NUMERICAL SIMULATION ON THE VIBRATION OF A VEHICLE DRIVETRAIN WITH DUAL MASS FLYWHEEL

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Abstract: This paper describes the results of numerical simulations of a vehicle drivetrain model with dual mass flywheel. The differential equations of the model are given. The vehicle inertia, the tire torsional stiffness and the transmission gear ratios are taking into account. Numerical simulations with given mass, elastic and damping parameters are carried out. Natural frequencies of the system are determined. Vibrational characteristics of the system are shown and analysed.

Keywords: DUAL MASS FLYWHEEL, TRANSMISSION, DRIVELINE, DYNAMICS, VIBRATION

1. Introduction

The Dual Mass Flywheel (DMF) is widely used in modern diesel or gasoline direct injection engines. Downsizing and downspeeding of engines, lowering friction in gearboxes and lightweighting of transmissions and drivelines cause increased vibration and noise. The periodic combustion cycles of a four-stroke engine create torque and speed fluctuations which cause torsional vibration to be passed down the drivetrain (Fig. 1). The resulting noise and vibration, such as gear rattle, body boom and load change vibration, results in a decrease in comfort [1].

As the DMF has an integral spring-damper system a rigid clutch driven disc is created and numerical simulations are performed. In work [14] a dynamic model of friction self-excited vibration of a vehicle drivetrain with conventional damper in the driven clutch disc is presented and test results for amplitude-frequency characteristics are shown. In [15] dynamic model of a vehicle drivetrain with spring and friction damper in driven clutch disk is presented and test results for amplitude-frequency characteristics are shown. In work [16] a linear mechanical model of hybrid electric vehicle drivetrain is considered, a modal analysis is performed and the effect of the control of the drivetrain on the eigenvalues of the vibrational system is studied. In this regard, the purpose of this publication is to draw out the differential equations of dynamic drivetrain model with dual mass flywheel with taking into account of the vehicle inertia, the tire torsional stiffness and the transmission gear ratios and to carry out numerical simulations with given mass, elastic and damping parameters.

2. Dynamic Model

A front wheel drive vehicle with dual mass flywheel drivetrain and its kinematic scheme are shown in Fig. 3 and 4 respectively. The system mainly consists of engine, dual mass flywheel (DMF), gearbox, final drive, drive shafts, drive wheels, driven wheels and car body. The symbols used in kinematic scheme are:

- mass moment of inertia of the crankshaft;
- mass moment of inertia of the primary mass of the flywheel;
- mass moment of inertia of the secondary mass of the flywheel and clutch pressure disc;
- mass moment of inertia of the clutch driven (friction) disc and primary shaft with drive gears of the gearbox;
- mass moment of inertia of the secondary shaft with driven gears of the gearbox;
- mass moment of inertia of the final gear and the differential;
- mass moment of inertia of the drive shafts;
- mass moment of inertia of the wheels;
- vehicle mass;
$J_2$ – mass moment of inertia of the secondary shaft of the gearbox;

$J_0$ – mass moment of inertia of the final gear and the differential;

$J_d$ – mass moment of inertia of the drive shafts;

$J_w$ – mass moment of inertia of the wheels;

$m$ – vehicle mass;

Fig. 5 Equivalent 3 DOF vehicle drivetrain dynamic model

The equivalent dynamic model shown in Fig. 5 has three degrees of freedom (3 DOF) and the vector of generalized coordinates is:

$$q = [\varphi_1 \varphi_2 \varphi_3]^T$$

The mass moments of inertia of the dynamic model are:

$$J_1 = J_1 + J_{f1}$$

$$J_2 = J_{f2} + J_{g1} + J_{g2} + J_0 + 2J_d + 2J_w$$

$$J_3 = 2J_w + J'_r$$

$J_1$ – mass moment of inertia of the crankshaft and primary mass of the flywheel;

$J_2$ – mass moment of inertia of the secondary mass of the flywheel, clutch, gears and shafts of the gearbox and final drive, drive shafts and drive wheels;

$J_3$ – mass moment of inertia of the driven wheels and mass of the car body reduced to the engine crankshaft;

The mass moments of inertia reduced (referred) to the crankshaft are [18, 19]:

$$J'_{g2} = \frac{J_{g2}}{i_{g2}}$$

$$J'_0 = \frac{J_0}{i_{g2}}$$

$$J'_d = \frac{J_d}{i_{g2}}$$

$$J'_w = \frac{J_w}{i_{g2}}$$

$$J'_r = m \left( \frac{r_w}{i_{g2}} \right)^2$$

where superscript $r$ means reduced or referred to the crankshaft;

$J'_r$ – reduced mass moment of inertia of translating mass of the vehicle to the crankshaft.

For the generalized coordinates can be written:

$$\varphi_1 = \varphi_{f1}$$

$$\varphi_2 = \varphi_{f2} = \varphi_{g1} = \varphi_{g2} i_{g2} = \varphi_0 i_{g2} = \varphi_0 i_{g2} i_0 = S_i_{g2} i_0$$

$$\varphi_3 = \varphi_{u} i_{g2} i_0 = \frac{S i_{g2} i_0}{r_m}$$

where $S$ is the driving distance, m.

$$k'_r = \frac{k_r}{i_{g2}^2}$$

$$c'_r = \frac{c_r}{i_{g2}^2}$$

where $k'_r$, $c'_r$ – tire torsional stiffness and damping reduced to the engine crankshaft.

The differential equations of the model are:

$$J_1 \dot{\varphi}_1 + k_1 (\varphi_1 - \varphi_2) + c_1 (\dot{\varphi}_1 - \dot{\varphi}_2) = M_1$$

$$J_2 \dot{\varphi}_2 - k_2 (\varphi_1 - \varphi_2) + k'_r (\varphi_2 - \varphi_3) - c_2 (\dot{\varphi}_1 - \dot{\varphi}_2) - c'_r (\varphi_2 - \varphi_3) = 0$$

$$J_3 \ddot{\varphi}_3 - k_3 (\varphi_2 - \varphi_3) - c_3 (\ddot{\varphi}_2 - \ddot{\varphi}_3) = -M_2$$

The excited moment from the engine is:

$$M_1 = M_{u} + M \sin \omega t$$

And

$$M_2 = \frac{M_R}{i_{g2}}$$

where $M_R$ is resistive moment acted on the vehicle. It includes rolling resistance, road inclines and aerodynamic drag.

3. Numerical Simulation

The numerical simulations are performed in program field of MATLAB. The parameters of the model are taken from different literature sources [13, 14, 19 and 20]. The actual values of the parameters are given in Table 1. Some of the parameters are reduced (referred) according to the formulas given above to the engine crankshaft for the accurate conduction of the simulations.
Table 1: Parameters of the dynamic model

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Dimension</th>
</tr>
</thead>
<tbody>
<tr>
<td>$J_c$</td>
<td>0.045</td>
<td>kg.m²</td>
</tr>
<tr>
<td>$J_{f1}$</td>
<td>0.115</td>
<td>kg.m²</td>
</tr>
<tr>
<td>$J_{f2}$</td>
<td>0.004</td>
<td>kg.m²</td>
</tr>
<tr>
<td>$J_g1$</td>
<td>0.003</td>
<td>kg.m²</td>
</tr>
<tr>
<td>$J_g2$</td>
<td>0.015</td>
<td>kg.m²</td>
</tr>
<tr>
<td>$J_0$</td>
<td>0.850</td>
<td>kg.m²</td>
</tr>
<tr>
<td>$m$</td>
<td>1765</td>
<td>kg</td>
</tr>
</tbody>
</table>

For overcritical operating conditions ($\omega_{ex} > \omega_{nat}$), it must be ensured that the minimum excitation frequency will in all operating points will remain to a sufficient degree above the natural frequency and the excitation frequency from the engine is [21]:

$$\omega_{ex} = \frac{z \cdot n}{2 \cdot 60}$$

where $z$ is the number of cylinders;

$n$ – engine speed, min⁻¹.

For 4-cylinder engine on idle speed - 900 min⁻¹:

$$\omega_{ex} = \frac{4 \cdot 900}{2 \cdot 60} = 30Hz$$
Analysis of the results for excited vibration shown in Fig. 7 to Fig. 12 indicates that the system effectively lowers the acceleration of the vehicle body (third mass of the model) and allows driving the vehicle on low engine angular speed. The acceleration of the second mass is less when the higher gear is engaged. Acceleration decrease when increase the angular speed of the engine.

4. Conclusion

The considered model enable to study the vibration in vehicle drivetrain and fluctuation in linear movement of the vehicles with dual mass flywheel. The shown consideration for reduction of all parameters to the engine crankshaft allows to be studied the vibration on various gears in vehicle gearbox. The numerical experiments with given parameters show good damping of acceleration of the third mass (vehicle) in all speed range of the engine and for all gears of the gearbox. The acceleration of the second mass (transmission) decreased with increase the angular speed and with engagement of the higher gear in the gearbox.

References:

[2] https://www.youtube.com/watch?v=nvgEiArV45c