Mechatronics 30 (2015) 27–54

Contents lists available at ScienceDirect

Mechatronics

journal homepage: www.elsevier.com/locate/mechatronics

Automotive drivetrain model for transmission damage prediction

S. Foulard [a,b,*], S. Rinderknecht [a], M. Ichchou [b], J. Perret-Liaudet [b]

[a] Institut für Mechatronische Systeme, Technische Universität Darmstadt, Germany
[b] LTDS, UMR 5513 CNRS, Ecole Centrale de Lyon, France

ARTICLE INFO

Article history:
Received 28 October 2014
Accepted 10 June 2015
Available online 30 June 2015

Keywords:
Automotive engineering
Drivetrain model
Transmission dynamics
Damage prediction
Load collective

ABSTRACT

This paper presents the development and the validation of an automotive drivetrain model aimed to investigate the impact of true-to-life operating conditions on the damage prediction of transmission gearwheels. The model is based on a torsional and non-linear multi-body system representing the rotating parts between the engine and the driven wheels. The boundary conditions are performed with an engine model and a tire model coupled with a suspension & pitch model. The generation of the driving inputs is fully automated through a tunable driver model relying on predefined driving cycles. The model allows the simulation of start-up processes, gear shifts and tire grip loss, as well as of the transmission dynamics and the eigenbehavior of the gearwheels. The damage estimation is computed continuously and in parallel, by means of a linear damage accumulation method. The drivetrain dynamics was validated with temporal and frequency analyses based on measurements, data from the transmission manufacturer and literature. The estimated damages are also reality-conform. They were validated with comparative data recorded on vehicles during a measurement campaign on open roads.

1. Introduction

Nowadays, the lightweight design is highly focused in the automotive industry. With the aid of accurate offline models a better correlation between the design and the loads occurring during service life may be achieved, or a better understanding of the impact of the loads on the lifetime of the mechanical components can be achieved. In comparison with field tests, advantageous aspects of simulation models are the associated cost & time efficiency, the reproducibility and the access to hardly measurable signals.

A lot of publications discuss the modeling of single drivetrain components independently of global approaches, like clutch [1], engine [2], driver [3], gearwheels [4], and backlash [5]. Other papers propose the development of complete drivetrain models, which are mostly simplified and only suitable for macroscopic studies and low-frequency dynamics [6–8]. Some other publications deal with the assessment of emissions and fuel consumption [9] or the development of control strategies (hybrid vehicles [10,11], gear shift strategies [12,13] or driving assistance systems [14]). Similarly, the proposed models are only adapted for the considered use case and cannot be used for damage calculation. Furthermore, a significant part of the developed models refers to commercial softwares with preconceived toolboxes, where the modeling approach, the adopted assumptions and the validity domain are not always clearly stated.

The modeling of a vehicle drivetrain for damage estimation purpose, exhaustively simulating dynamic events like engine cyclic irregularities, gearwheel stiffness variations, gear shifts for different driver profiles, tire dynamics, and tire grip loss, is not addressed in the literature. Having regard to this, it is proposed here to develop and validate a non-linear drivetrain model for the damage prediction of the transmission gearwheels of a standard rear-wheel drive car equipped with a manual transmission. The focus is set on the possibility to perform qualitative and quantitative analyses of the impact of true-to-life load cases occurring during vehicle operation.

1.1. Overview of the proposed drivetrain model

A modeling based on motion equations is adopted, where the complete mechanical system is divided into suitable machine elements (e.g. shafts, gear stages) by means of mass/spring/damper elements [15,16]. The model is consequently tunable, so that it may be adapted or extended for other configurations. An overview of the modeling process is proposed in Fig. 1. Only the longitudinal vehicle dynamics and the torsional drivetrain behavior are considered, but all the mechanical parts are modeled separately. Concerning the transmission, the synchronization and clutch

* Corresponding author at: Institut für Mechatronische Systeme, Technische Universität Darmstadt, Germany.

E-mail address: foulard@ims.tu-darmstadt.de (S. Foulard).

http://dx.doi.org/10.1016/j.mechatronics.2015.06.008
0957-4158/

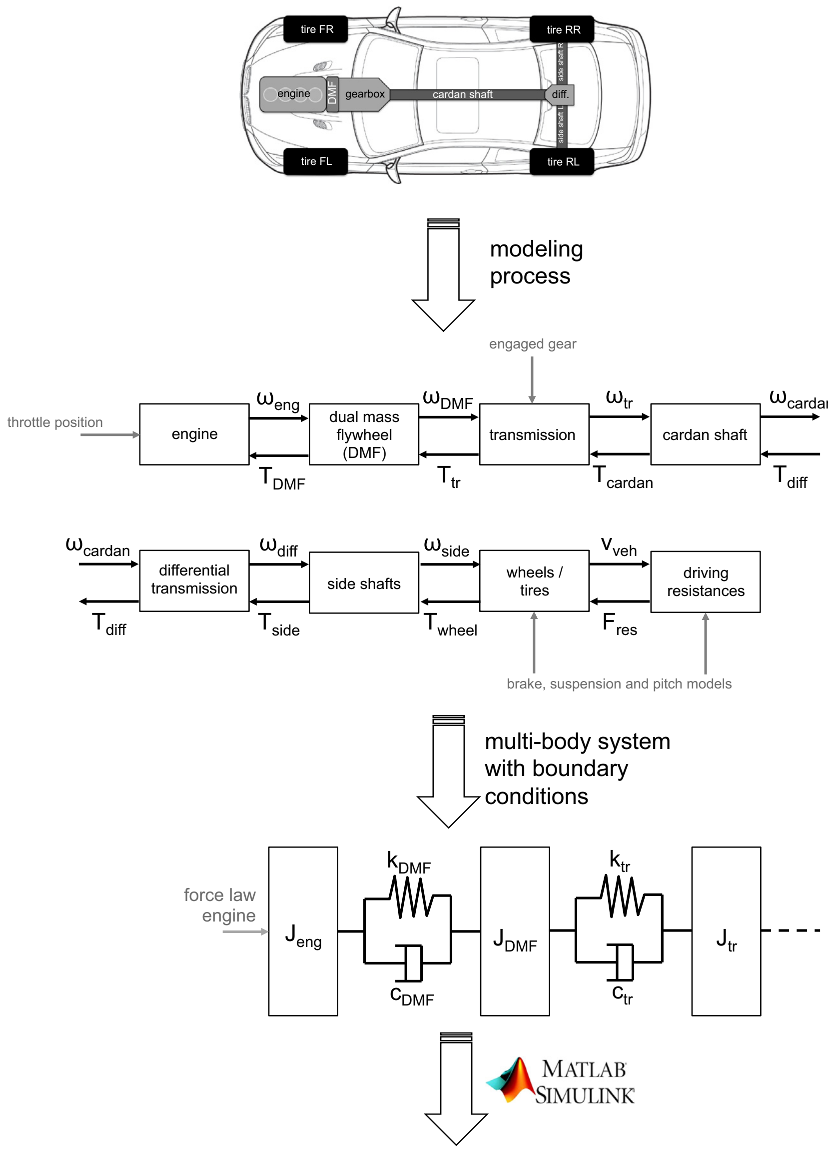

Fig. 1. Overview of the drivetrain power flow and the modeling process.

actuation are modeled according to [1,17]. The gearwheels are supposed to be ideal but the damping and the time-variation of the stiffness are taken into account [4,18,19]. An engine model provides the engine torque and the related cyclic irregularities [2,20]. A tire model with wheel load dependency and transient behavior provides for its part the longitudinal tire force [21–23]. The vertical wheel load is computed with a suspension model coupled with a pitch model [15,16].

A tunable driver model computes the driving inputs [3], and driving cycles deliver the speed target [24,25]. The selected gear is determined by consulting a gear shift schedule and a state chart defines the logic of the shift process. The proposed driver model is able to manage start-up and stop sequences.

The damage prediction refers to commonly spread industry procedures and relies on the combination of the Revolutions At Level counting method (RAL) and the damage accumulation method according to Miner–Haibach [26–28].

A model overview and the inter-dependencies between the subsystems is proposed in Fig. 2. The model is programmed modularly in MatLab® and its modules Simulink/Stateflow, so that extensions and modifications are easily manageable. A Simulink model is a sequence of blocks giving a visual representation of the model subsystems. Stateflow is an environment integrated in Simulink for representing sequential decision logic by means of state charts. The gear shift sequences are implemented in this environment.

The drivetrain model, including the engine and tire models, is presented in Section 2. The driver model is approached in Section 3. The damage calculation process is explained in Section 4. Section 5 deals with the model validation, where temporal and frequency analyses are proposed. Perspectives & conclusion are addressed at the end of the paper.

2. Drivetrain modeling

For comprehension purpose, the model description follows the kinematic chain, starting from the engine (Fig. 2, middle line). The engine model is addressed in Section 2.1. The multi-body system, regrouping the clutch, transmission, cardan shaft, differential transmission and side shafts, is developed from Sections 2.2–2.4. The tire and suspension & pitch models are presented in Section 2.5. The focus is set on the model specificities, which are