ACCUMULATING POWER STORAGE DEVICES FOR METRO TRAINS

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ABSTRACT

See positive results of the use of power storage devices for rolling stock traction, the article studies variants to use them for Metro motor coaches. The authors have held numeric simulation of moving of trains equipped respectively with moving with standard power system and the system with power cumulating storage devices, and compared operation of those systems using power efficiency ratio. The study resulted in conclusion on practicability of on-board power cumulating systems for metro rolling stock.

ENGLISH SUMMARY

Background. *The long experience of operation of rail rolling stock with electric traction has proved efficiency of electric braking system when traction electric engine operates under regenerative mode. As traction engine is connected to the axle of a wheelset of a motor coach by traction gearbox (speed transformer), then wheel rotation under the impact of forces of inertia of the train enacts rotation of engine rotor even in the case if there is no voltage at his phases. If a certain mode of tension control is enacted, the engine is transferred into recuperative mode, and three-phase AC-voltage system appears at its stator winding.*

The metro rolling stock is now equipped with systems of regenerative braking allowing transferring the power of train braking into the network. But to efficiently use this power within the limits of feeding section there is necessary to have trains under traction mode within the same section. And it is not always so if we see operation conditions. It happens so far that metro train is ready to transfer power into the network, but it is not possible to use this power. Besides, due to non-uniform loading of metro power supply lines, it is not always possible to effectively use power regenerated by rolling stock. But there is an alternative solution to regenerative power system, which is cumulative battery power storage system.

Most rational approach can be found by installing on-board storage devices. They are intended for cumulating the power, regenerated by traction equipment during braking. It is important that this system can be used under traction mode independently of other functions of metro electric power supply system, resulting in reducing power consumption for traction and reducing power losses under regeneration mode. Simultaneously metro power supply system can avoid overloading caused by regeneration during peak traffic hours. It is to note that special polymer Li-Ion batteries have been engineered for rolling stock (see their features in table 1 [1]).

Objectives. *The study has the goal to compare power consumption by a metro train equipped with standard power system and by a metro train equipped with cumulative power storage devices.*

Methods. *In order to achieve the objective of the study the researchers used simulation of moving of a standard and of an empiric train at a 3000 m long section, which was divided into three similar sectors of 1000 m each with 0‰ declivity.*

Simulation was executed for a train consisting of 5 six-axle motor coaches of 81–740/741 type of an empty weight of 46 t each and electric AC gear, the utmost car bogies being equipped with asynchronous engines (TAD, of DATE2–170–4U2 type; table 2). The gear of tractive axle is individual.

Maximum load of each coach was assumed to be equal to 26 t, resulting in axle load of 12 t.

Electric circuit of the model contains voltage transformer, traction asynchronous engines, cumulative power storage device (pic.1). To control and adjust parameters of power equipment operation, the researchers used algorithm of optimal control of TAD by extreme points (extremum) of П-shaped features (engines operation with maximum efficiency ratio). Ratio of efficiency of the system braking power regenerating was determined as ratio of power returned into the network (under the condition that it is fully consumed) to integral power used for traction and moving.

The model of power system of motor coach is based on equations of electrical and mechanical conditions of TAD fed by metro power supply system. The model of the engine under traction mode is described by the system of equations (1) ... Under the braking mode the model changes. In that case there are two sources of electric circuit of the coach: a contact network and kinetics energy of train movement. Model of the engine (2) was based so far on the methods of calculation of the features of asynchronous machine under generative mode [2], using vectogram (pic.2).

Results. *The results of simulation of <u>standard train</u> showed that total power consumption for 3000 m distance was of 117,3 KW×h, and regenerated power was estimated as 63,1 KW × h (pic.3). Power consumption of a train within given section with full use of regenerated power is equal to 54,2 KW×h.*

Kinematics features of such train are presented in pic.4. It will spend 216 sec to cover the distance of a section with three sectors with different traffic modes (respectively acceleration, moving with permanent speed, braking), and average sped will be 50,1 km/h. Analysis of the results has shown that maximum power consumption can be observed at acceleration and braking. The power consumption for driving away from the rest and speeding-up (sectors: 0–440 m, 1000–1440 m, 2000–2440 m) within one station-to-station block was of 30,5 KW×h while the total power consumption was of 39,1 KW×h (pic. 3). High power consumption under the mode «driving away from the rest and speeding-up» is explained by respect of technical specifications of metro coaches [3], which provide for train acceleration of 1,0 m/sec^2 with smoothness of movement of 0,6 m/sec^3. In the case if the electric current load of engines is limited by nominal value, it is possible to achieve maximum acceleration at the moment of driving away from the rest of 0,84 m/sec^2 while respecting necessary value of smoothness of movement of 0,6 m/sec^3 (pic. 4). During speeding-up process the acceleration of *the train diminishes to 0,44 m/sec², and when the speed comes up to 80 km/h, the power system of the coaches enters the mode of speed maintenance (sectors: 440–730 m, 1440–1730 м and 2440–2730 м) (pictures 3,4).*

The moment of transferring of power system into braking mode was determined by the necessity to stop the train at the station. Simulation results showed that within the range of speed rates 7 km/h < V ≤ 80 km/h it is possible to use regenerative braking. Such mode is characteristic of sectors between 730–995 м, 1730–1995 m, 2730–2995 мm (pictures 3, 4). Train power consumption for one braking mode process doesn't exceed 8,6 KW×h (it was assumed that the network is capable to consume all the regenerated power). According to [3] maximum deceleration of the train under braking mode was of 1,0 m/sec² with movement smoothness of 0,6 m/sec³ (pic. 4). The speed below 7 km/h requires use of pneumatic braking (sectors 995–1000 m etc.), and the train is definitely stopped by shoe-type brake system.

Analysis of power rates allowed to determine that, if all the power regenerated by a certain train is consumed by other trains within the limits of the same feeder block sector, then the efficiency ratio of regeneration system of that train is of 54%.

The initial basic condition of simulation of movement of a train with on-board cumulative power storage unit was that batteries were discharged at the moment of starting (t=0). It was assumed that cumulative system had minimum storage capacity of 186 KW×h, and that this value increased during braking up to 207 KW×h. The discharge of batteries under traction mode went till initial capacity. The cumulating mode was enacted at the sectors of braking: 630–995 m, 1620–1995 m, 2620–2995 m – for charge, 1000–1280 m etc. – for discharge (pic. 5).

The calculations proved that the use of battery storage devices reduces power consumption used for traction down to 77,2 KW×h, that is by 34% less than in standard system (pic. 5). But to achieve this effect it is necessary to equip motor coach with 4 cumulative power storage units, each of them consisting of 13 battery modules 16PLIA (see table 1). Quantitate study shows that the above number of cumulating units is necessary to avoid overloading under the modes «charging/discharging».

The proposed modernization of power system of the train will permit to receive maximum power of one braking mode process, and to discharge units at traction mode down to minimal admissible value (30% of nominal value). It is important to take into account that the overall weight of the train with cumulative storage units increases by 12 t. So its kinematic features are relatively worse: the average speed at 3000 m distance is of 48,4 km/h, it spends 223 sec to cover that distance. It is explained by the fact that simulation used the same traction engines for both types of train and similar limits of loading of traction machines. It is evident that in order to obtain the required kinematic features of modernized train, it is necessary to increase capacity of its power equipment.

It is worth noting that during the study on cumulative power storage system it is necessary to provide for a relatively large number of cycles of charging and discharging and therefore for reduction in efficiency ratio of the system itself and of its elements.

Conclusions. *Three similar sectors of traffic simulation were selected in order to demonstrate that if traffic schedule is respected and if synchronous and parallel operation modes of traction and braking within one feeding zone are well organized, then there is no need to equip metro coaches with cumulative storage systems as total power consumption of standard system is of 54,2 KW/h and that of modernized system is of 77,2 KW/h. But as the practices of metro train operation prove, it is impossible to obtain the mode of full regeneration of power of braking, and no more it is possible to obtain full transfer of free regenerated power to traction power substations [4, 5]. Because of that the use of on-board cumulating storage systems is an alternative to rheostatic (short-circuit) braking. Cumulative storage devices, capable of returning power during all the process of speeding-up, are advantageous for forthcoming development of metro rolling stock traction operation.*

The computation, made during the study, shows that power cumulated by the batteries during the braking from 80 km/h down to 7 km/h is sufficient to ensure further acceleration up to 67 km/h in 28 sec, while according to [4] condenser-type cumulative systems allow obtaining only the speed of 30 km/h using all the power cumulated during braking from 70 km/h.

Key words: *metro train, regenerative power, power cumulating system, mathematical model, model of coach's electric circuit, traction mode, braking.*

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