Draft Minutes
ASC OP1 Optics and Electro-Optical Instruments – Optical Elements and Assemblies – Wavefront Standard
Sunday, January 20, 2008, 2:00 p.m. – 5:00 p.m.
Fairmont Hotel, California Room
170 South Market Street
San Jose, CA 95113

Attending ☒	Committee Members (14 of 24 w/1 alt.)	Representing
☒	David Aikens	Savvy Optics Corp.
☒	Gordon Boultbee (Alternate)	JDSU
☒	Andre Brunfeld	Xyratex
☒	Benjamin Catching	JDSU
☒	Walter Czajkowski	APOMA (Edmund Optics)
☒	Marla Dowell	IEEE/LEOS (NIST)
☒	Lincoln Endelman	SPIE (Endelman Enterprises)
☒	Chris Evans	Zygo Corporation
☒	Krishna Gupta	Zygo Corporation
☐	John M. Hamilton	Northrop Grumman Corporation
☐	James E. Harvey	CREOL
☒	Hal Johnson	Harold Johnson Optical Lab
☒	Allen Krisiloff	Triptar Lens Company, Inc.
☐	Gene Martin	
☐	Jonathan McGuire	Northrop Grumman Laser Systems
☒	Wayne McKinney	Lawrence Berkeley National Lab
☐	Michael Morrill	Lockheed Martin Space Systems Co.
☐	Bruce Netherton	Lockheed Martin Coherent Technologies
☐	William Royall	Eastman Kodak Company (Retired)
☒	Peter Z. Takacs (by phone)	Brookhaven National Lab
☐	Trey Turner	Research Electro-Optics, Inc.
☐	Steven VanKerkhove	Corning Tropel
☒	Ray Williamson	Ray Williamson Consulting
☐	Dr. Valeriy V. Yashchuk	Lawrence Berkeley National Lab
	Observers (2)	
☒	Lahsen Assoufid	Argonne National Laboratory
☒	Gene Kohlenberg	OEOSC
☐	Stephen Martinek	4D Technology

Auditor's Summary of Meeting

A representative from Zygo Corp. described the robust peak-to-valley calculation that is being proposed as a replacement for the traditional visual peak-to-valley number that has been used to describe how closely a manufactured optical surface conforms to the design.

A representative from Lawrence Berkeley National Laboratory prepared an outline of the draft **BSR/OEOSC OP1.004, "Statistical methods for measuring wavefronts and surfaces."** A representative from Brookhaven National Laboratory had begun fleshing out the outline using some material from the **ISO 10110-8 standard, "Optics and optical instruments – Preparation of drawings for optical elements and systems – Part 8: Surface texture."**

A representative from Corning Tropel reviewed his draft outline of **BSR/OEOSC OP1.005, "Deterministic methods for measuring wavefronts and surfaces."**

The Task Force agreed to hold a teleconference to examine both drafts after suggestions provided by the Task Force had been incorporated. A second in-person meeting was also scheduled to be held in Rochester, NY during the OSA Annual Meeting in October.

1. Welcome and Introductions

S. VanKerkhove opened the meeting at 2:10 p.m. with a round of introductions.

2. Adoption of Agenda

C. Evans moved to adopt the agenda. B. Catching seconded the motion, which carried unanimously.

3. Approval of draft minutes of the Friday November 30, 2007 meeting

A. Brunfeld moved that the minutes be approved. M. Dowell seconded the motion, which carried unanimously.

4. Review of PVr

C. Evans presented a talk on the robust peak-to-valley term, PVr. He said that the first question is, "why does the optics community need a new parameter to describe surfaces and wavefronts?" His first answer is, "one doesn't need a new term because many use rms irregularity along with PSD and slope." But many have the historical custom of describing surfaces in peak-to-valley (PV) terms of wavelength, e.g. 1/10 λ. PV is a badly biased parameter for interferometers. However, it is difficult to move the community away from an amplitude term.

If one looks at the bias for a real surface, one can show that it is a function of the higher moments of the surface. Zygo has defined an amplitude parameter called PVr that is fit to 36 terms of the Zernike polynomial + 3 σ of residuals.

For circular apertures $PVr = PV_{36Zernikes^*} + N \times \sigma_{36ZernikeResid}$, default $N = 3$, $PVr \leq PV$

His first example was a 12 in. optic. He showed that PV changes greatly depending upon the number of pixels used to sample the surface wavefront, while the PVr yields a constant result for different detector resolutions. PVr is insensitive to shop floor noise.

His second example shows obvious fliers and noise in the data. He showed that if 2% of the data were discarded or clipped, the PVr changed very little.

There could be options specified, such as, 1<N<6, limit clip total area, and limit maximum contiguous clip area. However, C. Evans sees no reason why the optics industry should not agree upon using N=3.

D. Aikens said that he "fell in love" with PVr because PV has been used for over one-hundred years as an easy single value to describe and optical surface. It was never intended to be applied to statistical determination of a surface. PV was intended for smoothly changing surfaces without tiny spikes along the way. An optician was interested in the shape of the irregularity and how large it was. PVr gives a vendor a tool to communicate with a customer, who probably has less understanding than the vendor does about surface variation. The vendor is able to express his test results in terms of peak-to-valley errors used by the customer, but he can explain to that customer that he is interpreting the errors calculated by the PVr method. Ninety-nine per cent of the time the customer will not care if the errors are computed by the PVr method. Those customers who want a more rigorous interpretation of the test optical surface will not specify PV on their drawings.

W. McKinney said that he could see how the PVr method could cause less grief, but will the manufacturers add the function to their interferometers? D. Aikens said that Zygo has already included it, and he thought that Zygo would not object to other interferometer manufacturers also adopting the technique. C. Evans said that he would be delighted if others would adopt the PVr technique.

S. VanKerkhove asked if the optics industry would be setting itself up for a confusing situation where customers would become confused whether PV or PVr was being used. There should be a note on the drawing specifying which calculation method was being used.

D. Aikens said that he has met no one who is opposed to the PVr concept. He thinks that the idea will catch-on and manufacturers will begin using it without hesitation.

A. Brunfeld suggested that the PVr should be quoted over a scale length to remove the problem of different numbers of pixels being used for the calculation. D. Aikens replied that as soon as scale length is incorporated to describe the surface, the measurement becomes a statistical method and RMS should be used. The auto industry has abandoned PV measurements for their precision machined parts and are making specifications using RMS.

5. Wavefront Standards

a) OP1.004 – statistical methods for measuring wavefronts and surfaces

- **Reconciliation of definitions with ISO/DIS 25178-2 and ASME B46.1**

P. Takacs said that the first page of the draft 1.004 contains an outline of what should be covered in the specification. V. Yashchuk prepared the outline, and P. Takacs made some modifications. P. Takacs started with ISO 10110-8; he tossed out some things, modified others and added new material as he worked through the document.

There is a problem in obtaining other standards that may contain relevant material, e.g. terminology and symbols that could be incorporated into this draft. He is working with ANSI to see if he can get courtesy copies for his review. There are 25 standards that may have relevant terminology. The **SEMI MF1811-0704 – Guide for Estimating the Power Spectral Density Function and Related Finish Parameters from Surface Profile Data** standard, contains a lot of the work that Gene Church and John Stover have completed during the past two decades to express surface roughness using the power-spectral-density function. P. Takacs is adapting those sections that are pertinent to optics applications.

P. Takacs said that he has included symbols in the definitions of some of the terms. He does not know if these symbols are those customarily used. He asked the members of the Task Force for input concerning the appropriate symbology. As an example he is representing slope with “m” rather than “z” for difference in height.

C. Evans said that there is additional work by the ISO TC 213, “Dimensional and geometrical product specifications and verification” committee that does not, yet, appear on the ISO web site as a published standard. Paul Scott from Taylor Hobson and Professor Jane Xiang from the University of Huddersfield are involved in this work. D. Aikens agreed to contact E. Leitner at ISO to see if the pertinent drafts of TC 213 could be made available for this project. D. Aikens asked C. Evans to give him the list of TC 213 documents that are of interest.

- **Address micro-defects (defined both in 3.4 and 3.14)**

S. Martinek was not able to attend the meeting, so this item was postponed until a future meeting.

- **Expanded 2D PSD definitions**

P. Takacs said that the Task Force needs to decide how to approach this topic. The SEMI document does not cover this situation. The standard should indicate how to handle the higher spatial-frequency data derived from measurement machines such as optical-surface profilometers or full-aperture interferometers. S. VanKerkhove asked if P. Takacs wanted to tackle this topic alone, or if he wanted a small sub-group to work with him. P. Takacs said that he had an idea that he would like to document and circulate to the members of the Task Force for feedback before the next meeting.

- **A Higher Level Look at this Issue**

D. Aikens asked to talk about a higher-level issue. He reviewed the work done while struggling with this subject, and noted that the Task Force decided to separate the topic into the two drafts OP1.004 and OP1.005. The original concept was to expand ISO 10110-8 (which covers surface texture with definitions of the parameters and specifies a notation) to make it more robust. P. Takacs has done a lot of good work which is more of a test-and-measurement standard, not a notation standard. So the Task Force should consider creating a third document, which references the test-and-measurement document, to address notation a la ISO 10110-8.

P. Takacs said that he started with the original ISO 10110-8 outline, but realized that he had to explain what PSD and slope PSD are. He was not sure how to reconcile his resulting outline with ISO 10110-8. D. Aikens replied that in this case, the ISO approach to separate the definitions, terms, and mathematics from the notation document may be preferred.

S. VanKerkhove said that P. Takacs document should be finished before completing the ISO 10110-8 update. D. Aikens said that the two documents could be synchronized. He also said that he could draft and update for ISO 10110-8 in a day to be presented to TC 172/SC 1 meeting in Bucharest, Romania in May.

D. Aikens continued by saying that there has to be a US national standard covering notation. Perhaps notation should be incorporated into OP1.005, and the Task Force should move the Zernike polynomial decomposition process to OP1.004. P. Takacs said that there needs to be a lot of background information documented before moving into a notation. S. VanKerkhove assumed that notation would be included in each of the current drafts. M. Dowell proposed that the Task Force continue with the two drafts as planned, and put notations in each of them.

P. Takacs said that his approach was to generate a document that defines how to calculate the desired parameters from the machine data so that it can be recorded on a drawing. What he has written is background information that is necessary to understand the number that is included in the drawing notation specified by a US national standard. His work is analogous to ISO 14999-1 through 4.

D. Aikens concluded that there will need to be another sub-task force to update ISO 10110-8 for the upcoming meeting in Romania so that there is a good notation for roughness. The international committee is going to want a simple update of ISO 10110-8, which is being used in 13 countries. D. Aikens will look at the update Of ISO 10110-8 so that this Task Force can continue working with OP1.004. Sometime in the future the notations can be reconciled.

W. McKinney said that he does not know how to do 2D PSD fitting for non-isotropic surfaces. The way the data is detrended effects the results. Settling the problem will take some work.

- **rms, rms slope, PSD in the foreword**

P. Takacs said that once the power-spectral-density function is calculated, then rms and rms slope can be obtained by summing over the appropriate band widths. He will work up some examples.

- Slope

P. Takacs said that slope is more easily done in the frequency domain. He will add mathematics for filtering the slope.

C. Evans asked if P. Takacs had considered the structure function used by astronomers. It is the specification of a surface that is the expectation value as a function of separation of points on the surface. W. McKinney said that it would be like Church's D function.

S. VanKerkhove asked if there was an ISO document that defines slope. D. Aikens said that he knew of none; however, ISO 10110-12 references the specification of a local slope on an asphere, but there is no description about how to calculate the slope. S. VanKerkhove suggested that the Task Force find an industrial user who understands the use of slope and ask that person to propose how the standard should be written. D. Aikens suggested that P. Takacs would be that person. P. Takacs agreed that he should write the slope section.

S. VanKerkhove asked if a user specified either a 1D or 2D PSD, would the slope also need to be specified. W. McKinney replied that the slope would not need to be specified. He thought that metrology labs would like to see slope eliminated. D. Aikens said that slope is a direct predictor of focus-ability. The rms slope values tells the designer how well a spot can be imaged. S. VanKerkhove said that slope should be treated similarly to how peak-to-valley is handled. The standard should direct that designers specify PSD. D. Aikens agreed with that approach: do not give a good method for specifying slope because it should not be used. The Task Force should provide a definition that the manufacturers can reference to show how they calculate slope, if they insist upon using it.

P. Takacs reviewed the discussion by asking if the Task Force wanted to put emphasis on PSD rather than slope. S. VanKerkhove replied that the standard will need a provision similar to PVr for those who insist upon using slope. C. Evans said that Code V types of programs do not have a PSD optimizer. D. Aikens said that the stray-light programs are the ones that deal with surface scatter. He presumed that the computer program ASAP would already allow an engineer to enter a PSD value for a surface. One would never design a lens using PSD, but one would evaluate the design using PSD.

P. Takacs said that slope can be avoided when photons are considered to be bullets, but when one deals with coherent wavefronts you need detailed height or phase information for the wavefront. So the standard would have to provide for both incoherent and coherent optical systems.

S. VanKerkhove suggested that the topics of 2D PSD and Slope be combined for future meetings.

- **Structure of Measurement Section**

D. Aikens thought that it is too early to talk about the measurement section.

- **Bandwidth limits**

D. Aikens said that the Task Force should clarify bandwidth over the statistical property. The measurer needs to make sure that their measurements accommodate that specification.

S. VanKerkhove thanked P. Takacs for the work that he has done.

b) OP1.005 – deterministic methods for measuring wavefronts and surfaces

- **Background**

S. VanKerkhove reviewed the past efforts concerning the draft of this standard. He distributed copies of the draft outline of BSR/OEOSC OP1.005 that was posted on the web site for this meeting. He said that the new draft can look similar to ISO 10110-5 and 10110-14. He prefers the 1996 version as opposed to the current version. He proposed that the Task Force examine his draft outline at this meeting. The areas addressed are

Normative Reference
Definitions
Terms and Functions

Specification of Tolerances for Surface Form Error
Indication on Drawings
Examples of Tolerance Indications

S. VanKerkhove said that he would like to incorporate the Zernike Polynomial definitions that were included in the ophthalmic draft standard ISO/DIS 24157.

D. Aikens said that after standardized pixel-filtering is defined, then it could be discussed in the notations section or the one following.

C. Evans asked how those who use test plates would use this. S. VanKerkhove said that this requirement would be left off of the drawing. D. Aikens said that the "quarter-wave" type specification would be included in the section on notations.

A. Brunfeld asked if the user is assumed to be measuring the surface or the wavefront deviation. S VanKerkhove said that ISO decided to split wavefront measurement from surface-form measurement. For the US standard, the two measurements are being combined in one document. A. Brunfeld said that he wanted to point out that the wavefront deformation depends upon the propagation, and there is a problem, because the standard has to define where the wavefront is being measured. S. VanKerkhove replied that the standard is created to provide the user with a means for noting the specification, not where the value of the specification should be measured. The user of the standard should determine where the value is measured. D. Aikens pointed out that A. Brunfeld's comment is valid, but for the specification of long scale-length items, then the location of the measurement plane for a transmitted optical wavefront error of an optical system is not that critical. Short scale-length errors will cause problems, and for that instance a note on the drawing should point out the concern. D. Aikens cautioned the Task Force to avoid creating a notation for the location of the measurement of a transmitted wavefront error. He thought such a notation would confuse the optical manufacturing community. Transmitted wavefront specifications are only used when an optical surface cannot be directly measured (e.g. a buried surface).

A. Brunfeld stressed that the specification should be complete, and at a minimum a note should be required for this instance. M. Dowell pointed out that the Task Force is now looking at the outline, and this problem can be addressed when the document is drafted.

M. Dowell suggested that PVr should be added to the "Terms and Functions" section.

R. Williamson pointed out that section 6) should state, "Indication on Drawings: The indication on drawings ~~will~~may contain the following:" D. Aikens suggested that the phrase "(But not limited to:)" should be removed because this is the list of standard notation. Notes may be written for other parameters. S. VanKerkhove said that this was a phrase intended for the Task Force, not for the final draft.

C. Evans asked if the clear aperture is an inscribed or circumscribed circle. S. VanKerkhove said that he would add it to the list of items to be addressed.

- **Annex**

S. VanKerkhove said that these are some of the topics that have been discussed in the past. The Task Force should decide if they are to be included here.

  - **Measurement Methods**

S. VanKerkhove asked if the standard should tell the user how to do interferometric metrology. What happens when the reader is not using an interferometer?

  - **Visual Interpretation**

  S. VanKerkhove asked if the Task Force wanted to include topics such as "Visual Interpretation" in the Annex. D. Aikens said that this topic is included in ISO 14999-4, so that the ISO document could be referenced in the informative section of this OP1.005. He continued that a note could be placed somewhere directing the user to ISO 1499-4. He added that wedge is covered by ISO 10110-6.

  - **Non-Circular Apertures**

  S. VanKerkhove said that ISO 10110-5 described "non-circular test areas." He asked C. Evans if he had given any thought to employing PVr over a non-circular aperture. C. Evans said that polynomials can be defined for most common non-circular apertures. S. VanKerkhove concluded that this topic should be included. D. Aikens recommended that the Task Force not develop polynomials for the other shapes, but rather include a note describing what must be considered for non-circular apertures.

  - Power Spectral Density

  S. VanKerkhove said that this topic would be covered in OP1.004.

  - Validation of Standard

S. VanKerkhove said that D. Aikens had suggested this topic. D. Aikens said that it should be "Validation of the Specification."

- Uncertainty (K-value)

D. Aikens suggested that this could be covered by a normative reference to the document that defines uncertainty.

C. Evans said that the NIST Technical Note 1297, is "Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results." The combined standard uncertainty u_c is a widely employed measure of uncertainty. The NIST document states, "what is often required is a measure of uncertainty that defines an interval about the measurement result y within which the value of the measurand Y is confidently believed to lie. The measure of uncertainty intended to meet this requirement is termed **expanded uncertainty**, suggested symbol U, The value k is known as the **coverage factor** in the equation $U=ku_c(y)$. C. Evans said that the standard should say that $k=2$ unless otherwise specified. D. Aikens said that he prefers that $k=1$. M. Dowell said that $k=2$ is like saying 2σ. Depending upon the distribution of the data, it could be a 95% confidence interval.

6. Time and Place for next OP/TF 2 Wavefront Meeting

After looking at the options, M. Dowell suggested that the Task Force hold a teleconference in the spring, and then meet in Rochester in October. S. VanKerkhove replied that if there is a teleconference, then he wants specific action items on the agenda. Drafts should be made available before the call. G. Kohlenberg will not be available from May 1 through May 19, D. Aikens will be unavailable May 19 – 23, and P. Takacs will be unavailable the last week of May through the first week of June. S. VanKerkhove will be in Germany the second week of June. D. Aikens said the main reason for a teleconference is to encourage P. Takacs and S. VanKerkhove to get the documents ready. D. Aikens moved that the Task Force meet in person in Rochester during the October OSA Annual meeting and that it hold a teleconference, sometime before the October meeting, at a time chosen by S. VanKerkhove and P. Takacs. C. Evans seconded the motion. The motion carried unanimously.

7. Adjournment

D. Aikens moved that the meeting be adjourned. M. Dowell seconded the motion. The meeting was adjourned at 5:10 p.m.