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Design and Finite Element Analysis of Light Weighted Mirror for Space Applications

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Abstract: This Paper describes the design, finite element analysis of a light weighted mirror for space applications, particularly a "Scan mirror". As this is a Space application, weight has to be optimised. So, these mirrors are undergone weight reduction. This reduction in weight must ensure that the stiffness of material remains within the tolerance level with maximum amount of material removed. Main requirement here is the stiffness of the material so the deformations under self-weight must remain as minimum as possible. The deformation tolerances allowed here are in nanometer level. Therefore, different patterns are designed on to the back side of mirror, then analysed with different material assignments that are acceptable for mirror.
Keywords: Design, Finite element analysis, Light weighted mirror, Stiffness, Minimum Deformations, Space Applications.

I. INTRODUCTION

Mechanical design is a complex process, requiring many skills. Extensive relationships need to be subdivided into a series of simple tasks. The complexity of the process requires a sequence in which ideas are introduced and iterated. Design is an innovative and highly iterative process. It is also a decision-making process. Decisions sometimes have to be made with too little information, occasionally with just the right amount of information, or with an excess of partially contradictory information. Decisions are sometimes made tentatively, with the right reserved to adjust as more becomes known. The point is that the engineering designer has to be personally comfortable with a decision-making, problem-solving role.

II. DESIGN CONSIDERATIONS

Sometimes the strength required of an element in a system is an important factor in the determination of the geometry and the dimensions of the element. In such a situation we say that strength is an important *design consideration*. When we use the expression design consideration, we are referring to some characteristic that influences the design of the element or, perhaps, the entire system. Usually quite a number of such characteristics must be considered and prioritized in a given design situation. Hence the design considerations taken are:

A. Stiffness.
B. Surface finish.
C. Weight.
D. Strength.
E. Availability.
F. Machinability.

III. DESIGN TOOLS AND RESOURCES

The Mirror patterns are designed in SOLIDWORKS, a design software developed by Dassault Systems, then the model is imported to ANSYS Workbench in IGES format. All the tests are conducted in workbench, with different material assignments. Materials considered are:

A. Silicon Carbide
B. Zerodur
C. Beryllium

IV. REQUIREMENTS OF MIRROR

Scan Mirror is used in satellites to scan the required area and send the data to payload. These have to be highly accurate, have high resolution and must have high stiffness in order to prevent larger deformations. The required mirror is Rectangular flat surfaced with dimensions of 285±1mm length, 140±1mm width, 20±1 mm thick. This mirror must possess as minimum weight with maximum stiffness possible. The mirror must undergo weight reduction such that the stiffness barely changes and so does the deformations. This is only possible with having iso-grid pattern on the non-reflecting side of the mirror.

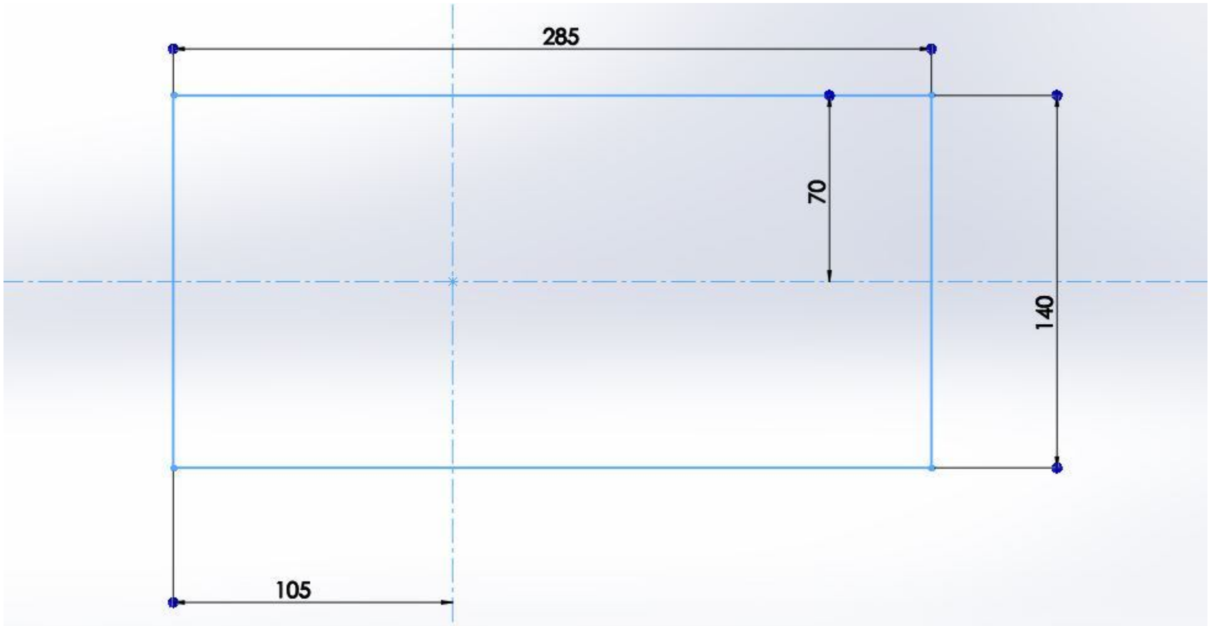

Fig. 1 Basic Dimensions of Mirror showing spin axis which is offset from geometrical centre

V. FINITE ELEMENT MODELS OF DIFFERENT PATERNS

For the purpose of this paper, four kinds of patterns, each with distinct design are made. Thus, designed CAD models are converted to IGES format, imported to ANSYS Workbench environment and then meshed using different material assignments. Modal and Static Structural Analyses are made with Boundary conditions varying from pattern to pattern and type of analysis.

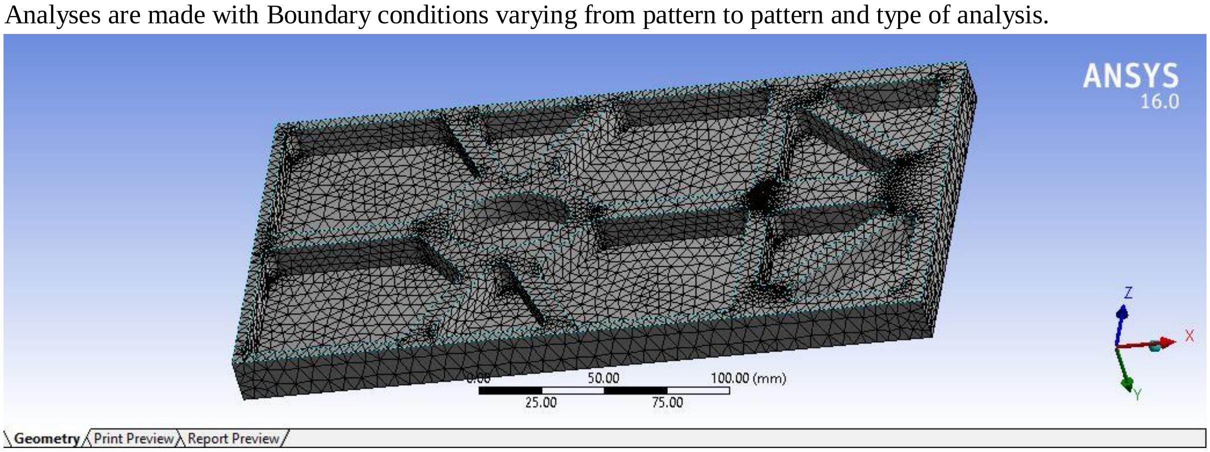

Fig. 3 FE Model of Pattern 1

Sizing	
Use Advanced Si...	Off
Relevance Center	Fine
Element Size	Default
Initial Size Seed	Active Assembly
Smoothing	High
Transition	Slow
Span Angle Center	Fine
Minimum Edge L...	2.87050 mm

Fig. 4 Mesh Size details for Pattern 1

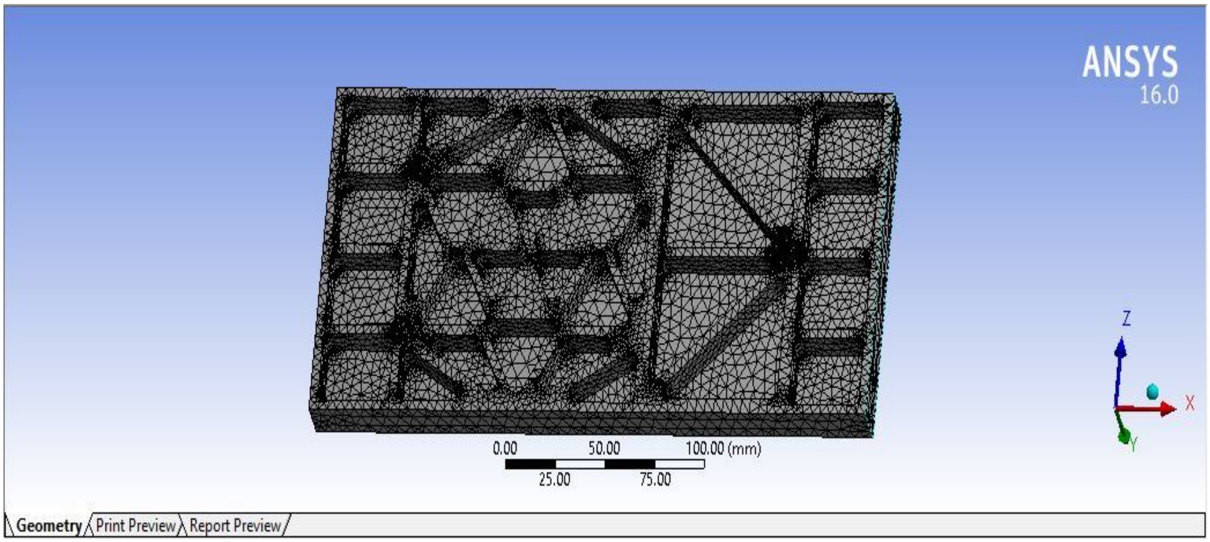

Fig. 5 FE Model of Pattern 2

Sizing	
Use Advanced Si...	Off
Relevance Center	Fine
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Smoothing	High
Transition	Slow
Span Angle Center	Fine
Minimum Edge L...	1.85710 mm

Fig. 6 Mesh Size details for Pattern 2

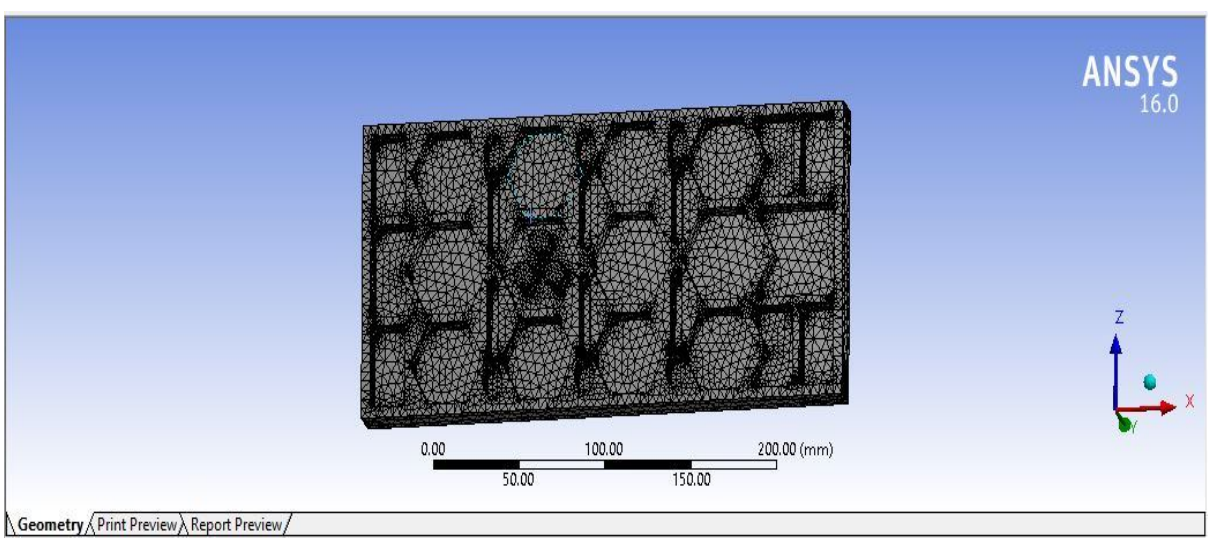

Fig. 7 FE Model of Pattern 3

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Sizing	
Use Advanced Size Function	Off
Relevance Center	Fine
Element Size	Default
Initial Size Seed	Active Assembly
Smoothing	High
Transition	Slow
Span Angle Center	Fine
Minimum Edge Length	4.18780 mm

Fig. 8 Mesh Size details for Pattern 3

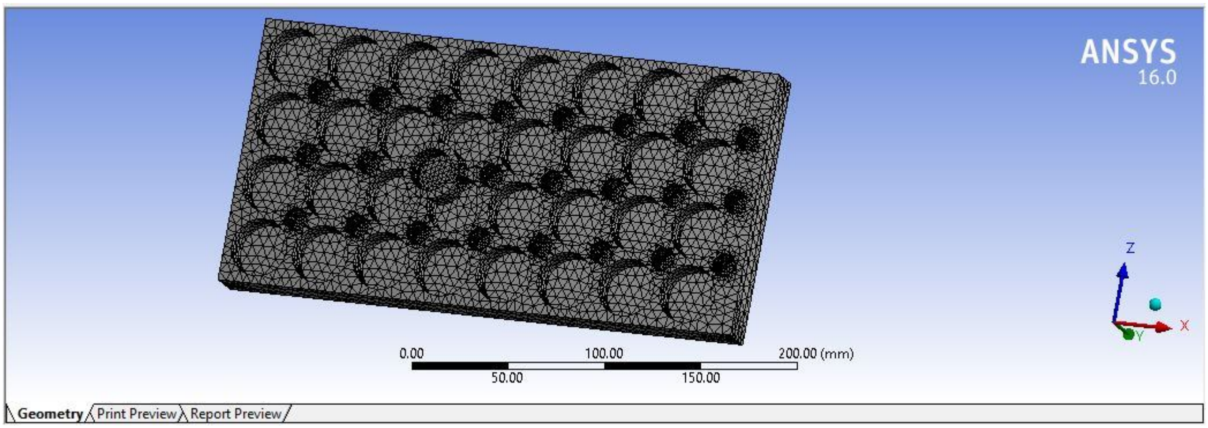

Fig. 9 FE Model of Pattern 4

Sizing	
Use Advanced Size Function	Off
Relevance Center	Fine
Element Size	Default
Initial Size Seed	Active Assembly
Smoothing	High
Transition	Slow
Span Angle Center	Fine
Minimum Edge Length	1.07810 mm

Fig. 10 Mesh Size details of Pattern 4

VI. BOUNDARY CONDITIONS

Each Pattern has its own boundary conditions. So, each pattern is to be analysed under its own boundary condition. However, for Modal Analysis, Boundary Condition must be different from that of static structural. The mirrors are to be mounted on a mounting stand with some kind of support at the back of their reflecting surface. Hence, these mounting points are considered as one Boundary Condition and the other being the self-weight.

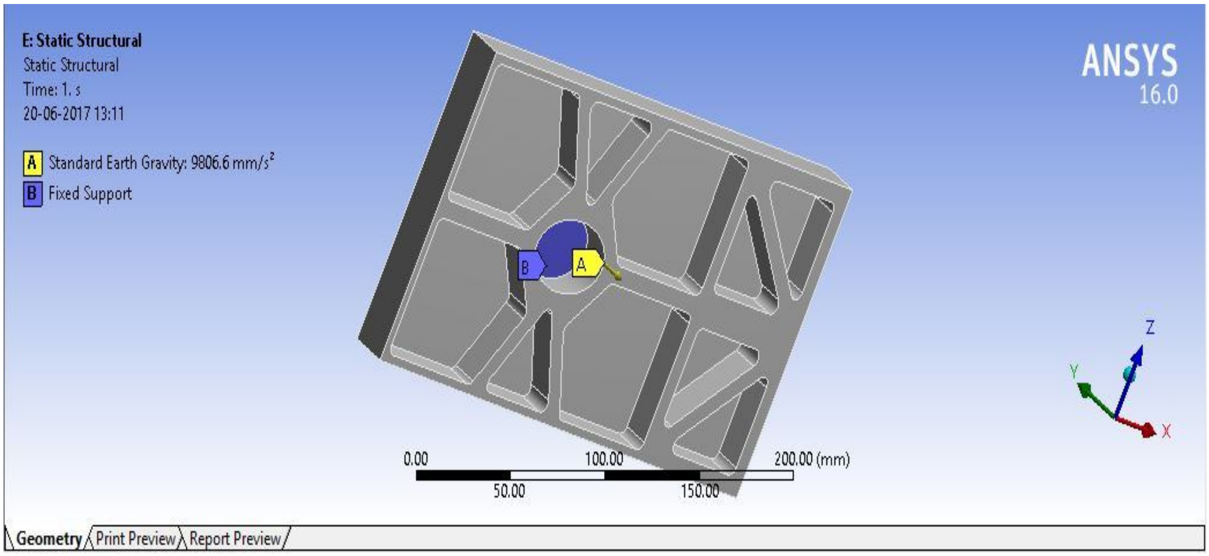

Fig. 11 Boundary Conditions for Pattern 1

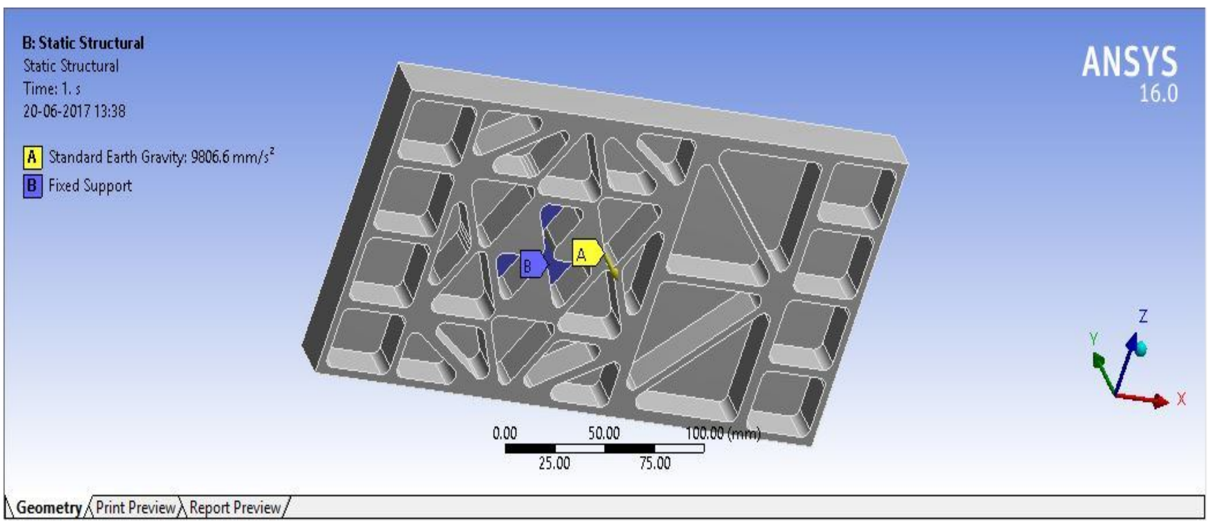

Fig. 12 Boundary Conditions for Pattern 2

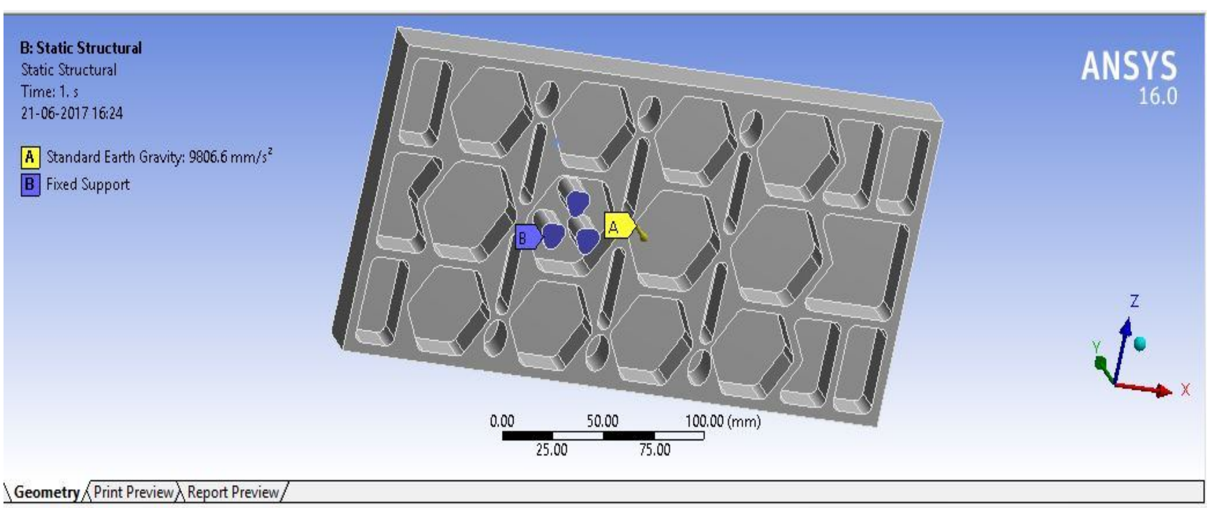

Fig. 13 Boundary Conditions for Pattern 3

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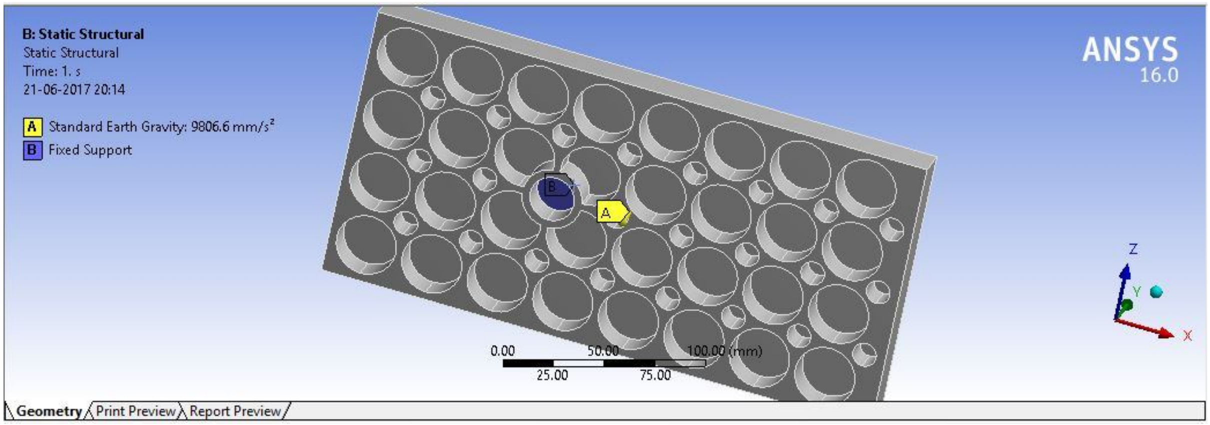

Fig. 14 Boundary Conditions for Pattern 4

VII. ANALYSIS OF PATTERNS

Now these four patterns with different boundary conditions and with different material assignments are analysed in Static Structural and Modal tabs of ANSYS Workbench. Static Structural Analysis shows deformation under self-weight while Modal Analysis shows natural frequency of the mirror and mode shapes, which determines its stiffness. In addition to these required results, weights of all four kinds of mirrors with three different kinds of material assignments are tabulated in order compare and to evaluate which one of them would be optimal for space applications.

VIII. RESULTS

All the results acquired individually are tabulated into single table and then compared.

Material	Silicon Carbide			Zerodur			Beryllium		
Pattern 1	0.000602	1.181	758.56	0.002156	0.96382	400.43	0.0004734	0.70477	855.55
Pattern 3	0.001179	1.2258	486.59	0.0041806	1.0004	258.48	0.0009318	0.73154	547.57

Fig. 15 Image of a table showing all results

Deformation in mm, Weight in Kg, Natural Frequency in Hz.

IX. CONCLUSIONS

In this paper, different patterns assigned with different materials are analysed by Finite Element Method. The materials chosen are most suitable for mirror use. In Design Process, any designer must consider material stiffness and geometrical stiffness. This means, a body attains stiffness by its material's mechanical properties and also by its geometric configuration. The patterns can be like isogrid, honeycomb pattern, Circular and or thogrid etc. These patterns are made on the non-reflecting side of the mirror and then analysed with different materials assignments in order to study about their behaviour. Isogrid pattern is a pattern having equilateral triangles arranged symmetrically. From the above comparison of results, Pattern 2 (The one with more number of triangles in its pattern) shows very less deformation compared to others. While Pattern 1 (Pattern with less triangles) shows less deformation after Pattern 1. Next comes Pattern 4 and Pattern 3 consecutively. Pattern 3 has a circular pattern; this means circular pattern allows less deformation when compared to hexagonal/ Honeycomb pattern (Pattern 3). By this we can conclude that, Isogrid does not allow deformation and geometrical stiffness is high. While Hexagonal Pattern allows best compactness so that light weighting is efficiently done. Between these two lies circular pattern and Orthogrid. So according to requirement, designer has to opt the pattern. Here these patterns are assigned to three materials (Silicon Carbide, Zerodur, Beryllium). A designer must also consider material stiffness for his design to meet the requirements. From comparison of results of FEA, it is clear that Beryllium showed very less deformation, followed by Silicon Carbide and next Zerodur. This indicates that the Beryllium>Silicon Carbide>Zerodur order has increasing deformations. But deformation and stiffness are not only criteria for opting optimal material. Considering Beryllium, it is a carcinogenic material. A material which causes cancer is called carcinogenic material. Since beryllium is metal, it needs to be grinded, so if the worker inhales beryllium dust when grinding, it becomes hazardous. Moreover, for metals to have surface finish, grinding isn't sufficient. Extra coatings are to be made. This makes mach inability for beryllium harder. A pure beryllium will not be available; it needs to be mixed with other substance. Considering Zerodur, it is a ceramic glass and is highly brittle yet has very low stiffness and is lighter than Silicon Carbide. But this shows more deformations and natural frequency too is very low. This means fracture fatigue is likely to occur more. In order to machine Zerodur, advanced machining processes like Ultrasonic Milling, Abrasive Jets etc. must be used, which makes it a costly process. This material is also costly than any other materials compared. Similar to Zerodur, Silicon carbide is hard to machine, which needs investment. Yet surface finish attained will not meet the requirement. Therefore, extra coatings are to be made and make the reflecting surface meet the requirement. More or less Silicon Carbide seems to be optimal material for the scan mirror as it exhibits properties in optimal range. Machining Silicon Carbide is not too harder as in case with Zerodur, nor it is carcinogenic as beryllium.

X. ACKNOWLEDGEMENT

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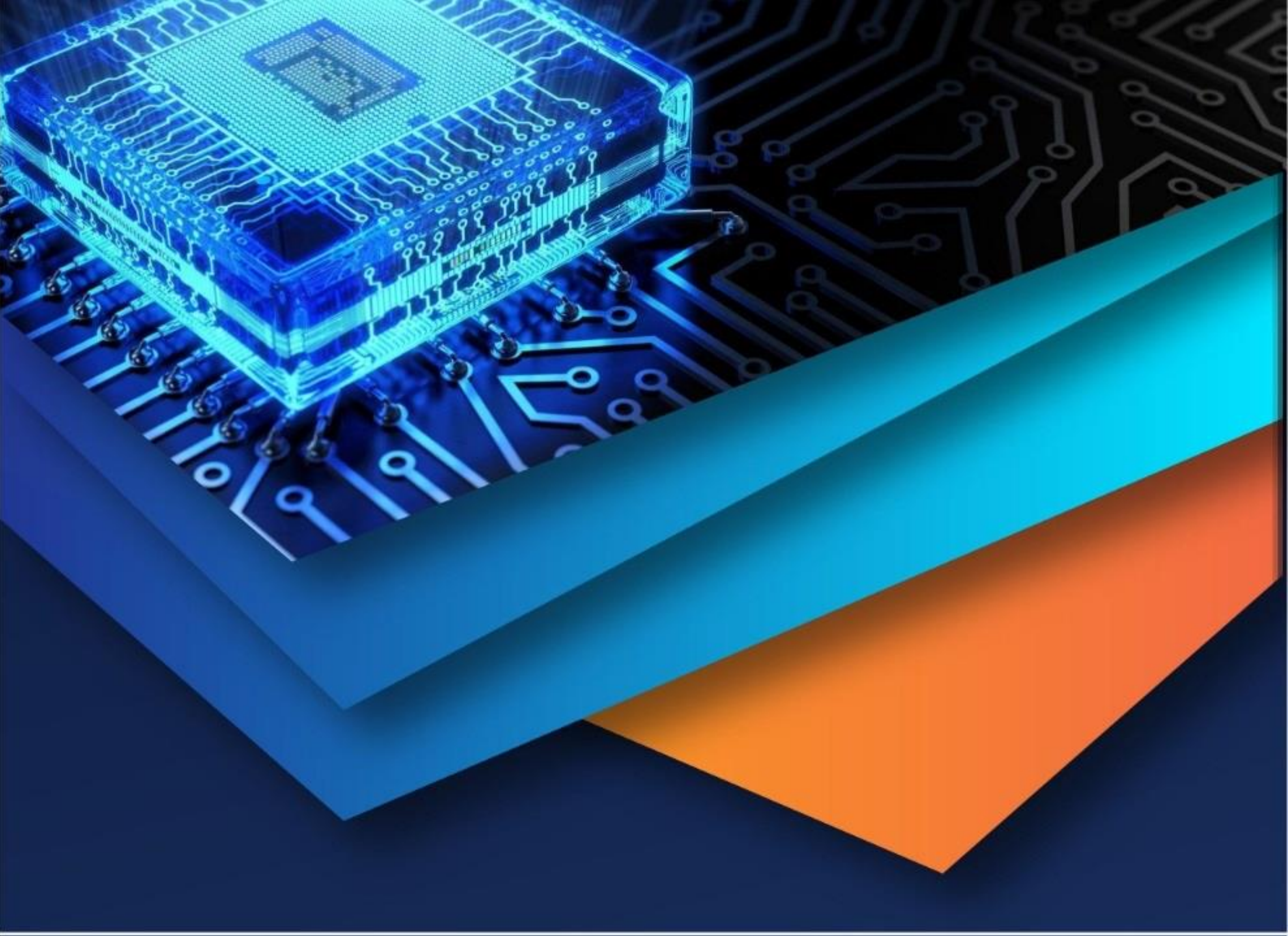

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