Dynamics of Synchronization of Rotational Motion of Contacting Triple-Body Systems

Viktor Berbyuk

Department of Applied Mechanics
Chalmers University of Technology
Hörsalsvägen 7A, SE-412 96 Göteborg, Sweden
viktor.berbyuk@chalmers.se

Abstract

Modern engineering systems often comprise power transmission with gearbox. To perform gear shifting inside the gearbox different synchronizer mechanisms have been developed. Transmission gear shifting improvement with respect to smooth, quick and energy efficient synchronizer's performance, is still one of the major concern area for automotive industry, see e.g. [1-3]. Typical synchronization process includes different phases of relative motions between functional components of synchronizer and gearbox that should be described by taking into account contact phenomenon in contacting interfaces, lubrication, temperature, and other issues. So, the dynamics of synchronization processes is a challenge. Solution to this engineering problem requires deep insight into dynamics of multibody system used to model the synchronization processes in power transmissions.

In the proposed paper an engineering model of the generic synchronizer mechanism is considered. The synchronizer mechanism is modelled by a contacting triple-body system (CTBS) consisting of the selector sleeve, the synchronizing ring and the gearwheel. It is assumed that all bodies of the CTBS can rotate completely independently of one another and perform rotational motion about the same axis under the action of external and internal loads. The external loads comprise the vehicle resistance torque $M_v(t)$ acting on the output side of the gearbox, the control torque $M_F(t)$ acting on the selector sleeve and arising due to the external axial force $\mathrm{F}(t)$, applied to selector level, and the drag torque $M_d(t)$ acting on the input side of the gearbox. The internal loads comprise the synchronizing torque $M_s(t)$ acting at contacting interface between the sleeve and the synchronizing ring and the synchronizing torque $M_r(t)$ acting at contacting interface between the synchronising ring and the gearwheel.

The following direct dynamics problem (DDP) for the CTBS is considered. For the given drag torque $M_d(t)$, the vehicle resistance torque $M_v(t)$, and the control torque $M_F(t)$ it is required to determine the synchronizing torques between contacting interfaces, $M_s(t)$, $M_r(t)$ and the rotational motion of the CTBS that all together satisfy the equations of motion, arbitrary prescribed initial conditions and guarantee synchronization of rotational speeds of the sleeve, the synchronizer ring and the gearwheel for the final time t_s, i.e. the following end conditions must be fulfilled:

$$\dot{\theta}_s(t_s) = \dot{\theta}_r(t_s) = \dot{\theta}_g(t_s) = \mathrm{r}\,\omega \tag{1}$$

Here in the expression (1) $\dot{\theta}_s(t_s)$, $\dot{\theta}_r(t_s)$, $\dot{\theta}_g(t_s)$ are rotational speeds of the sleeve, the ring and the gearwheel at the end of the synchronization process $t = t_s$, respectively, ω is rotational speed of the sleeve at the initial instant of time $t = 0$ and *r* is gear ratio.

In the paper the algorithm is presented for solving the DDP of the CTBS. The transcendental equation has obtained to determine the synchronization time t_s for the given torques $M_v(t)$, $M_d(t)$, $M_F(t)$ and system's structural parameters. Knowing the synchronization time t_s, the torques $M_s(t)$,

$M_r(t)$ between contacting interfaces are determined by solving the integral equations. And finally the rotational motion of the CTBS during synchronization process is determined by integration of the equations of motion with prescribed initial conditions. Following [4, 5] and assuming that the resistance torque on the synchronizer owing to the vehicle inertia, the drag torque due to the clutch and the synchronizing torques at contacting interfaces are substantially constant during the synchronization process it is shown that the developed algorithm gives the solution of the DDP of the CTBS in analytical form. Using the developed algorithm the sensitivity analysis of the synchronization time t_s and the synchronizing torques $M_s(t)$, $M_r(t)$ between contacting interfaces with respect to the drag torque $M_d(t)$, the vehicle resistance torque $M_v(t)$, the control torque $M_F(t)$, and system's structural parameters has been done and is presented in this paper. Particular focus is put on analysis of the effect of vibration excitations from driveline on the dynamics of synchronizing processes.

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