Study On Noise Attenuation Of Multi-Cylinder Diesel Engine With Existing And Modified Muffler

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ABSTRACT

Man's desire for pollution free atmosphere needs control of air pollution and noise pollution. The principal sources of noise in automotive engines are intake noise, radiator noise, combustion noise, exhaust noise etc. Out of these exhaust noise is predominant and it is to be controlled. Noise pollution affects human beings physiologically and psychologically. The cardiac patient may get cardiac arrest due to excessive dose of noise for a longer period of time.

In this paper one reactive muffler for a multi-cylinder diesel engine is designed and modified. More attenuation is given by making some changes in its configurations.

The Bond graph technique has been applied for the analytical results of the muffler. The modeling of acoustics and other systems are easily and logically achieved through BOND GRAPH. Bond graph is invented by Paynter and is a method of representation of physical system by means of symbols and lines, identifying power flow paths and lumped parameter elements of resistance, capacitance and inductance.

The Bond graph model is created by taking wave propagation in acoustic material into consideration. The analysis of Bond Graph model was carried out by using software COSMO-KGP. These results were compared with the experimental results and are found to be in close agreement.

KEYWORD

Bond Graph, Reactive Muffler and Transformer

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NOMENCLATURE

BSFC	Brake Specific Fuel Consumption
C	Compliance
db	Decibel
e	Effort
f	Frequency
f_1	Flow
GY	Gyrator
I	Inertance
P	Parallel Junction
S	Series junction
SE	Source of Effort
SF	Source Flow
SF1	Mass flow rate of exhaust gas measured by activated C element
SPL	Sound Pressure Level
TF	Transformer
ω	Angular Velocity
r	Resistance
t	Time

INTRODUCTION

A designer of engineering system is often perplexed when he or she embarks on designing a system, which resides in multi energy domains, which may have considerable complexities. He or she consults various domains' experts. However putting their expertise together to render a system model turns out to be even more baffling. Therefore a need for unified approach to system modeling and dynamics is deeply felt. In the present day multi disciplinary research activities, such situations are common. A programmatic and unified approach to engineering system analysis and design is the bond graph.

WHAT IS BOND GRAPH?

Bond graphs[1,2,3] are pictorial representations of the essential dynamics of physical system, which occur through exchange of power amongst the basic element of the system, and its environment. Power being the common currency exchange, interactions in several energy domains can be represented in a unified manner. Complex physical ideas may be represented by modelers and designers with extreme ease. Models can be quickly synthesized and easily modified making it a powerful tool for system synthesis and consolidation of innovative ideas immensely reducing the stages and the cost of prototyping. The entire process is algorithmic and extremely suitable for implementation on computing machines.

SOME BASIC BOND GRAPH ELEMENTS

In bond graph one need to recognize only four basic variables effort (e), flow(f), time integral of effort(p) and time integral of flow(q).
The basic bond graph elements consist of
1. JUNCTIONS There are two types of junctions used in bond graph viz.(a) S-Junction (1 junction) (b) P- Junction (0 Junction)
(a)S- JUNCTION shown in the following figure (Fig. 1(a))

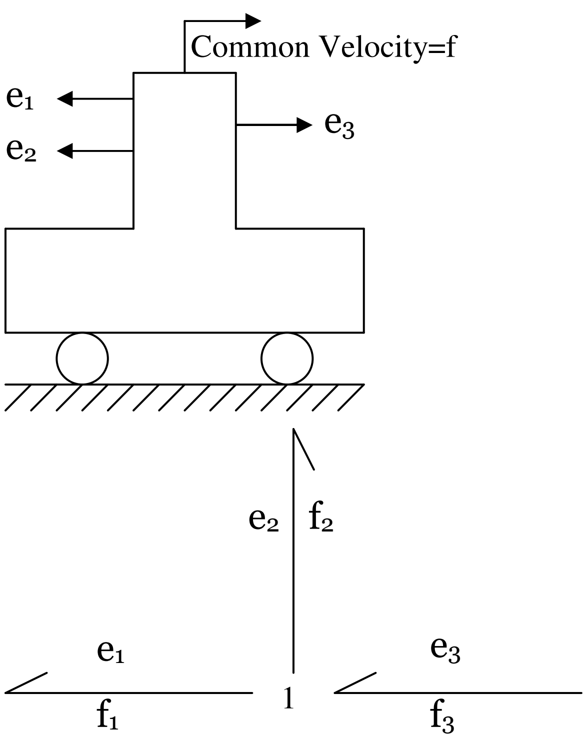

Fig1(a)

The constitutive law for this type of junction is all velocities are equal, given by $f_1 = f_2 = f_3 = f$

here the algebraic sum of powers at junction is zero, given by

$-e_1 f_1 - e_2 f_2 + e_3 f_3 = 0$ i.e. $e_3 - e_1 - e_2 = 0$
So in S-Junction algebraic sum of all effort is zero.

(b)P JUNCTION Shown in the following figure (Fig. 1(b))

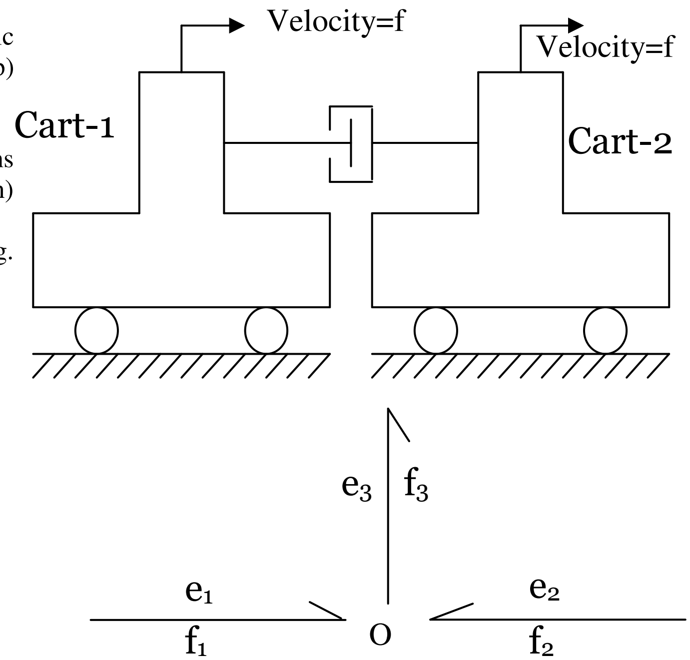

Fig1(b)

The constitutive law for this type of junction is all forces are equal i.e. $e_1 = e_2 = e_3 = e$ (say).
Since the algebraic sum of power at a junction is zero i.e. $e_1 f_1 - e_2 f_2 + e_3 f_3 = 0$
i.e. $f_1 - f_2 - f_3 = 0$
So in P junction the sum of flow is zero.
2. TWO PORT ELEMENTS Two types of two port elements transformer and gyrator are used in bond graph

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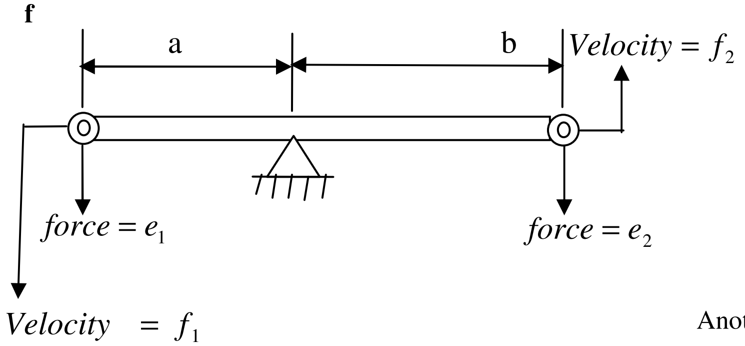
TRANSFORMER Fig 2(a)



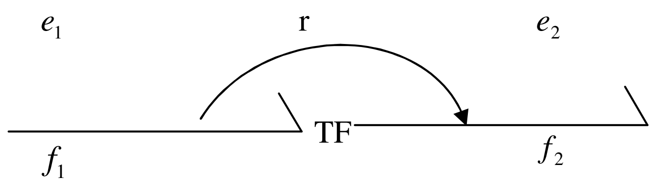
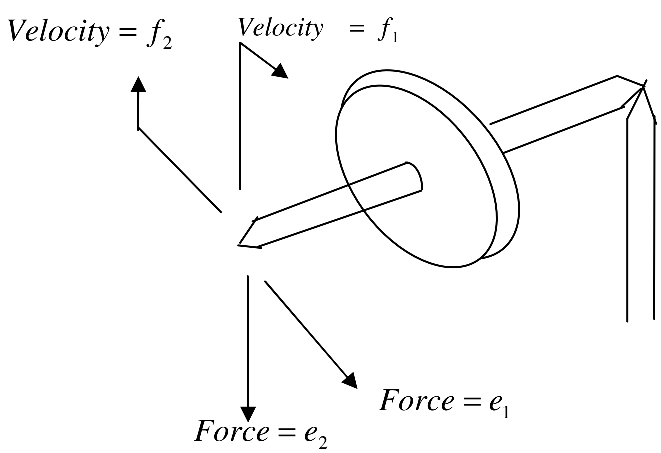


Fig 2(a)

A mass less lever can be represented by a transformer in bond graph. The relationship between the velocities of two ends is given by $f_2 = \frac{b}{a} f_1$ Conservation of energy implies $e_2 = \frac{b}{a} e_1$ In the bond graph r denotes modulus of transformer and has a value $\frac{b}{a}$. The arrow over the TF element represents the sense in which modulus is to be used with follow $f_2 = rf_1$ and $e_2 = \frac{1}{r} e_1$. If the modulus of transformer is in terms of system variable then the transformer is called a modulated transformer (M T F).

b) GYRATOR Fig-2(b)



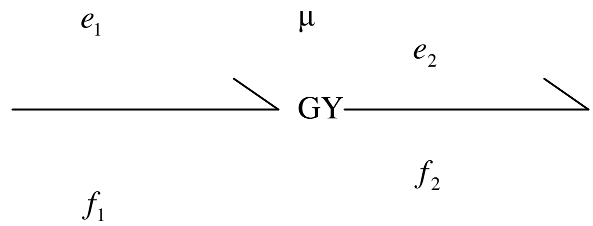


Fig2(b)

Another two port element is gyrator. It of course, conserves power, but an active bond communicates only one of these two possible signals in a single direction.

3. DIFFERENTIAL CASUALTY AND ITS REMEDY

Differential causalities occur in systems having a storage element with out integral casualty. In such cases the state variables associated with this storage element become redundant as these are now completely determined by algebraic relations from other state variables. This involves differentiation, which are computationally troublesome. Hence these should be avoided.

4. I- ELEMENT Proper casualty of the element should be determined by the constitutive law $P = \int_0^T edt$

In this relation effort is the cause and momentum (hence velocity) is the consequence.

The proper casualty is shown in the following figure (Fig- 4(a))

Fig4(a)

5. C- ELEMENT The consecutive law in this case is given by $Q = \int_0^T fdt$ or $e = k\int_0^T fdt$

Here flow is the cause and effort in the consequence.

6. R- ELEMENT

Any casualty can be assigned to this element. The constitutive laws for this case

Are $e = Rf$ and $f = \frac{1}{R} C$

REACTIVE MUFFLER

The pictorial view of the reactive muffler and its bond graph model is shown in figure

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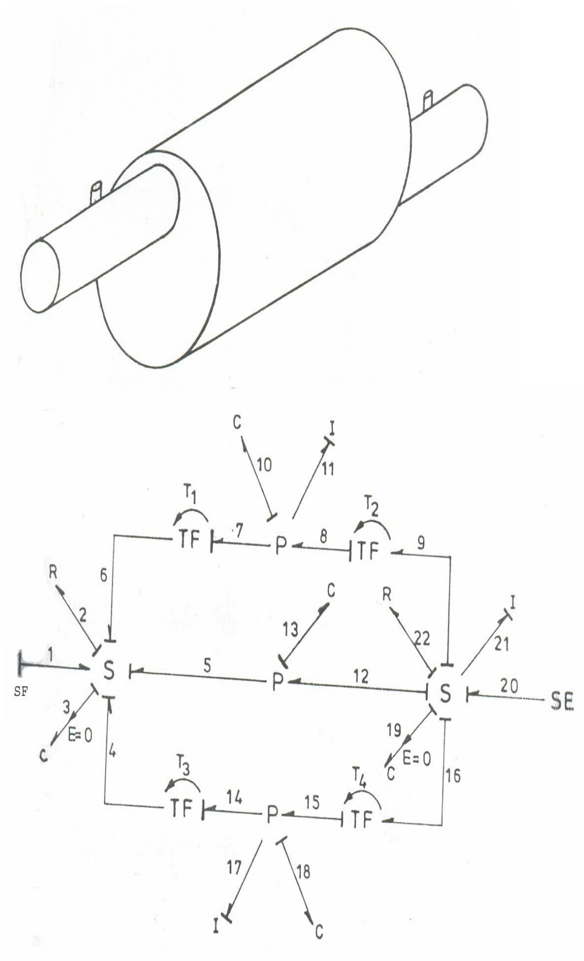

Fig Reactive Muffler

This muffler has no inlet pipe or duct through which exhaust gas enter the muffler or expansion chamber. The length of expansion chamber is 0.7 meter while the diameter is 0.25 meter. The length is approximately three times of diameter. This muffler is typical sell and tube type muffler. This shows typical cavity of the shell. For very high frequencies three dimensional models should be used.

$$\rho_0 \frac{\delta Q}{\delta t} = -\frac{\delta P}{\delta Q} S + f(x,t)$$

Consideration longitudinal modes for cavity are done by using equation.

$$\frac{S}{\rho_0 C^2}\frac{\delta^2 p}{\delta t^2} = \frac{S}{\rho_0}\frac{\delta^2 p}{\delta x^2} - \frac{1}{\rho_0}\frac{\delta f}{\delta x} + \frac{\delta q}{\delta t}$$

But with $f = 0$, the injected flow may be written as

$$q = Q_1 \delta(x - x_1) - Q_2 \delta(x - x_2)$$

There is no flow at $x = 0$ and $x = 1$, and so the boundary condition is $\frac{\delta p}{\delta x} = 0$ at the ends

from equations $\rho_0 \frac{\delta Q}{\delta t} = -\frac{\delta P}{\delta x} S + f(x,t)$

One may assume following expression for the pressure

$$P = \sum H_i(x)\eta(r)$$

The modes satisfy

$$\frac{\delta^2 \eta}{\delta t^2}\left[\eta = C^2 \frac{\delta^2 H}{\delta x^2}\right] H = Cons\tan t = -\omega^2$$

The mode shape arises as $H_1(x) = \cos\frac{i\pi x}{l}$

where i= 0,1,2,…………

The corresponding resonant frequencies are again $\omega_1 = \frac{i\pi c}{l}$

The equation for the modal generalized coordinates are found to be

$$i = 0 \qquad \frac{S}{\rho_0}\frac{1}{C^2}\eta_0 = Q_1 - Q_2$$

$$i \neq 0$$

$$\frac{S}{2\rho_0 C^2}\eta + \frac{i^2\pi^2 S}{2\rho_0 l}\int_0^T \eta_1 dt = Q_1 Cos\frac{i\pi x_1}{l} - Q_2 Cos\frac{i\pi x_2}{l}$$

$i > 0$ or $i < 0$

$$\frac{S}{2\rho_0 C^2}\eta_0 + \frac{i^2\pi^2 S}{2\rho_0 l}\int_0^T \eta_1 dt = Q_1 Cos\frac{i\pi x_1}{l} - Q_2 Cos\frac{i\pi x_2}{l}$$

These equations can be interpreted by recognizing η_i as a pressure component and coefficient as capacitance and inertia parameters. This first equation is exactly the equation one would obtain if the cavity were represented as a single lumped capacitance. The equation for $i \neq 0$ represent normal mode which can be included to extend the formulation to higher frequency ranges. The capacitance and the inertia parameter for the cavity are listed in the following.

The inertia element may be eliminated for the zero modes. It remains to compute the pressure P_1 and P_2 at the flow injection points x_1 and X_2 by using equation

$$P_1(t) = \sum_{i=0}^{i=1} Cos\ (i\pi x_1 / l)\eta_1$$

$$P_2(t) = \sum_{i=0}^{i=1} Cos\ (i\pi x_2 / l)\eta_1$$

For the tube with pressure forcing at the ends the mode shapes evaluated at the ends were only ± 1.0 in the equations. For the cavity tube muffler x_1 and X_2 are not generally at the ends. So non-unity coefficients appear in equation. This means that the bond graph must contain transformer with module of $\cos\frac{i\pi x_1}{l}$ and $\cos\frac{i\pi x_2}{l}$ as shown in bond graph reactive muffler.
In practice, only a few modes would be retained since the high frequency modes will
not all be longitudinal in any case. As the bond graph indicates, If only the zero mode
is retained, representation degenerates to the single lumped capacitance.

It should be noted from the discussion done above that when the tube doesn't perturb into shell cavity (as in the present case), then X_1=0 and X_2=1. in this case the transformer module degenerates to

$m_{11}=T_1=1.0$ $m_{12}=T_2=+1.0$

$m_{21}=T_3=1.0$ $m_{22}=T_4=-1.0$

As a fact, it is difficult enough to develop a complete match to real muffler. Karnopp has shown that a linear model approximates a real system closely for all lower modes.

DESCRIPTION OF SYSTEM BOND GRAPH OF THE REACTIVE MUFFLER

SF1 is the mass flow rate of exhaust gas measured by activated C element at bond 3. C_3 is the effort activated bond. This is flow input to the muffler through the inlet pipe .R_2 represents damping force, balancing the Compliance C_3. The damping force is a frictional force due to wall friction and turbulence of the flow. Acoustic modes are taken care in the same way and they can be easily recognized from the bond graph p junction
5,13,12 for the zero mode, p junction 14, 17, 18,15 for the first mode and p junction 7,10,11,8 for the second mode.C13 the muffler shell(cavity) compliance.

The muffler output is the acoustic mass flow rate. The mass flow rate is observed by C element at bond 19. T F 4-14 with module m_{11} (T_1) is the input to the first mode. TF 15- 16 is associated with outlet pipe of the muffler with module m_{12}. This represents output flow from first mode. TF 6-7 with module m_{21} is the flow input to the second mode. TF 8-9 is associated with outlet pipe of the muffler with module m_{22} from second mode. I 17 and C 18 represents inertia and compliance element of first mode. I11 and C10 represent the inertia and compliance element of the second mode. C13 represents compliance of the shell. The gas is exhausted out of the muffler is allowed to flow in the atmosphere. This is represented by SE 20. Out put flow or rate of output flow is observed by activated element C 19. R 22 represents damping for the compliance C19 while I 21 represents inertia element of the out let pipe.

FORMATED DATA

The COSMO-KGP package has facility of providing formatted data parameters papering in the model. The SF $\longrightarrow$ source of flow for the reactive muffler is given by

$$SF = a_1 SWI * (Cos(\omega * T), lv)$$

The exhaust gas flow is pulsating flow. This is indicated by providing SWITCH i.e. SWI in the expression.

SF= Source of flow
a_1 = Amplitude of the waveform
ω=Angular velocity of the cam rotation (Operating valve timing of the engine)
lv= Level of the switch

SWI represents switching operation from zero to one, whenever the magnitude of its arguments becomes greater than its switch level lv.

EXPERIMENTAL SETUP

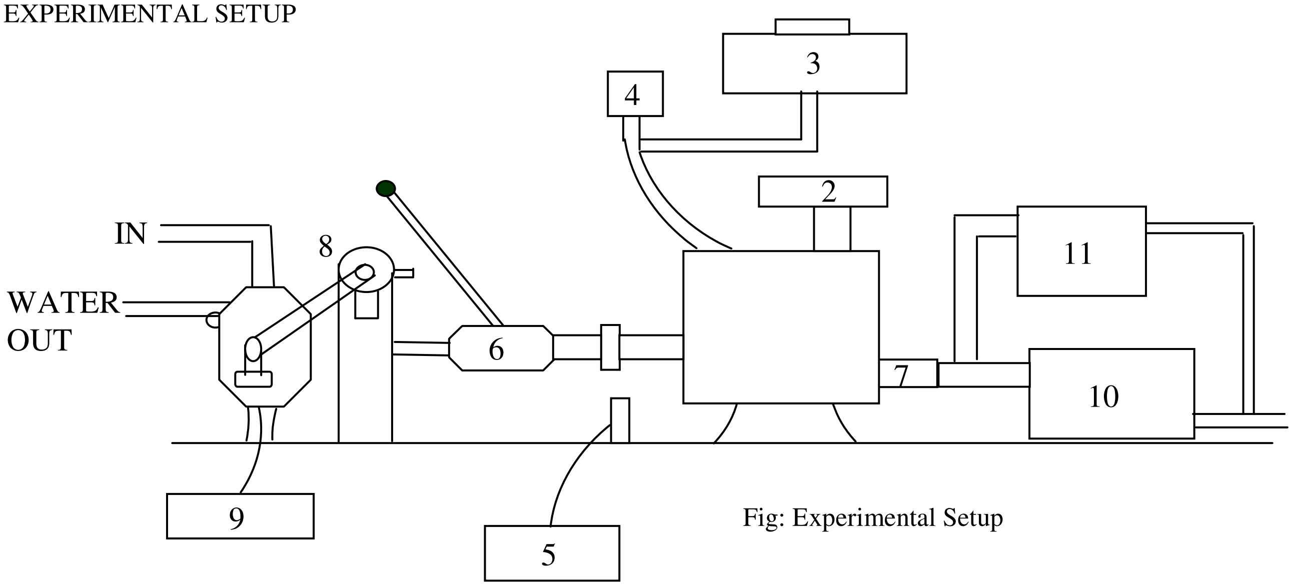

Fig: Experimental Setup

1.ENGINE
2.AIR FILTER
3.DIESEL TANK
4.DIESEL MEASURING BURRET
5.SPEED INDICATER
6.CLUTCH
7.EXHAUST PIPE
8.HYDRALIC DYNAMOMETER
9.TORQUE INDICATOR
10.REACTIVE MUFFLER
11.MANOMETER

SYSTEM EQUATIONS

$$DP2 = -K18/T4*Q18 - K13*Q13 - K10/T2*Q10 - R22/M21*P21 + SE20$$

$$DP11 = +K10*Q10$$
$$DP17 = +K18*Q18$$
$$DP19 = +1/M21*P21$$
$$DQ13 = 1/M21*P21 - SF1$$
$$DQ10 = -1/M11*P11 + 1/(M21*T2)*P21 - T1*SF1$$
$$DQ18 = 1/(M21*T4)*P21 - 1/M17*P17 - T3*SF1$$
$$DQ3 = SF1$$

RESULTS AND DISCUSSIONS

The bond graph model of reactive muffler is prepared and simulated on COSMO- KGP Package. Fig1. shows graph of impulse response of the reactive muffler. It is a graph of magnitude of out put flow Vs frequency (1/3 octave band frequency). It is observed from fig 1 the amplitude of the flow out put is ranging from $0.324\,m^3/s$ to $0.6533\,m^3/s$. The attenuation at the location of microphone is calculated analytically by preparing mathematically of sound radiation at the point of attenuation at 125Hz, 250 Hz and 500 Hz are 13.123 db, 15.23 db 15.23 db respectively. This shows that the reactive muffler is more effective bellow 500 Hz. This is due to the fact that large amount of energy is transferred at low range, it means that higher frequency component of energy having low frequency.

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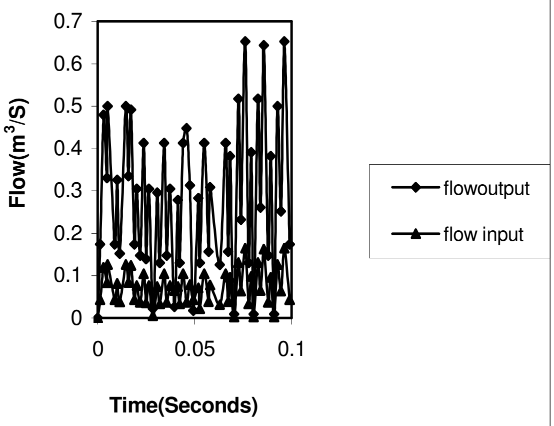
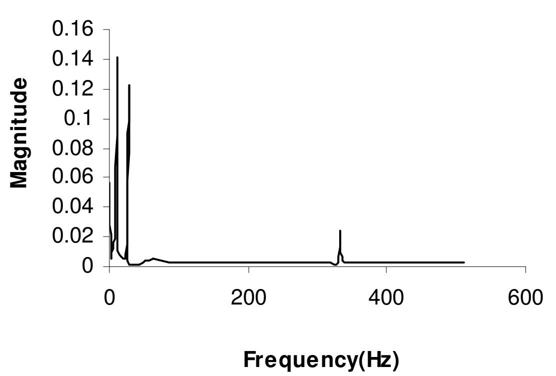
Fig.1:Flow Output of Reactive Muffler



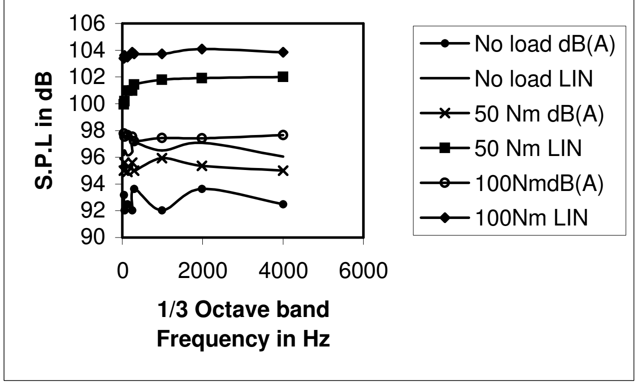
The fig 2 shows the Fast Fourier transform (FFT) of the flow output of the muffler. The curve shows that large amount of energy has been transferred at low frequencies the FFT of flow output indicates sudden rise of flow amplitude for very short duration of time. And again it follows the normal path .

Fig.2:FFT of Flow Output of Reactive Muffler



The experimental results are shown in Fig.3. The graph shows sound pressure level Vs frequencies (1/3 Octave frequency). The SPL is measured in weighted scale and linear scale. SPL with reactive muffler measuring linear scale. Insertion loss in reduction in SPL is calculated. It is observed that reduction in SPL is lower at low speed and at low torque (or low load). This is due to the reduced volume flow rate of exhaust gas through the muffler. From fig 3 the reduction in SPL on linear scale varies from 3db to 13 db. The experimental data are taken as various loads and at various speed. The load varies from 00 Nm to 100 Nm in the step 50 Nm at the engine speed 100 r.p.m. These rotational speeds proportional to the actual speed (linear speed) with which heavy loaded truck are playing on the road. TATA 6- Cylinder diesel engine is generally used as a truck engine. The normal speed of the vehicle is assumed to be range (30 – 60) Km/h.

Fig.3: S.P.L. Vs Frequency at 100 r.p.m.of Reactive Muffler



In Fig. 4 shows the graph of brake thermal Vs BHP. It is found that there is no considerable loss of power due to insertion of reactive muffler. This is due to simple configuration of muffler in which minimum backpressure is acing on the engine .The Brake Thermal Efficiency is 29% and at the load of 200 Nm which is 2% higher than the existing muffler at 100 rpm.

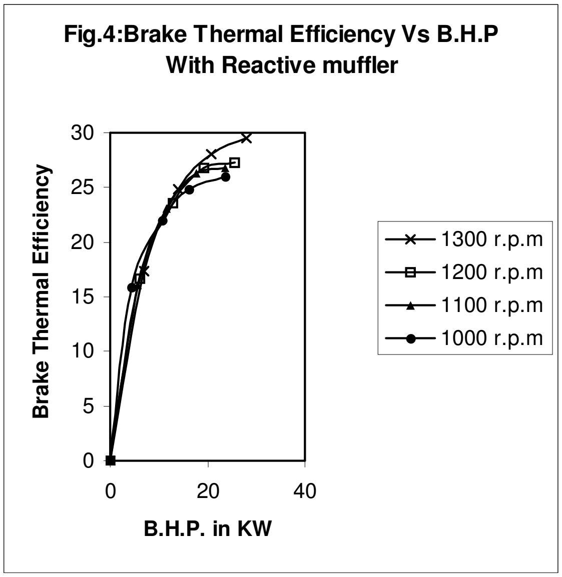


Fig.4:Brake Thermal Efficiency Vs B.H.P With Reactive muffler

Fig 5 shows a graph of BSFC Vs BHP. AS load increases fuel consumption increases as engine has to put more effort for maintaining the speed. It is noted that BSFC increases with increase in fuel consumption. At the load of 200 Nm and 1300 r.p.m. BSFC is 0.215 kg/ KW-hr which is 5.3% less as compared with the existing muffler.

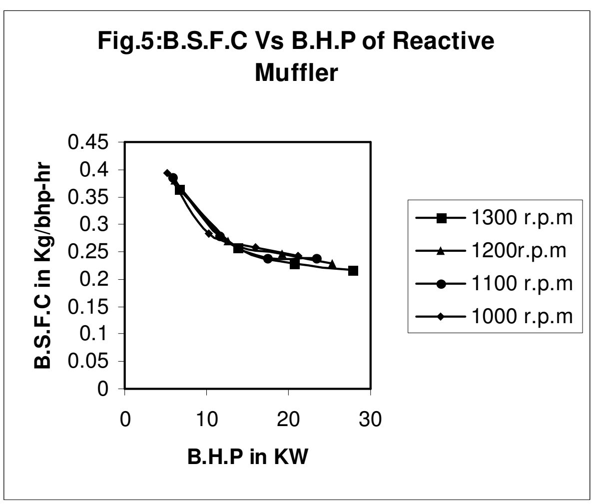


Fig.5:B.S.F.C Vs B.H.P of Reactive Muffler

Fig. 6 represents the analytical results Vs experimental results. The analytical results show reduction in SPL is 16 db.

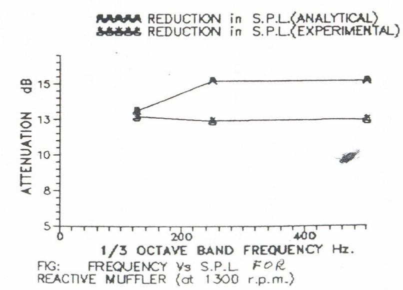


Fig.6

Conclusion

From results and discussions the following conclusions are drawn

1. The reactive muffler is effective at low frequencies.
2. The back pressure exerted on engine by coupling the reactive muffler is low as compared to existing muffler.
3. The brake thermal efficiency of engine is higher for reactive muffler as compared to existing muffler.
4. The Brake Specific Fuel Consumption is low compared to existing muffler.
5. The noise reduction with existing muffler is little more than the reactive muffler.
6. The Bond Graph model of reactive muffler indicates that sound pressure is maximum at the flow injection and gradually it decays. Thus it shows that muffler element has smoothen the flow. The analytical result shows a reduction of16 db in SPL.

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