281 N, the deformation was 35.8875 mm, the tensile was 0.8878 MPa and the elongation was 35.8875%.

Moreover, the sample of polyethylene polymer specimen with an area of 55 mm2 and 100mm length were subjected to tensile and elongation tests. As depicted in Table 5, the maximum force was 93.689 N, the deformation was 40.182 mm, the tensile was 1.7034 MPa and the elongation was 40.182%.

Lastly, the sample of polystyrene foam specimen with an area of 55 mm2 and 100mm length were subjected to tensile and elongation tests. As depicted in Table 6, the maximum force was 93.689 N, the deformation was 40.182 mm, the tensile was 1.7034 MPa and the elongation was 40.182%.

Table 2. Test results of chamois leather bag specimen standard no. GB/T 11063-2010

S/N	Parameter name	Sample 1	Mean
1	Area [mm*mm]	55.0000	55.0000
2	Maximum force [N]	48.8281	48.8281
3	Deformation [mm]	35.8875	35.8875
4	Original length [mm]	100.0000	100.0000
5	Tensile [MPa]	0.8878	0.8878
6	Elongation [%]	35.8875	35.8875

Table 3. Test results of brick masonry specimen standard no. GB/T 11063-2010

S/N	Parameter name	Sample 1	Mean
1	Area [mm*mm]	55.0000	55.0000
2	Maximum force [N]	14.0381	14.0381
3	Deformation [mm]	4.3000	4.3000
4	Original length [mm]	100.0000	100.0000
5	Tensile [MPa]	0.2552	0.2552
6	Elongation [%]	4.3000	4.3000

Table 4. Test results of floor tile specimen standard no. GB/T 11063-2010

S/N	Parameter name	Sample 1	Mean
1	Area [mm*mm]	55.0000	55.0000
2	Maximum force [N]	0.9155	0.9155
3	Deformation [mm]	1.2031	1.2031
4	Original length [mm]	100.0000	100.0000
5	Tensile [MPa]	0.0166	0.0166
6	Elongation [%]	1.2031	1.2031

Table 5. Test results of polystyrene foam specimen standard no. GB/T 11063-2010

S/N	Parameter name	Sample 1	Mean
1	Area [mm*mm]	631.4087	631.4087
2	Maximum force [N]	10000.0000	10000.0000
3	Deformation [mm]	10.0037	10.0037
4	Original length [mm]	100.0000	100.0000
5	Tensile [MPa]	0.0631	0.0631
6	Elongation [%]	10.0037	10.0037

Table 6. Test results of polyethylene polymer specimen standard no. GB/T 11063-2010

S/N	Parameter name	Sample 1	Mean
1	Area [mm*mm]	55.0000	55.0000
2	Maximum force [N]	93.6890	93.6890
3	Deformation [mm]	40.1820	40.1820
4	Original length [mm]	100.0000	100.0000
5	Tensile [MPa]	1.7034	1.7034
6	Elongation [%]	40.1820	40.1820

The specimens were subjected to a tensile test with a deformation rate of 5mm/minute. It can be noted that the displacement-time curves for all the specimens under test was increasing linearly until when the maximum force was attained and decreased linearly in the reverse direction until the end of test. Therefore, this result is acceptable to confirm that the test was accurate and precise.

6. Conclusions

The measurement and control system for the universal testing machine has been designed, developed and it successfully realized all functional testing machine system requirements. The computer software and programming test machine monitoring and control system has achieved the desired results. Practice has proved that the system has a precise motion control, high precision, high stability and powerful data analysis capabilities. Studies of material behavior under mechanical tensile have been widely performed using universal tensile testing machines. However, none of the studies have been done to study a critical property of wide range materials in relation to mechanical properties like our work. Specimens can potentially be different types of materials including metallic and non-metallic materials.

Future development efforts of the universal testing machine should involve improving the digital controller that is capable of achieving an industry-leading data acquisition rate as an integral component of a universal test machine. The machines will be able to acquire higher definition monotonic test data in fewer cycles and they will be able to include more complex quasi-cyclic test applications that are not possible with simple controllers.

Acknowledgements

The author would like to thank Dr. Jimin Zhao for his technical assistance during experimental tests and Mr. Lott Champuku for formatting the manuscript.

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