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Numerical model for distributors of railway vehicles equipped with composite blocks

Luciano Cantone[a]*,Gabriele Arcidiacono[b]

[a]*University of Rome Tor Vergata, Via del Politecnico 1, Rome, 00133, Italy*
[b]*Marconi University, Via Plinio 44, Rome, 00193, Italy*

Abstract

The paper describes the main features of a new numerical model of distributor for railway vehicles equipped with type K composite blocks, available in the *TrainDy* software. The composite brake blocks (CBB) type K guarantee better braking performance and quieter operation than traditional cast iron blocks (P10). Railway wagons with this type of shoes have different braking systems compared to wagons with traditional shoes, since their performance changes, for example, depending on the load carried by the wagon and the type of braking regime. The paper shows a series of tests comparing the numerical results provided by the new module with the experimental data. In this work, the parameters of the numerical model of the distributor are automatically calculated, by using the Mathworks "Global Optimization toolbox" for comparison between numerical and experimental data, provided by Faiveley Transport (Wabtec group) during the revision process of Leaflet UIC 421. The Frechet distance, which allows evaluating the degree of similarity of two curves, is the basis for the comparison. This approach allows identifying, on a rational and numerical basis, the parameters of the distributor, without having to use the support of an expert user.

Keywords: Noise reduction; CBB type k; TrainDy; autonomous identification

* Corresponding author. Tel.: +39 06 7259 7133; fax: +39 06 7259 7145.
E-mail address: Luciano.Cantone@uniroma2.it

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1. Introduction

Trains are an environmentally friendly way to move people and goods; nevertheless, especially freight trains can be cause of social problems, because of their noise. Since a lack of a dedicated railway infrastructure, freight trains run on the same railway lines of passenger trains, in many cases. Being the commercial speed of freight trains lower than that of passengers' trains, freight trains run during night and their noise is a social problem when they route a populated area. The friction material of freight wagons brake blocks is mainly cast iron (P10) and it equips more than the 75 % of freight wagons running in Europe. Experimental tests carried out by UIC (*Union Internationale Des Chemins de Fer* or *International Union of Railways*), in past years, have proved that one of the main reasons for freight trains noise is caused by the cast iron particles, which keep attached to wheels after a braking and determine noise during the rolling of wheels on rail. Bracciali et al. (2009) show that by using composite brake blocks (CBB), it is possible to reduce the noise at 100 km/h up to 10/15 dB, with respect to P10 brake blocks, because CBB keep the running surface of wheels smooth, reducing wheel/rail contact noise. However, this noise reduction requires that minimum the 75%-80% of trainset wagons use CBB. Introduction of CBB is the preferred option to achieve a substantial noise reduction; at this aim, several European Manufacturers of CBB have developed two types of shoes. The first type is labelled as "type k" (or k-blocks) and second type is labelled as "type LL" (or LL-Blocks); these types of shoes have values of friction coefficient higher than P10 and similar to P10, respectively.

This paper focuses only on CBB type k. Having a higher friction coefficient with respect to P10, equipment of wagons with this type of shoe requires a significant renewal of wagon braking system, resulting in a change of braked weight. Braked weight places a crucial role in determination of Longitudinal Train Dynamics (LTD), i.e. the relative motion of adjacent railway vehicles running in track direction. LTD is relevant for safety of freight train since both high in-train compressive and tensile forces are dangerous. Cole et al. (2017) review LTD topic and Wu et al. (2018) report a benchmark of several LTD simulators from all over the world. As requested by Leaflet UIC 421 (2012), these studies are carried on also by Railway Undertakings, for freight trains interoperability. On this approach, we can mention here the contributions of Ansari (2009), Arcidiacono et al. (2017)-(2018) and Cantone (2018).

In 2009, UIC established the TrainDy Special Group, formed by the major Railway Undertakings (DB AG, SNCF, TRENITALIA) and brake industries of Europe (Faiveley Transport – A Wabtec Company and Knorr-Bremse AG), with participation of the University of Rome Tor Vergata (URTV), to enhance the TrainDy software. TrainDy has been originally developed by URTV with the support of Faiveley Transport and it has been validated against Trenitalia data in Cantone et al. (2008)-(2009) and internationally in Cantone (2011). This software exists in two versions: one available to UIC TrainDy Special Group and another used for research purpose at University of Rome Tor Vergata. The UIC version has been recently subjected to an upgrade in the revision process of Leaflet UIC 421, see Cantone and Ottati (2018).

This paper continues the research activity initiated in Arcidiacono and Cantone (2018), about the modelling of control valves for wagons equipped with CBB type K, and in Cantone et al. (2018), about the automatic identification of TrainDy model parameters. Novelty of this paper is the application of the model described in Cantone et al. (2018) to the experimental data discussed in Arcidiacono and Cantone (2018). As it will be clear by the showed results, the automatic identification process allows the determination of some TrainDy pneumatic parameters bringing a better agreement between experimental measurements and numerical results with respect to an identification performed by an experienced user. The first part of the paper briefly reviews the pneumatic model of TrainDy as well as the features of the model for autonomous determination of parameters, and then it shows the benefits of autonomous determination model.

2. *TrainDy* Pneumatic Model - Review

The UIC braking scheme is based on Westinghouse's brake of late '800. This brake equips the majority of European freight wagons and Fig. 1 displays its main components (for the traction Unit). The compressor (9) produces compressed air able to fill up 5 bar the brake pipe (1) (BP), while the pressurized air of the main reservoir (10) ranges from 8 to 9 bar. During the braking, the driver's brake valve (11) spills out the air from the BP; this air pressure reduction activates the control valve (4) (CV) that fills the brake cylinder (7) (BC) by spilling air from the auxiliary reservoir (5) (AR). In this way, the AR is emptied and the BC is filled. The brake release occurs by spilling air from the main reservoir and filling the BP through the driver's brake valve. The compressor provides the main reservoir with air, which flows in the BP and in the AR, while, in the same time, the BC are gradually emptied.

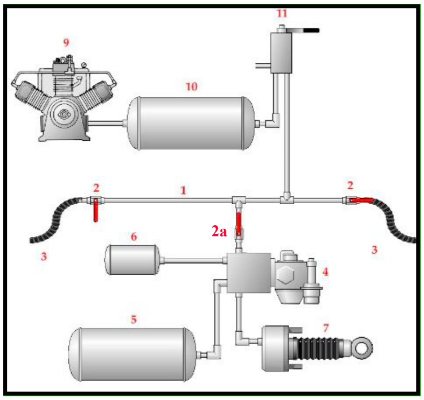

Fig. 1. UIC braking scheme

Following equations describe the air pneumatics in BP:

$$\begin{cases} \dfrac{\partial \rho}{\partial t} + u\dfrac{\partial \rho}{\partial x} + \dfrac{\rho}{S}\dfrac{\partial (uS)}{\partial x} = -\dfrac{\dot{m}}{Sdx} \\ \dfrac{\partial u}{\partial t} + \dfrac{1}{\rho}\dfrac{\partial p}{\partial x} + u\dfrac{\partial u}{\partial x} = \dfrac{\tau}{D} + \dfrac{u}{\rho}\dfrac{\dot{m}}{Sdx} \\ \dfrac{\partial q}{\partial t} + u\left(\dfrac{\partial q}{\partial x} + r\dfrac{\partial T}{\partial x}\right) + r\dfrac{T}{\rho S}\dfrac{\partial (\rho u S)}{\partial x} = 4\dfrac{\phi_T}{\rho D} - \dfrac{\tau u}{D} - \dfrac{\dot{m}}{Sdx}\dfrac{1}{\rho}\left[(c_v + r)T_l + \dfrac{1}{2}u_l^2 - q\right] \end{cases} \tag{1}$$

Where ρ is the density; u the axial velocity; p the pressure; T the temperature of the air and all of them must be considered as average values on the general cross-section S of diameter D and abscissa x. q is the specific energy, c_v specific heat at constant volume, τ takes into account the dissipative sources (both distributed and concentrated); ϕ_T is the exchanged thermal flux, r gas constant, $\dot{m}$ in-flow or out-flow mass flux; and, finally, subscript l refers to lateral quantities, which has to be computed by imposing the right boundary conditions.

Emptying of BP governs the filling of BC, which is determined by brake position, too. In UIC, there are the common brake positions: *P* for passengers' wagons and *G* for freight wagons; freight wagons can also run in brake position *P*. Main difference of the two brake positions is the time to reach the maximum air pressure in BC. Fig. 2 shows the experimental time evolution of air pressure in BC01 and BC23 of a 600 m train, running in brake position P. This figure shows that TrainDy model simplifies the first phase of BC filling, as displayed by dashed lines. Actually, by following the time evolution of air pressure in those two BC, it is possible to split the brake cylinder filling into four phases:

1) *Application stroke*: It is the first phase of brake cylinder filling when pressure rises in a short time because the hysteresis and the counteracting forces are exceeded. After initial "spike", air pressure is maintained constant for a certain time or until the air pressure, in brake pipe, is above a certain value.
2) *In-shot function*: After application stroke, air pressure in brake cylinder rises according to a linear function. At this end, it is enough to specify the duration and the final pressure reached at the end of in-shot function.
3) *Filling, according limiting curve or brake pipe pressure drop*: In-shot function is followed by air pressure increment in brake cylinder according to "limiting curve" or "transfer function". Usually, wagons close to the source of air pressure drop (i.e. close to the traction unit) follow the "limiting curve profile", whereas wagons far from the source of air pressure drop follow the "transfer function".

4) *Plateau*: When air pressure reaches the maximum value, it remains constant until air pressure in brake pipe does not increase because of a brake release.

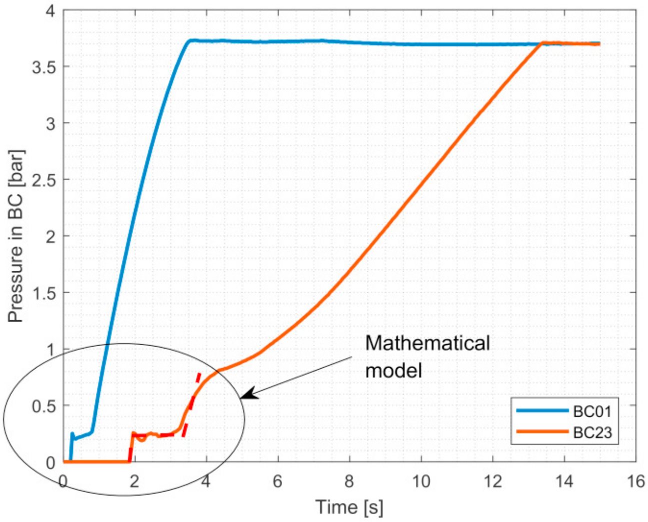

Fig. 2. Filling of first and last brake cylinder of a 600 m train

Fig. 3 summarizes the first two phases, whereas Fig. 4 synthetizes the last two phases, which refer to a train in braking position G ("Goods"). Curves, in both figures, refer to BC of first and last wagon of the train.

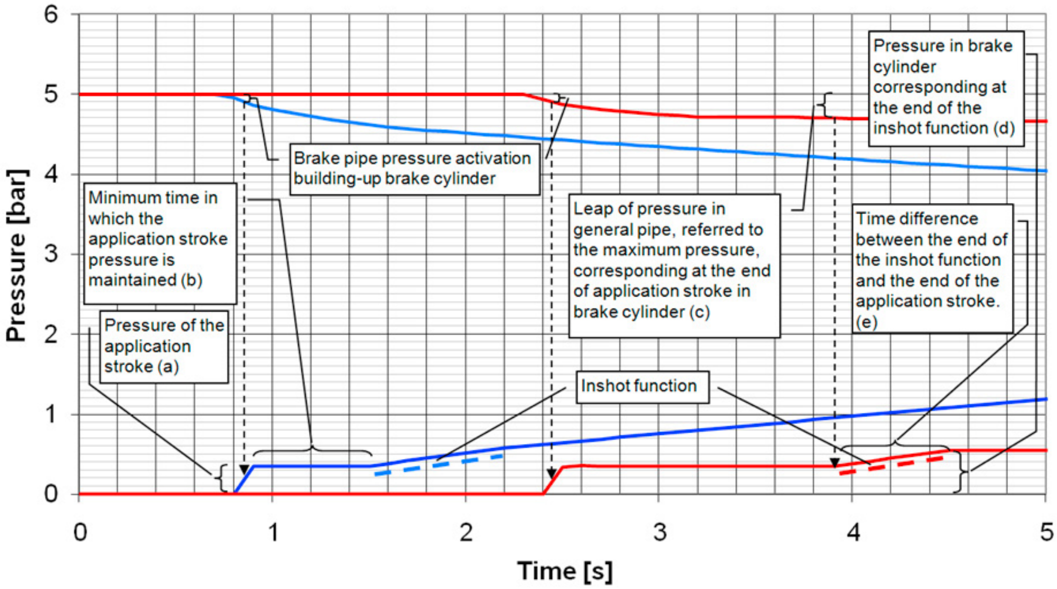

Fig. 3. Application stroke and in-shot function

As shown in Fig. 4, two time values define the limiting curve model: the first is the time, which starts with the application stroke phase, necessary to reach the 95% of maximum pressure (t_{95}); the second is the time to reach the 100% of maximum pressure (t_{100}). TrainDy pneumatic model of limiting curve considers a parabolic curve passing from these times and having a null slope at t_{100}. Fig. 5 shows a typical transfer function of a CV for brake application and its release. Transfer function is a design characteristic of CV and it provides, in a quasi-static way, the pressure in BC knowing the local pressure in BP.

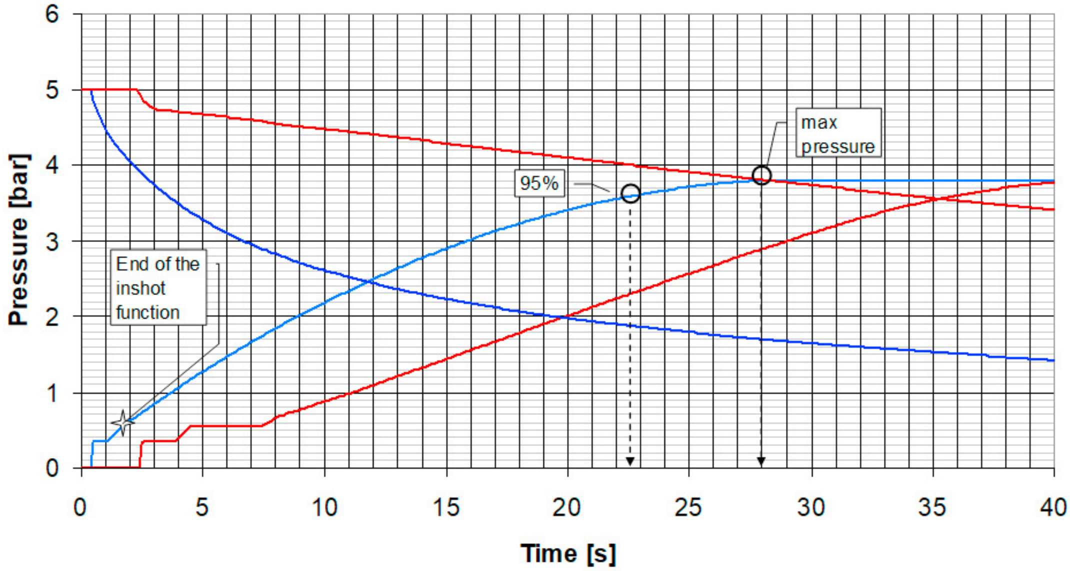

Fig. 4. Limiting curve and transfer function

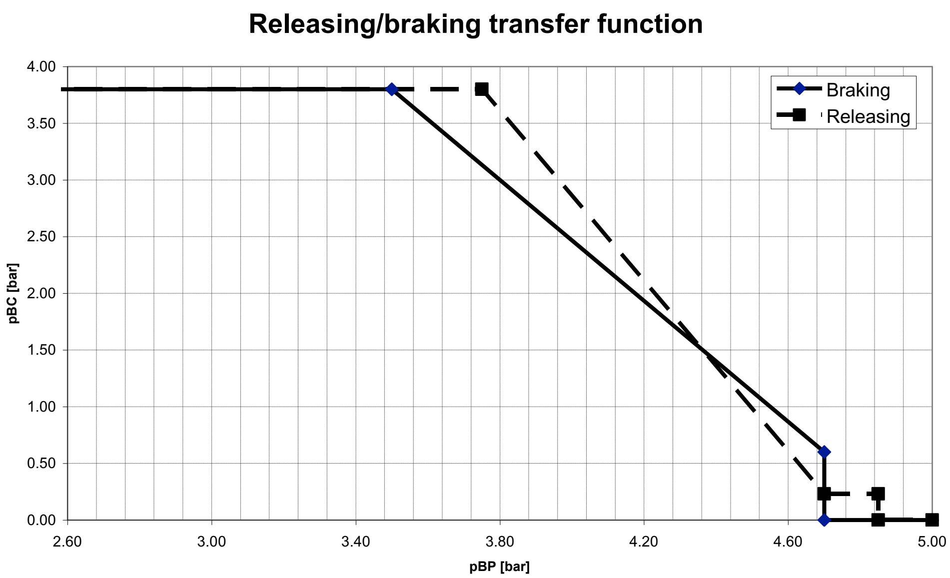

Fig. 5. Control valve transfer function for brake application and its release.

3. Model for Autonomous Determination of pneumatic parameters

Since the pneumatic model of TrainDy is simplified, it requires the employment of several tuning parameters that characterize (or map) a specific device (in this case a Control Valve) in TrainDy software. This parameters' identification is necessary only one time and allows the employment of that device in TrainDy software. Data used in this paper characterize the full behavior of a CV according to different conditions:

- Brake position: P or G
- Target pressure in BP: emergency braking (target relative pressure P_t is 0 bar), service braking (P_t =4 bar) and first time braking (P_t =4.5 bar).
- Gross mass of the wagon.

At this aim, a modern CV able to continuously adjust the pneumatic target of BC according to previous parameters is used. Device model cannot be disclosed. The overall number of available experimental tests is 18: 9 for brake position P and 9 for brake position G. For each brake position, three manoeuvres are tested: first time braking, service braking and emergency braking, with target pressures in BP of 4.5 bar, 4 bar and 0 bar, respectively. For each manoeuvre and brake position, there is a test for each wagon mass level: empty, half loaded and full loaded.

Autonomous model to identify CV parameters determines the variable listed in Table 1, which represent the CV model described in previous section. It is worthwhile to mention that the pressure for "Application Stroke" and "in-shot function" are function of the gross mass of the wagon; of course, this model has a backward compatibility by using always the same value for the pressure for different wagon mass. As a consequence, the number of variable to be identified is bigger that the eight variable listed in Table 1 since it has to consider the number of wagon mass levels considered; usually this number is 3: a) tare condition (i.e. zero payload); b) half payload; c) full payload. Anyway, since the data provided refer to air pressure in BC (for different operative conditions) all parameters of Table 1 directly connected to pressure in BP (i.e. ΔP_{actAC}, ΔP_{BPAS}, ΔP_{actBC}) are removed from the identification.

Table 1. Synthesis table of CV parameters to be identified.

Parameter short name	Meaning
ΔP_{actAC}	Pressure drop in brake pipe to activate accelerating chambers
T_{95} and T_{100}	Times to reach the 95% and 100% of target pressure in BC, respectively
P_{BCAS}	Pressure in brake cylinder for application stroke
T_{AS}	Time for "application stroke" phase
ΔP_{BPAS}	Pressure in brake pipe for "application stroke" phase
T_{IF}	Time for "in-shot function" phase
P_{IF}	Pressure in brake cylinder for "in-shot function" phase
ΔP_{actBC}	Pressure drop in brake pipe to activate brake cylinder

Genetic Algorithms from Global Optimization Toolbox of MATLAB are used to identify the CV parameters. MATLAB Genetic Algorithms (GA) have been launched considering a reference population size of 512 elements, a crossover fraction equal to 0.9, the "EliteCount" parameter equal to 52 and, finally, the function tolerance set to 10^{-3}: these reference parameters are the same of Cantone et al. (2018). The parameter to optimize is the Frechet distance, described in Eiter and Mannila (1994), which considers not only the distance of the curves, but also the similarity of their shapes: when Frechet distance is equal to zero, the two curves are overlapped.

4. Results

From above discussion, the number of the complete list of parameters to identify is equal to 11: 3 for the application stroke phase, 3 for the in-shot Function phase, 4 for the time to reach the maximum pressure in BC and 1 for the transfer function (since the other parameters are somehow standardized). In the following, we show several types of automatic identification with different parameters for the Matlab GA solver.

4.1. Application Stroke and In-Shot function parameters

The most important parameters to identify are the pressures that describe the application stroke and in-shot function phases. These six parameters (a couple for each mass level) have been identified by searching a solution within an interval of ±10% around the reference values found during the manual identification process. The time limit for each identification has been set to 12 h, as in Cantone et al. (2018); the population size tested was 512 and 256, in order to investigate the effect of this parameter on the solution. Fig. 6 shows the time evolution of the error for the two population sizes. Error is expressed as the ratio between the Frechet distance of the reference manual identification to the Frechet distance of the autonomous identification; as a consequence, a lower value indicates a better solution. The best solutions are displayed also in Table 2, where the reference values are reported as well.

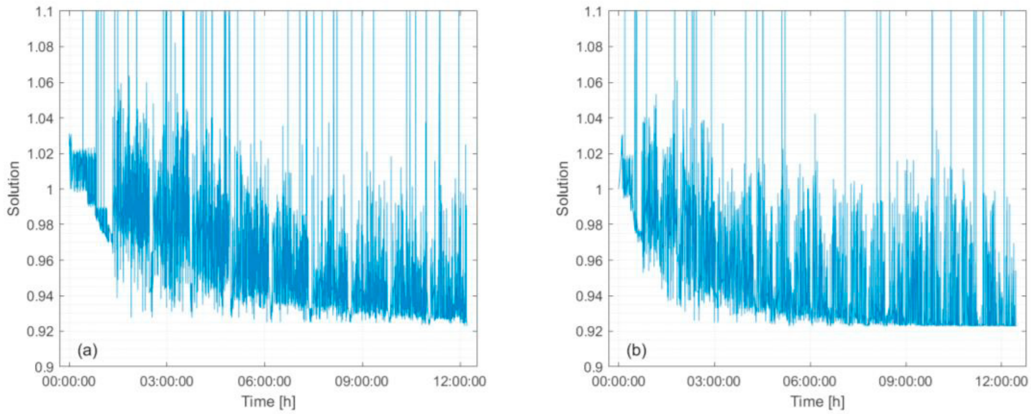

Fig. 6. Time evolution of the error, expressed as the ratio between the Frechet distance of the reference manual identification to the Frechet distance of the autonomous identification, for population size 512 (a) and 256 (b): lower values indicate a better solution

This analysis shows that 12h is a time more than enough to find a suitable solution and that the population size of 256 is adequate, as well.

Table 2. Identification of application stroke and in-shot function data according to the population size (oscillation around the reference of ±10%)

Pop Size	**Application Stroke [bar]**			**In-Shot Function [bar]**			**Error [%]**
Reference	0.4625	0.671	0.98	0.417	0.673	0.97	100
256	0.416	0.603	0.882	0.446	0.724	0.939	92.3
512	0.416	0. 603	0. 882	0.457	0. 606	0. 876	92.3

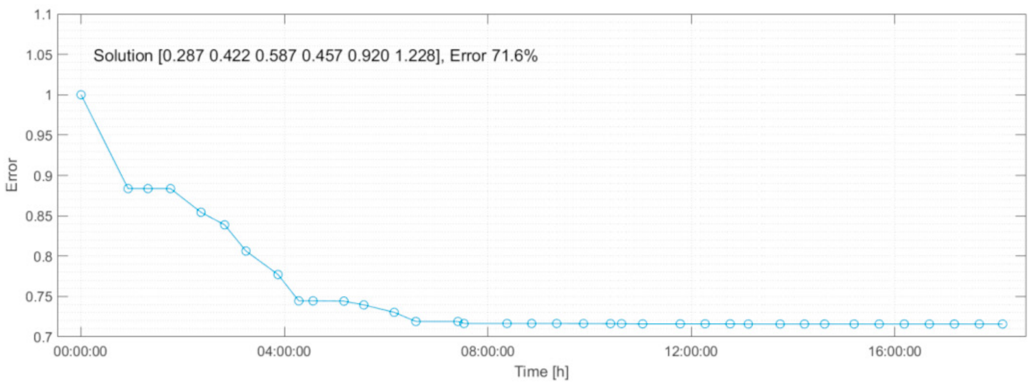

Fig. 7. Time evolution of the error with larger bounds: for each population, only the best error is displayed differently from Fig. 6

Increasing the field of variability of the parameters, by letting them vary from 0 to 2bar, a better solution is found. This result is displayed in Fig. 7 with the solution and the error: this time, for each population is indicated the best error and the time limit has been set to 18h: simulation shows that a time limit of 8h is enough.

Fig. 8 shows the time evolution of pressure in brake cylinder for the condition with worst (i.e. highest) Frechet distance (F.D.) obtained during the manual identification in (a); the same test with reference to the first and second identification is reported in (b) and in (c), respectively. Results clearly show that the manual identification already provided a good parameters identification, made even better by the two autonomous identifications.

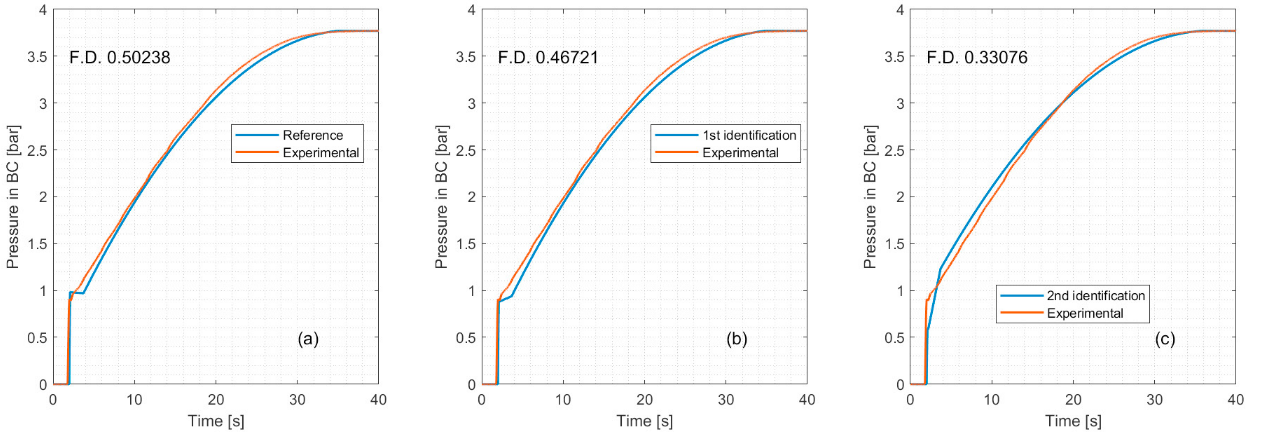

Fig. 8. Example of results with different identifications: (a) manual, (b) 1st and (c) 2nd identification. For each one, the Frechet distance (F.D.) is reported, as well.

4.2. Full set of parameters

Adding the other parameters (i.e. the time to reach maximum pressure in BC and the pressure for transfer function of the control valve) does not provide a relevant benefit in terms of error, both for narrow (±10% around the reference values) and wide (from 0 to 2 bar) variation of application stroke and in-shot function parameters. Fig. 9 shows the time evolution of the error, whose minimum value is 71.7%, therefore a bit higher than before.

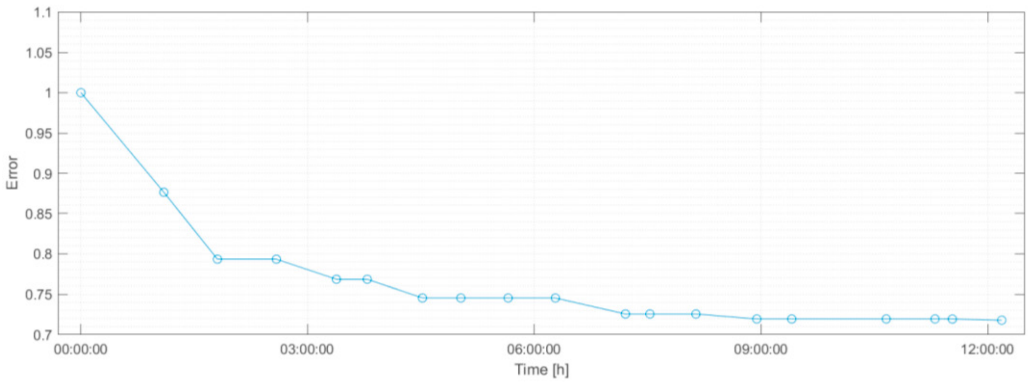

Fig. 9. Time evolution of the error with larger bounds and more inputs to identify: solution is not better then in Fig. 7

5. Conclusions

The present paper has reviewed the pneumatic model of TrainDy, which is the UIC (International Union of Railways) software for the computation of Longitudinal Train Dynamics of freight trains. A new model of TrainDy software to model Control Valves of wagons with Composite Brake Blocks type k has been here introduced. This model, as the general pneumatic model of TrainDy, needs the identification of some parameters to fit the behaviour of a specific control valve. This identification, usually performed manually, is here performed automatically by employing the MATLAB Genetic Algorithm solver. Paper shows different results of such identification, highlighting that that results of the automatic identification can be “far” from the manual identification but providing a better agreement among the experimental and numerical results, according to the Frechet distance.

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