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Inertial Capacitive Energy Storage Device for a Shunting Diesel Locomotive

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ABSTRACT

The relatively frequent change in the operating mode of a shunting diesel locomotive determines efficiency and feasibility of equipping it with an energy storage device. In addition to smoothing the load on the power plant, the energy storage device will allow to regenerate energy during braking, thereby increasing energy efficiency of a shunting diesel locomotive. This topic is frequently discussed in World of Transport and Transportation Journal, that is the evidence of its timeliness.

The theoretical background for developing an inertial capacitive energy storage device, which is technically designed as a DC machine with a super flywheel that makes it possible to smooth the load on the power plant, thereby reducing its power and mass and dimensions, is presented. The increase in mass thanks to the energy storage device can be compensated by a decrease in the mass of the engine. As the diesel locomotive is equipped with electromechanical transmission, then it minimizes the framework of development for it of a considered inertial capacitive drive, making it even more advantageous. The article provides initial calculations and circuits.

Keywords: *railways, shunting diesel locomotive, engine, super-flywheel, power plant, energy efficiency, recovery, regeneration, energy storage device.*

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Background. The estimated capacity of a power plant of a shunting diesel locomotive is determined by its peak load, which occurs, first of all, when pulling a train off. Obviously, most of the time the power plant works in an underloaded mode. A relatively frequent change in the operating mode of a shunting diesel locomotive determines efficiency and feasibility of equipping it with an energy storage device [1, 2]. The use of energy storage device will allow to smooth the load on the power plant and to thereby reduce its power, mass and dimensions.

In addition to smoothing the load on the power plant, the drive will allow to regenerate energy during braking, thereby increasing energy efficiency of a shunting diesel locomotive [3, 4].

So, the *objective* of the research was to substantiate equipping of shunting diesel locomotives with an inertial capacitive energy storage device. The general scientific, mathematic and engineering *methods*, as well as the electrical engineering calculations have been used for the study.

Results.

Theoretical prerequisites for creation of an inertial capacitive energy storage device

A DC machine [5, 6] with a super-flywheel can be considered as such an energy storage device. To reduce losses, a flywheel can be placed in an evacuated housing. The problems associated with operation of a DC machine in vacuum are completely solvable [7].

The supply of a constant voltage U to the armature winding initiates the following mechanical [8, 9] and electrical [10, 11] processes:

$$\begin{cases} J\dfrac{d^2\varphi}{dt^2}+k\dfrac{d\varphi}{dt}=B2lw\dfrac{D}{2}i; \\ B2lw\dfrac{D}{2}\dfrac{d\varphi}{dt}+Ri=U, \end{cases} \quad (1)$$

where J – total moment of inertia; k – friction coefficient; B – magnetic induction; $2l$ – active conductor length; w – number of turns of the coil; D – effective diameter of a rotor; R – electrical resistance. These equations are valid under the following assumptions: friction force is proportional to speed of rotation, and electrical resistance does not depend on current.

It is possible to enter a parametric coefficient:

$$BlwD = Y. \quad (2)$$

Let the initial conditions be:

$$\varphi(0) = \varphi_0,$$

$$\frac{d\varphi}{dt}(0)=\omega_0. \quad (3)$$

Following the equation of electric equilibrium:

$$\frac{d\varphi}{dt}=-\frac{R}{Y}i+\frac{U}{Y}, \quad (4)$$

$$\frac{d^2\varphi}{dt^2}=-\frac{R}{Y}\frac{di}{dt}.$$

Substitution into the first equation of the system gives:

$$-\frac{JR}{Y}\frac{di}{dt}-\frac{kR}{Y}i+\frac{kU}{Y}=Yi,$$

$$\frac{di}{dt}+\left(\frac{Y^2}{JR}+\frac{k}{J}\right)i=\frac{k}{J}\frac{U}{R}.$$

Let:

$$\frac{Y^2}{JR}+\frac{k}{J}=A,$$

$$\frac{k}{J}\frac{U}{R}=B.$$

Then:

$$\frac{di}{dt}+Ai=B. \quad (5)$$

The overall solution is:

$$i_1 = C_1e^{-At}.$$

The particular solution is:

$$i_2 = C_2.$$

Substituting it into the formula (5) gives:

$$0 + AC_2 = B,$$

$$C_2=\frac{B}{A}.$$

The current sought is equal to:

$$i=i_1+i_2=C_1e^{-At}+\frac{B}{A}. \quad (6)$$

Considering (3) and (4) we get:

$$i(0)=\frac{U}{R}-\frac{Y\omega_0}{R}.$$

With account of (6) we get:

$$C_1=\frac{U}{R}-\frac{Y\omega_0}{R}-\frac{B}{A}.$$

$$i=\left(\frac{U}{R}-\frac{Y\omega_0}{R}-\frac{B}{A}\right)e^{-At}+\frac{B}{A}.$$

$$i=\left(\frac{U-Y\omega_0}{R}-\frac{U}{Y^2/k+R}\right)e^{-t/\tau}+\frac{U}{Y^2/k+R}= \\ =\left(\frac{U-E_0}{R}-\frac{U}{R_k+R}\right)e^{-t/\tau}+\frac{U}{R_k+R}, \quad (7)$$

where $E_0 = Y\omega_0$.

$$\frac{1}{\tau}=\frac{1}{R\ J/Y^2}+\frac{1}{J/k}=\frac{1}{R\ J/Y^2}+\frac{1}{\left(J/Y^2\right)\left(Y^2/k\right)}= \\ =\frac{1}{RC_J}+\frac{1}{R_kC_J}=\frac{1}{\tau_e}+\frac{1}{\tau_m}. \quad (8)$$

When $k = 0$ $R_k = \infty$:

$$i=\frac{U-E_0}{R}e^{-t/\tau}, \quad (9)$$

$$\tau=\frac{RJ}{Y^2}=RC_J. \quad (10)$$

Formulas (9) and (10) are indistinguishable from formulas describing the charge of a capacitor.

When shorting the anchor winding terminals:

$$i = \frac{-E_0}{R} e^{-t/\tau}.$$

This formula is indistinguishable from the formula describing the discharge of a capacitor.

Expressions (7)–(10) indicate the capacitive nature of the considered power storage device.

The storage device capacity is equal to:

$$C_J = \frac{J}{Y^2}.$$

Electromechanical resistance is:

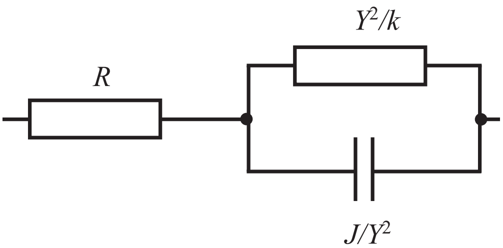
$$R_k = \frac{Y^2}{k}.$$

The energy stored by the device is equal to:

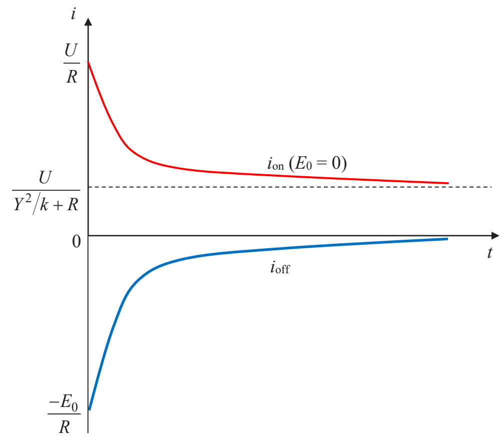
$$W = \frac{C_J U^2}{2} = \frac{JU^2}{2Y^2} = \frac{J\omega^2}{2}. \quad (11)$$

Pic. 1 shows the electrical circuit of an inertial capacitive energy storage device, Pic. 2 shows the characteristics of the electric current at charging and discharging.

Conclusions. Currently, high-performance super-flywheels have been created, and a possibility of using them on automobiles is being considered [12–14]. It is obvious that the use of a flywheel, particularly equipped with a fairly massive DC machine, on a shunting diesel locomotive is much less problematic due to the significantly less stringent requirements for the total mass. The increase in mass due to the energy storage device can be compensated by a decrease in the mass of the engine. Diesel locomotives possess an advantage as they have electromechanical transmission, that fact minimizes process of development of the considered inertial capacitive energy storage device.



Pic. 1. Electrical circuit of the inertial capacitive energy storage device.



Pic. 2. The characteristics of the electric current at charging and discharging phases of an inertial capacitive energy storage device.

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