An interefrometric method for measuring the dioptric and prismatic power of ophthalmic lenses

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Abstract

Objective: To accurately evaluate and measure the dioptric and prism power of ophthalmic lenses with an interferometric technique and correlate the results with those taken from automated focimetry.
Method and materials: Optical testing of trial ophthalmic lenses, spherical and cylindrical, was carried out based on an interferometric technique in order to estimate the dioptric and prismatic power of the lenses measured. The ophthalmic lenses were inspected with laser light, using a Twyman Green interferometer, and interference patterns were acquired and processed, obtaining the dioptric and prismatic power that theses lenses presented. Comparison of the respective results was conducted with those taken from an Auto-focimeter (TOMEY TL-100) in order to check if the two types of measurement are interchangeable, and statistical analysis was carried out for both types of measurements.
Results: The data showed, that the two methods Auto-focimeter and Interferometry (Twyman Green) are correlated. From the statistics the Pearsons correlation coefficient shows high statistical significant correlation between the two methods (r = 0.9996 - P<0,0001 having a 95% confidence interval for r = 0.9965 to 1,0000).
Conclusions: A new method is provided for measuring the power (dioptric and prismatic) of ophthalmic lenses and this alternative method is based on interferometry. More specific a Twyman-Green interferometer was set to measure trial lenses of known power. The fringe patterns were photographed and then the power of the wave front produced due to the insertion in the set-up of the trial ophthalmic lens was measured. This is equal to the power of the trial lens. The fringes were tested compared to the plano reference wave front produced when the system did not have any lens inserted.

Key words: interferometry, Twyman-Green, ophthalmic lenses, power.

Introduction

A method technique based on interferometry[1-6] and its validation are presented for measuring the total power of single vision trial spherical and cylindrical lenses. Although in the beginning a Michelson[7-10] interferometer was used for such a measurement, from the results it was seen that the final measurements carried on the interferograms aberrations due to the initial wave front (reference wave front) produced. Also it was understood that in order to get the actual information on performance from the fringe patterns when testing single vision lenses then the optics used, that means the mirrors, the beam splitter, and the lenses in the set-up should be of excellent quality.

Although that with the Michelson interferometer information about the power of the lenses tested could provided, due to the fact that the reference wave front was not plane this produced an error in the final result, which was carried in all the measurements. It was a systematic error that could be calculated but in order to get the actual information needed from the interferograms taken, a Twyman-Green[11-16] interferometer was preferred, which provided a reference wave front, which was plane. Information also is given about how the fringe patterns were captured and interpreted in order to get the total power result of the single vision tested lenses.
The principal concept was to use a simple low cost easy to operate with the least complexion in its set-up interferometer in order to get accurate measurements on the power of ophthalmic lenses. Although the Newton interferometer would be the first choice from the literature it was understood that only one of the surface of the lenses would be measured and not the whole lens. Also this type is a contact interferometer. These were the reasons that the Newton[17-18] and Fizeau[19] (modified Newton) interferometers were ruled out and not chosen for such an attempt.

Method and materials

As an experimental device a Twyman-Green interferometer was used in order to get fringe patterns of optical components, like prisms, spherical and cylindrical lenses. From the interferograms and their interpretation the power of the lenses tested could derive. **Figure 1** is a schematic representation of the experimental set up for such a purpose. The Twyman-Green interferometer used in order to measure lenses is actually like the Michelson only a lens +100 mm is inserted into the system in front of the laser at a distance of 10cm at the first principal focus of the lens in order to make the initial laser beam a plane wave front (parallel rays) which would be the reference wave front for comparison with the one produced by any lens element inserted into the system. The laser was a He-Neon laser (red) having a transmitting wavelength of 632, 8 x 10^{-6} mm and with a beam diameter of 0.8 mm.

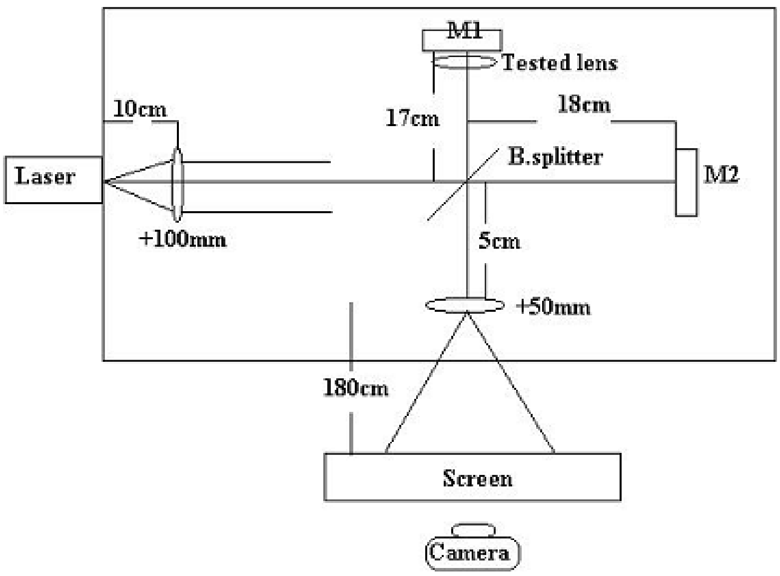


Figure 1. Schematic diagram of the experimental device constructed in order to measure

ophthalmic lenses with interferometry. It is a modified Michelson version with a collimating lens +100 mm placed in front of the laser at a distance equal to its first focal point in order to produce a plane initial wave front. Also the camera was placed in alignment with the screen where the fringes were projected.

Figure 2. It is an actual photo of the lab and the modified set-up of the interferometric device (Twyman-Green interferometer).

According to the above photo the set up consisted of:

a) A collimated lens +100 mm, which was placed in front of the laser at a distance equal to its first focal length. This produced the initial *"reference wave front"* which was *plane*.
b) A beam-splitter (50/50) was placed oriented at 45° to the laser beam direction in order to divide the initial laser beam into two other components one reflected and the other transmitted. The angle of the splitter related to the laser beam propagation and to the two mirrors of the system is very important. Flat mirrors (one fixed M_2 and the other movable M_1 in terms of three screws for directional movements) were used. The mirrors have a diameter of 35 mm, which is the same as the diameter of the trial tested lenses. This set up produced better optics with less aberration affecting the system.
c) The camera was placed exactly behind the semi-transparent screen at 0° angle. The exposure time, due to the direct alignment of the film with the fringe pattern (the camera is set 1 m away from the transparent grid), was quicker (better photographs taken by setting the camera with a speed 125 and the diaphragm set at 2)
d) The use of a granite table two tones of weight was necessary in order to reduce the interfering of vibrations on the device and on the fringe patterns produced. Even the least noise or air current could affect the fringe patterns producing a breathing phenomenon.

Before inserting into the system the trial lenses of known power, in front of mirror M_1 prisms of 1.00 D, prism 2.00 D and 3.00 D were placed (from the trial case) on a lens holder in order to assess how the system will react, and if it is possible to measure prismatic lenses. Then optical flats were used (1 mm thickness, 5 mm thickness, 8 mm

thickness, 10 mm thickness) in order to assess if the thickness of an optical element is affecting the fringe pattern[20-22]. Then trial lenses were inserted. These trial ophthalmic lenses spherical (-1.00, -2.00, -3.00 and +1.00, +2.00, +3.00 Ds) and plano-cylindrical (-1.00, -2.00, -3.00 and +1.00, +2.00, +3.00 Dc) were taken from a standard trial ophthalmic lens case Topcon TLS-FD trial lens set.
The fringe patterns were photographed and scanned on to a computer in order to calculate the power of the known prisms and lenses. The following equation[23] was used in order to find the power of the spherical and cylindrical lenses tested

$$x_n^2/R = n\,\lambda \;\Rightarrow x_n = \sqrt{n\,R\,\lambda} \;\Rightarrow R = x_n^2/n\,\lambda$$

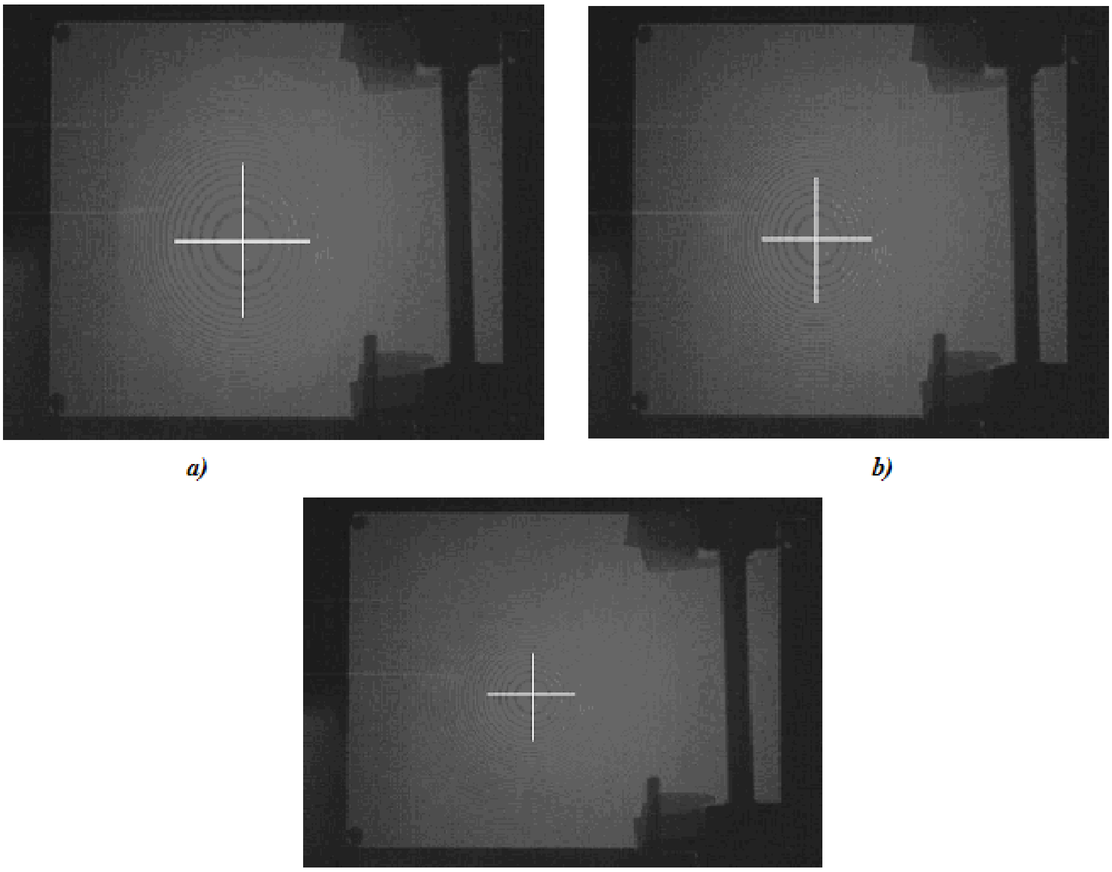
where x_n is the distance of the *n*th dark fringe R is the radius of curvature of the optical element under test n is the number of the dark fringe from the centre of the fringe pattern while λ is the wave length of the light source used ($\lambda = 632{,}8 \times 10^{-6}$ mm).
The prism power was derived by measuring the displacement *dx* of the centre of the circular fringe pattern from the centre of the grid with the metric scale. At first the displacement of the prism of 1 D was measured. Then a 2 D prismatic power or 3 D prismatic lens was inserted in the metric system and it was found that the displacement was 2x times or 3x times the displacement distance of the 1 prismatic dioptre lens.

Results

Some examples of the tested lenses (**Figure 3**) with the Twyman-Green interferometer are given below:

For a spherical trial lens of +1.00 Ds the fringe diameter of the 5^{th} dark fringe was 87 mm so $x_n = 87/2 = 43{,}5$ mm. The magnification used to make the fringe pattern visible was 35x. So the actual fringe size was 43,5/35 = 1,24 mm. By using the equation $\boldsymbol{R=x_n^2/n\lambda}$ then R = 488,20 mm = 0,488 m^{-1}. F_{lens} = 1/R = 2,048 Ds. But due to the double pass of the beam from the tested lens the wave front power is doubled *(Twyman, 1988)*. So F_{real} = 1,02 Ds.

It is obvious that with such an experimenting set-up the results taken were very near to the nominal power of the trial lenses tested. It should be mentioned that only the *absolute power* could be measured and it is not possible to know if the lens is positive or negative. The lenses in order to check the repeatability of the method were measured 3 times using this system.

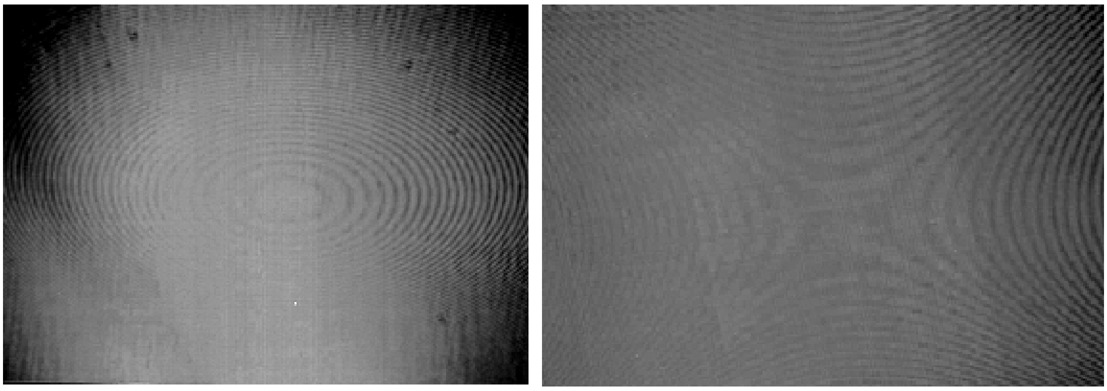


a) *b)*

c)

Figure 3. Fringe patterns of spherical trial lenses tested with a) +1.00 Ds power b) +2.00 Ds power c) +3.00 Ds power.

Figure 4 shows the fringe patterns for plano-cylindrical trial lenses tested.



a) *b)*

Figure 4. Fringe patterns of plano-cylindrical trial lenses tested with a) - 1.00 Dc power b) + 1.00 Dc power. The axis direction as it is seen is 180°

The statistical analysis of the results for the proposed method compared to Auto-focimeter is given below.

Statistics for the spherical lenses measured

The sample size for spherical lenses measured with the interferometric technique using Twyman-Green interferometer was 36 having arithmetic mean 0,0167 Ds

(95% CI for the mean -2,5429 to 2,5763) the standard deviation was SD=2,4390 having a standard error of the mean of SE=0,9957). Kolmogorov-Smirnov test for Normal Distribution showed that the data is normally distributed (accept Normality P=0,987).
The sample size for spherical lenses measured with the Auto-focimeter was 36 having arithmetic mean -0,0067 Ds (95% CI for the mean -2,4618 to 2,4484) the standard deviation was SD=2,3395 having a standard error of the mean of SE=0,9551). Kolmogorov-Smirnov test for Normal Distribution showed that the data is normally distributed (accept Normality P=0,990).
Comparing now the two methods Auto-focimeter and Interferometry the Pearsons correlation coefficient shows high statistical significant correlation between the two methods showing that the data are highly associated (r = 0,9996 P<0,0001 having a 95% confidence interval for r = 0,9965 to 1,0000). Conducting the Paired t-test for the two methods this showed that there is no bias between the two methods (Two-tailed probability P = 0,6502). The Mean difference was MD = 0,0233 while the Standard deviation SD= 0,1186 with 95% CI = -0,1011 to 0,1478. The Variance ratio test (F-test was = 1,0869 having P = 0,929.
In order to compare better the two measuring methods the Bland & Altman plot is used[24-25]. With this method the differences between the two measuring methods are plotted against the averages of the two methods. From the plot it is concluded that the limits of agreement between the two methods are (Lower limit = -0.2558 Ds and Upper limit = 0.2091 Ds). So both methods agree to about a quarter of dioptre (0,21 to -0,26 Ds). Also the limits of agreement between the two methods by performing Bland & Altman Plots for each set of the three repeated measurements for spherical lenses range to about a quarter of dioptre.

Statistics for the plano-cylindrical lenses measured

Comparing now the two methods Auto-focimeter and Interferometry for the plano cylindrical lenses, the Pearsons correlation coefficient shows high statistical significant correlation between the two methods showing that the data are highly associated (r = 0,9993 P<0,0001 having a 95% confidence interval for r = 0,9933 to 0,9999). Conducting the Paired t-test for the two methods this showed that there is no bias between the two methods (Two-tailed probability P = 0,8297). The Mean difference was MD = -0,0117 while the Standard deviation SD= 0,1261 with 95% CI = -0,1440 to 0,1206. The Variance ratio test (F-test was = 1,0758 having P = 0,938. From the plot it is concluded that the limits of agreement between the two methods are (Lower limit = -0,2355 Ds and Upper limit = 0,2588 Ds), showing that they fit the spherical lenses results.

Conclusions

A new method is provided for measuring the power of ophthalmic lenses and this alternative method is based on interferometry. More specific a Twyman-Green interferometer was set to measure trial lenses of known power. The fringe patterns were photographed and then the power of the wave front produced due to the insertion in the set-up of the trial ophthalmic lens was measured. This is equal to the power of the trial lens. The fringes were tested compared to the plano reference wave front produced when the system did not have any lens inserted. The results were compared with the results taken by measuring the lenses with an Auto-focimeter.
A statistical analysis of the results comparing the two methods, were given using

variance analysis and the Bland an Altman statistical method. From the statistics and especially the p-value its time taken in any tests done (p should be in all cases $p > 0,05$) showed that the two measuring techniques do not different significantly. Also from the Bland and Altman plot it shows that there is a difference of about 0.25 Ds between the two methods for both spherical and cylindrical lenses.

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Περίληψη

Στόχος: Η αξιολόγηση και η μέτρηση της διοπτρικής και πρισματικής δύναμης των οφθαλμικών φακών με την χρήση συμβολομετρίας (Twyman-Green) όπως και η στατιστική συσχέτιση των αποτελεσμάτων με εκείνα που λαμβάνονται από ένα αυτοματοποιημένο φακόμετρο.
Μέθοδος και υλικά: Ο έλεγχος, γνωστής δύναμης δοκιμαστικών σφαιρικών και κυλινδρικών οφθαλμικών φακών, πραγματοποιήθηκε με την χρήση συμβολομετρίας προκειμένου να υπολογιστεί η διοπτρική και πρισματική δύναμη των φακών που μετρήθηκαν. Οι οφθαλμικοί φακοί ελέγχθηκαν, χρησιμοποιώντας ένα συμβολόμετρο Twyman-Green, και τα συμβολογραφήματα που αποκτήθηκαν κατόπιν φωτογράφισης τους υποβλήθηκαν σε επεξεργασία και αξιολόγηση, για την μέτρηση της διοπτρική και πρισματικής δύναμη που αυτοί φακοί παρουσίασαν. Κατόπιν, έγινε σύγκριση των αντίστοιχων αποτελεσμάτων με εκείνα που λήφθηκαν από ένα αυτοματοποιημένο φακόμετρο (TOMEY TL-100) προκειμένου να καθοριστεί εάν οι δύο τύποι μετρήσεων είναι ανταλλάξιμοι. Επίσης πραγματοποιήθηκε στατιστική ανάλυση και για τους δύο τύπους μετρήσεων.
Αποτελέσματα: Τα αποτελέσματα έδειξαν ότι η μέτρηση των οφθαλμικών φακών με το αυτοματοποιημένο φακόμετρο και την συμβολομετρία με το Twyman-Green συμβολόμετρο συσχετίζονται. Από τις στατιστικές ο συντελεστής συσχετισμού Pearsons παρουσιάζει υψηλά σημαντικό στατιστικό συσχετισμό μεταξύ των δύο μεθόδων ($r = 0.9996$ - $P<0,0001$ και έχει ένα διάστημα εμπιστοσύνης 95% για $r = 0.9965$ έως 1.0000).
Συμπεράσματα: Μια νέα μέθοδος παρουσιάζεται για τη μέτρηση της δύναμης (διοπτρικής και πρισματικής) των οφθαλμικών φακών και αυτή η εναλλακτική μέθοδος είναι βασισμένη στην συμβολομετρία. Πιο συγκεκριμένα ένα Twyman-Green συμβολόμετρο χρησιμοποιήθηκε ως τεχνική για να μετρηθούν δοκιμαστικοί οφθαλμικοί φακοί γνωστής διοπτρικής δύναμης.

Λέξεις κλειδιά: συμβολομετρία, Twyman-Green, οφθαλμικοί φακοί, δύναμη.