2012

Hydraulic Drivetrain and Regenerative Braking

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Abstract

Since their development in 2006, hydraulic drivetrain systems have gained considerable attention as a result of their high efficiencies. However, due to size and weight constraints, their application has been exclusively for large trucks and commercial vehicles. Our senior design project investigates the use of hydraulic drivetrains on small-scale vehicles. We have established two main project goals: 1) to create a working model of a hydraulic system on a go-kart, and 2) to assess the efficiency of our hydraulic system in relation to other mechanical and hybrid drivetrains. As with many hydraulic drivetrain systems, our model incorporates regenerative braking in order to further improve efficiency values. The main components of the model include an electric motor, hydraulic pump, hydraulic motor and two 1.5 gallon accumulators. The present document describes the motivation, design, and analysis of our hydraulic drivetrain system.

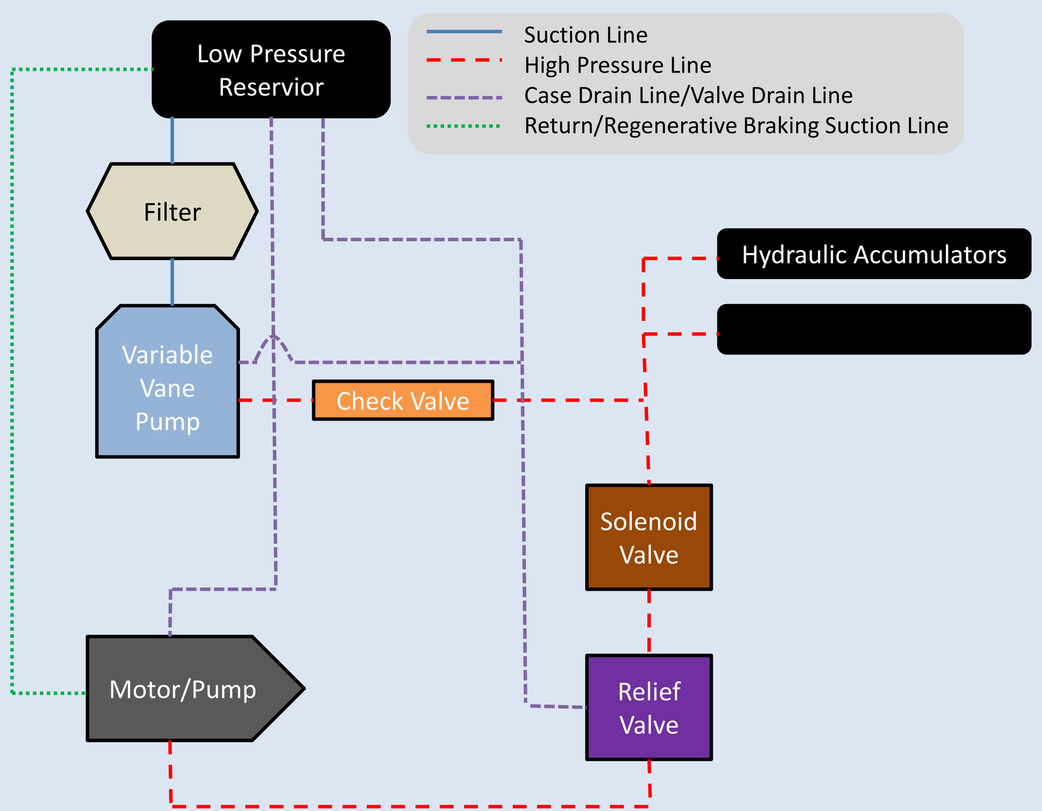
System Description

Decoupled Drivetrain – Unlike mechanical drivetrains, our system features no direct mechanical linkage between the power source and the wheels. Instead, the power source serves to charge the hydraulic accumulators. The motivation behind this design draws from the notable efficiency losses that combustion engines experience at non-optimal speeds. By decoupling the power source from the wheels, the power source can be operated periodically and at its most efficient power output, substantially reducing system losses.

Regenerative Braking – Our system incorporates a hydraulic regenerative braking system capable of capturing 24.7% of otherwise lost kinetic energy. The benefit to using hydraulics over electronics (batteries) for regenerative braking is that the charge rates associated with hydraulics are not limited by the storage device (accumulators), unlike current electronic systems.

Control System – The system is controlled by a lever to the left of the operator that can be rotated forward or backwards. The lever controls the swashplate angle of the variable piston motor/pump which controls the flow direction and rate. When the user pushes the throttle button, the one-way solenoid opens and allows flow to the hydraulic motor. The variable swashplate allows for infinite control of the motor's torque output. To brake and regenerate energy, the operator must simply pull the lever backwards which reverses the swashplate angle, reversing the flow. Reversing is achieved by pressing the throttle button in the back position.

System Schematic



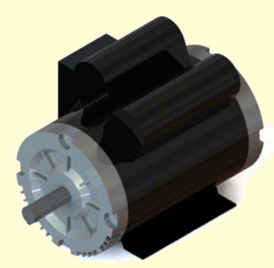
Testing Results

Braking Efficiency (% kinetic energy recovered)	24.73%
Drivetrain Efficiency	67.02%
Overall Efficiency	53.47%

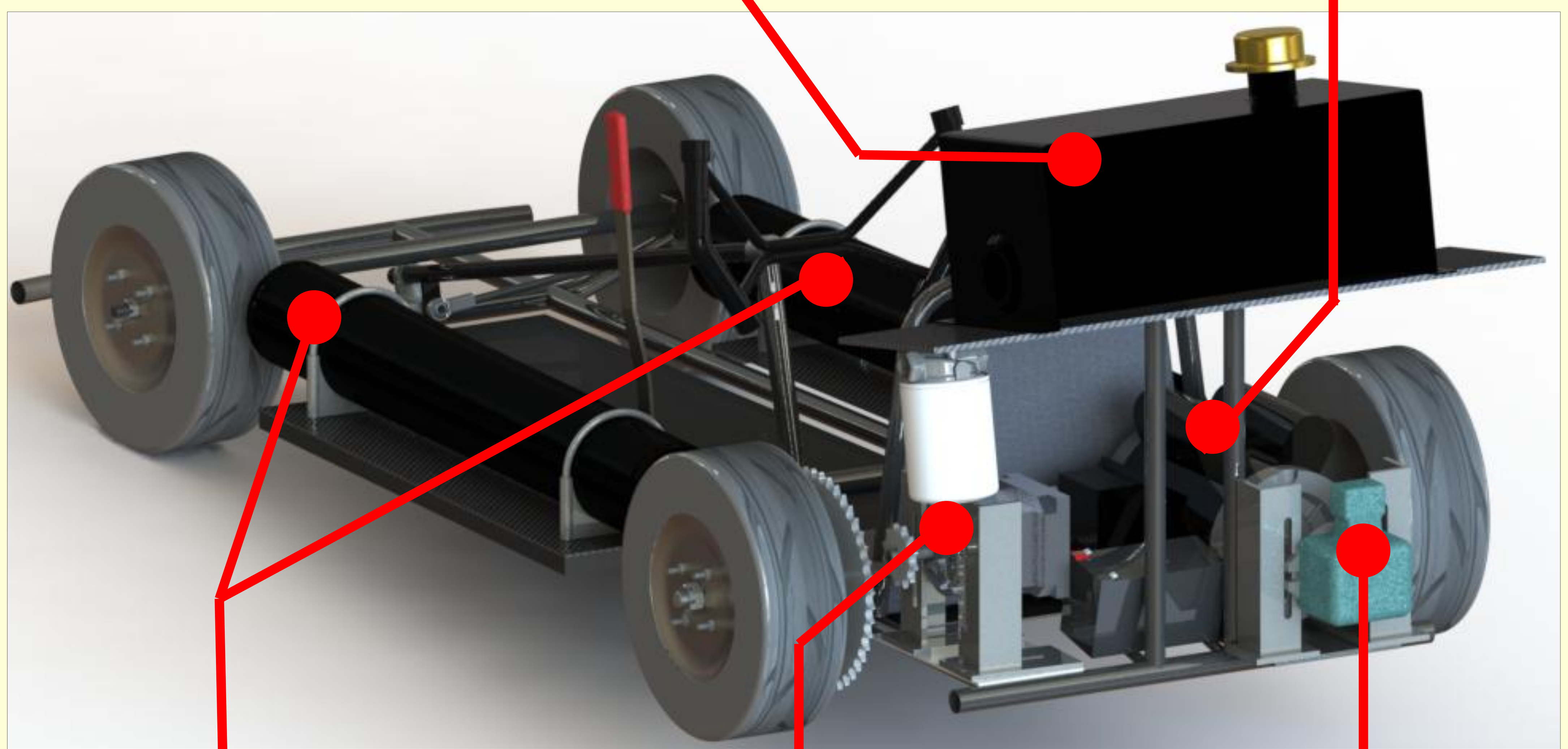
Current Electric Hybrid

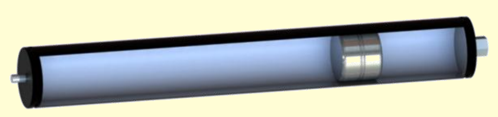
Electric Hybrid overall efficiency	75% (highway) 50.79% (city)

Reservoir: Stores hydraulic fluid at low pressure

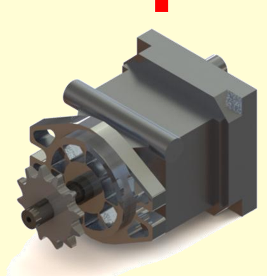


Electric Motor: Provides rotational energy to the hydraulic drivetrain

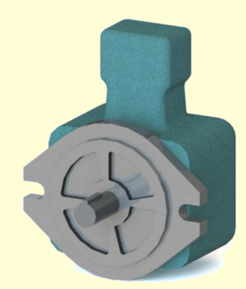




Accumulator: Stores high pressure fluid through energy captured from regenerative braking as well as excess energy produced by the engine

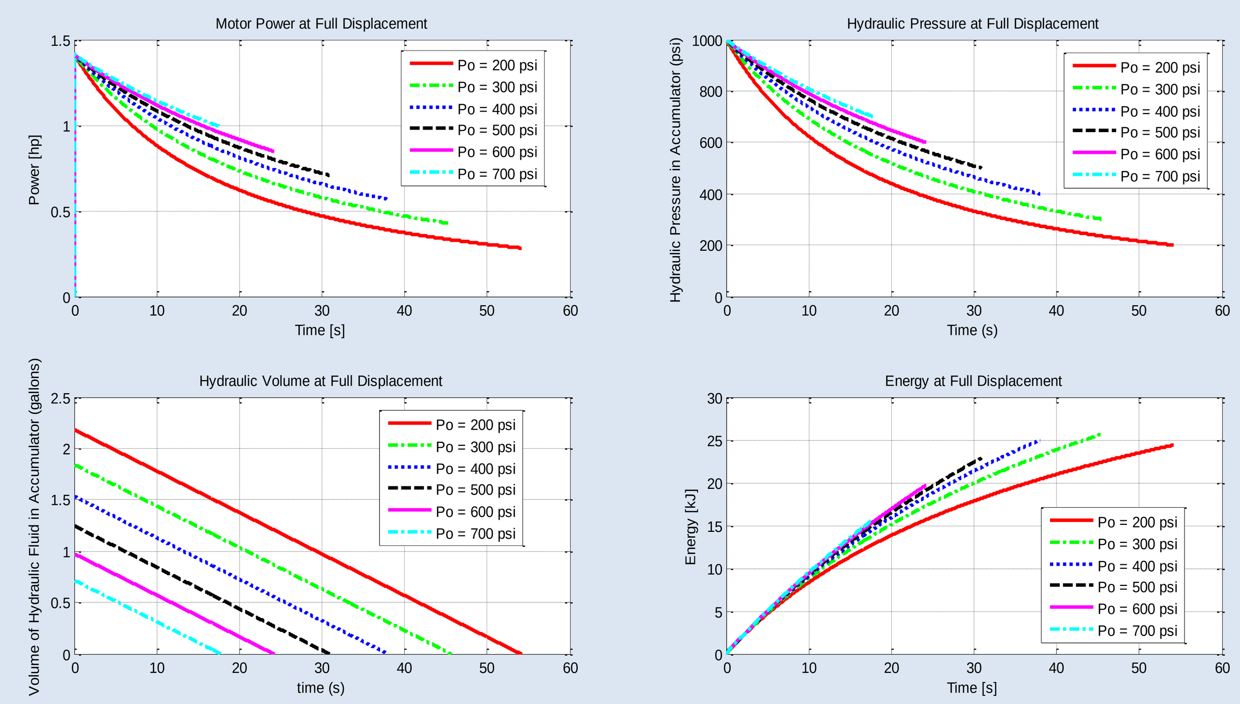


Variable Piston Motor/Pump: Converts high pressure fluid flow to rotational energy to drive wheels; also converts kinetic of the go-kart to high pressure fluid flow during regenerative braking



Variable Vane Pump: Converts rotational energy to high pressure hydraulic fluid flow

Accumulator Simulation



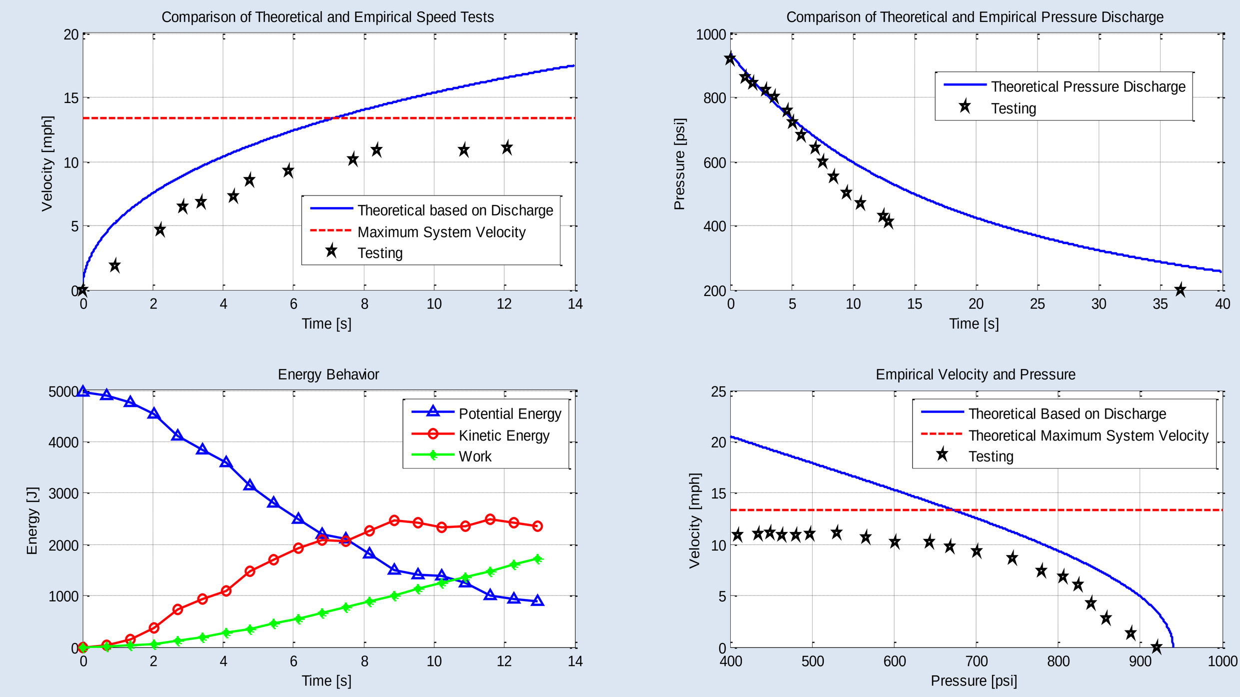
Relevant Equations

$pV^{\gamma} = constant$

$T = p * displacement$

$Power = T * \omega$

Validation



Relevant Equations

$Work = C_{rr} * Distance * F_{normal}$

$PE + KE + Work = Initial\ Energy$

Future Plans and Potential

Our project and subsequent analysis, along with current state of the art vehicles, show a large amount of potential for hydraulic hybrids. Given that potential, many areas of improvement are advocated by the group:

Carbon Fiber Accumulators – Weight is at a premium on passenger vehicles, and the heaviest component of a hydraulic hybrid is the accumulator. Steel accumulators offer better performance currently due to their higher maximum pressure, but an effort to make these carbon fiber accumulators stronger would greatly improve the efficiency of the system.

Lightweight Components – Hydraulic components are often very heavy parts because there is often no advantage to producing lighter ones. With results of our and other concurrent projects, it is now obvious that engineering lightweight components could help revolutionize the hydraulic hybrid industry.

Turbines – Turbines are capable of high efficiencies, but only in a very narrow range of rotational speeds and loads. By powering our system with a turbine engine, it is possible to take advantage of the increased efficiency because the axle is decoupled from the engine in our system.

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