International Journal For Technological Research In Engineering
Volume 5, Issue 9, May-2018 *ISSN (Online): 2347 - 4718*

EIGENVALUE ANALYSIS OF RAILWAY COACH USING FINITE ELEMENT METHOD

Srihari Palli[1], Ramji Koona[2]
[1]Mechanical Engineering Department, AITAM, Tekkali, A.P., INDIA.
[2]Mechanical Engineering Department, AUCOE, Visakhapatnam, A.P., INDIA.

ABSTRACT: The first step in understanding the dynamic behaviour of any ground vehicle is to find its natural frequencies. Dynamic response of railway coach is a critical portion in the design of coach as well as to improve the ride comfort of the passengers. The railway coach considered for the current study is an Indian railways ICF sleeper coach. Indian railway sleeper coaches typically consist of two railway bogies, where the central distance of the C.G. between the bogies is 14900mm. The geometric model of the Coach along with its two bogies and other components is built in Unigraphics Nx7.5 CAD package and is further imported into Hypermesh and ANSYS to build the finite element models of the bogie and coach. In this research paper, free vibration analysis or eigenfrequency modal analysis of the railway bogie as well as of the rail car body is carried out using finite element method to extract the first few modes of vibration under laden and unladen conditions. Modal analysis of the coach model is carried out in two stages, initially a single bogie is considered and later the entire coach model along with its two bogies is analysed using Block Lanczos method in ANSYS. The eigenfrequencies extracted along with the corresponding mode shapes of the bogie and coach models show that they are in good agreement with that of the values of the Indian railway coach observed in various standard articles.

KEYWORDS: Indian railway coach; Modal analysis; FE model; ANSYS; Modeshapes; frequency ***ACRONYMS and NOMENCLATURE:***

ICF	***Integrated Coach Factory***
DOF	***Degree of Freedom***
C.G	***Centre of Gravity***

I.INTRODUCTION

Railway transport is a means of conveyance of passengers and goods by way of wheeled vehicles running on rail tracks. In contrast to road transport, where vehicles merely run on a prepared surface, rail vehicles are directionally guided by the tracks they run on. Design and development of lighter and faster rail vehicle with better ride comfort is the main objective for rail dynamics engineers and researchers over the past few decades. Thorough investigation of the passenger car body interaction is essential to design a coach with better ride comfort [Carlbom, 2000] , [Sharma,R.C. et al, 2014a, 2014b, Sharma, S.K. et al 2014], [Sharma and Kumar, 2014], [Sharma,R.C., 2014], [Sharma, R.C.. et al, 2015a], [Sharma, S.K. et al, 2015]. In general, coupled lateral and vertical vibrations are transmitted to the passengers due to track surface irregularities via the bogies and the car body. The car body is not rigid, but it bends and twists from the excitation coming from the bogies. The railway coach motion on the rails is a combination of vertical and lateral motions. Natural frequencies and mode shapes for a chassis structure were determined using finite element techniques [Ali et al, 1970], [Kumar et al, 2012]. Dynamic behaviour of chassis structure was analysed for the finite element model of a diesel engine chassis and modal analysis was performed for various boundary conditions using ANSYS software [Jinzhu et al, 1988]. The dynamic interaction of the vehicle/track system was analysed by assuming the vehicle model as a rigid body subjected to a concentrated force, and represented a bogie carrying half of the car body weight [Abrahamsson and Nielson, 1992]. FE model of Indian railway coach was idealized using combination, shell and beam elements using HYPERMESH and ANSYS. Eigen frequency analysis is carried out to extractfew natural modes of vibration of the vehicle [Ramji et al, 2007], [Sharma et al, 2017a]. Eigen Frequency Modal analysis of the bogie model using Block Lanczos method in ANSYS is carried out to extract first few natural modes of vibration of the bogie. Harmonic peaks in response to the sinusoidal excitation fed at the wheels of the bogie are observed to be matching with the natural frequencies obtained [Palli et al, 2015], [Palli and Ramji, 2015], [Sharma & Kumar, 2016a, 2016a].

The primary and secondary hunting speeds of the railway vehicle were determined to investigate the dynamic stability. Critical parameters which influence the railway vehicle dynamic stability were analysed [Sharma, 2011a], [Sharma, 2013a], [Sharma, 2013b], [Sharma et al, 2015c], [Dhingra et al, 2015].A FE model was developed to simulate the steady state dynamic interaction between vehicle and track for any speed [Palli et al, 2014], [Sharma and Chaturvedi, 2016], [Sharma,R.C. et al, 2017], [Sharma & Kumar, 2017]. Finite element technique was used for analysis of bogie frame under load conditions such as vertical loads, transverse loads, self-weight of bogie frame, torque arm reaction loads with the usage of spring, shell, rigid and gap elements [Sam Paul et al, 2002]. Critical speed calculations were performed for numerical model of a Pendolino train generated in ADAMS/Rail using eigenvalue and transient analyses [Gugliotta et al, 1997]. An eighteen DOF model is developed to investigate coupled motion of driveline and the tire/suspension assembly in order to attain vehicle body longitudinal acceleration subject to engine excitations. Road surface irregularities are simulated as a stationary random process and further vertical acceleration of the vehicle body were obtained by considering quarter-car model including suspension/tire mechanisms and road input force. ISO diagrams are utilized to compare RMS vertical and lateral accelerations of the car body with the fatigue-decreased proficiency boundaries and to determine harmful frequency regions [Neda, 2011] 28. The dynamic response of a passenger vehicle in terms of acceleration and strain was computed at all nodes by giving PSD of acceleration as input to the tires of a passenger vehicle using random response [Karuppaiah et al, 1999], [Karuppaiah et al, 2003]. Three types of practically important imperfections in the vehicle/track system were investigated [Li and Young, 2003],[Sharma and Kumar, 2017],[Sharma and Kumar, 2018a], [Sharma and Kumar, 2018b]. The rail corrugation and wheel flat were assumed as sinusoidal functions. The ride behaviour of the rail vehicle was studied by varying its one parameter at a time in order to estimate its individual effect on vertical and lateral ride [Sharma, 2011a], [Sharma, 2011b]. Coupled vertical-lateral mathematical model of an Indian Railway General Sleeper coach using Lagrangian dynamics and its motion has been studied 37. It was concluded that in developing the mathematical model to study vertical response, it would not be adequate to include bounce; pitch and roll degrees of freedom of the components but yaw and lateral degrees of freedom also need to be considered [Sharma, 2012], [Sharma, 2016a], [Sharma, 2016b].

Literature reveals that various methodologies have been adopted by researchers across globe in the study of dynamic behaviour of the railway coach and bogie/chassis. Finite element analysis is used for the study of railway coach and bogie as well as to analyse its dynamic response. FE software has been found vital in performing dynamic analysis and also finding the natural frequencies of the vehicle under operating conditions.

II. OBJECTIVE AND SCOPE OF WORK

Eigen frequency modal analyses conducted on an Indian Railway coach in two stages. Initially, the first few natural frequencies of a 6 Ton ICF bogie are obtained under unladen and laden conditions as explained in the paper of the authors [Palli&Ramji, 2015]. Further, natural frequencies of the ICF coach with 52 Tons weight are obtained in modal analysis.

This paper is organised as follows. Section 1 provides introduction and review of literature on vehicle dynamics and railway coach. Section 3 presents the details of methodology for design and modelling of railway coach and bogie. Sections 4 and 5 give the descriptions of modal analysis results of bogie and coach respectively, and finally conclusions from present work are drawn in section 6.

III. MODELING OF RAILWAY COACH

The railway coach consists of a car body supported by two bogies one each at front and rear ends. Bolsters are the intermediate members between the car body and each bogie frame which are connected to the car body through a central pivot and side bearers. The body bolster is welded to the coach body whereas the bogie bolster is a free floating member which takes the entire load of the coach through the body bolster. The body bolster transfers the dead weight of the coach body to the bogie frame [Sharma, 2014]. The bogie frame supports the weight of the car body through a secondary suspension located between the car body and the bogie frame. The load taken by the secondarysuspensions of the bogie frame is in turn transferred to the primary suspensions at the wheels of the bogie. In passenger vehicles, each bogie usually consists of twowheel axle sets that are connected throughthe primary suspension to the bogie frame. Additionally, wheels of bogie are usually tapered or profiled to provide a self centering action as the axle traverses along the track.

3.1 Geometric Modeling of Coach

The coach model has been built in such a way that initially the bogie is modelled and then the car body shell, trough floor, under frame, end wall and other significant members together with the body bolster are modelled using appropriate part modelling commands in UNIGRAPHICS NX7.5 and saved as a part model. Further the car body part model and two instances of bogie part model are assembled using the assembling constraints in NX 7.5 to develop the geometric model of the coach. Geometric model of the Indian Railway 6 Ton ICF bogie as shown in Fig.1.

Assumptions in Geometric Modelling of Bogie:

- Geometric features which are insignificant from load bearing point of view are suppressed.
- The curvature of the bogie frame where cross-section changes takes place is neglected.
- Bogie frame, wheel set, axle set and bogie bolster are modelled and remaining components are neglected.

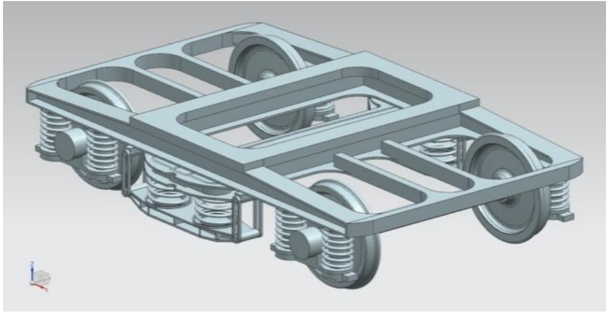

Fig.1: Geometric Model of ICF Bogie

Present study is concentrated on the dynamic behaviour of the coach as a whole; hence the following assumptions have been made in developing the geometric model of the coach.

- Coach interior features such as berths, electric equipment and other aesthetic components are ignored.
- Shell is treated as thin walled hollow girder, and hence thin surface is used to model external and internal walls around the members of the shell such as sole bars, cant rails, stanchions and between the window panels.
- As the body bolster is a welded member between the bogie bolster and the bottom surface of the trough floor of the coach, two thin solid blocks of a vertical height of 70 mm, which is equal to the clearance distance between the bogie and coach are modelled to connect the car body and the bogies at the front and rear end.
- The over buffer length of coach is ignored in modelling and only over body length of coach is only considered.

The geometric model of the Indian railway ICF coach[IRCAMT] built in Unigraphics NX7.5 is shown in fig.2.

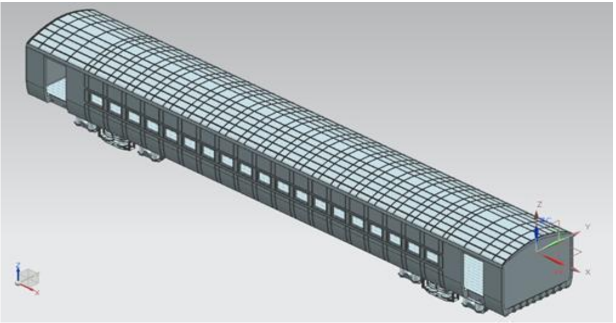

Fig.2: Geometric Model of Railway Coach

3.2 Finite Element Modelling of Railway Coach

Finite element analysis has been carried out for the coach model in two stages. In the first stage, geometric model of bogie developed in UNIGRAPHICS NX7.5 is exported to ANSYS in parasolid format. Primary and secondary suspensions modelled in geometric model have been replaced with spring elements using COMBIN14. Fig. 3 represents the finite element model generated after tetrahedral meshing using SOLID92 elements in ANSYS.

In the second stage, geometric model of the ICF railway coach developed in UNIGRAPHICS NX7.5 is exported to HYPERMESH 10 in parasolid format to develop the finite element model of the coach for carrying out the required analyses. Since the geometric model of the railway coach is a complex assembly to obtain its mesh, HYPERMESH is preferred due to its faster computing ability and also due to the interoperability between HYPERMESH and ANSYS in terms of element types and file extensions. The meshed coach model in HYPERMESH 10 is further exported to ANSYS 12.1 Mechanical APDL in cardscan database format.

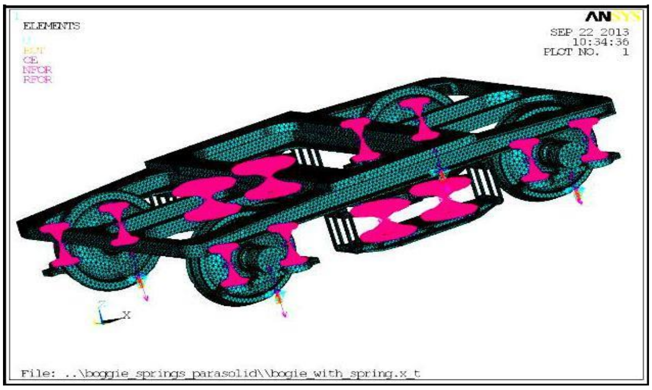

Fig.2: FE Model of ICF Bogie

Assumptions in Finite Element Modelling of Bogie:

- The Primary and Secondary suspensions are modelled as linear spring elements in the FE Model.
- As majority of the material in the bogie body is steel, material properties of steel are considered entirely for the element types used in the FE Model of the Bogie.

Various constants considered for Primary and Secondary suspension stiffness and damping have been taken from the Indian Railways maintenance manual of BG coaches and tabulated in Table 1 and Table 2 respectively. The material properties considered for different bogie components of steel are tabulated in Table 3.

Table 1: Stiffness values

Parameter Name	Parameter Value (N/m)
Primary spring vertical stiffness between wheel and bogie frame (K_{pz})	$1.077 * 10^6$
Primary spring lateral Stiffness between wheel and bogie frame (K_{py})	$23 * 10^6$
Secondary spring vertical stiffness between bogie frame and bolster (K_{sz})	$1.695 * 10^6$
Secondary spring lateral stiffness between bogie frame and bolster (K_{sy})	$0.4648 * 10^6$

Table 2: Damping Coefficients

Parameter Name	Parameter Value (N-s/m)
Primary spring vertical damping between wheel and bogie frame (C_{pz})	$0.082 * 10^6$
Primary spring lateral damping between wheel and bogie frame (C_{py})	$1 * 10^6$
Secondary spring vertical damping between bogie frame and bolster (C_{sz})	$0.118 * 10^6$
Secondary spring lateral damping between bogie frame and bolster (C_{sy})	$2 * 10^6$

Table 3: Material properties of steel

Property	Density ñ(Kg/m^3)	Young's Modulus E(N/mm^2)	Poisson's Ratio (õ)
Value	7.85e-9	2.0e5	0.3

The idealization of railway coach is done by considering car body shell with various channel sections, trough floor with cross beams, body bolsters on front and rear ends, and two bogie assemblies on either ends where as remaining parts are neglected.

Assumptions in Finite Element modelling of Coach:

- The major portion of the car body is the shell and hence the hollow shelled structure is considered without any interior elements.
- Constraint equations with line elements have been used to account for the stiffness between the body bolsters and car body.

To discretise the solid components of the coach like body bolster, bogie frame, bogie bolster and wheel axle sets SOLID 45 element type has been used in HYPERMESH 10. The coach shell with the channels such as sole bars, stanchions etc. are meshed using SHELL 63 in HYPERMESH 10. The suspensions between the car body of the coach and the bolsters are defined using the line element type COMBIN14. The discretised railway coach model along with the defined suspensions and element types is shown in fig. 4.

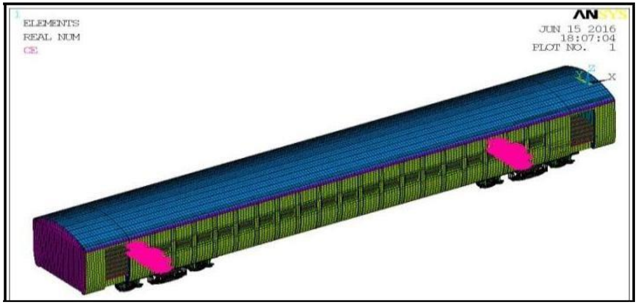

Fig.4: Finite Element Model of the Railway Coach

COACH MODAL ANALYSIS RESULTS AND DISCUSSION

In any dynamic analysis the eigenvalue free vibration analysis is performed to understand how it behaves when it is just disturbed momentarily and then left to oscillate freely under its self-weight. The Block Lanczos eigenvalue solver in ANSYS is used to predict the natural modes of vibration. This method computes first few natural frequencies and mode shapes for large and symmetric structures efficiently. The first few natural frequencies for the hypothetical unladen (without passenger load) condition and laden (with passenger load lumped at center of gravity of the bogie) condition are extracted. The key modes and their corresponding natural frequencies are tabulated in Table 4.The natural frequencies and modeshapes of an Indian Railway ICF bogie are extracted by using free vibration analysis .

Table 4: Natural frequencies of bogie

Mode No.	Frequency for Unladen condition (Hz)	Frequency for laden condition (Hz)	Shape
4	0.5463	0.5414	Roll
5	7.6805	7.6794	Bounce
8	13.012	13.145	Pitch
9	23.344	23.959	Twist

The natural frequencies and mode shapes of an Indian Railway ICF coach are extracted by using free vibration analysis. The Block Lanczos eigenvalue solver in ANSYS is used to predict the natural modes of vibration. Block Lanczos method is used as this method computes first few natural frequencies and mode shapes for large and symmetric structures efficiently. The first few eigen natural frequencies for unladen (without passenger load) condition and laden (with passenger load lumped at center of gravity of the coach) condition are extracted and are tabulated as shown in Table 5. The initial mode on the car body is observed to be a rigid body mode and is neglected. Further the bounce mode of the coach is observed to be at 0.6158 Hz in unladen condition and 0.5826 Hz in laden condition. The pitch mode is observed to be at 0.6894 Hz in unladen condition and 0.6539 Hz in laden condition. The roll mode is observed to be at 3.33 Hz in unladen condition and 2.272 Hz in laden condition. The respective mode shapes of the coach under unladen and laden conditions are shown from Fig.5 to Fig.10.

Table 5: Natural frequencies of coach

Mode No.	Natuarl Frequency for Unladen condition (Hz)	Natural Frequency for laden condition (Hz)	Shape
2	0.6158	0.5826	Bounce
3	0.6894	0.6539	Pitch
9	3.33	2.272	Roll

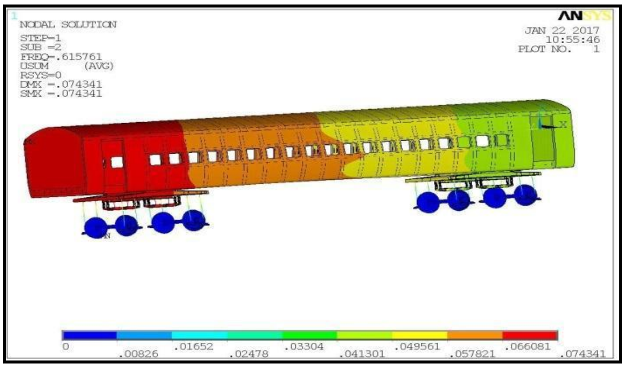

Fig.5: Bounce Mode of ICF Coach (Unladen)

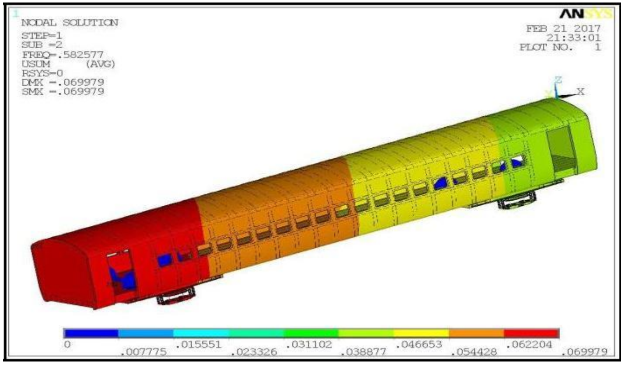

Fig.6: Bounce Mode of ICF Coach (laden)

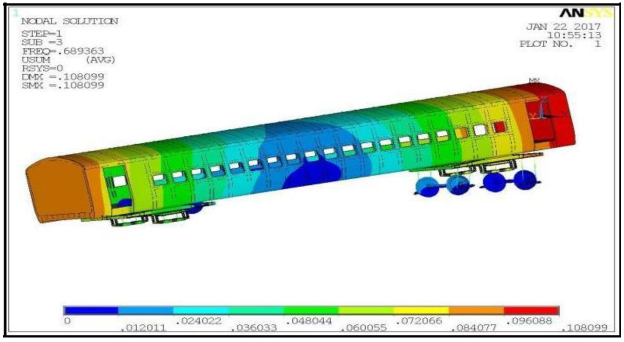

Fig.7: Pitch Mode of ICF Coach (Unladen)

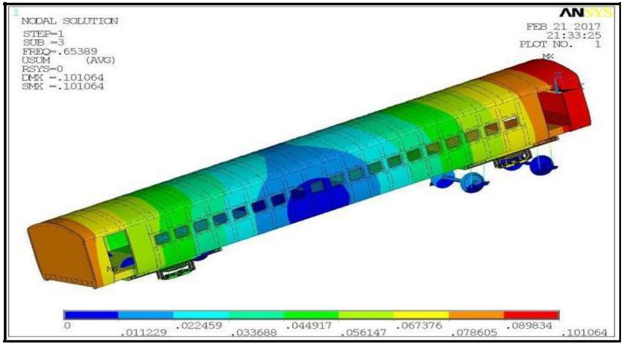

Fig.8: Pitch Mode of ICF Coach (laden)

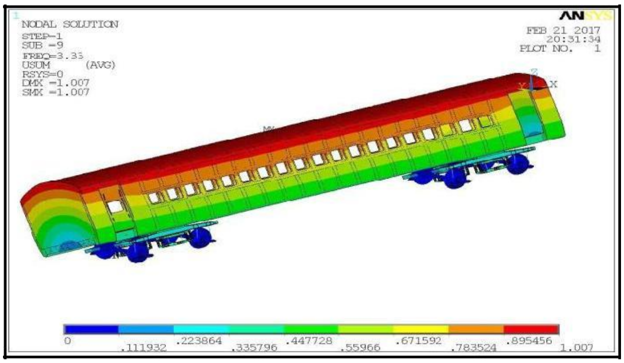

Fig.9: Roll Mode of ICF Coach (Unladen)

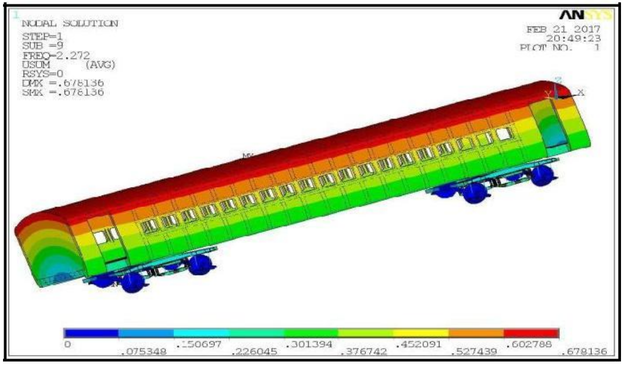

Fig.10: Roll Mode of ICF Coach (laden)

It is also observed that the obtained natural frequencies for the FE model of the Indian railway ICF coach matches well with the natural frequencies in the research work carried out in paper of Indian context. The comparative values of the eigenfrequencies for the FE model in ANSYS with the same of the Indian context literature are shown in Table 6.

Table 6: Comparison of natural frequencies of coach model

Mode	Natural Frequency as per Literature in Indian context (Hz)	Simulated eigen Natural Frequency Unladen case (Hz)	Simulated eigen Natural Frequency Laden case (Hz)
Bounce	0.65	0.6158	0.5826
Pitch	0.69	0.6894	0.6539
Roll	3.15	3.33	2.272

V. CONCLUSIONS

From the modal analysis of the railway coach it can be concluded that for both unladen and laden conditions the coach attains similar predominant values of natural frequencies and mode shapes. This means passenger load has less significance on the natural frequencies and modes of the ICF coach. These modes are bounce, pitch and roll modes respectively which influence the dynamic behaviour of the coach in the case of free as well as forced vibration. It can also be concluded that the eigenfrequency values obtained for the coach model are more realistic and in line with that of Indian context literature rather than that of the hypothetical cases of bogie model under unladen and laden conditions.

REFERENCES

[1] T.J.S. Abrahamsson and J.C.O. Nielson, "Coupling of physical and modal components for analysis of moving non-linear dynamic systems on general beam structures," International Journal for Numerical Methods in Engineering, vol. 33, no. 9, pp. 1843-1859, 1992.

[2] R. Ali, J.L. Hedges, B. Mills, C.C. Norville, and O. Gurdogan, "The Application of finite element techniques to the analysis of automobile structure," Proceedings of the Institution of Mechanical Engineers, vol. 185, pp. 44-71, 1970.

[3] P. Carlbom, "Carbody and Passengers in Rail Vehicle Dynamics", Doctoral Thesis, Department of Vehicle Engineering, Royal Institute of Technology, Sweden, 2000.

[4] P. Chennakesavarao and P. Srihari, "Design Optimization of Heat Sink in Power Electronics," International Journal of Engineering Research and Applications, vol. 4, no. 10, pp. 83-94, 2014.

[5] M. Dhingra, R.C. Sharma, M.H. Salmani, "An introduction & overview to magnetically levitated train," Journal of science, vol.5, no.11, pp. 1117-1124, 2015.

[6] A. Gugliotta, A. Soma, P. Arrus, and A. Lombardi, "Simulation of Rail Dynamics at Politecnico of Torino", 12thEuropean ADAMS Users Conference, Marburg 18-19 November, 1997.

[7] IRCAMT. (Indian Railways Centre for Advanced Maintenance Technology, A Directorate of RDSO). Maintenance Manual for BG coaches of ICF design, vol. 3, pp. 1-36.

[8] KamyarHaghighi Jinzhu and G.W. Krutz, "Dynamic analysis of an engine chassis mount bracket using the finite element method," SAE International Technical paper, 881854, 6. 1750-6.1758, 1988

[9] N. Karuppaiah, P.S. Deshpande, C. Sujatha, and V. Ramamurthi, "Vibration analysis in a light passenger vehicle by rigid body/Finite element modeling," Advances in vibration Engineering, vol. 2, no. 2, pp. 106-120, 2003.

[10] N. Karuppaiah, C. Sujatha, and V. Ramamurthi, "Modal and vibration/stress analysis of a passenger vehicle by FEM," SAE International Technical paper, vol. 990003, pp. 129-133, 1999.

[11] N. Kirankumar & P. Srihari, "Two-Dimensional Natural Convection in a Square Enclosure with Differentially Heated Two Walls," International Journal of Mechanical Engineering & Technology, vol. 4, no. 6, pp. 171-179, 2013.

[12] R. Kumar, M.P. Garg, R.C. Sharma, "Vibration analysis of radial drilling machine structure using finite element method," Advanced Materials Research, , vol. 472-475, pp. 2717-2721, 2012.

[13] C.Y. Li and T.H. Young, "Vertical Vibration Analysis of Vehicle/Imperfect Track Systems," International Journal of Vehicle Mechanics and Mobility. Vehicle System Dynamics, vol. 40, no. 5, pp. 329–349, 2003.

[14] N. Neda, “Ride Quality and Drivability of a Typical Passenger Car subject to Engine/Driveline and Road Non-uniformities Excitations,” Full Thesis, Linköpingsuniversitet, Sweden. 2011.

[15] S. Palli, D. Azad, & D. Sreeramulu, Optimization of rail inserts using finite element analysis, International Journal of Engineering, Science and Technology, Multicraft Publications, vol. 6, no. 2, pp. 65-75, 2014.

[16] S. Palli, R. Koona, R.C. Sharma and V. Muddada, “Dynamic Analysis of Indian Railway Integral Coach Factory bogie,” Int. J. Vehicle Structures & Systems, vol. 7, no. 1, pp. 16-20, 2015. http://dx.doi.org/10.4273/ijvss.7.1.03

[17] S. Palli and R. Koona, Analyses of Dynamic Response of a Railway bogie, Int. J. Vehicle noise and Vibration, vol. 11, no. 2, 103-113, 2015.

[18] S.S. Prabhu, P. Srihari, & D.Ramajogi Naidu, “Transient thermal analysis of modified emergency container,” International Journal for Research in Applied Science & Engineering Technology, vol. 4, no. 8, pp. 336- 340, 2016.

[19] K. Ramji, V.K. Goel, SASO Rao, and M.K. Naidu, “Dynamic behaviour of Indian Railway Coach and Bogie Frame using Finite Element Analysis,” Journal of the Institution of Engineers (India), Part MC, Mechanical Division, , vol. 87, pp. 7-17. 2007.

[20] Dr. C.J. Rao, , Dr. D. Nageswara Rao, & P. Srihari, “Influence of cutting parameters on cutting force and surface finish in turning operation,” Journal of Procedia Engg., Elsevier Science Direct, pp. 1405-1415, 2013.

[21] Ch. Ravikumar, P. Srihari, Y. Sagar, “Thermal analysis of artificial hip joint by using biodegradable materials,” International Journal for Research & Development in Technology, vol. 8, no. 3, pp. 211-216, 2017.

[22] M.H. Salmani, R.C. Sharma, H. Kumar, M. Dhingra, “Efficiency Analysis of Used Transformer Oil for Compression Ignition Engine,” International Conference on Newest Drift in Mechanical Engineering (ICNDME- 14), December 20-21, M. M. University, Mullana, INDIA. Mullana - Ambala: M. M. University, pp. 237-242, 2014.

[23] M.H. Salmani, R.C. Sharma, H. Kumar, M. Dhingra, “Effect of used transformer oil on efficiency of compression ignition engine,” International Journal for Technological Research in Engineering, vol. 2, no. 7, pp. 786-791, 2015.

[24] Sam Paul, P., Mohan Gift, M.D., Jawar, C.P., Sakthivel, “Finite Element analysis of Bogie frame,” Proceedings of 18th National Convention of Mechanical Engineers, pp. 331-338, 2002.

[25] R.C. Sharma, “Ride analysis of an Indian railway coach using Lagrangian dynamics,” Int. J. Vehicle Structures & Systems, vol. 3, no. 4, pp. 219-224, 2011. http://dx.doi.org/ 10.4273/ijvss.3.4.02

[26] R.C. Sharma, “Parametric analysis of rail vehicle parameters influencing ride behavior,” International Journal of Engineering Science and Technology, vol. 3, no. 8, pp. 54-65, 2011.

[27] R.C. Sharma, “Recent advances in railway vehicle dynamics,” Int. J. Vehicle Structures & Systems, vol. 4, no. 2, pp. 52-63, 2012. http://dx.doi.org/10.4273/ijvss.4.2.04

[28] R.C. Sharma, “Sensitivity Analysis of ride behaviour of Indian railway Rajdhani coach using Lagrangian dynamics,” Int. J. Vehicle Structures & Systems, vol. 5, no. 3-4, pp. 84-89, 2013.

[29] R.C. Sharma, “Stability and eigenvalue analysis of an Indian railway general sleeper coach using Lagrangian dynamics,” Int. J. Vehicle Structures & Systems, vol. 5, no. 1, pp. 9-14, 2013.

[30] R.C. Sharma, M. Dhingra, R. K. Pathak, M. Kumar, “Air cushion vehicles: Configuration, resistance and control,” Journal of Science, vol. 4, no. 11, pp. 667-673, 2014.

[31] R.C. Sharma, M. Dhingra, R. K. Pathak, M. Kumar, “Magnetically levitated vehicles: suspension, propulsion and guidance,” International Journal of Engineering Research & Technology, vol. 3, no. 11, pp. 5-8, 2014.

[32] R.C. Sharma, “Modeling and simulations of railway vehicle system,” International Journal of Mechanical Engineering and Robotics Research, vol. 1, no. 1, pp. 55-66, 2014.

[33] S.K. Sharma, A. Kumar and R.C. Sharma, “Challenges in railway vehicle modeling and simulations,” International Conference on Newest Drift in Mechanical Engineering (ICNDME-14), December 20-21, M. M. University, Mullana, INDIA. Mullana - Ambala: Maharishi Markandeshwar University, pp. 453–459, 2014.

[34] S.K. Sharma and A. Kumar, A comparative study of Indian and Worldwide railways, International Journal of Mechanical Engineering and Robotics Research, vol. 1 , no. 1, pp. 114–120, 2014.

[35] R.C. Sharma, Dhingra, M., Pandey, R. K., Rathore, Y., Ramchandani, D. Dynamic analysis of railway vehicles, Journal of Science, vol. 5, no. 3, pp. 193-198, 2015.

[36] R.C. Sharma, M. Dhingra, R.K. Pathak, “Braking systems in railway vehicles,” International Journal of Engineering Research & Technology, vol. 4, no. 1, pp. 206-211, 2015.

[37] S.K. Sharma, R.C. Sharma, A. Kumar, S. Palli, “Challenges in Rail Vehicle-Track Modeling and Simulation,” Int. J. Vehicle Structures & Systems, vol. 7, no. 1, pp. 1-9, 2015.

[38] R.C. Sharma, “Evaluation of Passenger Ride Comfort of Indian Rail and Road Vehicles with ISO 2631-1 Standards: Part 1 - Mathematical Modeling,” Int. J. Vehicle Structures & Systems, vol. 8, no. 1, pp. 1-6, 2016.

[39] R.C. Sharma, “Evaluation of Passenger Ride Comfort of Indian Rail and Road Vehicles with ISO 2631-1 Standards: Part 2 – Simulation,” Int. J. Vehicle Structures & Systems, vol. 8, no. 1, pp. 7-10, 2016.

[39] R.C. Sharma and S. Palli, “Analysis of creep force and its sensitivity on stability and vertical-lateral ride for railway vehicle,” International Journal of Vehicle Noise and Vibration, vol. 12, no. 1, pp. 60-76, 2016.

[41] S.K. Sharma and S. Chaturvedi, “Jerk analysis in rail vehicle dynamics,” Perspectives in Science, vol. 8, pp. 648–650, 2016. doi: 10.1016/j.pisc.2016.06.047

[42] S.K. Sharma and A. Kumar, “Dynamics Analysis of Wheel Rail Contact Using FEA,” Procedia Engineering, vol. 144, pp. 1119-1128, 2016. doi:10.1016/j.proeng.2016.05.076

[43] S.K. Sharma and A. Kumar,“The Impact of a Rigid-Flexible System on the Ride Quality of Passenger Bogies using a Flexible Carbody,” in Pombo, J. (ed.) Proceedings of the Third International Conference on Railway Technology: Research, Development and Maintenance, Stirlingshire, UK, 5-8 April 2016, Cagliari, Sardinia, Italy. Stirlingshire, UK: Civil-Comp Press, 2016, 87. doi: 10.4203/ccp.110.87

[44] R.C. Sharma, S. Palli and R. Koona, “Stress and vibrational analysis of an Indian railway RCF bogie,” Int. J. Vehicle Structures and Systems, vol. 9, no. 5, pp. 296-302, 2017.

[45] R.C. Sharma, S. Palli, S.K. Sharma and M. Roy, “Modernization of railway track with composite sleepers,” Int. J. Vehicle Structures and Systems, vo. 9, no. 5, pp. 321-329, 2017.

[46] S.K. Sharma and A. Kumar, “Impact of electric locomotive traction of the passenger vehicle Ride quality in longitudinal train dynamics in the context of Indian railways,” Mechanics & Industry, vol. 18, no. 2, pp. 222, 2017. doi: 10.1051/meca/2016047

[47] S.K. Sharma and A. Kumar, “Ride performance of a high speed rail vehicle using controlled semi active suspension system,” Smart Materials and Structures, vol. 26, no. 5, pp. 55026, 2017. doi: 10.1088/1361-665X/aa68f7

[48] S.K. Sharma and A. Kumar, “Ride comfort of a higher speed rail vehicle using a magnetorheological suspension system,” Proceedings of the Institution of Mechanical Engineers, Part K: Journal of Multi-body Dynamics, vol. 232, no. 1, pp. 32–48, 2018. doi: 10.1177/1464419317706873

[49] S.K. Sharma and A. Kumar, “Disturbance rejection and force-tracking controller of nonlinear lateral vibrations in passenger rail vehicle using magnetorheological fluid damper,” Journal of Intelligent Material Systems and Structures, vol. 29, no. 2, pp. 279-297, 2018. doi: 10.1177/1045389X17721051

[50] S.K. Sharma and A. Kumar, “Ride comfort of a higher speed rail vehicle using a magnetorheological suspension system,” Proceedings of the Institution of Mechanical Engineers, Part K: Journal of Multi-body Dynamics, vol. 232, no. 1, pp. 32–48, 2018.

[51] V. Singla, R.C. Sharma, and J. Singh, “Fault diagnosis of bearing for wear at inner race using acoustic signal,” International Journal of Mechanical Engineering Research and Development, vol. 1, no. 1, pp. 40-46, 2011.

[52] P. Sivakumar, P. Srihari, & N. Haribabu, “Optimization of Liquid Cold Plates Using Computational Fluid Dynamics,” International Journal of Engineering Trends and Technology, vol. 27, no. 5, pp. 274 – 277, 2015.

[53] K. Swathi, & P. Srihari, “Heat Transfer Enhancement in a Tube Using Rectangular Strip Inserts,” International Journal of Applied Engineering Research, Research India Publications, vol. 10, no. 20, pp. 41532-41544, 2015.

[54] A. Vashist, R.C. Sharma, S. Taneja, “Productivity improvement by defect analysis in Indian automobile industry,” International Journal of Mechanical Engineering Research and Development, vol. 2, no. 2, pp. 734-741, 2012.

[55] A. Vashist, R.C. Sharma, S. Taneja, “Productivity improvement by fixture modification,” International Journal of Mechanical Engineering Research and Development, vol. 4, no. 3, pp. 54-62, 2014.