Realization of SS Collimator using Electrical Discharge Machining Process

Manohar Pala*, Karumanchi Viswanatha Sarma, Amudhavel V, D Venkata Govinda Rao

ISRO Satellite Centre, Bangalore, India

Abstract— *In the present paper realization of stainless Steel collimator through Wire-cut Electrical Discharge Machining process is described. FeatureCam software was used to generate NC code for the wire-cut path and CUT 2000S wire-cut EDM machine was used for machining the slots. Three Trials were performed and dimensional `measurements were carried out on test pieces. Trials were executed using different tool path strategies in FeatureCam software to achieve 4 X 4 array. For all Trials 0.25 mm diameter Zinc coated brass wire was used.*

The pocket type tool path generated using FeatureCam software was found to be more promising tool path strategy in realizing the 128 slots in SS collimator within the defined tolerance.

Keywords—EDM, Wire-cut EDM, Collimator, FeatureCam.

I. INTRODUCTION

The most common technique employed in astronomical observations is to isolate a small portion of the light in the image plane using a small aperture or a slit and to spatially scatter light of different wavelengths by different amounts, making a linear image of the spectrum. The scattered light beams are made parallel by the application of collimator, which is an array of slots. The collimators used for space based astronomical observations are mainly made out of Aluminium, Copper, Stainless steel and Tantalum. For carrying out the low energy X-ray observations, factors like weight of the collimator, material which can attenuate high energy X-rays, minimum blockage fraction and manufacturing feasibility, are considered. Tantalum is found to be the ideal material for blocking the high energy X-rays, but due to the various manufacturing difficulties, stainless steel is generally preferred. To obtain the mechanical rigidity and accurate transmission of the photons, monolithic structure is ideal. The size and surface roughness of the each and every cell play an important role in high transmission rate of required photons. An optimized value of the same has to be arrived at for a given range of observable frequencies of X-ray photons.

Many fabrication techniques were used to realize the collimators for different applications. In [1] the collimator and anti-scatter grid was fabricated with the deep X-ray and optical lithography combined with electroforming process. The high degree of precision prevalent in micro fabrication techniques for collimator is demonstrated. Design and development of Tantalum X-ray collimators for LOFT (Large Observatory for X-ray timing) is discussed in [2]. The circular collimator slots were fabricated by employing laser machining of hole array and then chemical etching of the same on Tantalum. Around 15,000 holes with 53 micron diameter were produced using these techniques. The aspect ratio of the collimator was increased by stacking the individual plates by soldering or spot welding. [3] Presented the design of a novel compact 3D rapid-prototyped collimator which showed an improvement in the ratio of signal to background. The ability to tailor the fabrication process to meet the required customization of the collimator designs was demonstrated in the work. The inexpensive method of fabricating the different and difficult collimator designs which otherwise are not possible to realize in conventional fabrication techniques, was discussed. The method of producing the collimator structure by rolling and extrusion of alternate superimposed layers of absorbing metal and transmitting metal was discussed in [4]. After soldering the obtained composite, the structure was cut to the required length of order of 2mm or less. [5] Fabricated the collimator structure by stacking the plurality of spaced columns onto the grooves from the previous layer. A grid of collimation square holes was formed by a plurality of elongated metal sheets arranged in a grid pattern in [6]. The sheets are inserted into evenly spaced slots of other metal sheets.

The lithography and electroforming process discussed in [1] is an expensive method and is not possible way to achieve a monolithic structure of thickness of several mm and the same is applied to the laser drilling method used in [2].

Though Selective Laser Melting (SLM) technique discussed in [3], assists in realizing the monolithic structure of customized configurations, the surface roughness and dimensional tolerance of the slots have to be compromised to the greater extent. In the methods described in [4], [5] and

[6], the overall collimator structure is obtained by stacking, which defeats the requirement of monolithic structure.

The present work focuses on the realization of the monolithic collimator structure of cell size 4.7 mm X 4.7 mm with a length of 100 mm in SS 304 material. 128 slots are produced in an array with a wall thickness of 0.2 mm with ±50 microns tolerance, between any two cells as shown in Figure-1. To the best of the authors' knowledge, realization of the above mentioned design using Wire EDM is not reported elsewhere and hence same is reported in this work.

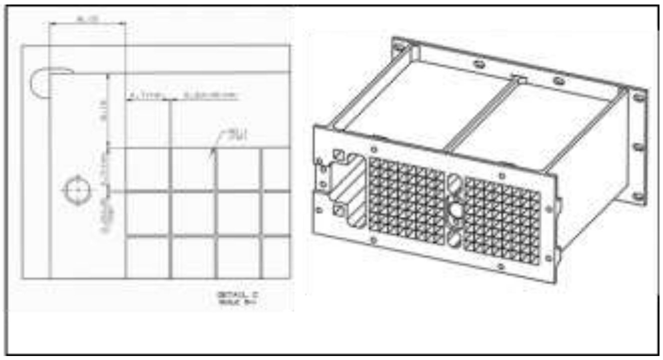

Fig.1: Slot in SS Collimator

II. MACHINING OF SLOTS - 4 X 4 ARRAY

Wire-cut EDM (Electrical Discharge Machining) is used for the machining of slots accurately in SS blocks. In this method wire entry holes were produced by conventional drilling process. Before Wire-cut EDM, SS blocks are annealed to remove internal stresses developed during drilling and any other machining operations. Respective NC tool path and machining technologies are used for machining of slots.

i). Trial-1 :

In trial-1, a SS block of 50 X 50 X 100 mm is taken to produce 16 slots (4 X 4 array). Details of the Trial-1 are listed in table-1.

Table.1: Details of the Trial-1

Machine model	CUT 100
Wire diameter	0.25 mm
Wire material	Zinc coated Brass
Dielectric	Deionized water
NC Tool Path	Profile type
No. of passes	01

In trial-1, a profile type tool path is used as shown in Figure-2. After completion of 16 slots, walls are inspected at top and bottom of the block using CMM. Thicknesses of walls are plotted and are shown in Figure-3.

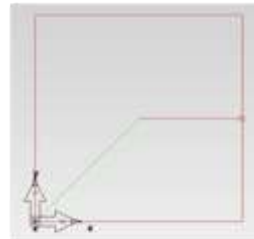

Fig 2. Profile type tool path

From the results of wall thicknesses for the Trial-1 (Figure-3), it is observed that that most of the walls are out of the tolerance especially at bottom of the block. Slots executed from the Trial-1 are shown in Figure-4.

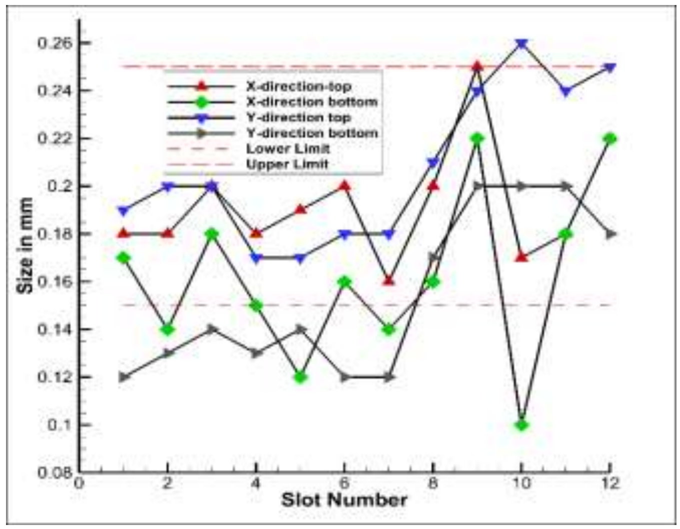

Fig.3: Thickness of walls from the Trial-1

From the Figure-4, it is observed that one slot was damaged fully and walls are not straight.

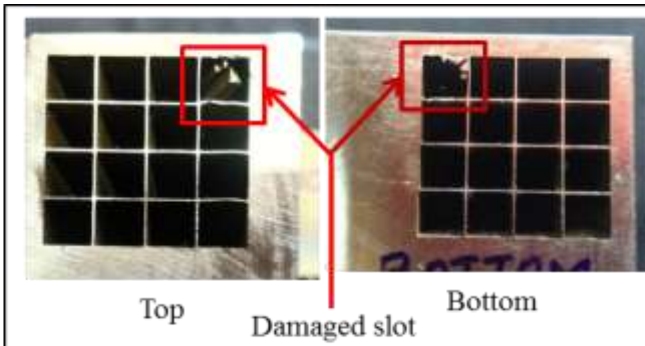

Fig 4. Slots form the Trial-1.

ii). Trial-2 :

In Trial-2, the same block is used which is used for the Trial-1 to produce 16 slots. Details of the Trial-2 are listed in table-2.

Table.2: Details of the Trial-2

Machine model	CUT 2000 S
Wire diameter	0.25 mm
Wire material	Zinc coated Brass
Dielectric	Deionized water
CAD/CAM software	FeatureCam
NC Tool Path	Profile type
No. of passes	01

FeatureCam software is used for the generation of the profile type tool path and generated tool path is used for the machining of 16 slots. An array of 4 X 4 is generated on CUT 2000S to automate the machining of the total array. Thicknesses of walls are plotted and are shown in Figure-5.
From the graph (Figure-5), it is observed that most of the walls are out of the tolerance. Slots executed from the Trial-2 are shown in Figure-6 and there is no slot and wall damaged.

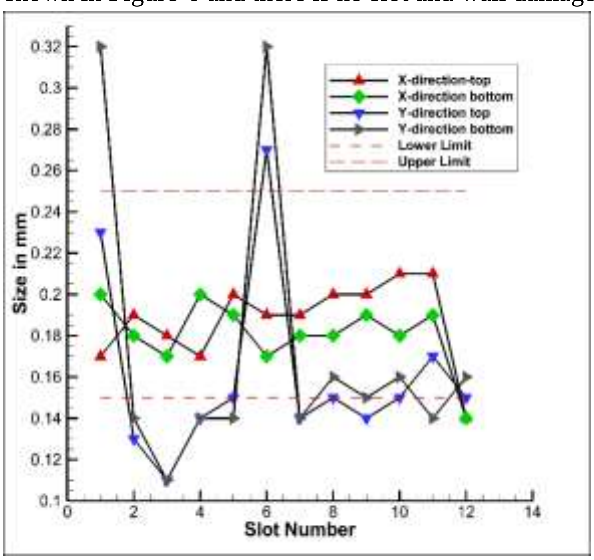

Fig.5: Thickness of walls from the Trial-2

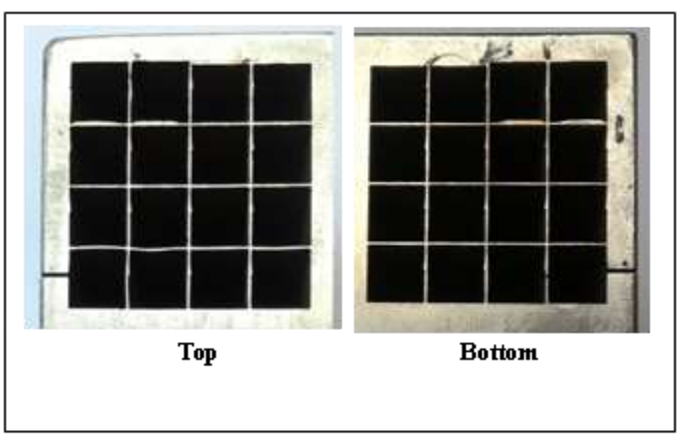

Fig.6: Slots form the Trial-2.

iii). Difficulties observed in the Trial-1 and Trial-2:

a). Slugs fallen on lower nozzle :

As Trial-1 and Trial-2 used Profile type tool path, a slug will be left over after machining the slot. Some of the slugs will freely fall on to the lower nozzle as shown in Figure-7a. Since the gap between the bottom surface of the block and the lower nozzle very small, it is very difficult to remove slug. For the removal of slug, lower head movement is required by moving the X-axis and Y-axis manually. Any wrong movement causes the permanent damage of the lower nozzle, lower guide and the slot in job.

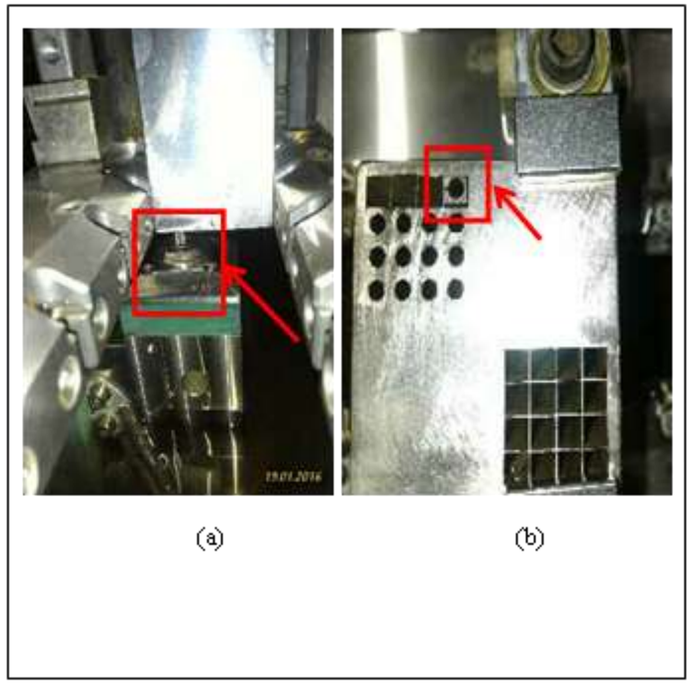

Fig.7: Slug removal issues (a) Slug fallen on lower nozzle and (b) Slug jammed in slot.

b). Slugs jammed in the slots :

Some of the slugs got jammed in the slot due to the deflection of the slug as shown in Figure-7b. This may be because of thermal stresses raised during Wire-cut EDM on the thin section of the slug. Such kind of slugs is removed by gently tapping. During the removal process walls of the slots get damaged and sometimes whole slot will get damaged.
Glue is commonly used in Wire-cut EDM but in this particular application, use of the glue will damage such thin 0.2 mm walls and machine had to be paused to fix the slug for every slot.
In above Trial-1 & Trial-2, machine had to be stop and slugs were removed manually. This slug removal activity damages the walls and consumes around 45 to 60 min of time for each slot.
It is also observed that there were wire entry and exit marks on the wall surfaces.

Form Trial-1 & Trial-2, it was found that profile type tool path is not accurate and precision for producing around 128 slots inn SS collimator.

iv) Trial-3 :

To overcome all the disadvantages and inaccurate results of profile type tool path which was used in the Trial-1 and Trial-2, a new Pocket type tool is proposed.

In pocket type tool path, total stock material inside the slot will be removed and no slug will be left over. In trial-3 a new SS block was used for producing 16 slots (4 X 4 array).

a). CAM Programming:

FeatureCam software was used for the generation of the Pocket type tool path. 60 % stepover was used for the 0.25 mm wire. Wire entry and exit are made at centre of the slot. Since the wire entry hole is 3.0 mm diameter, to avoid the non-cutting movements, machining was started at 1.5 mm from the centre of the slot. Pocket type tool path is shown in Figure-8. The NC code for same tool path is transferred to CUT 2000S machine.

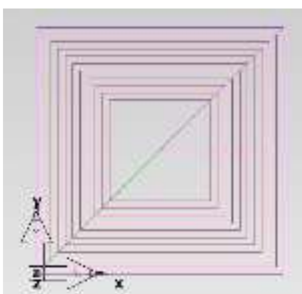

Fig.8: Pocket type tool path

b). Wire cut-Electro Discharge Machining :

Pocket type tool path is used to generate 4 X 4 array on CUT 2000S and is shown in Figure-9. SS block was held on the work table using clamps as shown in Figure-10. Pocket type array too path was used for the machining of 16 slots. It took around 40 minutes to machine each slot.

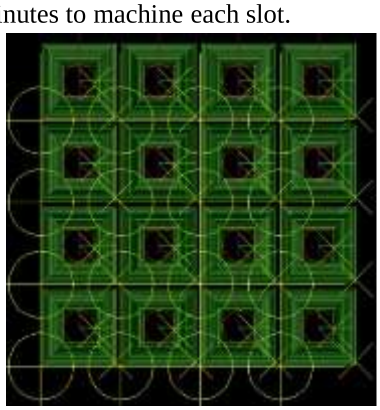

Fig.9: Tool path for 4 X 4 array

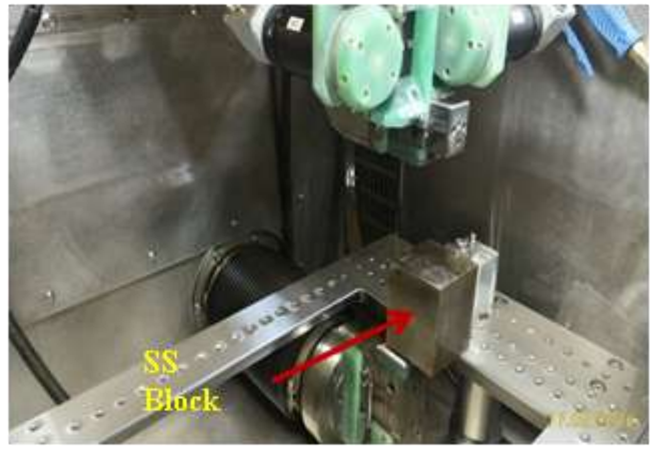

Fig.10: SS Block setup on machine for Trial-3

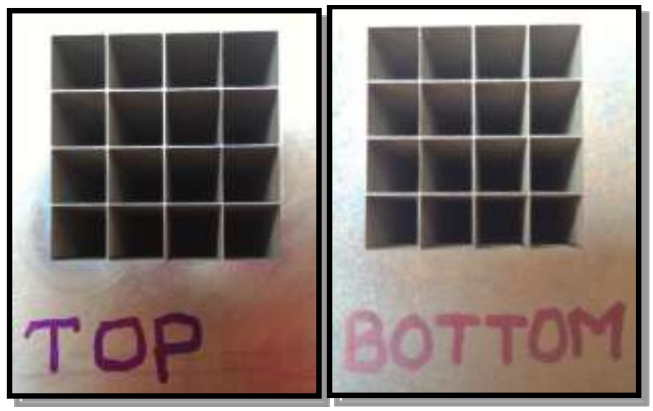

Fig.11: Slots machined using pocket type tool path (Trial-3)

Slots machined using pocket type tool path is shown in Figure-11.

CMM results for the Trial-3 are plotted and are shown in Figure-12. From the Figure-11, it is evident that no slot was found damaged and walls were found to be straight.

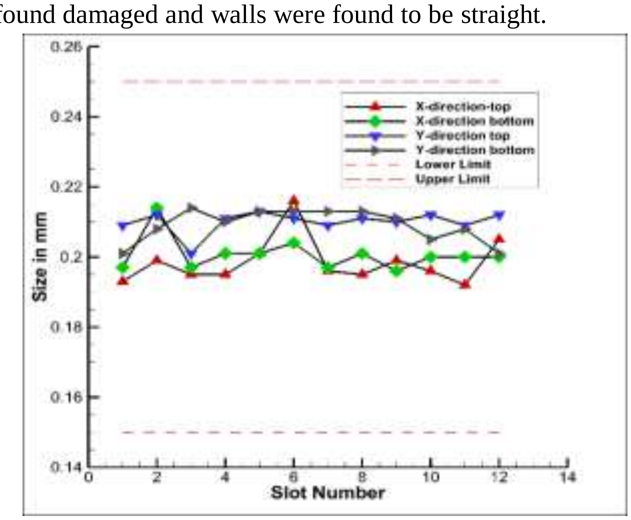

Fig.12: Thickness of walls from the Trial-3

From the graph (Figure-12), all the dimensions of the walls were observed to be within the tolerance limits. The results achieved are within the ±10 microns whereas the design requirement is ±50 microns. The repeatability of the process and degree of precision are very high. During the machining by using pocket type tool path, machine was not stopped at any stage to remove slugs since there was no slug left after slots finished and thus eliminated the lead time.

III. REALIZATION OF SS COLLIMATOR

From the previous Trials it was found that pocket type tool path used in Trial-3 to be efficient in achieving the 128 slots in SS Collimator within the tolerance limits.
Details of the SS Collimator fabrication are listed in table-3.

Table.3: Details of the SS Collimator fabrication

Machine model	TRIALCUT 2000 S
Wire diameter	0.25 mm
Wire material	Zinc coated Brass
Dielectric	Deionized water
CAD/CAM software	FeatureCam
NC Tool Path	Profile type
No. of passes	01

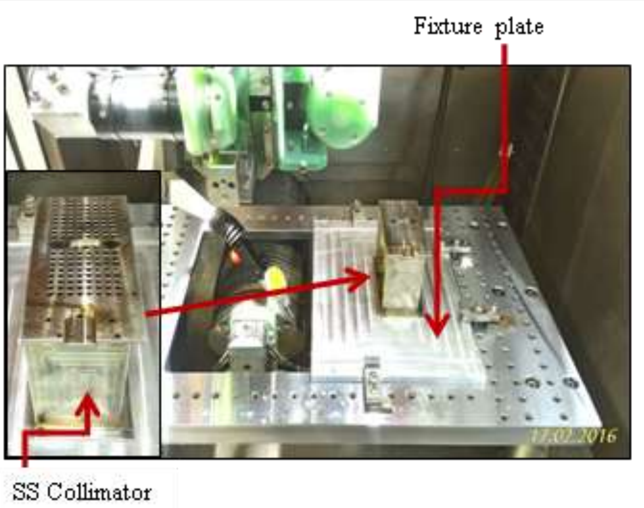

Fig.13: SS Collimator setup on machine

A special fixture plate was used to hold the SS collimator on machine as shown in Figure-13. CMM results for the SS Collimator are plotted and are shown in Figure-14. Finished slots of SS Collimator using pocket type tool path is shown in Figure-15, 16, and 17.

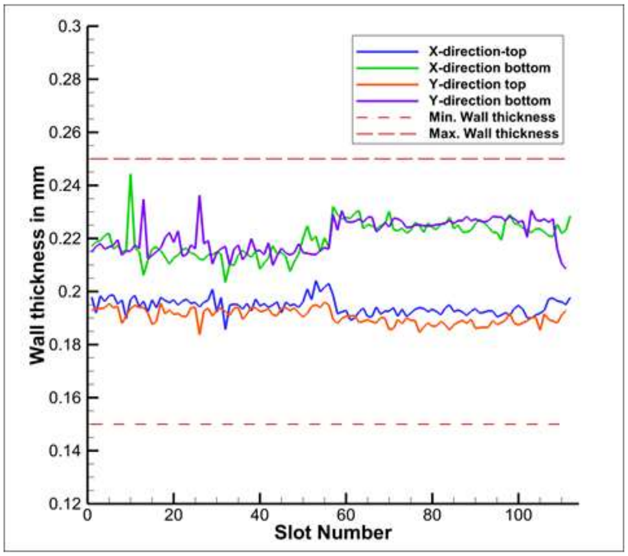

Fig 14. Thickness of walls for the SS Collimator

From the graph (Figure-14), all the dimensions of the walls were observed to be within the tolerance limits. From the Figure-15, 16 and 17, it is evident that no slot was found damaged and walls were straight, and collinear with each other.


Fig 15. Slots machined on SS Collimator - Top.

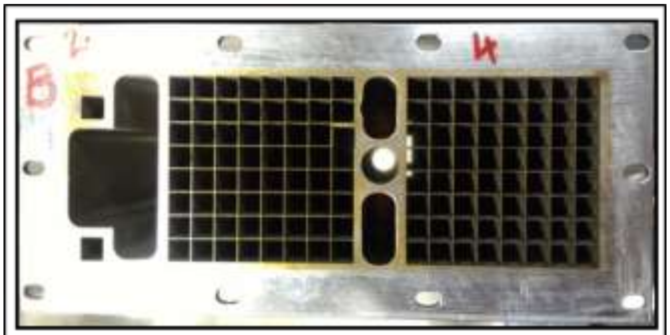
Fig 16. Slots machined on SS Collimator – Bottom.

Fig 17. Slots machined on SS Collimator.

IV. CONCLUSIONS

In the present work, capability of Wire-EDM technology in achieving the monolithic structure of SS Collimator is studied. Three Trials of 4 X 4 slots were performed on a Trial SS material by adopting the different machining strategies in FeatureCam software. The first and second Trials were done using profile type strategy. From the first Trial was found that wall thickness of the collimator achieved, was neither accurate nor precise. Second trial displayed the better precision but not accuracy. In the third trial, pocket type machining strategy was employed and this proved to be better in terms of accuracy and precision when compared to the other two trials and are met the design requirements. The SS Collimator was then realized using the strategy employed in the Trial 3. The CMM measurements performed on the wall thickness of collimator showed no deviation beyond tolerance limits. It was found from this work that, Wire-EDM technology is capable of producing the collimator slots of size 4.7mm X 4.7mm in the SS 304 monolithic structure of 100mm length and 0.2 mm wall thickness with tolerance of ± 50 µm.

The pocket type machining strategy can also be applied for Collimators with Hexagonal slots as shown in Figure-18 and 19. Hexagonal slots are used where more slot surface area requirements exist.

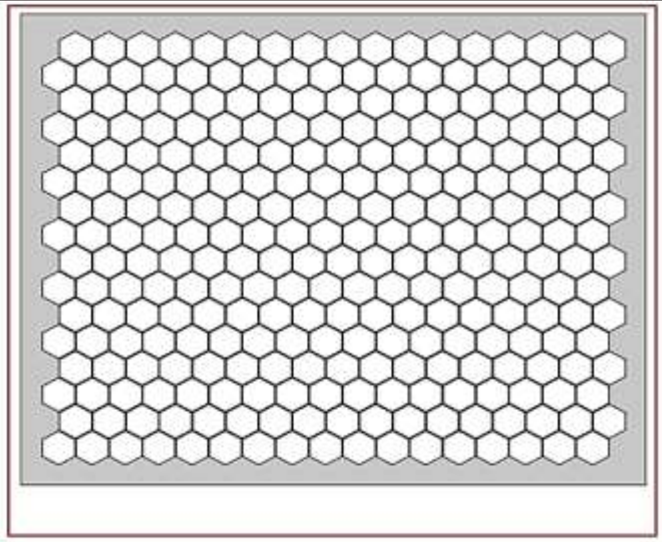

Fig.18: Collimator with Hexagonal Slots

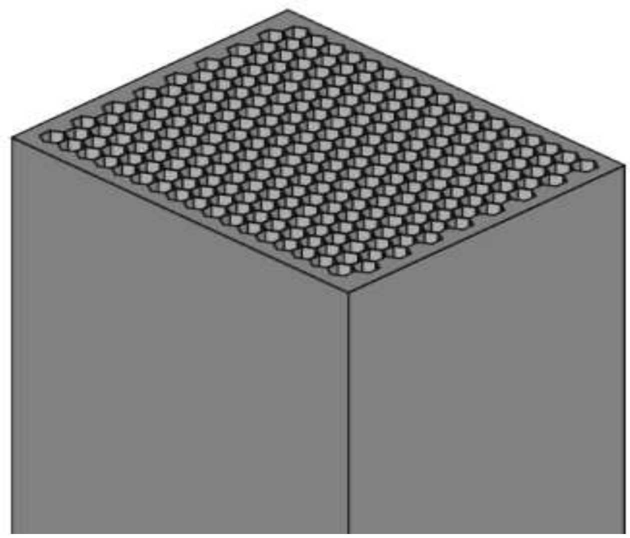

Fig.19: Collimator with Hexagonal Slots (3D-Model)

V. ACKNOWLEDGEMENTS

The authors are grateful to the support and encouragement given by Director, ISAC, CGM, Facilities and GM, Facilities. Authors are thankful to Ashoka D A, Sr.Technician-PFF and Shemi S, Sr.Technicnical Assistant-OLQC. Authors are also grateful to the people who are directly or indirectly involved in this endeavor.

REFERENCES

[1] Olga V. Makarova, Guohua Yang, Platte T. Amstutz and Cha-Mei Tang. "Fabrication of antiscatter grids and collimators for X-ray and gamma-ray imaging by lithography and electroforming" *Microsyst Technol* (2008) 14:1613–1619.

[2] M. Christophersen, B. F. Phlips, J. A. Christodoulides R. S. Woolf , and L. A. Jackson. "Laser-Machined Tantalum Collimator for Space Applications." *JLMN-*

Journal of Laser Micro/Nanoengineering Vol. 8, No. 2, 2013: 183-187.

[3] Christopher J. Ridley, Pascal Manuel, Dmitry Khalyavin, Oleg Kirichek, and Konstantin V. Kamenev. "A novel compact three-dimensional laser-sintered collimator for neutron scattering." *Review Of Scientific Instruments* 86, 095114 (2015): 1-7.

[4] B. E. Allman, A. Cimmino, A. G. Klein and W. A. Hamilton. "Metal Micro-Arrays for Collimating Neutrons and X-Rays." *Proceedings SPIE 3449*, SPIE Annual Meeting, San Diego, California 19-24 July 1998.

[5] John W. Leaslt. "Methods Of Collimator Fabrication." US Patent No 3988589. Oct. 26, 1976.

[6] Jinhun Joung and Samir Chowdhury. "Registered Collimator Device For Nuclear Imaging Camera And Method Of Forming The Same." US Patent No 20050017182. Jan. 27, 2005.