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A NEW METHOD FOR THE AUTOMATIC TESTING OF APPLANATION TONOMETERS

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Abstract: The exact measurement of the intraocular pressure is of great diagnostic importance in the field of ophthalmology. According to the international standard DIN EN ISO 8612, the tonometers being used are subject to strict type approval and, furthermore, must be checked on a regular basis.

For calibration of one of the most widely used and most precise tonometers known as applanation tonometers usually a mechanical cross-beam balance is being employed at present. However, as the use of this type of test equipment requires a lot of time and yields test results of limited accuracy only, it does no longer meet the requirements of an objective, metrological quality control. When using other conventional weighing or also force measuring equipment, such as DMS sensors or electromagnetically force-compensated balances, it was not possible to obtain the required parameters either because of insufficient accuracy or the prescribed horizontal service position.

With the aim to provide a solution to the above problem, this paper presents a new, optical interference test equipment which permits to carry out an automated test procedure of applanation tonometers of various types at very high speed, thus reducing the testing times of about 30 minutes at present to 5 minutes.

Keywords: applanation tonometer, tonometer test equipment, laser-interferometric force sensor

1 INTRODUCTION

According to the international standard DIN EN ISO 8612, the tonometers being used in ophthalmology for measuring the intraocular pressure are subject to strict type approval and must also be checked on a regular basis.

For calibration of one of the most widely used and most precise tonometers known as applanation tonometers a mechanical cross-beam balance is being employed at present. However, as the use of this type of test equipment requires a lot of time and yields test results of limited accuracy only, it does no longer meet the requirements of an objective, metrological quality control. This fact made it necessary to develop an automated test equipment with improved metrological parameters.

When looking for a substitute for the mechanical cross-beam balance in the form of a conventional electronic force measuring equipment, two types of devices had to be ruled out: the strain-gauge sensors because of their insufficient accuracy, and the electromagnetically force-compensated sensors because of non-existence of position insensitivity of force measurement.

With the aim to provide a solution to the above problem, this paper presents a new, optical interference test equipment which permits to carry out an automated test procedure of applanation tonometers of various types at very high speed and independently of the position, thus reducing the testing times of about 30 minutes at present to 5 minutes.

2 STATE-OF-THE-ART

When measuring the intraocular pressure by means of an applanation tonometer, a pressure-exerting frustum-like body of the tonometer makes the eyeball go out of shape until a well-defined applanation surface is obtained. The contacting force necessary for this is generated by an adjustable spring prestressing and is a measure of the prevailing intraocular pressure. When testing the applanation tonometers themselves, also the geometry of the pressure-exerting body as well as the applanation force setting must be checked. The geometry of the pressure-exerting body can be determined sufficiently well by means of a measuring microscope. At present, the applanation force is calibrated by using a mechanical cross-beam balance (Fig. 1).

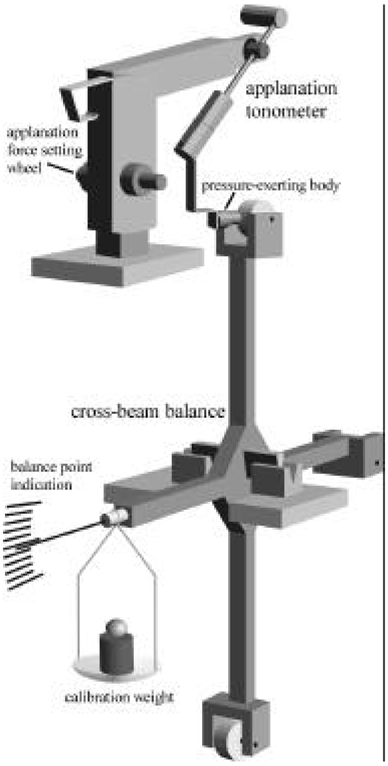

Figure 1. Checking of an applanation tonometer by means of a cross-beam balance

A turnstile of equal arm length resting on knife-edges supports on a horizontal cross-arm a balance pan for receiving the nominal weighing pieces, as well as an index moving over a scale having a mirror-like background. The ends of the three other arms of the turnstile are provided with small pivoted contacting wheels in order to ensure friction-free contacting of the pressure-exerting body of the tonometer. This permits to carry out a calibration both in horizontal and vertical position depending on the tonometer type.

A fine adjustment of the distance between tonometer and cross-beam balance guarantees that, according to the test specification, the applanation force comparison is effected in the middle of the moving range of the tonometer. However, this fine adjustment is only possible with limited accuracy, thus constituting one possible cause of measurement errors. The subjective setting of the contacting height in the middle of the pressure-exerting body may result in further errors. The resulting change in the effective tonometer arm length will also lead to measurement errors. In addition, the manual operation of the test equipment is very time-consuming.

All these shortcomings resulted in our endeavours to develop a test equipment which permits to carry out an automated test procedure with considerably improved metrological parameters with low measurement times.

3 OPTICAL INTERFERENCE TEST EQUIPMENT

When looking for a force sensor which can be used for an automatic test procedure, strain gauge sensors must be ruled out because of their high uncertainty in the load range up to 100 mN. However, also electromagnetically force-compensated systems, the uncertainty of measurement of which is comparably small , are not suitable as they can only be used in a horizontal service position.

The optical interference force sensors (IOK) developed at the Institute of Process Measurement and Sensor Technology of the Technical University of Ilmenau for a load range up to 100 mN are characterized, on the one hand, by a little uncertainty of measurement and, on the other hand, by a position-independent operation, which makes them highly suitable for solving the application task at issue /1/, /2/.

3.1 OVERALL SET-UP OF THE TEST EQUIPMENT

Figure 2 illustrates the principle of function of the optical interference tonometer test equipment: By means of an electromechanical drive consisting of a micromotor with gears and helical eccentric disk, the parallel spring guidance of the IOK is moved with the contacting hemisphere to the measuring body of the applanation tonometer. Let the moving speed of the parallel spring guidance be v_p. In order to determine the tonometer measuring force in the middle of the moving range of the tonometer, the following connections are then analyzed and evaluated, with the results being finally utilized for the automatic control of the measuring procedure.

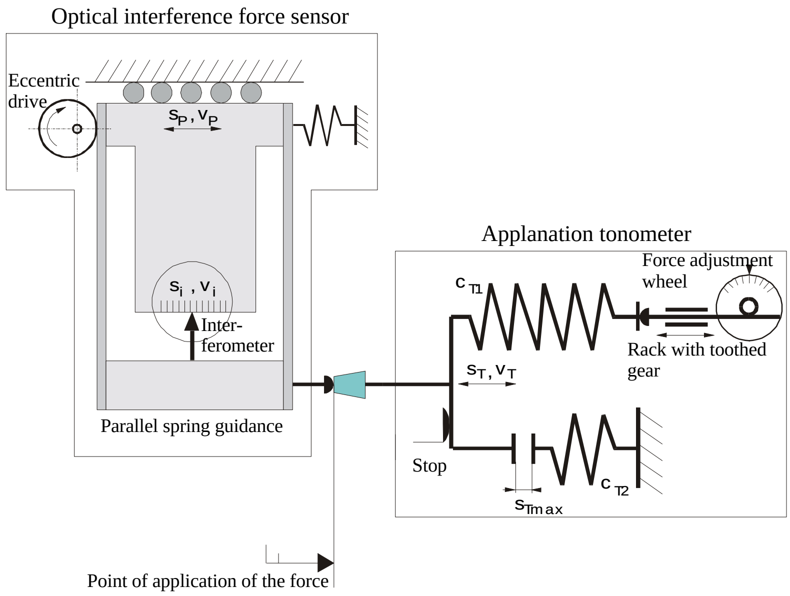

Figure 2. Test set-up for applanation tonometers including an optical interference force sensor

Between the speeds v_p (parallel spring set-up), v_i (1st derivative of the interferometrically measured deflection of the parallel spring) and v_T (1st derivative of the movement of the tonometer arm), the following relation holds:

$$v_p = |v_i| + |v_T| \tag{1}$$

Furthermore, because of the equilibrium of forces in the point of application with c_i being the spring constant of the parallel spring and c_T being the effective spring constant of the tonometer, the relation

$$c_i \cdot v_i = c_T \cdot v_T \tag{2}$$

is true.

From (1) and (2), it follows:

$$v_i = \frac{v_p}{1 + \frac{c_i}{c_T}} \tag{3}$$

Thus, depending on the position of the parallel spring set-up, the different deflection speeds v_i given in Table 1 result.

From the transitions of the different speeds, one can derive the moment of contact of the measuring body as well as the time when the spring strikes against the stop. Thus, the moving range of the tonometer is covered. Now, one can travel to the middle of the moving range where the effective force is determined from the interferometrically measured deflection of the parallel spring guidance.

Another measuring strategy consists in the dynamic measurement of the tonometer measuring force over the entire moving range. In doing so, the path-force-characteristic is continuously recorded with the eccentric disk revolving. The jumps in the speed v_i to be seen in Table 1 can be used for marking the characteristic line. This measuring procedure also permits to record the inversion range and to detect any non-linearities as the characteristic of the tonometer is recorded in both directions of movement.

State of movement	Effective spring constant c_T	Deflection speed v_i
Movement of the spring set-up before Contacting the measuring body	$c_T = 0$	$v_i = 0$
Movement of the spring set-up after Contacting until the prestressing spring Force of the tonometer is overcome	$c_T = \infty$	$v_i = v_p$
Movement of the spring set-up after Overcoming the prestressing spring force Until the spring stop is reached	$c_T = c_{T1}$	$v_i = \frac{v_P}{1 + \frac{c_i}{c_{T1}}}$
Movement of the spring set-up after Striking against the spring stop	$c_T = c_{T1} + c_{T2}$	$v_i = \frac{v_P}{1 + \frac{c_i}{c_{T1} + c_{T2}}}$

Table 1. States of movement of the test equipment

3.2 STRUCTURE OF THE OPTICAL INTERFERENCE FORCE SENSOR

Figure 3 shows the structure of the optical interference force sensor. An enclosure having the dimensions of 127 mm x 81 mm x 56 mm houses the parallel spring set-up, the elevating mechanical contacting system with motor, gears, the eccentric disc as well as the whole interferometer unit. The laser and the evaluation electronic unit with serial computer interface are located in a separate enclosure and coupled with the optical interference force sensor via optical fibres (LWL).

The quartz glass parallel spring guidance serves as hysteresis-free linear primary transducer for the force-path-conversion. Its sensitivity amounts to 5 mm/N. The deflection of the parallel spring caused by a measuring force is measured interferometrically. By employing a modified $\lambda/2$ Michelson interferometer combined with a suitable interpolation hard- and software, a path resolution of $\lambda/512$ = 1.24 nm is obtained. This corresponds to an internal force resolution of 0.25 µN. The smallest digital read-out value is 0.01 mN (1 mg). The optical interference force sensor functions both in a horizontal and in a vertical position. It is calibrated in a horizontal position with the calibration plate being inserted by using a 5g weighing piece.

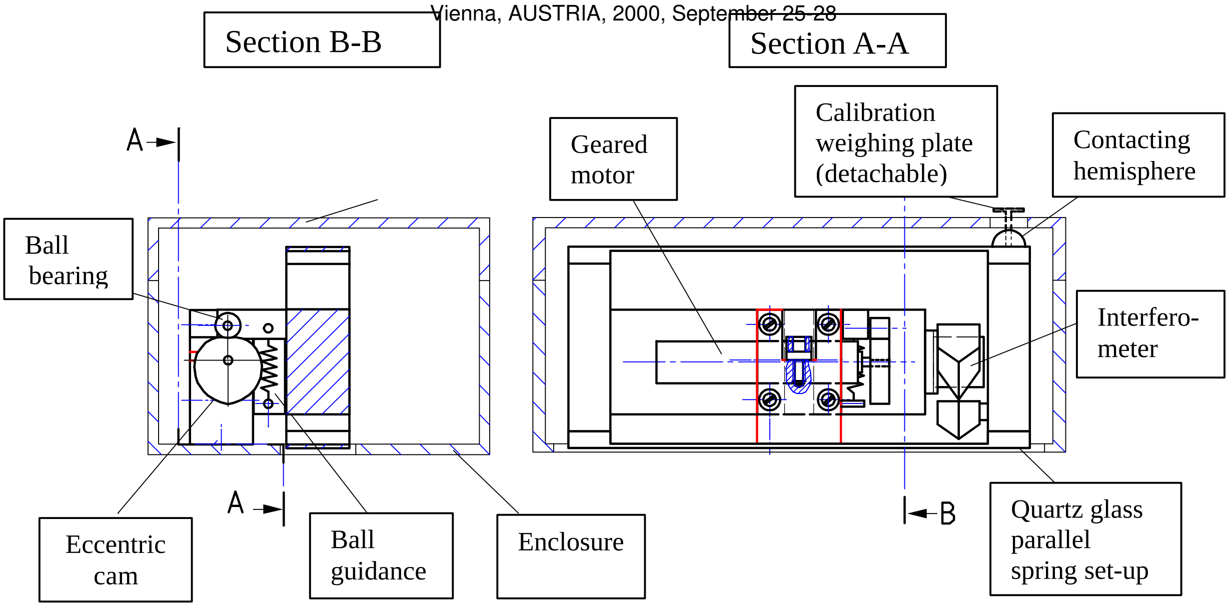

Figure 3. Optical interference force sensor

4 RESULTS OF THE METROLOGICAL INVESIGASTIONS

4.1 STATIC REPRODUCIBILITY OF THE OPTICAL INTERFERENCE FORCE SENSOR

For investigating the reproducibility, the optical interference force sensor was cyclically loaded with a 5g weighing piece. The measuring curves obtained are represented in Fig. 4. It can be seen that the deviations are always below 1 mg both at zero and under load.

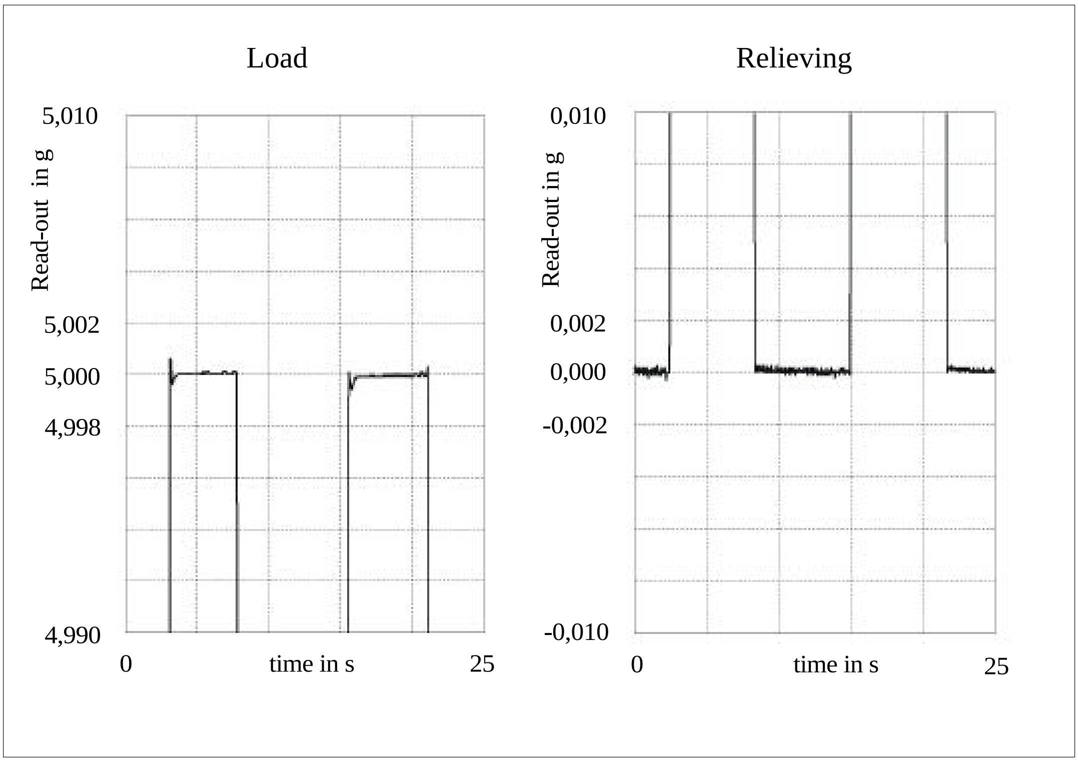

Figure 4. Cyclic load curves of the optical interference force sensor

4.2 METROLOGICAL INVESTIGATIONS WITH THE TONOMETER TYPE AT 020

For the practical testing of the optical interference test equipment, an applanation tonometer type AT 020 made by the Fa. Carl Zeiss Jena company was employed.

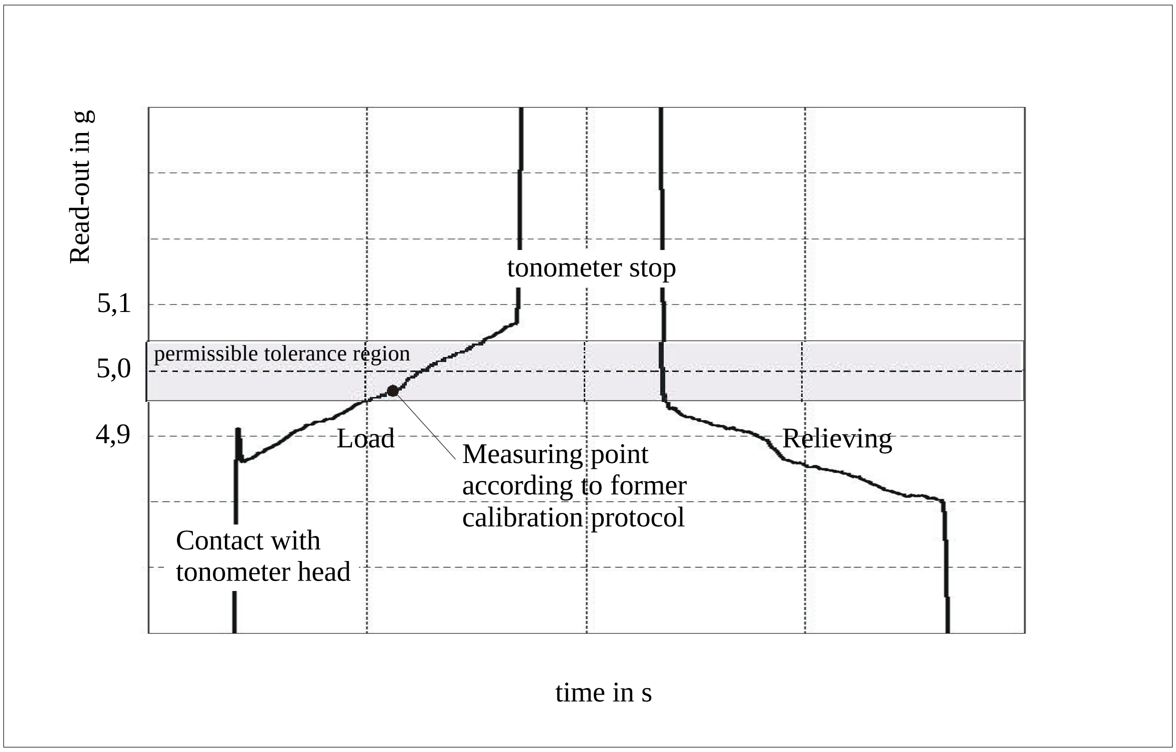

Figure 5. Behaviour of the tonometer characteristic measured at 5 g

The measurements were made with the eccentric cam revolving permanently at constant speed, which permitted to obtain a continuous record of the force behaviour of the tonometer. A comparison with the measurements made by means of the cross-beam balance has shown that the part of the load curve (Fig. 5) confirms the measuring values obtained so far by conventional means. However, after passing through the sprung tonometer stops, a wide inversion range can clearly be recognized. On the basis of repeated measurements, it was possible to prove the reproducibility of the measurements.

5 SUMMARY

The metrological investigations carried out by means of the new, optical interference applanation tonometer test equipment have shown that the requirements made can be fulfilled. It is possible to record a complete measuring step within less than 5 minutes. An essential advantage is that the whole spring characteristic can be recorded at each tonometer setting. Furthermore, the test equipment permits to assign the force to the moving range of the tonometer and to determine the magnitude of the moving range itself. Also, the inversion range and any characteristic non-linearities have become evident for the first time. Owing to the effective working temperature range from 15 ^{o}C to 30 ^{o}C the test equipment can also be used for checking the temperature behaviour of tonometers. This gives the manufacturer of applanation tonometers the possibility of carrying out quality controls and to draw conclusions for further improving the tonometer devices.

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