

Effect of different types of wagon connectors on longitudinal forces of a heavy freight train

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Abstract

Indian Railway operates full rake freight trains of 2200t which consist of BOXN wagons having payload 58.08t and tare weight 23.2t for each wagon. Longitudinal forces of a freight train have significant effects on safety parameters like derailment coefficient, comfort index and these forces are transmitted through the wagon connectors. For this reason, longitudinal forces are different for different types of wagon connectors. In this paper, the effect of different combination of wagon connectors on the longitudinal forces of a heavy freight train is studied. Nine combinations of the connectors are considered using three types of wagon connector, namely Sh-1-T, Sh-2-T, and Sh-2-V. The train model has one diesel locomotive and thirty open freight wagons each having 81.28t gross mass. The train moves on a 1520mm gauge track of S-type curve having 300m radius. All simulations are performed in Universal Mechanism UM 8.1 software. The simulation results reveal that Sh-2-T wagon connector when used across the train generates the least longitudinal force.

Keywords: Heavy freight train, longitudinal forces on coupler, auxiliary braking, service braking, wagon connector.

1. Introduction

Indian Railway carries the entire gamut of goods, ranging from parcel traffic and small consignments, agricultural products, raw materials like iron ore, crude oil, etc., finished goods like automobiles, petroleum products, cement, etc. Over the last decade, there have been several attempts to increase the transition speed of freight trains in Indian Railway. Longitudinal force has considerable effect on the speed and safety of a train. Longitudinal force is defined as the force which acts in the direction of the track. When the direction of a running vehicle and force are same then it is called coupler tractive force and when they are opposite in direction then it is called coupler pressing force. These tractive and pressing forces are mainly generated at the time of acceleration and deceleration of a train. Lateral oscillations are also generated due to these longitudinal forces.

From the hand book of railway vehicle dynamics (Iwnicki, 2006), we find that longitudinal forces have considerable effects on the lateral forces [1]. Derailment coefficient is the ratio of lateral forces to the vertical loading of the wheel. So the high longitudinal force increases the lateral force and due to this high lateral force, derailment coefficient may cross its critical value. For these reasons, we need to restrict longitudinal forces within the safe limit.

M. Ansari et al. (2009) investigated the longitudinal dynamics of freight trains [2]. They studied the effect of different parameters like coupler stiffness, coupler damping coefficient, train speed, acceleration, load distribution pattern, position of second locomotive, and position of empty wagon on the longitudinal dynamics of heavy haul freight trains. C. Chang et al. (2016) modelled and simulated a heavy haul train using newmark-beta method. They showed the effect of speed and car position on the longitudinal forces [3]. P. Liu et al. (2017) presented the effect of full service braking and emergency braking on the wheel rail dynamic interaction in a sharp curve [4]. J. Stoklosa et al. (2014) simulated a sixty wagon freight train and showed the longitudinal

forces in the 33rd and 60th wagon [5]. D. Younesian et al. (2010) investigated the effect of different parameters such as operational speed, fluid modelling, rail irregularities, and fluid density on the longitudinal forces and derailment quotient [6]. Z. Q. Xu et al. (2013) modelled a 2000t heavy haul train and showed the effect of coupler rotation on the longitudinal dynamics of the train [7]. They recommended that the maximum coupler free angle is 4°. F. Cheli et al. (2016) presented the effect of payload and braking power distribution on coupling forces for different types of train configurations [8].

In this paper, the effect of coupling devices on the longitudinal forces are studied with the help of Universal Mechanism UM 8.1 software. A train consists of thirty open freight wagons each having 81.28t mass and a TE10 diesel locomotive (126 t) is modelled. The train is made to run in a 1520mm gauge, S curve having 300 m radius track. Three different wagon connectors, namely Sh-1-T, Sh-2-T, and Sh-2-V are considered in this paper, and nine train configurations are made using these connectors. During simulation, auxiliary, service, and emergency braking are used at different times to get maximum coupler forces. Two different velocities, i.e. 144km/hr and 100km/hr are used during simulation. Finally, using the simulation results, the best wagon connector configuration is found. In India, maximum velocity of a freight train is 75km/hr. Thus, the findings cannot be experimented in a real setup. For this reason, computer aided modelling and simulation using a professional software are the only way to generate results.

The rest part of the paper is organised as follows. Modelling of a heavy freight train is shown in Section II. Simulation and results are discussed in Section III. Finally, conclusions are given in Section IV.

2. Models of a heavy freight train and its simulation

Previous papers on longitudinal train dynamics show that transitional processes have particular importance in the process of operation of heavy freight trains. Studies have shown that at the time of acceleration and braking, thrust forces in the coupling devices increase significantly. If the thrust force goes beyond a critical limit then it may cause a rupture of the coupling. The post processing of Universal Mechanism software is very advance. It can do linear analysis, statistics, multivariate calculation, optimisation, and export all results efficiently. Multi body and hybrid models like automobiles, robots, tracked vehicles, aerospace structure, railway vehicles can be modelled very easily using UM8.1. In India, freight trains mainly consist of BOXN type of open wagon. The mass of unloaded wagon or tare weight is 23.2t and payload is 58.08t. Thus, the weight of a full loaded wagon is 81.28t. Floor area of a wagon is 28.87 m² and capacity is 56.29 m³. Usually, coal, metal ore, raw materials of industries are transported using this type of wagons. The freight train is modelled with the help of train wizard in UM Input. Total number of vehicle is 31 where diesel locomotive TE10 is the only locomotive and other 30 vehicles are of open wagon cars. The gross mass of the locomotive is 126t and gross mass of a wagon are 81.28t. The length of the locomotive and a wagon is 16.969m and 14.73m, respectively. In this model, only the first coupler experiences different mass on two sides. So, we can differentiate between the first coupler position and other 29 couplers position. Using Sh-1-T, Sh-2-T, and Sh-2-V wagon connectors, we modelled nine train configurations which are shown in the TABLE I.

Table I. Arrangement of Couplers

Train configuration	Type of 1 st coupler	Type of other couplers
1 st Configuration	Sh-1-T	Sh-1-T
2 nd Configuration	Sh-1-T	Sh-2-T
3 rd Configuration	Sh-1-T	Sh-2-V
4 th Configuration	Sh-2-T	Sh-2-T
5 th Configuration	Sh-2-T	Sh-1-T
6 th Configuration	Sh-2-T	Sh-2-V
7 th Configuration	Sh-2-V	Sh-2-V
8 th Configuration	Sh-2-V	Sh-1-T
9 th Configuration	Sh-2-V	Sh-2-T

Simulation is conducted on a 1520mm gauge S curve track which is modelled using macro-geometry. The first 30 m is a straight track. Then 300m radius left curve which has 50m transition curve, 200m steady curve and again 50m transition curve, sequentially.

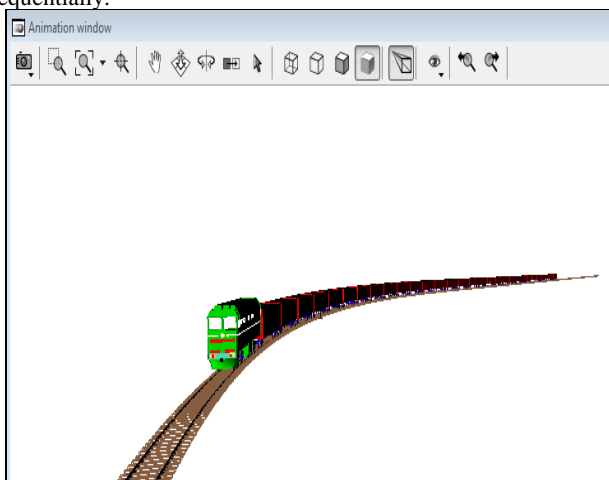


Fig.1. Model of a freight train made in universal mechanism

After that 10m straight track and 300m right curve is modelled with the same specifications as the left curve. So, the track has a 640 m long S curve and other portion of the track is straight. The train model is shown in Fig. 1.

The train model includes basic resistance models for locomotive and loaded freight car with long welded rails. The resistance model for motion in the curved track is also considered. Equation 1 is the resistance model for locomotive.

$$R_{loco} = (9.81 \times (2.4 + 0.009 \times v \times 3.6 + 0.00035 \times (v \times 3.6)^2)) \times \frac{M}{1000} \quad (1)$$

Equation 2 is the resistance model for loaded freight car.

$$R_{fr} = 9.81 \times \left(\frac{0.07 \times m}{1000} + (3 + 0.09 \times v \times 3.6 + 0.002 \times (v \times 3.6)^2) \times 4 \right) \quad (2)$$

where

M- the mass of the locomotive in [t],
m - the mass of the full loaded wagon in [t],
v - the velocity of the train in [m/sec].

Equation 3 is the resistance model for motion in the curved track.

$$R_{curve} = \frac{a}{r} \times \frac{l}{L} \text{ [N]} \quad (3)$$

where

r- the radius of the arc in [m],
a- the empirical factor,
l- the length of the curvature of the track in [m],
L - length of the train in [m].

Pneumatic brake is used in the simulation. The brake riggings of TE10 is iron shoes and for Freight cars, these are composite shoes. Service braking, 25s and emergency braking, 20s are used as brake ID.

Friction coefficient model grey iron acts for locomotive and other model composite acts for freight wagons.

Speed of the service brake wave, speed of the emergency brake wave, and speed of the release wave are taken as 300m/sec, 450m/sec, and 100m/sec, respectively.

So, the braking process using brake pipe is not simultaneous in all wagons.

After modelling simulation is done nine times for two different speeds.

3. Simulation and results

We have done the simulation using park solver. To get the maximum coupler force, an auxiliary brake of the locomotive is used as service braking at the beginning. Then at 45th sec, service braking is done using brake pipe and the final pressure of the brake cylinder is set to 60000pa.

At 50th sec again, an auxiliary brake is used in running repeater mode.

After that at 170th sec, we released all the brakes. Finally, an emergency braking is done at 250th sec. We use such braking pattern to get the possible coupling forces due to braking [9].

The braking forces are shown in Fig. 2. In the figure blue line is for locomotive braking force and others are for braking forces of thirty wagons.

Simulation is done for 300sec and range space method is used for solution.

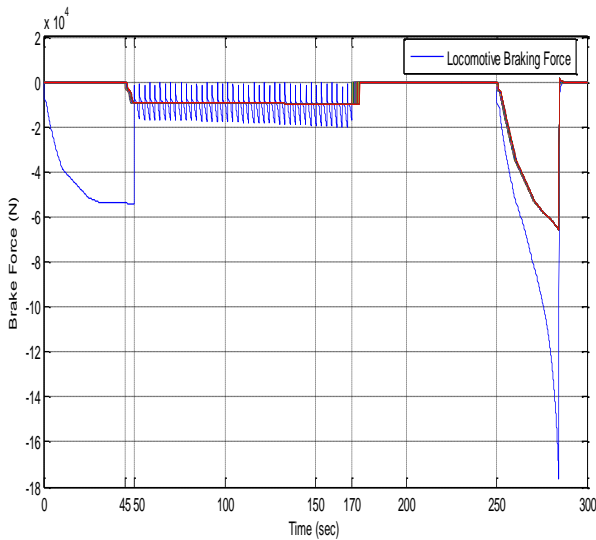


Fig.2. Braking force for 144 km/hr initial velocity

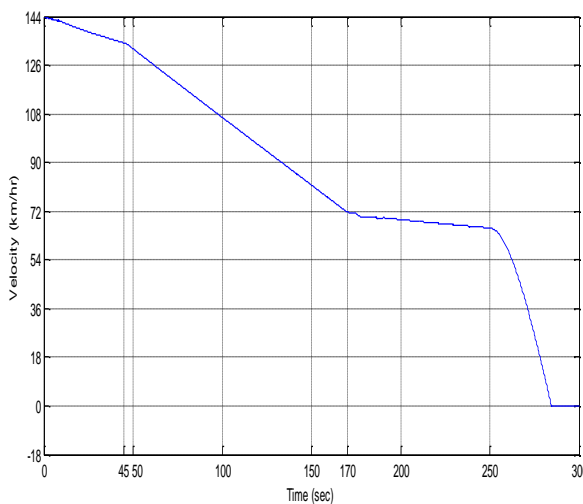


Fig.3. Maximum coupler forces on each coupler for 144km/hr initial velocity

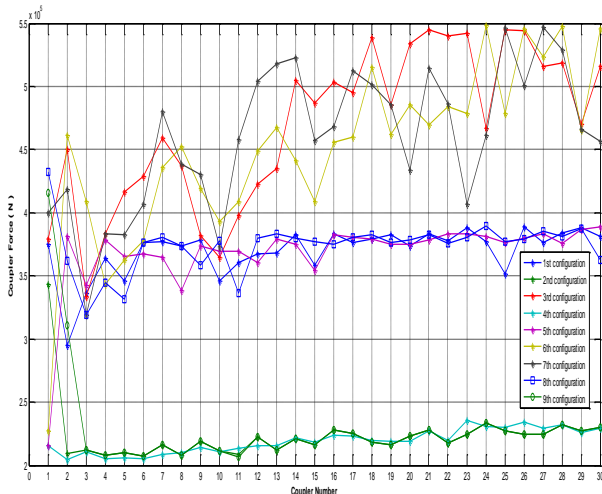


Fig.4. Velocity profile of the train for 144 km/hr initial velocity
At first, simulations of the nine train configurations are done with 144 km/hr initial velocity and the graph of maximum coupler forces on each coupler is shown in Fig. 3. The configuration which have lowest coupler forces is the best. From Fig. 3, we observed that the coupler forces in 2nd, 4th and 9th configurations are very close to each other. But considering the 1st, 2nd and 3rd coupler forces, it is apparent from Fig. 3 that the 4th configuration is the best. Throughout the braking process considered (shown in Fig. 2), the maximum coupler force of the 4th configuration is below 240 kN. For other wagon connectors, the maximum coupler

force sometimes crosses 500 kN also. Therefore, Sh-2-T wagon connector is the best for all position when initial velocity is 144km/hr. The velocity profile is shown in Fig. 4 considering the braking process. Initial velocity is reduced according to braking pattern. After 170sec, we released all types of brakes. So, the cause of velocity reduction after 170sec is the resistance of the locomotive, wagons, and curved track. An emergency brake is applied at 250th sec and it brings down the velocity zero within 30 sec.

The simulations are repeated for 100 km/hr initial velocity. Figure 5 shows the maximum coupler forces on each coupler for 100 km/hr initial velocity. From the graph, again, we see that 2nd, 4th and 9th configurations have lower maximum forces which are very close to each other. However, considering the coupler forces in 1st and 2nd couplers, we have found that the 4th train configuration has the lowest maximum coupler forces which is within 230 kN throughout the simulation. So, we can conclude that Sh-2-T wagon connector is the best for all position when initial velocity is 100 km/hr.

The braking forces are shown in Fig. 6 and corresponding velocity profile for these braking is shown in Fig. 7. In the Fig. 6 blue line is for locomotive braking force and others are for braking forces of thirty wagons. Nature of braking and timing of braking are same as before.

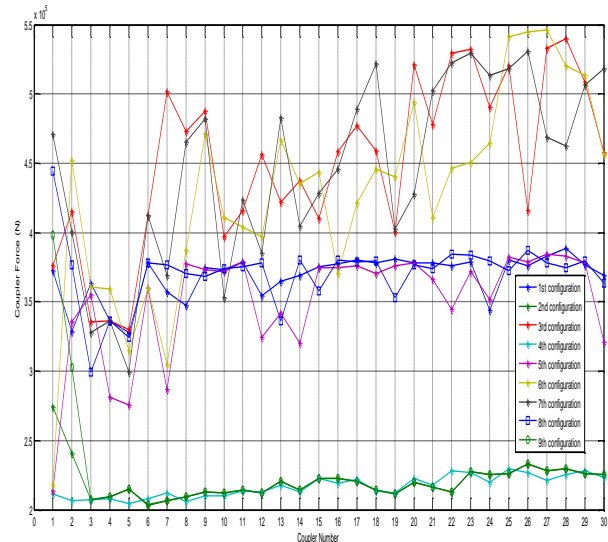


Fig.5. Maximum coupler forces on each coupler for 100 km/hr initial velocity

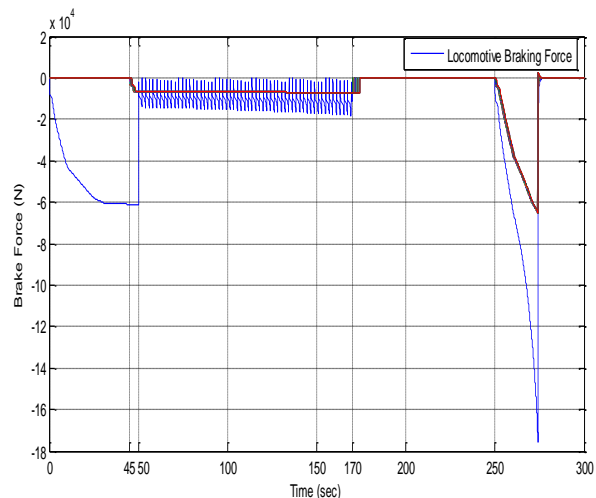


Fig.6. Braking force for 100 km/hr initial velocity

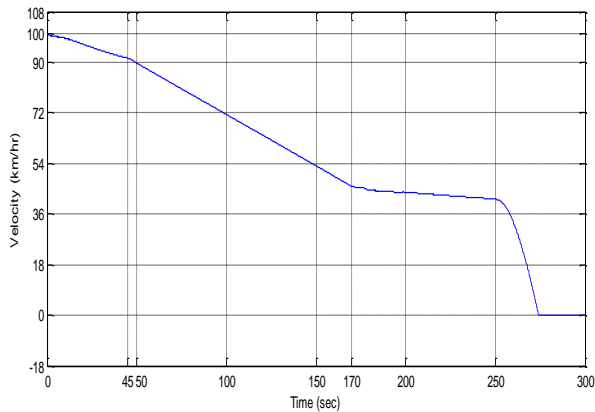


Fig.7. Velocity profile of the train for 100 km/hr initial velocity.

4. Conclusion

In this paper, the effect of wagon connectors on longitudinal forces have been studied in details. A freight train model is made with one diesel locomotive and thirty open freight wagons. A 1520 mm gauge, S curved track is used during simulation. Three different connectors, namely Sh-1-T, Sh-2-T and Sh-2-V wagon connectors are used for the analysis. Nine different combination of wagon connectors are considered. The simulation is carried out with 140 km/hr and 100 km/hr initial velocity. The simulation results reveal that Sh-2-T wagon connector in all positions of the freight train generates minimum coupling forces irrespective to the initial velocity. It is concluded that Sh-2-T wagon connector should be used in all position of the train when compare with Sh-1-T and Sh-2-V connectors.

In future, we will consider various loading like empty wagon, partially filled wagon and continue the present study to find if the Sh-2-T is the best connector irrespective to loading of the wagons.

References

- [1] Iwnicki S, *Handbook of Railway Vehicle Dynamics*, CRC Press, Boca Raton, (2006).
- [2] Ansari M, Esmailzadeh E & Younesian D, "Longitudinal dynamics of freight trains", *International journal of heavy vehicle systems*, Vol.16, No.1-2, (2009), pp.102-131.
- [3] Chang C, Guo G, Wang J & Ma, Y, "Study on longitudinal force simulation of heavy-haul train", *Vehicle System Dynamics*, Vol.55, No.4, (2017), pp.571-582.
- [4] Liu P & Wang K, "Effect of braking operation on wheel-rail dynamic interaction of wagons in sharp curve", *Proceedings of the Institution of Mechanical Engineers, Part K: Journal of Multi-body Dynamics*, Vol.231, No.1, (2017), pp.252-265.
- [5] Stokłosa J & Jaśkiewicz M, "Simulation study of longitudinal forces in the coupling device of heavy freight trains", *Journal of Advances in Science and Technology Research*, Vol.8, No.21, (2014).
- [6] Younesian D, Abedi M & Hazrati Ashtiani I, "Dynamic analysis of a partially filled tanker train travelling on a curved track", *International Journal of Heavy Vehicle Systems*, Vol.17, No.3-4, (2010), pp.331-358.
- [7] Xu ZQ, Ma WH, Wu Q & Luo SH, "Coupler rotation behaviour and its effect on heavy haul trains", *Vehicle system dynamics*, Vol.51, No.12, (2013), 1818-1838.
- [8] Cheli F, Di Gialleonardo, E & Melzi S, "Freight trains dynamics: effect of payload and braking power distribution on coupling forces", *Vehicle System Dynamics*, Vol.55, No.4, (2017), 464-479.
- [9] Universal Mechanism 8.1, *Simulation of Longitudinal Train Dynamics*. User's manual, (2016).
- [10] Cole C, Spiriyagin M, Wu Q & Sun, YQ, "Modelling, simulation and applications of longitudinal train dynamics", *Vehicle System Dynamics*, (2017), pp.1-74.