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Design of the Neutron Imaging Pinhole for use at the National Ignition Facility[a)]

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I. INTRODUCTION

The Neutron Imaging (NI) diagnostic is designed to be used at the National Ignition Facility (NIF). This instrument will be used to image both primary (14MeV neutrons) and downscattered (6-8MeV neutrons). The pinhole body sits 225mm from the target, while the scintillator and recording systems are located 28m from the target. The diagnostic uses port 90, 315 and the recording system is located in a specifically built room located outside of switchyard 1. The location of the pinhole and the recording system combine to give a magnification of 104. The recording of both the primary and downscattered image is done by recording the image from both the front and back side of the scintillator. (Figure 1.)

II. PARAMETERS DRIVING THE DESIGN

There are many challenges associated with the NI diagnostic. These challenges are reflected in the parameters that drive the design of the pinhole body. The three major areas of interest are the alignment, resolution and manufacturability. The design of this pinhole body attempts to optimize all these competing parameters.

The alignment of the NI diagnostic is challenging. The pinhole must be aligned to target location. The target itself is allowed to move within a sphere of ___µm. The DIM stability and repeatability must be factored in, and finally the scintillator must be aligned along this same line of sight. If there are multiple pinholes in a single pinhole body and all the pinholes point at the same location, then either the field of view must be opened up, or the risk must be taken to miss data on a shot, due to mispointing. At present there is a method to align to the target at Omega, which allows data to be taken from pinhole bodies that have all the pinholes pointing at the same location. The facility and requirements at the NIF are sufficiently different that a new method of alignment is being developed.

The resolution of the system is highly dependent on the magnification, size of each pinhole and the location of each image in the pinhole. When the images are located within a diameter of the wall of the pinhole, then edge effects are seen in the image that cannot be manipulated out of the image. The primary images have a diameter of ___µm and the downscatted images have a diameter of ___µm. If the shot has full ignition, then all the information is will be contained in the primary image. If the shot has smaller yield than expected, then the downscattered image will contain information about the cold fuel. However, due to the slow decay time in the scintillator, two images will need to be collected via two recording systems, and then the primary image subtracted from the downscattered image. The ideal size pinhole varies depending on which energy band is being collected. The resolution of the system drives the length of the pinhole body, as outside of the signal being transported through the pinhole, the rest of the noise should be dramatically reduced in the 20cm of tungsten.

The manufacturablilty of the pinholes and pinhole body also must be folded back into the design. An ideal neutron pinhole would be a double conic, with the two cones meeting for an instant near the center of the pinhole block. Machining that feature would require a tool bit that changes diameter as it cuts along the length. Using a tool that is some given diameter will, very close to the center section, give you a cut that is wider than it is deep. Since the true imaging part of the pinhole is in that very central region, this would not produce a pinhole of quality. To avoid this issue, the pinholes that we use are square. Each pinhole is made by cutting a triangular groove on a plate, and then cutting a matching groove on a different plate, and stacking these plates to make a complete square, on it's point, pinhole.

III. DETAILS OF THE PINHOLE ARRAY DESIGN

The pinhole array and pinholes are ____ Knowing that the alignment will be challenging led to creating a pinhole that is forgiving of misalignment. Creating an array of pinholes that each point to a known different place in the target plane allows the single pinhole body to have a field of view of 400µm. Since each of the pinholes covers a different location it is possible to record a smaller number of higher resolution images, than having all the pinholes pointed to the same location would allow. In addition, the recording of the images on the scintillator will give locational information about the alignment of the pinhole with respect to the target, as only the pinholes that see the target will collect any data. This should allow for real time feedback about the actual alignment of the pinholes.

The resolution of the system is driven by the magnification size of each pinhole and the location of each pinhole. The location of the centroid of the pinhole, or where the double conics

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meet, drives the magnification of the system. Placing this point 40mm back from the front face of the pinhole body makes the magnification as large as possible, without sacrificing the integrity of the pinhole. The mean free path in gold of neutrons is 33mm, so placing the centroid more than that behind the front face allows the optimization of magnification versus signal degradation. The design of the array of pinholes was based on a scintillator of diameter 160mm and two arrays of pinholes, collocated so the array of each size of pinhole covers the entire 400µm field of view (Figure 2). Interleaving these two arrays also means that each image should be collected in multiple pinhole field of views. These images will need to be processed before they can be summed, due to the fact that the edge effects will be different as each pinhole is looking a different direction.

The total number of pinholes in the pinhole body is 37. There are nine rows of pinholes and nine columns of pinholes. There are 21 of the smaller pinholes which have a FOV of 140µm. They are spaced on a 70µm grid, with the central pinhole located on center, and having 5 rows and 5 columns, missing the corner most pinholes. The remaining 16 pinholes have a FOV of 200µm and are spaced on a 70µm grid, with no central pinhole, but a 4 x 4 array of images centered on the central large pinhole. (Figure 3) This array has maximized the use of the scintillator face (Figure 4). The FOV of the pinholes is defined as a circle inscribed in a the square as projected into the target plane (Figure 5).

The simplified version of the pinhole body is that it is a 200mm x 15mm x 15mm tungsten block, with small pinholes running the long length of it. The actual fabrication of the pinhole is much more complicated. It is made from a total of 12 different layers. The outer most layers are made from tungsten, and at relatively thick plates. The inner 10 layers are made of gold, as the gold can have features of this size machined into it, using traditional machine tools. The two outer layers of gold are .508mm thick, and have this single thickness along the entire length of the pinhole. The 8 remaining middle layers are cut in a wedge shape, .155mm at the front edge and .262mm at the back edge. This wedge defines the centerline of the pinholes as they go from the target plane to the image plane.

The tungsten layers are machined and ground to precise dimensions. They are a wedge shape also, making up for the difference in height that the 10 central gold layers create. The tungsten layers are 6.371mm thick at the front, and 5.943mm thick at the back face. They provide stiffness to the structure, and also provide shielding around the signal.

The outer gold layers are the only gold layers with features machined only on one side. These layers were made thicker for easier handling. These two parts are mirror images of each other. The holes for assembly and the datums are located on different sides.

The inner layers of gold have features machined on both sides. Due to the interleaved array, the features on either side do not line up with each other. They also are not the same size. One side has the smaller pinholes cut into it, the other has the larger pinholes cut into it. There are 4 unique thin gold layers in the pinhole. The central layers alternate in a pattern, due to the symmetry of the pinhole array. Machining the groove into both sides of the gold foil is an art. The datums of the part are set on one side, and the part is machined, then the part must be turned over, and machining continued on the other side. Also, due to a complete pinhole being made by two layers of gold, it is critical that the features align to the next layer of gold. A error on the location of one set of grooves would cause a problem for an entire row of pinholes.

The pinholes are approximations of a double conic. This, when simplified into a square feature still means that the depth of the cut along the length of the pinhole varies. The smaller pinholes start with a depth of cut of .015mm at the front face of the pinhole, then this cut lessens to zero at the centroid location, 40mm behind the front face. It then starts to increase again until at the back face it is a cut of .060mm. This is a half angle of __. The large pinhole starts at a cut depth of .021mm, goes to zero at the centroid again 40mm behind the front face, then increases to .085mm at the back face of the pinhole. (This is a half angle of ___) Machining these grooves is a challenge, and is compounded by the fact that as the tool turns, it raises a burr along the length of the groove. This is not problematic while machining, but causes issued when assembling these thin layers.

The individual layers are carefully crafted, and then comes the next challenging step. Assembly of the layers is tricky. The burr that is raised while machining the grooves causes problems when attempting to stack the layers together. The entire pinhole must be stacked in place, and the tungsten layer placed on top before any of the layers are secured in place. This is because all that holds the layers together are the five #6 fasteners and nuts. Care must be taken to get all the layers stacked together, and secured, without bumping the stack, and misaligning the individual layers.

IV. FABRICATION TECHNIQUES AND MACHINING LIMITS

V. ACKNOLEDGEMENTS

Figures (to be added into text)

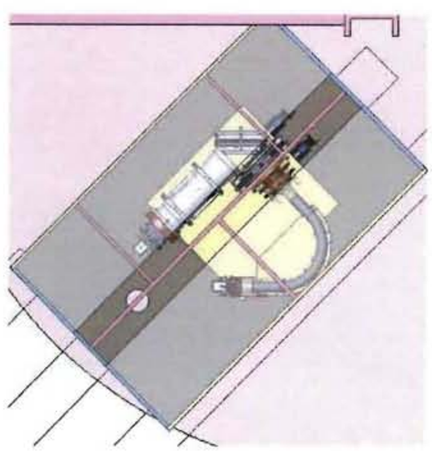

Figure 1

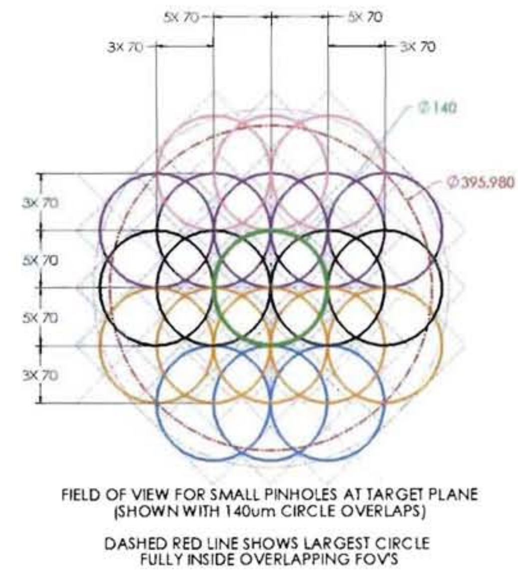

Figure 2

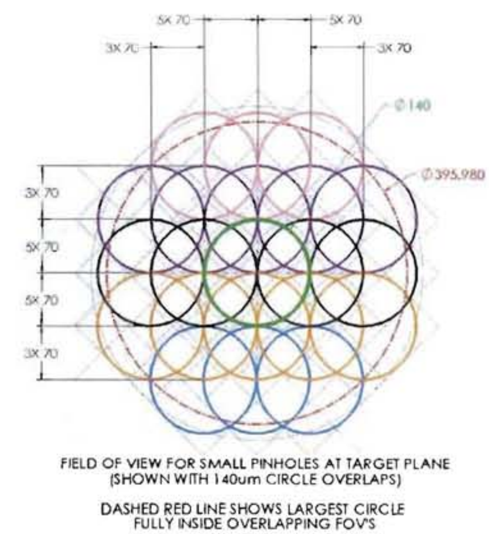

Figure 2a

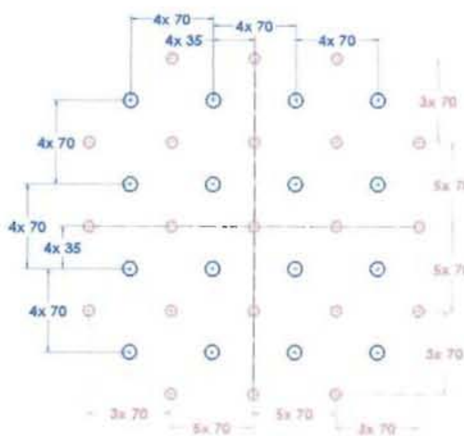

Figure 3

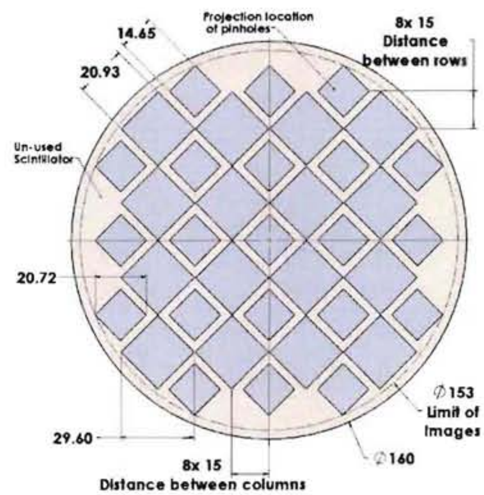

Figure 4

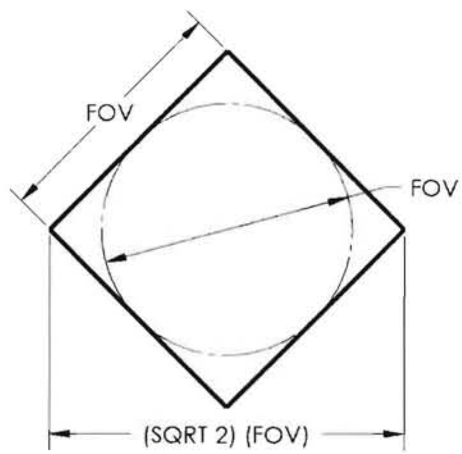

Figure 5