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CO-ORDINATED ACTION DESIGN OF RHEOSTATIC AND AIR BRAKES ON THE ELECTRIC RAILCAR SERIES 6 111

ABSTRACT

The paper presents the solution for the modification of the brakes on the electric railcar series 6111 used in suburban traffic. It also gives the results of the performed measurements as well as their analysis.

The mentioned electric railcar is fitted with air and rheostatic brakes whose activation is mutually independent. Since suburban traffic means frequent stopping, and since the engine driver does not use the rheostatic brake regularly, but only the air brake, the wear of the brake lining and wheels is higher, and the heat load on the brake elements is substantial. By regular application of rheostatic brake, the air brake could be used less thus contributing to a lower wear of the friction elements.

The presented solution for the modification of the brake consists of co-ordinated and automatic action of the rheostatic and air brake with every braking, without the engine driver influencing this co-ordination.

KEY WORDS

railcar, rheostatic braking, brake modification

1. INTRODUCTION

In suburban rail traffic in Zagreb, the Croatian Railways (HŽ) use electric railcars series 6 111, fitted with air (P-brake) and the rheostatic (E-brake) brakes. The P-brake is activated by appropriately positioning the handle of the drivers brake valve, and the E-brake by appropriately positioning the controlled switchgroup. Their activation and action are mutually independent. Since suburban traffic means frequent stopping, the brakes are also frequently used.

Braking effectuated by P-brake causes wear and heat load on the brake linings and wheels. Braking effectuated by E-brake causes the traction motor to switch into the generating mode of operation, thus creating the momentum opposite to the wheel rotation, i.e. braking is achieved. The generated current is led to the brake resistances, subjecting the traction motors and resistances to heat within the allowed limits.

By applying the E-brake instead of the P-brake, the wear and heat load on the brake linings and wheels is reduced. Since the E-brake is not efficient at low speeds, i.e. in braking to a complete stop, it is necessary to co-ordinately apply both brakes. This means, applying the E-brake at higher speeds and the P-brake at lower speeds (less than 25 km/h). Such co-ordination of brakes activation is performed by the engine driver and requires greater engagement and experience. It, therefore, happens most often that the engine drivers use the E-brake only when reducing the speed to regulate it, and in braking to stop they mainly use the air brake only. This leads to greater wear and heat load on the brake linings and wheels than would be necessary.

The modification of the brakes that would enable co-ordinate and automatic action of both brakes not depending on the engine driver would employ the mentioned advantages of a regular application of the E-brake. One such modification is presented in this paper.

2. TECHNICAL DATA OF THE CURRENT SOLUTION

The electric railcar of the 6 111 series is a three-unit train, consisting of one motor wagon in the middle and two driver wagons at the ends. Each wagon has got two bogies with two axles each. The motor wagon has four traction motors, i.e. all the motor wagon axles are driving ones. The railcar has the following characteristics regarding brakes:

– Empty railcar weight	145 t
– driver wagon weight	39 t
– motor wagon weight	67 t
– Loadeded railcar weight	175 t
– Air brake without the change in braking force	O-P
– Brake-weight	196 t
– Percentage of brake power:	
– empty railcar	135 %
– fully loaded railcar	112 %
– Diameter of the BF-2 block-brake cylinder:	
– motor railcar	8"
– driver wagon	6 3/4 "
– Length of the brake lining	400 mm
– Friction coefficient of the brake lining	
– BK 64	0.17 ÷ 0.22
– BK 70	0.20 ÷ 0.25
– Maximum pressure on the brake lining	
– motor wagon	134 N/cm²
– driver wagon	117 N/cm²
– Rheostatic brake	
– braking force at 80 km/h	54 kN
– maximum braking current	520 A
– Power of the traction motors (4 pieces)	1200 kW

The motor wagon is fitted with the E-brake and its excitation winding is powered by the contact wire. The effect of the E-brake depends on the excitation current and on the railcar speed, and is regulated by the position of the controlled switchgroup handle (regulating the excitation current). At speeds below 25 km/h, the E-brake becomes inefficient.

Air brake is designed as indirect, i.e. automatic brake with BF-2 block-brakes on the wheels and one brake lining per wheel. The data about the brakes show that the pressures per brake lining are very high (much higher than the declared 60÷100 N/cm² for this type of brake lining).

The brake linings are relatively long and it is very difficult to achieve uniform contact and force transfer across the whole surface, resulting in increased specific load of the middle part of the lining. This is particularly easy to observe in the worn out brake linings of the motor wagon.

These characteristics cause rapid wear of the brake linings (on the motor wagons they are replaced every 3,000÷5,000 km, and on the driver wagons every 6,000÷10,000 km). The generated heat during braking is transmitted also to the wheels, and the heat load causes great damages in the form of cracks on the wheel flange. This is especially present in the motor wagon due to its high weight.

On the driver wagons the braking forces are lower due to the lower weight of the wagon, and the wear of brake linings and the damage of the wheels is smaller. However, it is still significantly higher than the wear on similar vehicles with disc-brakes.

3. BRAKE MODIFICATION

On the initiative of HŽ (Croatian Railways) and in co-operation between HŽ and the KNORR BREMSE company from Vienna, as well as with the factory KONČAR - Električne lokomotive, a project was developed and a modification performed, for a co-ordinated and automatic action of both E- and P-brakes on the electric railcar series 6 111. The modification was carried out as part of the main overhaul of these railcars.

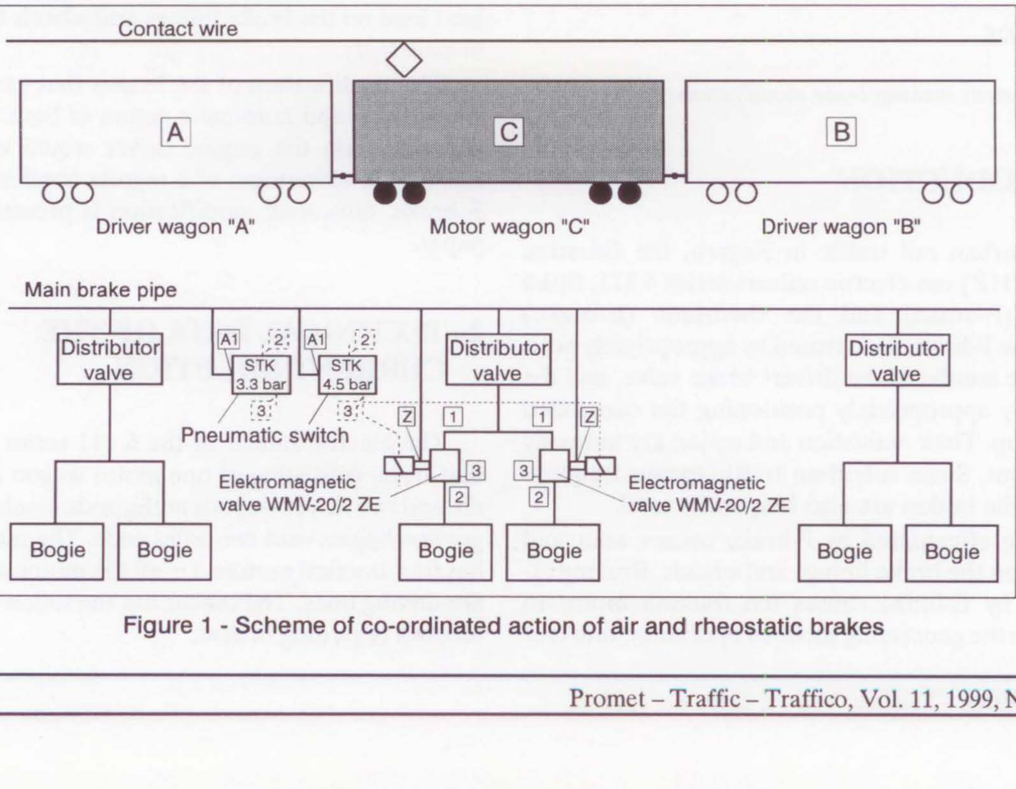

Figure 1 - Scheme of co-ordinated action of air and rheostatic brakes

The solution of a co-ordinated and automatic action of E- and P-brakes refers only to the motor wagon fitted with the traction motors. P-brake only acts on the driver wagons, and its function and operation is not affected by this modification. The solution is presented in Figure 1.

In every driving and stop braking, by activating the P-brake, by positioning the drivers brake valve into a certain position, the E-brake is activated, which brakes with full efficiency (depending on the running speed). The P-brake is not activated because the electromagnetic valves WMV-20/2 ZE shut off the air flow towards the brake cylinders. The pneumatic switches STK fitted on the main brake pipe control the electromagnetic valves.

A detail of the solution of the connection between the electromagnetic valves and the pneumatic switches is shown in Figure 2. By reducing the pressure in the main brake pipe below 4.5±0.1 bars, the pneumatic switch STK (1.2) activates the E-brake and supplies the electromagnetic valves WMV (3.1 and 3.2) with voltage, and they cut off the air input into the brake cylinders (4). The method of brake operation does not change until the pressure in the main brake pipe is reduced to below 3.2±0.1 bars.

If the pressure in the main brake pipe is reduced below 3.2 bars, the pneumatic switch STK (1.1) cuts off the current supply to the electromagnetic valves WMV (3.1 and 3.2), thus enabling normal air flow from the distributor valve (2) to the brake cylinders (E-brake remains switched on). This is the case with rapid and emergency braking (the E- and P-brakes are switched on).

The E-brake activation time amounts to about 3 s, which is within the activation time limits of the air brake.

When the speed of the train is reduced below 25 km/h, the E-brake switches off, and within 1-2 s the P-brake is switched on. For switching on the P-brake, the voltage on the electromagnetic valves WMV is switched off by means of the train regulation device. The P-brake is switched on within 1-2 s and at every other break in the operation of the E-brake, e.g. due to the switching off of the main switch or due to a possible malfunction of the E-brake, and the pressure in the brake cylinders depends on the degree of braking.

Unlike this solution of regulating the switching on and off of certain brakes, the more sophisticated solution consists of the control using microprocessor regulation devices. This solution is too expensive for the train reconstruction, and it is mainly applied to the newly manufactured trains.

4. TESTING

The described solution of co-ordinating the P- and E-brakes has been tested after being built in four railcars (6 111-005, 007 and 008, 023) at several levels.

- Testing done at the manufacturer's place,
- Testing of brake efficiency in cases of included co-ordination of P- and E-brakes as well as of the efficiency of the P-brake only, at various levels of braking,
- The behaviour of the solution in case of possible malfunction of the E-brake i.e. of the control system.

Testing at the manufacturer's site has been carried out on all the railcars. Also, the testing of the air brake has been done according to the on-the-spot testing protocol. Testing of the P- and E-brakes co-ordination was done with running simulation (speed greater than 30 km/h).

Testing of the brakes efficiency for the cases when the P- and E-brakes co-ordination is activated, as well as the efficiency of the P-brakes only, have been car-

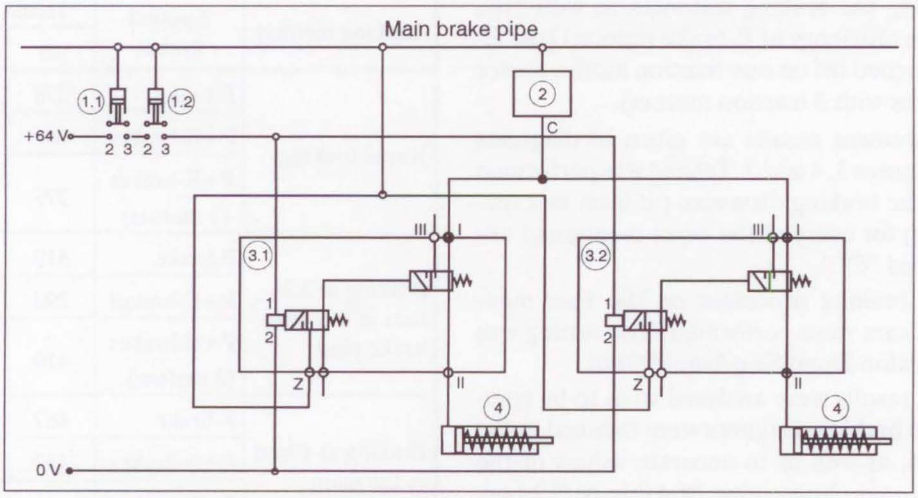

Figure 2 - Connection between the electromagnetic valves and the pneumatic switches

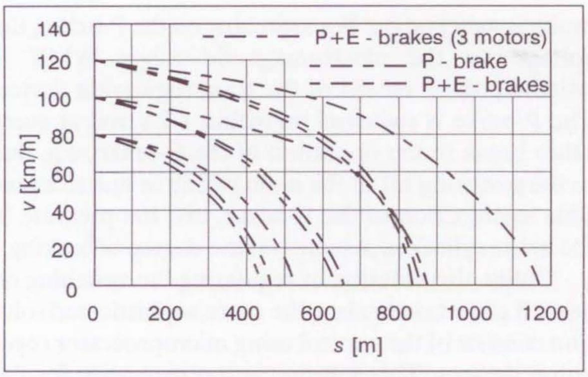

Figure 3 - Braking distance at 4 bars in the main brake pipe

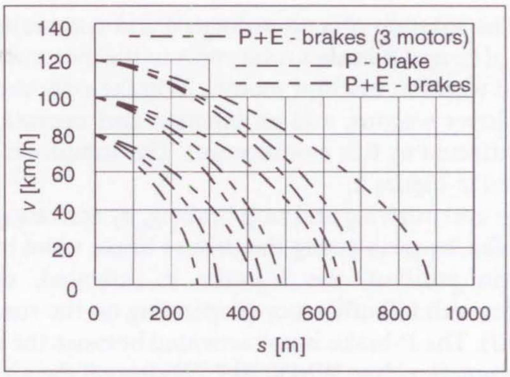

Figure 4 - Braking distance at 3.2 bars in the main brake pipe

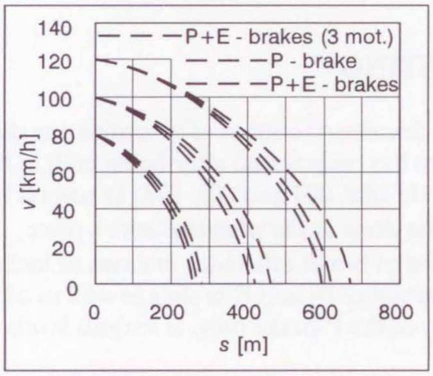

Figure 5 - Braking distance in rapid braking

ried out during travelling by measuring the braking distances for various starting running speeds, as e.g.:

A. By determining the braking distances only of P-brake from the starting speeds of 80, 100 and 120 km/h. For each speed the measurements have been done in braking with 4.0 and 3.2 bars in the main brake pipe, as well as in rapid braking.

B. By measuring the braking distances with the activated co-ordination of the P- and E-brakes at speeds and braking levels as with "A".

C. By measuring the braking distances as with "B", and with the efficiency of E-brake reduced (the E-brake is switched off on one traction motor, motor wagon brakes with 3 traction motors).

The measurement results are given in diagrams presented in Figures 3, 4 and 5. Testing was performed by measuring the braking distances (at least two successful braking) for every of the cases mentioned under "A", "B" and "C".

About 120 braking processes on the four mentioned trial railcars were performed. The testing was done on the section Dugo Selo-Ivanić Grad.

The testing results were analysed so as to be comparable. All the braking distances were reduced to the straight section, as well as to accurate values of the pressure in the main brake pipe of 4.0 bars, 3.2 bars and 0 bar (rapid braking). Braking was performed brusquely, at once up to the required pressure in the main brake pipe. The drivers brake valve handle was not adjusted after the braking had begun, and the obtained pressures in the brake cylinders have been recorded depending on the level of braking. Additionally, if there were deviations, the obtained values were calculated to the planned values. The forces in brake cylinders were corrected according to the forces diagram depending on the pressure in the brake cylinder. Subsequently, the braking distance has been corrected, according to the braking performance and the conditions of the tracks (up and down the inclines).

For the correction of the obtained values, the DB expression was used:

$$s = \frac{3.93 \cdot \xi \, v^2}{10 \cdot k \cdot \mu + w \pm i} + \frac{v\,t}{7.2}$$

Where:

s [m] – stopping distance,

ξ – the rotating weight coefficient,

k [%] – braking,

μ – friction coefficient,

Table 1 - Braking distances [m]

Braking method	Applied brakes	Initial speed [km/h]		
		80	100	120
Rapid braking	P-brake	278	450	654
	P+E-brakes	260	310	590
	P+E-brakes (3 motors)	275	415	605
Braking at 3.2 bars in the main brake pipe	P-brake	310	485	695
	P+E-brakes	290	430	645
	P+E-brakes (3 motors)	410	620	890
Braking at 4 bars in the main brake pipe	P-brake	467	646	850
	P+E-brakes	440	635	845
	P+E-brakes (3 motors)	510	870	1130

w [daN/t] – resistance to the movement of the train,

t [s] – time passed until the braking begins,

v [km/h] – vehicle speed,

i [‰] – longitudinal tracks gradient.

The obtained results of the measured braking distances according to the initial speeds and braking regimes are given in Table 1.

5. MEASUREMENT RESULTS ANALYSIS

Analysing the obtained results of measurements, the following may be pointed out:

- The efficiency of the P-brake has not changed by introducing the co-ordination of the P- and E-brakes, and the braking distances are within the regulated limits for the mentioned initial speeds.
- The percentage of brake power $\lambda = 135$ %, and the brake weight of the empty railcar $B = 196$ t have been kept, so that it is not necessary to change the data on the railcar brakes in the Instructions 233 and 52.
- The measured efficiency of the P- and E-brakes in drive or stop braking is higher by about 5%, than in the braking with the P-brake only, and it is not necessary to introduce any special handling procedures. If all the functions of the E-brake are correct, there is no noticeable difference in decelerating in braking. The difference can be seen only in rapid braking or emergency braking. In that case the percentage of brake power increases to $\lambda = 145$ %. This increase in the percentage of brake power is maintained, because it contributes to greater safety in traffic considering that these trains function in the suburban traffic.
- If one traction motor malfunctions, in which case normal running in traffic is allowed to the domicile workshop, the efficiency of the P- and E-brakes (in drive and stop braking) is somewhat less than of the P-brake alone. In that case it is necessary to introduce somewhat higher braking levels with regard to the previously described cases for the same braking distance. The braking level depends on the running conditions and the engine driver's control method, on the type of the brake and the braking regime on single cars. This is included in the regular training course of the engine drivers, so that this requirement presents no major difficulties in traffic. The somewhat lower efficiency of the brake in drive and stop braking does not endanger the traffic safety since the efficiency of rapid or emergency braking is still higher than the efficiency of the P-brake alone.

The analysis of the braking forces on the wheel flange reduced to one axle of the motor wagon, by using P-brake only, has shown that the braking force in

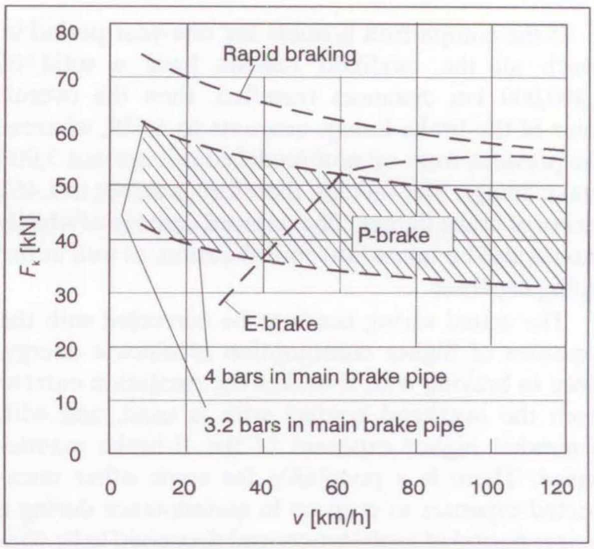

Figure 6 - The dependence of braking forces of the running speed

stop or drive braking ranges from 35 to 55 kN, since it depends on the running speed.

The braking force on the wheel flange of the E-brake does not depend on the braking level by the automatic brake valve and the set diagram depending on the vehicle speed determines it. The dependence of braking forces of the P- and E-brakes on the running speed is given in Figure 6.

The values of the P-brake forces have been obtained by calculation of the forces in braking distances whereas the E-brake force curve has been entered according to the manufacturer's data. The maximum braking force curve of the air brake presented with hatching is used only in testing the P-brake or in traffic in rapid braking when P-brake is switched on in combination with the E-brake.

6. ECONOMICAL JUSTIFICATION OF THE PERFORMED MODIFICATION

The described modification for the co-ordinated action of the P-and E-brakes on 6 111 trains has given the expected results, i.e. the wear of brake linings and the damage of the wheels has been reduced.

The following results have been obtained by monitoring the railcars with modifications in traffic;

During a total of 455,428 travelled kilometres, the total of 539 brake linings has been replaced, which means on the average 1.2 of brake linings every 1,000 km.

The previous results show that the railcars not subjected to modification had an almost doubled wear of brake linings, i.e. on the average 2.35 brake linings had to be replaced every 1,000 km. This further means that the ratio of the brake lining wear amounts to 1:1.95.

If the comparison is made for one-year period in which all the modified railcars have a total of 1,200,000 km distances travelled, then the overall wear of the brake linings amounts to 1,538, whereas the previous wear on non-modified railcars was 3,000 brake linings. The savings, therefore, amount to 1,462 pieces of brake linings. The reduced damage of wheels should also be taken into consideration, as well as the fitting expenses.

The actual saving needs to be corrected with the expenses of higher consumption of electric energy, since in braking with E-brakes the excitation current from the overhead contact wire is used, and with somewhat higher expenses of the E-brake maintenance. There is a possibility for some other unexpected expenses to crop up in maintenance during a longer period of exploitation, and they need to be considered, too.

7. CONCLUSION

The described and carried out solution of the co-ordinated action of the P- and E-brakes in electric railcars series 6 111, regular switching on of the E-brake at every brake activation has been ensured. This has eliminated the personal decision of the engine driver about switching on the E-brake and the negative effects of braking when the E-brake is not switched on.

The effect of the very P-brake has not changed, and the effect of the joint action of the P- and E-brakes in driving or full braking is by about 5 % better than when only the P-brake is used for braking. In case of rapid or emergency braking, the percentage of brake power increases to $\lambda=145$ %. This increased effect of braking contributes to greater traffic safety, especially taking into consideration that these trains operate in suburban traffic.

The application of the given solution reduces substantially the wear of brake linings and wheel damage. Thus, after the modification has been carried out, 1.2 brake linings are replaced on the average after every 1,000 km, whereas previously 2.35 brake linings had to be replaced, which is almost the double.

Taking into consideration all the expenses of installation, maintenance and additional training of the driving and working personnel, it may be concluded that the given solution for co-ordinated action of the P- and E-brakes is economically justified.

SAŽETAK

IZVEDBA KOORDINIRANOG DJELOVANJA ELEKTROOTPORNIČKE I ZRAČNE KOČNICE NA ELEKTROMOTORNOM VLAKU SERIJE 6 111

U radu se daje rješenje modifikacije kočnice na elektromotornom vlaku serije 6111 namijenjenom prigradskom prometu. Također se daju rezultati provedenih mjerenja kao i njihova analiza.

Spomenuti motorni vlak ima zračnu i elektrootporničku kočnicu čije uključivanje je međusobno neovisno. S obzirom na to da su u prigradskom prometu učestala zaustavljanja, te da strojovođe ne upotrebljavaju redovito elektrootporničku kočnicu, već samo zračnu, povećana su trošenja kočnih umetaka i kotača, a značajno je i toplinsko opterećenje kočnih elemenata. Redovita upotreba elektrootporničke kočnice rasteretila bi zračnu kočnicu i doprinijela manjem trošenju tarnih elemenata.

Ovdje prikazano rješenje modifikacije kočnice sastoji se u koordiniranom i automatskom djelovanju elektrootporničke i zračne kočnice pri svakom kočenju bez utjecaja strojovođe na tu koordinaciju.

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