Development of a large ion beam figuring facility for correction of optics up to 1.7 m diameter

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ABSTRACT

In the INAF-Astronomical Observatory of Brera (INAF-OAB) a new Ion Beam Figuring Facility, that adds to the previous one, is under advanced construction. The present facility is able to figure optics up to 50 cm in diameter meanwhile the new one is larger and will be able to figure optics up to 1.7 meter. It will employ a Kaufman Ion Source having three degrees of freedom (x-y-z) with step motors and encoders. The source will have two different grid sizes so to be able to figure the optics wit a broad or small removal function depending from the application. The control system will be computer controlled and designed to be autonomous and self-monitoring during the figuring by using a proprietary process control software. This software will use a time matrix map indicating the dwell times required for each pixel of the optical surface. The software and the mathematical tools used to compute the Time Matrix solution has been developed in INAF-OAB as well.

Keywords: Ion Beam Figuring, Removal Function , Kaufman Ion Source

1. INTRODUCTION

The technique of the Ion Beam Figuring (IBF) uses a beam of Argon ions able to remove material from an optic surface by means of kinetic impact. The beam is moved with variable speed, to correct the residual errors remaining on an optical surface after the conventional lap polishing processes. In fact it is able to sputter a desired amount of optic material correcting small depression or mountains having in input a time matrix map of the surface to correct. The Argon ions are accelerated by a suitable potential difference between the grids and exit from them hitting the optical surface. These graphite grid sets can have different dimensions so to be able to generate broader or smaller removal functions for the correction of low or high spatial frequencies present on the specific optical surface. In this respect, in the last few years in INAF-OAB it has been developed a Ion Beam Figuring concentrator useful to further decrease the removal function in the case it is necessary to correct small (down to 30 mm diam) optical surfaces[(1)]. In an IBF facility there is also a neutralizer that diffuse electrons inside the chamber so to create a necessary neutral environment. In fact, during the figuring process of a glass surface, a build-up of ions is created on the dielectric optical surface creating a positive charge cloud that tend to push back the new ions produced by the source. This could change the removal function with obvious problems in terms of errors correction. The removal function (RF) is defined as the material removal profile per unit time generated by the Ion beam during a steady run against a surface made of the same material of the optic to be corrected. The RF is typically smooth, symmetric and similar to a Gaussian in shape[(2)] and is generated by a comparison from two interferometric maps. One describes the surface before the realization of the RF and other is the same one after removal function treatment. The difference between them bring to the RF for a specific optical material and ion source setup. With this information and the map of the errors present on the surface to be corrected, the ion beam simulator software is able to calculate the time matrix used for the final ion beam figuring process. As shown in Fig. 1 this technique allows to obtain optical surfaces of very high quality, in terms of shape departure from the theoretical one, and it is probably the best corrective process for optics among those available nowadays. As visible, in it are shown the

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typical manufacturing steps necessaries for the production of an optical surface. The IBF is the very last step and is generally used when it is necessary to reach a superior optical quality. The main drawbacks of this technique are the use of the vacuum (cost and complexity) and the fact that the surface under figuring is heated by the ion beam. Typically the surface can reach temperature of 80-100 C°. Further, its micro roughness can increase depending from the material of the optics. Generally the glass is a good material because it is amorphous. Crystalline materials like metals tend to became rough very quickly losing the specular characteristics of an optical surface. In INAF-OAB is already functioning an ion beam figuring facility able to figure optics up to 500 mm diameter. The software that compute the figuring solution (the simulator) has been written in Visual Basic and it has been tested with success on numerous optics. This facility has been used for example to figure test space optics of the Nirspec Spectrograph for the James Web Space Telescope and for ground telescopes as LLT Subaru. In the present paper it is described the status of a new large IBF facility under construction at INAF-OAB bearing in mind the experience acquired on the smaller facility.

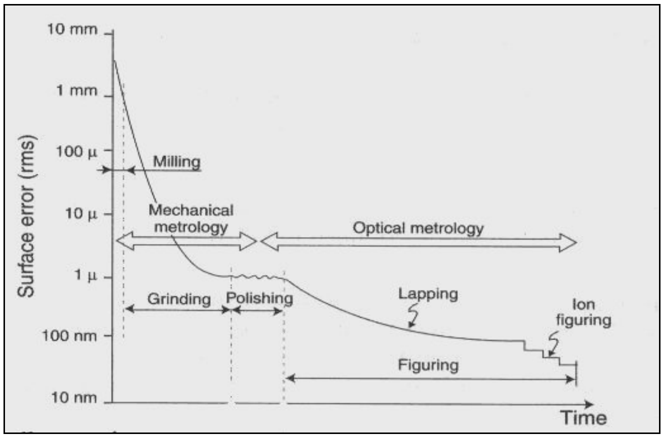

Fig. 1. Notional time history of surface errors during the milling, grinding, polishing, and figuring phases

2. DESCRIPTION OF THE LARGE ION BEAM FIGURING FACILITY

The availability of a large vacuum chamber and the successful experience obtained with the smaller IBF facility has permitted to start the construction of a larger IBF facility version with good confidence.
Here are described the hardware and the software parts of the facility and the current status of the construction.

3. Hardware

The chamber is composed by a stainless steel cylinder having a diameter of 2 m and length of 3 m; it is shown in Fig.2. The facility is composed by a vacuum system able to reach inside the chamber at least a value of 10^{-4} mbar, the working pressure for the ion source. The final vacuum reachable will be lower than this (it is expected to be in the range of 10^{-6} mbar) but tests has yet to be performed to confirm this. Such vacuum system consist of a primary mechanical vacuum section pump-down with a rotary pump and roots pump. The latter works in tandem with the former and both are shown in Fig 3 left. This section is able to reach a preliminary vacuum of 10^{-2} mbar that is necessary for the startup of the high vacuum system. This high vacuum pump section is characterized by two turbo-molecular pumps placed at both the sides of the chamber. One of these pumps is shown in Fig. 3 right. For the measure of the vacuum the chamber is equipped with a set of vacuum Pfeiffer measurements instruments (Pirani and Penning) that input the readings into the PC that control the system. Further, a Multi Gas Controller from MKS Instruments is used in order to insert a known quantity of Argon both for the neutralizer and the Ion Source during a figuring cycle. The controller act on two MKS flussometers: one is placed at the left side of the chamber and the other is in front of it. These devices are able to inject known quantities of Argon inside the Ion source and the neutralizer to produce the right amount of plasma for sputtering. A programmable power supply is connected to the Ion Source and provide the electrical alimentation to the different components of the ion head and the neutralizer, monitoring and maintaining the optimal running conditions during the figuring. Both these instruments, Gas Controller and Power Supply, are connected to the PC that can hence monitor and control the status of the system. For what concern the ion head movements, a stepper motor card on three axes is available and able to read also the relative encoders for the confirmation of the head position. The PC run a specific version of the custom control software already developed for the smaller IBF facility. This proprietary software is written in Visual Basic and permits the control and management of the full figuring process, unattended.

Fig. 2 Large vacuum chamber at OAB under conversion in IBF facility

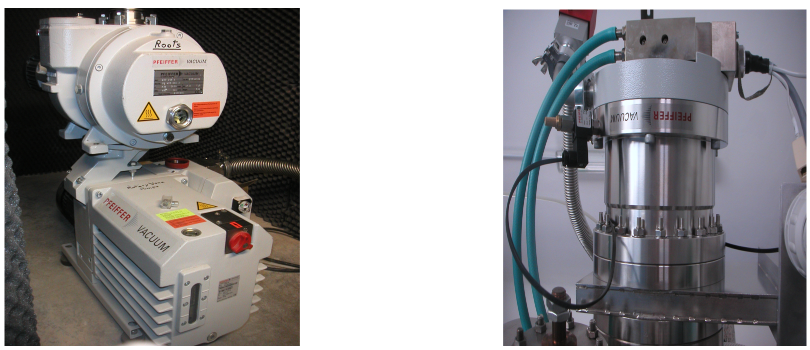

Fig. 3. Rotary and Roots pumps on the left side and one of the two turbo-molecular pumps for high vacuum on the right one

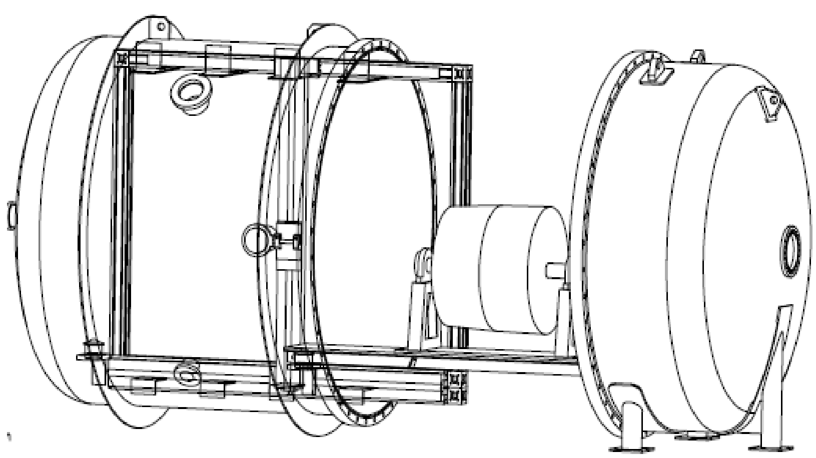

Fig. 4 Sketch of the vacuum chamber with inserted a x-ray mandrel to be figured

In figure 4 is shown a drawing of the chamber showing that it consist of two parts: one is fixed (right) and the other slide to the left running on rails. The carriages that hold the ion head are fixed into the left side of the chamber and hence move with it during the opening. The loading of the optic (in this case an x-ray mandrel) is made fixing it in the proper position in the free space between the two parts. Closing the chamber, the carriages and hence the ion head are placed in front of the optic to be figured. In Fig. 5 is visible the inside part of the vacuum chamber with the carriages during the assembly of the system.

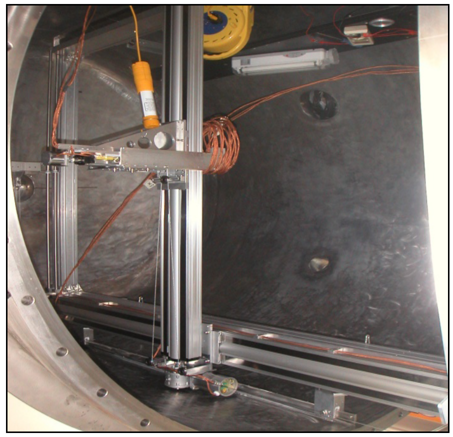

Fig. 5 Inner part of the facility with the carriages

The carriages permits to move the ion head also in Z. The Z axis will carry the ion source backward and inwards respect to the optic during the figuring of spherical or aspherical optics. In this case in fact the distance between the ion source and the optical surface could change too much depending from the position on the surface, changing hence the rate of sputtering in the external part respect to central part due to the different distance. Moving the ion source on this axis it will be so possible to follow adequately the geometrical form of the optic and maintaining constant the distance and the sputtering rate. The facility will be able to work in two configurations, Cartesian or Polar setup and coordinates. To this purpose it will be also installed a controller card which switches among the y axis and a rotational movement of the optics support. The classical setup will be the Cartesian one on three axis. This will permit to figure optics up to 1.4 m in size. Switching to the Polar setup, it will be possible to convert the y axis in a rotational axis. Hence the x axis will move the ion source along the radius of the circular optic meanwhile the rotational one will permit to reach all the points of the surface. This setup permits to obtain a better use of the available space in the chamber allowing the figuring of surfaces with diameter up to 1.7 m. In figure 5 is sketched the processing of two different kind of optics: a rectangular mirror and a cylindrical mandrel used for the manufacturing of X-ray optics. The ion source is depicted in red.

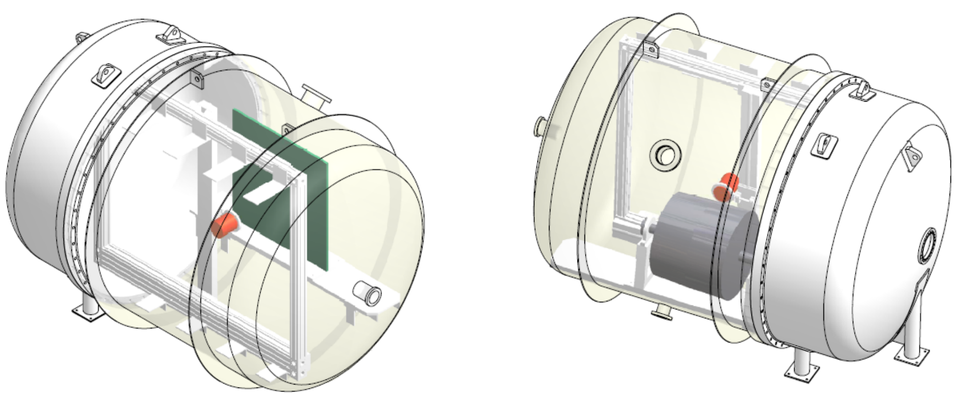

Fig. 5 Sketch of the inside of the chamber with a rectangular mirror mounted (left) or a x-ray mandrel (right)

4. Ion Source

The 50 mm Kaufman hollow cathode Ion Source is from Veeco and it is generally used because of its capability of producing a stable beam instead of the filament Ion Source. It is driven by a programmable power supply (Fig. 6) able to provide current densities up to 10mA/cm2. The neutralizer is separated from the source and has a hollow cathode too. Electrons are injected from neutralizer to reduce the electrostatic repulsion between ions and to prevent the electrostatic charge of dielectric targets. The 50 mm DC Ion Source has a 31 mm focal point grid pattern and provides the beam characteristics as described below. This grid set requires special machining from stock Pyrolytic Graphite in order to form its specific dished shape and was designed and tested to provide a narrow spot size specifically for Ion Beam Figuring applications. It was designed to provide the following characteristics:

- Ion beam power of a minimum of 8-10 mA on a 15-20 mm FWHM spot

- Beam maximum power of 150-200 mA.

- Beam Energy up to 2000 eV.

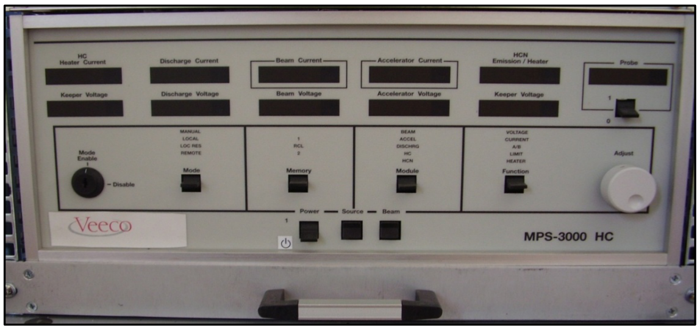

Fig. 6 Programmable power supply

Another grid set will be available having diameter of 15 mm. With this set it will be possible to correct higher spatial frequencies than with the previous one. To change the two sets it is simply necessary to remove the front section of the ion head as visible in Fig. 7.

The Ion Source will be placed in front of the optics that are maintained and figured in vertical position. The combination of vertical, horizontal and forward-inward movements (respectively X,Y,Z axes) allows to raster the whole surface of the optics. Further it is possible to select a rotational setup: in this last case the figuring process will be in polar coordinates that will allow to use more efficiently the available space, permitting the figuring of larger optics. To avoid the presence of the pole it will be necessary to figure the central part of the optic in Cartesian coordinates and then switch to the polar system continuing the figuring of the outer parts. This procedure will be fully automatic during a figuring requiring the polar approach.

Fig. 7 Grids of the Ion Source: 50 (right) and 15 mm (left) diameter

5. Software

Two Visual Basic programs are used during a figuring process: the first one is an Ion Beam Figuring Simulator software (Fig. 8) that compute the theoretical solution to be used for the specific optic under figuring. It uses as input an interferometric measure of the initial surface, a beam removal function and the target optical figuring quality value expressed in nm rms. This software is presently used for the computations related to the smaller IBF facility. To be used for the larger facility it will require some changes in the computing strategy due to the larger dimensions of the optics to be figured, in order to decrease the calculation time needed to compute the relative time matrix.

This goal will be reached using High Performance Computing (HPC) cards as Nvidia-Cuda for parallel calculus. With these systems it is nowadays possible to reach a computing power of the order of four-Teraflops. Further, besides the present algorithms used for the Time Matrix computation, it will be investigated the use of a Genetic Algorithm approach to find the optimal time matrix. In this respect, tests are already under progress in the smaller facility available in the Institute. An example of a Time Matrix obtained using the genetic algorithm approach is shown in Fig.9 where the figuring times in the map are larger passing from the blue to the red.

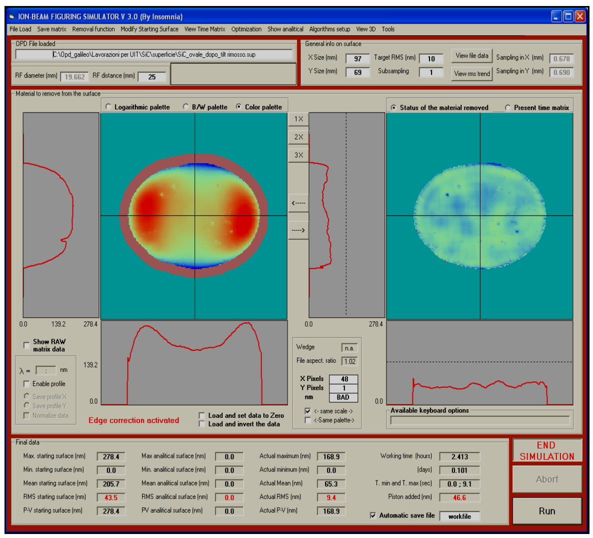

Fig.8 Example of Ion Beam Simulator run for the figuring of an elliptical optical surface
At the left side of the screen there is the interferometric map of the starting surface
At the right side of the screen there is the theoretical final surface obtained with the time matrix solution

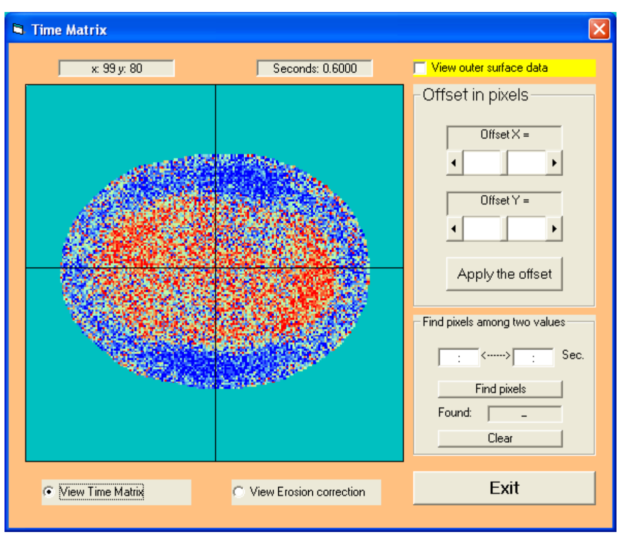

Fig. 9 Example of Time matrix obtained with Genetic Algorithms

The use of a Genetic algorithm for the computation of the time matrix is an interesting approach that will be investigated during the development and follow-up of the large IBF facility. It offer potentially a number of advantages respect to other approaches but the computational power necessary is larger and hence will need some kind of parallel process.

The second software controls all the aspects of the working process acting on the stepper motor movements that shift the Ion Source along the optical surface. This software will be an improved version of the one that is presently used in the facility already in use (Fig. 10). It uses as input a Time Matrix computed from the ion figuring simulator and act either as controller of the axis movement of the ion source imposing the correct times of sputtering for each pixel of the surface and also as controller of the working status of all the parameters of the facility. Infact it monitor in real time the vacuum pressure, the rate of the Argon flux, the status of the power supply and the ion head, the presence of electrical power in the grid. Since the PC that run the software is under UPS in case of a global shut-down of the power line it can sense this condition and save the last good position. In case of a different failure it can also shut-down the facility saving the last position figured with the error messages generated during the failure permitting to restart the work from the last good position on the surface and knowing the failure reason.

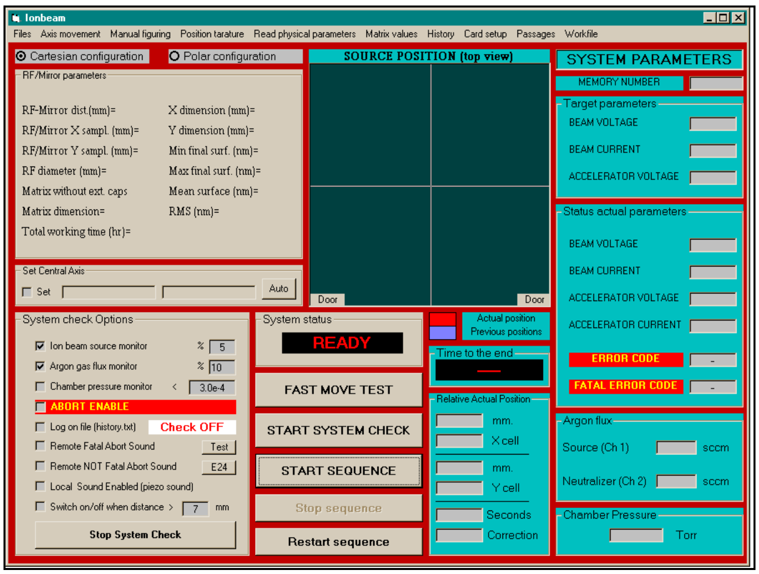

Fig. 10 Ion Beam Control Process Software

CONCLUSIONS

In INAF-OAB has been developed a working experience in the field of the Ion Beam Figuring technique. The first facility, able to figure optics up to 50 cm in diameter has shown in the years a good correction capability on a large number of materials and types of optical surfaces. All the experience gained during this period has induced the Observatory to build a second larger facility having diameter of 2 meters and length of 3 meters. The possibility to have a large Ion Beam Figuring Facility able to figure optics up to 1.7 meters in diameter will allow to figure large optics as for example single mirror segments for future ground telescopes (i.e. EELT) or light segments for adaptive optics. It will be possible to figure mandrels for future X-rays optics for space telescopes manufactured by replica processes that demand a tight control of the mandrel shape for production of shells. The facility will be one of the largest in Europe available for the Italian and European scientific community. It is foreseen that the software for the computation of the Time Matrix will be improved in terms of speed and computing philosophy testing the use of parallel processing cards and it will be investigated the use and implementation of a genetic algorithm approach to find the Time Matrix solution for the figuring of an optic. In the next few months the facility will be tested to evaluate its behavior during the figuring process of a number of different materials and optical profiles. In particular, it will be verified the effectiveness and reliability of the Ion Beam Control Process software.

REFERENCES

[1] Ghigo, M. Canestari, R. Spiga, D. Novi, A. "Correction of high spatial frequency errors on optical surfaces by means of Ion Beam Figuring", PROC SPIE 5962,798 (2005).

[2] Ghigo, M. Conconi, P. Antonello, E. Pareschi, G. "Accurate ion beam figuring of field correctors for optical and UV space instrumentation", PROC OPTRO 2005 International Symposium,(2005)