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OPTICAL PHASE SPACE MAPPING USING A DIGITAL MICRO-MIRROR DEVICE

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Abstract

Optical transition radiation (OTR) is routinely used to measure transverse beam size, divergence , and emittance of charged particle beams. Presented here is an experimental method, which uses micro-mirror device (DMD) to conduct optical phase space mapping (OPSM). OPSM will be a next step and significant enhancement of the measurements capabilities of an adaptive optics-based beam characterization system. For this measurements, a DMD will be used to generate a reflective mask that replicates the double slit. Since the DMD makes it possible to easily change the size, shape and position of the mask, the use of the DMD will greatly simplify OPSM and make it more flexible, faster and more useful for diagnostics applications. The process can be automated and integrated into a control system that can be used to optimize the beam transport.

INTRODUCTION

Optical phase space mapping (OPSM) refers to a method of masking the optical radiation produced by the beam. Some of the biggest advantages of this method are its non-invasive nature, as well as the fact that different types of radiation could be used. However, optical transition radiation (OTR) has proven to be an effective approach that provides information about the transverse phase space of charged particle beams. Specifically, a two foil OTR interferometer has demonstrated that due to high sensitivity of its angular distribution to divergence and beam's energy, it produces an interference pattern (OTRI) which can be used to acquire information on beam's trajectory angle, divergence, emittance, and obtain a complete transverse phase space map of a charged beam. [1]

This paper describes the OPSM carried out using digital micro-mirror device (DMD), a modulator that uses digital image data to modulate beam light. An interference or a diffraction pattern is necessary component of OPSM, as it is used to scan across the beam image to diagnose different beam quantities (e.g. beam's trajectory angle and divergence). A method of using a double-pinhole aperture to generate an interference pattern to reconstruct the full transverse beam profile has already been proposed. [2] In this work we suggest using DMD for creation of a double slit interference pattern. Moreover, the experimental setup used for these measurements could eventually be implement at an accelerator facility for OTRI measurements.

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Digital Micro-Mirror Device

A DMD is a chip (Fig. 1) that contains several million mirrors on its surface, arranged in rectangular arrays. The incoming optical beam can be manipulated in a different direction depending on these reflective mirrors' set states. Each mirror is controlled individually, and they can be positioned in two states, state 1 or 0, which corresponds to angles $+12°$ and $-12°$.

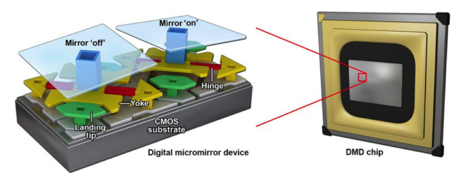

Figure 1: Digital Micro-mirror Device [3].

The DMD can produce a flexible, reflective mask of any size or shape, and can be used to scan and mask portions of the beam [4]. As every mirror represent a pixel on the camera, it is possible to create a mask based on the positions of the pixels. All the mirrors used to generate a mask will be rotated in one direction, and the rest in another. Therefore, when light hits the surface of the DMD it is possible to use two camera sensors and simultaneously capture an image of the mask and image of the masked part of a beam.

This principal was used to generate and upload a two slits mask onto the DMD, which created a double slit visible on one camera and interference pattern captured on another. This fully automated process allows for slit sizes and distance to be easily changed, and to be placed at any position relative to the beam. Using the DMD to generate the double slit interference pattern allows for more accurate, flexible, and faster measurements of the optical phase space mapping.

EXPERIMENTAL METHOD

The double slit interference measurements produce interference-diffraction pattern with high intensity maxima within the envelope of the diffraction. The DMD is used to simulate the double slit, allowing us to observe the effects of the DMD on the system.

Diode-Pumped Solid-State (DPSS) laser light (532 nm), used to simulate the Gaussian distribution found in most

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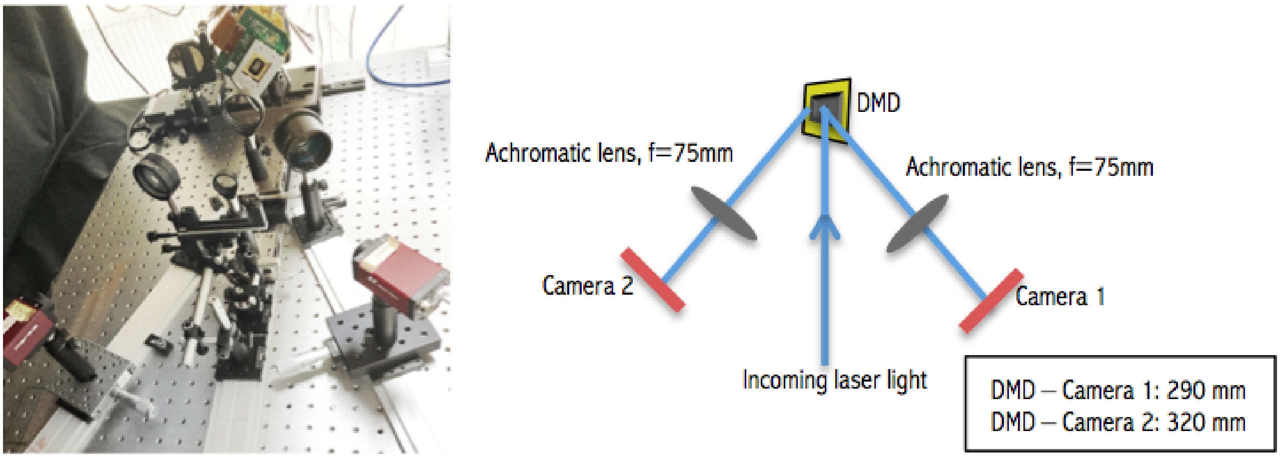

Figure 2: Left: Picture of the experimental set up at the Cockcroft Institute optics lab; right: schematics of the experimental setup.

particle beams, is guided towards the experimental set up shown on Fig. 2.

The set up consists of a DMD, and two optical arms. A two slits mask was generated and uploaded onto the DMD. Due to the mirrors flipping on the diagonal, the DMD was mounted at 45°, to allow the mirrors to move in the horizontal axis. As such, the slits on the masks used were rotated accordingly, so they were in the vertical axis when displayed on the DMD (see Fig. 3, left image). Size of the slits and distance between them can be manipulated, thus the system can easily be tested with various mask parameters. For the purpose of these measurements a range of values were used. For the image in Fig. 3, the size of the slits has been chosen to equal 42 pixels, and the distance to be 21 pixels (pixel size: 6.5992 µm). The slits correspond to mirrors which were rotated for +12°, and when light hits the surface of the DMD the portion of the light which hits the mask was guided to the camera sensor to the right (Fig. 2), through a 75mm achromatic lens. The CMOS camera was positioned in the image plane and it imaged the spatial distribution on the surface of the DMD. In other words, the camera on the right showed the image of the beam, or rather what was displayed on the DMD, Fig. 3. The camera has been rotated according to Scheimflug principle [4] to avoid depth-of-field problems.

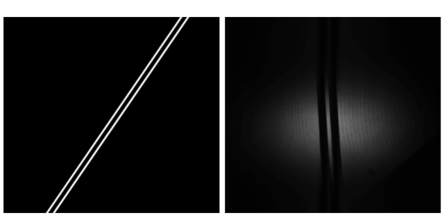

Figure 3: Left: Generated two slit mask uploaded onto the DMD; right: Double slit image of the beam.

The light reflected by the masked part of the beam image was guided through the left 75 mm achromatic lens (Fig. 2) to the camera positioned in the focal length of the lens. The camera images the far field, and displays the interference pattern.

To observe the effects of DMD, experimental and theoretical data have been compared.

RESULTS AND DISCUSSION

Figure 4 show the horizontal scan of the double slit interference pattern with theoretical calculation.

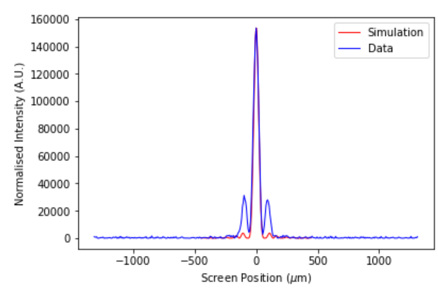

Figure 4: Experimental and theoretical comparison of the horizontal line scans of the interference pattern.

By observing the maxima of the peaks, we deduce that the position of the experimental and theoretical peaks line up, meaning that digital micro-mirror hasn't changed the angle of diffraction. The left maxima in the experimental data is slightly higher than the one on the right. After further analysis, we were able to conclude that that is a consequence of slight misalignment in optical component of the system, which will be corrected for further measurements. There is an intensity difference in the second maxima between simulated and actual data, and this discrepancy is still under investigation as these measurements are still in preliminary stage.

CONCLUSION

It has been demonstrated that there are no changes of the angle of diffraction, which bring us to conclusion that

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the interference fringes remain unchanged. This is a useful finding as it indicates that using DMD does not cause any unwanted changes to the system and has no effect on the measurements.

In addition, our results indicate that DMD can be used to simultaneously capture the spatial distribution and far field of the beam. Therefore, this setup and method can be used for OTRI measurements of transverse phase space, in which DMD will be used to replace a mechanical moving pinhole. [1] From the spatial distribution, information about the mask position relative to the beam is known, and from the far field it is possible for trajectory angle and divergence to be measured. These beam quantities can then be used to map transverse phase space of charged beams.

It has also been shown that there are some intensity disagreement of the experimental and theoretical data, as well as slight optics misalignment. These will be further investigated and corrected for final transverse phase space measurements.

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