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Modelica Usage in Automotive Problems at Chalmers.

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Modelica Usage in Automotive Problems at Chalmers

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Abstract

Modelica, and previously Dymola, has been used at Chalmers University of Technology, at Machine & Vehicle Design (MVD) and at Control & Automation Laboratory (CAL), for automotive engineering research for some years, 1995-2000. Primarily it has been used for automotive powertrain engineering, both fuel consumption and emissions analyses and faster transients, like take-offs, gearshifts, shunt and shuffle etc.

The paper presents the basic motives for equation oriented modelling at Chalmers, both in research projects as well as in undergraduate/graduate education.

The paper also gives an introduction to some of the present research projects involving Modelica. The research projects includes mainly powertrain modelling of both conventional powertrains as well as hybrid powertrains. The paper tries to point out how Modelica have been used and what future use that could been foreseen.

In undergraduate teaching Modelica/Dymola has been used for studying vehicle handling and will be introduced in modelling courses at CAL this winter.

1 Introduction

In the beginning of the 1990's, dynamic modelling of powertrains was applied in several projects at Chalmers University of Technology, especially at MVD. Models including dry friction, planetary gear trains and engine where used for simulating transient vehicle manoeuvres, power shifts and take-offs. The models where then typically coded in ACSL and Simulink formats.

A lot of effort was put into idealized models for improved computational efficiency and simple models for enhanced understanding. Examples of such idealizations where rotating inertias, rigidly connected by planetary gear trains, ideal sticking/slipping dry friction clutches and connection of turbo machineries directly at a base engine, without any gas volumes in between.

The models implemented in ACSL and Simulink became very dedicated and parts of the models where very difficult to reuse. When a project started, aiming for design of a modular simulation tool for vehicle propulsion, the need for reusable models was even more outspoken. At the same time, Dymola became more userfriendly, even if the first versions tried, didn't included any graphic model editor at all. Anyway, the potential for designing a *model library* with a high degree of *reusability* was predicted in this project, see [2], which led to the decision to go for the Dymola path. The motives can be concluded as in Figure 1, where the overall requirement on *efficient modelling* is fulfilled by *reuse of models*.

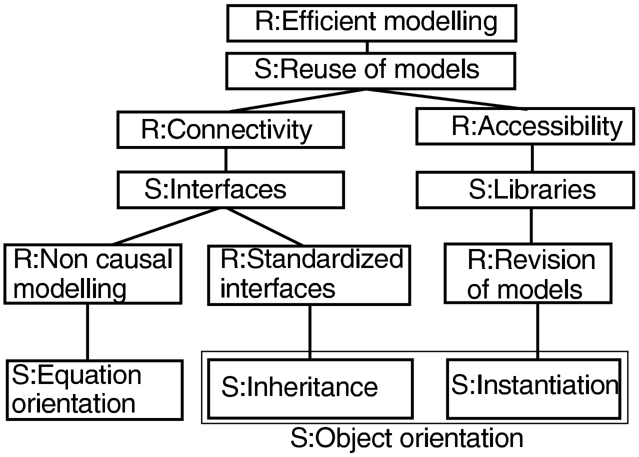

Figure 1: Requirements (R) and solutions (S) in a tool for modeling.

Today, there are mainly two research projects in the automotive area using Modelica regularly at Chalmers University of Technology.

The first project is called Integrated Powertrain Control, (IPC). This research project aims at finding new efficient concepts for integrated powertrain control. The project is motivated by the potential benefits in using computerization in combination with modern control techniques. The goal is to improve driveability, driving comfort and economy, as well as to reduce the environmental impact of driving. The activities focuses on dynamical characterization of complete powertrains and nonlinear control techniques. Important parts of these investigations are dynamical modelling/simulation. The project is carried out as a cooperation between MVD and CAL at Chalmers University of Technology and Volvo.

The second research project concerns configurations and simulations of vehicles with alternative powertrains. The project tries to answer questions like; Under which circumstances are hybrid powertrains profitable? How should the components in a such a system be sized and arranged? Typical vehicle characteristica of concern are fuel consumption, emissions and component cost for vehicles in city traffic. The project is a cooperation between MVD and Volvo Bus Corporation.

2 Engine Modelling

In the IPC project a powertrain component library has been developed. The purpose with the developed library is to make it easy to create and simulate different powertrain structures, passenger cars as well as heavy-duty vehicles. The library is still under construction.

The keyword when constructing such a library is reusable models, since many components can be used independently of the powertrain configuration. Only a scaling factor is necessary. For instance, it does not matter if a volume is part of a heavy-duty diesel engine or part of a small otto engine. The main problem is to choose an appropriate connector structure suitable for both types of engines, see [8] for a discussion of connectors in thermodynamical systems.

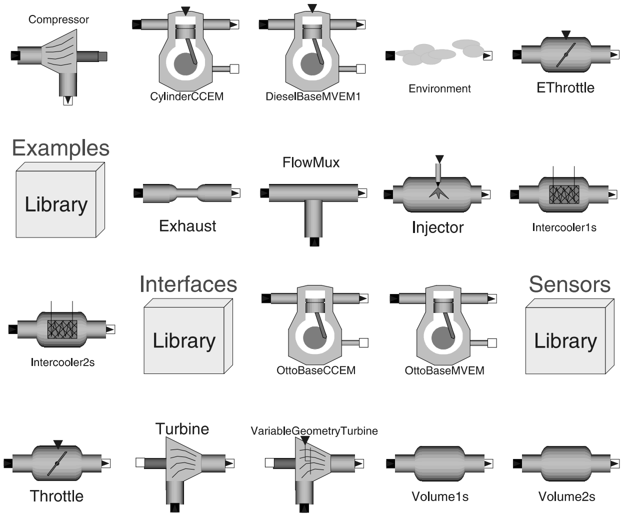

Figure 2: Engine component library.

Each component represents a physical object, such as a volume or a compressor. The engine component library is shown in Figure 2. The models are simple, but capture the main characteristics of the individual powertrain components. The component models developed are based on physical laws as far as possible. Though, some of the models are empirical due to complexity, such as the models for the compressor, turbine and the combustion chamber. So far the library includes mean value engine models for diesel and otto engines, see [3] and [6] respectively, and a crank angle based otto engine, see [6]. A crank angle based diesel engine is under development.

The developed powertrain library is compatible with other Modelica libraries, such as Modelica Standard Library for rotational dynamics.

By connecting the components it is possible to configure different engine or powertrain structures. See Figure 3 for a model of a turbocharged diesel engine with a variable geometry turbine. Combining the engine model together with some of the models in the rotational dynamics library it is possible to form a complete powertrain model for longitudinal dynamics, see Figure 4.

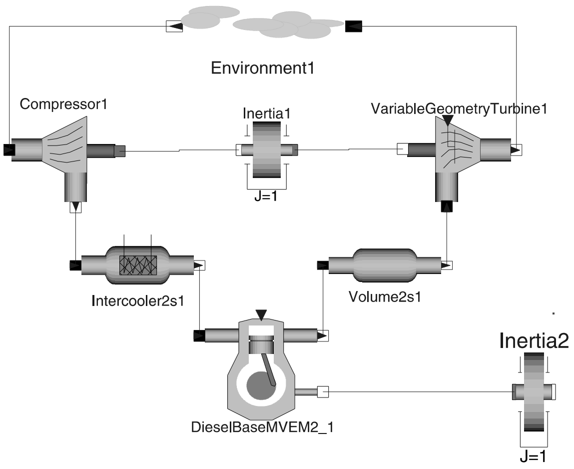

Figure 3: Turbocharged Diesel Engine in Dymola.

The powertrain models developed in Modelica for the IPC project are mostly used for evaluation of control algorithms and to give a better understanding of the complex world of automotive engineering. Applications studied so far are control of powertrain oscillations and gearshifting of an automated manual transmission, see e.g. [3]. Other applications studied are optimal control of otto engines for high frequency engine torque control, see [5]. For most of these applications the control algorithms were developed based on simplified models and evaluated on more complex models in Modelica/Dymola.

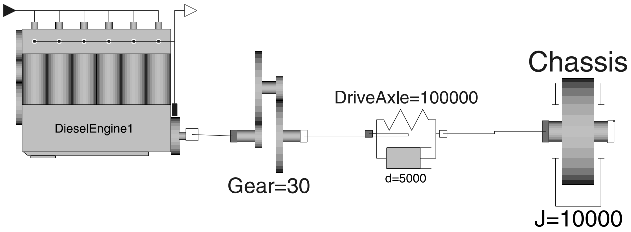

Figure 4: Powertrain model.

Typical transients studies lasts for a couple of seconds. See Figure 5 for a typical transient, the figure shows the engine speed and the engine torque during a gearshift of an automated manual transmission.

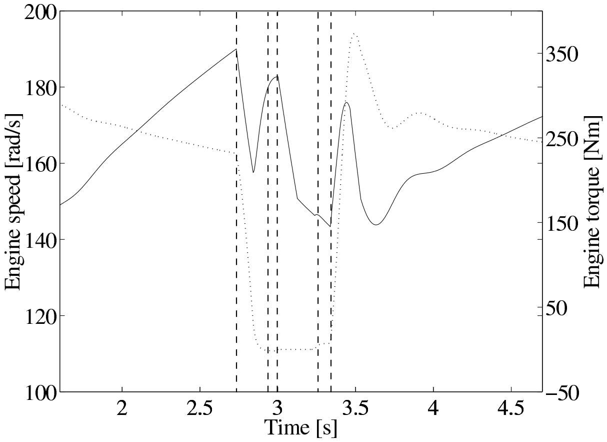

Figure 5: Engine speed (solid line) and engine torque (dotted line) during a gearshift of an automated manual transmission.

3 Alternative Powertrain Modelling

This section is divided into two parts, the first part concerns the research project on configuration and simulation of alternative powertrains. The second part is from an on-going master thesis work dealing with control of a parallel hybrid powertrain configuration during a start sequence.

3.1 Configuration of powertrain

The fundamental problem in the alternative powertrain project is to find the best powertrain for certain transport tasks. The questions are, basically, to find an appropriate configuration (e.g. series, split or parallel hybrid), sizing (e.g. power of ICE) and a control strategy for the specific transport task (e.g. on/off strategy or load-following strategy). An optimization method, based on genetic algorithms is developed. It is called Driveline Synthesis (DS) and described in [4]. The aim of making Modelica models of Hybrid Electric Vehicles (HEV) is to get a deeper understanding of HEV:s and to verify DS. By comparing simulations made in Modelica, based on accurate and verified models of components, with simulations in DS, based on simpler models of components, the accuracy of DS can be estimated. Figure 6 shows the top level of an early series hybrid model in Modelica/Dymola. In the future, other types of powertrains will be implemented in Modelica, e.g. fuel cells, parallel hybrids and CVT configurations.

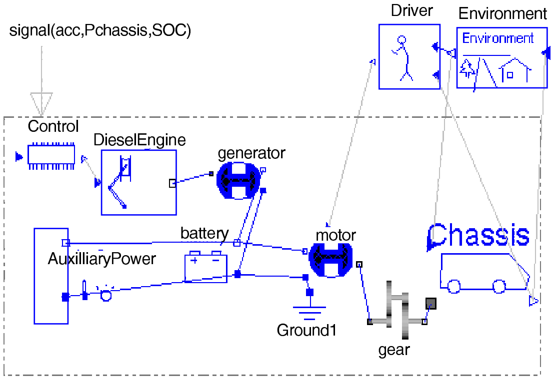

Figure 6: Top level view of model of series hybrid vehicle.

The simulations typically performed with the models are drive cycle simulations with parameter setting from DS. A drive cycle often covers some hundreds of seconds. Effort has been put into building model libraries also for these systems, e.g. including models of batteries, electric machines, super capacitors, etc.

3.2 Cranking of ICE for an Dual Shaft Parallel Hybrid

The objective with this work is to simulate and control the dynamic response of a parallel hybrid powertrain configuration during a start sequence. The work will be presented in [7]. The hybrid vehicle studied, starts from standing still using the electric motor. When steady state conditions is reached, the engine is started using a clutch to the electric motor. It is this start of the engine, which is in focus. The start of the prime mover can produce longitudinal jerk and clutch shuffle, which is to be avoided. The target variables when controlling the system during the start of the engine are longitudinal jerk and clutch shuffle.

To study the system, a model library is developed and implemented in Dymola. The library contains models for transmission, electric motor, conventional friction clutch, internal combustion engine, batteries and road load applied on the vehicle. It is important to point out that the internal combustion engine is to be simulated during starting conditions, which makes this specific model of considerable complexity. A system model is shown in Figure 7.

The cranking of the engine must be very fast due to two reasons. First, there might be situations when the driver asks for more power than the electric motor is able to produce. Then the engine must start to make it possible to produce the requested power. Secondly, the energy dissipation in the clutch would be too large if the cranking time where long. Typical time for the cranking is parts of a second.

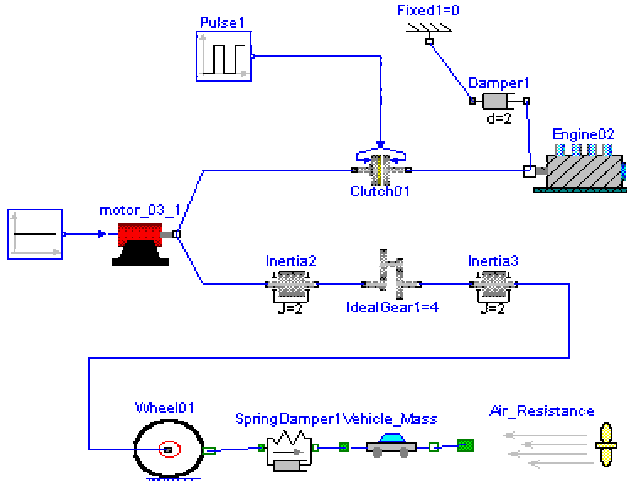

Figure 7: Dual shaft parallel hybrid vehicle model.

4 Vehicle Handling Modelling

In an undergraduate course in vehicle dynamics, Dymola has been used for studies of vehicle handling manoeuvres. By using the equation oriented way of describing the dynamics, the models can be very neatly implemented, which support the process of learning about the vehicle dynamics. Also, it is possible to make the models physically modular. Then more complex sets of vehicles can be studied, e.g. as shown in Figure 8. If such systems should be studied with ordinary block oriented simulation tools, each set of vehicles generate a DAE system, which requires a lot of algebraic manipulation before it can be translated into a block diagram.

The models where in some extent validated through tests with an experiment vehicle in the undergraduate course. The result is shown in Figure 9.

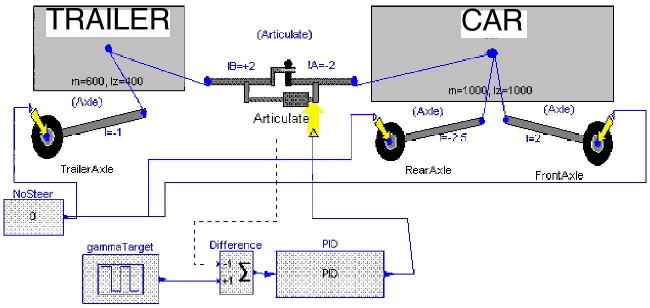

Figure 8: Handling model. Car with trailer connected by a force controlled articulated linkage. Each of the three wheel axles is steered.

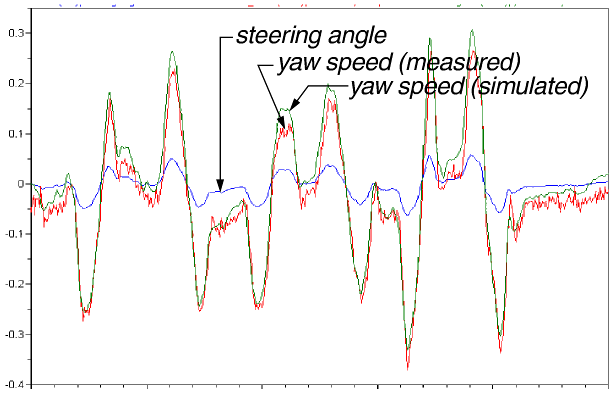

Figure 9: Plot of handling manoeuvre, several lane changes on plane ground.

5 Conclusions and Future work

In automotive engineering, simulations are used for concept evaluation of components, subsystems and complete vehicles. The overall driving force for using Modelica in such engineering areas is the reusability of the models. Modelica also makes it easy to change powertrain configurations and exchange models between project participants.

In the future the powertrain component library will be extended with models for complete vehicles, i.e. models for handling and comfort, alternative powertrains, etc. It will be important to stress compatibility between libraries and to create groups that can exchange models on an international basis. Important areas to develop the tool further are: optimization, control design support and system identification. Tight connections to other software, such as Simulink, is important. Connections to real time applications, Rapid Prototyping, HardWare-in-the-Loop and Human-in-the-Loop-Simulators, see e.g. [1], are extensions with great possibilities, especially for automotive engineering.

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