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Development of a fatigue test machine for high frequency applications

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Abstract

In this research, a complete system of a force control unit implemented on a home-built electro-mechanical fatigue test machine is proposed. The entire system includes an electro-mechanical shaker, a load cell, a controller, dedicated software, and an external metallic structure to constrain the specimen. Admittedly, the bending fatigue test on flat specimen has to be measured by applying a cyclic force with a constant frequency. The simplicity of the machine and its cheap overall price are the most important advantages of the proposed system. Moreover, the machine has been designed based on the specimens suggested in ASTM standard Bending Fatigue Testing for coating samples. For demonstration of machine functionality in this paper, the measured results of some fatigue tests have been presented in order to show the efficiency of the system. In this regard, Aluminium flat specimens were deposited by Bronze through cold spray coating and they have been used as samples for test. The results show that the machine is capable of following the perquisite requirements mentioned in the ASTM standard.

Keywords: fatigue test machine, fatigue coating tests, test design

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1. Introduction

To improve the mechanical characteristics of metals and metal alloys, the technique of coating [1] are often used. Verification of resistance of these modified materials in their external structure is carried out in various ways. One way to measure the material changes due to the coating effect is the fatigue test and, in particular, tests on specimens designed as described in the ASTM standard [2].

Again with reference to this specification, an entire system performing the fatigue tests were designed. This system utilizes such specimens measuring some defining characteristics.

Based on the existence of machinery already in operation, were selected very efficient individual components and built a test machine with the objective of maximizing the efficiency of the tests in terms of implementation, testing time and costs of the entire machine.

The working parameters on which we based the implementation of these tests are the excitation frequency of the specimen, the forces applied at one end side of the specimen and the displacement of this extreme [3, 4].

As noted in the frequency range of the execution of the tests is from 10 Hz to 30 Hz, the applied force is around 3-25 N and the displacements are about one tenth of a millimeter. In addition to the benefits of the choice of components, has been implemented a control software that can handle the evidence with maximum efficiency and safety.

Automation concerns the disruption of the test in the specimen's rupture moment. In this way you will not have downtime, and there is less danger on the movement of the machine with broken specimen still vibrant.

The article is structured to highlight in the first paragraph a general introduction to the problem, in the second section a detailed description of the lay-out, HW and SW, in paragraph three experiments on samples of metal alloy covered with spray Bronze and paragraph four conclusions about the system.

2. The fatigue test machine

In this section a short description of the fatigue test machine is proposed. The main features required by the test rig are the high frequency (about 20 Hz), with respect to the common hydraulic test machines, and an harmonic force with a zero-peak amplitude up to 100 N. To satisfy these requirements the layout reported in Fig. 1 is adopted.

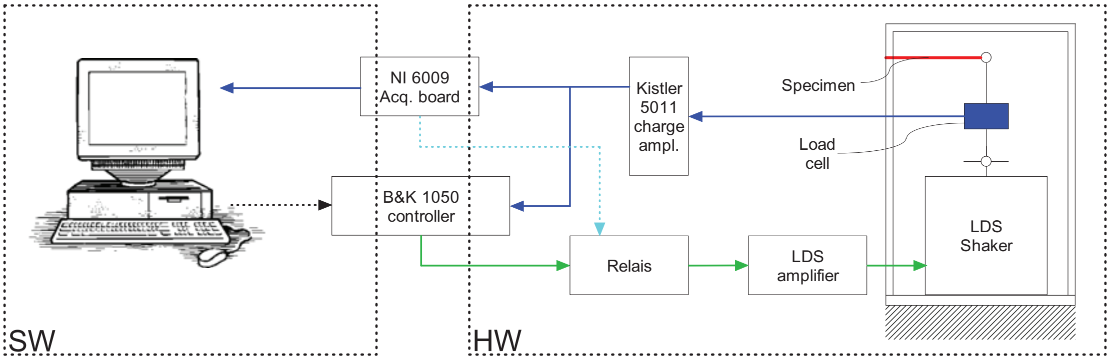

Fig. 1. The fatigue test machine layout

It is possible to distinguish two different levels: the hardware (HW) and the software (SW).

(a) (b)

Fig. 2. The machine hardware level: (a) the shaker and the reaction structure, (b) the specimen and the load cell

The HW level includes the test machine composed by a LDS type V406A electrodynamics shaker and a reaction structure on which the specimen is rigidly connected (clamp, Fig. 2). The main characteristics of the shaker are summarized in Table 1. It is important to underline that, due to the specimen high flexibility, also the displacement limit ($A_{p\text{-}p}$ sine equal to 17.6 mm) has to be considered during the test design.

Table 1. The LSD V406A shaker main features

Specification	Limit
Min frequency	2 Hz
Resonant frequency	9000 Hz
Max displacement ($A_{p\text{-}p}$ sine)	17.6 mm
Max velocity ($A_{0\text{-}p}$ sine)	1.78 m/s
Max acceleration ($A_{0\text{-}p}$ sine)	490 m/s^2
Max force ($A_{0\text{-}p}$ sine)	100 N

On the other side the specimen is linked to the shaker by means of a rod on which a piezoelectric 2.5 kN load cell (type 9301) is mounted. The transducer allows to measure the force applied to the specimen and to feedback it to the controller unit. The double-hinge connection avoid the undesired bending moment transfer.

The controller unit is a Brüel&Kjær 1050 (±10 V input and output signals, 1 MHz clock base, PD compensator) driven by a software developed in NI LabVIEW. The controller allows to set the test frequency and amplitude that is continuously compared with the actual value measured by the load cell. Moreover a NI 6009 acquisition board is able to sample the force signal (1 kHz sampling frequency) and to send it to the SW (Fig. 3). This stores the data with a given law (e.g. 20 cycles every 60 s), analyzes the signal in real time (min/max value, FFT…) and runs an algorithm to manage the alarm condition. In fact, to automatically stop the test when the sample is broken, it is possible to define a suitable threshold on the measured force harmonic component at the assigned frequency.

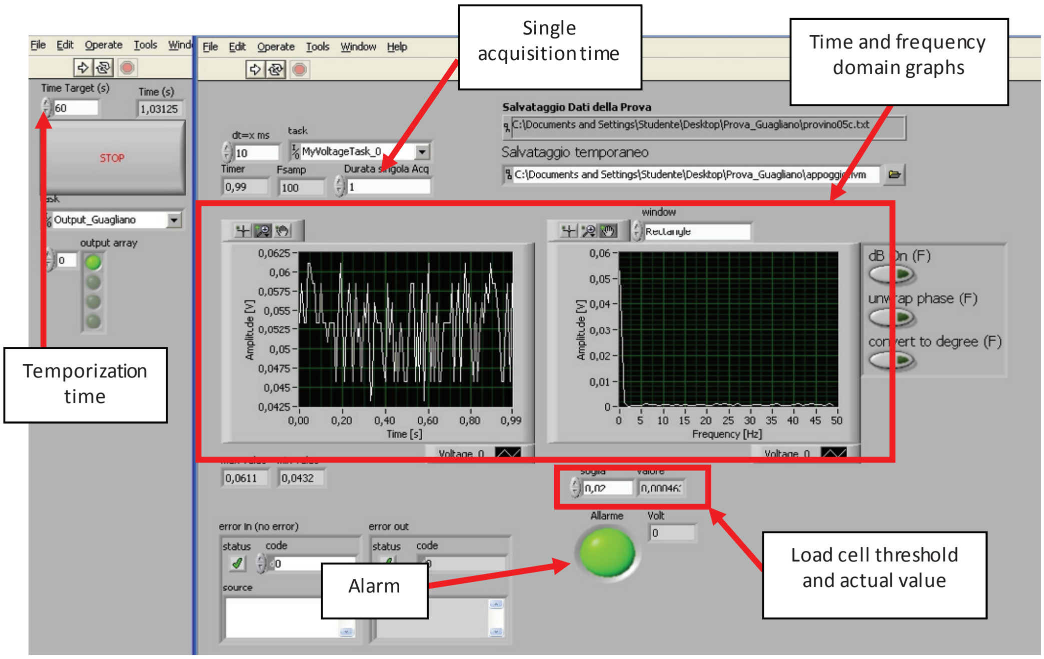

Fig. 3. The machine software level

In order to evaluate the benefits introduced by the proposed solution, a rough economical insight is reported in Table 2. The total cost can be directly compared with the commercial machines one, quantifiable in about 120 k€, with a cost reduction greater than 80%.

Table 2. The proposed solution economical effort

Component	Cost
NI 6009 acquisition board	300 €
LDS V406A shaker + amplifier	5000 €
Kistler 9301 load cell + amplifier	3700 €
B&K 1050 controller	12000 €
Personal computer	500 €
Other	500 €
TOTAL	22000 €

3. The coating tests

For showing the test machine capability, 11 aluminum specimens which are geometrically followed the ASTM coating standard have been tested with the machine. Fig. 4 shows the two series of specimens with and without coating which have been tested. Five specimens are coated with cold spray coating by bronze powders. The cold spray coating is an emerging technique in which the particles deposited on the substrate by their high kinetic energy due to their supersonic velocity [5].

Fig.4: a) Aluminum specimen coated by bronze and b) non coated specimens

On the specimens, different loads have been applied in order to examine the fatigue limit of two different types of shown specimen in Fig. 4. Fig. 5 shows the quality of applied load by the machine for two different range of the loads 3N and 20N. As it is shown in Fig.5 there is some disturbance in the applied load (at about 40Hz) in both low and high force due to the small non-linearity in the mechanism. Fig. 6 shows the final results of the number of cycles and applied stress on the specimens. The number of specimens is not enough in order to have a complete estimation of the Wöhler diagram [6], but it shows that the machine is capable of applying different loads and can restore the data for a long period of time. Fig.6 shows a slight improvement in fatigue life of coated specimens. Anyway it needs more information and study for a better conclusion of the specimens' behaviour.

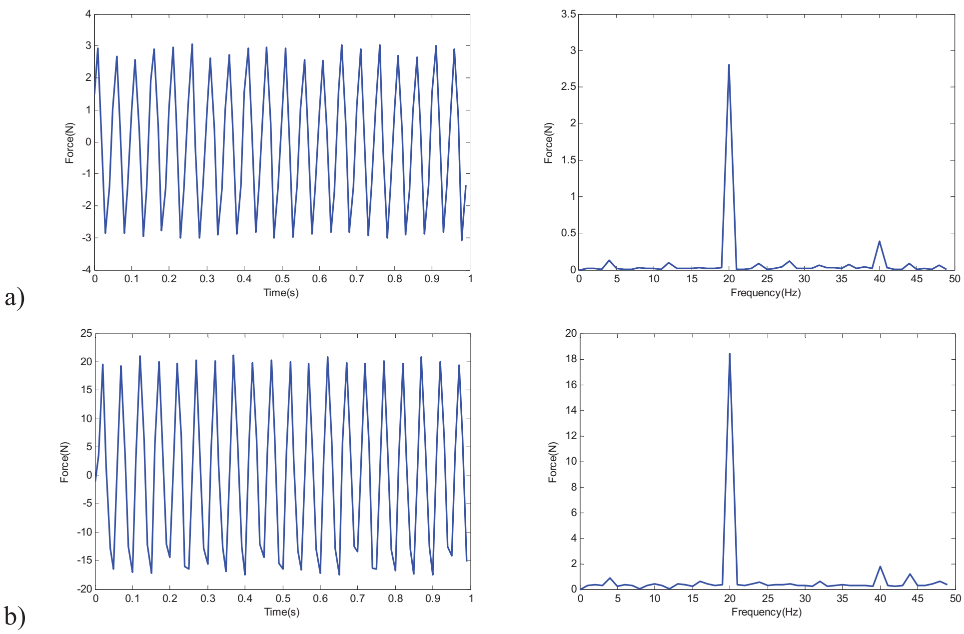

Fig.5 the load applied by machine for 60s of working at a) 3N and b) 20N

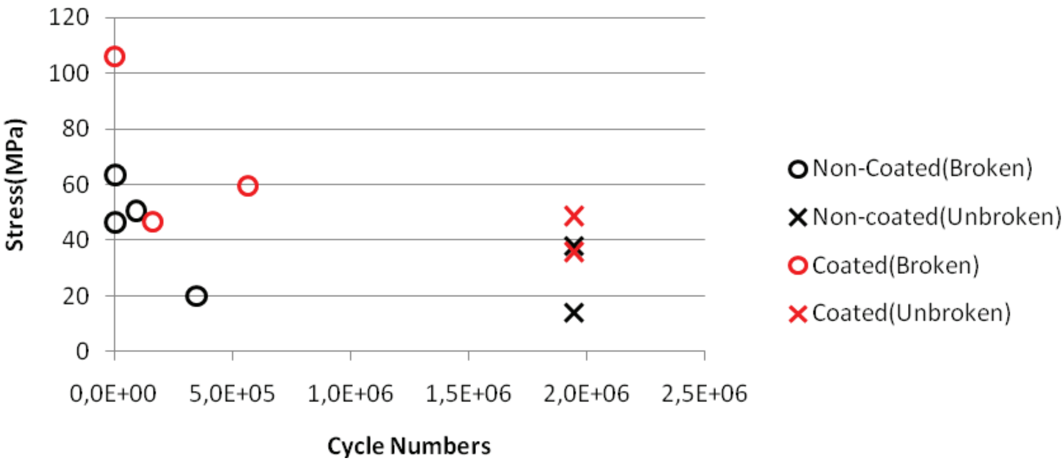

Fig.6 Cycle-stress diagram for both coated and non-coated specimens.

4. Conclusions

A test machine based on the standard description has been developed. The machine is capable of doing the fatigue test in different range of loads with different frequencies; by combing the SW and HW with a developed code, the machine can restore the data during the test by any needed resolutions. Two series of tests on the suggested specimen by the standard have been examined on the machine in order to check the performance of its different aspects. Although, the applied forces are not completely noiseless, not only the performance of the machine follows the perquisite requirement mentioned in the standard, but also the cost of the machine is considerably less than the commercial competitors in the market. Based on the presented results, the machine is able to continue working for a long period of time and meanwhile it can restore the data of applied load. The connection between SW and HW stop the machine when the specimen breaks for the safety of the machine and counting the number of cycles. There are more steps for taking in order to improve the performance and data acquisition of the test machine.

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