Dynamic Analysis of Electric Bus Chassis Using Finite Element Method

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***Abstract*— This paper deals with the investigation of vibrational characteristic of electric bus chassis including natural frequency and mode shapes. Chassis protects the passenger from the external impact force and gives the strength and flexibility of the bus in a changing condition. The chassis is subjected to load which are static, dynamic and cyclic loading, therefore the chassis should have good properties that can withstand those types of load. During the travel, chassis was excited by road roughness, engine, transmission and more. Natural frequencies and mode shapes can be obtained by using finite element method. Simulation was carried out by using commercial finite element packages Abaqus in order to find the optimum design that has good dynamic characteristic. Three materials were used in simulation with various of thicknesses. Based on the result of simulation, the AISI 4130 Alloy steel with 6 mm thickness has been chosen as the best model that has less possibility to resonance.**

Keywords: Electrical Bus, Chassis, Finite Element Method, Natral Frequency

I. Introduction

Chassis is a main part of vehicles. Dynamic characteristic of chassis affects the overall performance of vehicles. Chassis is the most important part in a vehicle as well as in bus. Road roughness, passenger loads, engine vibrations and others are examples of external forces on the chassis. It can cause failure if the frequency of external excitation is equal to the natural frequency of chassis and it was called as resonance [1].

Currently the technology development moves very fast including the electrical vehicles such as bus and truck. the bus. One of them is the development of electrical systems. Many researchers have been carried out the investigation dynamic characteristic of chassis using Finite Element Method (FEM) [2]–[7]. FEM has been used by many researchers due to the many benefits. In early stage of design FEM can reduce much cost since designer no need to expense much money for making a prototype of models. This paper investigates the vibration characteristic performance regarding the possibility of resonance on the electric bus chassis. A chassis model with several materials and thicknesses has been simulated on ABAQUS commercial packages to obtain their natural frequencies. The natural frequencies of each models was analyzed and compared to the frequencies of excitation forces to get the possibility to resonances for each model. This possibility to resonance was scored. The score shows the possibility to resonance of each model, the higher the score the lesser the possibility to resonance will be occurred on that model. Therefore, the best model will be indicated by the highest of score of its model.

II. Finite Element Simulation

A. Model of Electric Bus Chassis

The model was drawn using Solid Works commercial packages software. The model of chassis was shown in Fig.1. The model has length of 7.9 m and width of 1.01 m.

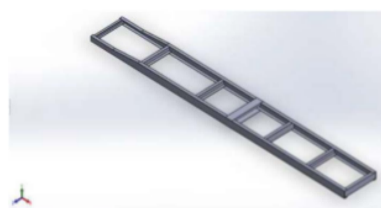

Fig. 1. Model of minibus chassis

The electric bus chassis was modelled by quadratic tetrahedral elements of type C3D10 (Tet-10) solid elements. There are three types of material were used in this work, namely: AISI 4130 Alloy Steel, AISI A 514 GRADE B Alloy steel and Grey Cast Iron. The thickness of models is: 2 mm, 4 mm and 6 mm. The properties of materials were shown in TABLE 1.

TABLE I. MECHANICAL PROPERTIES OF MATERIALS [8]

Mechanical Property	Material		
	Grey Cast Iron	**AISI 4130**	**AISI A 514**
Density (kg/m^3)	7200	7850	7850
Ultimate Tensile Strength (MPa)	450	450	760
Tensile Yield Strength (MPa)	280	435	690
Elongation at Break (%)	0.52	21.5	18
Modulus of Elasticity (MPa)	140	190	210
Poisson's Ratio	0.211	0.27	0.27
Shear Modulus (GPa)	69	80	80

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III. RESULT AND DISCUSSION

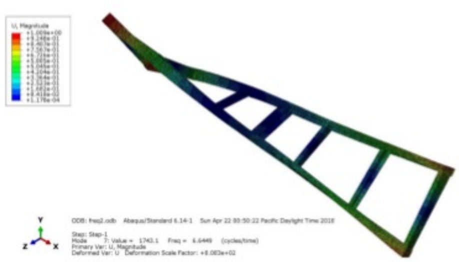
A. Natural Frequency

There are a 28 mode shapes in the simulation result in range between 0 and 100 Hz frequency. The detail of simulation result for natural frequency for AISI A 514 GRADE B Alloy steel was shown in Fig. 2. Fig. 3 shows the 7^{th} mode shape until 10^{th} mode shape for material AISI A 514 GRADE B Alloy steel with 2 mm thickness.

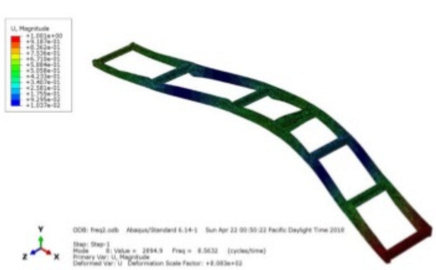
E I G E N V A L U E   O U T P U T

MODE NO	EIGENVALUE	FREQUENCY (RAD/TIME)	FREQUENCY (CYCLES/TIME)	GENERALIZED MASS	COMPOSITE MODAL DAMPING
1	-3.74576E-05	0.0000	0.0000	6.17307E-02	0.0000
2	-1.44861E-05	0.0000	0.0000	5.41549E-02	0.0000
3	-9.41391E-06	0.0000	0.0000	4.41299E-02	0.0000
4	-8.43460E-07	0.0000	0.0000	6.96061E-02	0.0000
5	2.29935E-05	4.79516E-03	7.63173E-04	6.25989E-02	0.0000
6	2.72959E-05	5.22455E-03	8.31513E-04	0.21654	0.0000
7	1743.1	41.751	6.6449	3.44563E-02	0.0000
8	2894.9	53.804	8.5632	5.66204E-02	0.0000
9	3364.2	58.002	9.2313	4.95585E-02	0.0000
10	8440.4	91.872	14.622	2.23243E-02	0.0000
11	10548.	102.70	16.346	2.10463E-03	0.0000
12	11328.	106.43	16.940	2.12878E-03	0.0000
13	19490.	139.61	22.219	4.39513E-02	0.0000
14	26847.	163.85	26.078	4.51438E-02	0.0000
15	33295.	182.47	29.041	5.29113E-02	0.0000
16	37316.	193.17	30.744	2.47820E-02	0.0000
17	46171.	214.88	34.199	2.49023E-03	0.0000
18	50601.	224.95	35.801	2.16618E-03	0.0000
19	77622.	278.61	44.342	3.24743E-02	0.0000
20	86493.	294.10	46.807	4.14538E-02	0.0000
21	95235.	308.60	49.115	4.67805E-02	0.0000
22	1.12441E+05	335.32	53.368	1.12452E-03	0.0000
23	1.13770E+05	337.30	53.683	1.12573E-03	0.0000
24	1.20805E+05	347.57	55.318	3.23101E-02	0.0000
25	1.94583E+05	441.12	70.206	2.20246E-02	0.0000
26	2.07138E+05	455.12	72.435	4.45410E-03	0.0000
27	2.15847E+05	464.59	73.942	3.79025E-03	0.0000
28	2.49260E+05	499.26	79.460	5.28755E-03	0.0000

Fig. 2. Natural frequencies of electric bus chassis



(a)



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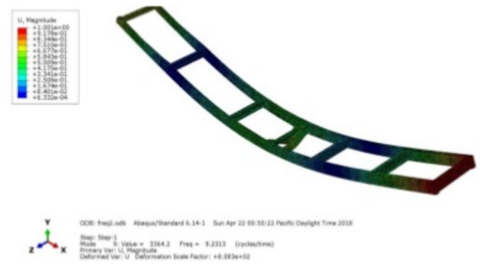

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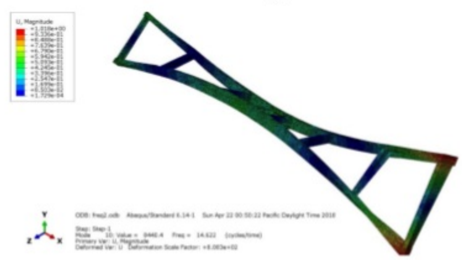

(d)

Fig. 3. Mode shapes of chassis with material AISI A 514 GRADE B Alloy steel, thickness of 2 mm: (a) 7^{th} mode; (b) 8^{th} mode; (c) 9^{th} mode; (d) 10^{th} mode

B. Analysis of Natural Frequency with Motor Initial Condition as an excitation force

The motor works in range of frequencies between 1 to 80 Hz. The initial condition when the motor was started is 7 Hz. The analysis will be taken by comparing the natural frequencies of model which nearest to the frequency of motor in initial condition (7 Hz). The score was obtained from two sides, above and below 7 Hz. The score for both analyses were shown in TABLE 2 and TABLE 3 for above and below frequency respectively.

TABLE II. SCORE ANALYSIS FOR ABOVE FREQUENCY WITH INITIAL STARTED MOTOR AS EXCITATION FORCE

Material	Thickness (mm)	Initial Frequency of Motor	*Above Frequency*	Range	*Score*
Grey cast iron	2	7	8.5632	1.563	15
	4	7	10.053	3.053	30
	6	7	11.200	4.200	42
AISI 4130 Alloy steel	2	7	7.3141	0.314	3
	4	7	7.3662	0.366	3
	6	7	7.1990	0.199	1
AISI A 514 GRADE B Alloy steel	2	7	7.5041	0.504	5
	4	7	7.5576	0.557	5
	6	7	7.3860	0.386	3

TABLE III. SCORE ANALYSIS FOR BELOW FREQUENCY WITH INITIAL STARTED MOTOR AS EXCITATION FORCE

Material	Thickness (mm)	Initial Frequency of Motor	*below Frequency*	Range	*Score*
Grey cast iron	2	7	6.6449	0.355	3
	4	7	6.7155	0.284	2
	6	7	6.5734	0.426	4
AISI 4130 Alloy steel	2	7	0	7	70
	4	7	0	7	70
	6	7	0	7	70
AISI A 514 GRADE B Alloy Steel	2	7	0	7	70
	4	7	0	7	70
	6	7	0	7	70

C. Analysis of Natural Frequency with commonly used motor frequency as an excitation force

The common frequency that usually motor often used is 25 Hz. Above explained that frequency motor is often used is 25 Hz. The analysis will be taken by comparing the natural frequencies of model which nearest to the frequency of motor in commonly used (25 Hz). The score was obtained from two sides, above and below 25 Hz. The score for both analyses were shown in TABLE 4 and TABLE 5 for above and below frequency respectively.

TABLE IV. SCORE ANALYSIS FOR ABOVE FREQUENCY WITH COMMONLY USED MOTOR AS EXCITATION FORCE

Material	Thickness (mm)	Initial Frequency of Motor	*Above Frequency*	Range	*Score*
Grey cast iron	2	25	26.078	1.078	17
	4	25	30.013	5.013	51
	6	25	26.707	1.707	17
AISI 4130 Alloy steel	2	25	29.28	4.280	42
	4	25	27.504	2.504	25
	6	25	29.845	4.845	48
AISI A 514 GRADE B Alloy steel	2	25	25.514	0.514	5
	4	25	28.218	3.218	32
	6	25	30.621	5.621	56

TABLE V. SCORE ANALYSIS FOR BELOW FREQUENCY WITH COMMONLY USED MOTOR FREQUENCY AS EXCITATION FORCE

Material	Thickness (mm)	Initial Frequency of Motor	*Below Frequency*	Range	*Score*
Grey cast iron	2	25	22.219	2.781	27
	4	25	24.598	0.402	4
	6	25	19.378	5.622	56
AISI 4130 Alloy steel	2	25	24.868	0.132	1
	4	25	21.211	3.789	37
	6	25	21.849	3.151	31
AISI A 514 GRADE B Alloy steel	2	25	19.599	5.401	54
	4	25	21.762	3.238	32
	6	25	22.417	2.583	25

D. Analysis of Natural Frequency with road roughness frequency as an excitation force

Excitation from the road is the main disturbance to the truck chassis when the truck travels along the road. In practice, the road excitation has typical values varying from 0 to 100 Hz. At high speed cruising, the excitation is about 3000 rpm or 50 Hz. The analysis will be taken by comparing the natural frequencies of model which the nearest to the frequency of excitation force from the road (50 Hz). The score was obtained from two sides, above and below 50 Hz. The score for both analyses were shown in TABLE 6 and TABLE 7 for above and below frequency respectively. Total score for all models was tabulated in TABLE 8. From the TABLE it can be seen that the model with AISI 514 Grade B Alloy Steel material has the highest score. It means that it model is the best based on the vibration performance especially in the possibility to resonance without consideration of stress condition and the cost for material.

TABLE VI. SCORE ANALYSIS FOR ABOVE FREQUENCY WITH ROAD ROUGHNESS AS EXCITATION FORCE

Material	Thickness (mm)	Initial Frequency of Motor	*Above Frequency*	Range	*Score*
Grey cast iron	2	50	53.368	3.368	33
	4	50	53.002	3.002	30
	6	50	50.297	0.297	2
AISI 4130 Alloy steel	2	50	52.345	2.345	23
	4	50	50.243	0.243	2
	6	50	54.883	4.883	48
AISI A 514 GRADE B Alloy steel	2	50	50.564	0.564	5
	4	50	51.549	1.549	15
	6	50	56.309	6.309	63

TABLE VII. SCORE ANALYSIS FOR BELOW FREQUENCY WITH ROAD ROUGHNESS AS EXCITATION FORCE

Material	Thickness (mm)	Initial Frequency of Motor	*BelowFrequency*	Range	*Score*
Grey cast iron	2	50	49.115	0.885	8
	4	50	48.312	1.688	16
	6	50	49.139	0.861	8
AISI 4130 Alloy steel	2	50	49.284	0.716	7
	4	50	39.157	10.843	108
	6	50	41.810	8.190	81
AISI A 514 GRADE B Alloy steel	2	50	41.394	8.606	86
	4	50	40.174	9.826	98
	6	50	42.896	7.104	71

TABLE VIII. TOTAL SCORE FOR ALL MODELS IN POSSIBILITY TO RESONANCE

Material	Thickness (mm)	*Score* For initial condition	*Score Commonly used frequency*	*Score For road roughness*	*Total*
Grey cast iron	2	18	44	41	103
	4	32	55	46	133
	6	46	73	10	129
AISI 4130 Alloy steel	2	73	43	30	146
	4	73	62	110	245
	6	71	79	129	279
AISI A 514 GRADE B Alloy steel	2	75	59	91	225
	4	75	64	113	252
	6	73	81	134	288

[1]

IV. CONCLUSION

Based on the simulation and scoring result, it can be concluded that electric bus chassis model with 6 mm of thickness and AISI 514 Grade B Alloy Steel material has the highest score. It can be chosen as a best model

ACKNOWLEDGMENT

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PAGE 1

PAGE 2

PAGE 3

PAGE 4