XVII IMEKO World Congress
Metrology in the 3rd Millennium
June 22–27, 2003, Dubrovnik, Croatia

METROLOGICAL CHARACTERIZATION OF A FATIGUE TEST MACHINE FOR TESTING IMPLANTOLOGICAL AND PROSTHETIC MATERIALS FOR DENTAL APPLICATIONS

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Abstract – A fatigue test equipment is presented for the mechanical characterization of dental implantological and prosthetic materials. An automated control system, based on the digital processing of the feedback signals coming from field sensors, is proposed, in order to perform long-period, non-observed tests in a secure way.

The metrological characterization of the realized equipment is discussed and an automatic compensation of the mechanical errors is proposed.

Keywords: Biomechanics, fatigue, Automatic tests.

1. INTRODUCTION

It is well known that, in order to obtain the correct characterization of implantological and prosthetic materials submitted to fatigue stress, it is important to stress the materials correctly, with cyclic loads.

In the literature, different fatigue test machines and test procedures have been proposed [1-9], but the main problem of the proposed methods is that they don't allow to work near the dental elements. Moreover, the proposed methods allow to stress the specimens only with fixed loads in directions and values.

In previous works a fatigue test machine able to simulate the behaviour of the mandible in the masticatory stage both in a physiological and in a pathological way has been proposed [9,11].

A fixed loom equipped with a mobile part (simulating the mandible) realizes the mechanical structure of the machine.

The fatigue test machine is able to realize the three movements necessary to simulate the behaviour of the mandible in the masticatory stage:

- opening and closure movement,
- latero-laterality movement,
- longitudinal rotation movement.

The proposed operating principle of the machine is schematically reported in fig. 1.

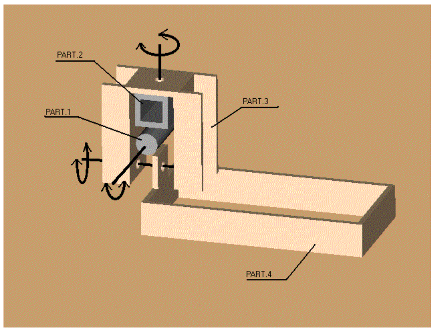

Fig. 1 a schematic of the realized mechanical structure

The views related to the three different movements of the machine are reported in figs. 2, 3, 4. The relative functional diagrams are depicted in the same figures.

In particular, fig. 2 represents the opening and closure movement, while fig. 3 and fig. 4 represent respectively the latero-laterality movement and longitudinal rotation movement.

The control of these movements was carried out by placing, in the same-gear case, three channels at the service of the relevant driving gears; this gear-case drives the pneumatic system of transmission and control of the load, formed by three differently sized pistons (with respect to the loads transmitted) linked to the mobile parts of the system. The load transmitted by each of these pistons can be modulated by acting on the pressure regulator valve placed at the source of each of them.

Anyway, the main problem of the machine reported in [11] is that it is manually controlled.

For this reason a Virtual Instrument (VI) acting as supervisor of the system has been realized.

The VI, whose architecture will be described in section 3 and 4, is devoted to the control of the system; it is implemented into two sections, both working "on line": a control and measurement section and a diagnostic section.

The aim of the present work is the complete characterization of the test machine presented.

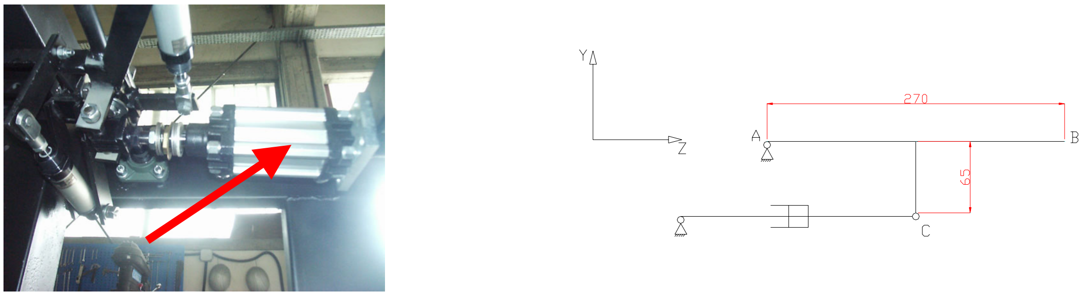

Fig.2 Drive of opening and closure movement; the arrow shows the piston devoted to the load transmission

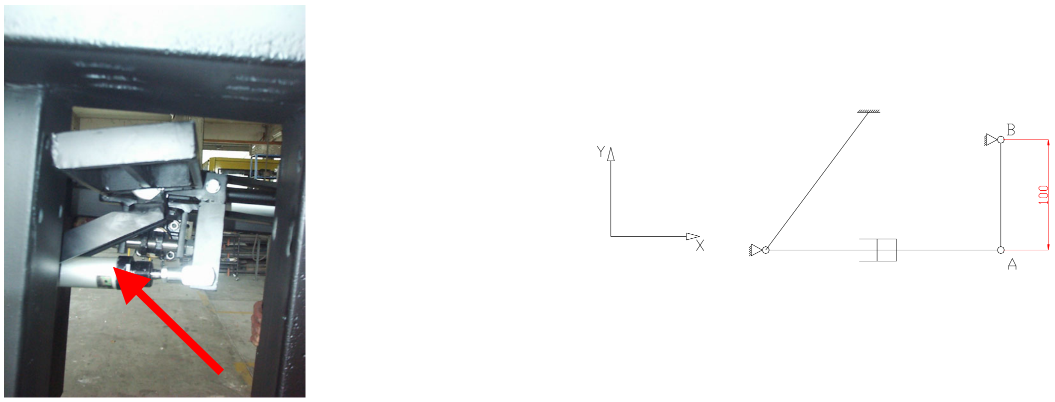

Fig.3 Drive of latero-laterality movement; the arrow shows the piston devoted to the load transmission

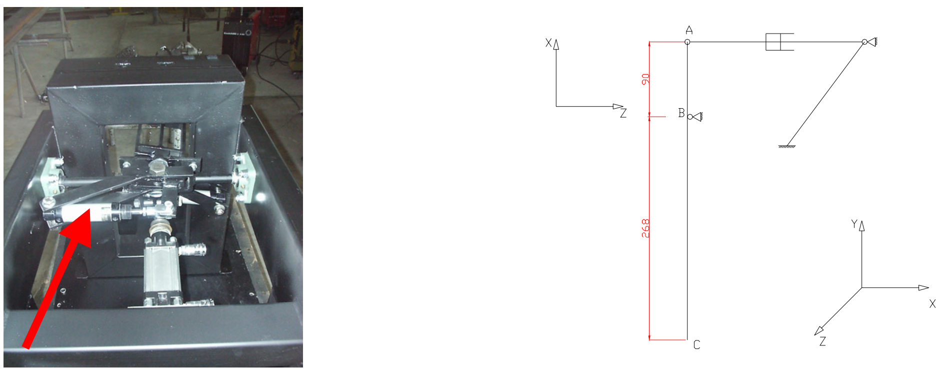

Fig.4 Drive of longitudinal rotation movement; the arrow shows the piston devoted to the load transmission

2. ELECTROPNEUMATIC STRUCTURE AND SYSTEM SOFTWARE SPECIFICATION

The electro pneumatic structure shown in fig. 5, has been projected in order to ensure, in the test conditions, the repeatability of the force values applied to the samples. The choice of this structure is fundamentally based on two principles: the first one is to completely automate the fatigue test with respect to the imposed test conditions, the second one is to realize a structure suitable for long period, non-observed tests; this characteristic has led to the choice of a structure on which electric control securities are redundant compared to the pneumatic ones.

The realized system software can be logically divided into three sections.

- Generation of the test waveforms
- Acquisition and management of the test signals from the sensors
- Diagnostic, test reports and man-machine interface.

The whole software has been developed in a LabView environment. The choice of this operating environment has been suggest by the possibility of creating a highly adaptable and easily reconfigurable software.

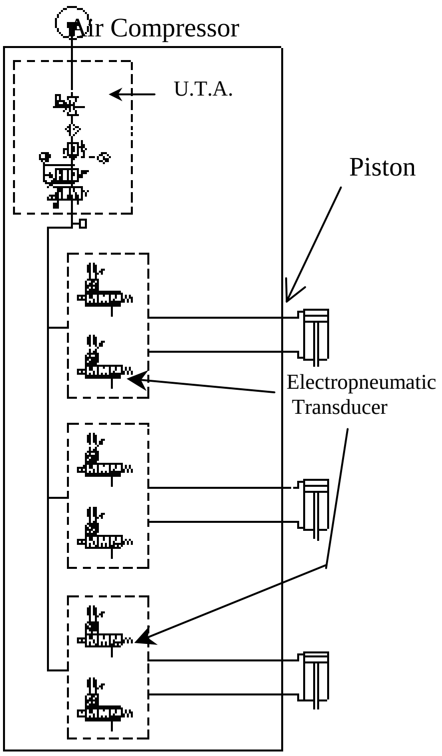

Fig. 5: *Electropneumatic scheme*

3. THE MEASUREMENT HARDWARE

In this first stage of the prototype characterization, an existing, very flexible hardware has been employed, in order to find the most suitable solution for the final version. The employed hardware is shown in fig. 6.

In this preliminary solution, the generation unit and the acquisition unit are physically located in two separated host computers. Due to the small amount of information that must be exchanged between the two units during the test operation, a small LAN interconnecting the two computers proved to be an effective solution at this stage.

The generating section is realized by a Macintosh computer and a NI NB-AO-6 D/A board: this board features by 6 analog output channels, with 12-bit D/A converters and output range ± 10V.

The acquisition section is realized by another Macintosh computer equipped with two NI NB-A2000 acquisition boards. These boards are characterized by a “half-flash”, 12-bit resolution A/D converter (± 5V input range), four input channels with simultaneous sampling and maximum sampling frequency variable from 250kHz to 1 MHz based on the number of input channels employed on each board.

The composition of movements of:

- opening and closing
- laterality
- rotation

which allow to simulate the real mastication movement on a a specimen of dental element, are realized by the pneumatic action of the three pistons. The air flow is controlled by the use of electropneumatic transducers; in particular, in order to allow the piston charge and release, two electropneumatic transducers have been used for each piston, each one driven by a separate DAC channel.

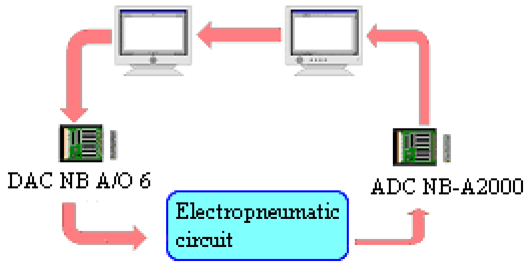

Fig. 6: The employed hardware

Both the feedback signal made available by the electropneumatic transducers and the pressure value provided by a pressure sensor on the pneumatic circuit (this sensor is located upstream of the three pneumatic channels) are processed by the acquisition section. This section takes care of the diagnostic and interface functions and generates also the test report.

4. THE REALIZED SOFTWARE

The section controls the generation of the test waveforms and allows the user to select all force parameters that are intended to be used to stress the sample. Waveform and frequency are common parameters to the three pneumatic channels of the system, while the force values to charge and release the single piston are to be chosen independently by the user.

The section about signal acquisition and processing is aimed at acquiring the six signals provided by the feedback output of the sensor control loops and by the pressure inside the pneumatic system. The two sections in which the control and measuring system is divided into are linked by a dedicated net (apple talk net); the information flow is one way: this means that the information coming from the field is processed and sent to the generation section by the acquisition section. With this structure the acquisition unit takes the role of “Master” unit of the whole system while the generation unit behaves like a “slave” unit. Depending on the values originating from the field, the “Master” can stop the test execution and report the presence of malfunctions by means of virtual leds on the front panel of the virtual instrument.

The system is therefore able to control “on line” the correct operation of the system itself, thanks to the connection of the two units.

The realized diagnostic section operates essentially on the pressure values measured by the sensors.

A first control is performed on the pressure value on the compressor output pipe; if the pressure doesn’t stay at least 50 kPa over the selected working point (according to the specification of the valve manufacturer) the system master closes the six valves that operate the pistons, so that the test execution is stopped.

It is possible to check the right functioning of the sensors using their feedback signals, verifying if the waveform parameters are coherent with the set values in the preliminary phase of the test. In the case of a malfunction, the system manager routine chooses whether to show it by turning on the front-panel led or by breaking off the test execution, depending on its gravity.

Both the set-up parameters (waveform, frequency and amplitude) and the acquired values (pressure values on the compressor output pipe and maximum pressure values detected by the feedback signals analysis) are stored in a report file.

Since the dialog between the two computers is always active, a system state report is always generated for each working cycle. This allows to create a complete history of the test, capable also to signal any malfunction or deviation of the test parameters from the set-up ones during the test.

5. SYSTEM CALIBRATION

The verification of the effectiveness of the three jaw movements allowed both to verify the system capability of generating the requested loads, as well as evaluate its capability work under the different load conditions. This validation allowed also to calibrate the system by comparing the experimental values collected during the measurement procedure with the theoretical expected values.

The calculation of the theoretical load values was made by modelling the load systems of the three jaw movements as beam-constraint structures:

$$F_{th} = \frac{F_p \cdot b_1}{b_2}$$

where:

- F_p represents the force obtained as the product of the pressure transmitted to the piston room, multiplied by its transversal section;
- F_{th} is the force acting on the test specimen; b_1 is the lever arm related to the force transmitted from the piston to the mobile structure while b_2 is the lever arm related to the force transmitted to the specimen.

A 50 mm diameter piston has been used for the opening and closing movements; for the longitudinal and lateral rotation movements two 32 mm diameter pistons have been used.

The calibration procedure has been conducted using a digital dynamometer as the reference instrument. The tests have been performed reproducing the same operating conditions applied by the mechanical structure when charging the test specimen, under static conditions. The digital dynamometer replaces the test specimen. The mechanical load was controlled by the realized generation unit.

The system behavior in the emulation of the opening/closing and laterality movements has been verified in the range of 0–740 kPa, with 20 kPa steps. Similarly, the rotation movement has been verified in the range of 0–660 kPa, again with 20 kPa steps. These ranges are supposed to cover all physiological load values involved in mastication.

This procedure allowed the characterization of the three mandible movements through the evaluation of the deviation between the experimental values and the expected theoretical load values.

5.1 Opening and closing movement

Fig. 7 shows the plot of the experimental and theoretical load values versus the applied pressure values (experimental load values are obtained by averaging four different measurement results).

For the opening and closing movement a maximum deviation of 0.53% has been detected (referred to the full scale value).

By analyzing the results it is possible to observe that the highest deviations can be found in the pressure range of 20-80 kPa, while the deviations are always lover than 3.96 N (0.64% of the full-scale value) in the interval 100-740 kPa.

5.2 Laterality movement

Fig. 8 shows the plot of the experimental and theoretical load values versus the applied pressure values (experimental load values are obtained by averaging of four different measurement results).

By analyzing the results it is possible to observe that the highest deviations (never higher than 5.41% of the ful scale value) were found for the pressure range of 20 - 180 kPa. For the pressure values between 180 -740 kPa the deviation values that have been found were lower than 3 N (0.64% of the full-scale value).

These deviations can be attributed to the reduced capability of the mechanical structure employed to emulate the laterality movement without being affected by friction and inertia of the mechanical parts.

5.3 Longitudinal rotation movement

Fig. 9 shows the plot of the experimental and theoretical load values versus the applied pressure value (experimental load values are obtained by averaging four different measurement results

In contrast with the previous movements, when the highest deviations have been found for the lowest pressure values, in this case significant deviations have been found in the rotation movement in the whole pressure range investigated, with a maximum difference of 30 N with a pressure of 480 kPa.

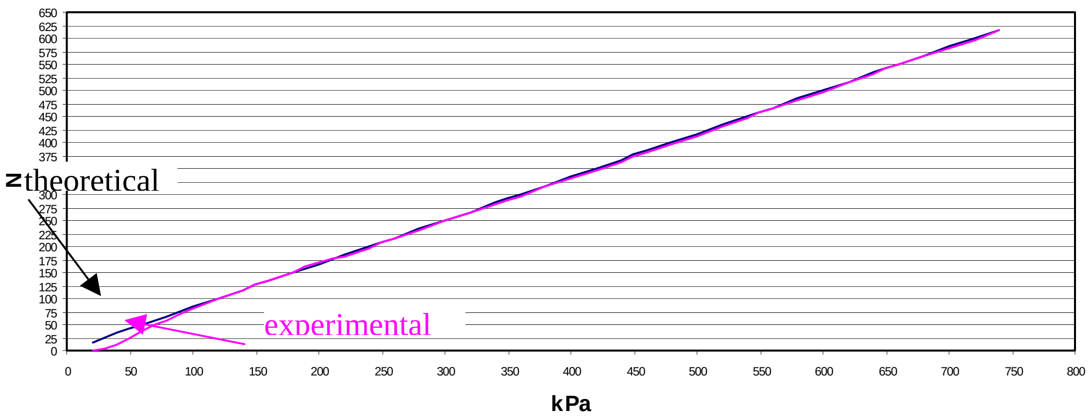

Fig.7 Opening and closure movement.

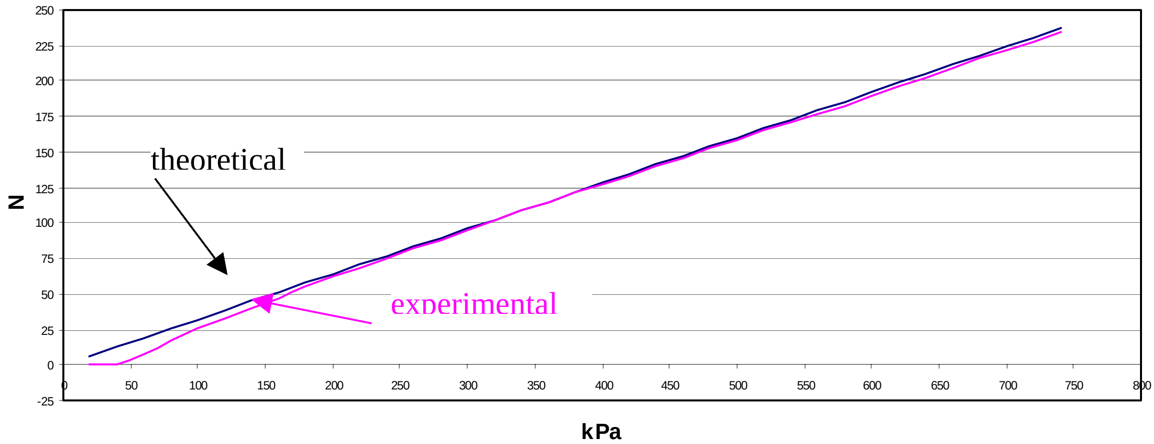

Fig. 8 Latero-laterality movement.

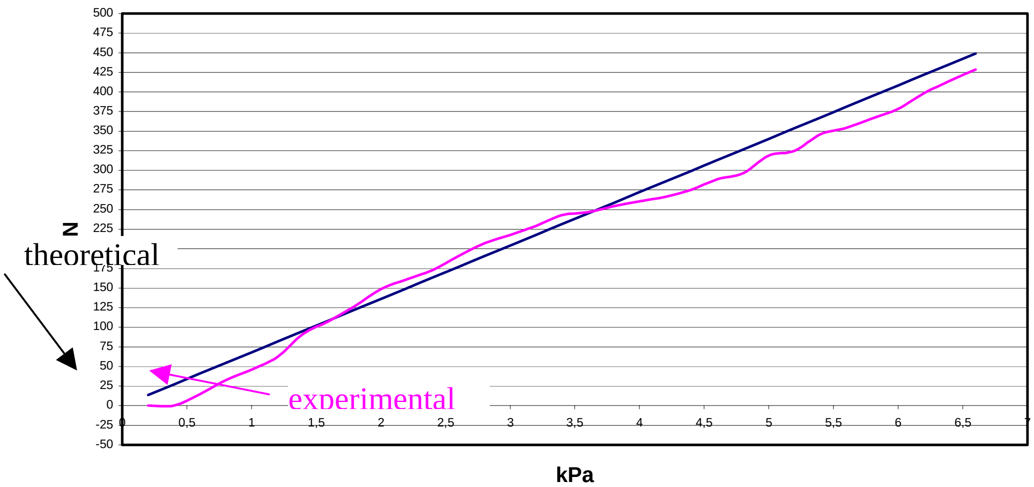

Fig. 9 Longitudinal rotation movement.

These deviations can be once again attributed to mechanical imperfections of the test machine. In the case of the rotation movements, the possible clearance between the moving parts affects the resulting movements in a more significant way than in the other emulated movements. On the other hand, the resulting deviations between the theorethical and experimental values seem not to be due to the control and measurement strategy, since this is the same for all movements and there is no reason for expecting a different behavior for the different movements.

6 SYSTEM LINEARIZATION

The results obtained in the calibration of the fatigue test machine, allow a complete characterization of the system in its functioning field.

This allows also to provide calibration data, in order to automatically compensate the mechanical errors due to the non ideality of the whole structure.

The experimental data can be interpolated by suitable interpolation functions that allow to find the corrected pressure values in order to obtain the desired force on the specimen for each movement.

Since the actuation section of the machine is managed by a digital programmable system, it is possible to apply all corrections identified during the calibration process in order to make the system behavior as close as possible to the theoretical one.

This procedure allows to operate in a sort of "self-correction" mode of the system, thus improving the accuracy with which the generated load approximate the requested one.

The final accuracy, after this compensation, is upper bounded by the resolution of the actuation.

7 CONCLUSIONS

The paper has presented an automatic method and equipment for fatigue tests on dental implantological and prosthetic materials.

A measurement and control system has been implemented as a Virtual Instruments.

The metrological characterization of the whole equipment allowed to define calibration curves for the automatic compensation of the mechanical imperfection.

The results of this work confirm the versatile nature of the whole test system and represent a further step towards the complex simulation of the masticatory movement and load in order to determine, in a very accurate way, the mechanical characteristics of the physiological, implantological and prosthetic elements.

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