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EXHAUST DESIGN FOR GO-KART

ACOUSTICAL DESIGN AND TESTING WITH MATHEMATICAL MODELLING

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Abstract: Exhaust Systems for the vehicle are the most crucial system required in the transmission which follow IC engine trend. Concerning race car, the exhaust systems determine the performance along with the treatment of exhaust gases. Mufflers, catalytic convertors and resonators make up the system complete for treatment of exhaust gases. Exhaust gases norms getting strict all over the world makes the topic more interesting and important for the innovation and development. In this paper the exhaust system is designed using Volumetric Theory followed by Acoustic Theory specifically the free flow absorptive muffler. In order to optimize the engine performance and the sound limit, the free flow muffler is designed with minimum back pressure. Further modelled using design software Creo Parametric 1.0 and simulation carried by software Ansys (Fluent) and tested by Matlab validates the model. Thermal stress analysis carried in Ansys gives safe results. Mathematically modelled the design and verified with the simulation results are presented in the paper. Confining to the rule book of GKDC Season 6 the acoustic limit of 100 dB is achieved that further validates the Vehicle with Technical Inspection OK report.

***Keywords -** Absorptive muffler, acoustic limit, catalytic convertors, perforated tube, engine back pressure, free flow.*

I. INTRODUCTION

Go-Kart is a type of open, four-wheeled vehicle. Go-karts vary widely in speed and some can reach speeds exceeding 260kmph while recreation go-karts intended for the general public may be limited to lower speed. **American Art Ingels** is generally accepted as a Father of karting. It has generally low capacity engine (in our event it is restricted to 150cc) and suspension is not mandatory for go-karts.Go karts have specific systems as transmission, steering, brakes of which our area of focus is transmission system which is further divided into power train, intake and exhaust system. With our main concern of reducing exhaust noise and emissions the project is directed.

The exhaust system of an automobile consists of manifold, catalytic convertor and muffler connected with the tail pipe. Hot gases along with the sound waves are generated at the exhaust stroke are sent to the exhaust manifold through exhaust valve. Sound waves along with exhaust gases pass from exhaust manifold to catalytic convertor through a pipe. Due to partial combustion the gases entering the catalytic convertor consist of a mixture of CO, HC and NO_x which are harmful to the environment. Gases first enter one of the ceramic blocks of a three-way catalytic convertor and heat it up causing catalyst to react with toxic gases which further continues in the next ceramic block. The exhaust gases coming out of the CATCON (Catalytic Convertor) are less toxic containing mixture of CO_2, N_2, H_2O (vapour). These gases are now less toxic sound waves which are then passed into the muffler. Muffler is an expansion chamber where sound waves can be absorbed or cancelled or both together. Depending on the configuration and working principle mufflers are classified into reactive, absorptive and reactive absorptive type of muffling chambers. In reactive mufflers the principle of destructive interference is used while in absorptive mufflers the sound waves are absorbed by the insulating material which then converts incident sound energy into heat. Various insulators can be used as according to the requirement of the system. Approaching towards more efficient sound cancellation additional component in the expansion chamber can be equipped called as Helmholtz resonator. Finally, the exhaust gases consisting of less harmful gases along with considerably low sound waves move out of tail pipe into the atmosphere.

Along with the main purpose of the exhaust system serves it is to be well tested for the performance of the vehicle with parameters such as back pressure or back fire. Depending upon the requirement of GO KART and the rules bonded

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the exhaust system is designed with the components including exhaust pipe, muffler and tail pipe. According to the requirement of the vehicle with the study and analytical results absorptive type of muffler is found most suitable. Targeted transmission loss for the muffler is 98 dB.

With the calculations based on volume theory of muffler with respect to engine (BAJAJ PULSAR 150 CC old model) used in the vehicle the design is formulated and cad models are designed in modelling software Catia and Creo Parametric 1.0 and analysis performed in ANSYS (fluent) along with the analytical techniques. Further with the experimental validation with the manufactured model system is installed in kart which is then tested for performance of vehicle.

II. SELECTION OF MUFFLER TYPE FOR THE SYSTEM

GO-KARTS use four stroke or two stroke internal combustion engines, air cooled or water cooled engines for their operations. According to specifications confining to the rule book, Bajaj Pulsar 150 Engine is selected for the Kart Power Train. The maximum engine power 13.5 bhp at 8500 rpm, the types of mufflers are judged from Absorptive type, Reactive Type and Combined Absorptive and Reactive Type of mufflers. Absorptive muffler gives less back pressure reducing the chances of back firing in engines and used for low capacity low power engines without baffles is selected for the exhaust system of GO-KART.

Components of exhaust system

Absorptive mufflers consist of shell that is the outer cover of the expansion chamber, the packing porous material and the perforated tube creating the hollow cavity duct in the chamber. The packing material is fixed inside the gap between perforated tube and external shell.

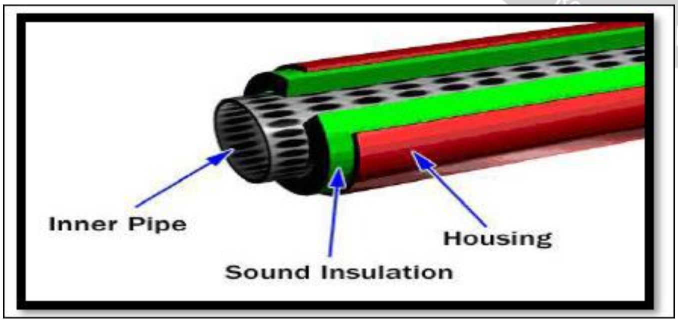

Fig 1: Absorptive type of muffler

2.1 *Housing (shell):* Shell performs the function of external cover which has to be high in strength structurally and thermal strength to withstand high temperature of about 300◦C to 500◦C with the strength capacities and availability criteria Mild steel and Stainless steel-304 (2 mm thickness) is selected for the manufacturing of the component.

2.2. *Porous material:* [1] There are three types of porous materials used in exhaust muffler. They are as following:

- Glass wool
- Ceramic wool
- Steel wool

2.2.1 *Glass wool :-* Glass wool is preferable porous medium because it is relatively inactive chemically, relatively non hygroscopic, its fibers are strong and elastic, making in bulk a resilient mass that will' retain its characteristics; and the fibers can be made in an almost unlimited range of sizes. A wide range of permeability is therefore obtainable that is absolutely essential for latitude in the design of flow meters. In addition, the wool is inexpensive and easy to procure.

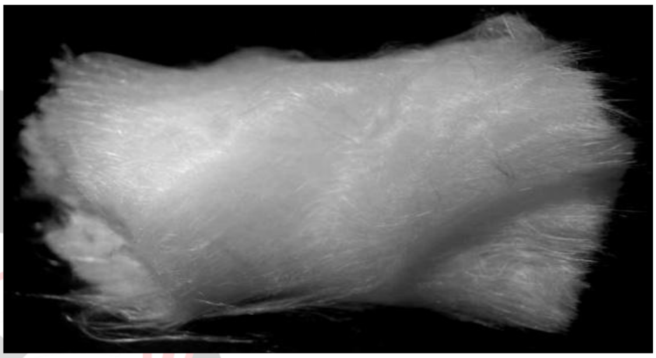

Fig 2: Glass wool

2.2.2. *Ceramic wool:* Ceramic fibre is a lightweight insulating product. It has low thermal mass which means that it does not retain heat, low thermal conductivity and is an extremely effective insulation material. Its high thermal shock resistance makes it suitable for applications where traditional refractories cannot be used. So called Refractory Ceramic Fibre is made from high purity alumino-silicate materials. Ceramic fiber is produced by melting these products in an electric arc furnace, a stream is poured and cooled to form the fibre strands from which the ceramic fibre products are produced.

Fig 3: Ceramic Wool

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2.2.3 Steel Wool: Steel wool, also known as iron wool, wire wool, steel wire or wire sponge, is a bundle of very fine and flexible sharp-edged steel filaments. It was described as a new product in 1896. It is used as an abrasive in finishing and repair work for polishing wood or metal objects, cleaning household cookware, cleaning windows, and sanding surfaces. Steel wool is made from low-carbon steel in a process similar to broaching, where a heavy steel wire is pulled through a toothed die that removes thin, sharp, wire shavings.

Fig 4: Steel Wool

From the above three materials ceramic wool is chosen for manufacturing as it has more life than the glass wool. Glass wool has a tendency to deteriorate under prolonged exposure to heat whereas ceramic wool lasts longer. Also Glass wools maximum service temperature is less than 500^{o}C and much less than that of ceramic wool which is about 950 ^{o}C. And on the other hand steel wool is extreme by our requirement as it has strength nearly equal to ceramic wool but it is expensive.

2.3. *Perforated steel tube:* Perforation on the sheet allows the sound waves to reach the absorbing material. This tube is manufactured of the same material as that of housing shell. SS-304 is used in the perforated tube with the same properties.

Figure 5: Perforated sheet

III. Design of Exhaust System [8]

A. Design of housing of muffler

Designing the muffler for Go-Kart or any of the automobile can be achieved by various theories. In this project we have focused on the volume-based theory for the expansion chamber followed by Acoustical theory and then verified with the thermal and fluid pressure computational analysis. With these additional structural mathematical modelling also helps in finalizing the model of muffler and the components in the system. With the volume theory the design is initiated and iterations are carried out which are then filtered by acoustical theory designing procedure.

3.1. Volume Theory*:* Volume of expansion chamber has to the multiple of swept volume of engine. This will ensure the expansion of flue gases in the chamber reducing its pressure and sound waves are absorbed by absorbing material at the greater surface area reducing the sound intensity at the outlet of the muffler. [2]

Generalized equation can be given as:

$V_m = F*V_s$

Where,

V_m= Volume of muffler,

V_s = Swept Volume of engine,

F = Factor (multiple of swept volume)

Factor to be multiplied to swept volume of engine is to be selected from 10 to 24. Selection is based on the space availability to accommodate the muffler. Since exhaust system is the last part of the transmission department which has to be adjusted with respect to the space and structure of rest of the components of the systems in the vehicle. [2]

Step1: Input Data:

Bore (D): 57 mm

Stroke (L): 56.4 mm

No. of cylinders: 1

Engine Power: 13.5 bhp

Max. RPM: 8500 rpm

Step 2: Volume of Muffler

Swept volume of engine,

$$V_s = \frac{\pi * L * D^2}{4}$$

V_s = 143.9 cc

Assuming the values of factor, below iterations were carried out:

$V_m = F*V_s$

Iteration 1: Factor 20, V_m= 2878.0 cc

Iteration 2: Factor 16, V_m= 2302.4 cc

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Iteration 3: Factor 12, V_m= 1726.8 cc

Depending on the space availability we proceed with design models having expansion factors 16 and 12 for further analysis. Expansion chambers can be of varied shapes, we select a combination of frustum and cylinder. This is to utilize the maximum available space with optimum results concerned with volume-based design followed by Acoustic Design. [9]

Step 3: Internal configuration

Assuming total length of the muffler to be 0.3 m, based on space available.

Length of frustum: 0.1 m and length of cylinder: 0.2 m

$$Vm = \pi R^2 0.2 + \frac{\pi * 0.1[R^2 + r^2 + rR]}{3} \quad .... (1)$$

Substituting the values in the equation above:

Iteration 1: V_m = 2302.4 cc

we get: R = 0.0544 m

Iteration 2: V_m = 1726.8 cc

we get: R = 0.0468 m

3.2 Acoustic Theory: [4] As confirming to the rule book of "Go Kart Design Challenge Season-6" the acoustical performance is to be considered in the design of expansion chamber. Given that sound decibel level not to be exceeded than 100 dB. From the Study of literature through BAJAJ PULSAR 150 cc engines specifications and visiting company's service stations, we could get the information of engines exhaust decibel level of about 105-110 db.

The targeted transmission loss is from 5 to 10 dB.

Using the two Iterations from Volume Theory we calculate transmission loss for the two chambers.

Transmission loss (TL) is defined as difference between power incident on a duct acoustic device and that transmitted downstream into an anechoic termination. TL is independent of source and presumes an anechoic termination at the downstream end. [6]

4 Pole Matrix:

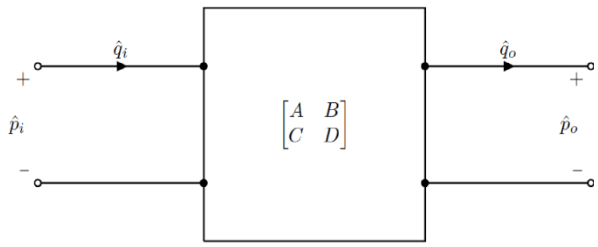

Fig. 6: Four Pole matrix for expansion chamber

$$\begin{pmatrix} P_i \\ q_i \end{pmatrix} = (A\ B\ C\ D) \begin{pmatrix} P_o \\ q_o \end{pmatrix} \quad ......(2)$$

Where,

P_i, P_o are sound Pressures at input and output

q_i, q_o are volume Velocities at input and output

A, B, C and D are complex numbers

$$TL = 10Log_{10}\left[\frac{1}{4}\left|A + B\frac{S}{\rho c} + C\frac{\rho c}{S} + D\right|^2\right] \quad ......(3)$$

Where,

S is an area of cross section at inlet and outlet

P is media density

c is sound velocity

$$(A\ B\ C\ D) = \begin{pmatrix} cos\ cos\ kL & j\frac{\rho c}{S_2} sin\ sin\ kL \\ j\frac{S_2}{\rho c} sin\ sin\ kL & cos\ cos\ kL \end{pmatrix} \quad ......(4)$$

Substituting in the above equation we get,

$$TL = 10Log_{10}\left[\frac{1}{4}\left|cos\ cos\ kL + j\frac{\rho c}{S_2} sin\ sin\ kL\ \frac{S}{\rho c} + j\frac{S_2}{\rho c} sin\ sin\ kL\ \frac{\rho c}{S} + cos\ cos\ kL\right|^2\right] \quad ......(5)$$

Where,

h = ratio of area of cross section

$$h = \frac{S_1}{S_2} \quad ....(6)$$

L = length of chamber

k = wave number

$$k = \frac{w}{c} \quad ......(7)$$

w = sound energy density

c = speed of sound

Assuming the section at the inlet of the muffler as 28 mm inner diameter and 32 mm Outer Diameter pipe connected to the expansion chamber the following iterations are for Cylindrical part of muffler, we apply the acoustic theory to get the transmission loss as below:

Iteration 1: Dimensions are as follows

Diameter = 0.10886 m, Length = 0.3 m

S1 = 615.7521 mm2, S2 = 9307.36 mm2, H=0.06615

w=109200, c=520 at 400◦C, k=210

Therefore, TL= 9.3086 dB

Iteration 2: Dimensions are as follows

Diameter: 0.09369 m, Length: 0.3 m

S1 = 615.7521 mm2, S2 = 6894.08 mm2, H= 0.08931

w = 109200, c = 520 at 400◦C, k = 210

Therefore, TL= 7.4431 dB

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Iteration 1 gives better transmission loss than that of iteration 2 according to Acoustical analytical performance which also satisfies the volume theory of design. Hence Iteration 1 is finalized with the dimensions of cylinder of length 300 mm and diameter 110 mm. The Cad Model is designed in Designing software Creo Parametric 1.0 and is represented as:

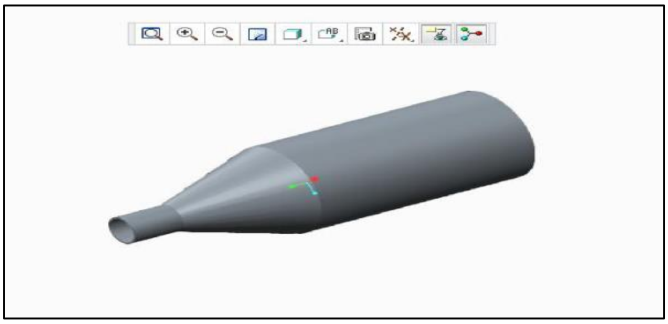

Fig. 7: CAD model of Muffler

B. Design of Perforated Tubes

[2] Perforated tube is the stainless steel perforated plate of material same as that of housing rolled to form a cylindrical tube. This tube is fixed inside the expansion chamber concentric with it. The perforations in the plate are circular holes. These holes are to be drilled or punched in the plate. Diameter of the perforation is given by the empirical relation as:

$d_1 = \frac{1.29}{\sqrt{N}}$ ……(8)

Where, d1 is diameter of perforation

$\sqrt{N}$ is Maximum Frequency in RPM

Input: Maximum RPM = 9000, d_1= 13mm

Smaller diameter of the tube is 35 mm and larger diameter of tube is 65 mm length same as that of housing 300 mm with thickness of 2 mm. Calculating number of holes in the plate 300 mm*100 mm.

Number of holes in the plate is 330.Cad Model of the Perforated Tube with design dimensions is given below:

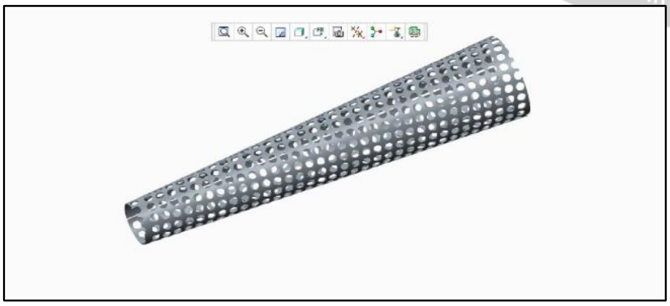

Fig. 8: CAD model of perforated tube

Surface Area of Plain sheet is,

Dimension = 300mm*110mm

Surface area = 33000mm^2

Area of perforation of holes is,

Area of holes = (area of one hole) *(no. of holes)

Area of holes (Theoretical) = 15981.6

Area of perforation = 0.478

According to the theoretical calculations the diameter of the hole in the perforated sheet is 13 mm.But while manufacturing the available standard diameters of the hole are 3 mm and 6 mm, among which we have selected the larger diameter that is 6 mm. By selecting this diameter, we have increased the number of hole by keeping the area of perforation of holes same as that of theoretical value.

Calculation for number of holes (Practical):

Area of holes (theoretical) = Area of holes (Practical)

15918.6 = (π * 3^2) * No of holes

Therefore, Number of holes = 563.

C. Porous Material (Ceramic Wool):

Ceramic wool is selected material for the muffler which is to be fixed between housing of expansion chamber and the perforated tube. Average thickness of ceramic wool is determined by:

$$t = \frac{D - d}{2} \qquad \ldots\ldots(9)$$

Where, t = thickness of ceramic wool

D = cylinder diameter of expansion chamber = 110 mm

d = maximum diameter of perforated tube = 65 mm

Therefore, t = 22.5 mm

D. Exhaust Pipe:

Exhaust pipe is the connection between exhaust port of the engine and the muffler. The literature study from the research papers as well as the industrial design information from the service stations directs the diameter of the exhaust pipe to be equal or just greater than the exhaust port diameter of the engine. The length of the pipe is decided by volume theory for exhaust pipe and deciding the mounting points of muffler from the engine. Since the engine mount in go karts can be side mount or the rear mount, our vehicle has side mounted engine.

Diameter of pipe:- ID: 28 mm , OD: 32 mm, Length of pipe: 630 mm

The cad model is prepared using Creo Parametric 1.0 and viewed as below:

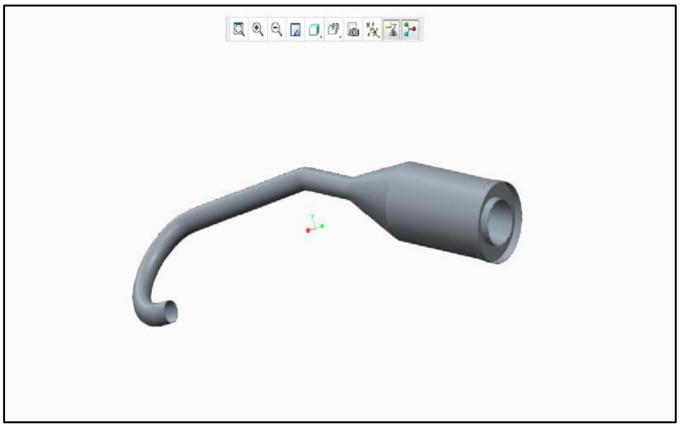

Fig. 9: CAD model of exhaust system

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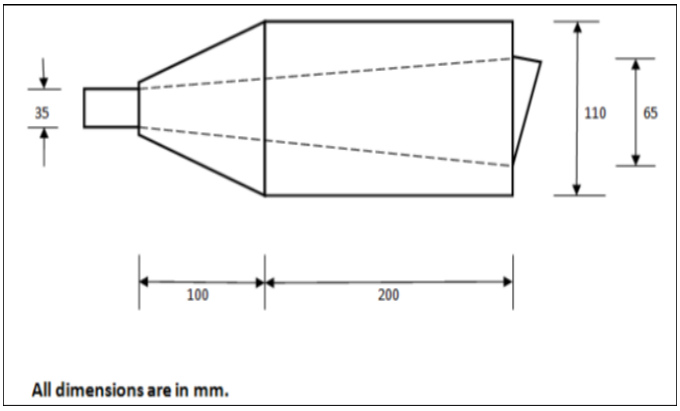

Fig. 10: 2D of Muffler model

IV. ANALYSIS OF CAD MODEL

The model is analysed using Ansys simulation software for Computational Fluid Dynamics and Thermal Analysis. [7]

4.1 CFD (Pressure Distribution): Here the model is judged for back pressure in the system. Software used is Ansys R15. We can perform various analyses using different solvers. Since the pressure distribution is to be determined, the available suitable solver is Fluent. From the information studied the pressure at the exhaust port is known and the corresponding input parameters are provided for the analysis. Pressure distribution usually is to be judged through the exhaust pipe. Input Boundary Conditions:

Inlet Pressure: 2 bar (gauge),
Outlet Pressure: 1.01 bar (absolute)

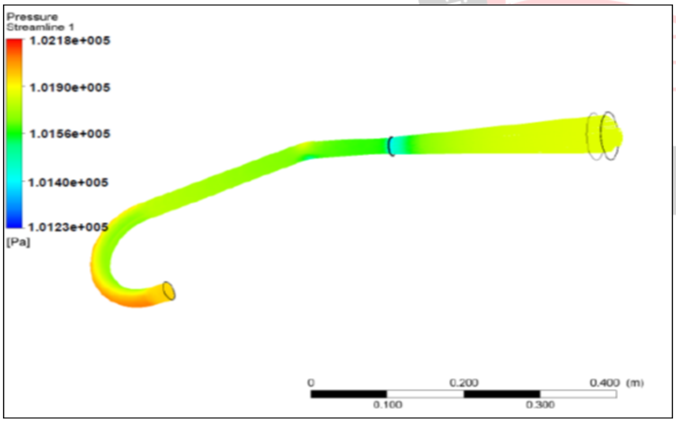

Fig. 11: Pressure distribution

Results:
Maximum Pressure: 1.0218 bar
Minimum Pressure: 1.0123 bar

Since the pressure in the system is greater than atmospheric pressure through the muffler there won't be back force acting in the exhaust pipe. At the end section after the muffler pressure is lower than atmospheric pressure by 125 Pa which can create a back pressure in the muffler. Since muffler is the expansion chamber with greater diameter than that of the pipe it causes the back pressure gages to expand. Hence it is not affecting the performance of the engine without causing any back firing.

4.2 CFD (Temperature Distribution):

This is carried out to get the temperatures at different points throughout the system which can also be used in variant thermal analysis.

Input Boundary Conditions:
Temperature at inlet of system: 650◦C, Temperature at outlet: 25◦C

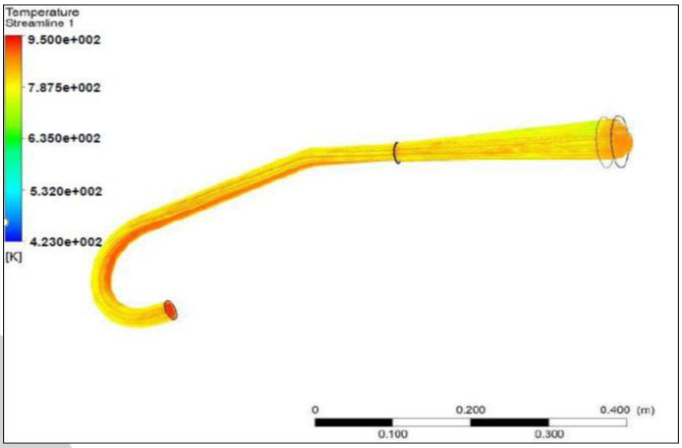

Fig 12: Temperature Distribution

Results:
Maximum Temperature: 650◦C
Minimum Temperature: 423◦C

The results from the temperature streamline are also used for the thermal analysis of the system which gives the deformation of the muffler thermally. Here the heat dissipation is observed is more and giving better results thermally.

4.3 CFD (Velocity Distribution):

This model is verified through velocity distribution also which will give the flow characteristics clearly through the pipe as well as the muffler.

Analysis: Velocity distribution,
Software: Ansys, Solver: Fluent

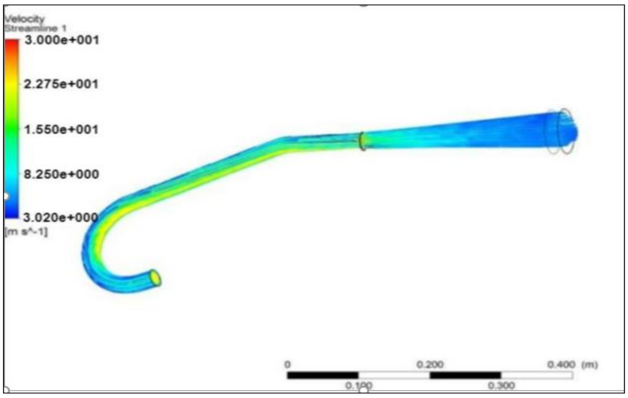

Fig. 13: Velocity Distribution

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Results:

Maximum Velocity: 30.00 m/s

Minimum Velocity: 3.02 m/s

Velocity distribution helps in understanding the flow of flue gases through the duct. The velocity reduces in muffler as the flue gases expand and the energy is absorbed by Ceramic wool. Hence reducing the speed in the portion after muffler too. As Maximum velocity is 30.00 m/s the flue gases moves through the duct faster and does not cause back pressure and chances of back firing of engine is reduced.

From the above illustrations of analysis, the model is safe through Computational Fluid Dynamics in all three analyses of pressure, temperature and velocity distribution streamlines.

4.4. Thermal Analysis:

Thermal analysis gives the deformation and stress induced in the model due to temperature of the system. Since the temperature distribution is known from CFD analysis, the transient flow analysis with varying temperatures in the system can be judged for deformation.

Analysis: Transient Thermal Analysis (Static structural),

Software: Ansys R18, Solver: Thermal

Input Data: Temperature at inlet of Pipe: 650◦C, Temperature at inlet of Muffler: 355◦C

Temperature at outlet: 25◦C,

Film Coefficient: 970.84 W/mK

4.4.1.Deformation:

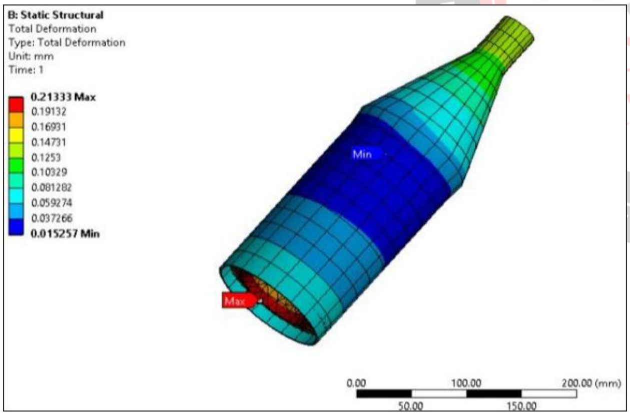

Fig. 14: Deformation

Results:

Maximum Deformation: 0.2133 mm

The deformation can be as viewed maximum at the exhaust pipe. Since the deformation is within limits and does not hinder working of any other component of the system the system is said to be safe in terms of deflection. This result is also further analysed analytically with Finite Element Analysis (Dynamic Analysis).

4.4.2 Stress (Von Misses):

Results:

Maximum Stress: 167.28 MPa

Tensile Strength (yield): 215 MPa

$$\textit{Factor of Saftey} = \frac{\textit{tensile strength of SS303}}{\textit{max. stress occured in model}}$$

$$\textit{Factor of Saftey} = \frac{415}{325.1}$$

$$\textit{Factor of Saftey} = 1.276$$

The factor of safety of the design from above analysis is 1.285.

From the above analyses the components are observed to be safe and hence are finalized for manufacturing. The system is also analysed analytically as the finite element Analysis and mathematically modelled.

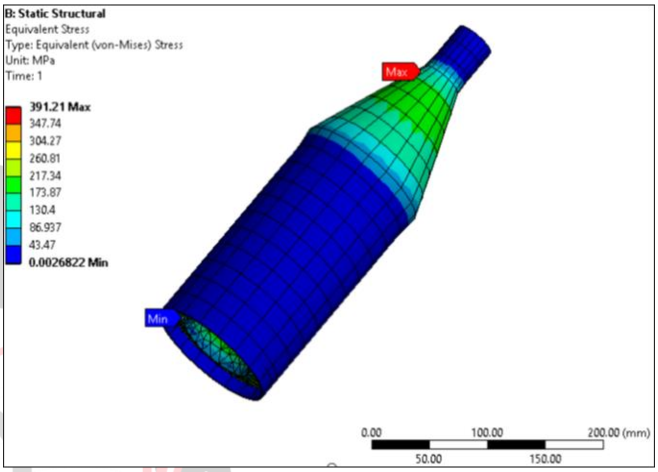

Fig. 15: Von Misses Stress

V. MATHEMATICAL MODELLING OF EXHAUST SYSTEM

The system is classified under semi-definite systems also called as unrestrained or degenerative systems. These systems are based on the considerations that they are not attached to any stationary frame. Simple example can be Railway Wagons. [5]

To calculate displacements of engine and exhaust due to force from engine:

Numerical values required:

m1:35 kg, m2: 1.5 kg

k1: stiffness of engine mounts,

k2: stiffness of exhaust pipe,

k3: stiffness of muffler mounts

F10=force by engine,

F20=0 N

We know,

$T = F_0 * r$ …….(10)

Where,

Torque, T = 253 Nm, Radius, r= 5.5 inch, F_0= 1811.0236 N

Force is given by,

$F = F_0 e^{iwt}$ …….(11)

Where,

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Forcing Frequency,
w= 942.47 rad/s
Stiffness Constant (k):
For engine mounts:Number of mounts= 6

For Mount 1 and 2,
Length= 3.5 inch
k_1=k_2= 7266.325 N/mm
For Mount 3 and 4,
Length= 4.8 inch
K_3=k4= 2817.05 N/mm
For Mount 5 and 6,
Length= 6.0 inch
K_5=k_6= 1442.33 N/mm

Equivalent Stiffness K_{eq}= 23051.42 N/mm

For muffler mounts:
Number of mounts= 2
For Mount 1 and 2,
Length = 2.0 inch
k_1=k_2= 40882.96 N/mm

Equivalent Stiffness K_{eq}= 81765.8 N/mm

Exhaust Pipe: K_{pipe} = 58.816 N/mm
Now, $m_{11} = m_1$ = 35 kg, $m_{12} = m_{21}$ = 0 kg, m_{22} = m2 = 1.5 kg
Also, $k_{11} = k_1+k_2$= $2.311*10^7$ N/m, k_{12} = -58816 N/m,
$k_{22} = k_3+k_2$ = $8.182462*10^7$ N/m
Impedance can be calculated as:

$$Z_{rs(iw)} = -w^2m_{rs} + iwc_{rs} + k_{rs} \quad \text{……..(12)}$$

$Z_{11} = -79.7873*10^5$, Z_{12} = -58816, $Z_{22} = 5.073588*10^7$
The displacement is given by:
Engine:

$$X_{1(iw)} = \frac{F_{10}Z_{22(iw)} - Z_{12(iw)}F_{20}}{Z_{11(iw)}Z_{22(iw)} - Z_{12(iw)}^2} \quad \text{…….(13)}$$

$X_{1(iw)}$= 0.2268 mm
Muffler:

$$X_{2(iw)} = \frac{-F_{10}Z_{12(iw)} - Z_{11(iw)}F_{20}}{Z_{11(iw)}Z_{22(iw)} - Z_{12(iw)}^2} \quad \text{…….(14)}$$

$X_{2(iw)}$= $2.631*10^{-4}$ mm

The displacement of Engine is 0.2268 mm and that of muffler is $2.63*10^{-4}$ mm. These deformations do not disturb the system and are in safe limits. The model is mathematically represented and the results are obtained in the form of deformations. Also these deformation results are the same as analysis performed in Ansys (Static Structural).

VI. MANUFACTURING OF MUFFLER

Material selection for manufacturing of exhaust components is already discussed in the previous chapter. Similar to the design procedure manufacturing of the system is segmented into two parts that is the manufacturing of muffler and the manufacturing of exhaust pipe. The procedure followed is as stated below

6.1. Manufacturing of Muffler: Muffler constitutes of three components which are manufactured individually and then assembled as the complete product. It involves the manufacturing of housing, perforated tube and the glass wool insertion into the assembled product them.

6.1.1. Housing of Expansion chamber:

Material used: SS-304 Sheet

Dimensions of Raw material: 500mm*500mm

Dimension of Processed Material: 400mm*255mm
Dimensions of Finished component:
Length: 300 mm, Diameter: max -110mm , min - 35 mm according to the shape
Manufacturing Processes: Cutting, Folding to form cylinder and fastening to join the metal sheets.

6.1.2. Perforated tube:

Material used: SS-304 Sheet
Dimensions of Raw material: 500mm*500mm
Dimension of Processed Material: 400mm*115mm
Dimensions of Finished component:
Length: 300 mm, Diameter: 35mm
Manufacturing Processes: Cutting, Punching, Folding to form cylinder and fastening to join the metal sheets.

6.1.3. Ceramic Wool:

Material used: Corning Ceramic Wool
The material is filled into the gap between the housing and the perforated tube after assembling the two. The ends of the housing are fastened and closed keeping the inlet and outlet pipes with a diameter of 28 mm open to further connect it with exhaust pipe.
The assembled muffler with glass wool and perforated tube inside the housing is viewed as below:

Fig. 16: Manufactured muffler

6.2. Manufacturing of Exhaust Pipe:
Material: MS 409L Dimensions of finished product: 630 mm.
Manufacturing Process: Cutting, Bending, welding. The pipe is bent in with the angle of 180◦ to obtain the required dimensions.It is then welded with the

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flange so that it can be further fastened to engines exhaust port.

These two components muffler and the exhaust pipe are joined by welding and connected to the engine and muffler mounts to record the observations for testing of the components.

VII. ACOUSTICAL TESTING OF EXHAUST SYSTEM. [3]

Testing of manufactured system is conducted in terms of acoustics. The Sound waves after firing the engine are recorded in the .wav file format and this input is provided to the programming software MATLAB with the valid set of codes. The sound file is judged for Sound Power level, Sound Pressure level, Wave number and Sound Energy. Following are the Codes for the Testing of Sound file:

7.1. Sound Power: Here key function used to obtain power of sound wave is pwelch (). This function provides power of Sound File Stored with an extension .wav. The signal file is first sampled based on the length of signal which then yields power.

Code for Sound power is as follows:

S=audioread('muffler.wav');
{y,fs}=audioread('muffler.wav');
Pxx=pwelch(y);
Disp(Pxx)

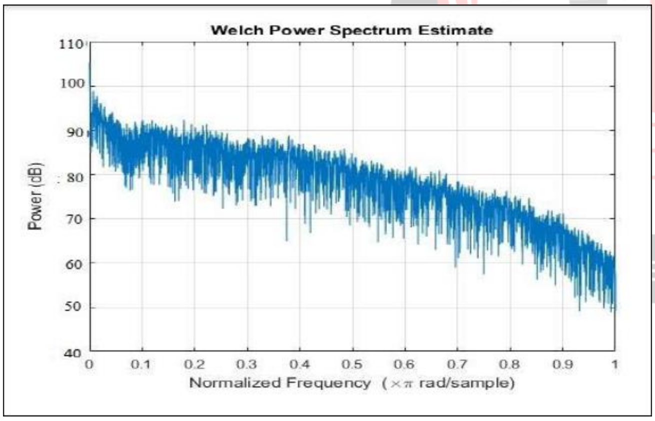

Fig. 17: Power Spectrum for Sound power

7.2. Sound Pressure: Sound Pressure Level Code also follows the same basic program for audio file (.wav) using function audioread() and further analysed for pressure level using function SPL(). The audio file is first sampled discretely which is worked for Sound Pressure Level Function SPL. Plot for SPL is generated as SPL (dB) against time (sec). Code for sound pressure level is given as:

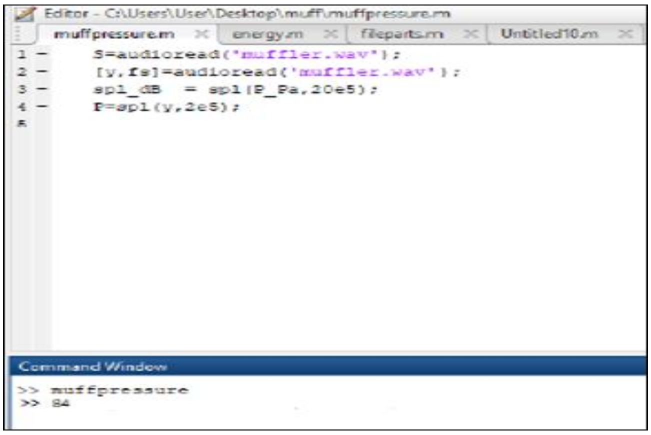

Fig.18: Sound pressure code and results

7.3. Sound Energy: Sound energy of the audio file is obtained using function abs() which is then modified with length of samples to get Average Sound Energy. Code for sound Energy is given as:

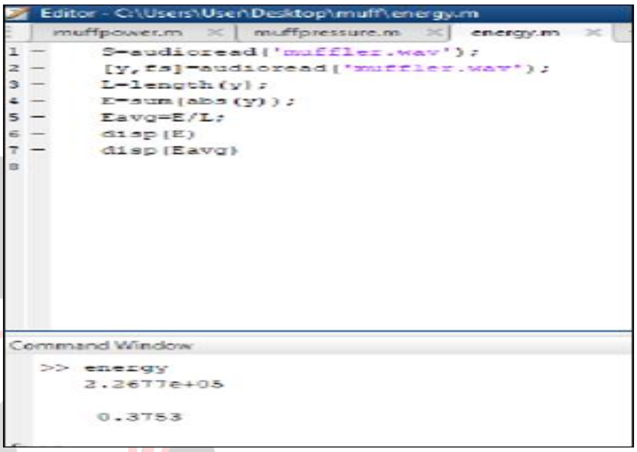

Fig. 19: Sound energy code and results

VIII. RESULTS AND CONCLUSIONS

Analysis Results

The designed model was analyzed for CFD, Static Structural and FEA using both Software Simulations and analytically. Mathematical modeling including FEA for Exhaust System is performed and the behavior of the system is predicted.

1. **CFD (Computational Fluid Dynamics)**
   Pressure:
   Maximum: 1.0218 bar
   Minimum: 1.0123 bar
   Temperature:
   Maximum: 650°C
   Minimum: 423°C
   Velocity:
   Maximum: 30.00 m/s
   Minimum: 3.02 m/s
2. **Static Structural (Thermal)**
   Maximum Displacement: 0.2133 mm
   Maximum Stress (Von Misses): 167.28 Mpa
   Factor of Safety: 1.276
3. **FEA (Finite Element Analysis)**
   Displacement:

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Engine: 0.2268 mm

Muffler: $2.631*10^{-4}$ mm

Conclusions

1. Exhaust System for GO KART is designed successfully based on two theories and analysed for its performances using CAE tools which is then manufactured selecting best material and design.
2. This design process gives transmission loss of 9.3 dB at optimal design parameters, which is satisfactory and not compromising engine performance.
3. Analysis performed includes Thermal, Structural and Acoustical tools optimizing variables confirming to the objectives from the rule book of GKDC.
4. The system is mathematically modelled using FEA (Vibrations) for the entire Exhaust System for year 2018-19 with completion of testing.
5. The system satisfies the requirement of sound limit within 98 dB as tested results give 84 dB as emitting Sound Level from the tail pipe of exhaust.
6. This system model is used by team STALLION KARTING and has also cleared Technical Inspection in GKDC-6 event.

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REFERENCES

[1] Absorption Materials Used In Muffler A Review, UjjalKalita, AbhijeetPratap, Sushil Kumar, 2015, ISSN 2348-7593

[2] A Practical Approach towards Muffler Design, Development and Prototype Validation by Shital Shah Defiance Technologies Ltd, Chennai Saisankaranarayana K, Kalyankumar S. Hatti Ashok Leyland Technical Centre, Chennai.

[3] Acoustic Performance Design of Automotive Muffler by Asutosh Prasad and Raj C Thiagarajan (ATOA Scientific Technologies Pvt Ltd, 204).

[4] Optimal topology of reactive muffler achieving target transmission loss values: Design and experiment by Jin Woo Lee

[5] Design Analysis and Testing of Silencer (1Mohit Juneja, 2Dilip Verma, 3 Anoop Singh Chauhan, 4 Shivam Pathak, 5Mohit Yadav, 6Ashish Gupta)

[6] Transmission Loss (Duct Acoustics)

https://en.wikipedia.org/wiki/Transmission_loss_(duct_acoustics)

[7] Design and Analysis of an Automobile Exhaust Muffler

P. Srinivas*, Venkata Ramesh Mamilla, G. Lakshmi Narayana Rao, Sowdager Moin Ahmed

[8] General Design principles for an Automotive muffler, Potente Daniel, Day Design Pty Ltd, Acoustical Consultants, Sydneym NSW.

[9] Exhaust System Muffler Volume Optimization of Light Commercial Vehicle Using CFD Simulation, C.P. Om Ariara Guhan, G. Arthanareeswaran, K.N. Varadarajan, S. Krishnan

 DOI : 10.35291/2454-9150.2021.0103