ISSN 2395-1621

Analysis of Exhaust Manifold by Thermal Coupled Approach

[#1]Miss Pooja Nemade, [#2]Dr. R. K. Patil

[1]poojanemade23@gmail.com
[2]rkpvpit@gmail.com

[#12]Mechanical Department, SPPU University,
Padmabhooshan vasantdada payil college of engineering , pune.
Savitribai Phule Pune University
Paud Road Bavdhan Pune Tal: Mulashi Dist: Pune Pincode: 411021

ABSTRACT

The heat transfer conditions in automotive exhaust piping are only recently being studied in depth because of their important role in the design and the optimization phases of exhaust after treatment systems .With the advent of the EURO 4 norms the design of the exhaust manifold plays a very crucial role. In order to fulfill the above, the temperature of the exhaust gas has to be maintained above a particular level in order to make sure that the catalytic convertor works to its full efficiency. If the temperature of the exhaust gas entering the catalytic convertor reduces less than 5500C reduces the efficiency of the convertor by 80%. Here the exhaust manifold in the cylinder head is modeled in CATIA. The various inputs required for ANSYS and coolant velocity values, for various thicknesses and mass flow rate are calculated. From the resulting tabulation a polynomial expression relating mass flow rate and coolant velocity is formed. Inputs are then given to ANSYS to analyze the stress developed in each case. From this the best possible result is obtained

ARTICLE INFO

Article History

Received :29th February 2016

Received in revised form :

1st March 2016

Accepted : 4th March 2016

Published online :

6th March 2016

Keywords— Exhaust manifold, catalytic convertor, coolant velocity

I.INTRODUCTION

Although the first works on automotive exhaust Systems are more than 10 years old the study of Heat transfer in these systems has only recently attracted the importance they deserve Due to their key role in the design of modern exhaust after-treatment systems. Such studies are today important for better understanding of these systems and, thus, being able to influence cold-start warm-up of the catalytic converter, thermal ageing of the converter.Oncoming automotive exhaust emissions standards focus on the minimization of cold start emissions for catalyst-equipped diesel automobiles. In that context, all passive means of achieving Maximum possible catalyst efficiency must be exhaustively examined. The complex geometry of the exhaust manifold and the special flow conditions complicate the problem of accurately estimating several heat transfer parameters. The acquisition of useful data for the estimation of heat transfer rates and their application in the optimized design of various exhaust configurations forms the subject of the present work. Here we take advantage of computer models to analyze the effect of the variation of various parameters that govern the heat transfer in the manifold. Selected results are illustrated in form of temperature, stress and deformation distribution plots. Some suggestions for design improvements are therefore also presented.

The exhaust manifold is a pipe which connects the Exhaust valve to the catalytic converter either through the exhaust pipe or directly. It is an Integral part of the exhaust system and is Crucial to the functioning of any vehicle. The Basic function of the exhaust manifold is to Contain and direct combustion exhaust gases from each cylinder to the vehicle exhaust pipe. Exhaust system components design vary for Different engines depending on the load, Application and the type of cooling system. Optimal exhaust manifold design plays a vital Role in engine performance and in the life span of the catalytic converter. The pipe diameter, Component length, catalytic converter size, Muffler size, and exhaust manifold design are engineered to provide proper exhaust flow, Silencing, and emission levels on a particular Engine. In the most recent exhaust.Architectures, the catalyst are attached to the Exhaust manifold without intermediate downpipe.

Exhaust manifolds, dependent on vehicle application, could additionally provide some of the following functions:

• Exhaust gas supply to the exhaust gas re-circulation (EGR) system

• Location for mounting a heated exhaust gas oxygen sensor (HEGO)

The exhaust manifold which is made of cast iron or tubular steel either mounts to the exhaust side of the cylinder head for air cooled exhaust manifolds or is cast within the cylinder head in case of water-cooled.

II.LITERATURE REVIEWS

The exhaust manifold was introduced as an engineering device in the early 20th century. At the same time, researchers started to investigate its working mechanism. In a paper published **Monika weiner** (2004) 'Virtual service-life testing',Fraunhofer magazine 1-2004-34_tcm6-10202 [1] presented the first comprehensive theoretical and experimental analysis of the exhaust manifold problem. The constant-pressure mixing model and the constant-area mixing model developed by Monika weiner became the basis of design and performance analysis since then. Based on these 1-D analytical approaches, much research effort has been devoted to the improvement of exhaust manifold design methods and hundreds of papers relating to this are published. In the derivation of analisis of exhaust manifold model, Monika weiner (2004 [1] assumed that the fluids of the primary flow and secondary flow were the same gas. Monika weiner [1] also neglected gas velocity and and frictional effects. This method is not very accurate, but it avoids the complicated expressions of thermodynamic properties for mixed flow as well as the use of experimentally determined constants.

Nowadays many researches are available which uses computational fluid dynamics for the performance improvement of the exhaust manifolds**. Said Zidat and Michael Parmentier** (2003) 'Exhaust Manifold Design to Minimize Catalyst Light-off Time', Delphi, Technical Centre Luxembourg, SAE technical paper series, 2003-01-0940. [2] carried out a numerical analysis to study about the influence of geometric arrangement on the performance of exhaust manifold used in conjunction with a exhaust gas recirculation.Numerical simulation was employed to investigate the thermal-flow behaviour. The performance is measured by the entrainment ratio, i.e., the secondary (suction) flow rate from a vapour plenum over the primary gas jet flow. It is observed that any downstream resistance will seriously impede the suction flow rate. In addition, the entrainment ratio is sensitive to the location of the jet exit, and there is an optimum location where the primary flow should be issued. A well-contoured diffuser can increase the entrainment ratio significantly.

I.P. Kandylas, A.M. Stamatelos(1999) 'Engine exhaust system design based on heat transfer computation'Laboratory of Applied Thermodynamics, Mechanical Engineering Department, Aristotle University of Thessaloniki, Thessaloniki, Greece.. [3] in their paper studied the use of exhaust gas in desalination system, particularly multi effect desalination (MED) system. In this study, CFD (computational fluid dynamics) analysis based on the finite volume method was employed to investigate the influence of angle of converging duct on the manifold performance. The using of CFD method allowed not only the accurate prediction of the performance but also the identification of the expansion wave, the circulation zone, and the pressure distribution of the axial direction. CFD studies show that the increase of converging angle affects the increase of static pressure field inside the mixing duct. Hence, the length of shock train region is also influenced by the angle of converging duct. It is observed from this study that the entrainment ratio of ejector is influenced by the angle of converging duct. Ejector with degree of angle 0.5 gives the highest value and then decrease with reference to the increase of converging angle. The flow visualization of stream functions inside the ejector shows that the flow separation phenomena and recirculation conditions occur in the ejector with larger converging angle.

Yasar Deger,(2004) 'Coupled CFD Coupled CFD-FE-Analysis for the

Exhaust Manifold for the Exhaust Manifold of a Diesel of a Diesel Engine' [4] studied using semi-empirical models design and rating of gas manifold. The model gives the entrainment ratio as a function of the expansion ratio and the pressures of the entrained vapour, motive gas and compressed vapour. Also, correlations are developed for the motive steam pressure at the manifold exit as a function of the peak pressure and cylinder pressures and the area ratios as a function of the entrainment ratio and the gas pressures. This allows for full design of the manifold, where defining the manifold load and the pressures of the motive gas, which gives the compression ratio.

Sulzer Technical Review, 10/2003,Germany. [5] published a paper which discusses the behaviour of exhaust gases through an manifold, operating with a low temperature thermal source. For the detailed calculation of the proposed system a method has been developed, which employs analytical functions describing the thermodynamic properties of the gas.

R.C.Sachdeva,(2003) ' Fundamentals of Engineering Heat and Mass Transfer' New age international publishers,2003,India..[6] studied a computer simulation model for thermal heat problems. The model was developed by application of the equations of continuity, momentum and energy to individual operation of manifold, mixing chamber and cylinder. Two different approaches used to develop two models are presented. The effect of motive steam pressure, evaporator temperature, and pressure rise across the manifold, and the results presented. To test the adequacy of the models, these results were compared with empirical graphs and are found to be in good agreement.

III.OBJECTIVES OF ANALYSIS

Following are the objectives of Analysis of Exhaust Manifold by Thermal Coupled Approach

1) To determine the optimum coolant velocity over the manifold for the varying mass flow rate in order to maintain the temperature of gas entering the catalytic convertor above 550°C .Only if this temperature is maintained will the catalytic convertor work with an efficiency of above 80 percentage.

2) To obtain a polynomial expression to determine the particular coolant velocity at various mass flow rates for a particular thicknesses. This can be implemented in the cooling system thereby maintaining catalytic convertor efficiency.

3) To identify and suggest the thickness of the manifold at which the stress developed is minimum and hence reduce the chances of failure.

IV.METHODOLOGIES

In related for the Analysis of Exhaust Manifold by Thermal Coupled Approach, the following two methods have been adopted:

4.1 Analytical Method: - here the equations are generated and the calculations are carried out.

4.2 Numerical Method:-FEM Software (ANSYS) is used to determine the results.

4.1 Analytical Method: heat transfer calculations

Exhaust gas temperatures: Tgas in=650°c, T gas out=550°c

mgas=.016kg/s@1500rpm

• Tbulk =(650+550)/2 =600°c

Internal convection:

Properties of exhaust gas at bulk temperature,

Density, ρg=.404kg/m3

Kinematic viscosity, γg=96.89∗10 −6 m 2 /s

Prandtl number, Prg=0.699

Thermal conductivity, Kg=62.22∗10 -3 w/mk

Specific heat Cpg=1.114∗10 3 kJ/kg k

• Heat lost by exhaust gases, Q=mg∗Cpg∗(Tgas in-T gas out) =0.016 ∗1.114 ∗103 ∗(650 –550)

=1782.4W

Internal convection heat transfer:

• Velocity of exhaust gas, Vg = mg /(ρg∗(∏/ 4) ∗ Di 2)

= 0.016 / (0.404 ∗0.25Π ∗0.0325 2) = 47.73 m/s

• Reynolds number, Reg= (Vg ∗Di)/ γ g

= (47.73 ∗0.0325)/ (96.89 ∗10 -6) = 16013.5

• Nusselt number, Nu st= 0.023 ∗Reg 0.8 ∗Prg 0.3

= 0.023 ∗16013.5 0.8 ∗0.699 0.3 = 47.71 23

• (Nu bent / Nu st) = 1+ (21∗Di) / (Reg0.14∗Dbend)

= 1+ (21∗0.0325) / (16013.5 0.14 ∗0.070) =3.51

Corrected Nusselt number, Nu bent =167.65

• Internal heat transfer coefficient, Hi= (Nu bent/ (Di/Kg))

= (167.65/(0.0325/(62.22∗ -3)) =320.97 w/m

Heat lost by exhaust gases= Heat transferred by internal convection=Q

• Heat transferred by convection, Q= Hi∗Ai∗(Tbulk –Tsi)

= Hi∗Π∗Di∗li ∗(Tbulk –Tsi)

1782.4=320.97∗Π∗0.0325∗0.183∗(600−Tsi)

Tsi =302.79°c

Conduction heat transfer:

Heat lost by exhaust gases= Heat transferred by conduction

Thermal conductivity of wall, Kw=54.47

For a thickness of 10mm, Dext =0.0525m

• Heat transferred by conduction,

Q= [Tsi −Ts ext]/[ln(Dext/ Di)/(2Π∗li∗Kw)]

1782.4= [302.79 −Ts ext]/[ln(0.0525/ 0.0325)/(2Π∗0.183∗54.47)]

Ts ext=289.14°c

External convection heat transfer:

Heat lost by exhaust gases= Heat transferred by external convection

Coolant initial temperature,T∞ =70°c , li=lext

• Film temperature, Tf =(Ts ext + T∞)/2

= (289.14 + 70)/2

=179.57°c

For =179.57°c for water,

Kinematic viscosity, γ l =0.173∗10 −6 m 2 /s

Prandtl number, Pr l =1.044,

Thermal conductivity, K l=675.7∗10 -3 w/mk

Heat transferred by External conduction,

• Q=Hext∗Ao∗(Tf - T∞)

Q=Hext∗Π∗Dext∗lext∗(Tf - T∞)

1782.4=Hext∗Π∗.0525∗0.183∗(179.57 – 70)

Hext=538.95w/m 2k

• Nu ext= Hext∗Dext/k l = 538.94∗0.0525/(675.7∗10 -3) =41.806

• Nu laminar=0.664∗√ (Re l) ∗3√ (Pr l)=0.673∗√(Re l)

• Nu turbulent = (0.037∗Re l 0.8 ∗Pr l)/(1+2443∗Re l -0.1 ∗(Pr l 2/3 -1))

= (0.0386∗Re l 0.8)/(1+71.14∗Re l -0.1)

• Nu ext= 0.3+√(Nu laminar 2 + Nu turbulent 2)

⇒41.806= 0.3+√[(0.673∗√(Re l)) 2 +((0.0386∗Re l 0.8)/(1+71.14∗Re l -0.1)) 2]

⇒Re l =3826.21

Reynolds number of coolant,

Re l = (V l∗Dext)/(γ l)=3.0345∗10 5 ∗V l = coolant velocity required l = .01246m/s

Similarly by varying mass flow rate as 0.015 and 0.014, different cooling velocities are obtained.

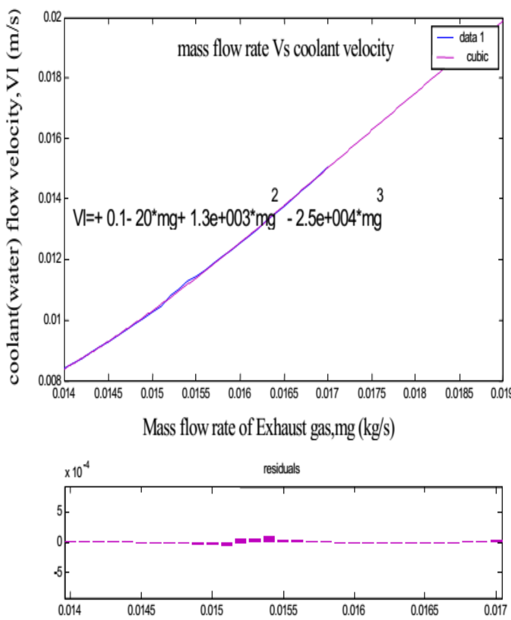

Fig4.1: mass flow rate Vs coolant velocity

V.RESULT AND DISCUSSIONS FOR ANALYTICAL METHOD

The optimum coolant Velocity over the manifold for which the exhaust temperature is maintained above the minimum required for efficient operation of the catalytic converter is determined and the polynomial expression that denotes the coolant velocities required for different mass flow rates of the exhaust is as below

$$V_l = 0.1 - 20*mg + 1.3e{+}003*mg^2 - 2.5e{+}004*mg^3$$

Further thickness value for the manifold that would result in reduced thermal stress and simultaneously maintain the exhaust temperature is found out to be 6mm. therefore this value of thickness is suggested as a design modification and the polynomial expression for this thickness value is found to be

$$V_l = 0.12 - 2.7e - 23*mg + 1.5e{+}003*mg^2 + 004*mg^3$$

Numerical Method:-FEM Software

The 3d plots that are generated in this process are 1st principal stress distribution, 2nd principal stress distribution, 3rd principal stress distribution, Strain distribution, Deformation distribution .These plots give us a fair idea of the stress distributions on the surface and also the maximum stress that is met by any node in the whole model. The various values that are obtained from this finite element process are tabulated for further analysis.

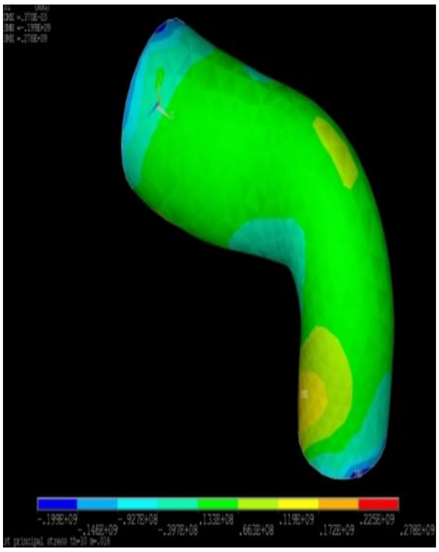

Fig. 1st principal stress distribution

Further 2nd principal stress distribution, 3rd principal stress distribution, Strain distribution, Deformation distribution are obtained for different mass flow rates of 0.015, 0.014 by Ansys Software,

the following table shows the results obtained for the

m=.014 (kg/s)					
Thickness	Strain	Deformation	1st principal stress (N/m^2)	2nd principal stress (N/m^2)	3rd principal stress (N/m^2)
10	0.005803	3.84E-04	3.13E+08	5.32E+07	4.97E+06
9	0.00593	3.83E-04	2.95E+08	5.50E+07	5.24E+06
8	0.005538	3.85E-04	2.76E+08	3.93E+07	2.77E+06
7	0.005102	3.87E-04	2.81E+08	3.44E+07	7.67E+06
6	0.005132	3.83E-04	2.77E+08	2.81E+07	2.20E+06
5	0.005216	3.81E-04	2.79E+08	3.41E+07	9.96E+06
4	0.00522	3.80E-04	2.90E+08	3.35E+07	8.80E+06
3	0.005481	3.78E-04	2.88E+08	3.93E+07	1.81E+07
2	0.005832	3.77E-04	3.04E+08	3.59E+07	2.06E+07
1	0.005671	3.77E-04	2.91E+08	7.14E+07	2.63E+07

Table4: results from ansys for m=.014 kg/s

Effect of thickness: The same procedure is completely repeated for all values of thickness from 10mm to 1mm.the respective values to be applied as loads are obtained from the table for particular thicknesses.

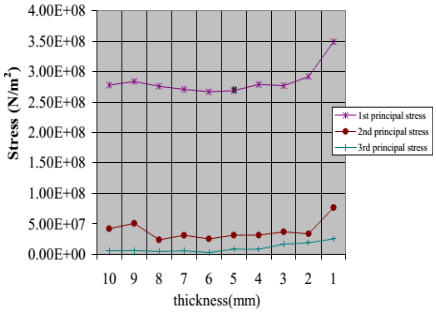

Fig. 4.3 thickness vs stress

VI.RESULTS AND DISCUSSION FOR NUMERICAL METHOD

From the tabulations and the graphs plotted, we observe that the stress developed in the manifold with a decrease in thickness:

• Decreases gradually from a thickness of 10mm to 6mm and then

• Increases steeply from thickness of 6mm to 1mm.

Therefore, selection of either too thick or too thin a manifold would result in stress and therefore cracking. From the patterns in the graphs we identify that the 6mm thickness has the minimum stress of all options.

• Thickness 1mm was found to out rightly violate maximum principal stress theory. Therefore would work out to be a failure model.

VII.CONCLUSIONS

The optimum coolant Velocity over the manifold for which the exhaust temperature is maintained above the minimum required for efficient operation of the catalytic converter is determined and the polynomial expression that denotes the coolant velocities required for different mass flow rates of the exhaust is as below

Vl = 0.1- 20*mg + 1.3e+003*mg -2 - 2.5e+004*mg 3
Further thickness value for the manifold that would result in reduced thermal stress and simultaneously maintain the exhaust temperature is found out to be 6mm. therefore this value of thickness is suggested as a design modification and the polynomial expression for this thickness value is found to be
Vl= 0.12- 2.7e - 23*mg + 1.5e+003*mg 2 +004*mg 3

REFERENCES

1.**Monika weiner (**2004**)** ‘Virtual service-life testing’,Fraunhofer magazine 1-2004-34_tcm6- 10202

2.**Said Zidat and Michael Parmentier** (2003) ‘Exhaust Manifold Design to Minimize Catalyst Light-off Time’, Delphi, Technical Centre Luxembourg, SAE technical paper series, 2003-01-09403.

3**.I.P. Kandylas, A.M. Stamatelos**(1999) ‘Engine exhaust system design based on heat transfer computation’Laboratory of Applied Thermodynamics, Mechanical Engineering Department, Aristotle University of Thessaloniki, Thessaloniki, Greece.

4.**Yasar Deger**,(2004) ‘Coupled CFD Coupled CFD-FE-Analysis for the Exhaust Manifold for the Exhaust Manifold of a Diesel of a Diesel Engine’

5**.SulzerTechnicalReview**, 10/2003,Germany.

6. **R.C.Sachdeva**,(2003) ‘ Fundamentals of Engineering Heat and Mass Transfer’ New Age publishers,2003,India .

