Brake resistors power determination technique at the wheel vehicle with traction electric drive engineering stage

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Abstract. This paper presents electric brake system parameters determination problem on the multiaxial wheel vehicle with traction electric drive engineering stage. Brake resistors power determination method using vehicle motion imitational mathematical modeling is proposed.

The first paragraph after a heading is not indented (Bodytext style) During the last decade traction electric drive usage for terrestrial vehicle is being developed. It happens due to endeavor to improve ecological indicators and fuel economy of urban cars motion and to reduce losses during long-distance energy transfer in all-wheel multiaxial chassis.

There are different requirements to terrestrial vehicle (TV) traction electric drive elements. For example, traction electric engines (TEE) are used for TV’s acceleration, motion constant speed maintaining and also braking. At the same time electric brake system can seriously unload TV’s main mechanical brake system or completely replace it in some motion conditions. Among all the papers dedicated to a research of processes taking place in TV’s electromechanical braking system there is a paper [4] which deserves attention because its authors determine wheeled vehicle electromechanical braking control functioning effectiveness at the engineering stage considering mechanical braking system parts thermal stress and using imitational mathematical modeling. This paper presents the wheeled TV’s with traction electric drive electrical braking system parameters selection, brake resistors power in particular.

During the TV’s braking process all its kinetic energy has to dissipate in braking mechanisms in a quite a short period of time (except for cases of internal combustion engine (ICE) braking). It must be taken into consideration that heavy car acceleration process is estimated to take dozens of seconds, while it takes seconds for an emergency braking process to complete. This means that braking system executive parts always work in conditions of high loading, thermal stress and wear. Modern TV’s mechanical braking system executive parts (brake discs, brake drums and brake blocks with saddles) are placed directly in the wheels and occupy most of it. There is a need to reduce mechanical braking system parts overall dimensions due to the fact that TEE is also placed in the wheels because of motor-wheels usage. It can be achieved by its stress reduction and transferring part of its functions to electric braking system.

It is known that wheeled TVs have four kinds of braking system [1]: a working system, a spare system, an auxiliary system and a parking system.

A working braking system is supposed to regulate TV’s speed in any motion conditions. Deceleration, which can be achieved by this system, is j≥4,0…5,0 m/s².
A spare braking system is used to stop TV in case of working braking system failure. It usually works as a part of the working braking system which ensures at least 30% of its effectiveness. Maximum deceleration, which can be achieved by this system, is \( \geq 2.8 \text{ m/s}^2 \).

An auxiliary braking system is intended to be used in case of TV’s prolonged braking at protracted descents without usage of other braking systems. Maximum deceleration, which can be achieved by this system, is \( \geq 2.0 \text{ m/s}^2 \).

A parking braking system is supposed to withhold a fully loaded TV on a slope predetermined by specifications.

Electric braking system can be used as an auxiliary braking system or partially as a working braking system. Electric braking system can maintain not more than 70% of working braking system braking forces because spare braking systems functions cannot be entrusted to electric brakes due to its lower reliability compared to mechanical ones.

TEE goes into generator mode and produces electric energy if TV electric braking system with traction electric drive functions. TEE’s ultimate braking moment is usually equal to its ultimate traction moment. That is why electric power, which is produced by TEE in case of braking and depends on braking efficiency, cannot exceed TEE’s power. That means that in case of TV braking electric energy total power cannot exceed TEE’s total power considering their efficiency.

This electric energy can be stored in energy storage devices (molecular storage devices or accumulator batteries) or dissipated in brake resistors. Energy storage devices power is usually determined in traction mode based on the acceleration ensuring condition or TV motion without using the ICE condition.

It is necessary to consider two different modes in case of brake resistors power determination. These are the emergency braking starting from maximum speed mode and the downhill motion with constant speed mode.

Firstly, the emergency braking mode is considered. Nowadays wheeled TV systems parameters determination calculations are expedient to be done using imitational mathematical modeling due to computer software wide use. Wheeled cars and off-road tracked vehicles motion mathematical models are described in detail in [2-5]. The analog mathematical model is used in this paper.

Wheel dynamics in braking mode (Fig. 1) without considering air resistance force can be described by the following equations:

\[
m \cdot \ddot{V}_x = -R_x + P_x \]
\[
J_k \cdot \dot{\omega}_k = R_x \cdot r - M_t - M_f
\]

where \( m \) - automobile mass related to one wheel; \( \ddot{V}_x \) - center of mass linear acceleration; \( \dot{\omega}_k \) - wheel angular acceleration; \( J_k \) - wheel moment of inertia; \( M_t \) - wheel braking moment; \( M_f \) - wheel rolling resistance moment; \( R_x \) - interaction force between a propulser and a bearing base; \( r \) - distance between a wheel axis and a bearing base; \( P_x \) - lateral force applied to a wheel axis.

Wheel braking moment can be determined by using the equation:

\[
M_t = M_{TEE} + M_{\text{mech}}
\]

where \( M_{TEE} \) - braking moment related to a wheel and produced by TEE; \( M_{\text{mech}} \) - braking moment produced by mechanical brakes.

In case of emergency the braking system works at full power which means that braking is caused by TEE and mechanical brakes simultaneously. This mode is short-term (not more than 10 sec.) and happens once. This means that after the emergency braking starts the braking system has enough time to return to the original condition; mechanical brakes and brake resistors have enough time to cool down. To determine brake resistors power the car’s braking on bituminous concrete process is modeled. Mechanical braking system produces the maximum braking moment on each wheel. Wherein wheel blocking is not allowed – anti-lock braking system (ABS) work is modeled (if any wheel rotational frequency comes close to zero the wheel brakes switch off).
Power, which must be dissipated in brake resistors, can be determined using the equation:

\[ \sum_{i=1}^{n} M_{\text{TEE}i} \cdot \omega_i \cdot \eta_i \]  

where \( M_{\text{TEE}i} \) – moment related to the \( i \) wheel and produced by TEE during the braking process; \( \omega_i \) – wheel angular velocity; \( \eta_i \) – drive efficiency; \( n \) – the number of wheels.

Drive efficiency can be calculated as follows:

\[ \eta_i = \eta_{\text{TEE}i} \cdot \eta_{\text{tr},i} \]

where \( \eta_{\text{TEE}i} \) – TEE’s efficiency for the given work mode; \( \eta_{\text{tr},i} \) – transmission efficiency.

In Figure 2 moment and efficiency relation with transport vehicle typical TEE shaft angular velocity is shown.

Thus braking time, deceleration and braking distance can be estimated. Electrical and mechanical braking system characteristics can be optimized using these parameters.

For example, 4-axial wheeled vehicle (weight 50 tons, starting speed 50 mph) braking process is considered. The vehicle TEE total power is 480 kw. Mechanical braking system can produce maximum braking moment 7 kn*m on each wheel. TV braking results are shown in Figures 3 and 4.
Figure 3. TV braking results: a) distance; b) TV center of mass linear velocity; c) wheels angular velocities; d) TV center of mass linear acceleration

Figure 4. Power, which is emitting in electric transmission during the braking process

Figures' analysis shows that the vehicle stopped in 4.8 sec. and made the way 62 m long, wherein deceleration was 3.3-7.3 m/sec². Angular velocity graph shows that ABS started working in order to prevent some most unloaded wheels from stopping. From this moment on power, which is emitting in electric transmission during the braking process, starts to reduce drastically. Maximum power during the braking process is 480 kw, which coincides with TEE total power. This power is necessary to dissipate in brake resistors.

Secondly, downhill motion with constant speed mode is considered. In this case the braking system must maintain vehicle constant speed and not let it to accelerate. Wherein the more is vehicle speed the more power must be consumed by the braking system. Since downhill motion can be quite long-time (dozens of minutes) the main mechanical braking system cannot be used due to its overheat and failure. Therefore calculation is expedient to be done for electric braking using TEE. In this case electric brakes will be used as an auxiliary braking system.

In order to determine brake resistors power TV motion is modeled. TV is moving at different velocities downhill at a 10, 15 and 20 degrees angle on good condition dirt road.
Power, which is necessary to dissipate in brake resistors, can be calculated using (1). During the calculation fulfillment of the following condition is controlled: 
\[ M_i \cdot \omega_i \leq N_{TEE}, \]
where \( N_{TEE} \) – TEE power.

For the given TV moving at a 10, 15 and 20 degrees angle maximum velocities were 40, 19 and 12 mph respectively. In Figure 5 power, which is emitting in electric transmission during TV motion, graph is shown.

![Figure 5](image.png)

**Figure 5.** Power, which is emitting in electric transmission during TV motion at 19 mph and a 15 degrees angle

**Conclusions**

Brake resistors of multiaxial TVs with electric transmission and their cooling system must be chosen in order to dissipate 90-100% TEE total power.

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