# *Validation of Rail Vehicle Dynamics Model Using Accelerations Data*

**Paper Field: Interaction between track and rolling stock**

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### *ABSTRACT*

In this paper, the validation of complete rail vehicle model which includes a carbody, two bogies, and four axels with 70 degrees of freedom (DOFs) is investigated. In the vehicle model, nonlinear behaviors of primary and secondary suspension components are considered. The vehicle moves over straight line with simplified track model. To validate developed model, complete dynamic test of one IRICO DMU was performed in Tehran-Ghazvin route and measured axles accelerations are provided for the vehicle model as reference inputs. Results represent remarkable agreement between proposed model and experimental data.

### *KEYWORDS*

Rail Vehicle Dynamics, Model Validation, Experimental Results, Air Spring Model.

### *1- INTRODUCTION*

Nowadays, speed up in technology and its new features bring higher speed, with reliable safety and better ride comfort in rail transportation industries. Traffic jam in capital cities all around the world, wasting passengers' time at the airports, huge mass transportation and so on bring a good opportunity for rail industries to attract more and more passengers and cargos to their services. In addition to safety, the other important issue for passengers to decide about transportation type is ride comfort during their trip.

To study the influence of suspension components behaviors on the ride comfort of passengers, complete nonlinear model of one IRICO DMU trailer car was developed by Sayyaadi and Shokouhi [1]. In that work, dynamic behaviors of all components are validated by some experimental results and track rails assumed to be rigid with viscoelastic bed in vertical and lateral directions [2-3].

In the current work, complete dynamics validation of the one IRICO DMU trailer car with nonlinear components behavior is addressed.

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## 2- VEHICLE DESCRIPTION

IRICO DMU train is composed of four cars; two motor cars at each end and two trailer cars in the middle. The composition of one complete train is shown in Figure 1.

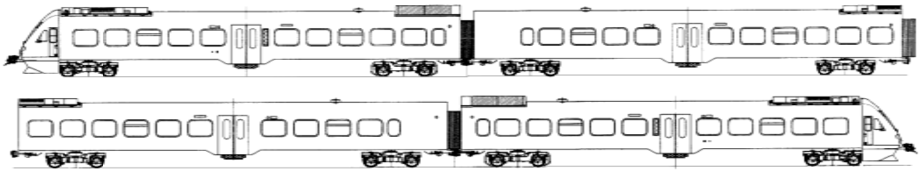


**Figure 1: Composition of IRICO DMU**

Each car is supported by two bogies. The side view of two axles IRICO DMU trailer bogie is shown in Figure 2. To attain proper stability and good ride comfort for the passengers, bogies are equipped with primary and secondary suspensions. The secondary suspension has two air springs to suspend the vehicle body, four vertical and lateral dampers and two connection links to connect the bogie frame to the carbody. The primary suspension is made of two coil springs, two leaf springs and one vertical damper at each side of wheel–set.

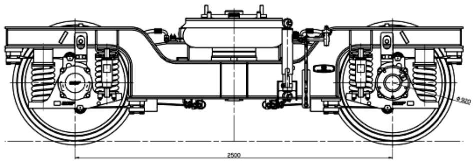


**Figure 2: Side view of IRICO DMU trailer bogie**

## 3- DYNAMIC MODEL

Track geometrical irregularities in the rail–vehicle dynamics are modeled by using simplified version of Jin and Wen [3-4] track model. In the developed model, four track irregularities are included as bed disturbances and the effects of ballast and sleepers masses in the vehicle dynamics and coupling effects between left and right ballast masses are ignored.

By using four geometrical contact parameters and the method proposed by Shabana and Zaazaa [5], contact point between rail and wheel is determined. Two contact parameters are calculated based on the geometrical constrains and the other two contact parameters are calculated by a searching algorithm which guarantees the perpendicularity of rail reaction force and tangent plane of the wheel at the contact point. To do this, four geometrical parameters denoted $\delta_L$, $\delta_R$, $\theta_A$ and $\psi_A$, which are shown in Figure 3 are used. Creep forces are calculated based on the Polach theory [6].

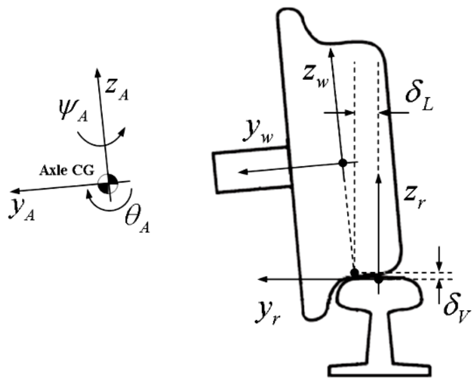



**Figure 3: Effective parameters $\delta_L$, $\delta_V$, $\psi_A$ and $\theta_A$ for contact point extraction**

In this work, real behaviors of all components are considered and due to the complexity of components behaviors, especially for air springs, the vehicle is modeled as modular type and internal forces of each component are calculated, using nonlinear description functions and system states. Newtonian approach is implemented for dynamics modeling of different parts and the interacting forces and moments between them are investigated. The vehicle model with 7 lumped masses and 42 DOFs is shown in Figure 4.

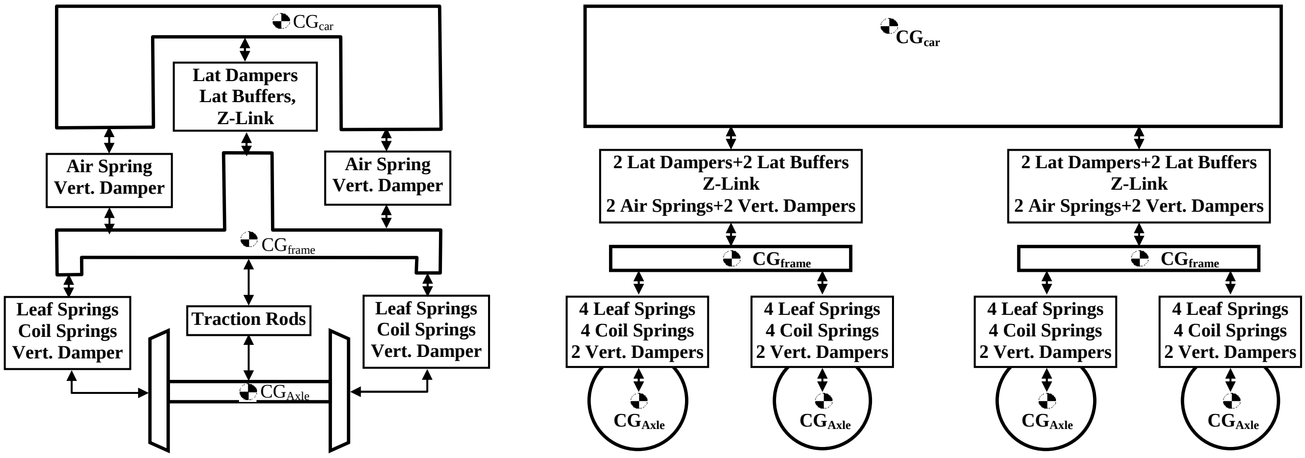



**Figure 4: Vehicle model with 42 DOFs**

### *3- 1- COMPONENTS MODELS*

The secondary suspension of the modeled vehicle is equipped with air springs. Air springs, which are made of Carbon Black Filled Natural Rubber (CBFNR), have long lifetime and can isolate the vehicle body from the unpredictable noise and vibration. For simulation of CBFNR behaviors, a model was developed by Haupt & Sedlan [7] which has elastic and viscoelastic elements. In this research work, Berg [8] model which is validated by some experimental data up to 16 Hz frequencies [8], is utilized to simulate the air spring dynamics. However, because of difficulties comprises from assigning previous turning point displacement to the variable, which is essential part of the equation, the frictional part of this model is replaced by the simplified viscoelastic model defined by Haupt & Sedlan. The proposed model was validated using experimental data which the results showed remarkable agreement between proposed model and test results. Detailed description of this model and validation procedure is presented in [9].

Dampers of IRICO DMU primary and secondary suspension were tested in Sachs Co., Germany. Results are shown in Fig. 5. According to the test results, damping rate of each damper is described by bi–linear function.

$$F = a\,\dot{\Delta}_{damper} + b \qquad (1)$$

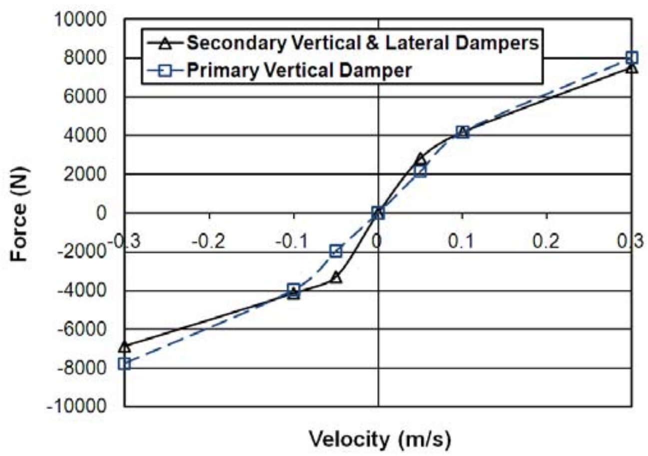



**Figure 5: Test results of IRICO DMU Dampers, done by SACHS Co., Germany**

Lateral displacement of the carbody is restricted by four lateral buffers, installed on the bogie frame as shown in Figure 6. Each lateral buffer has primary compression force equal to 100N. An air gap of 17 mm between carbody and lateral buffer lets the carbody moves freely in this range. Lateral displacement of carbody is restricted over ±40 mm by two stoppers installed on the bogie.

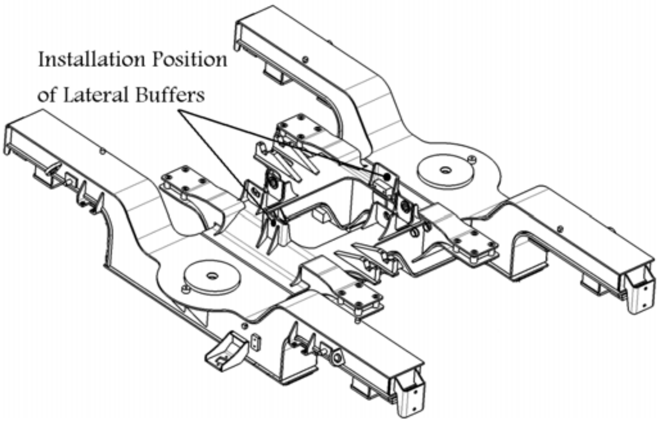



**Figure 6: Installation Position of lateral Buffers**

Each center pivot is linked to the bogie frame by two connection links. Each link has a rubber bush at each end. Based on tests done by GMT Co., Germany, the static stiffness of the bush in radial, torsional and cardanic movements are determined. Section view and installation position of the connection link is shown in Figure 7.

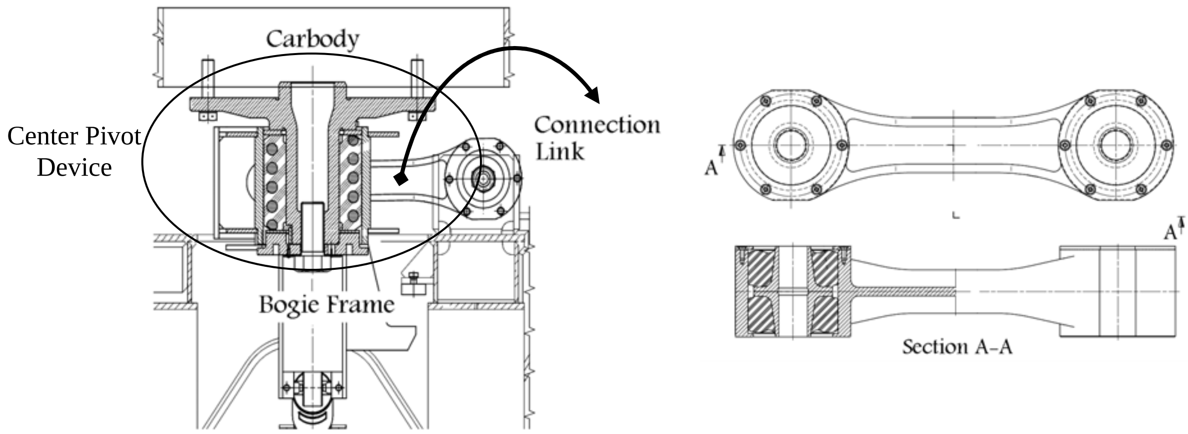



**Figure 7: Connection Link**

### *3- 2- COMPLETE VEHICLE MODEL*

All components model used in the rail–vehicle dynamics with related internal DOFs are listed in Table 1. It can be seen that suspension components add 28 internal DOFs to the model. Whereas the vehicle masses have totally 42 DOFs; 24 for four axles, 12 for two bogie frames and 6 for carbody, the complete rail–vehicle will be a model of 70 DOFs.

**Table 1: Suspension components of rail vehicle model (28 internal DOFs)**

| Components | No. | Identifier equations | | Internal DOF |
|---|---|---|---|---|
| Secondary Vert. Damper | 2 per bogie | Bi–Linear function | | – |
| Secondary Lat. Damper | 2 per bogie | | | |
| Primary Vert. Damper | 2 per bogie | | | |
| Air Spring | 4 per car | Vertical | Nonlinear, Berg & Sedlan Model | $x_2, w_s$ |
| | | Lateral | Nonlinear, Berg & Sedlan Model | $x_2, u$ |
| | | Longitudinal | Nonlinear, Berg & Sedlan Model | $x_2, u$ |
| Lateral Buffer | 4 per car | Nonlinear–polynomial, Order 4 | | – |
| Bush – Link | 2 pairs per bogie | Nonlinear, Sedlan Model | | $x_2$ |
| Coil Spring | 4 per bogie | linear in space, based on experimental data | | – |
| Leaf Spring | 4 per bogie | linear in space, based on analytical calculations | | – |

### *4- TEST SETUP*

To validate the performance of the proposed dynamic model, dynamic test of the IRICO DMU was performed in Tehran–Ghazvin route.The accelerations of one trailer car masses are recorded by means of accelerometers, installed on two axles, two bogie frames and on the floor of carbody inside the car. Figure 8 shows the trailer car before the test.

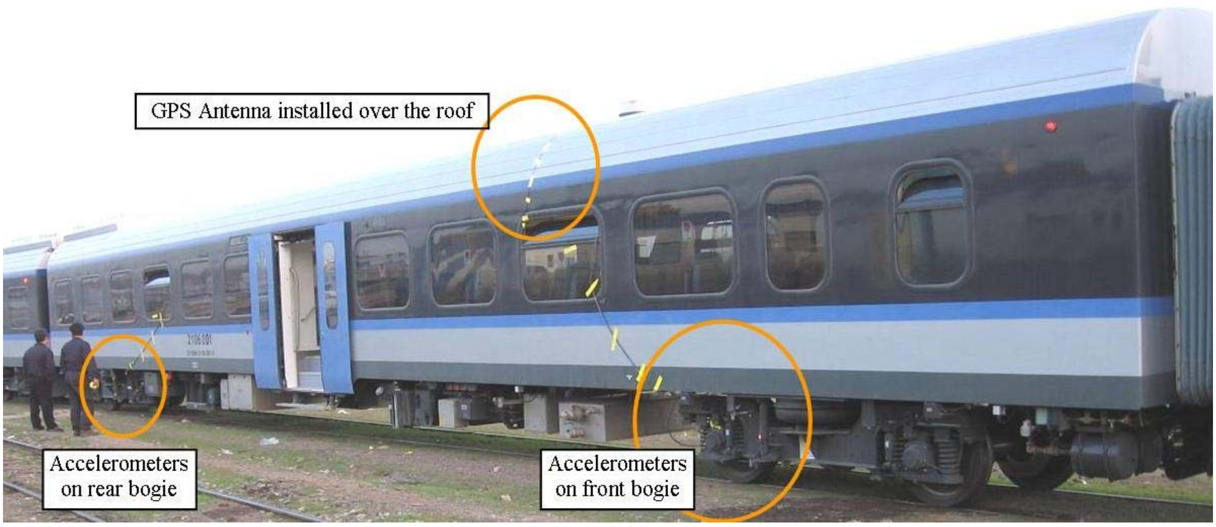



**Figure 8: Sensors installation position on the trailer car**

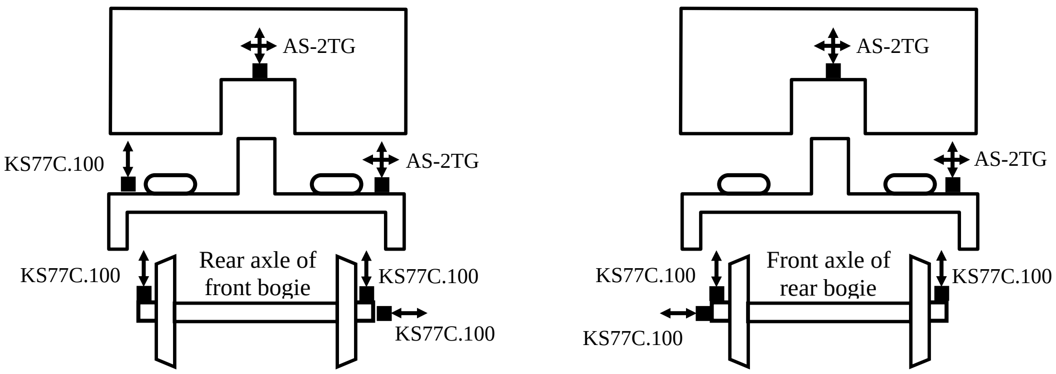
### *4- 1- DATA ACQUISITION SYSTEM*

The accelerations of the trailer car masses were recorded by means of three axes and one axis accelerometers. Technical specifications of utilized accelerometers are presented in Table 2.

Table 2: Accelerometers specifications

| | Single axis accelerometers | Three axes accelerometers |
|---|---|---|
| Manufacturer | Manfred Weber | Kyowa |
| Model | KS77C.100 | AS-2TG |
| Type | ICP® compatible | Strain gauge |
| Range | ± 60 g | ± 2 g |
| Linear frequency range ($f_{3dB}$) | 0,13 ... 24k (Hz) | 0,13 ... 24k Hz |

Because rail vehicle is modeled for moving in straight line with constant speed, only vertical and lateral accelerations are investigated. The installation positions of accelerometers are presented in Figure 9.




a) Front bogie, Axle 2 b) Rear bogie, Axle 3

**Figure 9: Accelerometers installation position**

VBOX III GPS, manufactured by Racelogic, UK, is used to measure the exact position and speed of the train. This GPS is also equipped with accelerometers which made it possible to measure the accelerations which are applied to the GPS. These data are analyzed in VBox Tool software which is shown if Figure 10. Technical specifications of the VBOX III GPS are tabulated in table 3.

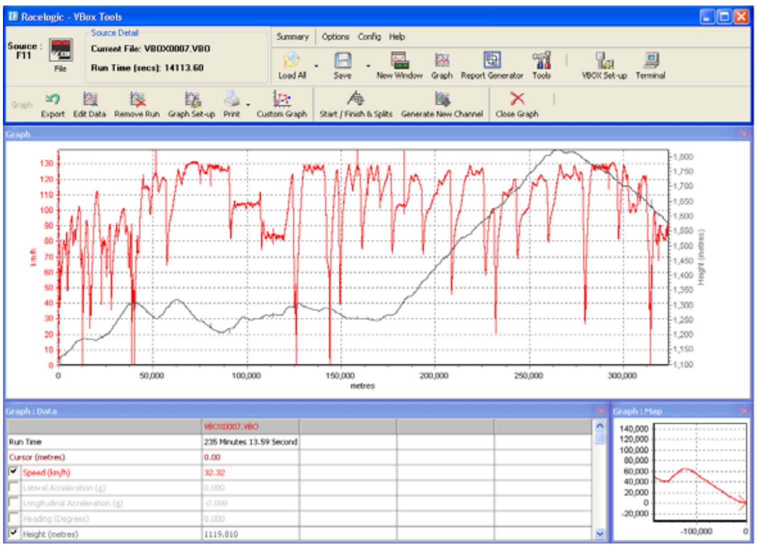



**Figure 10: VBox Tool software for analyzing GPS data**

Table 3: VBOX III GPS technical specifications

| Item | Description |
|---|---|
| Velocity Accuracy | 0.1 Km/h |
| Distance Accuracy | <50cm per Km |
| Distance Resolution | 1cm |
| Update rate | 100 Hz |
| Heading Resolution | 0.01° |
| Heading Accuracy | 0.1° |
| Acceleration Accuracy | 0.5% |
| Acceleration Resolution | 0.01 G |

Measured speed is monitored and recorded by one of the 16 channels of CRONOS PL data acquisition system manufactured by imc, Australia, which was connected to the portable computer. The data acquisition system is shown if figure 11. The acquired data are stored in binary format which are convertible to the other formats.

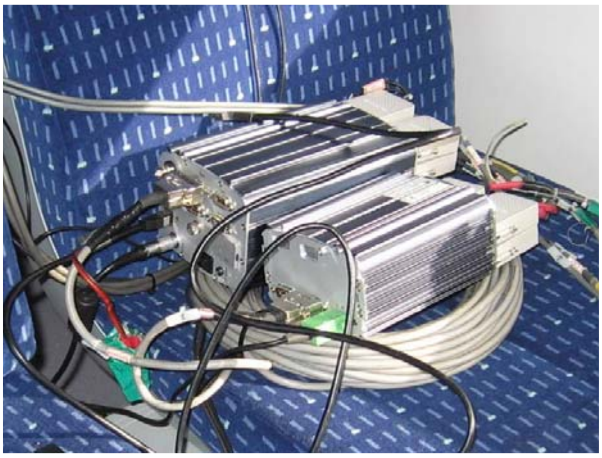
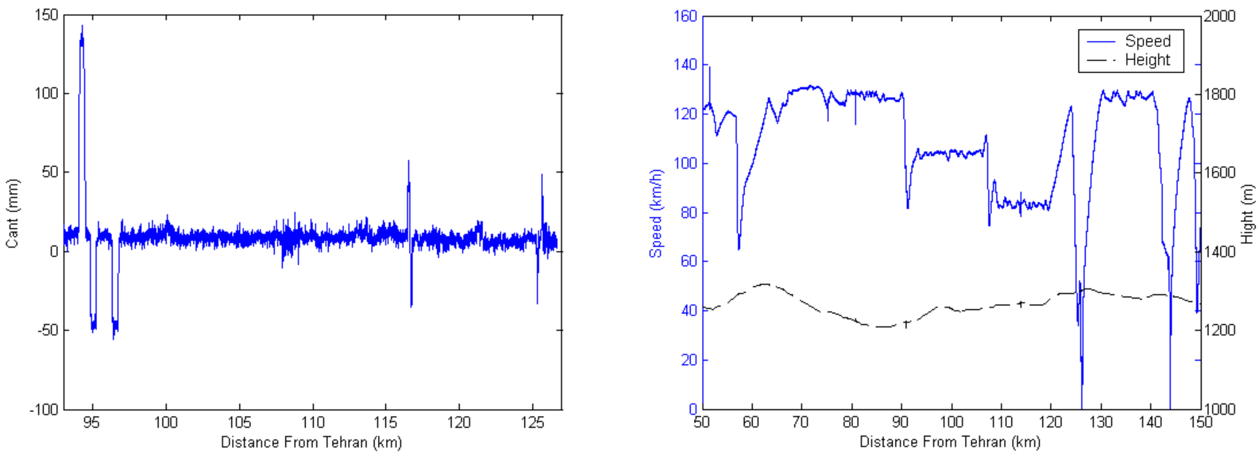


**Figure 11: data acquisition system**

### *4- 2- Route Segment Selection For Validation*

Cant variations of the track recorded by EM120 machine, vehicle speed and height profile of Tehran–Ghazvin route are shown in Figure 12.




a) Cant variation of Tehran–Ghazvin route

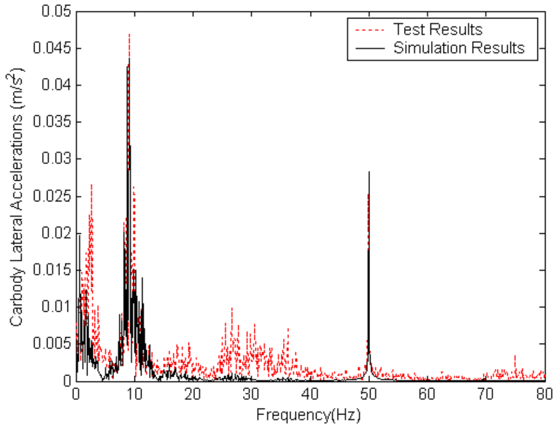
b) Speed and height profile of Tehran–Ghazvin route

**Figure 12: Tehran-Ghazvin route data**

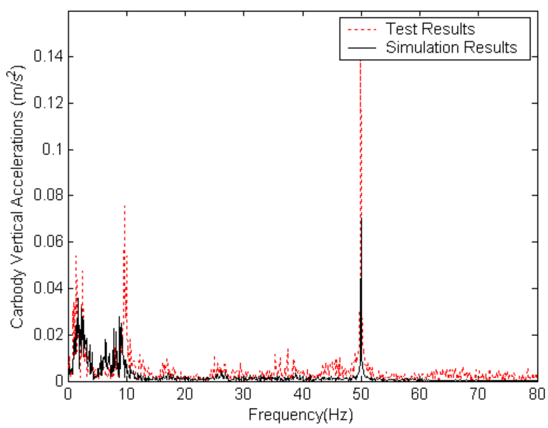
Referring to this figure, it is perceived that cant parameter in the interval between 110 to 115 km doesn't have any significant variation that means the track line is almost straight without significant curvature. So, this section of the test route is suitable for validation of the proposed vehicle model.

### *5- MODEL VALIDATION*

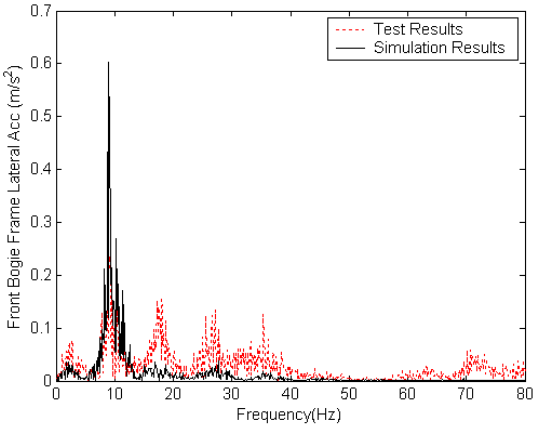
As track data and geometrical irregularities recorded by EM120 machine are not up–to–date and were recorded 25 months before dynamic test, by using track data, poor agreement between test and simulation results is achieved.



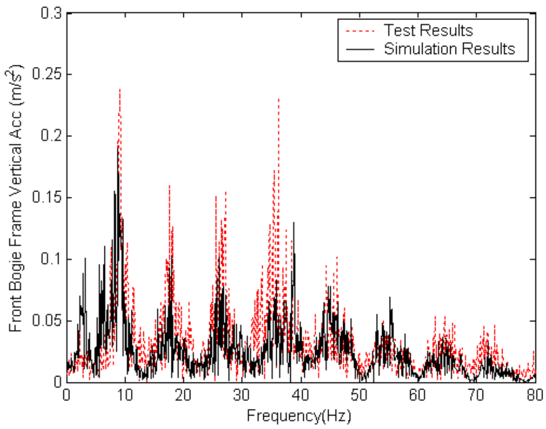

a) FFT of carbody lateral acceleration



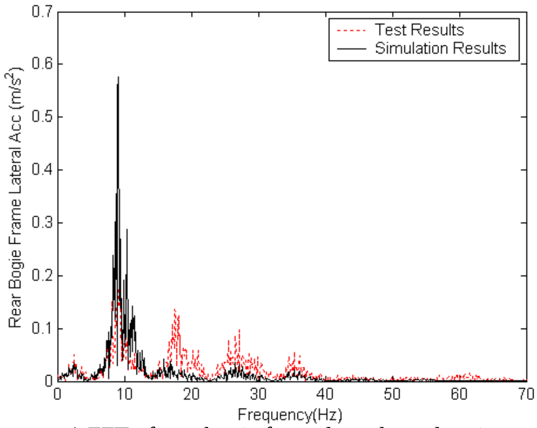

b) FFT of carbody vertical acceleration



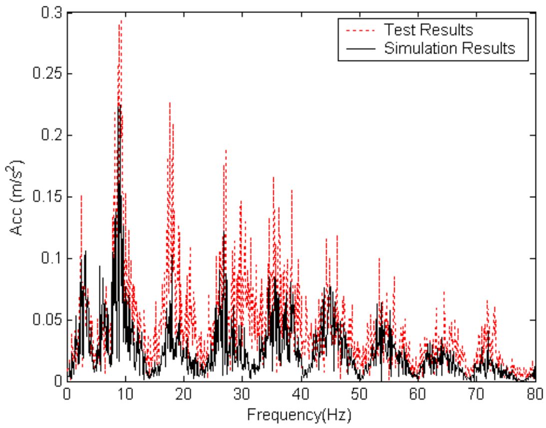

c) FFT of front bogie frame lateral acceleration




d) FFT of front bogie frame vertical acceleration




e) FFT of rear bogie frame lateral acceleration




f) FFT of rear bogie frame vertical acceleration

**Figure 13: Validation of complete vehicle model**

For this reason, the vehicle model is studied by measured axle accelerations within 200 meters of the track with their integrals in time domain as reference states to validate complete vehicle model. Whereas the accelerometers are not installed on the axles Nos. 1 and 4, the accelerations of Axle 2 and 3 are used with a constant lead/lag equal to axle base for axles 1 and 4. FFT of test and simulation results are shown in Figure 13. Whereas each car is equipped with an Auxiliary Power Unit (APU) which works with an internal combustion engine, there is a peak response in carbody accelerations signals in 50 Hz frequency. To simulate the effect of APU on the system, a sinusoidal force with relevant amplitude and frequency is added to the vehicle model as a disturbance. It can be seen that the vehicle test results and the proposed vehicle model have almost the same behavior.

### *6- CONCLUSION*

This research work validates a new model for studying influences of suspension system components behavior on rail vehicle dynamics. In the developed model, complete track–vehicle model with 70 degree of freedoms is addressed as a modular type and behavior of each component is defined and validated using real test data from field experiments. The presented air spring model can be easily used in dynamic modeling of air springs. For validation of the proposed vehicle model, dynamics test of the vehicle was carried out. Comparison of the results show good agreement between proposed model and test results that says this new model can be used for simulation of the vehicle performances very well and then it is a good model for further applications such as improvement in ride quality, comfort index and so on.

### *ACKNOWLEDGMENTS*

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