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ANTILOCK BRAKE SYSTEM OF TROLLEYBUS

The antilock brake system (ABS) was developed, which co-ordinates actions of auxiliary and working braking systems of a trolleybus. A trolleybus type 321 "Belkommunmash", equipped with the proposed ABS was tested in road conditions. The results of tests confirmed compliance of the trolleybus with requirements of the rules UN EEC No 13. Decrease in slippage of the driving wheels, improved stability, roadability and traffic safety of the trolleybus was noted.

1. Introduction

It is well known that the trolleybus working brake systems and the auxiliary one (braking by the engine) is controlled by means of one pedal. As there are possibilities of using a combination of the two systems, it becomes obvious that the process of slowing the trolleybus down will not always be effective and its parameters not always optimal without an algorithm coordinating their actions. The necessity of such an algorithm is determined by the fact that the standard approach to designing the working brake system (WBS) excludes any interference of the auxiliary brake system (AuxBS), which is also highly effective [1, 2]. As a result, the joint action of the brake systems often causes loss of stability and control of the vehicle due to intensified slippage of the driving wheels [3]. In the present-day designs, there aren't any coordinating algorithm developed yet.

Due to the intensified slippage of the driving wheels, the control of the braking process of the trolleybus equipped with the antilock brake system (ABS) also becomes problematic, as the algorithm of its function does not take into account the influence of the AuxBS, i.e. the engine, on the process

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of deceleration [4]. There is no algorithm of the combined action of the standard ABS and the auxiliary brake system, either. Besides, the efficiency of the AuxBS in the existent analogs [1] is controlled by the braking pedal only, and does not consider the amount of trolleybus' load, road quality, and specific usage of the coupled vehicles. It seems remarkable that there are such algorithms for pneumatic and hydraulic gear of the working brake systems of mobile vehicles [1, 2, 4]. Because of that, there have been offered algorithms which solve, some partially, some in combination, the above-described problems, and which allow optimization of the trolleybus braking process (see papers [5-12]).

2. ABS algorithms

It is noteworthy that the most optimal and universal parameter, which evaluates the controllability and stability of the vehicle, provides feedback in the automatic system regardless of the operating conditions, and leads to a complex solution to the problem of slippage of the trolleybus driving wheels [2,3]. The algorithms of the braking process control, based on estimation of the slippage value and thus taking into account the principles of operation of the ABS, seem to be most promising. However, as mentioned before, in the existent analogs, the functions of the ABS don't cover the AuxBS, and there is no algorithm of the joint operation of the standard ABS and the AuxBS. Besides, the UN rules EEC No 13 [13] require the ABS be installed in trolleybuses, which, besides the action on the working brakes, should control the installed AuxBS. However, the existent ABS either does not provide the control of the engine in the braking process, or this control is limited to the engine switch-off. The importance of the coordination problem is confirmed by trolleybus tests results [3, 14]. The tests show a sharp drop in the angular velocity and the consequent blocking of the driving wheels in 2 sec after the start of braking, which continues in spite of active operation of the ABS till the full stop of the trolleybus.

One of the possible ways of solving this problem can be either the complete switch off of the AuxBS in the case of instant urgent braking, or creation of a braking moment by the engine, which could be completely compensated by the inertia of the gear rolling parts [11]. In the first case, the moment transmitted from the engine to the driving wheels is close to zero, and the working brake system together with the ABS will fulfill the effective braking demands by themselves. Keeping the engine in action on the condition of its control according to the given algorithms will definitely enable unloading the working brake mechanisms and will also guarantee the possibility of recuperative braking in modern trolleybuses.

For this purpose, we have developed a joint control system of the AuxBS and the ABS which coordinates the pressure value in brake chambers with the engine moment value and improves the usage percentage of the engine especially during the intense braking operations. A mathematical model of the trolleybus braking dynamics [15, 16] and the corresponding algorithm of the system control [9-12] have been used for a preliminary analysis of this variant. During the period of work of the AuxBS, the applied algorithm reduces, in the case when the top critical value of sliding of one of driving wheels is reached, the traction motor torque in a cyclic mode until a value of sliding S is established within an admissible interval. In order to improve the braking force exerted on the wheels for low values of sliding of driving wheels (below the assumed range of values), the engine moment increases until S exceeds the lower limit. If sliding of driving wheels is within the assumed limits, the brake moment of engine M is stabilized. Thus, during this period, the algorithm provides unremitting formation of the brake characteristic of the engine of the kind:

$$M = f\,(stup, \omega, S)\,,$$

where *stup* – positions of a brake pedal, ω – angular speed of the engine shaft. During joint actions of AuxBS and WBS, sliding of driving wheels is also traced, and depending on its value the brake moment of engine M and (or) pressure p in brake chambers of driving wheels are decreased or increased or stabilized. The following sequence is observed.

1) In the case when the top limit of sliding is exceeded, first of all, decreases p. The pressure drop lasts until S is established within the admissible interval. If it is not possible to lower sliding to the required level through this action, and the pressure in the brake chambers approaches the atmospheric pressure value, the second stage begins, and the brake moment of the engine decreases.

2) In order to increase the brake force exerted on wheels for low values of sliding of driving wheels, the sequence of actions is reversed. First, M increases and when its effect is not sufficient (S has not risen to the level required), then the pressure increases further in the brake chambers.

3) If the slip is within the specified limits, the values of M and p are stabilized.

Thus, in the joint " AuxBS + WBS " operation, the algorithm provides interconnected brake characteristics of the kind:

$$M = f\,(stup, \omega, S, p)\,; \qquad p = f\,(stup, S, M)$$

The control of brake force applied to the remaining (not driving) wheels is carried out in the way usual for ABS mode, i.e., by known principles and algorithms of its work.

The major aim of the research consists in the definition of effectiveness of the braking process control algorithm as well as in the search for optimal values of operating parameters of the system. The requirements of the Rules [13] concerning the overall efficiency of the brake system as well as the ABS should also be fulfilled.

3. Experimental results

The theoretical findings, partially presented in [14], are as follows. It has been found out that the speed of change of pressure in the brake chambers of the driving wheels during the process control is not very essential for the slowing-down characteristics under all identical conditions, and can be selected within the range from 1,5 to 5 MPa/s depending on characteristics and operation speed of the pneumatic gear. The speed of change of the braking moment of the engine with ABS should be selected within the range of 100–200 N·m/s. It is accompanied by the optimal quality of transitional processes (minimal values of the dynamics coefficient and the time of the transitional process) which lowers the transmission load and improves the comfort of motion and precision of the control process.

One of the major indices of efficiency of the overall brake system, as well as of the ABS effectiveness, according to the Rules [13], is the mean value of the limit of deceleration, which is determined by good conditions and the actual adhesion coefficient on different road surfaces. Because of that, the analysis of the trolleybus braking dynamics revealed that the value of the deceleration on the asphalt road is equal to 6.4 m/s^2 against $j \geq 4$ m/s^2 which is required for this type of vehicles. The normative value γ, determined by the relation between the maximal braking coefficient j/g and the adhesion coefficient $\varphi(S)$, $\gamma = (j/g)/\varphi$ must not be lower than 0.75. As it has been mentioned, the algorithm maintains the wheel slippage S within the optimal range in which adhesion coefficient φ is close to maximum values of the considered road surfaces (on asphalt – $\varphi = 0.85$, on snow $\varphi = 0.25$). As a result, on asphalt there is $\gamma = (j/g)/\varphi = 0.77$, and on solid snow $\gamma = 0.8$.

Another step in the development of the proposed ABS was the creation, testing and application of a test sample of the system in a trolleybuses produced at “Belkommunmash” works. The laboratory and road trolleybus tests were aimed at finding the solution to a set of problems, the most essential of which are the following:

- estimation of braking efficiency with the help of the AuxBS and WBS, including the one related with the ABS;
- analysis of the AuxBS, WBS ABS interaction and impact on their joint operation;

– estimation of movement stability of the trolleybus transmission at braking;
– estimation of the degree of adequacy of mathematical models for the real object;
– estimation of efficiency of the developed trolleybus complex ABS, including the one according to the requirements of Rules [13].

A passenger, low-floor trolleybus of 321 Belkommunmash model, equipped with the AuxBS, WBS and the traditional ABS and with the developed system which fulfills the functions of the ABS and the anti-slippage regulation system (ASR) installed was chosen for road testing.

In the course of testing of the AuxBS, WBS and the ABS coordinated operation, the necessity of their coordination was confirmed experimentally. In the case of urgent braking of the equipped trolleybus on wet asphalt without the use of ABS, the driving as well as the driven wheels get blocked in 0.5 s. In the case of a traditional ABS, which controls the WBS only, the driven wheels don't get blocked (Fig. 1). There are long periods of blocking the driving wheels already 0.5 s after the braking start due to the non-controllable braking moment of the engine.

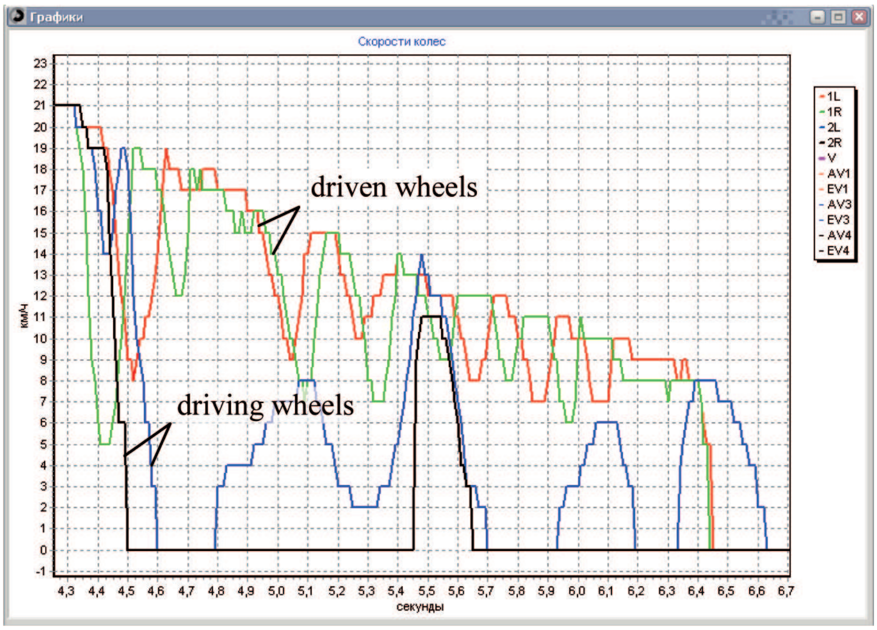

Fig. 1. The wheel velocity in trolleybus braking on snow surface with the application of the traditional ABS

The results of application of the urgent braking with engine switch-off algorithm demonstrate the following (Fig. 2). The operation under these conditions is accompanied with a sharp drop in the braking moment of the engine to 120 N·m (8.10% of the maximum) with the programmed wheel deceleration value 3 m/s^2. Further operation of the ABS is accompanied by typical control pneumatic modulators of the WBS. The driving wheel slippage in this case does not exceed 20% on asphalt surface. It becomes evident that the applied algorithm is not adaptive, as the deceleration depends on the road surface. In the case of the low adhesion coefficient, the wheel deceleration will be less than 3 m/s^2 and the system will not reduce the engine braking moment during the critical slippage period. If the 3 m/s^2 slowdown threshold is lowered, the engine operation in good road adhesion conditions would be poorer.

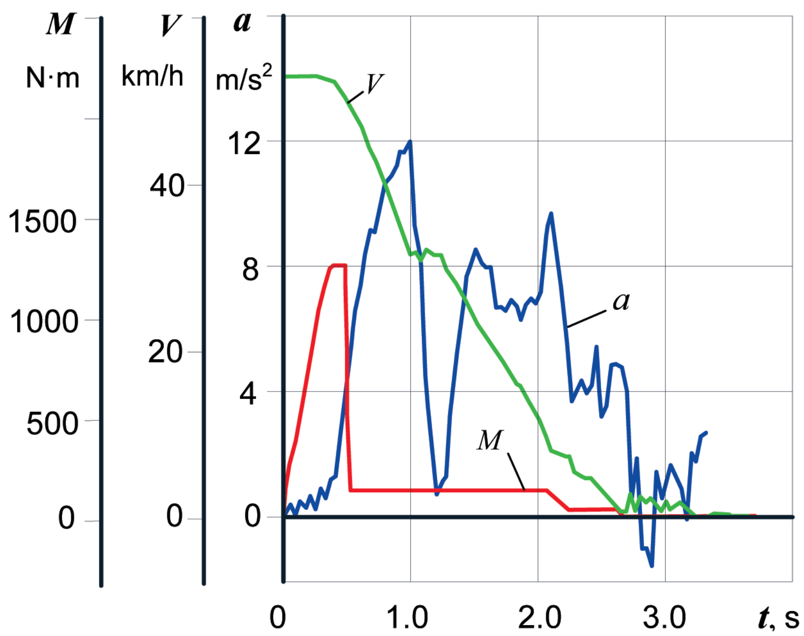

Fig. 2. Characteristics of urgent braking of trolleybus "Belkommunmash" with engine switch-off: M – the brake moment of the engine; V – speed of driving wheels; a – deceleration of driving wheels

The investigated system was tested in two regimes. The system operation algorithm, which presupposes the individual wheel regulation, has not been changed. Each wheel slippage value was defined on the basis of the highest wheel speeds. In the course of operation in the first regime, a forced switch-off of the braking gear of one of the driven wheels was applied. It is obvious that in this case the current speed of this wheel corresponds to the actual speed of the trolleybus. This enabled us to modify the major part of the algorithm which directly coordinates the WBS and the AuxBS operation without the necessity of solving the actual speed calculation problem. As shown in figure 3, we can observe a cyclic system operation regime, without blocking the wheel even on snow surface, till the minimal trolleybus speed (≈ 6 km/h) below which the ABS stops functioning.

The wheel slippage in this period occurs twice for a period of 0.1 s and equals 45-50%. The values of the deceleration observed while testing were quite high and for different surfaces were as follows: 6.4 m/s^2 for the asphalt road and 1,5 m/s^2 for the snow surface. Henceforth, the effectiveness of the developed system and its qualitative advantages in comparison to the traditional ABS become obvious. (See figures 1,3).

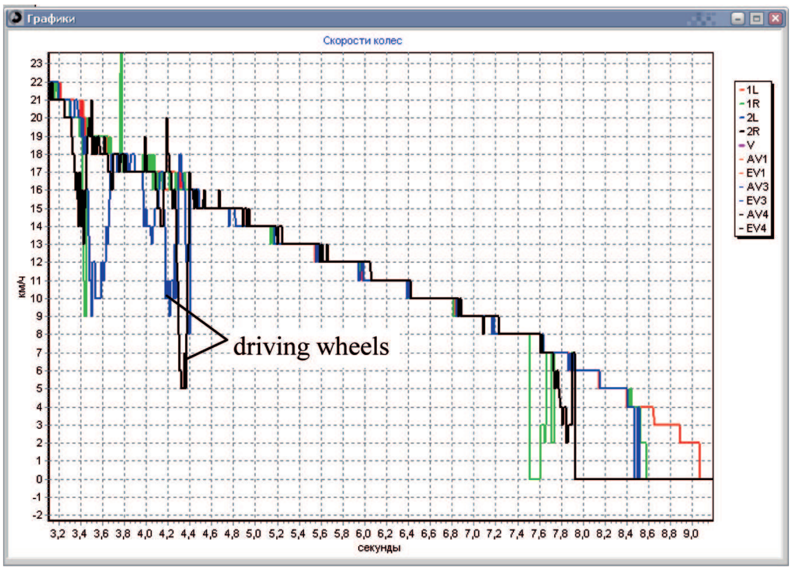

Fig. 3. The wheel velocity in trolleybus braking on snow surface with the application of the developed ABS

While defining the quantitative indices of deceleration and the realized adhesion coefficient efficiency, another testing regime was applied. It differed from the first one because actual conditions of the braking gear operation were changed. The testing results are as follows. According to the requirements of the Rules [13], the trolleybus brake system is equipped with the offered ABS, which controls not only the working brake system but also the installed (auxiliary) brake systems. This system guarantees:

– 6.4 m/s^2 deceleration on asphalt road against the allowed 4 m/s^2 minimum;

– cyclic ABS operation;

– adhesion utilization coefficient value for different road surfaces higher than 0.75.

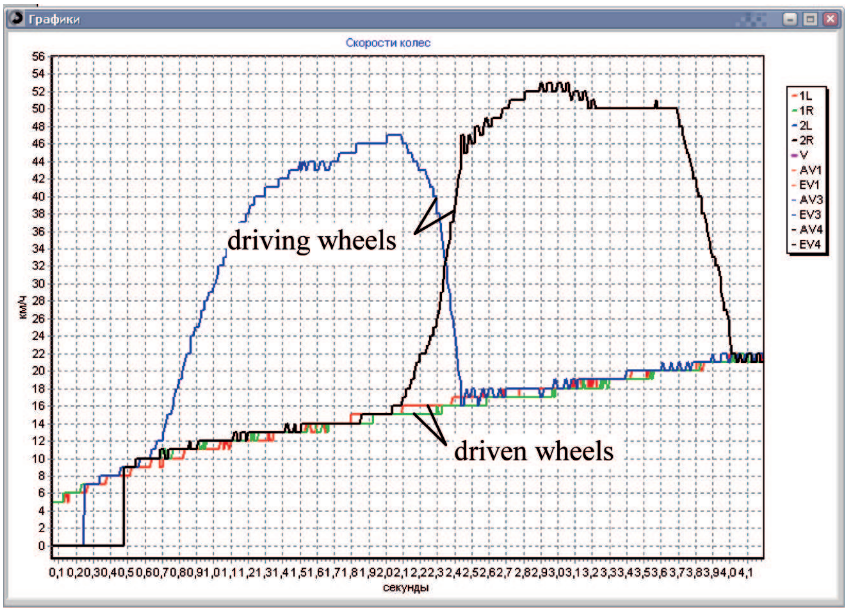

Fig. 4. Wheel velocity in trolleybus acceleration on snow surface without application of the ASR

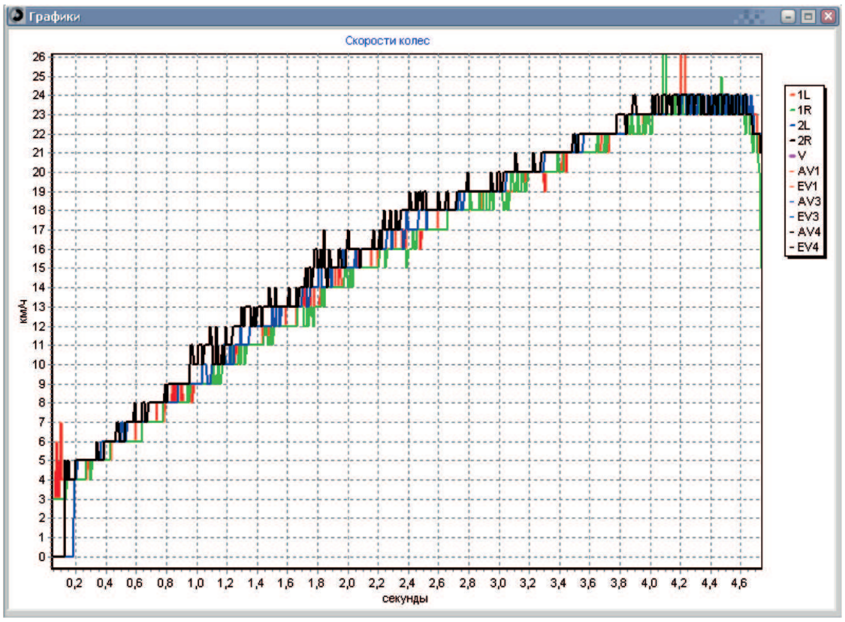

Fig. 5. Wheel velocity in trolleybus acceleration on snow surface with application of the developed ASR

Figures 4 and 5 illustrate some characteristics of the trolleybus acceleration dynamics, and allow us to estimate the efficiency of the offered system in ASR operation conditions according to the algorithm described in [11,12]. The efficiency is estimated on the basis of driving wheels slippage of the trolleybus equipped with the ASR and the trolleybus without it. As shown in figures 4 and 5, the slippage of each of the driving wheels without the ASR reaches 65%. With the applied ASR, the wheel slippage does not exceed 15%.

4. Conclusion

The developed system provides the normative efficiency indices of the braking process. The system improves the quality of the braking process, which consists in applying optimal values of wheel slippage. Consequently, it maintains high trolleybus stability under any road conditions, and guarantees good coordination of the AuxBS, WBS and ABS/ASR operation. It provides an evidence for the necessity and possibility of uniting all these braking systems into one system of braking process control.

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Przeciwpoślizgowy system hamulców trolejbusu

S t r e s z c z e n i e

Opracowano przeciwpoślizgowy system hamulców (ABS), który koordynuje działanie dwu systemów hamowania trolejbusu: roboczego i pomocniczego. Trolejbus typu "Belkommunmash 321", wyposażony w proponowany system ABS, był testowany w warunkach drogowych. Wyniki testów potwierdziły zgodność trolejbusu z wymaganiami normy UN EEC No 13. Odnotowano zmniejszenie poślizgu kół napędzanych, poprawę stabilności trolejbusu, lepsze trzymanie się drogi i lepsze bezpieczeństwo w ruchu.