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Virtual Prototyping of Electric Vehicle Powertrain Using Multibody Dynamics and Spline-Based Motor Models

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Abstract: This paper presents the development and validation of a multibody dynamics (MBD) model for the VW e-Up Boost electric vehicle using Adams/Car software. The study focuses on modeling the vehicle's powertrain system, which includes a front-mounted electric motor and two rear Emrax 288 electric motors. The powertrain model utilizes spline-based torque characteristics to accurately represent electric motor behaviour. A three-level modeling approach (template, subsystem, and assembly) is implemented to create a comprehensive vehicle simulation environment. The vehicle model incorporates a modified suspension system with MacPherson struts at both front and rear axles. The electric motor model consists of stator and rotor components connected by a revolute joint, with torque computed using state variables based on motor speed and pedal position. The model's validity is demonstrated through straight-line acceleration simulations from 10 km/h initial velocity with 80% pedal depression. Results show the dynamic behaviour of powertrain components including rotor angular velocities and motor torques. The developed MBD model provides a valuable tool for virtual testing and optimization of electric vehicle components, enabling evaluation of performance characteristics without physical prototypes.

Keywords: Adams/Car; VW E-up Boost; Electric motor; Powertrain

1. Introduction

Simulations play a key role in the modern vehicle development process [1,2]. They enable virtual testing of functionality, reliability, and safety of components before their physical production. Thanks to simulations, development time can be significantly shortened, prototype costs reduced, and design optimization improved. An additional advantage is the ability to test extreme operating conditions and various configurations without the risk of damaging real components. Simulation tools thus enhance the quality and innovation of the final product.

VW e-Up! (Fig. 1a) was one of the first affordably priced electric vehicles from Volkswagen [6], designed primarily for urban operation with compact dimensions and sufficient range for everyday use. The front suspension utilizes an independent MacPherson strut suspension. The rear axle features a torsion beam axle. The front suspension is equipped with an anti-roll bar. Both front and rear suspensions are fitted with helical coil springs and shock absorbers. The electric motor is mounted at the front side of vehicle and drives the front axle.

The VW e-Up Boost (Fig. 1b) represents a modified sport model. The vehicle is equipped with an identical front suspension. Rear suspension, the torsion beam has been replaced with a MacPherson strut suspension [8,9], a rear anti-roll bar has been added,

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along with drive shafts powered by two Emrax 288 electric motors [7], located in the rear section of the vehicle.

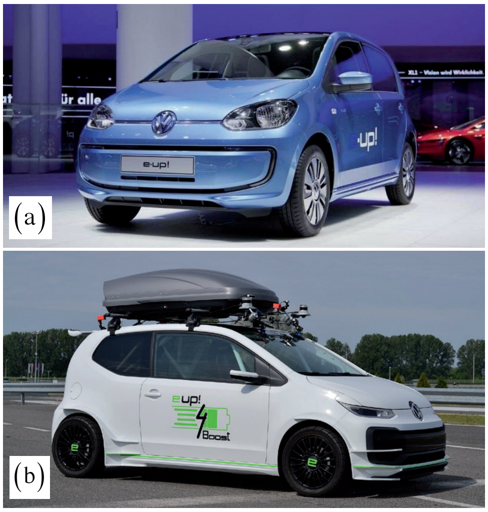

Figure 1: (a) Stock vehicle VW E-Up (b) Modified (sport) version VW E-Up Boost

Fig. 2 shows general diagram of drivetrain. Blue rectangle shows front section of the vehicle, which is same both for VW-Eup and VW-Eup Boost, red rectangle shows rear section of the vehicle, which is used only in VW-Eup Boost. Fig. 3 shows components of front section of vehicle which are used both in VW-Eup and VW-Eup Boost.

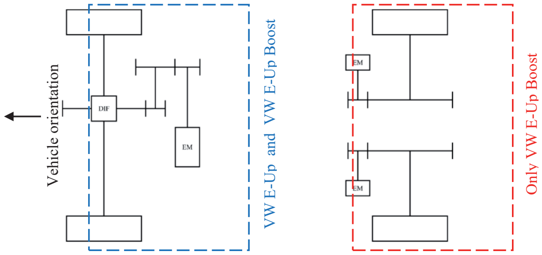

Figure 2: Vehicle powertrain diagram

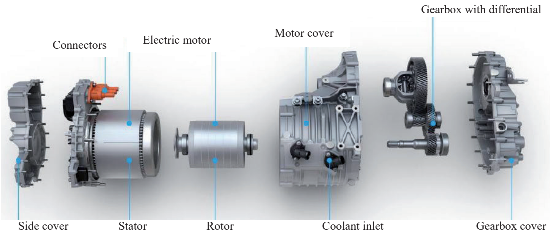

Figure 3: Front section of vehicle powertrain

2. MBD model of VW E-up Boost in Adams/Car

The Adams/Car program uses a three-level vehicle modeling system (Fig. 4) [1,2].

1. Template. Templates are parametric models that define topology of models. Basic property of every template is Major Role, which defines the functional part of the vehicle e.g. suspension, steering, ... Every template contains special model elements called communicators, which main role is exchanging data later in assembly.

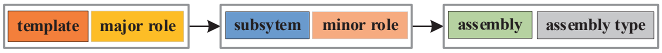

Figure 4: Three-level vehicle modeling system used in Adams/Car

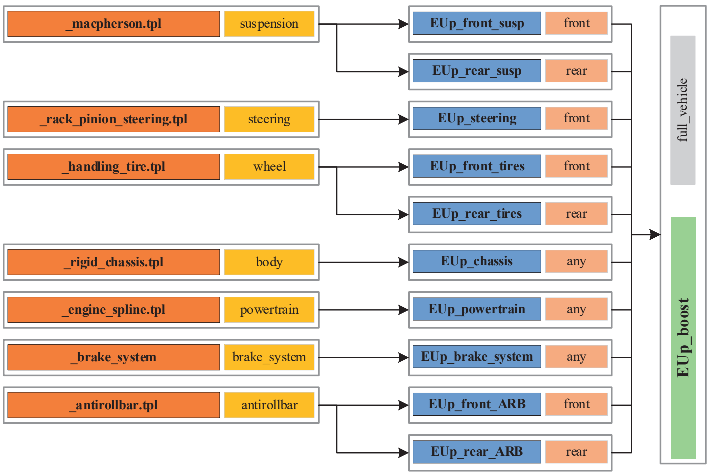

Figure 5: Block diagram of VW E-up Boost vehicle in Adams/Car

2. Subsystem. Subsystems are based on templates and allow users to change the parametric data of the template as well as the definition of some components. Basic property of every subsystem is Minor Role, which defines the functional area of the vehicle template.

3. An assembly represents a collection of subsystems, along with optional test rig, which when assembled forms a system that can be analysed and simulated using Adams/Solver.

Fig. 5 shows block diagram of vehicle. Full vehicle assembly of the vehicle contains 10 subsystems which are based on 7 templates. Assembly with necessary test rig can be simulated. In presented paper MDI_SDI test rig is used.

Fig. 6a shows MBD model of VW E-Up Boost created in Adams/Car. Model contains all necessary subsystems (Fig. 5). Fig. 6b shows same model only geometry of chassis (Subsystem *EUp_chassis* (Fig. 5) is hidden).

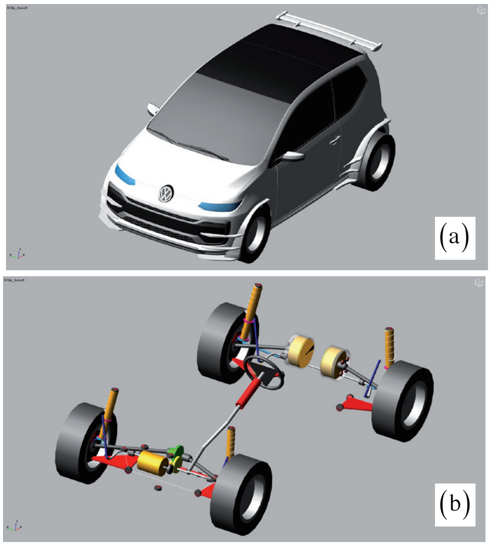

Figure 6: (a) Full vehicle MBD of VW Eup Boost (b) Same model with hidden chassis geometry

2.1. Spline model of electric motor

Fig. 7a shows general model electric model used in powertrain template (*engine_spline*) (Fig. 5):

It consists of two parts:

– *Stator*
– *Rotor*

Mutually connected with revolution joint. Stator is fixed to vehicle chassis by fixed joint or bushings. Moment acting between rotor and stator is modeled using point-torque actuator oriented in z-direction of the revolute joint. The value of torque acting on rotor is defined using state variable [3,4]. Steps to determine value of torque are shown in Fig. 7b.

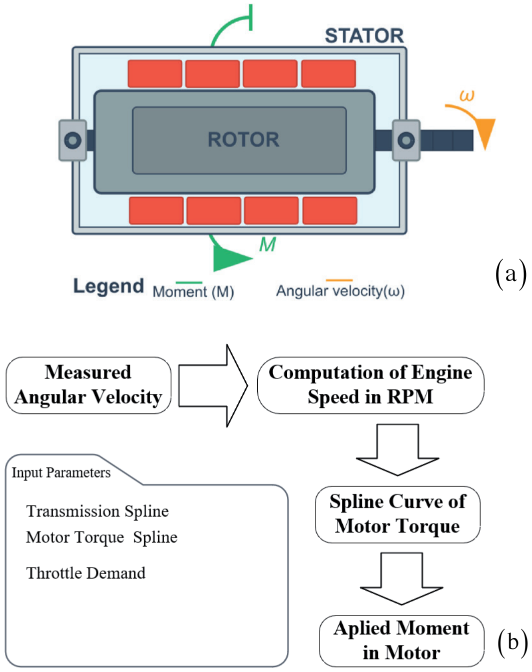

Figure 7: (a) General model of the electric motor (b) Steps of computation of the torque

2.2 Template of powertrain

Powertrain template of VW Eup Boost is based on diagram (fig 2), front part design (Fig.3).

Front section (Fig. 8a) contains 6 parts. Housing and stator parts are hidden. All revolute joints (Fig. 8a) are constrained to housing. Template contains two reduction gears (2 joint coupler), first reduction gear is defined between rotor with 1st gear and 2nd gear, second reduction gear is defined between 2nd gear and input of differential. Model contains one differential gear (3 joint coupler) between differential input and differential outputs.

Rear section (Fig. 8b) contains also 6 parts. Left and right stators, rotors and final gears. Revolute joints are defined between rotor and stator and between final gear and stator. Rear section contains also reduction gear (2 joint coupler) between rotor and final gear. Rear section is symmetrical.

Powertrain is based on same principle as in Fig. 7a and Fig. 7b:

1. Measured angular velocity: Measured velocity is obtained using Adams subroutine 1004.0: 1004.0(IPart marker, JPart marker, RPart marker,Wheel forces). Reason for using subroutine is because subroutine can correctly compute angular velocities both in static and dynamic analysis.

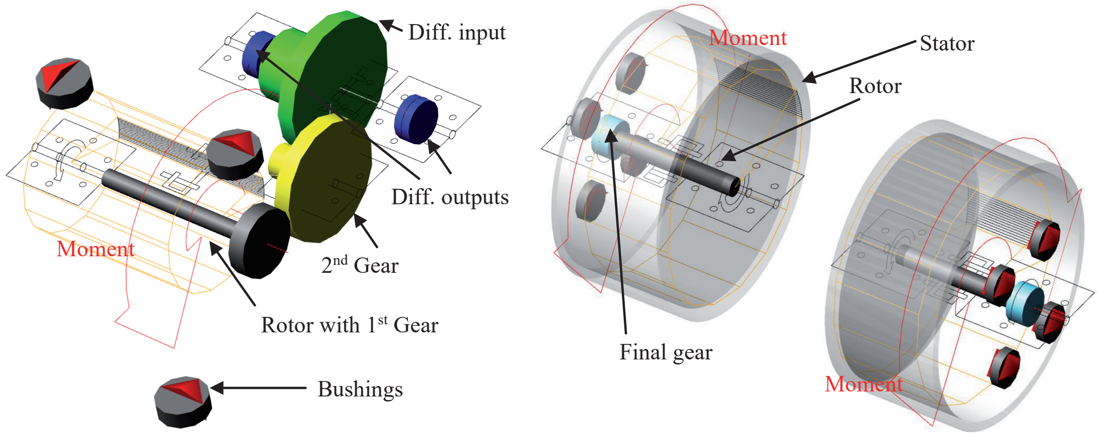

Figure 8: (a) Front section of powertrain template (b) Rear section of powertrain template

2. Measured angular velocity is converted to RPM.

3. Torque is determined using AKISPLINE function: AKISPL(motor rpm, throttle demand, torque spline)

4. Moment is applied to Point-Torque Actuator.

Fig. 9a shows data used for creating spline models of front electric motor, fig 9b shows data used for creating spline models of rear electric motors.

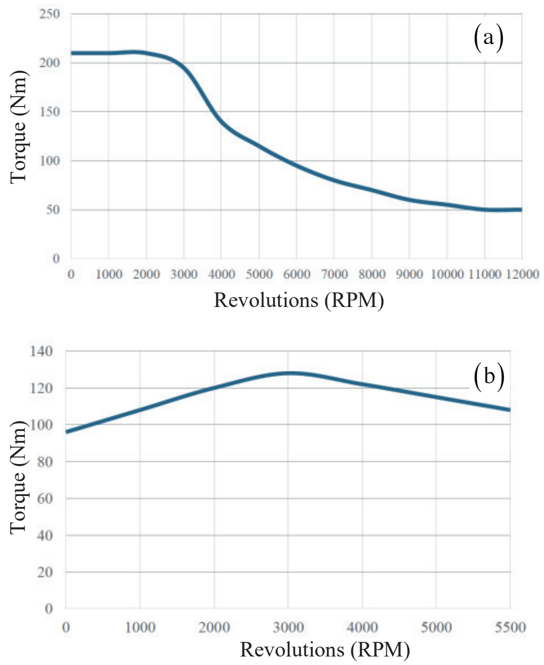

Figure 9: (a) Front motor (b) Rear motors

3. Simulation of driving event

For verification and testing straight line acceleration was carried out.

Setup of event was as follows:

- *Length of simulation: 10 s.*
- *Initial velocity of vehicle:10 km/h.*
- *After 1 second of simulation, acceleration pedal is pressed in 2 seconds to 80% value.*
- *Vehicle is maintained in straight line.*
- *Road is straight, planar modeled as 3D spline.*

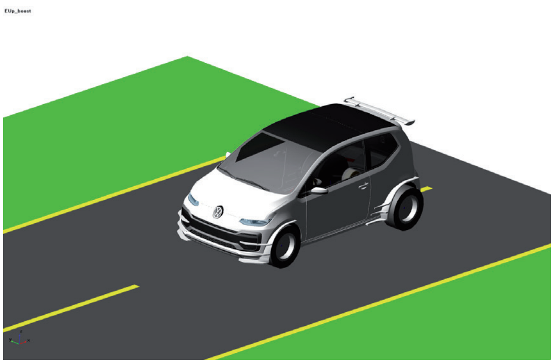

Figure 10: Straight line acceleration event

2.3 Results of simulation

Fig. 11 illustrates the gas pedal depression profile. The graph shows the depression starting at 1 second and reaching the set value of 80% at 3 seconds.

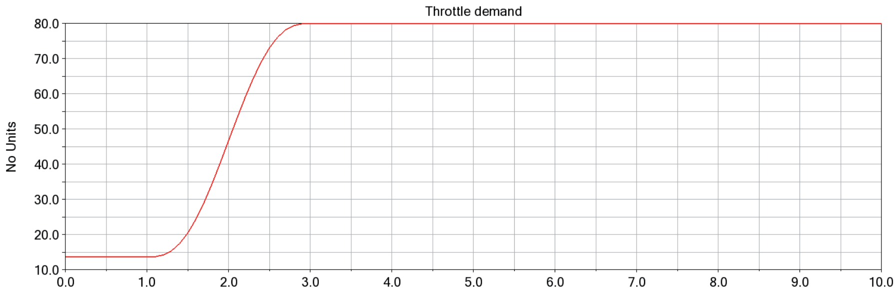

Figure 11: Progression of acceleration pedal depression

Fig. 12 shows longitudinal velocity of vehicle.

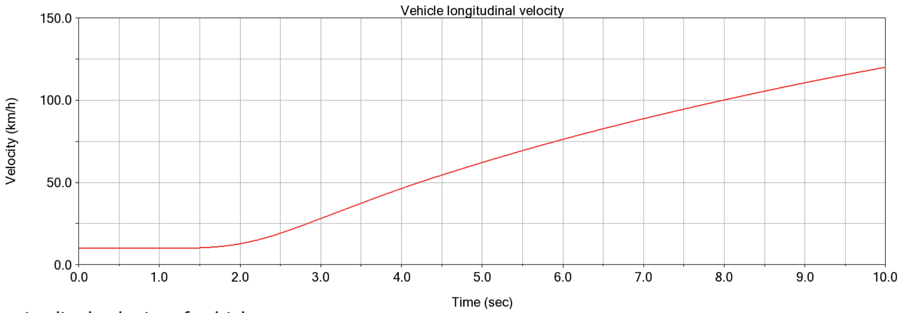

Figure 12: Longitudinal velocity of vehicle

Fig. 13 shows angular velocities of each vehicle rotor, Fig. 14 shows computed torque used in spline modes of electric motors. Rear left and rear right motor has same values of angular velocities and torque because vehicle is moving in straight line.

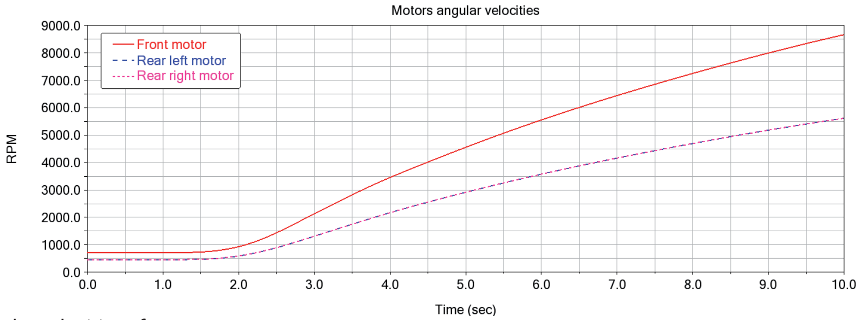

Figure 13: Angular velocities of rotors

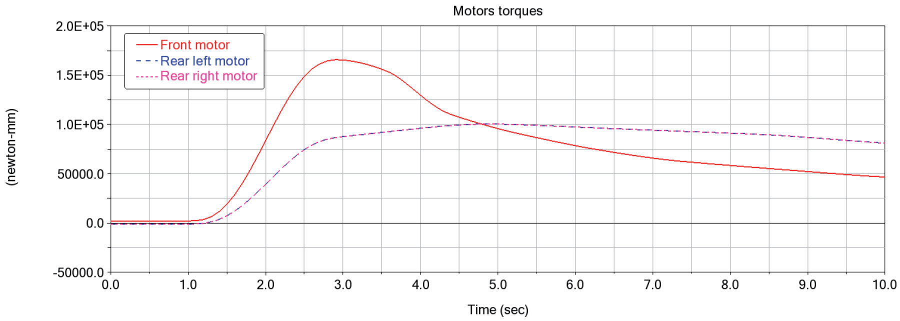

Figure 14: Torques in motors

4. Conclusions

This paper successfully demonstrated the development and validation of a comprehensive multibody dynamics model for the VW e-Up Boost electric vehicle using Adams/Car software [1,2]. The three-level modeling approach (template, subsystem, and assembly) provided a structured framework for creating an accurate and flexible vehicle simulation environment.

The key achievements of this work include the implementation of spline-based electric motor models that accurately capture the torque characteristics of both the front-mounted motor and the two rear Emrax 288 motors [7].

Simulation results from the straight-line acceleration event validated the model's capability to predict dynamic powertrain behaviour [3,5]. The model accurately computed rotor angular velocities and motor torque under realistic driving conditions, demonstrating its utility for virtual testing and optimization of electric vehicle components. The ability to test vehicle performance without physical prototypes offers substantial benefits in terms of development time and cost reduction.

The developed MBD model serves as a valuable tool for future research and development activities, enabling comprehensive evaluation of design modifications and performance optimization strategies for electric vehicle powertrains.

Acknowledgments

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