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Comparison of four methods of interferogram reduction and interpretation

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Abstract

This paper will address the problem of accurate reduction and interpretation of interferograms. Peak-to-valley wavefront deformation will be the main criterion of evaluation. Interferograms containing power, spherical aberration, coma, and astigmatism will be evaluated using four different methods. These methods will be 1) visual interpretation using a "harp," 2) manual interpretation, 3) automatic digitization (Zygo Zapp), and 4) computer interpretation (fringe). The strengths and weaknesses of these methods, including cost, time, accuracy, and repeatability, will be discussed. Reference will be made to "Optical Interferograms-Reduction and Interpretation" an ASTM publication.

Introduction

Whenever an interferogram is produced there is always left, the task of reducing and interpreting it. The reduction of the interferogram can take many forms, each of which can be believed to some degree of reliability. For the purpose of comparison we have used the following four methods: visual, manual, automatic, and computer-aided.

It is always possible to interpret an interferogram to a small fraction of the wavelength at which the interferogram was taken. The degree to which one can believe these results and the aforementioned methods of reduction will be discussed during the course of this article.

Description

Visual Method

This method of reduction is primarily for "ball park" approximations. It incorporates the use of a HARP for an aid in reduction. The HARP is a parallelogram with variable spacing of equal intervals (Figure 1).

Manual Method

The manual method used is described in Appendix 1 of ASTM Publication #astp666 Optical Interferograms-Reduction & Interpretation. This technique extracts quantitative information from an interferogram by comparing an actual fringe pattern to an ideal pattern of equally spaced straight lines. The comparison is carried out by superimposing a set of straight lines on the fringes of the interferograms and measuring the deviation of the interferogram fringes from the straight lines (Figure 2).

Automatic Method (Zygo ZAPP)

The Zygo-ZAPP is an automatic fringe reduction system. ZAPP automatically acquires the fringe center coordinates, performs the data reduction, and displays the output. ZAPP evaluates an interference pattern by performing at least square fit to an array of points located on the center of fringes using a processor module. The processor module is essentially a video fringe center coordinate digitizer with the numerical computational capability to do rapid analysis of the data. The output is peak-to-valley distortion, the root-mean-square value of the distortion and the optical path differences (Figure 3).

Computer Aided (fringe)

Fringe is a computer program written at the Optical Sciences Center, University of Arizona, Tucson for the analysis of interferometric test data. Fringe fits a high order polynomial to the data by using the Gram Schmidt method of least squares fitting. The fringe coordinates are manually digitized by use of a platten digitizer. Fringe output contains peak to valley wavefront deformation, root mean-square value of the deformation, stretch ratio, and individual aberration quantities (Figure 4).

Evaluation Technique

The interferograms used in this evaluation were chosen for three purposes: their singular form of aberration, the limited fringe reduction capability of the Zygo ZAPP system, and due to the common occurrences of these fringe patterns in a typical "lab environment" (Figure 5). All interferograms with the exception of #9 were taken from the Zygo publication, "Interpretation and Evaluation Handbook."

For the ZAPP, Fringe, and Manual methods described previously each interferogram was digitized three times. Peak-to-Valley wavefront deformation was used as the criteria of evaluation.

The relative accuracy (Table 1) of each system was established by the following:

- 1) A mean was established by taking an average of the three reductions and defined as the baseline.
- 2) A percentage of the baseline was calculated for each reduction and from these values on a cumulative average was obtained.
- 3) Using the cumulative averages obtained in each method, a system repeatability was established.

The relative accuracy (Table 2) of each system was established by the following:

- 1) Using the aforementioned baseline for each interferogram in the ZAPP, Fringe, and Manual methods, a new mean was established.
- 2) A percentage of the new mean was calculated for each interferogram and from these values on a cumulative system average was determined.
- 3) Deviation from this system value was used as an indicator of relative accuracy for each method.

Pros and Cons

Each method of evaluation has its respective advantages and disadvantages. The following are inherent to each method:

METHOD	ADVANTAGES	DISADVANTAGES
visual	very fast convenient inexpensive	not accurate
manual	accurate inexpensive	inconvenient time consuming
automatic	very fast accurate accepted by industry	expensive fringe reduction capabilities fringe contrast quirks*
computer aided	most accurate list of aberrations comprehensive output	expensive manual digitization

* on the Mark II Zygo Zapp system in the Optics Evaluation Laboratory at Los Alamos National Laboratory, the following quirks have been frequently observed:

When zero order is reversed peak-to-valley deformation changes as much as 1/4 which raises the question of which evaluation to believe.

When cancelling power from an interferogram frequently, Zapp will contract a much larger amount than the total peak-to-valley deformation of the interferogram.

Figure 1. $P-V = 1.3F$

Figure 2.

$$D_1 = 50.5 \text{ mm} \quad D_2 = 48 \text{ mm} \quad N = 5$$

$$F_s = \frac{D_2 + D_1}{2(N+1)} = \frac{50 + 48}{2(5+1)} = \frac{98}{8} = 12.25 \text{ mm}$$

$$\Delta F_{Lmax} = 4.3 \text{ mm} \quad \Delta F_{Hmax} = 7.2 \text{ mm}$$

$$\Delta F_{max} = \Delta F_{Lmax} + \Delta F_{Hmax} = 4.3 + 7.2 = 11.5$$

$$OPP = \frac{\Delta F_{max}}{F_s} = \frac{11.5 \text{ mm}}{12.25 \text{ mm}} = .94 F$$

Figure 4.

Figure 3

```

2 TEST 2
THU, FEB 28, 1985, 3:45 PM filename: WTEST2
--FSCAN
--FIDS 14771 8912 16289 7405 14660 6015 13380 744
--TILT STEP .5 END
DO YOU WISH TO ADD ANOTHER LINE OF OPTIONS ?N

```

PUPIL CENTER AND RADIUS		
XC	YC	RAD
14834.5000	7463.5000	1458.9734

```
ZTEST 2
THU, FEB 28, 1985    3:45 PM          filename:  WTEST2
```

WAVEFRONT DEVIATION IN UNITS OF WAVES
WAVELENGTH .633 MICRONS
INTERFEROGRAM HAS 5 FRINGES AND .3 DIGITIZED POINTS.

QUALITY OF FIT FOR DIFFERENT POLYNOMIAL ORDERS

	N	RMS	MAX
PLANE	2	.422	.748
SPHERE	3	.082	.183
4TH ORDER	8	.028	.068
5TH ORDER	15	.022	.059
8TH ORDER	24	.014	.034

```

STREHL. RATIO  .765  AT BEST FOCUS
      TILT      2.738      174.4 DEG.
      FOCUS      1.451

```

FOURTH ORDER ABERRATIONS		
MAGNITUDE	ANGLE	DESIGNATION
WAVES	DEG	
2.561	176.9	TILT
.348		FOCUS
.138	-87.6	ASTIGMATISM
.226	136.0	COMA
.914		SPHERICAL ABERRATION

FOLLOWING TERMS WERE SUBTRACTED FROM DATA-
TILT

RESIDUAL WAVEFRONT VARIATIONS EVALUATED AT DATA POINTS:

PTS	RMS	HIGH	LOW	P-V
43	.422	.695	-.748	1.444

RESIDUAL WAVEFRONT VARIATIONS EVALUATED AT DATA POINTS

PTS	RMS	HIGH	LOW	P-V
705	.394	.908	-.249	1.500

Figure 5.

1	ASTIG 1	2	ASTIG 2
3	COMA 1	4	PWRI
5	SPHR 1	6	ZTEST 1
7	ZTEST 2	8	ZTEST 3
9	NOAB 1		

Conclusion

The standard in industry when qualifying an optical component is usually given in terms of an absolute value of wavefront quality. At Los Alamos we frequently receive optics that have been qualified by the supplier to have some value of OPD to a ridiculous accuracy. An example of which would be $1/10.3337$. Certainly this cannot be correct.

The limiting resolution of each system should be stated as a percentage of the overall wavefront deformation of each interferogram rather than an absolute value. This percentage which we have termed "believability" is arrived at by taking the smaller of the relative precision and relative accuracy (Tables 1 and 2).

We would encourage a simple test of repeatability for whatever method or system is available to the user. This should reveal that only cheaters repeat to 100% accuracy.

References

1. Optical Interferograms-Reduction and Interpretation STP666 an ASTM Publication, designation: F 529-77 T
2. Interferogram Interpretation and Evaluation Handbook, a Zygo publication copyright 1977.

Relative Precision

ZYGO ZAPP:	CASE 1		CASE 2		CASE 3		MEAN	CUMULATIVE AVERAGE*
	P-V	PERCENTAGE OF MEAN	P-V	PERCENTAGE OF MEAN	P-V	PERCENTAGE OF MEAN		
1) ASTIG1	1.745	91	1.834	95	2.190	88	1.923	91
2) ASTIG2	.968	98	1.041	95	.906	97	.992	97
3) COMA1	.576	94	.559	96	.483	90	.539	93
4) PWR 1	1.208	90	.958	88	1.085	100	1.084	93
5) SPHR1	1.171	96	1.084	97	1.101	98	1.119	97
6) ZTEST1	.981	100	1.047	94	.927	94	.985	96
7) ZTEST2	1.309	90	1.059	90	1.154	98	1.174	93
8) ZTEST3	.138	93	.124	96	.126	98	.129	96
9) NOAB1	.161	89	.152	94	.117	82	.143	88
SYSTEM REPEATABILITY								94

FRINGE:

1) ASTIG1	1.904	93	1.821	98	1.613	91	1.779	94
2) ASTIG2	1.043	97	1.011	100	.973	96	1.009	98
3) COMA1	.419	90	.431	93	.544	85	.465	89
4) PWR1	1.043	96	1.085	100	1.141	96	1.090	97
5) SPHR1	1.113	97	1.086	100	1.049	97	1.083	98
6) ZTEST1	.947	98	.978	99	.975	99	.967	99
7) ZTEST2	1.444	98	1.385	97	1.438	99	1.427	98
8) ZTEST3	.065	97	.054	86	.070	90	.063	91
9) NOAB1	.124	96	.136	96	.130	100	.130	97
SYSTEM REPEATABILITY								96

MANUAL:

1) ASTIG1	1.628	94	1.921	90	1.620	94	1.724	93
2) ASTIG2	1.077	99	1.076	99	1.047	98	1.067	94
3) COMA1	.570	90	.688	92	.636	99	.631	94
4) PWR1	1.114	94	1.200	92	1.009	91	1.108	94
5) SPHR1	.991	96	1.020	99	1.091	94	1.044	97
6) ZTEST1	.929	94	.929	99	.949	99	.946	94
7) ZTEST2	1.394	92	1.584	94	1.447	97	1.511	94
8) ZTEST3	.056	82	.074	83	.074	92	.068	89
9) NOAB1	.112	86	.114	89	.094	82	.111	89
SYSTEM REPEATABILITY								94

* Cumulative average calculated by averaging the percentage of mean for each interferogram.

RELATIVE ACCURACY

	<u>ZAPP</u>		<u>FRINGE</u>	
	<u>AVERAGE P-V</u>	<u>PERCENTAGE OF MEAN</u>	<u>AVERAGE P-V</u>	<u>PERCENTAGE OF MEAN</u>
1) ASTIG1	1.923	94	1.779	98
2) ASTIG2	.992	97	1.009	99
3) COMA1	.539	99	.465	85
4) PWR1	1.084	99	1.090	100
5) SPHR1	1.119	96	1.083	100
6) ZTEST1	.985	98	.967	100
7) ZTEST2	1.174	86	1.422	96
8) ZTEST3	.129	67	.063	72
9) NOAB2	.143	90	.130	99
CUMULATIVE AVERAGE		92		94

	<u>MANUAL</u>		<u>VISUAL*</u>	
	<u>AVERAGE P-V</u>	<u>PERCENTAGE OF MEAN</u>	<u>MEAN</u>	<u>PERCENTAGE OF MEAN</u>
1) ASTIG1	1.723	95	1.808	88
2) ASTIG2	1.067	96	1.023	79
3) COMA1	.631	86	.545	92
4) PWR1	1.108	99	1.094	91
5) SPHR1	1.034	96	1.079	93
6) ZTEST1	.936	97	.963	96
7) ZTEST2	1.511	91	1.369	95
8) ZTEST3	.068	78	.087	87
9) NOAB1	.113	88	.129	78
CUMULATIVE AVERAGE		92		89

1) ZYGO ZAPP	8
2) FRINGE	6
3) MANUAL	8
4) VISUAL	11

* Visual method not used in calculation of mean.