Stitching Interferometry for the Wavefront Metrology of X-ray Mirrors

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ABSTRACT

We discuss the possibility of using Stitching Interferometry for the surface shape metrology of X-ray Mirrors. Indeed, Stitching Interferometry combines a large field of measurement with a high lateral resolution. In other words, it provides large-scale and medium-scale measurements in a single instrument. Small-scale deformations is considered here to be "roughness", and will not be dealt with in this article.

The only potential problem in Stitching Interferometry is large-scale fluctuation. This is not due to the Stitching Process itself, but to small measurement errors which get "amplified" by the long dimension of the typical X-ray Mirror. This will be addressed, and it will be shown that it need not be a problem.

As we have not completed our series of experimental measurements, we will illustrate our article with stitching measurements performed on large MégaJoule components (800 × 400 mm), and show an example of "Mixed Stitching", involving measurement files of different origin.

Keywords : X-ray optics, Stitching interferometry, Interferometry.

1. INTRODUCTION

1.1. General

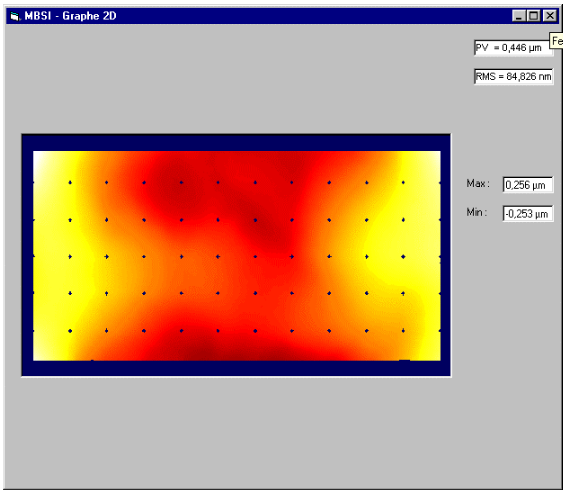
The ideal metrology of X-ray Mirrors would combine a large field of view with a small lateral resolution. The length of usual X-ray Optics, 500 to 1000 mm, means the ideal interferometer would have an exit beam 1000 mm in diameter, and would have, say, 0,1 mm resolution, resulting in a detector size of 10 000 × 10 000 pixels.

If this interferometer existed, it would be expensive, cumbersome, difficult to set up, would need long stabilisation time, and a very good optical system to obtain the desired resolution.

1.2. Stitching interferometry

Stitching Interferometry has been in use in industry for some years now :

- Some Laser MégaJoule components are currently been measured with the world’s first commercial Stitching Interferometer, developed by the author at his previous company;
- The VIRGO (Gravitational Wave Detector) mirrors are being measured with Stitching Interferometry in France, using a tailored version of the Stitching Interferometer supplied by the author.



PV = 0,446 µm
RMS = 84,826 nm
Max : 0,256 µm
Min : -0,253 µm

Figure 1 : MégaJoule Laser Slab (800 × 400 mm)

Figure 1 illustrates a Laser MégaJoule Slab wavefront measured with 66 (11×6) sub-apertures (The little "dots" were added for convenience). Lighter colours are "higher", and PV (Peak-to-Valley) is equal to 446 nanometres.

2. STITCHING MEASUREMENTS

We do not yet have experimental measurements. We will be starting a series of measurements in association with ANL (Argonne National laboratory) in August 2001, about the time this article is published.

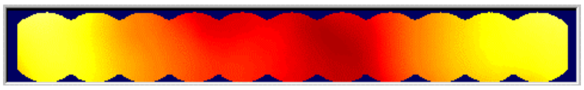


Figure 2 : Row number 3 from Figure (L = 800 mm) (Independently restitched)

However, we have "simulated" an X-ray mirror by extracting a single row from the MégaJoule component illustrated in Figure 2 above, and *independently restitching it*. This is the third row from the top, and covers a rectangle approximately equal to 800 × 90 mm (Figure 2). PV is 269 nm.

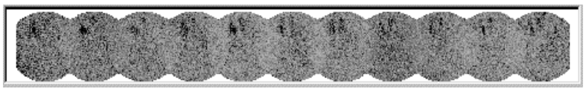


Figure 3 : Slope magnitude of Figure 2 above

As a matter of interest, Figure 3 shows the slope magnitude of Figure 2. RMS slope is 1,1 µrd approx. (Including surface deformation, and calibration and measurement errors). Stitching errors are negligible

2.1. Single vs. Multiple overlap

Stitching Interferometry for large components usually means generating a 2 dimension array of measuring locations. This prevents measurement errors from propagating too much, as each sub-aperture is constrained somewhat by its numerous surrounding neighbours (Figure 4).

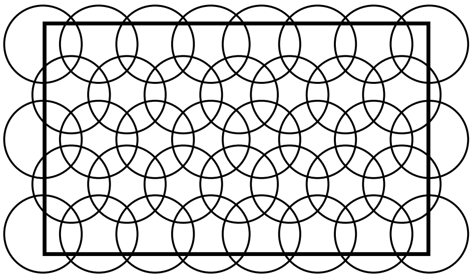


Figure 4 : 2 Dimension Stitching

In the case of X-ray Mirrors, this is not the case : The sub-aperture topography is one-dimensional, and a single error will propagate fully (Figure 5, error in "A" propagates to the edges of the component).

The answer is, of course, to perform "Double-overlap", whereby each overlap is completely constrained by an independent sub-aperture (In Figure 6, error in "A" is reduced by the large overlap). Also, lateral coverage is better allowing, *e.g.*, 90 mm wide mirrors to be adequately measured with a 100 mm interferometer.

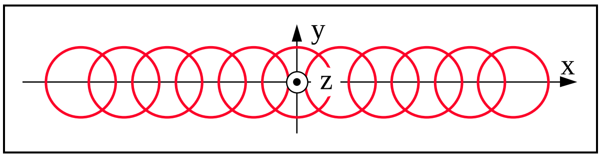


Figure 5 : Single overlap (Error-prone)

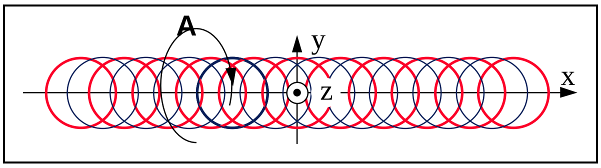


Figure 6 : Double overlap (Much less error-prone)

2.2. Measurement errors

2.2.1. Error scale

Calibration and measurement errors come in many kinds and flavours and are discussed, in part, in another paper at this same symposium (Ref. 1).

For the purpose of discussion, we loosely define the scale of defects as follows :

- Large-scale : Lateral size larger than the individual size of the interferometer measurement;
- Small-scale : Lateral size smaller than the pixel size of the interferometer measurement;
- Mid-scale : Anything between the two scales defined above.

Small-scale defects, by definition, are out of the scope of the type of interferometry we are discussing here.

Mid-scale defects are really due to errors in the individual sub-aperture measurements, and it is up to the user of the interferometer to provide proper calibration, in order to get meaningful results (However, this in itself is not an easy task, if complete surface knowledge is required).

But, in any case, the stitching process does not affect sub-aperture measurements, which can be individually accessed for detailed analysis.

2.2.2. Large-scale errors

Large-scale errors are due to imperfect overlap of individual sub-apertures.

Such errors have numerous sources :

- Interferometer random noise and non-linear effects;
- "Static" errors (*i.e.*, calibration errors)
- "Dynamic" errors (*i.e.*, Thermal, mechanical , etc.)

It can be shown that interferometer random noise has a negligible effect, and non-linear effects should be minimal by design of the interferometer. This last point could be discussed in a future paper, if it appeared to be a limiting factor in real measurements.

Static and dynamic errors both generate a type of Stitching error, which we illustrate here by considering a set of sub-apertures with constant power error, as in Figure 7.

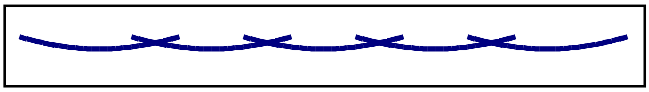


Figure 7 : Sub-apertures with calibration error (power)

The net result will be that illustrated in Figure 8 : The *overlap* errors are nil, but the overall *figure* is erroneous.

With other more random sub-aperture errors, it can be shown that overlap errors would still be small, even with large overall figure error.

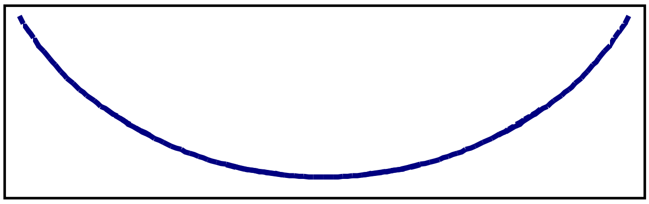


Figure 8 : Result of stitching from Figure 7

As we have said, it is up to the user to insure proper calibration, but it is clear that the stitching process amplifies any overlap error, and we address this in the next chapter, in which we combine "standard" Stitching with other measurement means, to reach the correct overall figure.

3. MIXED STITCHING

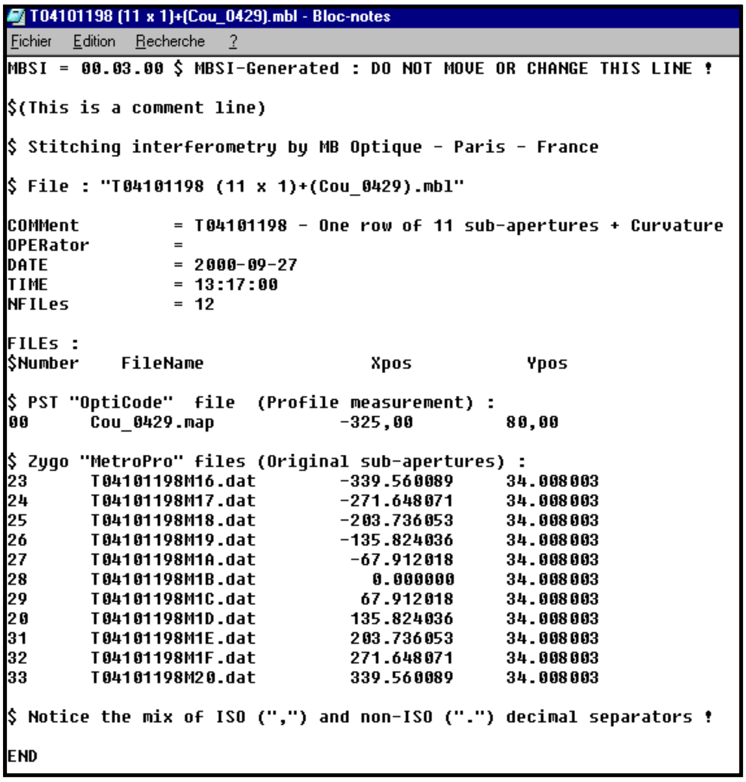
3.1. General

Even with proper calibration, thermal fluctuations can still degrade overall figure ("Large-scale" errors) by a slight, but sometimes unacceptable, amount.

It could also be possible that overall figure be known by some other means :

- Profilometry (Laser beam);

- Glancing angle interferometry (large-scale, low-resolution);
- etc.



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MBSI = 00.03.00 $ MBSI-Generated : DO NOT MOVE OR CHANGE THIS LINE !

$(This is a comment line)

$ Stitching interferometry by MB Optique - Paris - France

$ File : "T04101198 (11 x 1)+(Cou_0429).mbl"

COMMent          = T04101198 - One row of 11 sub-apertures + Curvature
OPERator         =
DATE             = 2000-09-27
TIME             = 13:17:00
NFILes           = 12

FILEs :
$Number    FileName                Xpos          Ypos

$ PST "OptiCode"  file  (Profile measurement) :
00      Cou_0429.map            -325,00        80,00

$ Zygo "MetroPro" files (Original sub-apertures) :
23      T04101198M16.dat        -339.560089    34.008003
24      T04101198M17.dat        -271.648071    34.008003
25      T04101198M18.dat        -203.736053    34.008003
26      T04101198M19.dat        -135.824036    34.008003
27      T04101198M1A.dat         -67.912018    34.008003
28      T04101198M1B.dat           0.000000    34.008003
29      T04101198M1C.dat          67.912018    34.008003
20      T04101198M1D.dat         135.824036    34.008003
31      T04101198M1E.dat         203.736053    34.008003
32      T04101198M1F.dat         271.648071    34.008003
33      T04101198M20.dat         339.560089    34.008003

$ Notice the mix of ISO (",") and non-ISO (".") decimal separators !

END
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Figure 9 : A mixed-format List-File of our MBSI software

The stitching software developed by our company can mix, in a single stitching sequence, data from various sources and formats.

This is illustrated by Figure 9, which shows a typical "List-File" from our software "MBSI".

It includes :

- One profile measurement :
  ("Cou_0429.map"), with X-Y location. It is a spherical surface, with a PV value of 429 nm;
- 11 sub-apertures :
  (Files "T04101198Mxx.dat"), also with X-Y locations. They make up the 1-D measurement shown in Figure 2 above.

Notice the mix of ISO and non-ISO decimal separators, readily understood by the MBSI software …

3.2. Measurements

Figure 10 shows the result of performing Mixed-Stitching :

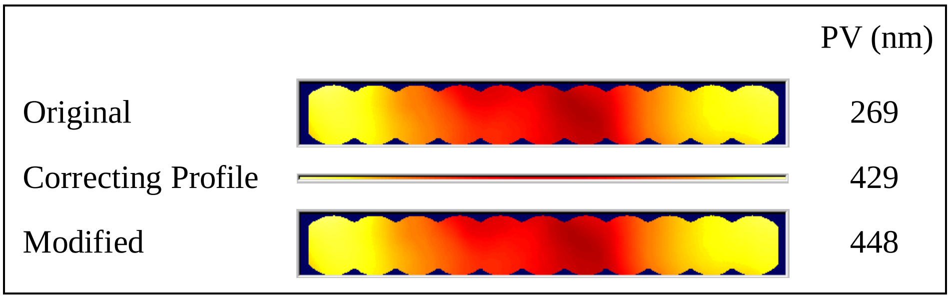

Figure 10 : Mixed Stitching : Input and result (see text)

- The top image is the same as Figure 2 above (11 sub-apertures, stitched). Light "colours" are highest, and the shape of this surface resembles a convex sphere (detailed examination would actually show up 159 nm of departure from the said sphere). The PV value of this profile is 269 nm;
- The middle image is the "reference profile", reputedly correct ("Cou_0429.map"). The PV value of this surface is 429 nm. For this Stitching example, it was generated by the synthesis function of our MBSI software, which was instructed to generate a sphere and save it in PST format.

The departure of the original stitching (first picture) from the "reference profile" is 160 nm.

- The bottom image is the result of the Mixed Stitching : The overall shape of the Stitched surface conforms almost perfectly with the "reference profile" (PV of 448 nm, for a theoretical 429 nm, a departure of 19 nm instead of the initial 160 nm).

Most importantly, it can be seen that the mid-scale shape has been retained, as witnessed by the almost identical layout of the grey level image between the original and the modified images.

This example was a simplified one. For a start, we took a perfectly *valid* stitching measurement, and forced it to take on a different curvature. But we see that Stitching Interferometry need not be confined to "just" simple stitching, and that complex measurement schemes may be set up in order to provide useful and complete data.

4. FUTURE WORK

Experimental measurements will begin in association with ANL (Argonne National laboratory) in August 2001, about the time this article is published. As with all interferometric measurements, environment will play the greatest role in determining the overall measurement quality.

We will first aim for slope errors of the order of 1 µrd RMS. After analysis of measurement errors, our goal will be slope errors of the order of 0,1 µrd RMS.

This should not be impossible to achieve, as MégaJoule components have been measured, for years now, with stitching interferometry to better than 1 µrd RMS slope error, with a much less favourable environment, *i.e.* : Large component and XY-stage (Leading to vibration) and measurement duration (Leading to thermal fluctuations).

5. CONCLUSION

Stitching interferometry has been used for years in industry, for the measurements of large optics (*viz.*, MégaJoule Laser component).

We have shown that "1-D" components (*e.g.*, X-ray Mirrors) could benefit from such a technique. Errors source were briefly addressed, and it was shown how these will be handled.

Stitching Interferometry has the huge advantage of supplying *large-scale* and *mid-scale* values over *all the useful area*, in one operation, for a relatively low cost, and could well become a major metrology method for X-ray Mirrors in the near future.

6. ACKNOWLEDGEMENTS

The author would like to thank Lahsen Assoufid, of ANL (Argonne National Lab.), for his interest and support, and for providing the means of performing the world’s first real X-ray Mirror Stitching measurements (starting soon).

7. REFERENCES

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