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Dynamical modelling of the excavating chain of a ballast cleaning machine

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ABSTRACT
The ballast bed as part of the railway track fulfils the important functions as the binding element between sleepers and substructure. Fouling increases over the years for various reasons. When the necessary good functioning is no longer assured, ballast bed cleaning must be performed. The machines, that perform that task, are equipped with various complex mechanics - hydraulic systems that ensure high productivity, efficiency and quality of the works. In this article is presented one way of studying the work of the machine for excavating ballast from the ballast bed to the sieving machine. We suggest a dynamic model for simulating the work of a scraper chain of a ballast cleaning machine with different working parameters.
Keywords – ballast cleaning machine, dynamic model, excavating chain

I. INTRODUCTION

The ballast bed distributes the loads of the trains uniformly onto the track substructure and assures a firm, unshifting position of the sleepers. To withstand these dynamic impacts the ballast bed has to be very elastic. The good function depends on the depth of the ballast bed, the size of the ballast stones and the degree of fouling.

Using ballast bed cleaning machines, the ballast can be cleaned without dismantling the track. The central features are powerful scraper chain (Fig.1) that excavate the fouled ballast and at the same time prepare the foundation for the new ballast. The ballast is cleaned in large oscillating screens with several screening levels which ensures optimum quality. The clean ballast is returned to the track directly behind the excavating chain. The residue from the cleaning is passed into a spoil conveyor and transport system.

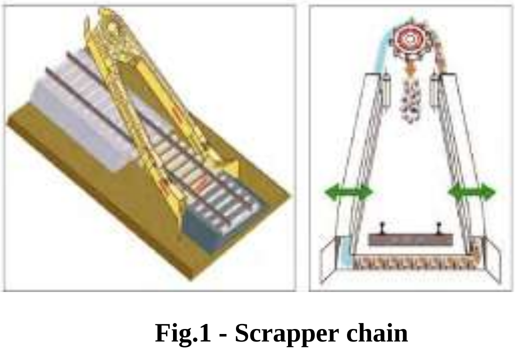

Fig.1 - Scrapper chain

II. MAIN SCHEMATIC

The excavating chain, together with the hydraulic transmission and the diesel engine (Fig.2), are a machine aggregate, composed of a driving machine (el. 1), transmission (el. 3,4,5), and a driven machine(el 6,7).

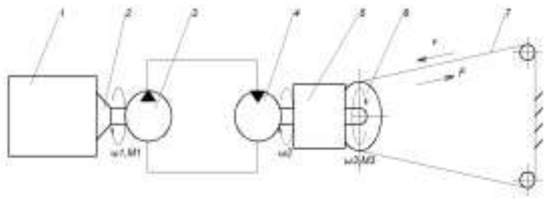

Fig.2 - Main schematic of the machine aggregate

1-engine; 2-flywheel; 3-hydraulic pump; 4-hydraulic motor; 5-planetary reducer; 6 –driving chain wheel; 7- excavating chain.

The work of the aggregate in both stationary and non- stationary regimes can be greatly affected by the dependence of the reduced moment of inertia J_r and the reduced torque M_r of kinematic (driving) and resistance torques on the angle velocity ω_r of the chain wheel's shaft.

III. DYNAMIC MODEL

The machine aggregate in Figure 2 could be substituted by a single mass rotating model, with one degree of freedom (Fig. 3), by using the principle of dynamical similarity [1].

The mass and the power parameters are reduced to the driving chain wheel's shaft.

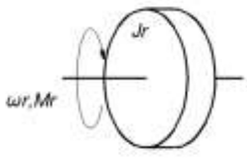

Fig. 3 - Dynamic model

The equation, describing the motion of the machine aggregate and the corresponding dynamical model, is derived from the second kind Lagrange equation. It can be presented as follows:

$$J_r \frac{d\omega_r}{dt} = M_r(\omega_r) \quad (1)$$

The reduced mass moment of inertia J_r=const. and the reduced torque $M_r = f(\omega_r)$ that means that the non- stationary regime is aperiodic.

IV. REDUCED PARAMETERS

1.Reduced mass moment of inertia J_r

$$J_r = (J_1 + J_2 + J_3)\left(\frac{\omega_1}{\omega_r}\right)^2 + (J_4 + J_5)\left(\frac{\omega_2}{\omega_r}\right)^2 + + m_7\left(\frac{v}{\omega_r}\right)^2 + J_6, kgm^2 \quad (2)$$

where:
$J_{1,2\ldots6}$ - the moments of inertia of the engine, flywheel, hyd. pump, hyd. motor, planetary reducer and chain wheel, according to fig.2, kgm^2;

m_7 - the mass of the scraper chain, *kg*;

ω_1, ω_2 – the angular velocities of the engine and hyd. motor, s^{-1};

$\omega_r = \omega_3$ –the angular velocity of the chain wheel, s^{-1};

v – the velocity of the scraper chain, *m/s*; ($v = \omega_r R_6$)

R_6 – radius of the driving chain wheel, *m*.

2.Reduced torque M_r

$$M_r(\omega_r) = M_k(\omega_r) - M_{res}, Nm \quad (3)$$

where:
M_k - reduced driving torque, *Nm*;
M_{res} – resistant torque, *Nm*.

The reduced driving torque M_k is defined as:

$$M_k = M_e(\omega_e)\frac{\omega_e}{\omega_r} \quad (4)$$

where:
M_e – engine's torque, *Nm*;
$\omega_e = \omega_1$ - engine's angular speed, s^{-1}.

The engine's characteristic (torque curve) $M_e = f(\omega_e)$ [2] could be approximated with second order polynomial:

$$M_e(\omega_e) = -0{,}02\omega_e^2 + 6{,}4\omega_e + 522 \quad (5)$$

where the approximation is done using the polynomial curve fitting *polyfit* in MATLAB.

As $\omega_e = i_{1r}\,\omega_r$, where $i_{1r} = \omega_e/\omega_r$, the reduced driving torque can be expressed as:

$$M_k(\omega_r) = \left(-0{,}02\omega_r^2 i_{1r}^2 + 6{,}4\omega_r i_{1r} + 522\right) i_{1r} \quad (6)$$

The resistant torque M_{res} depends on the resistant force F [N], which appears during the excavating chain's movement:

$$M_{res} = F.R_6 \quad (7)$$

Determination of resistance F is fully described in [3].

V. SOLUTION TO THE EQUATION OF MOTION

Equation (1) has two case solutions:

1.Idle phase (evolution of the model from rest to a stationary velocity, without resistance).

In this case the solution describes the evolution of the transition process when the aggregate is in idle motion. The transition process can be altered by changing the moment of inertia via adding an extra flywheel.

Equation (1) is solved numerically with a Runge-Kutte integration scheme (ode45 in MATLAB), for three different values of the moment of inertia.

The solutions have been plotted in Figure 4.

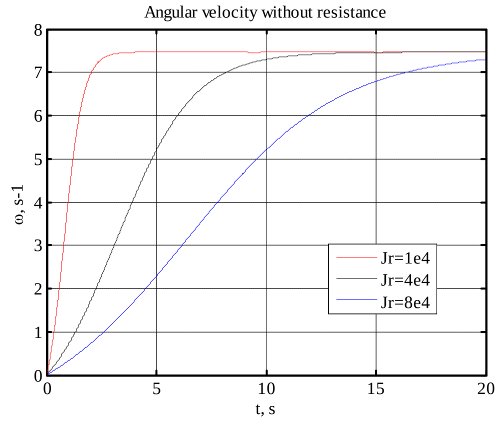

Fig.4 Solution – case1 (idle phase)

2.Working phase (loading after reaching a stationary velocity)

The solution of case 2 shows a non-stationary state until reaching a new stationary angular velocity.

The solution is performed as in the first case, for three different values of the moment of inertia.

The solutions have been plotted in Figure 5.

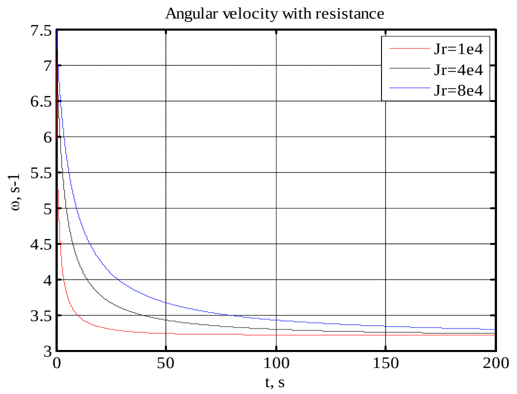

Fig.4 Solution – case 2 (working phase)

The other technical parameters for solving the equation of motion are taken from the ballast cleaning machine Matisa C330, diesel engine Deutz F12L413FW, hydraulic transmission Sauer 2x H1-165 and 130 MF [4].

VI. CONCLUSION

The diagrams (fig. 4,5) show the dependence of the non- stationary regime's time on the mass parameter which could be varied in wide limits.

The presented equations (2, 6) referring to the reduced parameters are valid only for the presented main schematic of the machine aggregate.

We presented a dynamical model for the machine aggregate for excavating the ballast. In our model the user can choose the principal scheme as well as modify the parameters in order to obtain the desired work performance.

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