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UNIVERSAL TESTING MACHINE AND A VERIFICATION OF NON-CONTACT REAL-TIME STRAIN MEASURMENT BY DIGITAL IMAGE CORRELATION METHOD

UNIVERZÁLNÍ ZKUŠEBNÍ ZAŘÍZENÍ A OVĚŘENÍ BEZKONTAKTNÍHO MĚŘENÍ DEFORMACÍ METODOU DIGITÁLNÍ KORELACE OBRAZU

Abstract

The universal testing machine which serves mainly for research of the strength criteria and investigation of the fatigue strength is briefly described in introductory part of this paper with emphasize on its control system. Using the laboratory testing system a non-contact real-time strain measurement based on the Digital Image Correlation Method (DICM), has been successfully established for uniaxial cyclic/fatigue tests of steel. It allows recording of the evolution of strain during the short fatigue life of the steel under test. A frequency of 10 Hz for strain data acquisition was reached. The success of this method would facilitate performing various types of fatigue tests on different kinds of material and would allow gaining better insight and understanding of their fatigue and failure behaviour.

Abstrakt

Univerzální zkušební stroj, který je používán zejména pro výzkum kritérií statické i únavové pevnosti, je stručně popsán v úvodní části článku se zaměřením na řízení stroje. S využitím tohoto zkušebního stroje bylo úspěšně realizováno bezkontaktní měření deformační odezvy pomocí metody digitální korelace obrazu při cyklickém jednoosém namáhání. Metoda byla použita pro měření deformace během krátkého úseku klasické zkoušky nízkocyklové únavy. Snímání průběhu deformace bylo provedeno s frekvencí 10 Hz. Úspěšnost této metody v případě víceosého namáhání by umožnila provádění únavových testů pro rozmanitou oblast materiálů a napomohla by porozumění jejich únavového a poruchového chování.

1 INTRODUCTION

Strain gauges and extensometers have served as conventional strain measurement tools in most mechanical experiments. Their use in cyclic/fatigue tests could meet some difficulties. For example, strain gauges could not be used if fatigue life of the gauges was shorter than that of the material tested. For relatively soft materials such as polymers, the knives of the extensometer could cause local damage (even with protective film) and thus the obtained fatigue life could be much shorter than that of a specimen with a smooth surface. Fatigue tests can be carried out under load (stress)-controlled or deformation (strain)-controlled modes. In most cases, the local strain values are not directly measured or carefully monitored during the entire test procedure. Availability of an

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effective non-contact strain measurement method becomes increasingly necessary to gain more insight into the fatigue behaviour of various materials.

2 UNIVERSAL TESTING MACHINE

This section describes control of the universal testing machine for research of the strength criteria and research of the fatigue strength – see [1]. The laboratory testing machine is based on the frame INOVA 200 ZUZ. This testing machine consists of two pillars fixed in the bottom and top cross beam. There are two hydraulic motors. The top cross beam carries a rotation hydraulic motor, which can stress the test sample by torque up to 300 Nm. The bottom cross beam contains a build in linear hydraulic motor, which enables stressing of the test sample by axial tensile (or pressure) force up to 200 kN. The test sample is fixed from the top in rotation jaws, while from bottom is specimen fixed in measuring jaws. The rotation jaw is connected with rotation hydraulic motor and makes impossible axial shifting of the sample. Bottom (measured) jaws is connected with linear hydraulic motor and makes impossible rotation of the test sample. The model of testing machine is at Fig. 1.

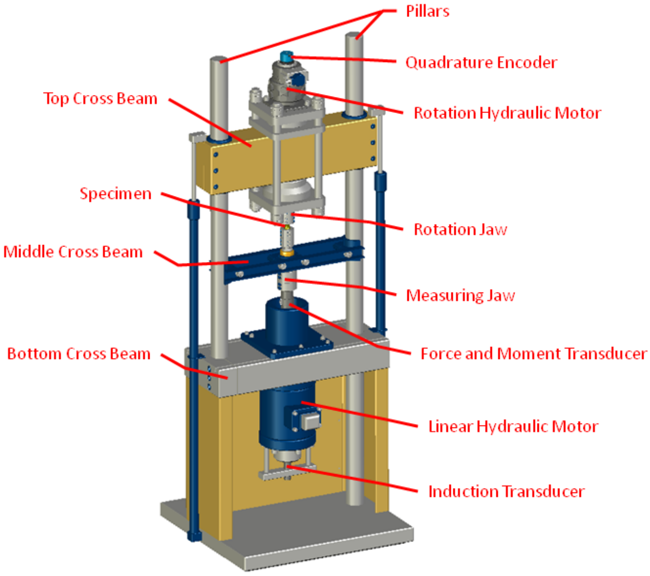

Fig. 1 The laboratory universal testing machine

The control system is divided to two independent hardware parts (distributed system) – controlling computer (measurement, controlling and collecting dates) and operator's computer (provides graphical user interface for communication with the controlling section). This conception makes possible to separate time critical tasks (for example enquiring dates, control algorithm) out of problems which are not from measuring and controlling point of view so important (for example communication with operator).

Operator's computer is standard personal computer (processor Pentium 4 2,8 GHz, RAM 1 GB) with Windows XP Professional SP2. Second one is based on PXI system. Controlling computer (PXI system) is based on NI PXI – 1010 case with controller NI PXI – 8184 RT (processor Celeron 850 Hz, RAM 256 MB) and with DAQ devices (NI PXI – 6251, NI PXI – 6602) and with signal conditioning hardware (SCXI – 1121/1321). Hardware architecture of the system is schematically displayed in Fig. 2.

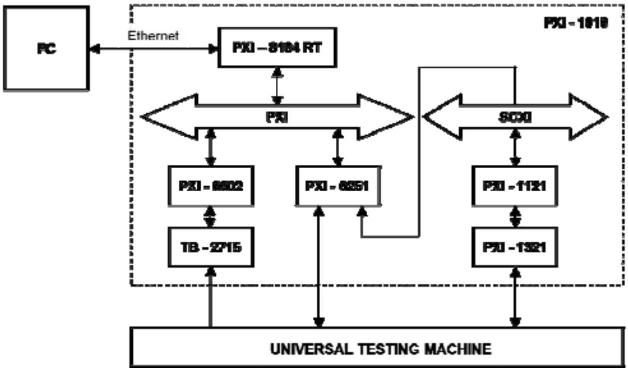

Fig. 2 Hardware architecture of the controlling system

Control and data acquisition is realized by own software developed in NI LabVIEW Real – Time. National Instruments LabVIEW is graphical programming development environment for creating design, control and test systems. The Real – Module extends the LabVIEW development environment to deliver deterministic, real – time performance.

The control application is divided to two high level independent parts (client/server architecture). Visualization part (GUI) of software is running on the PC. The front panel of visualization part is at Fig. 3. This part is client Control and measuring part is running on PXI Real – Time controller. This part acts as server. Both parts communicate via Ethernet connection by TCP/IP protocol. Main control loop used software Proportional-Integral-Derivative (PID) algorithm.

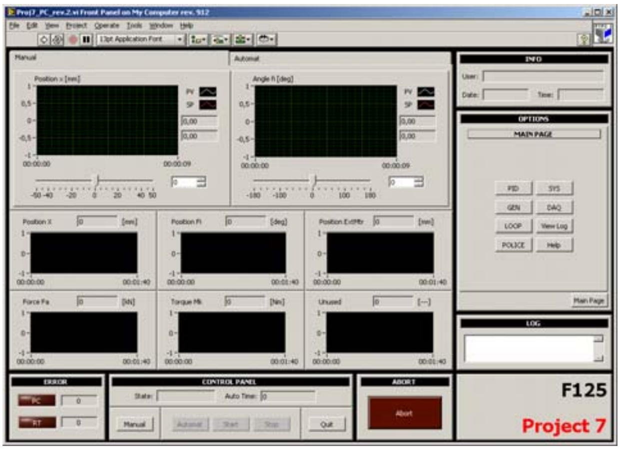

Fig. 3 Front panel of application

3 THEORY OF DIGITAL CORRELATION METHOD

The Digital 3D-Correlation System Q-400 used in this work is an optical instrument for full field, non contact and three-dimensional measurement of deformations and strains on components and materials. The system uses two high resolution digital cameras to record surface changes of the object under investigation while loaded or moved. The recorded images are analysed and compared by a special correlation technique which allows the determination of the object contour as well as the surface displacements with high local resolution.

Images, taken before and after deformation of an object, represent the positions of the object at these two moments of time. To retrieve the in-plane displacements at a certain point of interest on the object, a small subset surrounding this point in the reference image (taken before displacement) is selected to match the similar subset area in the target image (taken after displacement). This procedure is called digital image correlation. The correlation algorithm based on the tracking of grey value pattern in small local neighbourhoods. When G(x, y) marks the grey value of a pixel with the coordinate x and y inside of the subset or facet the correlation algorithm minimized the sum [2], [3]:

$$C = \sum_{i} (G_t(x_{t,} y_t) - G(x_t, y_t))^2 \tag{1}$$

$$(G_t(x_{t,} y_t) = g_0 + g_1 G(x_{t,} y_t) \tag{2}$$

$$x_1 = a_0 + a_1 x + a_2 y + a_3 xy \tag{3}$$

$$y_2 = a_4 + a_5 x + a_6 y + a_7 xy \tag{4}$$

where:

$G_t(x_t, y_t)$, $G(x_t, y_t)$ – grey valuess of each pixel in the reference and target images,

C – correlation coefficient [-],

x, y – coordinate inside of the subset [m] ,

a_i – affine transmission [-],

g_i – illumination parameters [-]

However, in the practical application of 3D image correlation techniques some basic conditions have to be observed. As example, the calibration of the cameras has essential influence on the performance of the complete system.

4 SAMPLE TESTS RESULTS

The specimen was sprayed due to creation of the subset containing little facet elements (Fig. 4). Then a digital image correlation process determines the shift and/or rotation and distortion of little facet elements determined in the reference image. A strain-range-controlled uniaxial cyclic test was carried out with strain range of 0.6% and mean strain of 0% (Fig. 7). Due to the fact that extensometer hid the part of the specimen surface, the strain measured by DCIM was evaluated from displacement values measured at the points near the extensometer´s knives (Fig. 6a) using equation (5). Due to the required time for digital image processing, the sampling frequency of the current correlation system is not as high (the sampling frequency of digital cameras was 10 Hz) as that by using the traditional strain gauge or extensometer (100 Hz). Firstly, the main task of this work was focused on capturing the sampling frequency of the extensometer by the help of DICM. Due to the fact of the low hardware capacity, this was successfully done for the time range from 45s to 51,5s of the experimental data of strain-range-controlled cyclic test (Fig. 7). Secondly, we verified the possibility of data capturing with regard to strain gradient. The strain values between the extensometer’s knifes are evaluated as average strain values (Eq. 5) from the experimental data acquired by extensometer. On the contrary, the DICM is able to capture the strain gradient at the observed area of the specimen (Fig. 6b).

$$\varepsilon_x = \frac{\Delta L}{L} = \frac{\Delta x_1 - \Delta x_2}{L} \tag{5}$$

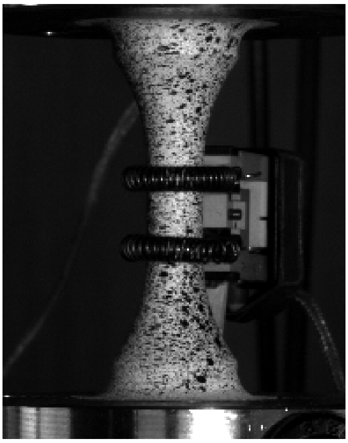

Fig. 4 Sprayed specimen

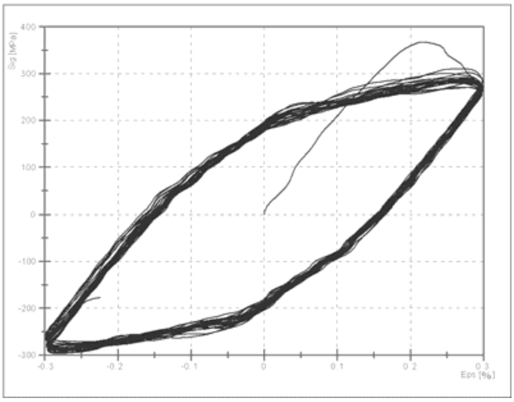

Fig. 5 Stabilisation of stress response (25 cycles)

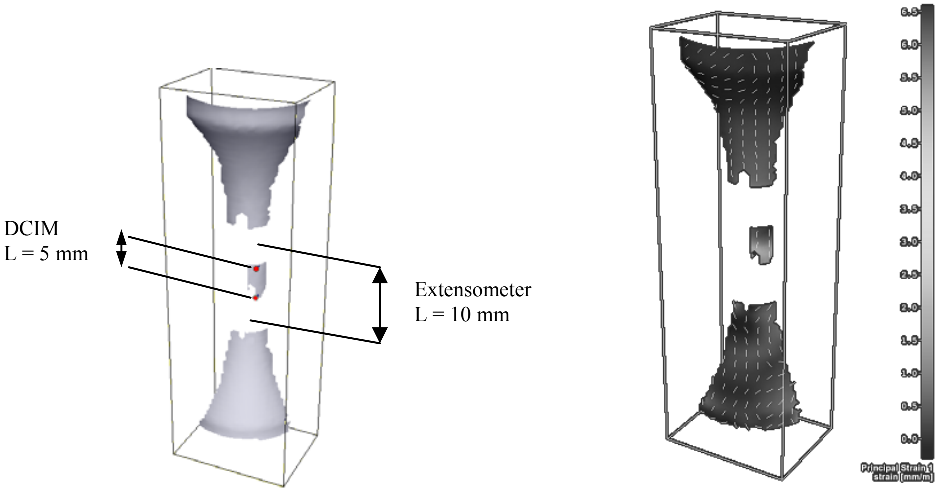

Fig. 6 (a) Contour of the specimen evaluated by DCIM; (b) Strain gradient evaluated by DCIM

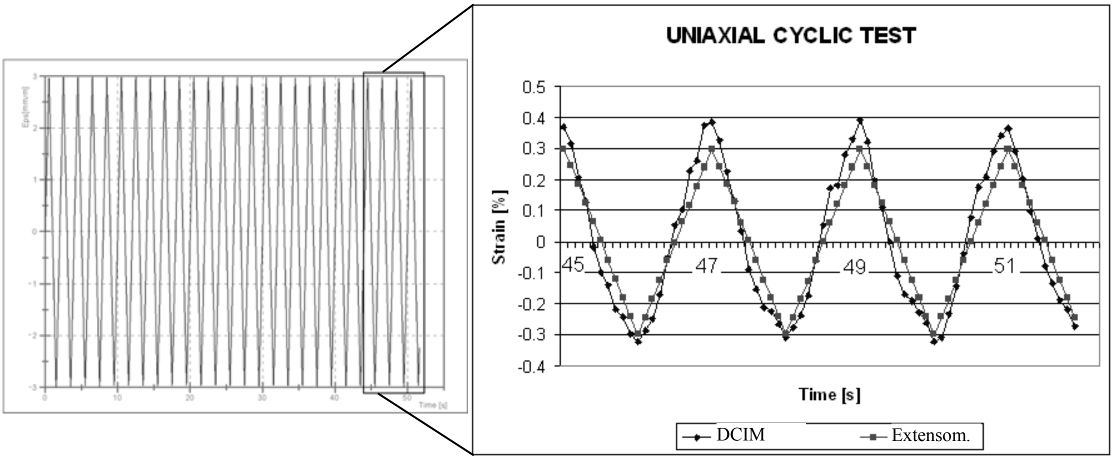

Fig. 7 Sampling frequency range measured by DCIM and extensometer

The axial strain computation using equation (5) was found to be more accurate than the commercial algorithm for strain computation. During the measurement the strain accuracy 0.1 % only was achieved, because too large area was focused and it was possible to consider only very short distance between evaluated points. Unfortunately, it was not possible to come more closely to the specimen.

5 CONCLUSIONS

A non-contact real-time strain measurement based on the digital image correlation technique has been established. Currently, the system can measure strains with an accuracy of 0.01% in the ideal case of measuring area 20 x 15 milimeters and a frequency of 10 Hz for strain data acquisition. The capability of the system has been verified through the strain-range-controlled cyclic uniaxial test. In a future study the digital 3D-correlation system Q-400 will be also used for axial/shear strain component measurement in cyclic tests under tension/torsion loading and the main aim will be an evaluation of available cyclic plasticity models.

A biaxial state of stress or strain can be imposed in the thin-walled tubular specimen using the universal testing machine described in section 2. Three loading configurations are possible: (a) axial force (tension-compression) and torsion, (b) axial force and differential pressure (internal-external), and (c) axial force, torsion and differential pressure. The universal testing machine was also extended by the device for rolling contact fatigue research [4].

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