Modeling & Development of a Hydrostatic Hybrid Vehicle

Manufacturing 503 Report

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Executive Summary

During the summer of 1999 I worked as an intern at General Motors (GM) Research and Development (R&D) in Warren, Michigan. I participated in a team project that is part of a Cooperative Agreement between the US Government and GM. The overall intent of the project is to evaluate the potential of a hydrostatic powertrain in sport utility vehicles. A Chevrolet S-10 vehicle has been retrofitted to demonstrate the concept. Although my primary assignment in the team was powertrain modeling and software evaluation I also participated in prototype building on behalf of GM R&D.

In this report three parts of the projects I worked on are discussed; Retrofitting, component-level modeling and system-level modeling. Prototype building consumed twenty per cent of the project. The general framework of the Mfg. 503 summer internship project is described and some details are omitted due to the fact that they involved proprietary information of GM R&D, and Imagine, Inc., a software vendor.

The modeling approach is described. The combination of steady-state and dynamic tools for simulation was needed at the component and system level. By using the software product AMESim by Imagine, Inc., we were able to built a simulation that gives the designer information about the dynamic characteristics of the system, such as time delay, at the component and system level. A proprietary hybrid powertrain simulation program was used for steady-state simulation tests, such as fuel economy.
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Mfg. 503 Report

1.0 Introduction

Utilization of hydrostatic drives for power transmission along with hydropneumatic accumulator energy storage can provide significant opportunities for improvements in vehicle design. Research and development in this technology has primarily focused on fuel economy improvements. The accumulator permits the engine power to be uncoupled from the road load, thus enabling the engine to be operated at a more efficient point. By using wheel drive units that can operate as either motors (when driving) or pumps (when braking), regenerative braking can also be achieved, with the energy stored in the accumulator. Opportunities for size and weight reductions exist particularly by utilizing
an auxiliary hydrostatic drive unit for accessories such as the air conditioning compressor. The compact size of hydrostatic pump/motors and the relative ease of distributing the power permits significant design flexibility in locating the principle powertrain components.

2.0 Tasks

The primary tasks of the project were:

1. Retrofitting of an existing Hybrid Hydraulic Vehicle (HHV) concept. Components from a new supplier were installed and resulted in an improved overall system efficiency.

Three-member team was responsible for the completion of this part of the project: Arlene Smithson from the Environmental Protect Agency (EPA), Vimesh Patel from the General Motors Powertrain (GMPT) division and the author from General Motors Research & Development (GM R&D) center.

2. Evaluation of AMESim, a simulation software capable to capture dynamic properties of the various subsystems/components of the system. The evaluation included data gathering and modeling.
Two-member team was responsible for this part of the project: Frederic Brix from Imagine Inc., and the author from GM R&D.

3. Utilization of a proprietary hybrid powertrain simulation program (HPSP) by GM R&D for system level modeling of the powertrain.

Two-member team was responsible for this part of the project. Trudy Weber and the author from GM R&D. Chris Mader was the supervisor of this project from GM R&D.

**FIGURE 1.**

Project organization

### 3.0 **Retrofit**

The main components of the powertrain are as follows.

1. High pressure accumulator.
2. Low press accumulator.

3. Front motor/pump.

4. Rear motor/pump.

5. Engine/pump.

6. Valve body.

7. Engine.

The hydraulic system layout and the component specifications represent proprietary information of GM R&D and cannot be included in this report.
The following tasks were executed throughout the retrofit process:

1. Repositioning of accumulators.

2. Installment of new motors/pumps.

3. Installment of valve body.

4. Packaging of valve body and the two motor/pumps.

5. Connectivity among the (a) high pressure accumulator, (b) low press accumulator, (c) front motor/pump, (d) rear motor/pump, (e) engine/pump, (f) valve body and the (g) engine.

FIGURE 3. Components of HHV mule.
Primary goal of the prototype building was to prepare the vehicle for fuel economy tests. If this concept is adopted for mass production, packaging engineers will redesign the layout of the powertrain.

4.0 Component level modeling

4.1 Data

Data for the following components were available from the Environmental Protect Agency,

(a) Engine Pump

(b) Motor pump

(c) Valves

However, the available data for the two motor/pumps was taken prior the retrofitting. Data for the newly replaced motor/pumps were not available. As a conclusion the engine pump data was used for modeling. The modeling approach follows.

4.2 Modeling

The following modeling procedure was used.
(a) Identify trends and validate data through input-output (i/o) formulations.

(b) If data proved to be valid, import the map to AMESim.

This procedure is illustrated by using the engine pump data as an example. The available data included volumetric and mechanical efficiencies for different displacements, pressures, and engine operating speeds.

The mathematical models based on the i/o formulations are proprietary information of Imagine, Inc., and GM R&D and cannot be included in this report.

A physics-based i/o formulation based on Bond Graph theory was derived. By using the derived formulation, substitution of data and plotting followed. In Figure 4 plots for the mechanical and volumetric efficiencies are depicted. For higher displacements (100 and 82.9%) we recognize that we don’t have the same trends for all pressures. In the other hand for lower displacements (66.5, 40.7, 25.3 and 11.5) the trends are approximately the same.

For example, let’s compare the plot for displacement 11.5% and the displacement for 100%. We recognize that for displacement
11.5% all the lines are decaying as the pressure increases. In the other hand for displacement 100% one can see that one line is ascending as the pressure increases and other is descending. As a result, the validity of the data for higher displacements is under question.

FIGURE 4.
Trends derived from an input-output formulation based on data from the Engine-Pump
The next step was to process the data in MATLAB and converted in AMESim format. AMESim proved to have difficulties in importing 4th dimensional data. In figure 5 the engine pump map is depicted.

ENGINE PUMP - Mechanical Efficiency

![Mechanical Efficiency Graph](image)

ENGINE PUMP - Volumetric Efficiency

![Volumetric Efficiency Graph](image)

**FIGURE 5.** Engine pump map
The following models developed with AMESim:

(a) a leakage model that analyses the losses in the engine pump,

(b) a valve body model using the pressures drop data for each valve.

Additionally an engine and pump/motor model that were developed from Imagine Inc. have been added to the simulation. Description of AMESim follows.

4.3 AMESim

The following capabilities are differentiating AMESim from other simulation software:

(a) Each module has multiple input/output ports.

(b) The ability to model the connectivity of the system.

(c) The interfaces among hydraulic/pneumatic/mechanical/electrical components.

(d) The graphical representation of the modules.

(e) The ability to simulate a system in the component level.
In Figure 6 a hydraulic/mechanical system is depicted. Each module, i.e., pump/motor, etc., is represented by an i/o “black box” representation of multiple ports. These modules are intelligent. They do not allow the user to connect them with other components where the transformation energy is not compatible. This is a beneficial feature in electromechanical systems where the connectivity of the system is not trivial.

FIGURE 6. Multiport approach
In Figure 7 a powertrain is depicted. Here we have two user-created modules, the valve body and the engine. The option of creating multiport modules is available to the user as well. Also, AMESim incorporates different levels of modeling the connectivity of the system. Finally the system deals with four interfaces -- pneumatic, hydraulic, electrical and mechanical.

FIGURE 7. Interfaces among hydraulic/mechanical/electrical/pneumatic components

One of the major advantages of AMESim is its approach to handling discontinuities and nonlinearities. First, it monitors the characteristics of the equation, it then detects the numerical difficulties, and finally it switches among the seventeen different
methods for handling differential equations (ordinary and algebraic).

AMESim has been built in such way that it can analyze both the steady-state and the dynamic behavior at the system and component level. As a result the user can also simulate the control design of the system by building a single model.

4.4 Evaluation

AMESim proved to be user-friendly, well documented and well supported from Imagine Inc., engineers. The basic advantage of this modeling tool is that it can utilize kinds of data at various levels of the system hierarchy. The fact that it includes seventeen different integrators and the way that handles nonlinearities and discontinuities makes it a powerful analysis tool.

AMESim proved to be “immature” in the vehicle design simulation. To date it has been used primarily for hydraulic applications. Imagine Inc., made commitment to compensate this deficiency by offering additional support at a consulting level.
The author proposed the purchase of this product to the management and the software was acquired by GM at the conclusion of this project.

5.0 System level modeling

An input/output simulation of the vehicle prior to the retrofitting phase was developed in the HPSP. This software is appropriate for fuel economy estimations.

HPSP will be used for steady-state system-level simulation and AMESim for dynamic component-level modeling and simulation.

A procedure that guides the user how to import data in HPSP has been written by the author. Any additional data from the retrofitted vehicle will be added to HPSP using this procedure.

All the information related to HPSP is proprietary information of GM R&D and cannot be included in this report.

6.0 Conclusions

The opportunity to participate in two parts of this project, the actual development of the hardware (retrofitting) and the modeling part through AMESim evaluation gave the author a complete
sense of vehicle development process. This was especially beneficial, due to the fact that the author intends to use powertrain models in his future research.

From Mfg. 503' perspective the author feels that has fulfilled its mission. He worked with six engineers in this project that they all have diverse backgrounds. Moreover the hardware part of the project made him familiar with prototyping building that is an essential stage from a manufacturing perspective.