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Normal Mode Analysis for a Six Cylinder V-Engine

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ABSTRACT

In an automobile, IC engines are a critical component that generates a significant amount of noise and vibration. The combustion cycle generates forces in this location. As a result, the components fail as a result of these forces. In this paper, an attempt is made to perform Normal Mode Analysis (NMA). The values of various parameters are monitored, and the design is validated as a result. To mesh and pre-process the data, a pre-processing workbench called Hyper Mesh was used.

Keyword:Automobile, IC Engine, Noise, Vibration, NMA

Introduction

Because the automobile is one of the most commonly used modes of transportation, engineers are constantly working to improve its efficiency. The engine's moving parts generate noise and vibration. When the level of noise increases, the rider's comfort suffers. As a result of increased vibration, the parts are acted upon by additional forces, causing them to wear out before their time.

Mode Analysis

The study of the dynamic properties of systems in the frequency domain is known as modal analysis. Traditionally, this was accomplished using a SIMO (single-input, multiple-output) approach, in which one excitation point is used, and the response is measured at numerous other points. A hammer survey in the past, using a fixed accelerometer and a roving hammer as excitation, produced a MISO (multiple-input, single-output) analysis, which is mathematically identical to SIMO due to the principle of reciprocity. MIMO (multi-input, multiple-output) has become more practical in recent years, with partial coherence analysis determining which part of the response comes from which excitation source.

Excitation signals are typically classified as impulse, broadband, swept sine, chirp, and possibly others. Each has its own set of benefits and drawbacks. Modal analysis aids in determining the vibration characteristics (natural frequencies and mode shapes) of a mechanical structure or component by demonstrating the movement of various parts of the structure under dynamic loading conditions, such as those caused by electrostatic actuators. Natural frequencies and mode shapes are critical parameters to consider when designing a structure for dynamic loading conditions.

- **Modes**

A mode in a dynamical system is a standing wave state of excitation in which all of the system's components are affected sinusoidally at a fixed frequency associated with that mode, according to wave theory of physics and engineering. Because no real system can perfectly fit within the standing wave framework, the mode concept is used as a general characterization of specific states of oscillation, allowing the dynamic system to be treated in a linear fashion, allowing for linear superposition of states.

- **Nodes**

In a one-dimensional system, the vibration will have nodes, or places where the displacement is always zero, at any given mode. These nodes correspond to mode shape points where the mode shape is zero. Because a system's vibration is given by the mode shape multiplied by a time function, the displacement of the node points is always zero.

Pre-Processing

In terms of NMA, pre-processing entails providing excitation points, load, contacts, and meshing the body.

- **Meshing**

To perform the meshing and pre-processing, Hypermesh, a pre-processing workbench, is used.
The engine body is meshed with a volume tetra mesh.

- **Mesh Details**
    - Element Size:4.00
    - Minimum element size: 0.800
    - Feature angle: 30.0

- 2D elements: Trias
- 3D elements: Tetras
- Proximity and curvature are used to increase the mesh quality
- Nodes generated: 532637
- Elements generates: 4509331

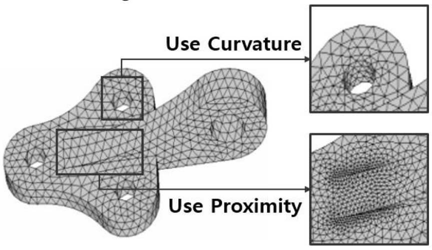


Fig 1: Curvature and proximity

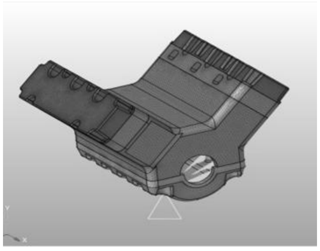


Fig 2: Mesh body of engine

- **Load**

A load should be applied to the model in order to understand its behaviour in relation to the various parameters. A load of 1000N is specified in this analysis. 1000N was chosen because a literature review revealed that 1000N is used as a default load by various industry personnel.
The number of nodes required for the post processor is specified as 10.

- **Excitation point**

As a result of accurately defining the excitation points in relation to the physical model, a node is created at the lower part of the engine block that replicates the primary excitation location in order to improve the model's accuracy.

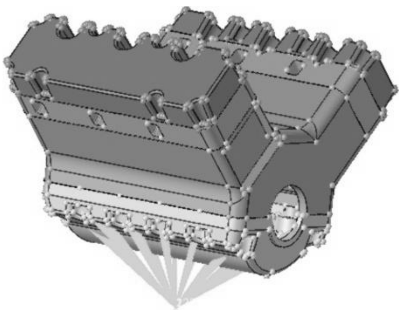


Fig 3: Excitation point location

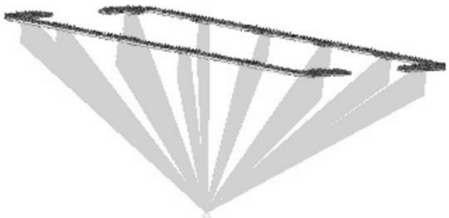


Fig 4: Excitation point

- **Materials Used**

In order to resemble a precise physical model materials are assigned to the model.
Engine block

Table 1: Material properties of GCI ASTM40

Grey cast iron ASTM 40				
Chemical composition: C=2.7-4%, Mn=0.8%, Si=1.8-3%, S=0.07% max, P=0.2% max				
Property	**Value in metric unit**		**Value in US unit**	
Density	$7.06*10^3$-$7.34*10^3$	kg/m^3	441-458	lb/ft^3
Modulus of elasticity	124	GA	18000	ski
Thermal expansion (20 °C)	$9.0*10^{-6}$	$°C^{-1}$	$5.0*10^{-6}$	in/(in* °F)
Specific heat capacity (25 °C)	490	J/(kg*K)	0.117	BTU/(lb*°F)
Thermal conductivity	53.3	W/(m*K)	370	BTU*in/(hr*ft^2*°F)
Electric resistivity	$1.1*10^{-7}$	Ohm*m	$1.1*10^{-5}$	Ohm*cm
Tensile strength	276	MPa	40000	psi
Elongation	1	%	1	%
Shear strength	400	MPa	58000	psi
Compressive yield strength	Min. 827	MPa	Min. 120000	psi
Fatigue strength	138	MPa	20000	psi
Hardness (Brinell)	180-302	HB	180-302	HB
Wear resistance	Low			
Corrosion resistance	Low			
Weldability	Low			
Machinability	Good			
Cast ability	High			

- **Cylinder Head**

  Material Used: Malleable cast iron ASTM A220

Table 2: Material properties of CI ASTM220

Malleable cast iron ASTM A220				
Chemical composition: C=2-2.7%, Mn=0.25-1.25%, Si=1-1.75%, S=0.03-0.18%, P=0.05%max				
Property	Value n metric unit		Value n US unit	
Density	$7.2*10^3$-$7.45*10^3$	kg/m^3	450-465	lb/ft^3
Modulus of elasticity	172	GPa	25000	ksi
Thermal expansion (20 ºC)	$11.9*10^{-6}$	$ºC^{-1}$	$6.6*10^{-6}$	in/(in* ºF)
Electric resistivity	$3.9*10^{-7}$	Ohm*m	$3.9*10^{-5}$	Ohm*cm
Tensile strength	586	MPa	85000	psi
Yield strength	483	MPa	70100	psi
Elongation	3	%	3	%
Hardness (Brinell)	217-269	HB	217-269	HB
Wear resistance	Low			
Corrosion resistance	Low			
Weldability	Impossible			
Machinability	Medium			
Castability	Good			
Shock resistance	Good			

- **Oil pan**

  Material Used: Alloy steel SAE 4027

Table 3: Material properties of SAE 4027

SAE 4027				
Chemical composition: C=0.40%, Mn=0.8%, Mo=0.25%				
Property	**Value in metric unit**		**Value in US unit**	
Density	$7.872*10^3$	kg/m^3	491.4	lb/ft^3
Modulus of elasticity	205	GPa	29700	ksi
Thermal expansion (20 ºC)	$12.0*10^{-6}$	$ºC^{-1}$	$6.60*10^{-6}$	in/(in* ºF)
Specific heat capacity	477	J/(kg*K)	0.114	BTU/(lb*ºF)
Thermal conductivity	44.6	W/(m*K)	309	BTU*in/(hr*ft²*ºF)
Electric resistivity	$2.45*10^{-7}$	Ohm*m	$2.45*10^{-5}$	Ohm*cm
Tensile strength (annealed)	515	MPa	74700	psi
Yield strength (annealed)	325	MPa	47100	psi
Elongation (annealed)	30	%	30	%
Hardness (annealed)	78	RB	78	RB
Tensile strength (normalized)	640	MPa	92800	psi
Yield strength (normalized)	420	MPa	60900	psi
Elongation (normalized)	26	%	26	%
Hardness (normalized)	88	RB	88	RB

Result

Results of various parameters are observed and based on this the design is validated. Below are the deformation plots of 10 modes

Mode 1

Normal mode analysis (Fig 5) done on the engine at force (F) =6.0811E+02 N at an angle 180,Therespective outcome are Max= 4.073E+00 , Min= 0.00E+00.

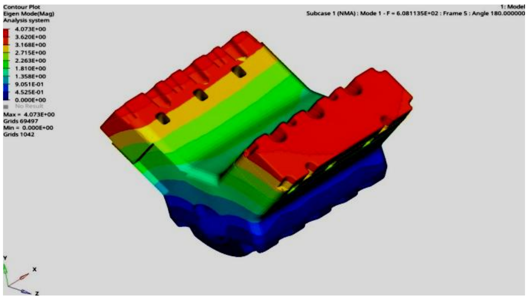


Fig 5: Eigen mode contour plot of mode-1

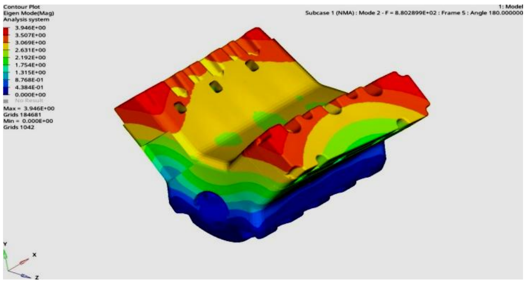


Fig 6: Eigen mode contour plot of mode-2

Mode 2

Normal mode analysis (Fig 6) done on the engine at force (F) = 8.802899E+02 at an angle180,The respective outcome are Max= 3.946E+00 , Min= 0.00E+00.

Mode 3

Normal mode analysis (Fig 7) done on the engine at force (F) = 1.058613E+03 at an angle 180,Therespective outcome are Max= 5.381E+00 , Min= 0.00E+00

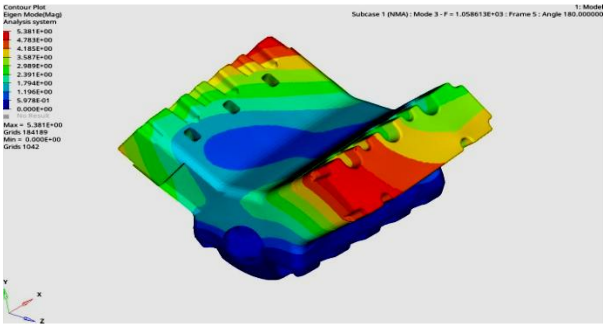


Fig 7: Eigen mode contour plot of mode-3

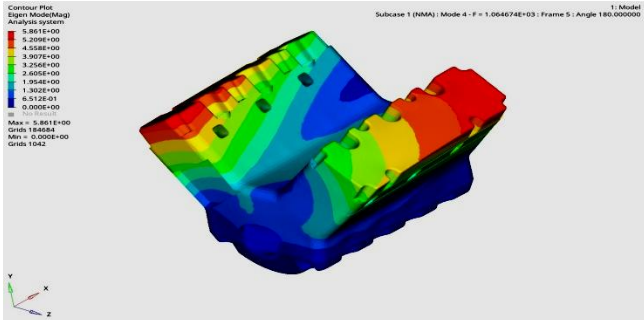


Fig 8: Eigen mode contour plot of mode-4

Mode 4

Normal mode analysis (Fig 8) done on the engine at force (F) =1.064674 at an angle 180,Therespective outcome are Max= 5.8615E+00 , Min= 0.00E+00.

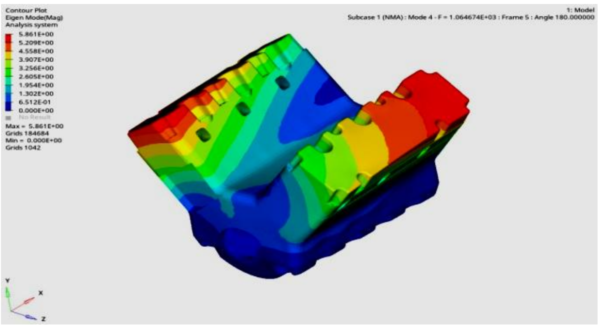


Fig 9: Eigen mode contour plot of mode-5

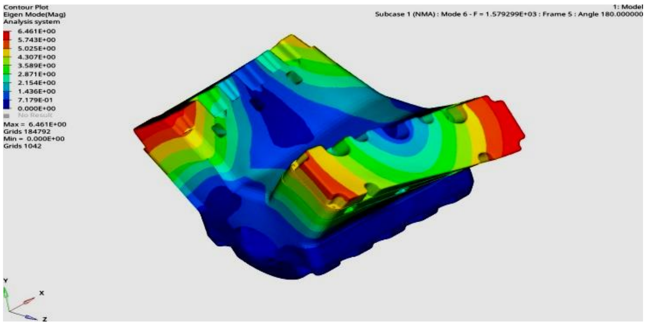


Fig 10: Eigen mode contour plot of mode-6

Mode 5

Normal mode analysis (Fig 9) done on the engine at force (F) =1.064674E+03 at an angle 180,Therespective outcome are Max= 5.861E+00 , Min= 0.00E+00.

Mode 6

Normal mode analysis (Fig 10) done on the engine at force (F) =1.579299E+03 at an angle 180,Therespective outcome are Max= 6.461E+00 , Min= 0.00E+00.

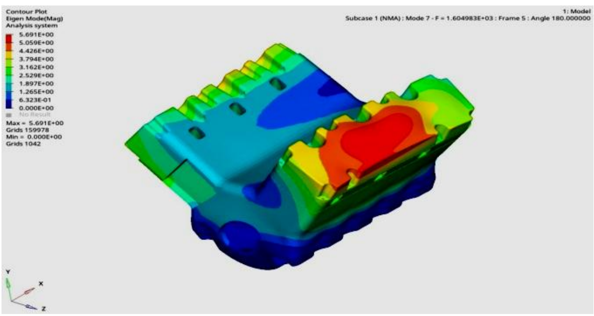


Fig 11: Eigen mode contour plot of mode-7

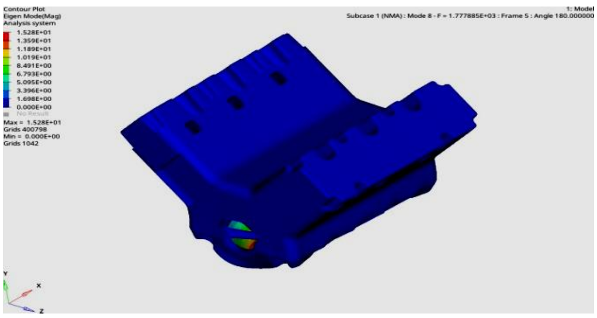


Fig 12: Eigen mode contour plot of mode-8

Mode 7

Normal mode analysis (Fig 11) done on the engine at force (F) =1.604963E+03 at an angle 180,Therespective outcome are Max= 5.691E+00 , Min= 0.00E+00.

Mode 8

Normal mode analysis (Fig 12) done on the engine at force (F) =1.7778885E+03 at an angle 180,Therespective outcome are Max= 1.528E+01 , Min= 0.00E+00.

Fig 13: Eigen mode contour plot of mode-9

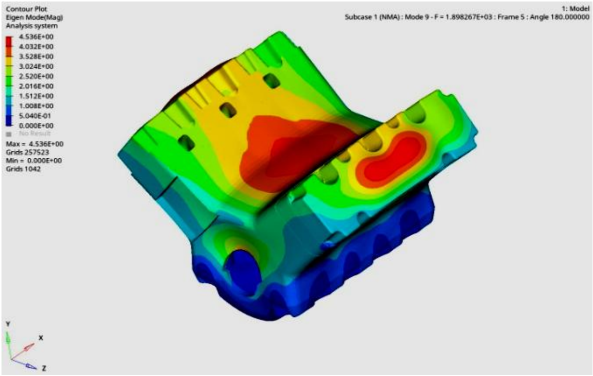
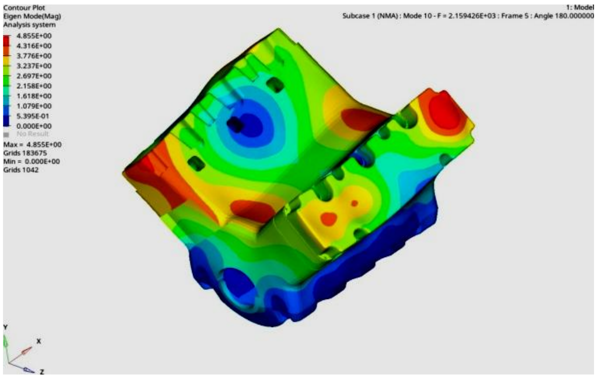


Fig 14: Eigen mode contour plot of mode-10



Mode 9

Normal mode analysis (Fig 13) done on the engine at F= 1.898267E+03Hz at an angle 180, Therespective outcome are Max= 4.536E+00, Min= 0.00E+00.

Mode 10

Normal mode analysis (Fig 14) done on the engine at F= 2.159426E+03Hz at an angle 180, Therespective outcome are Max= 4.855E+00, Min= 0.00E+00.

The results of Frequency at mode1 to mode 10 are compiled in the below table 4. It is clear from the table that maximum value of frequency comes out to be 8.802899E+02 Hz at mode 2 and Minimum value is 1.064674E+03 Hz at mode 4

Table 4: Frequency at modes

S. No	Mode	Frequency(Hz)
1	1	6.081135E+02
2	2	8.802899E+02
3	3	1.068613E+03
4	4	1.064674E+03
5	5	1.364984E+03
6	6	1.572999E+03
7	7	1.604983E+03
8	8	1.777885E+03
9	9	1.898267E+03
10	10	2.159426E+03

Conclusion

IC engines are one of the critical part creates large amount of noise and vibration in an automobile. Here forces are generated due to the combustion cycle. As a consequential effect these forces causes failure of the components. In this paper an effort is made to carry out Normal Mode Analysis (NMA) at 10 modes and Eigen mode contour plots are drawn at different frequency. Results of various parameters are observed and based on this the design is validated Hyper mesh a pre-processing workbench has been used to carry out the meshing and pre-processing.

References

1. LeiLi, Yufan Zheng, MaolinYang, JiewuLeng, Zhengrong Cheng, Yanan Xie, Pingyu Jiang, Yongsheng Ma, A survey of feature modeling methods: Historical evolution and new development Robotics and Computer-Integrated Manufacturing, Volume 61, February 2020, 101851
2. Gerges S N Y, De Luca J C and Lalor N (2005), 'Effect of cylinder lubrication on piston slap', SAE paper 2005-01-2165.
3. Haddad S D (1995), 'Theoretical treatment of piston motion in IC piston engine for the prediction of piston slap excitation', Mechanism and Machine Theory, 30(2), 253–269.
4. Anastasios Zavos, Pantelis G Nikolakopoulos, (2017) Measurement of friction and noise from piston assembly of a single-cylinder motorbike engine at realistic speeds, Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering ISSN: 0954-4070. Nayak, N., Reddy, P., Aghav, Y., Sohi, N. et al., "Study of Engine Vibration Due to Piston Slap on Single Cylinder High Powered Engine," SAE Technical Paper 2005-26-046, 2005, https://doi.org/10.4271/2005-26-046.
5. Kelly P, Biermann J W, Using Taguchi methods to aid understanding of a multi-body clutch pedal noise and vibration phenomenon, Multi-Body Dynamics: Monitoring and Simulation Techniques, Mechanical Engineering Publications Ltd, 2004
6. Cheng Z, Analysis of Automobile Crash Response Using Wavelets, SAE Paper 2002-01 0183, 2002.
7. Fabi, P., Flekiewicz, M., Madej, H., Wojnar, G. et al., "Influence of Piston Slap on Engine Block Vibration," SAE Technical Paper 2007-01-2163, 2007, https://doi.org/10.4271/2007-01-2163.
8. Doğan, S. N.; Ryborz, J.; Bertsche, B.: Rattling and Clattering Noise in Automotive Transmissions – Simulation of Drag Torque and Noise, Symposium – Transient Processes in Tribology, Leeds–Lyon Symposium, Lyon, September 2003.