Designation: F3654 – 23

Standard Test Method for Non-Subjective Optical Requirement Testing of Plano Protective Eyewear[1]

This standard is issued under the fixed designation F3654; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

INTRODUCTION

The optical testing requirements of plano-protective eyewear rely on subjective evaluation methods that are negatively impacted by factors such as accommodation, depth of focus, field of view and resolving power differences that exist in the various optical systems that are used. These challenges lead to significant variation in the testing results. This test method provides an objective means for testing the optical requirements of plano-protective eyewear using wavefront analysis.

1. Scope

1.1 This test method is used to quantify the amount of refractive power (spherical and cylindrical powers) found in planoprotective eyewear.

1.2 This test method is used to quantify the optical performance of plano-protective eyewear as identified by the weighted root mean square average wavefront error.

1.3 This test method may also be used to measure the refractive powers of other plano-protective eyewear or ocular devices, or both.

1.4 *Units*—The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.6 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ANSI/IEA Standard:*[2]

ANSI/ISEA Z87.1 American National Standard for Occupational and Educational Personal Eye and Face Protection Devices

2.2 *ISO Standard:*[3]

ISO 16321-1 Eye and face protection for occupational use — Part 1: General requirements

3. Terminology

3.1 *Definitions:*

3.1.1 *total peak-to-valley value (PV)*—the maximum variance of the wavefront in the observed area.

3.1.2 *root-mean-square (RMS) wavefront error*—extent of image deterioration caused by wavefront deformations due to its deviation from spherical averaged over the entire wavefront.

3.1.2.1 *Discussion*—The RMS wavefront error is calculated as the square root of the difference between the average of squared wavefront deviations minus the square of average wavefront deviation.

3.1.3 *intensity weighted root mean square average value (WRMS)*—the weighted average RMS where higher intensity spots in the pupil center have more weight than lower intensity spots away from the center.

[1] This test method is under the jurisdiction of ASTM Committee F08 on Sports Equipment, Playing Surfaces, and Facilities and is the direct responsibility of Subcommittee F08.57 on Eye Safety for Sports.

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[2] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.org.

[3] Available from International Organization for Standardization (ISO), ISO Central Secretariat, Chemin de Blandonnet 8, CP 401, 1214 Vernier, Geneva, Switzerland, https://www.iso.org.

3.1.4 *plano-protective eyewear*—an optical lens which are designed to protect the eyes from ocular injuries and hazardous external factors but provide no corrective power and as such should have a refractive power of 0.00D.

3.1.5 *refractive power*—(also known as the optical power) is the degree to which a lens or optical system converges or diverges light.

3.1.6 *Strehl ratio (SR)*—the ratio of the value of intensity of central maximum point spread function (PSF) of a real optical system (real lens elements and tolerances) to the value of intensity of central maximum PSF of an aberration-free system.

3.1.6.1 *Discussion*—The ratio specifies the level of image quality in the presence of wavefront aberrations.

3.1.7 *optical performance identifier (OPI)*—a calculated value between 0 and 1 (0 indicating poor optical performance, 1 indicating excellent optical performance) that objectively determines the image formation quality of plano-protective eyewear lenses.

3.1.8 *Zernicke polynomials*—mathematical descriptions of optical wavefronts propagating through the pupils of optical systems.

3.1.8.1 *Discussion*—In optical tests the type of aberrations that occur can be expressed in the form of Zernike polynomials.

4. Summary of Test Method

4.1 This test method describes a single-pass Shack-Hartmann test for measuring the wave-front aberration of plano-protective eyewear lenses and calculating spherical power, cylindrical power, WRMS, and OPI from the acquired wavefront data (Zernicke coefficients).

4.2 The wavefront analysis optical tester (WFAOT) consists of an optical arm mounted on a tri-axis mechanical platform with an angular motion mount (Fig. 1). This setup allows the movement with an accuracy of 1 mm of a headform mounted on the device in the horizontal and vertical direction. The device can also rotate the head about an angular motion axis.

4.2.1 The optical arm of the WFAOT consists of a SHWS and a 542 nm collimated laser setup. SHWS provide accurate measurements of the wavefront shape and the intensity distribution of optical beams. During operation, light is incident on a microlens array (MLA), which creates a matrix of focal spots on a CMOS camera sensor. The centroid locations of the focal spots are analyzed and this provides wavefront measurements. The WFAOT is equipped with programable motion control and is compatible with the custom-built Laser Eye software control user interface.

4.3 The WFAOT can move the test head to the predefined positions to enable wavefront optical testing of as-worn protective eyewear. The WFAOT reads and reports the required values from the SHWS to the computer running the Laser Eye application and gives the user the ability to control the machine in manual or automatic predefined testing modes.

4.4 Laser Eye outputs sensor information on beam centroid and diameter, modal and zonal reconstructed wavefront, max variance of the wavefront, peak-to-valley (PV), and RMS of Wavefront. It also outputs Zernike representations of tilt, defocus, astigmatism, coma, and spherical, aberrations as well as Fourier and refractive power parameters.

4.5 To acquire refractive power measurements first a laser beam is sent through the ocular apertures of the headform to the wavefront sensor. The wavefront acquired is the planar (baseline/reference) wavefront. The plano-protective eyewear is then mounted on the headform anterior to the laser (Fig. 1). A subsequent laser beam is sent traveling through the protective eyewear and the ocular aperture of the headform towards the SHWS, this is the measurement wavefront. The optical aberrations that exist are derived from subtracting the planar (reference/baseline) wavefront from the measurement wavefront.

5. Significance and Use

5.1 This test method offers a procedure for evaluation of the refractive components of plano-protective eyewear.

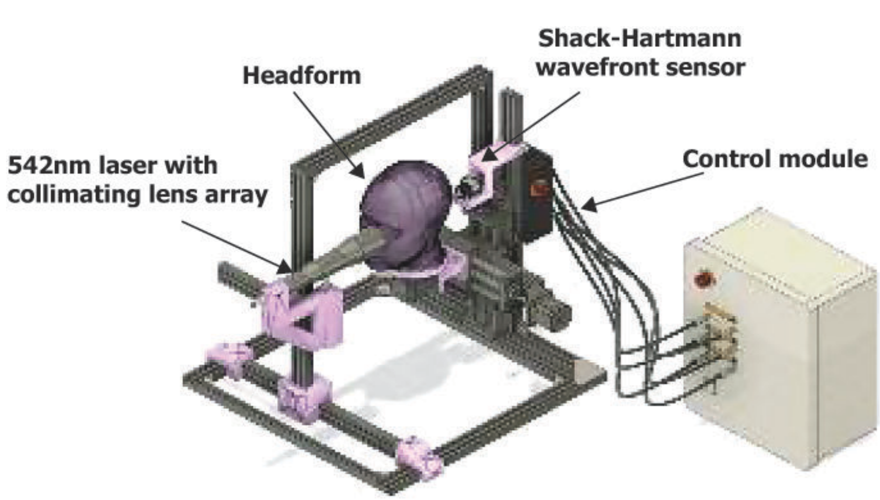

FIG. 1 Wavefront Analysis Optical Testing Apparatus

5.2 This test method has been specifically designed for protective eyewear that will not fit into conventional automatic/digital focimeters.

5.3 This test method has been designed to provide a determination of the image formation quality of plano-protective eyewear.

5.4 This test method offers a comprehensive refractive power measurement scanning protocol that measures the refractive power over a total 50 mm^2 area in front of each eye. This measurement protocol known as the Multiple Gaze Direction Detailed Scan (MGDDS) measures the refractive powers of the zones of the plano-protective eyewear that are typically used as the wearer performs micro eye movements.

6. Apparatus and Materials

6.1 *Collimated Laser Module*—A collimated laser diode module that produces an output beam that has a round beam shape. The module contains a Diode-Pumped Solid State (DPSS) laser, with an internal attenuator used to reduce the output power to a Class 2 safety rating. Polarization Extinction Ratio of 5 dB, Beam Divergence of 0.5 mrad, or equivalent collimated laser source.

6.2 *Beam Expanding Lens Array,* capable of expanding a beam of light up to 5×, with a wavefront error of <λ/4 (peak to valley).

6.3 *Shack-Hartmann Wavefront Sensor (SHWS),* with a minimum 2048 by 2048 pixel CMOS Camera, 10 mm by 10 mm active area, wavelength range of 400 to 900 nm, effective focal length of 14 to 15 mm, lenslet pitch of 300 µm or better, wavefront accuracy at 633 nm of λ/40 rms; or equivalent. The wavefront sensor should be accompanied by wavefront sensing software capable of outputting optometric values of spherical and cylindrical powers, peak-valley ratios, and weighted root mean square of the measured wavefront.

6.4 *Headform,* conforming to ISO 16321-1, 1S, 1M or 1L headform for optical testing.

6.5 Vertical and horizontal translation stage capable of moving a headform in the horizontal or vertical directions with a ±1 mm accuracy.

7. Hazards

7.1 (**Warning—**Improperly used laser devices are potentially dangerous.) Class 2 lasers, which are limited to 1 mW of visible continuous-wave radiation, are safe because the blink reflex will limit the exposure in the eye to 0.25 s. This category only applies to visible radiation (400 to 700 nm).

8. Eyewear Preparation

8.1 Prepare the eyewear by cleaning the lenses with a soft lens cleaning cloth or follow manufacturer instructions.

9. Procedure

9.1 The wavefront analysis optical testing apparatus is outlined in Fig. 1.

9.2 *System Alignment*—The head form used shall be an optical version of the 1S, 1M or 1L headform as described by ISO 16321-1. Using the translational stage, the headform is positioned so that the center of the SHWS coincides with the center of the pupil of the selected headform. The collimated laser module is turned on and directed towards the wavefront sensor. The laser beam is aligned with the beam expanding lens to produce a minimum of 30 mm^2 collimated light area going through the ocular aperture of the headform, propagating towards the SHWS with no plano-protective eyewear in place.

9.3 *Taking Baseline/Calibration Reference Measurement*—Prior to the measurement of the refractive component of the plano-protective eyewear, the baseline or calibrated plane wave measurement must be performed (Fig. 2). This will serve as a reference or baseline from which the measured wavefront of the protector will be calculated from. This is done by taking a measurement of the planar wavefront, that is, the wavefront produced by the collimated beam of light without any test plano-protective eyewear in place. This baseline/calibration file should be stored. When this is performed correctly, the refractive power read out will be between 0.00 and ±0.004 for both sphere and cylinder.

9.4 Mounting the protective eyewear after the baseline, the protective eyewear is mounted on the headform in the as-worn

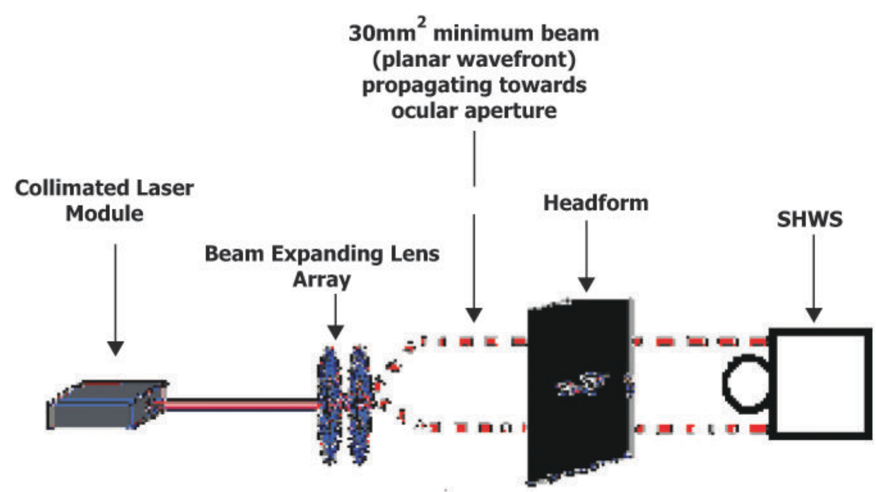

FIG. 2 Setup for Taking Baseline Measurement/Calibration Reference Measurement