Design Analysis of Exhaust Muffler With VOC Emission Filter

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Abstract - *The major source of noise pollution is IC Engine. In today's world human requires pollution free atmosphere, hence need assist to control noise and air pollution. Physiologically and psychologically human being is affected by noise and air pollution. Muffler is used for noise reduction emitted by IC Engine exhaust. To design and manufacture of exhaust muffler is the main purpose of this study. By using mufflers back pressure amount of noise level with pollution free gases will get reduced. Exhaust muffler for engine test rig has been designed. Experiment was carried out with designed and fabricated muffler and minimum noise of 88 DBA with no load condition with maximum 5100RPM speed is obtained. In this paper the complexity behind different mufflers and present muffler with noise reduction, design and performance evaluation are discussed.*

Key Words: **VOC emission filter, Noise pollution, Muffler, Back pressure.**

1. INTRODUCTION

For decreasing the noise level emitted by exhaust of an IC engine, muffler is used. Normally noise which is larger than 80dB is injurious for human ears. The basic requirement of muffler is it should operate quietly. If without muffler we drive the vehicle, then fumes emitted by exhaust of an engine will be getting stuck inside of vehicle which should be very dangerous this is the basic reason behind using muffler. Due to the combustion in the engine cylinder high intensity pressure wave generated and radiates from the exhaust pipe termination. Due to friction occurring inside of the engine noise is created. As engine rpm increases sound emitted with larger frequency. Basically in combustion chamber the mixture of air fuel is burned which is required to generate the power or to drive the vehicle. Due to the emission nitrogen monoxide, carbon monoxide, hydrocarbon, carbon dioxide etc. gases are getting mixed in the environment which will get contribute to increase air pollution so need arises to reduce the toxic content of exhaust gases from engine.

2. EXHAUST SILENCER WITH VOC EMISSION FILTER

Muffler is divided into two chambers namely Resonating chamber and VOC emission filter.

2.1 Resonating Chamber:

To reduce the noise is the main function of resonating chamber. From engine exhaust gases are removed with direct shock, these shock of gases can be absorbed by thin layered brass sheet backed with glass wool. Using this arrangement, we can reduce muffler length as compared to conventional muffler, but also back pressure by engine exhaust should be maintained as low as possible.

2.2 VOC Emission Filter:

Vapour phase activated carbon is used to remove VOC (Volatile Organic Compound) emission filter compounds like solvents, hydrocarbons, toxic gases. Chemically activated carbons are used to control inorganic pollutants like lead, hydrogen sulphide etc. We have used Bamboo charcoal in chambers separated by perforated sheets.

The below figure shows actual construction of muffler.

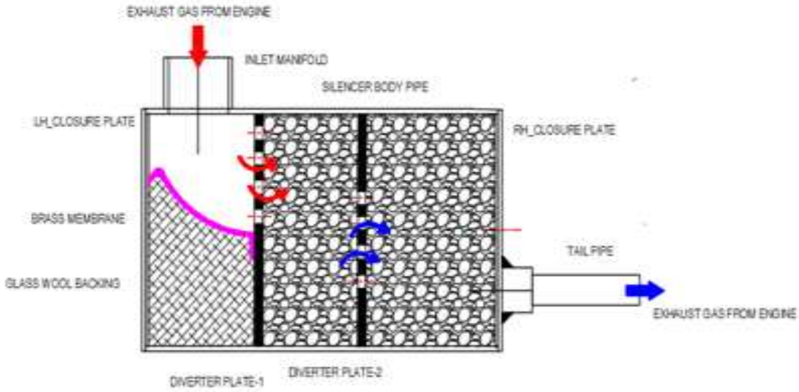

Fig-1: Exhaust Muffler with VOC Emission Filter

Exhaust air from an engine strikes the brass membrane with maximum energy, due to the shock absorbing tendency of membrane Maximum noise is reduced. Further gas is diverted by diversion plate 1 & 2. In between these two plate filter material like bamboo charcoal is used. After the second stage of filtration via tail pipe gases are discharged in atmosphere

3. VALIDATION OF MUFFLER DESIGN

Analysis of muffler is done by using FEA software ANSYS 16 & 14.5. By using this software, we can analyze stress, strain effect on muffler part. By comparing actual result obtained by software and theoretical result, we can find out it is suitable for manufacturing or not.

3.1 Casing Pipe

Tailpipe length can have an important effect in all design of muffler. The tailpipe couples with muffler cavity, acts as a resonant cavity. The characteristics of a muffler are modified, if the tailpipe design is not used. Also, flow speed of gas, exhaust gas has an effect on the muffler performance.

a) ANSYS Pre-Processor

The CAD model is imported into ANSYS Mechanical APDL as a neutral file format.

This model is then imported into ANSYS which is seen as below Fig.2

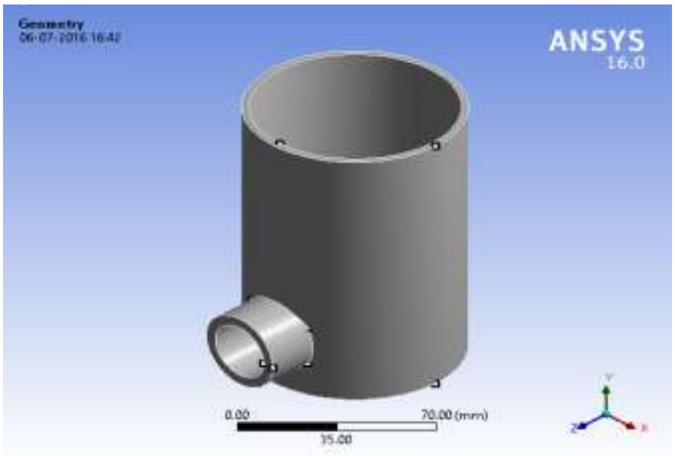

Fig -2: Geometry of casing pipe

b) Material Properties

The Input data are also important hence it becomes evident to follow proper Input codes defined by ANSYS.

The element is defined by nodes, a reference pressure, and the isotropic material properties. To calculate the element sound pressure level reference pressure is used. The speed of sound (c) in the fluid is input.

where k is the bulk modulus of the fluid.

$$K = \frac{(F) Force}{(A) Area}$$

The dissipative effect due to fluid viscosity can be included as it is given that the fluid medium is air, properties of air are given as

Density of air (ϱ) = 1.2040 kg/m^3,

Sonic velocity(C) = 343.24 m/sec

c) Meshing

Determination is most important factor for generating wave number, mesh and wavelength since by using FEA we are doing analysis. If we are to do analysis using BEM or Boundary element method which would easier to analysis since number of nodes definition is not necessary. Hence we have gone mandatorily with the rule of wavelengths. Basically, it is necessary to maintain 4 elements per wavelength, to have more accuracy in FEA.

Since the range of frequencies in muffler is from 0-300Hz.

Maximum frequency (F) = 300Hz

Sonic Velocity or sound velocity, (C) =343 m/sec

And there has to be 4 elements per wavelength,

then the Mesh density or Max element size

$$= \frac{\lambda}{4}$$

$$= \frac{1.14}{4}$$

= 0.285 m

= 2.85 mm

The above is the mesh density at frequency of 300 Hz for max safety of the muffler.

Then we will proceed with mesh tool of ANSYS.

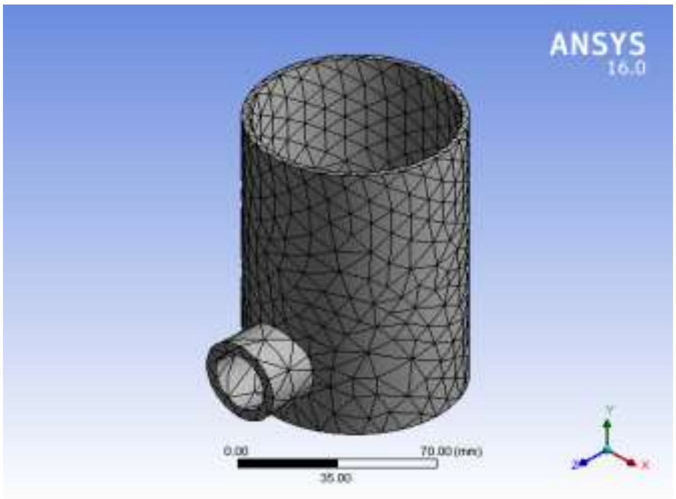

Fig -3: Meshing of the casing pipe

d) Boundary Conditions

For starting any analysis, it is always necessary to define the boundary condition so that the ANSYS can understand the nature of the problem we are about to solve otherwise it won't understand the problem properly. Hence, we need to define boundary conditions. First we will do "definition of ports" which is nothing but defining inlet and outlet ports to make the problem visible to ANSYS. Inlet port is the port from where sound source comes and Outlet port is the port where it goes out of the muffler.

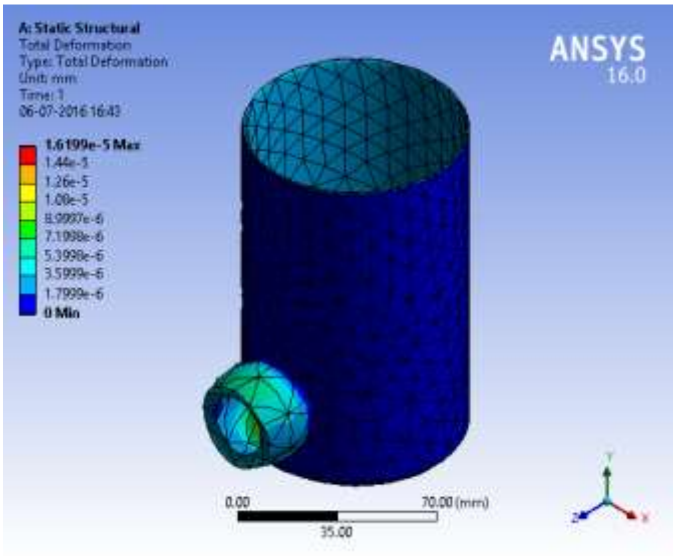

Fig -4: Static structural fixed support with total deformation

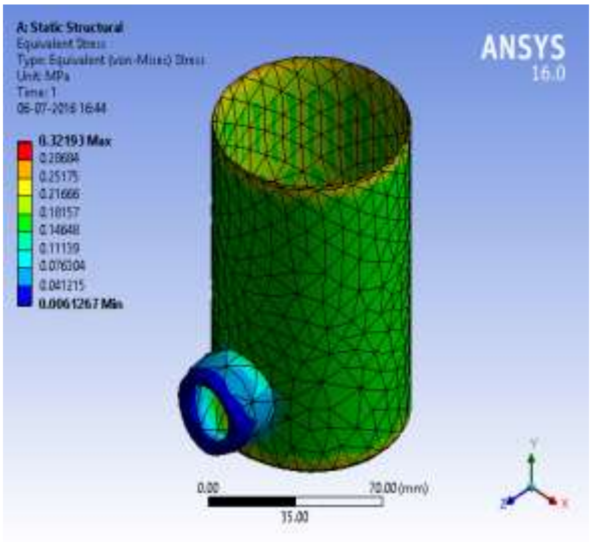

Fig -5: Static structural fixed support with vonmises stress

e)Comparison Of Actual And Theoretical Result

A detailed analysis is performed from 0 Hz to 300 Hz in the step of 50Hz.

These methods & boundary conditions are well validated & can be used for future analysis.

Table -1: Comparison of actual and theoretical (hoop stress) result of casing pipe

Part Name	**Maximum theoretical hoops stress N/mm²**	**Von-mises stress N/mm²**	**Maximum deformation mm**	**Result**
Casing pipe	8.1	0.307	2.12 E^{-6}	Safe

Table -2: Comparison of actual and theoretical (longitudinal) result of casing pipe

Part Name	**Maximum theoretical longitudinal stress N/mm²**	**Von-mises stress N/mm²**	**Maximum deformation mm**	**Result**
Casing pipe	4	0.307	1.15 E^{-5}	Safe

f) Hoop's Stress Due To Exhaust Gas Pressure

Diameter of casing pipe (d) = 81 mm

Thickness of casing pipe (t) = 1.5 mm

Maximum pressure induced in system due to exhaust gases (p) = 3 bar = 0.3 Mpa

$$fch = \frac{P \times d}{2t}$$

$$fch = \frac{0.3 \times 81}{2 \times 1.5}$$

fch = 8.1 N/mm^2

As $fc_h < fc_{act}$;

Hence casing pipe is safe.

g) Longitudinal Stress Due To Exhaust Gas Pressure

Due to exhaust gases, in system maximum pressure gets induced.

(p) = 3 bar = 0.3 Mpa

Diameter of casing pipe (d) = 81 mm

Thickness of casing pipe (t) = 1.5 mm

$$fcl = \frac{P \times d}{4t}$$

$$fcl = \frac{0.3 \times 81}{4 \times 1.5}$$

fcl= 4.05 N/mm²

As $fc_l < fc_{act}$;

Hence casing pipe is safe.

From above discussion it is clear that,

1. Maximum stress by theoretical method and Von-mises stress are well below the allowable limit, hence the casing is safe.
2. Casing shows negligible deformation under the action of system of forces.

3.2 Resonator Membrane

In all reactive muffler designs the resonating bracket can have an important effect. The resonating bracket is used for diversion of exhaust gases which falls directly on membrane. Due to direct attack of exhaust gases there is need to analyze membrane.

a) ANSYS Pre-Processor

The CAD model is then imported into ANSYS Mechanical APDL as a neutral file format. This model is then imported into ANSYS which can be seen as below.

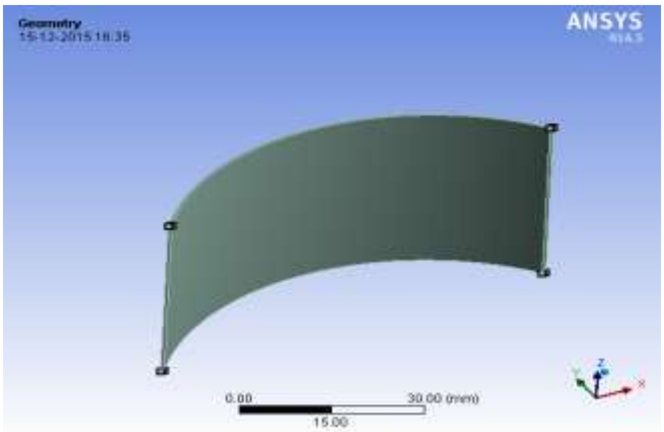

Fig -6: Geometry of resonating membrane

b) Selecting Mesh Element

For proper estimation of analysis, it is necessary to define proper element for this type of application. Apparently, ANSYS does have element that can suit for our type of applications.

c) Material Properties

Following are the properties of material .

Table -3: Material properties of brass

Material	Ultimate Tensile Strength(N/mm^2)	Yield Strength (N/mm^2)
Brass	580	410

d) Meshing

To include damping within the fluid as well as damping of sound absorbing material is the capability of element. To perform damped or unsymmetrical modal, full transient and harmonic method analysis, element with other 3-D structural element scan be used. The element is applicable to modal analyses when no structural motion.

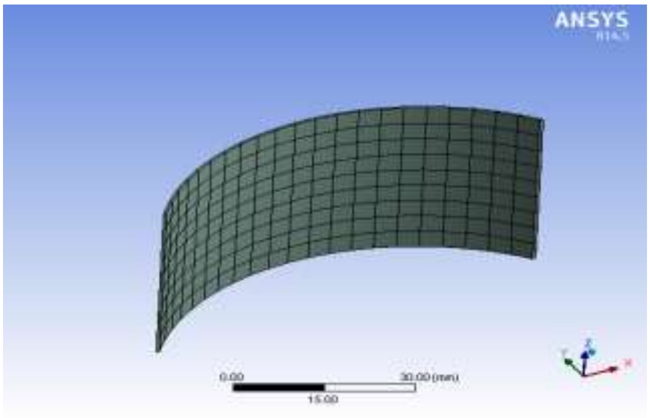

Fig -8: Meshing of resonating membrane

e) Boundary Conditions

For starting any analysis, it is always necessary to define the boundary condition so that the ANSYS can understand the nature of the problem we are about to solve otherwise it won't understand the problem properly. Hence, we need to define boundary conditions. First we will do definition of face on which exhaust gases bombardment takes place.

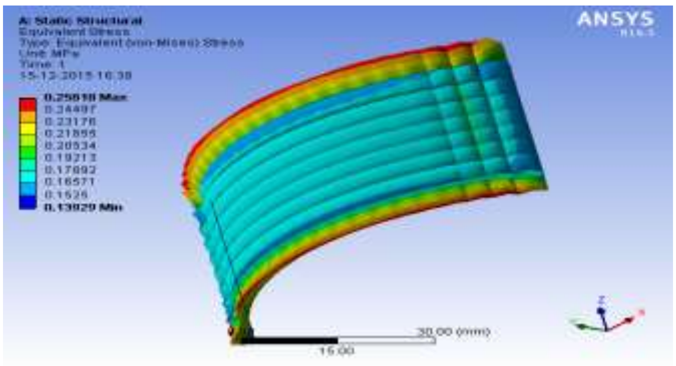

Fig -9: Static structural fixed support with von mises stress of resonating membrane

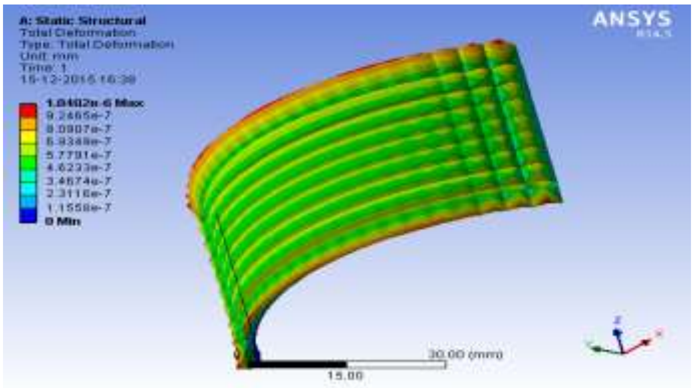

Fig -10: Static structural fixed support with total deformation of resonating membrane

f) Comparison of Theoretical And Actual Result

A detailed analysis is performed from 0 Hz to 300 Hz in the step of 50Hz.

These methods & boundary conditions are well validated & can be used for future analysis.

g) Detailed Mass Properties

Analysis calculated using accuracy of 0.99000

Information Units kg - mm

Density = 0.000007831 kg/mm^3

Volume = 1426.808 mm^3

Area = 5861.698 mm^2

Mass = 0.011172820 kg

$$\text{fs max} = \frac{\text{UTS}}{\text{FOS}}$$

$$\text{fs max} = \frac{800}{2}$$

$$= 400 \text{ N/mm}^2$$

Considering the pressure inside the resonator chamber = 0.3 Mpa

The force acting on the membrane = 0.3 x 10^6 x (5861 x 0.5) x10^{-6}

= 879 N

Thus maximum stress induced in membrane is given by,

$$\text{Stress} = \frac{\text{Force}}{\text{Area}}$$

$$\text{Maximum induced stress} = \frac{\text{Force}}{\text{projected area}}$$

$$= \frac{879}{70.9 \times 36}$$

= 0.344 N/mm^2

As the induced stress < maximum allowable stress;

Hence the resonator membrane is safe.

Table -3: Comparison of theoretical and actual result of resonating membrane

Part Name	Maximum theoretical stress N/mm^2	Von-mises stress N/mm^2	Maximum deformation Mm	Result
Resonating bracket	0.344	0.2518	1.04E-6	Safe

1. Maximum stress by theoretical method and Von-mises stress are well below the allowable limit; hence the resonating membrane is safe.
2. Resonating membrane shows negligible deformation under the action of system of pressure.

4. EXPERIMENTAL SET UP

Following process is used to conduct experiment

1. IC engine is started.
2. At no load condition to generate maximum rpm throttle is fully opened.
3. By using tachometer output pulley Speed of engine is measured.
4. By using noise meter, the exhaust noise is measured. Approximately 10% throttle is closed.
5. By using tachometer output pulley speed is measured.
6. Digital noise meter is used to measure muffler exhaust. In the same way readings are taken and tabulated.

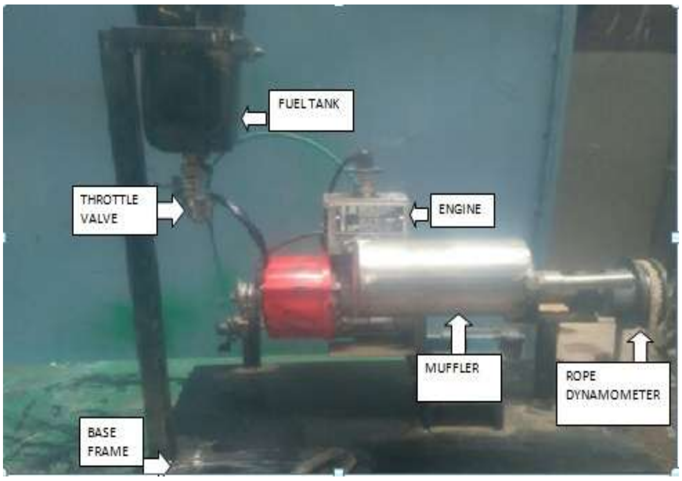

Fig -11:Experimental set up of muffler

5. RESULT

Data on fuel consumption and noise level were recorded.Fig.12 shows graph of load vs noise. It shows that with minimum value i.e. by applying min. Load 0.5 kg we get minimum noise (dba) i.e. 87.5 dba whereas in old muffler we get 112.4 dba. With maximum value i.e. by applying max. load 2.5 kg we get maximum noise (dba) i.e. 97.3 dba whereas 128 dba noise is observed in old muffler. From the graph it is concluded that as the load on engine increases noise level increases. Also as compared to old muffler we get maximum noise reduction in new muffler.

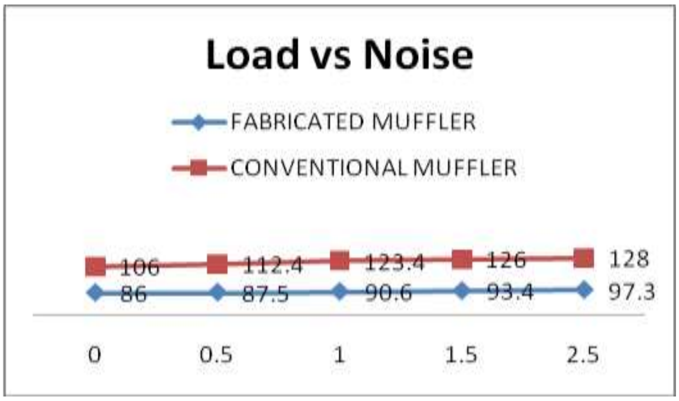

Chart -1: Graph of load (kg) vs noise of conventional & fabricated muffler.

Fig. 13 shows graph of load vs carbon monoxide (CO). It shows that with minimum value i.e. by applying min. Load 0.5 kg, we get minimum emission of co % i.e.0.88 and with maximum value i.e. by applying max. load 2.5 kg we get maximum emission of % co i.e. 1.23. From the graph it is concluded that as the load on engine increases % emission of carbon monoxide (co) increases. Also as compared to old muffler we get maximum carbon monoxide removal in new muffler.

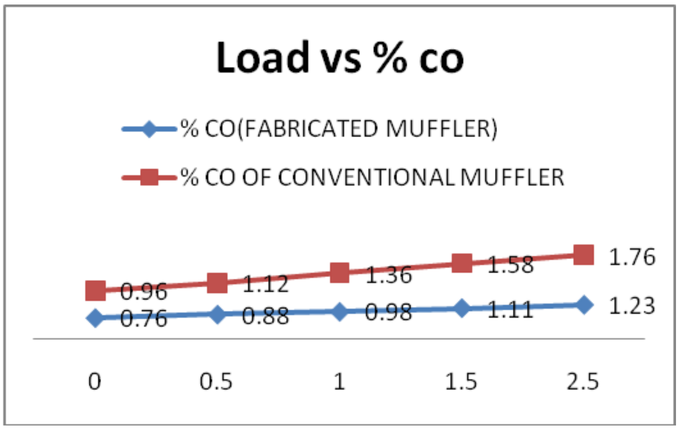

Chart -2: Graph of load (kg) vs % CO of conventional & fabricated muffler.

6. CONCLUSION

The model manufacturing is done based on design. The complete assembly is perfectly assembled as per the design. The analysis of geometric parameters of muffler is done. From the experiment it is concluded that maximum 11.61 % of noise reduction takes place. Also maximum pollution control gets possible by using charcoal layer as pollution control. This also shows that the project is practically implementable and has a wide scope in the field of automobile. The experimentation done on the muffler shows that it comes true to the expectation and did not fail.

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BIOGRAPHIES

Pooja Vishnu Lokhande received her M.E. in Mechanical (Design) Engg. From Savitribai Phule Pune University.