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A STUDY ON RELEASING MANOEUVRE TO IMPROVE FREIGHT SAFETY AND EFFICIENCY

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ABSTRACT

The paper investigates the in-train tensile forces that occur during a braking manoeuvre followed by brake release and train acceleration. More in detail, it analyses the effect of traction unit characteristics, in terms of power application gradient and time of power application, on highest in-train tensile forces, for different braking and releasing regimes. By taking into consideration both uniformly and not-uniformly loaded trains, it is shown that it is possible to significantly increase freight efficiency, also avoiding train disruption risk, by smoothly applying power to traction unit just after the initiation of brake releasing operation.

Keywords: brake releasing, freight trains, train disruption, railway efficiency.

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1. INTRODUCTION

One of the most important topics to consider when assembling innovative compositions of freight trains is the value of Longitudinal or in-train Forces (LFs) exchanged by consecutive wagons of the train. This topic is usually addressed as Longitudinal Train Dynamics (LTD) and it refers to the relative motion of adjacent railway vehicles running in track direction. Paper [1] provides an excellent review of this matter and [2] reports a benchmark of several LTD simulators coming from different Research Centres and Universities around the world. LTD is a key factor in determining safety of freight trainsets: high in-train compressive forces (also referred as Longitudinal Compressive Forces-LCF) can determine train derailment, whereas high in-train tensile forces (also referred as Longitudinal Tensile Forces-LTF) may cause train disruption (i.e. the train division into two or more parts). Both scenarios must be avoided, since both are dangerous and decrease freight transportation efficiency. Such high values of LFs arise from design of classical UIC braking scheme that equips common freight wagons used in Europe and that does not allow a synchronous braking of the wagons [3]. As a matter of fact, during a braking the first wagons brake before than the last wagons and this cause high LCF; on the contrary, during the brake release, the first wagons have their brake released whereas the last wagons can have their brake still (partially) activated, resulting in high LTF.

From Railways experiences and from in-line tests general limits are set on train mass/length according to the type of wagons (2 axle wagons or bogie wagons) and braking regime (P, G, GP, LL), in order to limit the values of 10 m LCF, i.e. the minimum value of LCF (in absolute sense) occurring in the previous 10 m [4]-[5]. There is a lower knowledge on the causes that brings to high values of instantaneous LTF, which can cause a train disruption and that occurs more frequently than train derailment. From Railway Undertakings experience, there are known limits to respect to avoid high values of LTF, according to train mass and track profile, but their operative experience shows that train disruption event is affected also by train length, train braking regime, specific train operation (releasing/braking), and, of course, it depends on mechanical resistance of employed draw gears.

The aim of this paper is to clarify the effect of some of previous aspects in a more rigorous way, with reference to a specific train operation: braking application followed by a brake releasing and a train acceleration up to initial train speed. By investigating such type of manoeuvre, which occurs when a driver encounters a yellow light that becomes, after a while, green again, it is possible to investigate which are the effects of acceleration force application and of its application time on in-train tensile forces and on train speed. Possible main advantages of such type of study are: i) improvement of driving rules to decrease the disruption risk; ii) increase of freight transportation efficiency, by an increment of average train speed. Such advantages are particularly relevant for new trainsets (long and heavy hauled trains, trains with distributed traction/braking, etc.) that can be employed in a near future to increase the attractiveness of railway freight.

Simulations are carried out by employing *TrainDy* software [6]-[8], which is an UIC (*Union Internationale Des Chemins de Fer* or *International Union of Railways*) certified software for computation of LTD of freight trains. This software is capable to compute, at the same time, the air pressure in brake pipe and brake cylinders (i.e. train pneumatics) and in-train forces (i.e. train dynamics); it has been certified for comparison against more than 30 experimental tests provided by **Deutsche Bahn AG (DB AG)**, SNCF and Trenitalia. Official version has been modified to simulate the brake release. In the continuous process of software improvement, the original model [9] has been updated with innovations to simulate the control valves of wagons equipped with composite brake blocks type k in [10] and in [11] by means of a new automatic procedure to identify equivalent parameters. As a matter of fact, TrainDy pneumatic model is based on a “device library”, which needs to be computed from experimental tests. This approach is different from what is proposed in [12], where design parameters of the components of air brake system, such as nozzles diameter, springs stiffness, cams position and so on are directly managed. This paper generalizes the pneumatic module of TrainDy, making it able to simulate the brake releasing manoeuvre by filling or emptying the brake cylinders only based on the value of air pressure in brake pipe.

Even if off-design performance of pneumatic brake [13] and distribution of payload [14], [15] have a relevant impact on LTD, this type of analysis is not carried out extensively in this paper, but it is restricted to two types of trains with (A) homogeneous and (B) heterogeneous distribution of hauled mass, having traction unit always placed in front of train wagons.

2. NEW RELEASING MODULE VALIDATION

TrainDy numerical model has been explained in [8]. [9] reports more in detail the modelling of pneumatic brake and shows some validation results against pneumatic brake simulator of Faiveley Transport of Italy (currently a Wabtec Company). Pneumatic module has been recently improved in terms of numerical solver and identification process of equivalent parameters in [11].

As reported in [9], pneumatic model of *TrainDy* is capable to simulate pneumatic brake release. Anyway, results showed in this paper have been obtained with a revised model of driver's brake valve, which has been verified against experimental tests data provided by Trenitalia and reported in [16]. Among different experimental tests carried out, Figure 1 shows time evolution of air pressure in brake pipe and brake cylinders for first and last vehicle of a 900 m train, performing a full-service braking followed by a brake release.

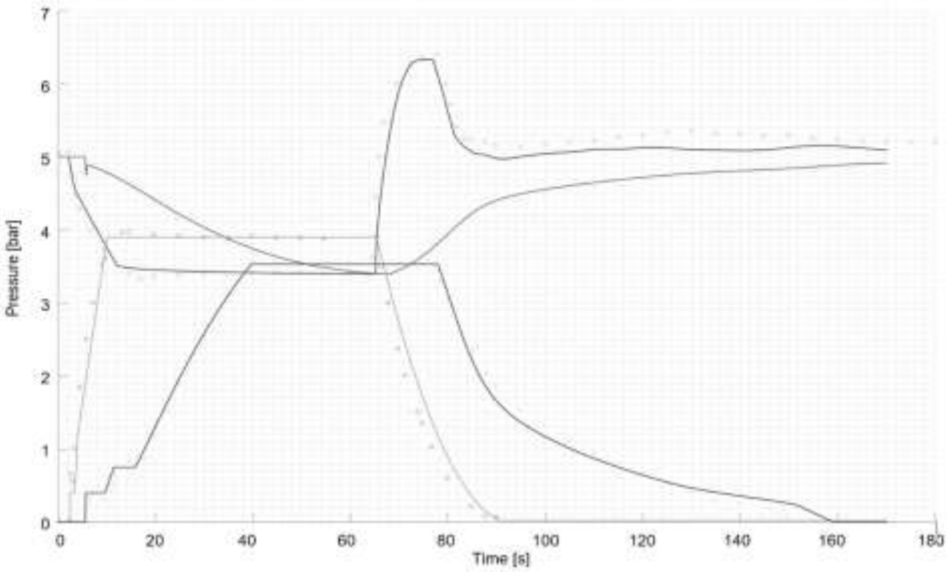

Figure 1 Full service braking followed by a brake release performed on a 900 m train: points are experimental data and solid lines are numerical results.

To achieve such result, it has been necessary to consider as input the pressure in pilot chamber and the equivalent-diameter of driver's brake valve: both have been described by as a series of points. The points describing the pilot chamber represent experimental (or target) time evolution of air pressure in pilot chamber, hence they come directly from the Driver's Brake Valve Manufacturer; the points describing equivalent diameter of driver's brake valve have to be found by an experimental tuning and they characterize the driver's brake valve independently from the experimental dataset used for its tuning, as for all other equivalent parameters of *TrainDy* device library. Table 1 reports the time evolution of equivalent diameter of driver's brake valve, as tuned using provided experimental data.

Table 1 Equivalent diameter of driver's brake valve, according to time

Time [s]	0	0.1	10	∞
Equivalent diameter [mm]	11.5	13.1	11.5	11.5

Moreover, differently from the standard pneumatic module of *TrainDy*, sequence of filling and emptying of brake cylinders depends only on the air pressure evolution in brake pipe, which in turn follows the imposed train operation: this results in an improved capability of simulating arbitrary sequences of filling and emptying of brake pipe from different traction units.

3. MAIN DATA AND TRAIN OPERATIONS

In this paper, two types of train compositions are investigated: the first (A) has a homogeneous distribution of hauled mass whereas for the second (B) hauled mass is heterogeneous; both (A) and (B) have traction unit placed in front of the train and wagons are all the same. Chosen braking positions (i.e. braking regimes) are those typical for freight trains: P, all wagons are in brake position “Passengers”; GP, traction unit is in brake position G (“Goods”) and all wagons are in brake position P; LL, traction unit and first five wagons are in brake position G and remaining wagons are in P; G, all vehicles are in brake position G. Different brake positions, P and G, differ from the timings to fill/empty the brake cylinders during a braking application/releasing. [3] provides those timings.

With regard to the trainsets, they respect for (A) and (B) the limits prescribed by UIC 421; for the purposes of this paper, the most relevant limits are related to the maximum length of the train, that must be 700 m, excluding the traction unit and to the maximum hauled mass (always referred to freight wagons only), which according to different braking regimes must be: 800 tons for P; 1200 tons for GP; 1600 tons for LL; 2500 tons for G.

Cases (A) and (B) are tested considering the following operative scenario: train is running at constant commercial speed of 100 km/h. Since train signal closes, driver has to slow down the train up to a target speed (in this paper, 80 and 60 km/h are considered as examples of two target speeds): this train operation is performed by only a pneumatic service braking (with target pressure of 4 bar in brake pipe); typically, the driver also performs an electro dynamic braking (EDB), but it has not been considered to emphasize the effect of brake releasing for the purpose of this paper. For a not-specified reason, the train signal opens again, and the driver can release the brake and accelerate up to commercial speed. Simulation results shown hereafter answer to following important operative questions:

- when it is more suitable to apply power at traction unit?
- which gradient of application (“Fast” or “Slow”) is more suitable to be applied?
- which are the differences (if any) among different braking (and releasing) regimes, in terms of maximum LTF?

Beyond the cases (A) and (B), in-train tensile forces (LTF), which occur in a train of 2000 tons (uniformly distributed) running in brake position P, LL and G, are investigated to highlight the correlation between braking regime and LTF, during a braking application.

Wagon and traction unit data are reported in Table 2 along with gradient of traction unit power application/removal.

Table 2 Main data of the wagon and traction unit

<table>
<tr><th></th><th>Wagon type T (cereal)</th><th>Loco type BB437000</th></tr>
<tr><td>Length [m]</td><td>15</td><td>19.52</td></tr>
<tr><td>Tare [t]</td><td>25</td><td>90</td></tr>
<tr><td>Mass max (tare + load) [ton]</td><td>40</td><td>90</td></tr>
<tr><td>Number of axes</td><td>4</td><td>4</td></tr>
<tr><td>Type of brake</td><td>Block / 2 x Bgu, cast iron</td><td>Disc</td></tr>
<tr><td>“Fast” application / removal gradient of traction unit power [kN/s]</td><td>N/A</td><td>50</td></tr>
<tr><td>“Slow” application / removal gradient of traction unit power [kN/s]</td><td>N/A</td><td>12.5</td></tr>
<tr><td>Braked weight</td><td>Auto-continuous<table><tr><td>25 t</td><td>120%</td></tr><tr><td>83 t</td><td>65%</td></tr></table></td><td>90 t</td></tr>
</table>

4. RESULTS

First results of this paper refer to homogeneous trains with 2000 ton of hauled mass, performing an acceleration from 0 km/h up to 30 km/h, followed by the application of an emergency braking (EB). This dangerous train operation can occur when there is a loss of communication between traction unit and rail track and an emergency braking is automatically applied. Even if such train operation rarely occurs, it should be considered in a risk assessment analysis of train compositions. Figure 2 shows in-train forces (positive stands for tensile forces and negative for compressive forces) for the train and manoeuvre previously described. The reported results refer to two gradients of application of traction unit power. Even if, from the point of view of LTD, uniform trains are usually of no concern, i.e. small in-train forces occur, the high hauled mass can cause high LCF, depending on braking regime.

Moreover, it should be emphasized that Figure 2 reports instantaneous values of longitudinal forces, whereas the safety against derailment caused by high LCF is checked evaluating the 10 m LCF. It is important to remark that longitudinal compressive forces at 10 m (LCF 10 m), at any point on the track, are given by the minimum LCF (with absolute value), occurred in 10 m before the point of interest.

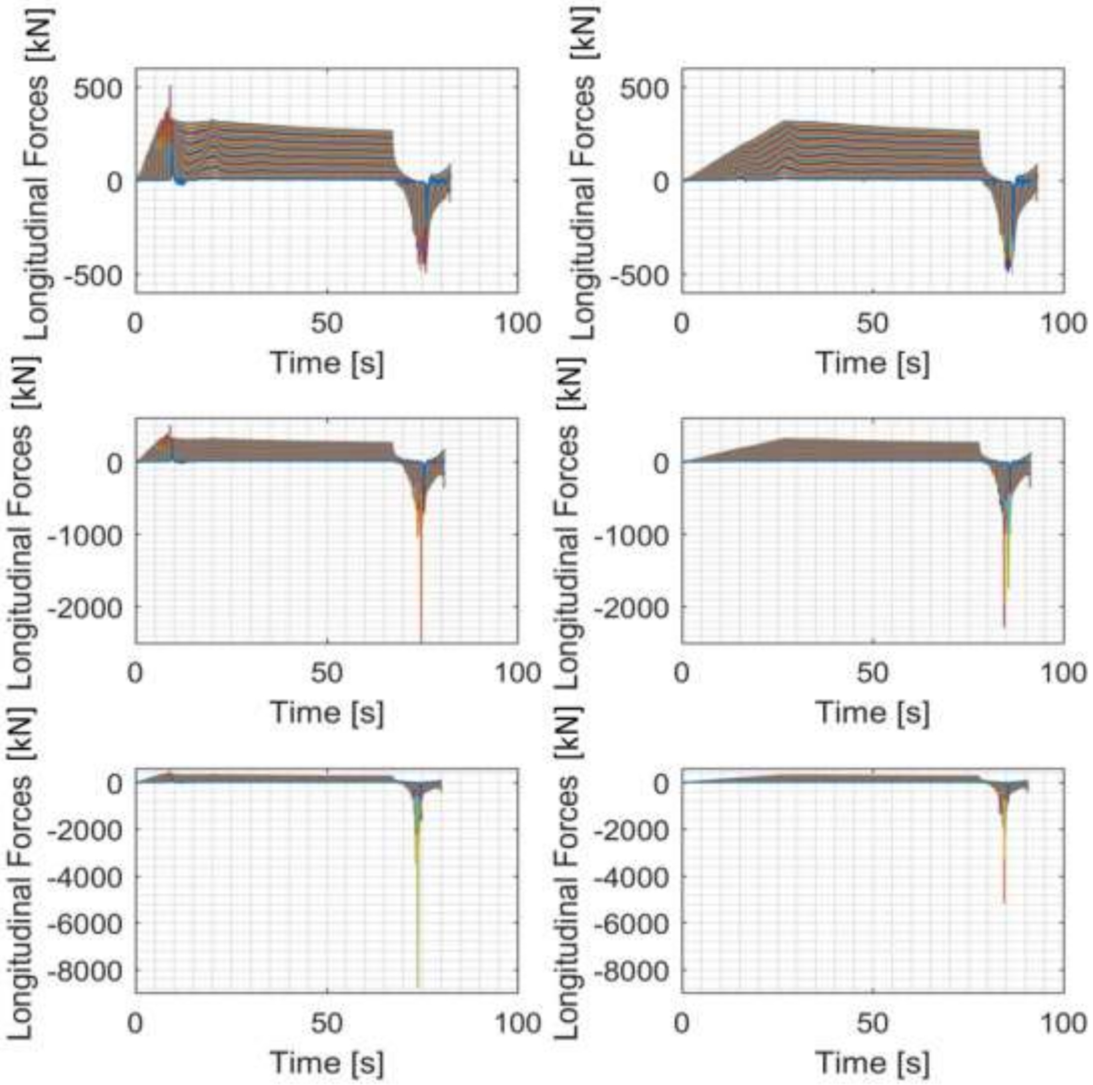

Figure 2 Longitudinal force for an emergency braking that follows an acceleration from zero speed, with Fast (on the left column) and Slow (on the right column) application of power at traction units. From top to bottom: brake position G, LL and P.

Table 3 reports maximum instantaneous LTF, LCF and LCF 10 m, according to different brake positions and application of power at traction unit, during acceleration phase.

Table 3 Maximum values of longitudinal forces, for different regimes

	G		**LL**		**P**	
	Fast	**Slow**	**Fast**	**Slow**	**Fast**	**Slow**
LTF [kN]	511	318	511	318	511	318
LCF [kN]	-493	-504	-2508	-2291	-8800	-5191
LCF 10 m [kN]	-367	-370	-582	-663	-825	-776

High performance wagons (with respect to the risk of derailment) have a value of admissible LCF of 400 kN. This admissible LCF characteristic is generally compared to 10 m LCF to analyse the safety. As stated in the introduction of the paper, here we focus attention on LTF that does not cause train derailment, but only train disruption. Such forces should be intended as instantaneous forces since they bring to a sudden hook's breaking. On one side, Figure 2 shows that Fast application of power causes higher LTF: such result is well known and here simply confirmed. On the other side, Fast application of traction unit power leads to an increase of average train speed and, consequently, to an increase of train efficiency and rail capacity. Results of Figure 2 confirm that there is no relevant effect of brake position on LFT for this type of train operation: anyway, this result is applicable to homogeneous trains, when heterogeneous trains are considered, according to mass distribution maximum LTF can change, as shown in [17]. Second sets of results, refer to the operational scenario described in section 0 and applied to a uniformly loaded train of 2000 ton running in different braking regimes: G, LL and P. When a scenario like the one described before occurs, usual habit of the driver is to wait until brake cylinder pressure, displayed at traction unit cabin, is almost zero. Driver waits the filling of brake pipe is rather finished (pressure of BP does not vary anymore) too: this can last (depending on releasing regime) around 20 s or 40 s, for P and G regime, respectively. Therefore, train slows down much more than the desired target speed (in the example, 80 km/h or 60 km/h) and the efficiency of freight train has got worse (since the average speed is reduced).

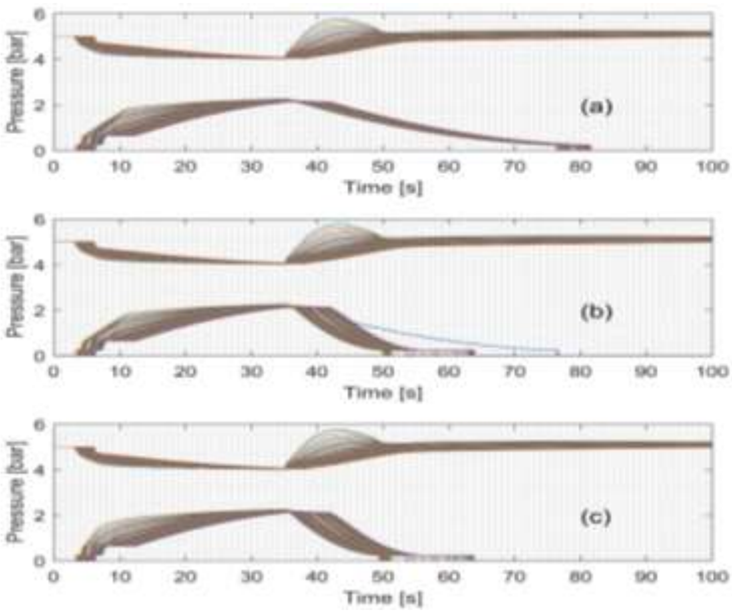

Figure 3 Time evolution of air pressure in brake pipe and brake cylinders for different braking regimes: (a) is G; (b) is LL and (c) is P. Vertical dashed line indicates when brake releasing starts and when the train acceleration can theoretically begin.

Figure 3 shows for different braking/releasing regimes (G, LL and P) time evolution of air pressure in brake pipe and brake cylinders for a service braking application followed by brake releasing operation. Dashed vertical line, indicates the time when brake is released and the reference time from which the power application can theoretically start: in the next results this time is parametrically changed. To make the comparison clearer, figure refers to the same train with different braking/releasing regimes.

Figure 4 shows the train covered distance, in (a) and (b), 65 s after the brake release starting, for different delay time between the brake releasing and train acceleration commanded by the driver: this time frame is somehow arbitrary defined, but it has been chosen to catch dynamic oscillations of in-train forces caused by application of traction power. Therefore, when train acceleration is applied 40 s after the brake release, there are no significant oscillations in LFs outside the chosen time window, hence the maximum of LTF is mastered. Moreover, since the target speeds in (a) and (b) are different and equal to 80 km/h and 60 km/h, respectively, the time to reach the target speeds are different, hence, it has been decided to monitor the longitudinal train dynamics for the same amount of time (65 s) after brake release. Figure 4 (c) and (d) report the train speed after 65 s from brake release: in this case too, results are parametrically reported considering different delay time between brake release and power application. “Delay” label on x-axis means the delay of traction unit power application since brake release: a parametric study has been performed considering 1 s, 5 s and so on for such delay. Solid line is used for “Fast” gradient and dashed line for “Slow” gradient. In (a) and (c) the target braking speed is 80 km/h, whereas in (b) and (d) it is 60 km/h.

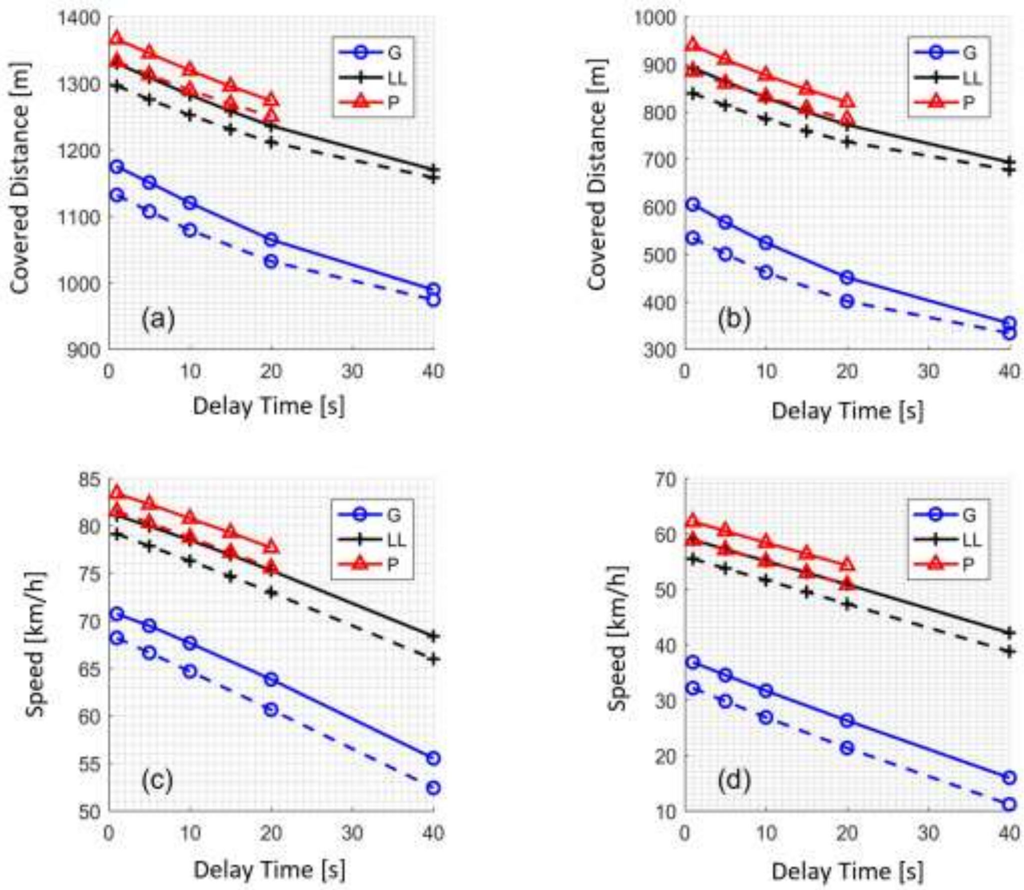

Figure 4 Train covered distance, (a) and (b), and train speed, (c) and (d), after 65 s since the brake release starting: in (a) and (c) target speed is 80 km/h; in (b) and (d) it is 60 km/h.

It is obvious that by applying traction unit power just after the brake release starting, the train covered distance increases, and it increases even more if traction unit power is applied quickly (Fast gradient). This result is confirmed for all braking regimes, independently from target speed.

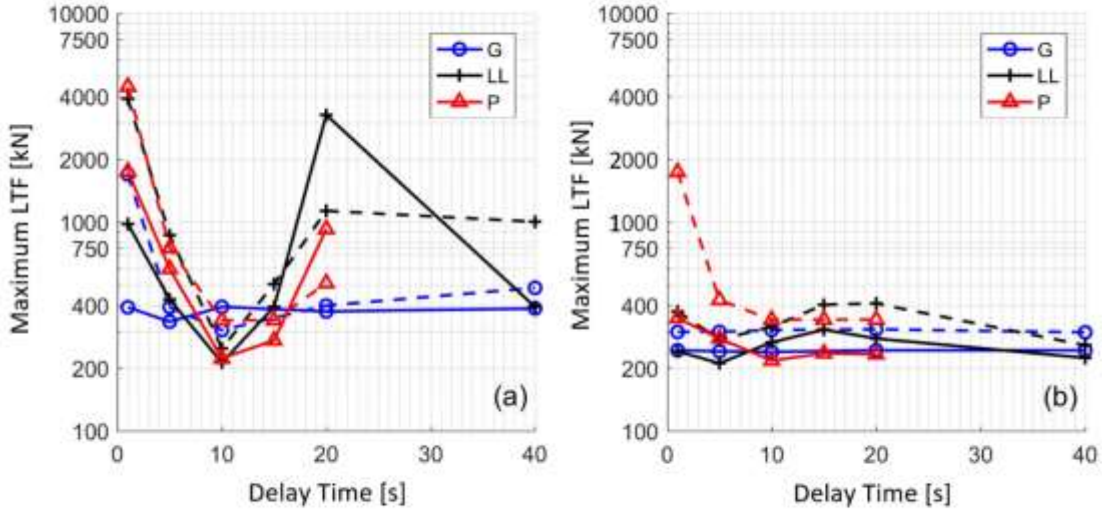

Figure 5 Maximum longitudinal tension force: solid line and dashed lines refer to target speed of 80 km/h and 60 km/h, respectively; (a) and (b) refer to Fast and Slow gradient, respectively.

Quickness of application of traction unit power has consequences that are less obvious and are shown in Figure 5, which reports the maximum LTF that occurs by applying the power after 1 s, 5 s and so on after the brake release. The left side of the figure refers to “Fast” gradient, whereas the right side refers to “Slow” gradient. Because of non-linear behaviour of maximum in-train forces with braking regime and with delay time, it is not possible to find out general conclusions like before. Anyway, from above figures (Figure 4 and Figure 5), aiming to increase the efficiency of freight train, it is advisable to apply the power just after begin of brake releasing, but with a Slow gradient in order to avoid the train disruption. Considering what previously stated on the usual behaviour of train drivers, this suggests a revision of usual train operations. Previous results also show that for a train in P regime, that slows down from 100 km/h to 60 km/h, the application of power just after the begin of brake release (1 s) is not safe against the train disruption risk, even in case of Slow gradient. Anyway, as stated in UIC 421, a train in P regime that hauls 2000 ton is not allowed to be operated (even if it is uniformly loaded), because of a not-negligible train derailment risk. Therefore, other two types of trains are analysed, having hauled mass within the limits prescribed by UIC CODE 421: the first type of train is homogeneously loaded (as before), the second has a different payload for each wagon. For uniformly loaded trains having target speed of 60 km/h, both Fast and Slow gradient are considered and maximum LTF are reported in Figure 6, where solid and dashed lines are used for Fast and Slow gradients, respectively. These results show that by applying power just after the brake release with a Slow gradient, the maximum LTF is always below 350 kN. The reason why LTF forces in G regime are bigger than LTF in P regime is simply because the hauled mass in the two regimes are different as pointed out by the figure legend. To provide an example of average speed increment (i.e. increment of railway efficiency) Figure 7 reports the time evolution of train speed for an uniformly loaded train in G regime with 2500 ton of hauled mass and target speed of 60 km/h (blue dashed line of Figure 6).

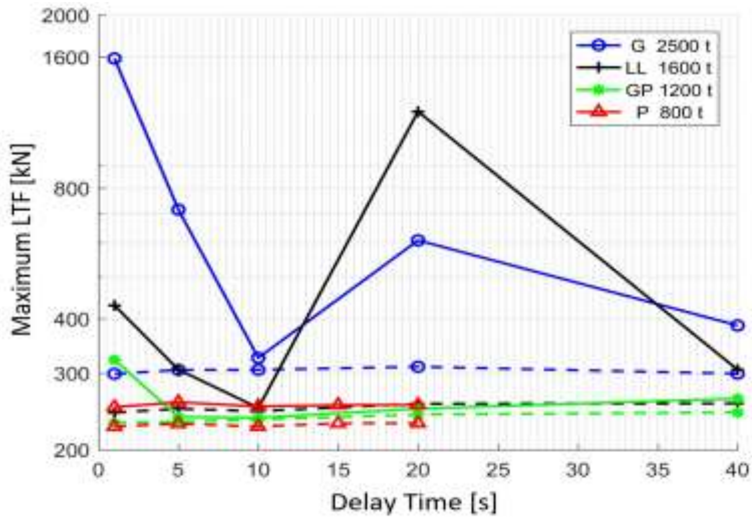

Figure 6 Maximum LTF for different brake regimes and different delay of power application: solid and dashed lines are for Fast and Slow gradients, respectively.

Standard operation refers to the current behaviour of driver that accelerates when brake cylinder is emptied in the traction unit cabin, i.e. after around 50 s from brake release. New operation refers to the application of power after 1 s of brake release with a Slow gradient. First simulations terminate when train speed reaches 100 km/h, the second terminates after the same amount of time. From the y axis on the right part of the graph an increment of around 15% for average train speed can be read.

Last result reported in this paper deals with heterogeneous trains where wagons are 50% fully loaded and 50% empty. Payload distribution is randomly changed by employing a Latin Hypercube Sampling with 300 random trains generated for each braking regime. Figure 8 reports the Cumulative Function of in-train tensile forces for random trains according to different braking regimes. Train operation is the same described before: Slow gradient after 1 s of brake release and target speed of 60 km/h for service braking. Figure 8 shows that this new train operation brings effective benefits in terms of railway efficiency, keeping low the disruption risk, also for the case of heterogeneous trains. Maximum values of LTF increase with hauled mass increase, but their values are always far from disruption risk.

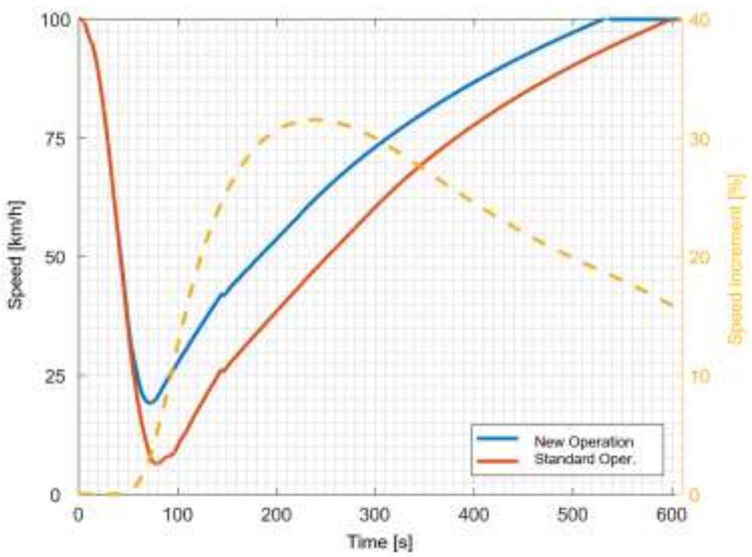

Figure 7 Time evolution of train speed according to the new and standard operation. The y axis on the right reports the percentage of average speed increment over time.

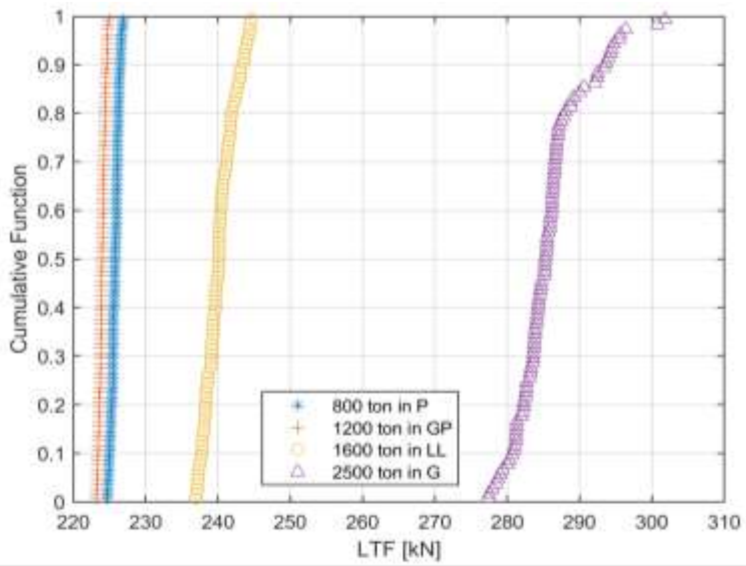

Figure 8 Cumulative Function of in-train tensile force for heterogeneous trains in different braking regimes, performing the same operation of Figure 7.

5. CONCLUSIONS

The possibility to accurately study Longitudinal Train Dynamics occurring during the brake release gives room to a series of investigations that usually are not carried out, since assessment of trains' compositions is achieved by focusing attention mainly on longitudinal compressive forces, which are mainly relevant for derailment risk. Longitudinal Tensile Forces can be significant also during a common braking train operation, also depending on train regime, but are for sure relevant during a braking / releasing manoeuvre followed by a train acceleration. The results here obtained show that, independently from train regime, it is advantageous to apply traction unit power smoothly, by means of a low gradient of application, even if train acceleration is commanded just after brake release. Such driving strategy differs from what usually happens.

The results here reported demonstrate that this new driving strategy is safe and economically convenient, from the point of view of the increase of average train speed both for homogeneous and heterogeneous trains, independently from braking regime.

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