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Study and comparison of stress and displacement distribution on different perforated proof mass of micro fabricated MEMS capacitive accelerometer

Shashi yadav
ECE Department
BIET, Lucknow
UPTU,Lucknow

Assot . Prof. Sumit Kumar Gupta
ECE Deptt.
BIET, Lucknow
UPTU,Lucknow

Asst.Prof. KamranAkhtar
ECE Deptt.
SCERT, Barabanki
UPTU, Lucknow

Abstract:- ***This work represents a study of perforated proof mass of a micro fabricated accelerometer with different perforation shapes, by application of load on different perforation shapes, stress and displacement is measured and comparison is done to know the deflection and flexibility of the proof mass. Previous research have proved that this step is very significant in deciding the suitable shape of perforation for desire application. Perforation shapes of proof mass of capacitive accelerometer affects the sensitivity and other performance parameters of accelerometer. Eigen frequency analysis is done to know the stress and displacement distribution on vibrating proof mass which are used to measure and compare the sensitivity and mechanical strength of proof mass. As a result of this study it has been found that the proof mass with perforation shape of nozzle/diffuser is the most efficient perforation shape to get better performance from an capacitive micro fabricated accelerometers.***

Keywords: - **Accelerometer, Eigen frequency, MEMS, perforation.**

I. INTRODUCTION

Accelerometer is a device used to detect magnitude and direction of the proper acceleration (or g-force), as a vector quantity, and can be used to sense orientation (because direction of weight changes), coordinate acceleration, vibration, shock, and falling in a resistive medium.. Different types of accelerometer are available such as capacitive, piezo-resistive, tunnelling, thermal etc., studies and research on these accelerometer have proved that capacitive accelerometers are more efficient and widely used. Capacitive accelerometer is one of the earliest inertial instruments studied intensively in MEMS (Micro-Electro-Mechanical Systems) field since 1980s because of its simple structure and easy integration with integrated circuit. Perforation is done to reduce the air damping which has significant effect on the performance Proof mass of capacitive accelerometer will act as movable plates which causes change in distance between the plates so capacitance will change. This change in capacitance will be measured as acceleration.

II. DEVICE DESCRIPTION

Proof mass of accelerometer is act as a movable plates when load is applied, proof mass moves causes change in capacitance which can be measured as acceleration. Proof mass with different perforation has different stress and displacement distribution means flexibility and sensitivity of proof mass changes with perforation shapes.

d is distance between the plates when load is applied this distance will change accordingly capacitance will change. Capacitance C is defined as:-

$$C=€A/d,$$

€ is electrical permittivity of dielectric medium and is defined as $€=€_0€r$, for air as dielectric medium $€=€_{0.}$

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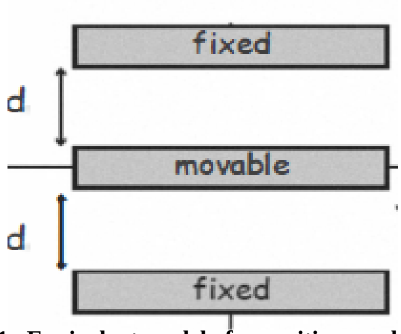

Fig 1. Equivalent model of capacitive accelerometer

If x is not equal to zero, then the capacitance is,
$C_1 = \epsilon A / d+x$, ------(1)
$C_2 = \epsilon A / d- x$, ------(2)
Now, Change in capacitance can be calculated as,
$C_2 - C_1 = 2\Delta C = 2\, \epsilon A\, x / d^2 - x^2$ ------(3)
Displacement can be solved by solving the equation:-
$\Delta C\, x^2 + \epsilon A\, x^2 - \Delta C\, d^2 = 0$ --------(4)
For small displacement ΔCx^2 can be neglected,
$x = d^2\, \Delta C / \epsilon A = d\, \Delta C / C_0$ --------(5)
Where,
C_0 is the capacitance between the movable and fixed plates before application of load
d= Original distance between the plates
x= displacement of the movable plate.

Displacement is approximately proportional to change in capacitance.
Voltage V_x after application of load can be measured as ,
$V_x = x\, V_0 / d$ --------------------------(6)
So, voltage is proportional to the displacement.
Accelerometer can be modelled as system composed of proof mass, spring, damper. This system can be expressed as:-

$$F=ma=md^2z/dt^2+bdz/dt+kz$$

Where z id displacement is spring constant,b is damping coefficient and m is mass of proof mass, a is applied stress. Poly-silicon is used in proof mass as well as in fixed plates since poly -silicon has excellent mechanical and yield strength. *1kpa* load is applied along negative z-axis.

Table1:- Model dimension

	Length in µm	Width in µm	Height in µm
Proof mass	5000	5000	100
Square hole	1000	1000	100
Anchor	1500	1500	100
Beam	5000	1500	100
Shin	3000	500	100

III.SIMULATION

All the simulations are done in COMSOL (multi physics), version 4.3 and version 4.3a

1) Proof mass with square perforation:-

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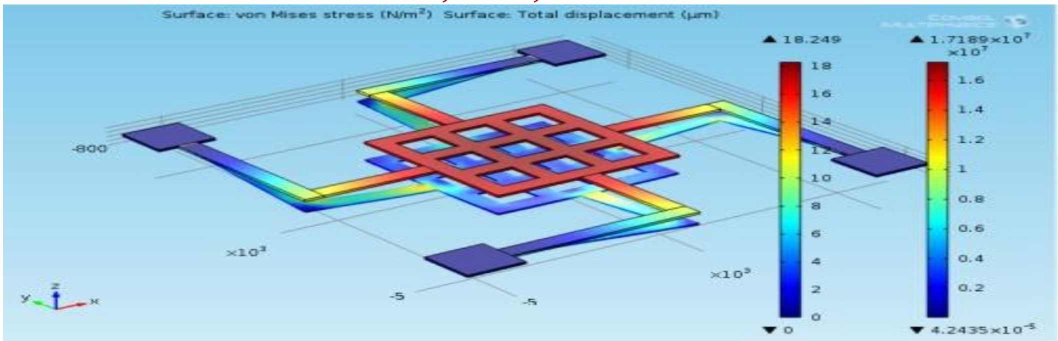

Fig.2:-Proof mass with square perforation

2) Proof mass with cylindrical perforation:-
Radius of circular hole=500 µm

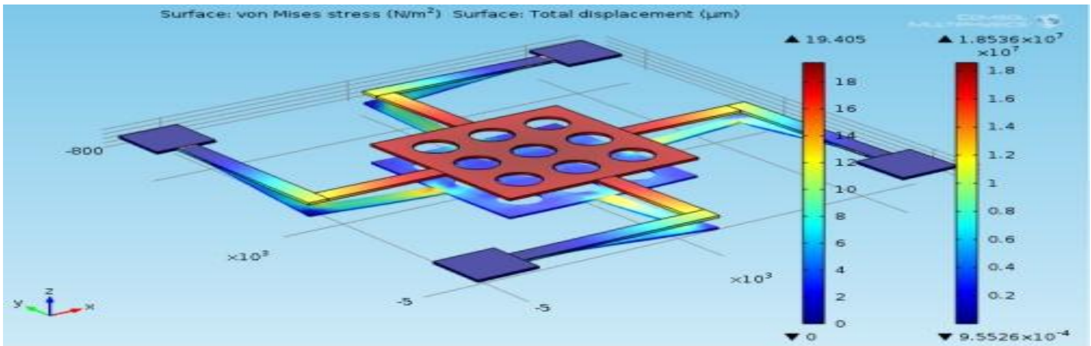

Fig. 3. Proof mass with cylindrical perforation

3) Proof mass with nozzle and diffuser perforation:-
Nozzle a-semi axis =500 µm
Nozzle b-semi axis =500 µm
Height =100 µm. Ratio=0.5

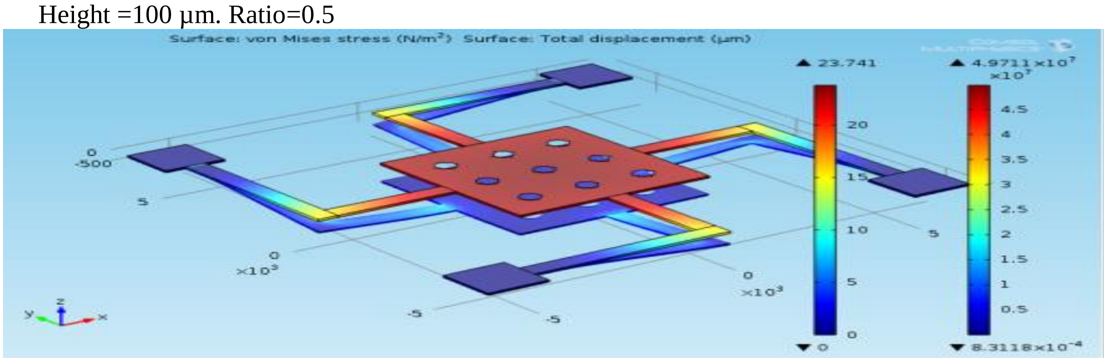

Fig. 4. Proof mass with nozzle diffuser perforation

4) Proof mass with pyramidal perforation:-
Base length 1=1000µm
Base length 2=1000µm
Height= 100µm
Ratio = 0.5

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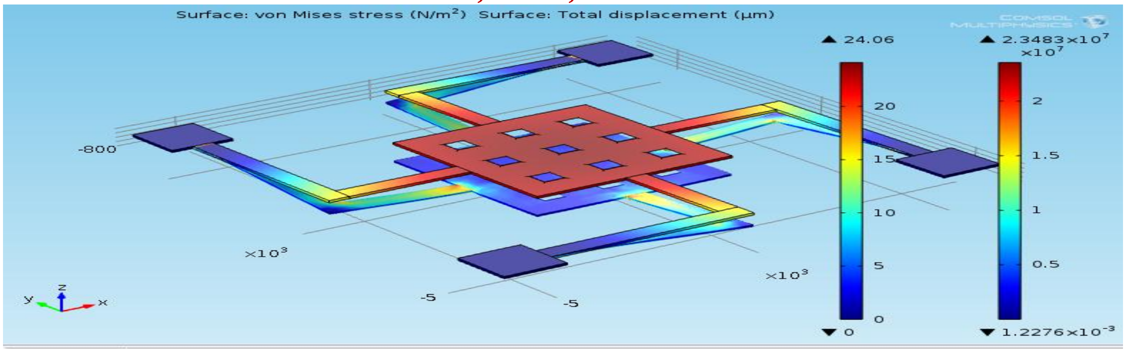

Fig. 5.Proof mass with pyramidal perforation

Table2:- Maximum stress and displacement values On the proof mass of different perforations

Perforation	Stress in N/m^2	Displacement in µm
Square	1.71E7	18.25
Circle	1.85E7	19.40
Nozzle diffuser	4.97E7	23.74
Pyramidal	2.34E7	24.06

IV. EIGEN FREQUENCY ANALYSIS

In this analysis proof mass vibrates in six different modes at six different frequencies. These frequencies decides the maximum stress and maximum displacement of the vibrating proof mass. These frequencies depend on the model design and some characteristics of the material used.

1. Proof mass with cylindrical perforation

Table 4:- Stress and displacement values at six modes.

Modes	Frequency In Hz	Stress in N/m^2	Displacement in micro meter
Mode1	2111.25	2.28E12	2.35E6
Mode2	4436.62	5.46E12	3.51E6
Mode3	4438.59	5.54E12	3.53E6
Mode4	8231.76	8.50E12	4.43E6
Mode5	9971.85	1.11E13	4.58E6
Mode6	13094.56	1.88E13	4.17E6

2. Proof mass with square perforation:-

Table 5:- Stress and displacement values at six modes.

Modes	Frequency in Hz	Stress in N/m^2	Displacement In micro meter
Mode1	2173.43	2.28E12	2.31E6
Mode2	4477.34	5.30E12	3.56E6
Mode3	4478.34	5.40E12	3.56E6
Mode4	7887.52	8.23E12	4.58E6
Mode5	9721.36	9.572E12	4.66E6
Mode6	13010.51	2.40E13	5.57E6

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3. Proof mass with pyramidal perforation

Table 6:- Stress and displacement values at six modes.

Modes	Frequency In Hz	Stress in N/m^2	Displacement in micro meter
Mode1	4385.68	5.98E12	4.37E6
Mode2	4385.95	5.94E12	4.36E6
Mode3	8339.22	8.34E12	4.46E6
Mode4	10062.45	10.4E12	4.64E6
Mode5	12997.44	2.35E13	5.65E6
Mode6	13010.51	2.40E13	5.57E6

4. Proof mass with nozzle diffuser perforation

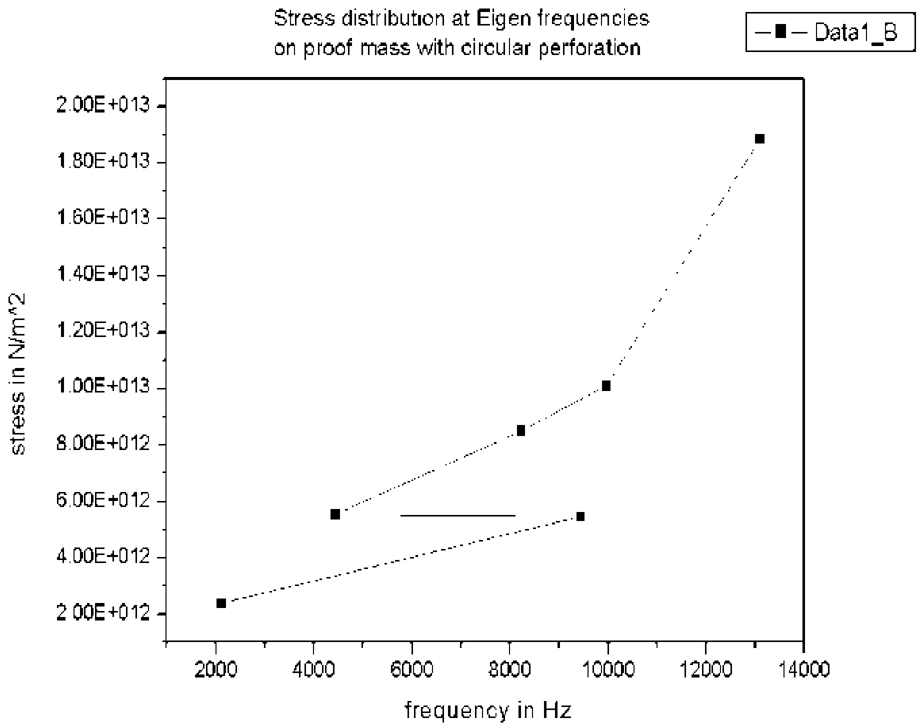
Table7:- Stress and displacement values at six modes

Modes	Frequency In Hz	Stress in N/m^2	Displacement in micro meter
Mode1	2028.33	3.29E12	2.31E6
Mode2	4376.26	5.80E12	3.88E6
Mode3	4379.78	5.88E12	3.79E6
Mode4	8875.34	27.52E12	4.63E6
Mode5	10375.38	16.62E12	4.76E6
Mode6	13199.45	28.87E12	5.73E6

V. GRAPHICAL REPRESENTATION

Stress distribution

1. Proof mass with circular perforation



2. Proof mass with square perforation

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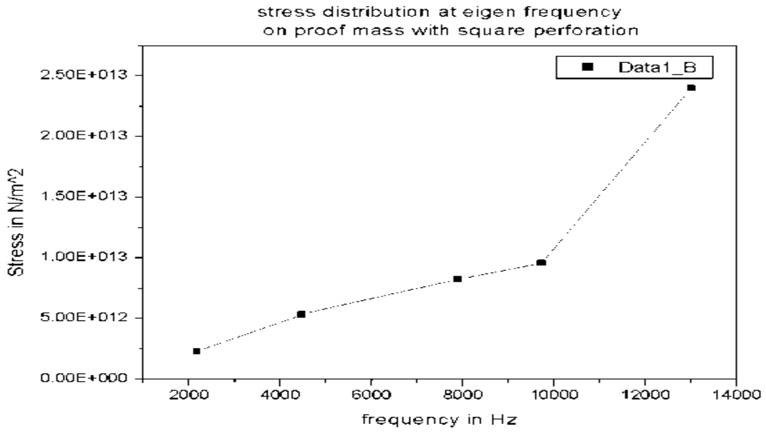
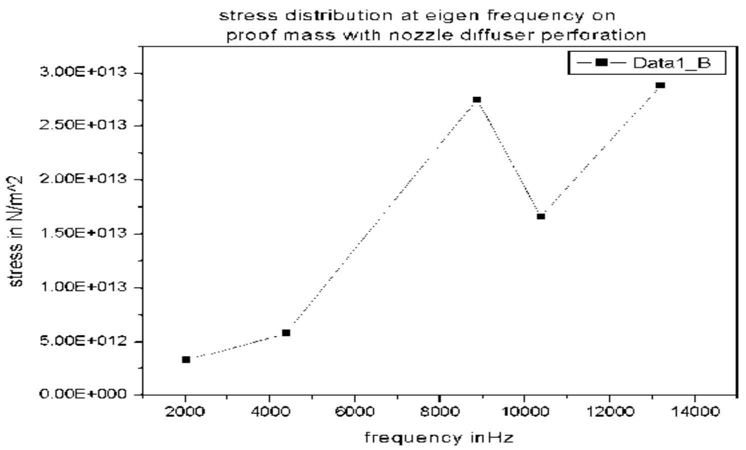
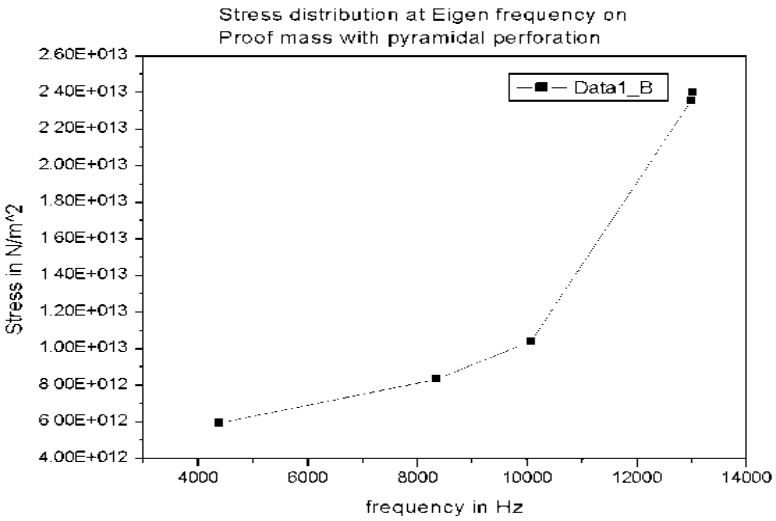


1. Proof mass with nozzle diffuser perforation



2. Proof mass with pyramidal perforation



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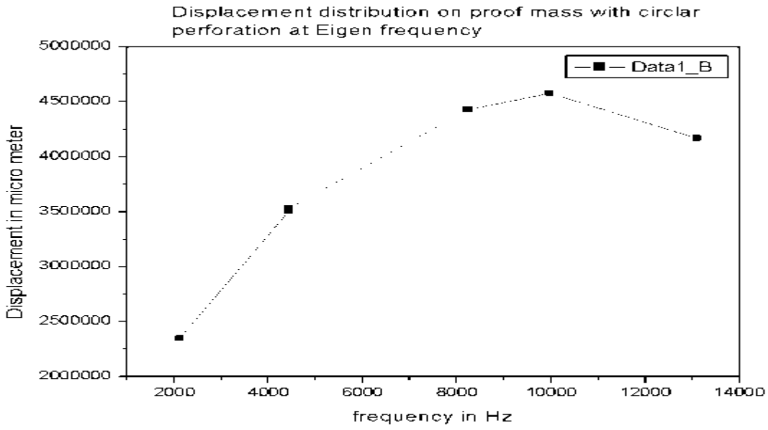
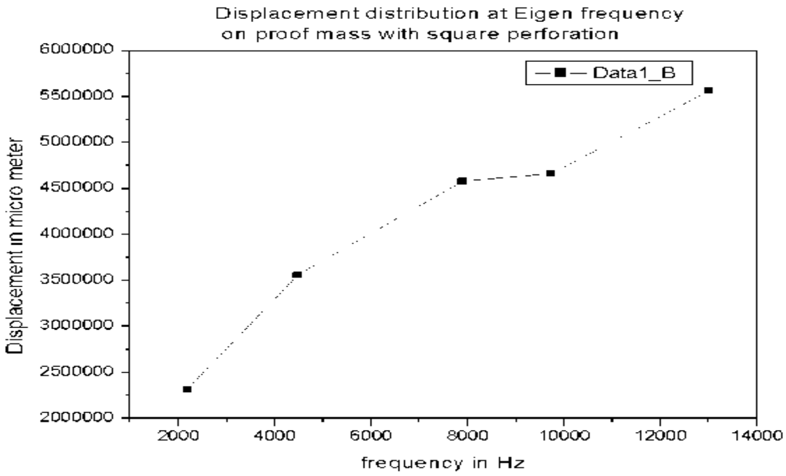
Displacement distribution

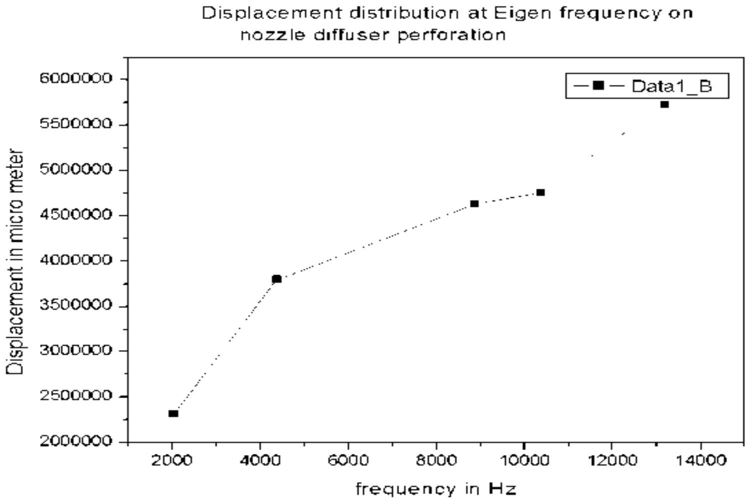
1. Proof mass with circular perforation



2. Proof mass with square perforation



3. Proof mass with nozzle diffuser perforation



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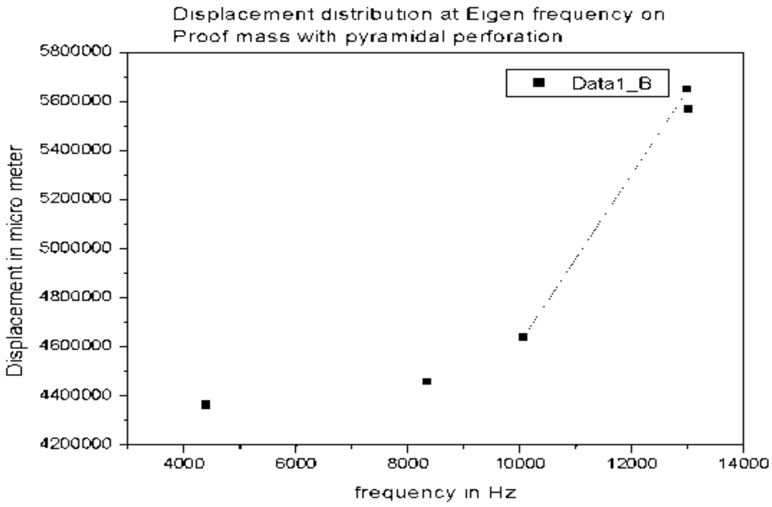
4. Proof mass with pyramidal perforation



VI. RESULTS

In the same perforated proof mass it is seen that if position of spring changes maximum displacement and maximum stress will also change. Maximum stress is observed in proof mass with *nozzle-diffuse* perforation. Minimum stress is observed in proof mass with *square* perforation when spring position changes. Maximum displacement is observed in proof mass with *nozzle-diffuser* perforation when spring position changes. Minimum displacement is observed in proof mass with *square* perforation.

VII.CONCLUSION

Maximum Stress and maximum displacement in nozzle diffuser perforation shows that it is more sensitive to stress and displacement on application of load. Minimum stress and displacement in square perforation shows that it is less sensitive to stress and displacement on application of load. So nozzle –diffuser perforated proof mass is more sensitive as well as has better mechanical strength.

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