Investigation on Advantages and Problems of Air Springs in Railway Transportation

(محور همایش: ناوگان)

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Abstract

In this paper, we study the history, advantages and disadvantages which are related to thermodynamics issues. Furthermore, the air spring pneumatic diagram of IRICO Rail Bus is presented. Comparison between a conventional wagon with helical springs and a wagon with air springs as secondary suspension is carried out. Two types of springs are modeled and simulated by Adams/Rail. The model analyzed dynamically and the results are used for some main indices such as ride comfort, wear number and derailment.

Keywords: Air Springs, Helical Spring, Simulation, Wear number, Derailment

1. Introduction

In railway industry, passenger trains are equipped with primary and secondary suspension. Clearly, primary suspension is located between wheelset and frame and secondary suspension is placed between frame and wagon. Nowadays, manufacturers prefer to produce the secondary suspensions which utilize air springs as a suspension component. Figure 1 shows the example of bogie-IRICO Railbus which uses air spring.

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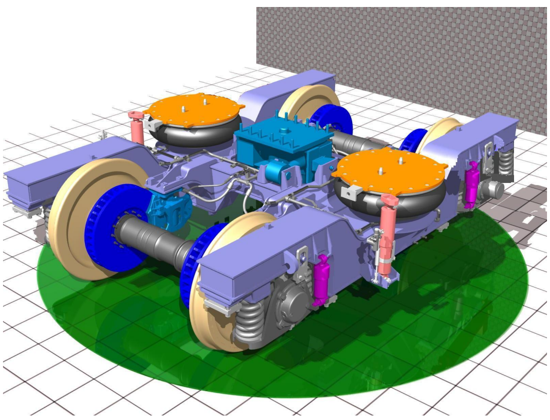


Figure (1) Bogie-IRICO Rail Bus [5]

The quality of ride, experienced by passengers, is predominantly controlled by the design of secondary suspension. Vertical excitation is most disturbing at 8.4 Hz and lateral excitation is 1.1 Hz that these frequencies are important for ride comfort. The secondary suspension must filter out the frequencies causing discomfort from the bogie frame while maintaining car body displacements within acceptable limits. Air springs are increasingly important suspension component in rail vehicles. This stems from the need for higher preload, higher speed as well as improved ride dynamics and noise levels. Vibration isolation is achieved conventionally by supporting a body on a vibration isolator. As a general rule, the natural frequency of the body and isolator system must be substantially lower than the excitation frequency. The deflection of the isolator under the load of supported body is inversely proportional to the square of the natural frequency. Thus, the static deflection is large when the natural frequency is low. The combined of a large static deflection and a large load carrying capacity require the storage of large quantities of potential energy in the isolator. The material used to construct mechanical springs has a limited energy-storage capacity per unit volume of material. Therefore, a spring, which must carry large loads and provides large static deflections, tends to become excessively bulky. [2]

A pneumatic spring, which employs gas as its resilient element. Since the gas is usually air, such a spring is often called an air spring. The ability of the air spring to support a given mass is governed by the effective area and the confined gas pressure. The gas in the air spring can be compressed to the pressure required to carry the load and therefore air springs do not require large static deflection. The compressibility of the gas provides the desire elasticity for spring. If the load and static deflection are large, there is usually a large weight reduction resulting from the use of air springs.

2. History[2]

The history of air suspension goes back more than a century and a half. In 1847, the year Thomas Edison was born, only three years after Charles Goodyear's rubber vulcanization patent was issued, inventor John Lewis was granted U.S patent No.4,965 for "pneumatic Springs for Railroad Cars, Locomotives, Burden-Cars, Bumpers and etc", (figure(2)). But Lewis invention was a century ahead of rubber technology. Air springs wouldn't achieve success until post-World War II polymers, including nylon tire cord and synthetic rubber elastomers came along. Today all European buses and passenger rail vehicles ride on air.

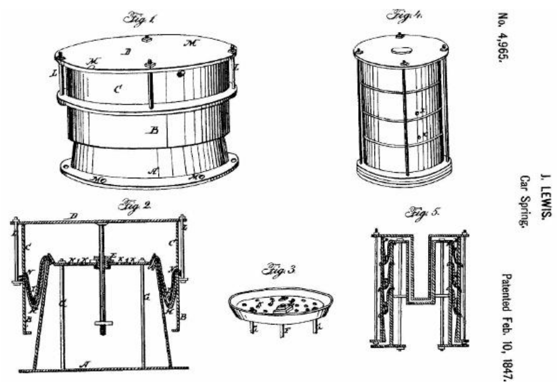


Figure (2) first Air Springs was made with flexible rubber material [2]

3. **Principal behavior** [1] [2] [5]

As shown in figure (4) package of air springs that holds the air. This package is very important, because it controls the shape of the air inside which greatly affects the air springs performance. The axial stiffness of air springs is inversely proportional to the volume. The air spring softens in the vertical direction with increasing volume. To increase the volume and lower the stiffness of air spring, an air reservoir may be connected to the air bag via a large passageway. The increased volume reduces the natural frequency as the square root of the increased volume. In the simplest case, the air spring system consists of an air bellow is connected to an auxiliary volume via a surge pipe. When the system is exposed to vibration, the air inside the bellow is compressed (or expanded) and pressure differences between the bellow and the auxiliary volume arise. Through the surge pipe air can interchanges and pressure differences can be neutralized.

During spring loading the air streams from the air bag to the reservoir, during unloading it streams in the opposite direction. Depending on the size of the pipe, more or less phase shift between the pressure in the bellow and the reservoir arises.

A more complex air spring system would contain a leveling valve and a compressor (e.g. ***IRICO*** Rail Bus), which gives an automatic height control. A pneumatic system with leveling valves offers an essentially constant natural frequency regardless of the load. When the weight is added to the vehicle and additional air is pumped into the spring to restore the design height, the pressure is increased. Because the spring rate is a function of the absolute pressure of its contained air, the spring rate goes up in proportion to the mass added, resulting in a constant natural frequency constant ride.

4. **Problems** [2] [5] [8]

1- The lower spring rates and frequencies usually mean greater difficulty in controlling vehicle roll and handling.
2- An operational cost is that air springs may require more maintenance than mechanical springs.
3- They are subject to damage by sharp and hot objects.
4- The operational temperature range is also restricted compared to those of mechanical springs.

5. **Advantages** [2] [5] [8]

1- A readily attained low system natural frequency for a soft ride and lower shock inputs.
2- Almost constant system natural frequencies throughout the normal vehicle load range, again providing a good ride and lower shock inputs.
3- One suspension height for all loads conditions, allowing more usable compression deflection for the load condition that needs it most.
4- Increased cargo capacity is possible because of lower vehicle weight and constant empty and loaded height.
5- Better passenger, cargo and vehicle protection, which is attributable to low-spring rates and very low friction.
6- Length of air spring is shorter than helical spring so the static and dynamic gage is increased.

6. **Spring rate** [2] [5] [8]

When the volume of an air spring is reduced during the jounce stroke of a suspension, confining the particles more closely together, this not only increases the pressure, but also the temperature. The explanation is that the energy imparted in the squeeze has been transformed into increased kinetic energy of the particles-which is measured as heat. The gas pressure in the air spring varies with speed and magnitude of deflection; for a unit of deflection, the pressure and therefore, the spring rate will different for an isothermal, adiabatic, or polytrophic process [2].

For a specific spring design, the minimum pneumatic spring rate occurs with adiabatic compression. The poly tropic rate, n, varies between the isothermal and adiabatic, i.e. $1<n<\gamma$.

In real situation, isothermal process for air springs is impossible. During compression and expansion heat is generated by air spring so temperature increases and also the process is much closer to adiabatic than isothermal:

$$p_1 / V_1^{\gamma} = p_2 / V_2^{\gamma} = const \qquad \gamma = 1.4 \tag{1}$$

Consequently, the spring rate is [2]:

$$K_{z,dyn} = \frac{dp}{dz} / A_e = \gamma / (p_a + p_g) / \frac{A_e^2}{V}$$
$$K_{z,stat} = \frac{dp}{dz} / A_e = (p_a + p_g) / \frac{A_e^2}{V} \tag{2}$$

7. Air spring pneumatic diagram of *IRICO* Rail Bus [3]

As it can be seen in figure (3) the air spring pneumatic diagram, air pressure comes from the MRP[1]-pipe via the air filter (62) and overflow valve (63).

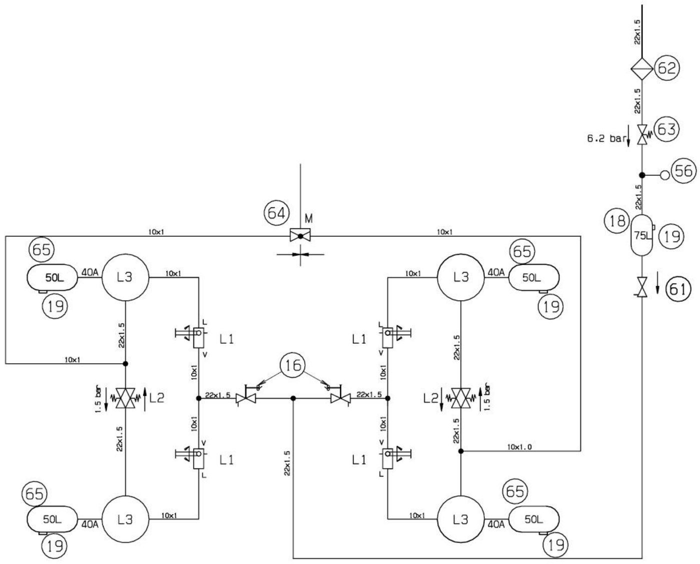


Figure (3) Air spring pneumatic diagram of IRICO Rail Bus [3]

The purpose of the overflow valve (63) is to preserve air for the brake system. The valve does not allow air to pass to the air suspension equipment until a determined preset pressure value is achieved. The vented cut-out cock (61) isolates the leveling system of each bogie in case of failure or during maintenance operation. The leveling valves (L1) adjust the required working air pressure of the air bags. Double overflow valves (L2) regulate pressure differences between bellows from two sides of the car, opening at a pressure setting of 1.5bar.
The air bags (L3) and the air reservoirs (65) will be provided. A mean pressure valve for the load weighing pressure (64) takes the average of each suspension side and sends it to the pneumatic brake control unit (20).

8. Simulation

It is possible to simulate the air spring by Adams/Rail. There are different models in Adams rail such as NISHIMURA and KRETTEK. Model of NISHIMURA is shown in figure (4).

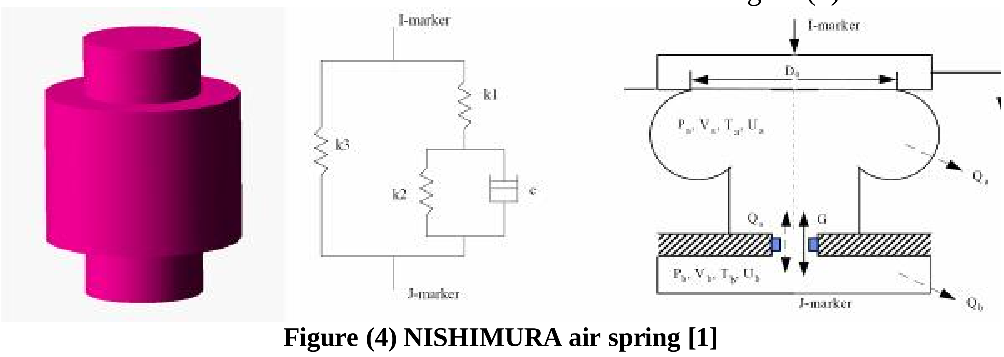
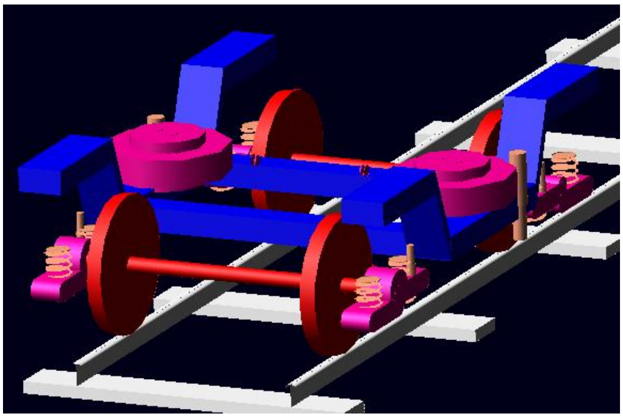


Figure (4) NISHIMURA air spring [1]

For simulation, IRICO Rail Bus wagon and a track are modeled that are suitable for air spring and helical spring. Then results are used to discuss about wear rate and derailment. The specification and data of the wagon and the track is according to IRICO wagon data and the Adams/Rail default track.

[1] Main Reservoir Pipe

In figure (5) the bogie with air springs is shown. It is possible to change the magnitude of parameters and repeat the simulation, and then results are used for investigating some parameters such as ride comfort, wear number, derailment and so on. For example, it is possible to change the polytropic coefficient for the isothermal and the adiabatic process and it is possible to change the effective area and the volume for design optimization.



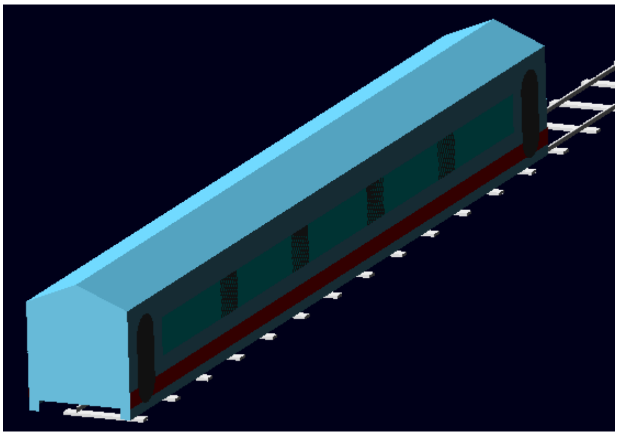


Figure (5) bogie and air spring that is modeled in Adams/Rail [1]

9. Wear rate

Wear of Rail/Wheel contact is a main problem in maintanance. Because this increase the cost of maintanance. So railway company seek to improve contact of the Wheel/Rail system. Many projects were proposed to optimize wheel profile and to change materials and alloys of the wheelset to decrease the wear rate. Therefore in this part the wear rate in a wagon with air springs and wagon with helical springs are compared. wear number is used to compare wear rate in these two type wagon[6]:

$$W_n \propto (T_y \gamma_y + T_x \gamma_x) \tag{3}$$

The peformance of a wagon with the air spring is similar to tilting trains. Because of rolling movement around the longitudinal axis. The forces distribution are balanced and lateral forces are less than conventional trains. Consequently wear rate in the wagon with the air spring is less than the conventional wagon. So the wear number in a special wheelset for two kind of wagons that were simulated, is shown in figure (6). You can see the wear rate in the wagon with the air spring is less than the conventional wagon.

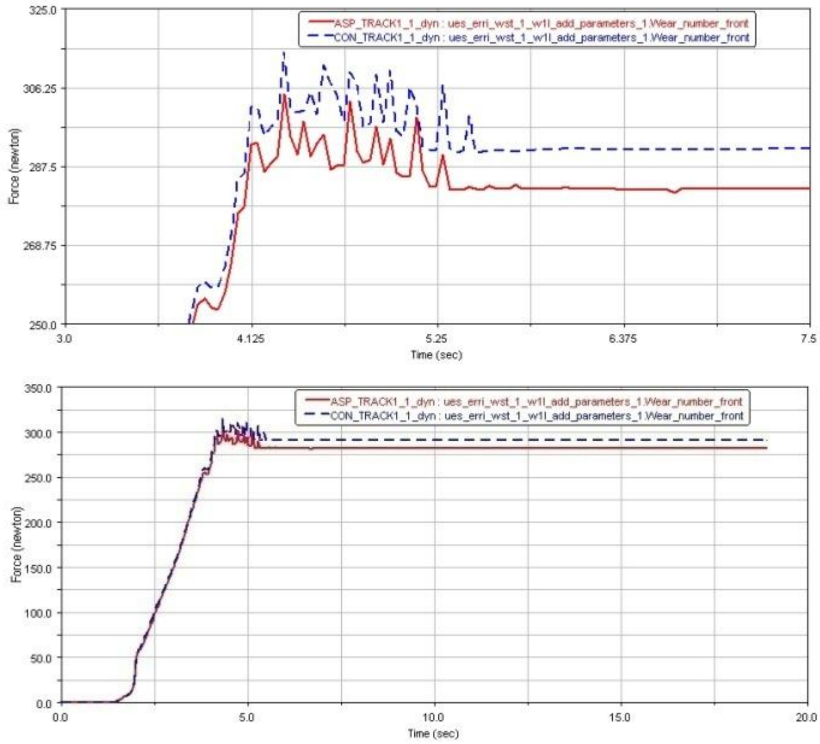


Figure (6) Wear number-wagon with air spring (continuous line) and conventional wagon (dash line)

It is possible to predict wear rate by the wheelset displacement angle. In figure (7) the displacement angle in the conventional wagon is more than the wagon with air spring so we can say the wear rate in the conventionan wagon is more than the wagon with air springs.

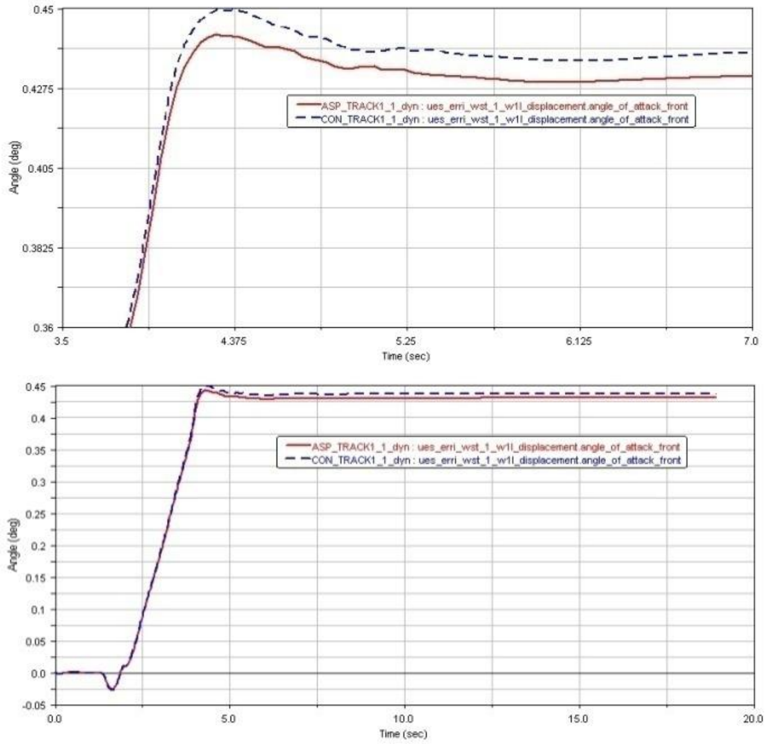


Figure (7) Displacement angle-wagon with air spring (continuous line) and conventional wagon (dash line)

10. Derailment

A derailment is an accident on a railway in which a train leaves the rails, which can result in damage, Injury, and death. There are several main causes of derailment: broken or misaligned rails, excessive speed, and faults in the train and its wheels. Derailment can also occur as a secondary effect in the aftermath of a collision between two or more trains [8].

When the air spring is used for a wagon the forces distribution are balanced and the magnitude of lateral forces is less than conventional wagons so it can be claimed that in a special speed risk of derailment in the wagon with air spring is less than the conventional wagon.

Theory of the deraiment is so complicated and it depends on several nonlinear parameters in wheel/rail contact, such as contact area, contact angle, contact geometry, creep forces and so on. Many theories were presented that are ratio between lateral forces and vertical forces ($\frac{L}{V}$). In safe condition $\frac{L}{V}$ should be less than 1.2 ($\frac{L}{V} < 1.2$) [7].

For example NADAL theory is:[6][10]

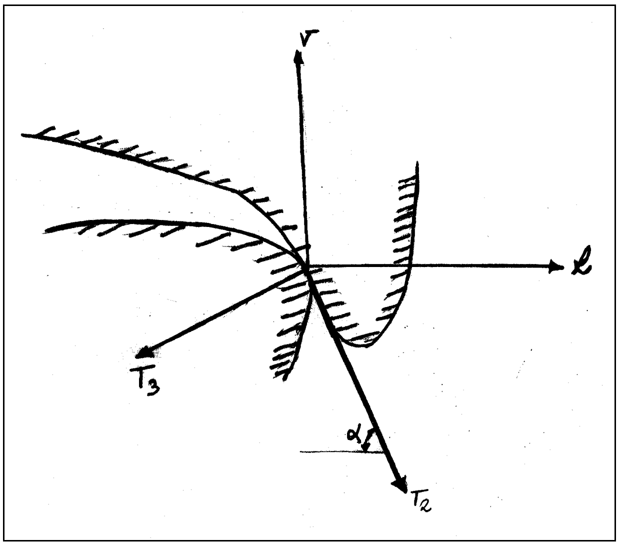


Figure (8) Contact forces that is used in NADAL theory

$$\begin{aligned} L &= T_2 Cos(\alpha) - T_3 Sin(\alpha) \\ -V &= T_2 Sin(\alpha) + T_3 Cos(\alpha) \end{aligned} \tag{4}$$

It can be supposed $T_2 = \mu T_3$ $\Longrightarrow$ $\frac{L}{V} = \frac{Tan(\alpha) - \mu}{1 + Tan(\alpha)}$

Results in the postprocessor can be used to calculate derailment index. As shown in figure (9) the risk of the derailment in the conventional wagon is more than the wagon with air spring. In both of them, the derailment index is less than 1.2.

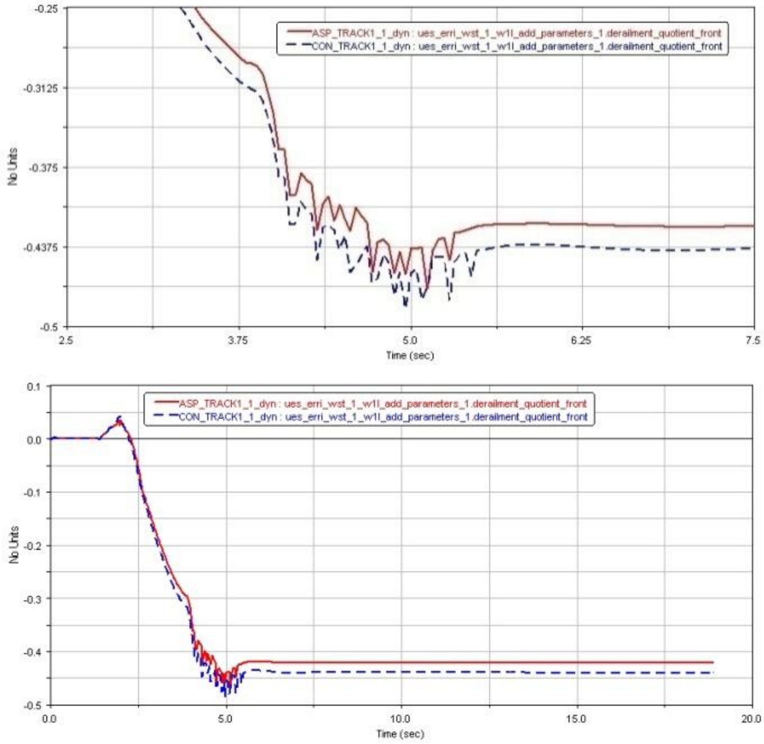


Figure (9) Derailment index-wagon with air spring (continuous line) and conventional wagon (dash line)

11. Conclusion

The main purpose of this paper is the fact that the air spring is an efficient suspension that is used in the railway transportation particularly in passenger trains. A wagon with the air spring and a conventional wagon are simulated by Adams/Rail. It is possible to change the magnitude of the parameter for different purposes such as design optimization for selecting a suitable suspension for different operational conditions and maintenance. The air spring as a secondary suspension improves the ride comfort, furthermore in this paper it was shown that wagon with the air spring has low wear rate in comparison with the conventional wagon and the risk of the derailment by the air spring is lower than the conventional wagon, so it is possible to increase the speed of trains in curves.

12. References

[1] MSC Software, Adams/Rail Help, 2005

[2] Derivation of Air Spring Model for Train Simulation, Malin Presthus, Lulea University, 2002

[3] Operating Manual, **IRICO** Rail Bus, 2008

[4] Mounting instructions and inspection requirements for ContiTech ® air springs for rail vehicles, 2008

[5] Drawings and Documents of IRICO Rail Bus, 2008

[6] Final project, Tilting Trains, Vahab Fazli Kechidi, Railway Department, Iran University of Science and technology, 2008

[7] UIC 518, 2003

[8] Internet, Wikipedia, The free encyclopedia, Derailment, 2008

[9] ABB Daimler-Benz Transportation (Deutschland) GmbH, “Information Regio-Swinger”, 1.1998

[10] Matsu, M. “Quasi-Static Derailment of a Wheelset”, Quarterly Report of RTRI, Vol. 27, No. 3,1986

13. Nomenclature

A_e	Effective area
V	Volume
F_z	Vertical force
$K_{z,dyn}$	Dynamic vertical stiffness
$K_{z,stat}$	Static vertical stiffness
p	Absolute pressure
p_g	Gauge pressure
p_a	Atmospheric pressure
A	Contact area
T_z, T_y	Vertical and lateral forces
L	Lateral force
V	Vertical force
T_2	Planar force
T_3	Normal force
α	Flange angle
μ	Adhesion coefficient
γ	Is the value $C_p / C_v = 1.4$
γ_z, γ_y	Vertical and Horizontal creepage