"Analysis of Vibration in Diesel Engine Considering Combustion Gas Forces: Using Grey Cast Iron Material"

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Abstract: In the today world, the diesel Engines are now replacing the petrol engines due to its fuel economy. Also they are mostly being used as commercial vehicles. However diesel Engines generate comparatively higher NVH (Noise, Vibration and Harshness) levels. They are known to generate a lot of noise as a result of piston slap. In conventional diesel engines it is always found that piston slap occurs at near the top dead centre while at bottom dead centre and mid stroke slaps may be suppressed at some low speed operating conditions. Most of the researchers have found for the mechanical noise i.e. piston slap. Very few efforts are devoted for combustion gas force analysis. Little attention was paid on noise and vibration due to combustion gas force. This work focuses on this issue. The main purpose of this work is to analyze the vibration in diesel engine cylinder liner considering combustion gas forces and cylinder liner temperature using finite element software ANSYS. Also Grey cast iron material is being tested in the software for this purpose. The output results were quite satisfactory to predict the behavior of deflection under different pressures. The combustion gas forces calculated for varying compression pressures. Results are presented the displacement vs frequency shows the amplitude of vibration. By comparing the analytical results, the validity of the proposed analysis has been confirmed. Furthermore, this analysis is applied to evaluate the vibration of grey cast iron material along with increase in thickness, and revealing the closer response according to the material and vibration.

Keywords:* - *VCR [14] (Variable Compression Ratio) Diesel engine, Cylin liner, Combustion gas force, Harmonic analysis (ANSYS 10.)

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1. INTRODUCTION

Most of the noise sources appertaining to the diesel engine have received extensive investigation. Piston slap is initiated wherever the piston side thrust force changes direction. This takes place under two conditions: (a) when the force in the connecting rod changes from tension to compression and vice versa; (b) when the component of the connecting rod force normal to the cylinder axis changes direction as a result of subsequent changes in the crank angle. The latter condition always occurs at top and bottom dead centre while the former condition is realized when the total inertia force contribution to side thrust just balances the resulting gas force. In conventional diesel engines it is always found that piston slap occurs at or near the top and bottom dead centre while mid-stroke slaps may be suppressed at some low speed operating condition when the aforementioned force balance cannot be obtained.

The noise generates a lot of vibration in the cylinder chamber which causes cylinder liners to vibrate; there is also the effect of the combustion and piston slap which is the result of the piston side thrust on the cylinder liner. As it moves to and fro from TDC to BDC, the net effect of which makes the cooling fluid in the cooling chamber to undergo vibration and then the production of the unwanted cavitations in the cooling chamber. The forces causing the cavities to form and collapse due to a continuous series of high frequency pressure pulsation in the liquid. It has been a fact that the effects of vibration are very worrying. Some of these effects are so damaging that they can even destroy the whole cylinder liner and thus a new one needs to be purchased. Looking towards the threat of vibration which is hazardous which may lead the total failure of the systems need to addressed. From few research efforts continuously focus their attention towards vibration or deflection analysis from different means which further causes the depth in analysis of vibration considering combustion gas force. In this work comparatively higher pressure zones were analyzed to understand the vibrational behaviour of the engine. It imparts different material analysis with or without additional thickness to view the vibration with different aspects.

W.J.Griffiths and J.Skorecki[1964] [1], investigated that the effect of cooling water temperature on vibration was investigated that diesel engines are noisier when cooling water temperature is low and vice versa. Piston slap was investigated by motoring the engine and removing certain sources of the vibration from the engine. As a result piston slap was identified and the instants of slap were determined. These were compared with the instants of slap calculated from a theoretical analysis of the dynamics of the moving parts of the engine. **S.D.Haddad and H.L.Pullen[1974]**[2], they presented the various methods for estimating the pistons slap. This phenomenon of piston slap has been investigated by oscillographic and simulation technique to determine its relative magnitude, compared with the other noise sources of the engine. It has been found that this source of noise is important and its significance will become greater as other sources, such as combustion are reduced. **L. Chabot PSA Peugeot Citroen, Oliver G.K.Yates Ricardo Group [2000]** [3], this paper summarizes a study that has been undertaken to assess and optimize the dynamic behavior of a current production 1.6 litre gasoline engine with the objective of reducing low frequency radiated noise from the cylinder block. **M. S. Khan, C. Cai and K. C. Hung, Institute of High Performance Computing, Singapore [2002]** [4], presents a article, to examine the acoustic finite element analysis coupled with structure, and provides the necessary information to apply ANSYS for a wide class of structural acoustics problem. Results are presented for global cancellation of a primary monopole's sound field by the use of multiple piezoelectric elements bonded to the surface of the elastic structure to provide control forces. **S.H. Cho, S.T. Ahn And Y.H. Kim [2002]** [5], they present an analytical model, which can predict the impact forces and vibratory response of engine block surface induced by the piston slap of an internal combustion engine. When slap occurs, the impact point between piston skirt and cylinder inner wall is modeled on a two-degree-of-freedom vibratory system. The equivalent parameters such as mass, spring constant and damping constant of piston and cylinder inner wall are estimated by using measured (driving) point mobility. Those parameters are used to calculate the impact force and for estimating the vibration levels of engine block surfaces. **Takayushi Aoyama, Sigeo Suzuki, Atasushi Kawamto, Takashi Noda, Toshihiro Ozasa, Takeyushi Kato, Takashi Ito [2004]** [6], this paper presents an analysis of noise occurrence at a diesel engine and a design to prevent the noise which occurred unperiodically with frequency over 5kHz. The mechanism of noise occurrence was assumed to be follows: The noise occurred when the following conditions were combined: (1) cavitation appeared in the oil film at the main bearing (2) main journal vibration in the radial direction induced further appearance and collapse of cavitation. The mechanism was verified by the following items derived from numerical and experimental analysis results (a) the existence of cavitations at the time of noise occurrence (b) the instability of main journal oil film (c) the simultaneously fluctuation of combustion pressure. **G O Chandroth, A J C Sharkey and N E Sharkey Department of Computer Science, University of Sheffield, Sheffield, UK [2007]** [7], focuses on the detection of incipient faults in an internal combustion engine using a minimum number of sensory information. Inducing several faults in a 4 stroke diesel engine, cylinder pressure (P) and vibration (V) data are acquired. **Y.V.V.SatyanarayanaMurthy Mechanical Department, Gitam University, Visakhapatnam [2011]** [8], the purpose of this paper is to detect the “knock” in Diesel engines which deteriorate the engine performance adversely. The methodology introduced in the present work suggests a newly developed approach towards analyzing the vibration analysis of diesel engines. The method is based on fundamental relationship between the engine vibration pattern and the relative characteristics of the combustion process in each or different cylinders. Knock in diesel engine is detected by measuring the vibration generated by the engine using The DC-11 FFT analyzer with accelerometer. **Anthony Deku, Subramanya Kompella, Department of Mechanical Engg., Blekinge, Sweedon, [2006]** [9], the main aim is to actually study these vibrations and try to model it. A foundation is also laid to study cavitations in the engine. A model to calculate pressure variation in the system is carried out using Modeling software, with the help of Finite Element Analysis and Fluid Structure Interaction Analysis.

2. AIM AND OBJECTIVES

i. The purpose of this work is to model a cross section of engine cylinder as a two dimensional beam and 3-dimensional model, consisting of thickness and stroke length of engine cylinder.
ii. Applying the combustion gas forces, which are calculated from compression pressure and temperature of cylinder liner.
iii. Analyzing the vibration level in the diesel engine cylinder liner due to combustion gas forces and cylinder liner temperature.

3. METHODOLOGY

i. An overview is given based on a literature survey of general theory for the vibration phenomenon.
ii. The system is modelled using ANSYS Version 10 software to create needed geometry, and carry out simulations.
iii. The problem is described in a two dimensional beam and three dimensional model.
iv. Calculating combustion gas forces for the certain peal ranges of compression pressure (between 45-75 bar).
v. Considering cylinder liner temperature [9].

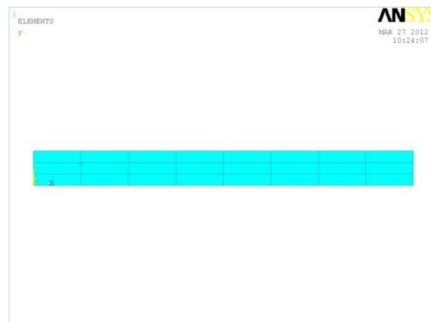

Fig1: Figure showing the application Combustion Gas Forces in 2-Dimensional Beam after Meshing

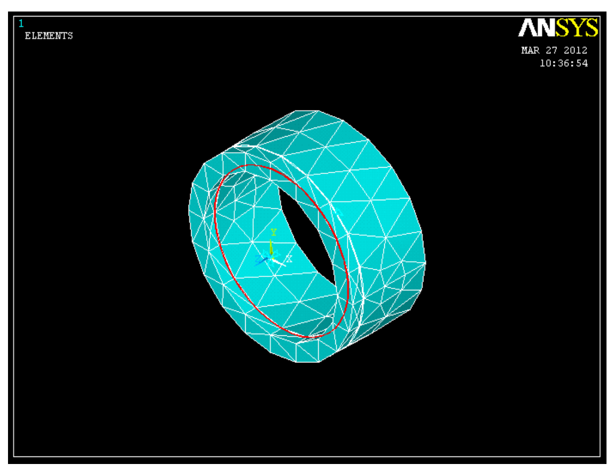

Fig. 2: Figure showing the application Combustion Gas Forces in 3-Dimensional Model after Meshing

4. PISTON FORCES CALCULATION AND FOR GAS FORCES

For the geometry analysis the work includes single cylinder, four stroke, and VCR (Variable Compression Ratio) Diesel engine. The specifications of engine are as shown in table1. In dealing with this there are some basic assumptions that need to be addressed.

Table 1: Specification of Diesel Engine [12]

Features	Specifications
Model	TV1
Make	Kirloskar oil Engine
Type	Four stroke, Water cooled Diesel
No. of cylinder	One
Combustion Principle	Compression ignition
Max speed	2000 rpm
Min speed	750 rpm
Min operating speed	1200 rpm
Crank Radius	39.5mm
Connecting Rod length	234mm
Cylinder diameter	87.5mm
Thickness of cylinder	10 mm
Piston diameter	87.44mm
Compression ratio	17.5:1
Material of cylinder	Grey cast iron
Stroke length	110mm
Cut off ratio at 2000rpm	2.5

Assumptions

i. The piston contacts the cylinder bore at the top and bottom of the piston skirt.
ii. Piston skirt deformation and linear elasticity are considered negligible.
iii. The skirt/liner oil film exhibits little effect on the transverse motion of the piston.
iv. Take the range of Compression pressure as 45, 50, 55, 60, 65, 70, 75 bar. And from that pressure calculate the combustion gas force.
v. The gas forces are assumed to act through the centre line of the piston so that the equations of motion apply no matter where the piston is in the cylinder.
vi. Behaviour of gases is considered close to ideal gases.
vii. Pressure developed after compression is calculated on the basis of assumption that compression process is following isentropic.

4.1 Calculation of Gas forces

Calculation of gas forces were carried out to define the compression pressure during combustion in an engine. Following are the calculations performed for featured analysis of vibration due to combustion gas force.

Force acting due to gas pressure on piston

$Force = P * \pi / 4 * d_p^2$ [10]

Where, P = Compression Pressure

d_p = Piston Diameter

5. Modelling and Simulation

Simulation technique can never be complete replacement for an experimental testing. But they can provide a useful service in that the effect of parameter changes may readily be expressed without resource cutting metal, leaving experiment to confirmatory role. Experiment must also provide the evidence needed to validate the mathematical model in first instance. Since, vibration characteristic can be found with empirical relations it is also helpful to get the point load that impact on the side of the cylinder, data was taken from books, which were used to run the program.The studied system representing an I.C. combustion engine is modeled as a cylinder liner which is consisting of cylinder thickness and stroke length. Simulation with the finite element software ANSYS lends to the integration to the piston and cylinder liner.

5.1 Finite Element Analysis

Finite element models were created based on the geometry of the system assembly. The modeling and simulation was carried out using the finite element software ANSYS [13]. For the problem use was made of a two dimensional beam and 3-dimensional cylinder liner. A job was created with its attendant job name. I the pre-processor domain, modeling was picked and then area selected to create the job dimensions. In element type regions the pre-processor for selecting the element type for 2-D (plane 42) and for 3-D (Solid 45). The type of material and its properties were chosen in the material properties - material models for solid. An element size edge of 0.001 was used to mesh the model. This was done signifying the default attribute and the plane 42 and Solid 45 with the material model1. Plane 42 is selected to mesh a plane in 2-dimensional beam and solid 45 is selected to mesh a plane in 3-dimension model.

Table 2 Properties of Material [11]

Material name		Modulus of elasticity	Poison's ratio	Density
Grey cast iron	FG 150	100800	0.26	7050
	FG 260	128500	0.26	7250
	FG 400	146100	0.26	7300

Also apply the reference cylinder liner temperature 473K [9].

5.2 Harmonic Analysis for 2-Dimensional Beam (Cylinder Liner)

Harmonic analysis deals with the response of structure to harmonically time varying loads. It gives the ability to predict the sustained dynamic behavior of structure. While the steady state deals with point loads the harmonic analysis deals with varying loads with frequency. For actuating the harmonic analysis, the meshing of 2D beam were completed to process further analysis of the work. It includes entering into solution and to select proper harmonic analysis. Choosing Full solution method and selecting the Frontal solver. In this work the damping ratio 2% for vibration or deflection analysis. Apply boundary conditions, by selecting the define load, by selecting the displacement from structural, as fix the left side of beam (cylinder liner) as all DOF zero and fix the right side of beam as UX zero. Selecting the force / moment, apply the combustion gas force at TDC of cylinder liner and also apply gravity force. Specified in cycles per second (Hertz) by a frequency range and number of sub-steps within that range (take harmonic frequency range 0-50Htz and number of sub-steps 10). And solve the problem. To select the time history postprocessor, in that plot the displacement vs. frequency. But before going to plot graph first define the post 26 variable. For these pick nodes that might deform the most, and then choose the DOF direction then graph them. In post processing the software gives the results for amplitude with the characteristics such as displacement vs. frequency. Firstly, select the Y-component of displacement and take the nodal solution and repeat the procedure for each material range and for each compression pressure.

5.3 For the material FG260 for 2-D

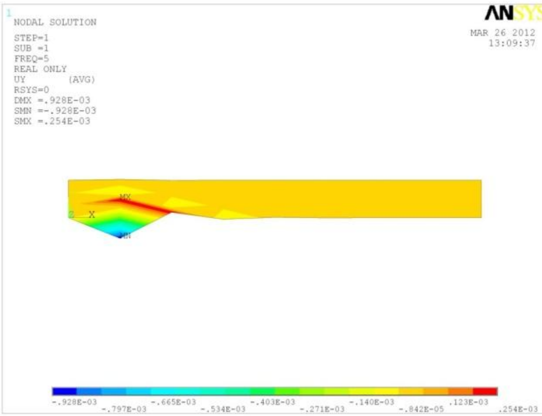

Fig3: Nodal solution for 45 bar compression pressure (FG 260)

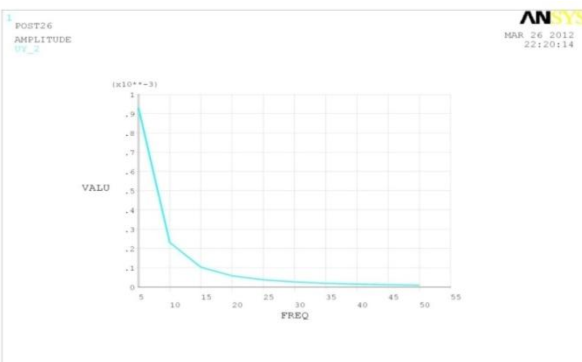

Fig4: Graph for 45 bar pressure (FG 260)

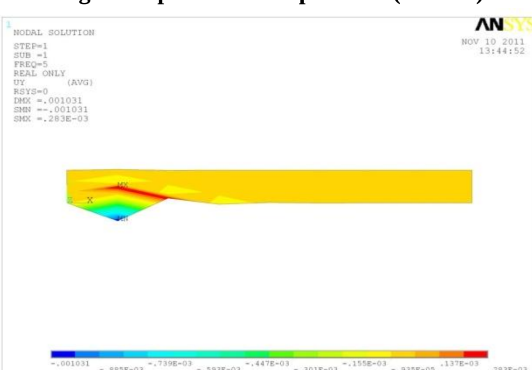

Fig5: Nodal solution for 50 bar compression pressure (FG 260)

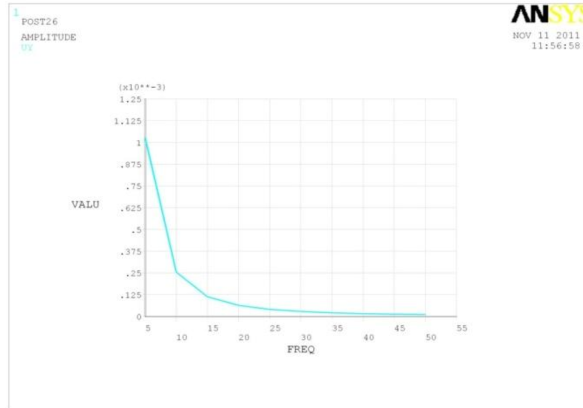

Fig6: Graph for 50bar pressure (FG 260)

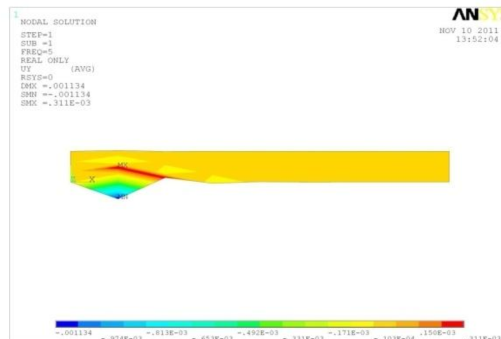

Fig7: Nodal solution for 55 bar compression pressure (FG 260)

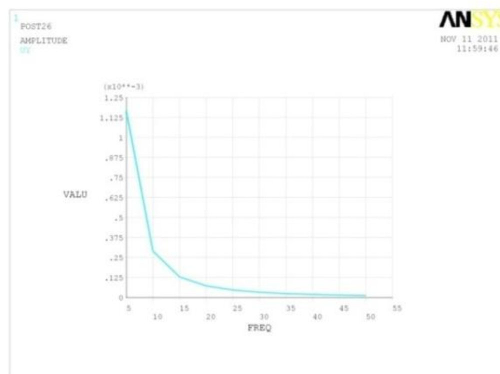

Fig8: Graph for 55 bar pressure (FG 260)

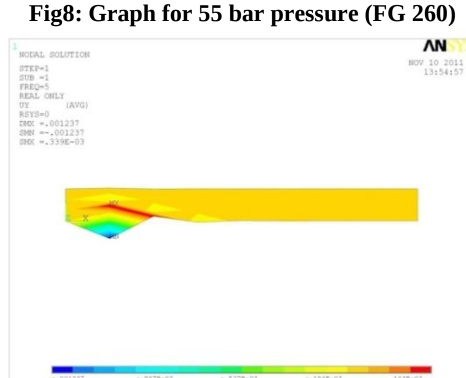

Fig9: Nodal solution for 60 bar compression pressure (FG 260)

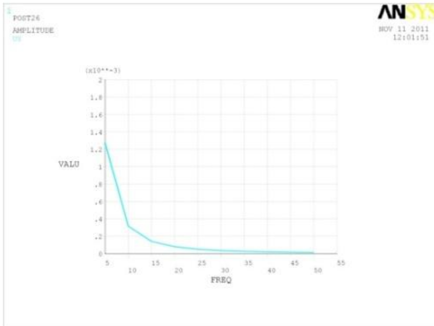

Fig10: Graph for 60bar pressure (FG 260)

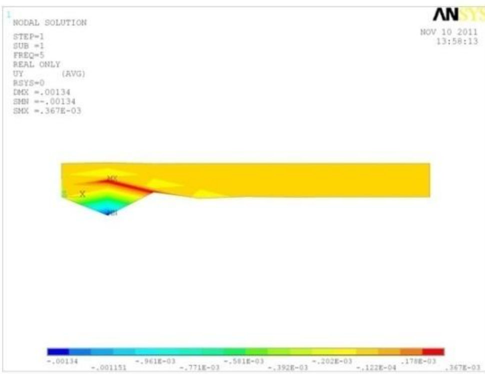

Fig11: Nodal solution for 65 bar compression pressure (FG 260)

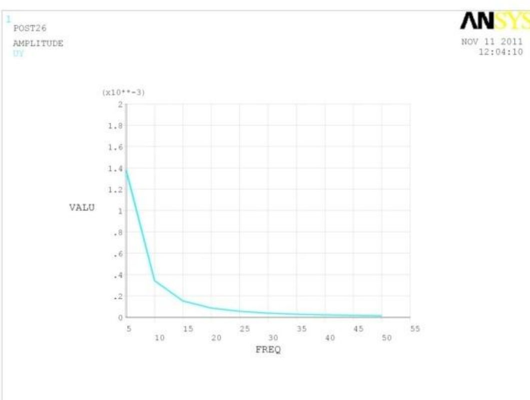

Fig12: Graph for 65bar pressure (FG 260)

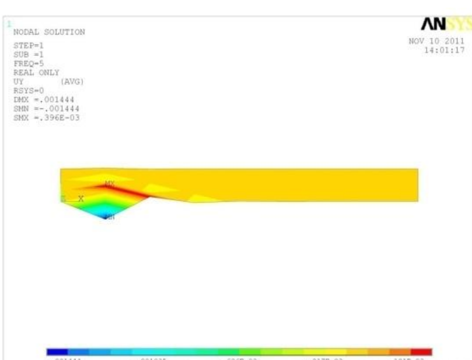

Fig13: Nodal solution for 70 bar compression pressure (FG 260)

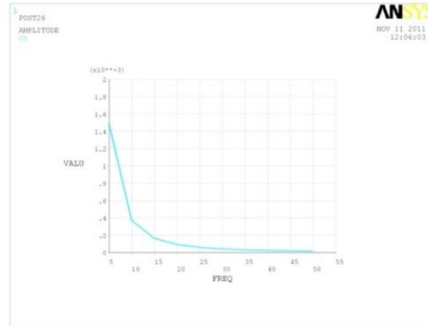

Fig14: Graph for 70 bar pressure (FG 260)

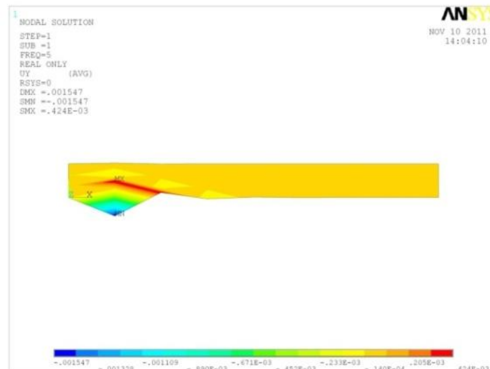

Fig15: Nodal solution for 75 bar compression pressure (FG 260)

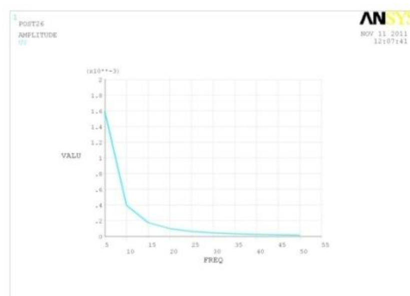

Fig16: Graph for 75 bar pressure (FG 260)

5.4 Harmonic Analysis for 3-Dimensional Model (Cylinder Liner)

For 3-dimensional model, drawing the two concentric circles, considering the thickness and diameter of cylinder and extrudes the same. After extruding, mesh the models. And start the harmonic analysis. In harmonic analysis, repeat the procedure as in 2-D up to boundary conditions. Instead of applying the combustion gas force, apply only compression pressure to 3D model. After that, repeat the same procedure as in 2D for getting nodal solutions. 3D model can deflect in two directions i.e. in Y and Z-direction.

6. RESULTS AND DISCUSSION

This chapter describes the results obtained after the analysis which includes different materials along with the directions. After applying gas forces to 2-dimensional and 3-dimensional cylinder liner, we get some results. In this chapter we discuss the node number at which we get the deflection due to each compression pressure for each material.In following table, at node 22, the 2-dimensional beam deflects in Y direction due to combustion gas force.

Table 3: Nodes at which 2-Dimensional beam Deflects in Y direction

Compression pressure / Property	FG 150 (Grey cast iron)	FG 260 (Grey cast iron)	FG 400 (Grey cast iron)
45bar	0.95242E-03	0.92803E-03	0.92293E-03
50bar	0.10583E-02	0.10312E-02	0.10255E-02
55bar	0.11641E-02	0.11343E-02	0.11280E-02
60bar	0.12699E-02	0.12374E-02	0.12306E-02
65bar	0.13757E-02	0.13405E-02	0.13331E-02
70bar	0.14815E-02	0.14436E-02	0.14357E-02
75bar	0.15874E-02	0.15467E-02	0.15382E-02

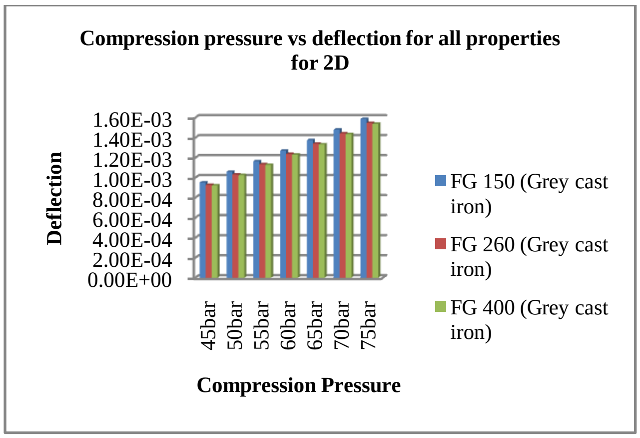

Fig.17: Compression Pressure vs. Deflection for all properties of materials for 2D

From above Graph at 45 bar compression pressure the minimum value of deflection for the material FG 400. And the maximum deflection value at 75 bar pressure for the material FG 150.

The 3-dimensional Model deflects in Y as well as in Z-direction due to combustion gas force. Firstly discuss the deflection in Y-direction. In following table, for the Grey Cast Iron material at node 167.

Table 4: Nodes at which 3-Dimensional Model Deflecion in Y direction

Compression pressure / Property	FG 150 (Grey cast iron)	FG 260 (Grey cast iron)	FG 400 (Grey cast iron)
45bar	2.09E-06	2.08E-06	2.10E-06
50bar	2.32E-06	2.31E-06	2.34E-06
55bar	2.55E-06	2.54E-06	2.57E-06
60bar	2.78E-06	2.77E-06	2.80E-06
65bar	3.01E-06	3.00E-06	3.04E-06
70bar	3.24E-06	3.23E-06	3.27E-06
75bar	3.48E-06	3.46E-06	3.51E-06

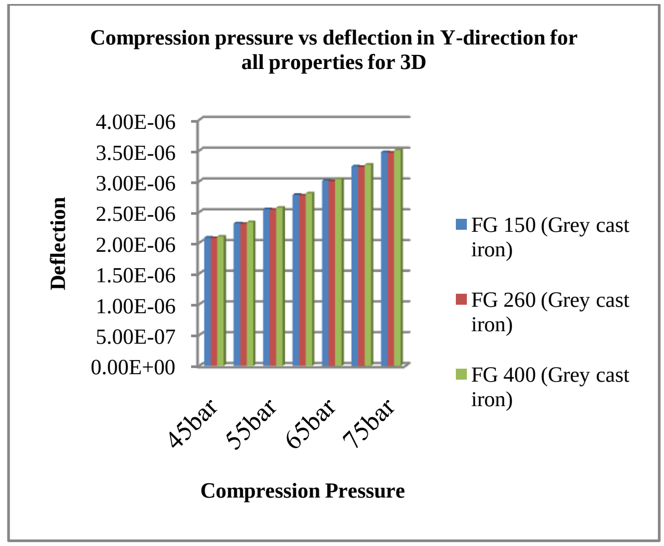

Fig.18: Compression Pressure vs. Deflection in Y-direction for all properties of materials for 3D

From above graph it is seen that, for grey cast iron material, at 45bar pressure the minimum value of deflection for the material FG 260. And the maximum values of deflection at 75 bar pressure for the material FG 400.
In following table, the 3-dimensional model deflects in Z direction at node 109 due to combustion gas force.

Table 5: Nodes at which 3-Dimensional Model Deflects in Z direction

Compression pressure / Property	FG 150 (Grey cast iron)	FG 260 (Grey cast iron)	FG 400 (Grey cast iron)	22588(HF 18) (Aluminum)
45bar	0.89688E-05	0.10823E-04	0.13033E-04	0.65291E-04
50bar	0.99653E-05	0.12026E-04	0.14482E-04	0.72546E-04
55bar	0.10962E-04	0.13229E-04	0.15930E-04	0.79800E-04
60bar	0.11958E-04	0.14431E-04	0.17378E-04	0.87055E-04
65bar	0.12955E-04	0.15634E-04	0.18826E-04	0.94309E-04
70bar	0.13951E-04	0.16837E-04	0.20274E-04	0.10156E-03
75bar	0.14948E-04	0.18039E-04	0.21722E-04	0.10882E-03

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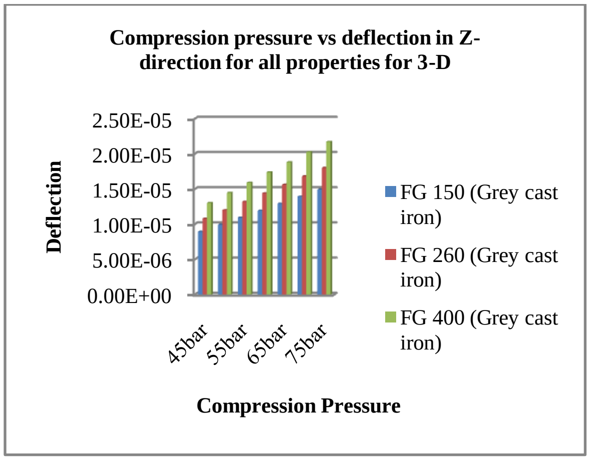

Fig.19: Compression pressure vs. Deflection for all properties of materials in Z-direction for 3D

From above graph it is seen that, the minimum value of deflection at 45 bar pressure for the FG 150 material and the maximum value of deflection at 75 bar pressure for the FG 400 material in Z-direction.

6.1 Reduction of Vibration

In this work, second major part undertaken to reduce the vibration with design point of view. In addition to this it is proposed from theoretical findings from the analysis that if we add 1mm thickness of cylinder from outer periphery, we obtained better result for reduction in vibration. Thus to reduce the vibration in diesel engine due to combustion gas forces by optimization method through increasing the thickness of cylinder by 1mm found better and the same results were demonstrated by the analysis. Some of the results of 2-dimensional beam for the material FG 150 are shown, and vibrations get reduced as compared to the conventional thickness of cylinder. Also same results were found for 3-dimensional model for the FG 400. ANSYS-10 version was utilized for post processing the results which are applied for 2-dimensional and 3-dimensional analysis. During the analysis the results obtained for different materials like FG 150 and FG 400. The results demonstrated by ANSYS were detailed discuss with reference to plots available for vibration reduction testing.

In 2-dimensional beam, the maximum deflection for Grey Cast iron at 75bar for FG 150 (0.15874E-02). But by increasing thickness by 1mm, deflection (shown in fig 20) which is less compared to old.

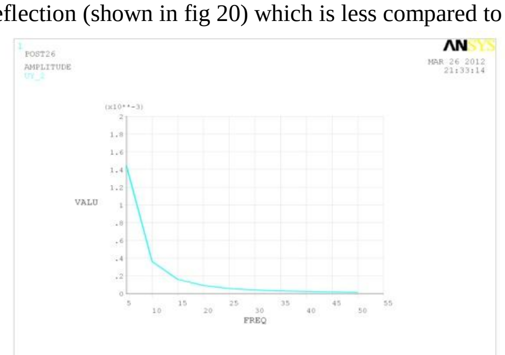

Fig 20: Figure showing the reduction of vibration for the material FG 150 for 2D

In 3-dimensional model, the maximum deflection for Grey Cast iron at 75bar for FG 400 (0.35052E-05). But by increasing thickness by 1mm, deflection (shown in fig 9.39) which is less compared to old.

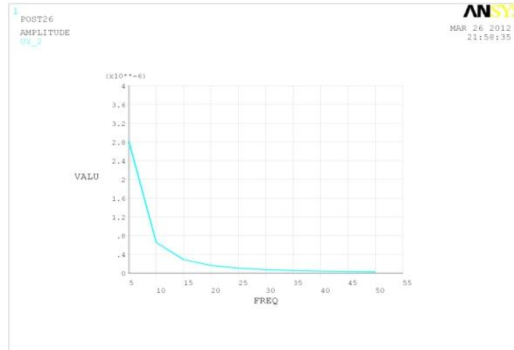

Fig 21: Figure showing the reduction of vibration for FG 400 material for 3D

7. CONCLUSION

In this paper, vibration analysis was carried out for 2-D and 3-D model along with different direction for different materials and nodes. In the analysis it is observed that 2-dimensional beam deflects least for FG 400 in Y-direction.

In 3-dimensional model it is observed that, FG 400 behaves similar to FG 150 and the difference in deflection between these two is negligible. In Z-direction the deflection of FG 400 is approximately same to all other materials.

Further in order to reduce vibration level, thickness of outer periphery of cylinder increased by 1mm. Better results were obtained i.e. the level vibration is found to be less for all materials. Therefore it is observed that we can predict and understand vibration levels in a better way during engine operating conditions.

REFERENCES

[1] W.J.Griffiths and J.Skorecki [1964] “Some aspects of vibration of a single cylinder diesel engine”, Journal of sound and vibration vol.1 (345-364).

[2] S.D.Haddad and H.L.Pullen [1974], “Piston slap as source of noise and vibration in diesel engine”, Journal of sound and vibration 34(2), (249-260).

[3] L. Chabot PSA Peugeot Citroen, Oliver G.K. Yates Ricardo Group, “Noise and Vibration Optimization of a Gasoline Engine”, Fifth Ricardo Software International User Conference in Detroit [2000].

[4] M. S. Khan, C. Cai and K. C. Hung, Institute of High Performance Computing, Singapore [2002], “Acoustics Field and Active Structural Acoustic Control Modeling in ANSYS”.

[5] S.H. Cho, S.T. Ahn And Y.H. Kim [2002], “A simple model to estimate the impact force induced by piston slap”, Journal of Sound and vibration Vol. 255 (229-242).

[6] Takayushi Aoyama, Sigeo Suzuki, Atasushi Kawamto, Takashi Noda, Toshihiro Ozasa, Takeyushi Kato, Takashi Ito “Preventive Design and Analysis of Cavitation Noise on

Diesel Engine"[2004], R and D Review of Toyata CRDL Vol. 40 No.1 36-42.

[7] G O Chandroth, A J C Sharkey and N E Sharkey Department of Computer Science, University of Sheffield, Sheffield, UK, "Cylinder Pressures and Vibration in Internal Combustion Engine Condition Monitoring", the research project sponsored by the EPSRC grant No. GR/K84257 [2007].

[8] Y.V.V. Satyanarayana Murthy Mechanical Department, Gitam University, Visakhapatnam, "Combustion Analysis and Knock Detection in Single Cylinder DI-Diesel Engine Using Vibration Signature Analysis" International Journal of Engineering Science and Technology (IJEST), Vol. 3 No. 1 [Jan 2011] page from 10-16.

[9] Anthony Deku, Subramanya Kompella, Department of Mechanical Engg., Blekinge, Sweedon, "Cavitation in Engine Cooling Fluid Due to Piston Cylinder Assembly Forces", ISRN : BTH-AMT-EX-[2006]/D-13—SE.

[10] R.S.Khurmi and J.K.Gupta, "Machine Design", S.Chand Publication[page no.[1137].

[11] Dr. Sadhu Singh, "Machine Design", Khanna Publication Table A.4, page no. 1126 and 1143.

[12] VCR Engine Test set up, 1-cylinder, 4-strike, Diesel (Computerised), Kirloskar Oil Engine make, Instruction manual, Apex Innovations.

[13] ANSYS Release 10 Documentation.