Software and Hardware Implementation of a Microtorquemeter

Matteo Giunta
University of Catania
Department of Industrial Engineering
Viale A.Doria 6, 95125, Catania, Italy
Email: matteo.giunta@studium.unict.it

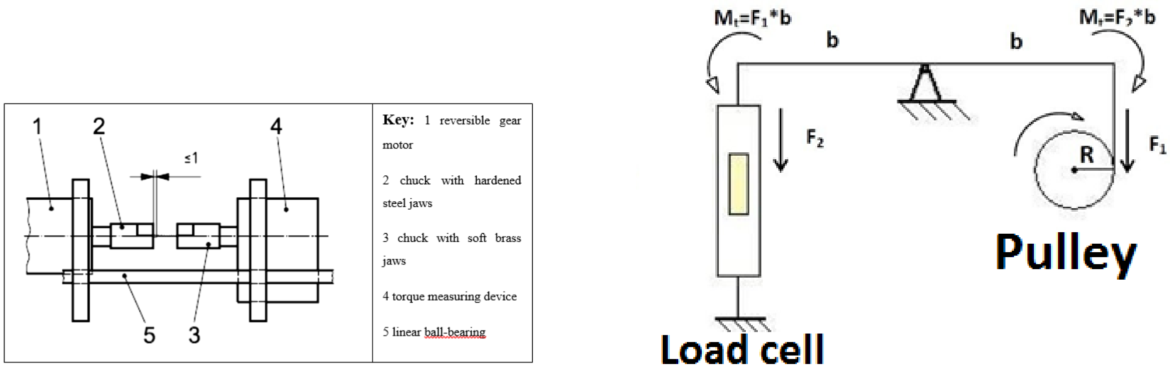
***Abstract*—The present work aims to improvement hardware and software of a torque-meter able to perform static and dynamic tests of Ni-Ti instruments for root canal treatment. Based on ISO 3630-1 standards, the device provides the real-time measurement of the torque, exerted on the various types of endodontic instruments by a servo-controlled motor, as a function of the shaft rotation angle. The standards require the use of a low-speed motor (2 rpm) and the connection of the root canal instrument between two chucks. The torque-meter is composed by a stepper motor operating on a lever with equal arms. The first one drives a chuck transmitting the torque to the base of the root canal instrument, while the second one is connected on one side to a pulley, connected to a second chuck that allows the locking of the free end of the root canal instrument. In this work the hardware was improved by a modern real-time NI-PXI Platform, mounted on a 64-bit PC, on which it was implemented, in LabVIEW environment, a software that merges the reading of data from load cell and encoder and the management of the stepper motor. In order to verify the efficiency of the new device, the same type of endodontic instrument previously tested by the old one, was analyzed. The results were compared by highlighting a remarkable improvement of measurement accuracy.**

I. Introduction

The study of endodontic instruments (files) is a continually growing and, by keeping up with the innovations of technology and materials, even the testing machine that allows to study the behavior they have undergone significant changes. This to make more accurate the study of their response to the mechanical stresses to which the clinical application submits them [1]. The most significant change of files took place mainly in the choice of materials to be used, going from stainless steel to alloys in Ni-Ti [2]. This step led to an increase of the force that can be exercised on the files and to a greater flexibility but, at the same time, have made them more vulnerable to breaking [3], [4]. Although in clinical practice the instruments failure rate is 5% [5], a study has proved that the tools made of Ni-Ti break seven times more frequently than those made of stainless steel [6]. The causes of failure are due to the exerted torque and the stress caused by typical cyclic actions of rotational tools [7]–[9]. In the first case, the elements characterizing the phenomenon are: the maximum torque exerted on the tool and the angle of the channel in which the instrument works. To increase the torsion fracture and the angle before the occurrence of the failure, more advanced machining techniques are designed (EDM, CM-wire, M-wire) [10]–[12] and new design to keep the shape of the channel as constant as possible. In effect, it was demonstrated that, before fracture, the tool is twisted on itself [13], therefore it is tried to have instruments in which this winding is manifested after a larger rotation possible. To measure these two values, different machines have been made to test to failure endodontic instruments [14], [15]. In them, the tool tip is locked, while the base is set in rotation at a constant speed up to failure. In the laboratories of Mechanical Engineering of the Catania University was developed a testing machine capable of providing the failure torque values and the angle at which it occurs. The use of such a device has produced numerous scientific publications [16]. To enable this category of testing devices to accurately operate, is necessary each time obtain a correct synchronization between the various measured quantities [17], [18]. The objective of this study was to improve the testing machine by implementing both hardware and software. The device in question was realized according to the parameters specified by ISO 3630-1 (2008).

II. Endodontic instruments testing machine

The principle for testing of torque resistance of root canal instruments is based on measurement of their torque and angular deformation during a test [19]. To measure the torque on the files a torque tester is designed and manufactured that, based on the ISO 3630-1 standard, provides the real-time measurement of the torque exerted on the various types of files by a servo motor. To measure the torsion on the root canal instruments a torque-meter has been designed and realized which, based on ISO 3630-1 standards , provides the real-time measurement of the torque exerted on the various types of files by a servo-controlled motor. This choice was dictated by the guidelines of ISO (Fig. 1a), which require the use of a low-speed motor (2 rpm) and the connection of the root canal instrument between two chucks. The testing machine exploits the operating principle of the precision balance (Fig. 1b). This consist of a yoke with equal arms that allows carrying out the indirect comparison between the torque produced on the



(a) (b)

Fig. 1. (a) ISO 3630-1 scheme, (b)precision balance scheme.

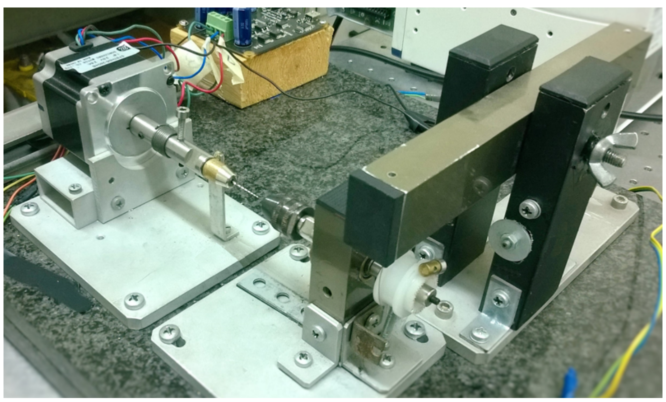


Fig. 2. Testing Machine.

endodontic instrument by the stepper motor and the resisting torque misurate by strain gage load cell. This device, shown in Fig. 2, is composed of a stepper motor, which controls a chuck that transmits the torque to the root canal instrument, and of the yoke at equal arms that is connected on one side to a pulley, the other side is rigidly attached to a custom-made load cell, in turn connected to the base. The pulley is connected, via a shaft, to a second chuck which allows the locking the free end of the root canal reamer. Finally, the root canal instrument is clamped between the two chucks: the first, integral with the drive shaft, transmits the torque; the other, connected by the torque transducer to the strain gage load cell, returns the resistant torque.

$$F_1 = F_2$$
$$M_t = F_2 R$$

The load cell provides the value of the force F_2 that is equal and opposite to the force F_1 exerted by the steel wire connected to the pulley. Then, F_1 note, you get the value of the torque as the product of the F_1 multiplied for pulley radius R. This torque is the one that brings the tool to failure. Commercial available load cells were not suitable for application in this testing device. In effect, did not ensured the necessary flexibility and lead immediately to breaking of files. It was, therefore, necessary to create a custom-made load cell. For the excellent characteristics of mechanical resistance, high elasticity and recovery of the silicone, the strain gage cell was made by placing a strain gage between two silicone strips of 1 mm thickness (Fig. 3). The two ends of the strain cell were fixed on one side to the rocker arm and the other to the base. It was necessary to carry out careful initial calibration to define the response curve of the instrument as a function of the applied loads ($\mu m/m/N$). The calibration law is shown in Fig.4.

The actuation system consists of a bipolar stepper motor (Sanyo 103 - H7123 - 5040) and a board Phidgets Stepper Bipolar 1 - Motor 1063, which allows to control the position, velocity and acceleration of stepper motor. In order to be able

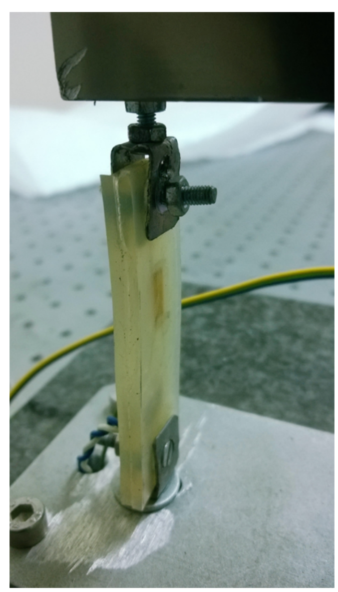


Fig. 3. Custom-made load cell.

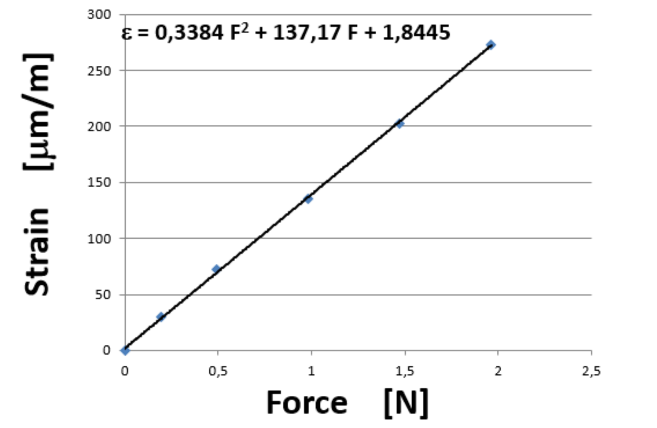


Fig. 4. Second degree equation obtained with calibration.

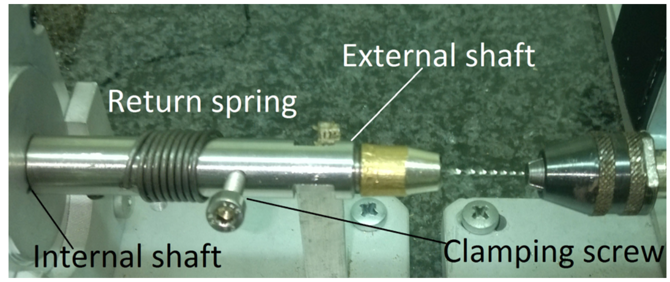


Fig. 5. Chuck details

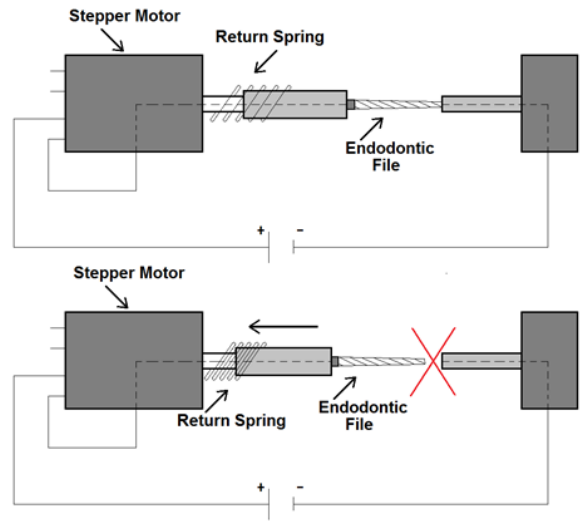


Fig. 6. Switch circuit scheme.

to remove between their chucks in the mounting phase of the endodontic instrument and bring them in the working phase, the motor shaft has been replaced by two coaxial shafts. The interior is fixed to the motor shaft, the outer slides on the first and is tightened with a locking screw once the desired position is reached. In this way it is therefore possible to space the chucks during assembly and approach them in that work. The gripping of the instrument to 35 mm from the tip is ensured by a reference needle, consisting of a plate integral with the base and a double flat groove formed on the shaft outer diametrically opposite generatrices. These latter covering the dual function of the reference point for clamping to 5 mm and a flat key of the attachment section to tighten the chuck motor side (Fig. 5).

Since the electric engine is controlled by the hardware card with a preset rotation to a value much higher than that of the tested tool breakage, the shaft would continue to rotate after the breakage occurred, making it impossible for an accurate reading of the angle. It is therefore designed a system to shut off the power at the exact time of the file breakage. This system, shown in Fig. 6, is based on an electric circuit obtained by connecting a power supply pole of the stepper motor between the two chucks, in this way the endodontic instrument acts as a switch. As long as it remains intact, the circuit is closed and the shaft rotates; as soon as failure occurs, a return spring brings the two sliding shafts in the rest position [20], separating the two parts of the endodontic instrument. In this way the circuit is interrupted and the motor stops. In order to associate a rotation angle to the torque necessary to generate the breakage of the file, the motor shaft has been equipped with a two channel optical incremental encoder (HP - HEDS 5500).

III. Software implementation

Before this study, data obtained from the strain gage cell and encoder were acquired and processed in Excel at a later stage. Load cell data were read via the National Instruments SCXI 1600 strain module, able to create a Wheatstone bridge structure with the load cell of the testing machine and to output the value of the deformation of the same in m/m. The software that allowed the management of the controller has been developed entirely in LabVIEW installed on a PC with a 32-bit operating system. The only purpose of the software for data acquisition was to take the signal from the control unit, convert it in Newton and create a report file with the data relating to the test. These were then manually processed, together with the encoder data acquired through a NI Card 6009, to obtain the graphs that relate torque and angle. Moreover, in this case, the electric motor was connected to the system via USB and the software used to manage it, provided by the same manufacturer, worked in parallel with the system developed in LabVIEW. With this work it was made the transition to a modern NI-PXI Platform mounted on a 64-bit PC on which it was implemented, in LabVIEW environment, a software that has merged the reading of data from strain gage cell and encoder and the management of the stepper motor. Regarding the motor, the transition from dedicated software to LabVIEW was trivial since the company that produces the card that manages the motor also provides libraries for LabVIEW that contain the subVIs needed to manage the various parameters. The issue was different for the

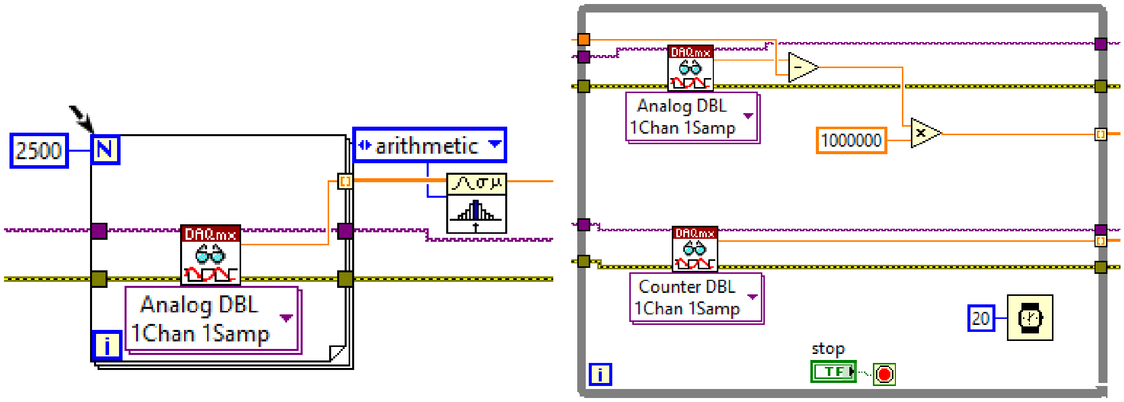


Fig. 7. (a) ”For” loop, (b) ”While” loop

management of the load cell and encoder. In the new system, we have two data streams (the force from the strain gage cell and the rotation from the encoder) and the engine management so it had to create a more complex software. This works in two distinct phases. In the first, the motor remains stationary, in the second, its actuated. In the first phase, channels from which read data are initialized and the reading procedures have been created. Moreover, always with the engine stopped, 2500 samples are taken from the load cell (Fig. 7a). What it read in this case, when the load is absent, are the values of the signal noise. To make it less influential it is then made the mean of the 2500 values that, in the second phase of the program, was subtracted to the single value read from the load cell. In the second phase, takes place the acquisition of data from the load cell and encoder and the noise study. Since the aim of the study is to have the torque/angle data pairs, it was decided to take the data through two parallel processes, creating two different arrays of data both from the encoder readings and from the load cell. Then, these are merged to creating a cluster of arrays from which directly extrapolate the complete test graph that correlates the torque (expressed in Ncm) and the rotation (in degrees). For this purpose, it was necessary to set the reading of data to have only one value of the rotation angle coupled to a single value of the force. Therefore, we have opted for the acquisition of the data on demand. In fact, the encoder, unlike the load cell, is too slow compared to the speed of acquisition of the data that the acquiring unit allows to have. From the data collected before synchronizing the devices, it was noted that the encoder returned the same angle for different force values read from the load cell. Since, as shown in Fig. 8, these values were very close to each other (in the order of thousandths of N), it is chosen to insert the two instances of measurement within a single while loop (Fig. 7b). This loop operates with the frequency of 1 cycle every 20 ms, which made the reading exclusively dependent by a parameter that can be modified as necessary.

However, data acquired from the load cell, are referred to the deformation of the strain gage load cell and are expressed in m/m, then must be converted into Newton. To do this, was wrote a code, in a subVI, which allows the solution to the second-degree equation obtained during the load cell calibration. Once these operations have been performed, the individual readings are inserted into an array. This is, then, filtered through a low-pass filter to obtain the noise-free signal. At the same time the data from the encoder are acquired. The incremental rotary encoder used has a quadrature output, is able to rotate at a maximum speed of 30,000 rpm and with a resolution of 500 pulses per revolution. This type of angular speed transducers is designed for direct mounting of drive shafts, and are capable of producing two digital waveforms with 90 phase shift. This provides information on resolution and direction. The acquired data are in degrees and, as occurs for the strain gauge cell, the individual readings are inserted in an array. This, together with the array of the data obtained from the strain gauge cell, are combined into a cluster of arrays from which is generate a graph (Fig. 9). Another improvement involved the export of data. This was previously done by the LabVIEW’s VI called ”Write to measurement file” that exported to an Excel spreadsheet the arrays of data obtained in the form of columns. In this study was realized a report file that not only exports data but also creates graphs and performs some data elaboration needed for the study.

IV. Data analisys

For the analysis and processing of experimental data it was decided to use Excel. The load cell data are saved by LabViews File Report in a file *.xls, where three columns of data are created. These report, respectively, the angle of rotation (degrees), the deformation (m/m) of the strain gauge load cell and the force (N) transmitted from the balances arm to the load cell during the test. The deformation measured by the load cell is due to the force that the pulley radius (R = 1 cm) transmits to the steel cable. Therefore, the strength values are equivalent to the torque values expressed in Ncm. With the torque and angle values, it is possible to realize a chart that correlates the torque applied to the tip of the endodontic instrument with its rotation until the breakage. Prior to this study, the graph obtained was of the kind shown in Fig. 10. In the first part of the curve, it can be seen a lag phase due to the

Degrees	ε
96,48	0,171306
96,48	0,171424
96,48	0,171544
96,48	0,171662
96,48	0,171774
96,48	0,171869
96,66	0,171938
96,66	0,171979
96,66	0,172009

Fig. 8. Data example.

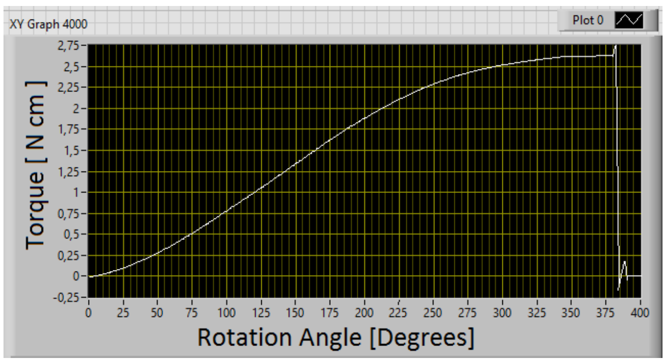


Fig. 9. Graph obtained in the front panel.

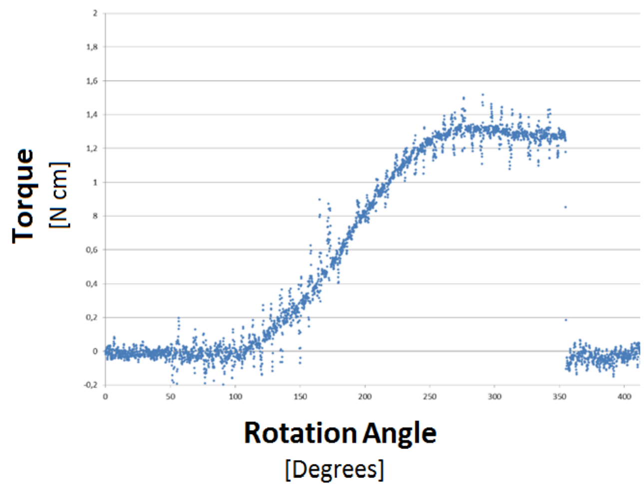


Fig. 10. Graph obtained with the previous system.

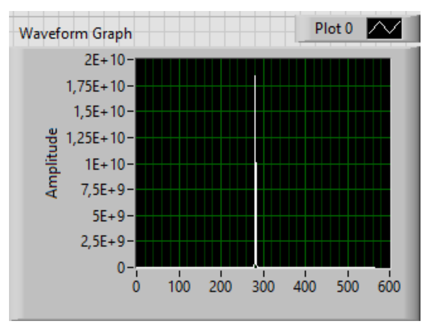


Fig. 11. Graph that shows the noise frequency.

fact that the operator had to first start the software to acquire data and then start the engine by using a different software. Moreover, there was also a delay due to the compilation of the program that controlled the engine. Because of this initial delay the graph does not show an accurate value of the rotation angle.

With the encoder use we achieved a substantial improvement in data processing. With the new system, in fact, the values of the load cell are directly coupled to those of the encoder. In addition, being the new one a system based on a unique software that manages all parts of the testing machine, we have no more delays due to the use of different softwares. In general, the transition to a more modern and faster system has brought a saving in terms of test time duration. Clearly, the time required to rotate the instrument until the break remained unchanged since the speed of rotation is always the same. What is considerably changed is the time used in the test preparation operations. In fact, the time required to calibrate the load cell before each test was reduced making this an almost immediate operation. Another improvement is regarding the noise present on the signal. As it can be seen from the graphs, the data provided by the new software, are virtually noise-free. This improvement was achieved thanks to the noise frequency study, which it allowed to set the low-pass filter that processes the data received from the load cell. Noise frequency was identified by applying the Fourier transform to the strain gauge cell input data (Fig. 11). Thanks to the filtration was obtained significantly more accurate graphics as it can be seen from Fig. 12. This figure shows the graphs of two tests performed on the same type of endodontic tool (F6 SkyTaper 25 mm length, 6% taper), at the top there is the graph obtained with the old system and below there is the graph obtained with the new one.

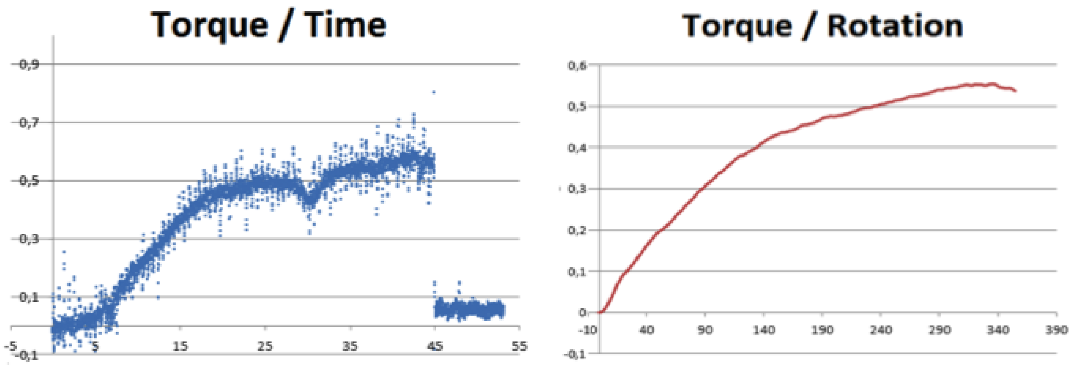


Fig. 12. Comparison between graphs obtained with old and new system.

V. CONCLUSIONS

The present study has contributed to improving a previously realized testing device. This machine was created as a part of a larger research program performed in co-operation between research groups of Engineering and Medicine departments of the Catania University on the behavior of Ni-Ti instruments for root canal treatment. The realization of this torque-meter, based on ISO 3630-1 standards, was possible thanks to a careful optimization performed as well as on the individual components and on a global device. Particularly, the choice of the material and of the geometry with which it was realized the strain gage load cell (suitable for the measurement of a low-torque amount without providing an excessive torque), the torque transmission system and the mounting of the instrument on the chucks. The further implementation made in this study involved both the hardware and the software. The previous hardware has been improved by the use of the NI-PXI Platform, which gives the possibility to acquire in real time the output signals from sensors and especially to synchronize with each other. The new software has merged the reading of data from strain gage cell and encoder and the management of the stepper motor. In this way, there are no longer delays due to the use of different software. Along with this improvement was been joined the system's ability to process a development in FFT of the plotted signal. In fact the use of advanced soft computing techniques has became progressively an effective option in many contexts [**?**], [**?**], [21]–[23]. Thus, it is possible to derive the main frequency of the electronic noise and, by means of a low-pass filtering, clean up the signal, improving the accuracy. The good performances of the device have been highlighted by both the result of the tests performed on the root canal instruments, which are in good agreement with the values found in the technical literature, as well as for the quality of the graphics, compared to ones obtained using the old system.

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