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HYBRID STEAM – GASOLINE ENGINE TEST STAND

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ABSTRACT

Internal combustion (IC) engines lose too much energy to waste heat. Water could be injected intermittent with fuel into an IC engine in order to utilize waste heat and improve efficiency. The resulting production of steam would make harvesting of excess heat possible. This project was created to provide the tools needed to understand the feasibility of such an engine. A test stand has been designed and built to make performance evaluation of a "hybrid" gasoline-steam engine possible. An existing IC engine will be slightly modified and used as an engine for benchmarking purposes. The test stand must incorporate instrumentation to control inputs and measure outputs of a "hybrid" engine. The collected data will serve to improve the understanding and implementation of this technology. Specifically, the data should consist of power and efficiency as well as sensor information for optimization.

The test stand was considered successful because it met all customer needs. The test stand can provide information to characterize the efficiency of a motor based of consumables used.

NOMENCLATURE

AC:	Alternating Current
DAQ:	Data Acquisition Board
DC:	Direct Current
Engine:	Kohler CH5 Gasoline Engine
Hybrid Engine:	Steam-Gasoline 6-Stroke Engine
Permanent Magnet:	PM
PM Motor:	Baldor ME-4090-FL-6B (Temporary Solution)
Series Motor:	D&D Systems #ES-15-26 (Preferred)

INTRODUCTION

Group member Tim Francis liked the idea of using water injection to help improve the efficiency of an existing IC engine. The original project proposed by David Scott and Tim Francis was to modify a standard IC engine to operate as a gasoline/steam engine. It was decided by the R.I.T. multidisciplinary senior design department that the modified engine project would be more effective if the engine could be properly tested. The project was then changed to build a test stand that is capable of controlling a hybrid gasoline/steam engine that could support, test, and collect data on such a modified engine.

This project was designed to bring validity to the claim that a hybrid gasoline/steam engine can operate more efficiently than a standard IC engine. As this project will provide a means of testing a modified engine, a future MSD team now has the opportunity to modify an engine to be fitted to the test stand.

PROCESS

The TEAM STEAM hybrid engine test stand houses the engine and motor and is controlled through LabVIEW software with a laptop computer. The test stand mounts and provides an interface for the Kohler CH5 engine. The stand is capable of measuring power output of a hybrid engine and fuel consumed so that relative efficiencies of two different tests can be compared. Each of the subsystems can be referenced in the systems architecture below

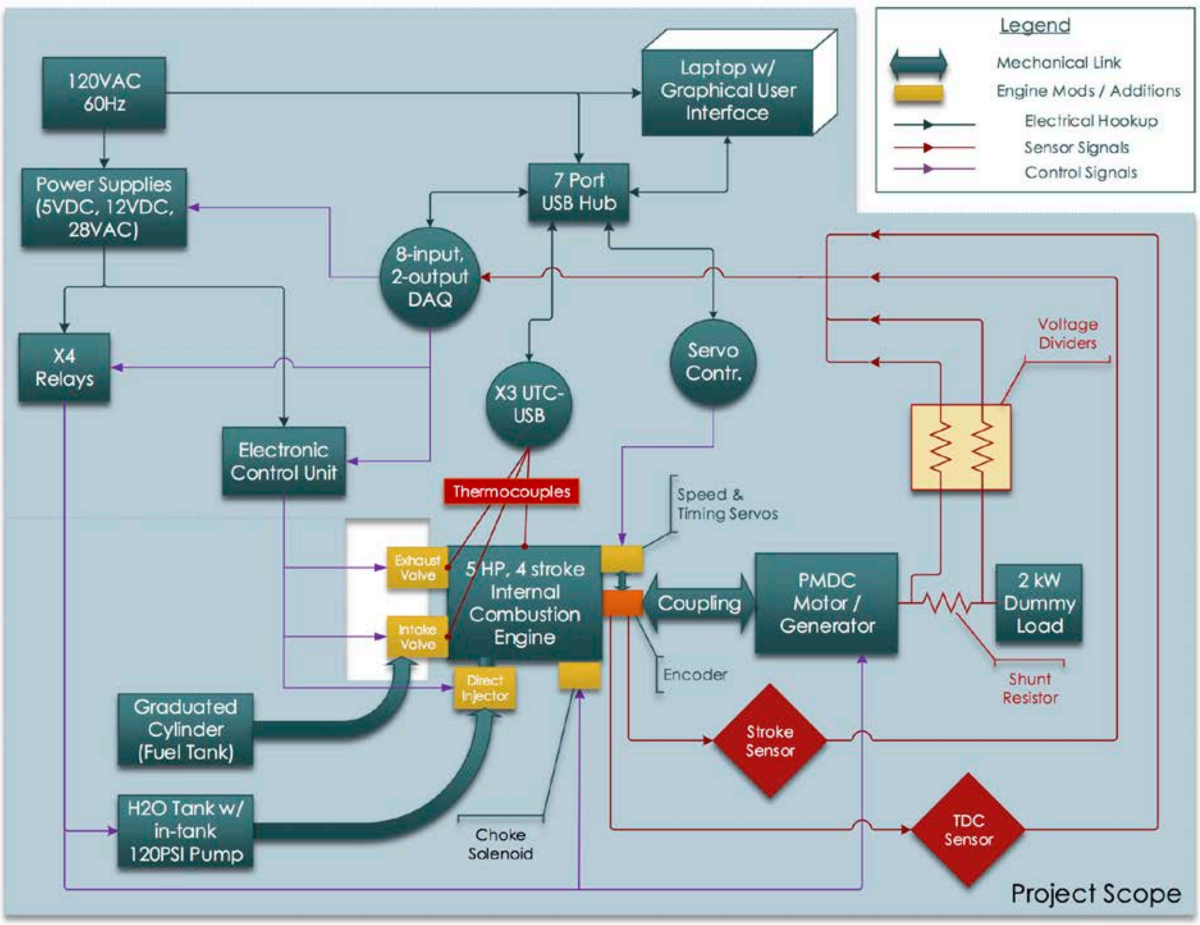

Figure 1 Systems Architecture

LabVIEW Controls

The test stand will be controlled through a tablet computer. The graphic user interface (GUI) was required to be capable of displaying the test data through an intuitive graphic user interface. The GUI is capable of starting the engine, enabling the choke, setting throttle position, enabling the load, advancing or delaying the water injection timing, enabling 6 stroke operation of the engine, viewing the temperature readings, and displaying power generation. The testing manual may be referenced for additional information.

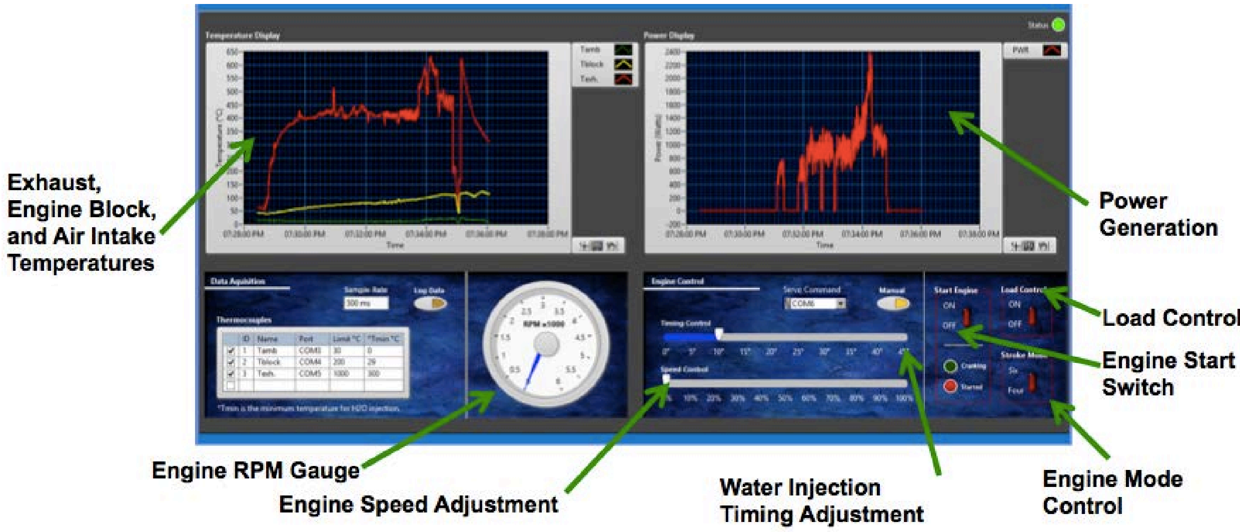

Figure 2 LabVIEW Graphical User Interface (GUI)

Test Stand Construction

The test stand was built on top of a heavy duty pallet that was donated to the steam. The baseplate is made from ½" thick aluminum to be very stiff. The stiffness of the aluminum and the flexibility in the wooden stand worked in tandem reduce vibrations during testing. The aluminum made a secure fit for the engine and motor and the wood helped dissipate some of that extra energy.

The motor mounts

Throttle

The throttle is controlled mechanically with a heavy-duty servomotor. The motor attaches directly to the engine's throttle arm and operates it through the full factory range of motion, allowing the mechanical rev limiter to still fully function.

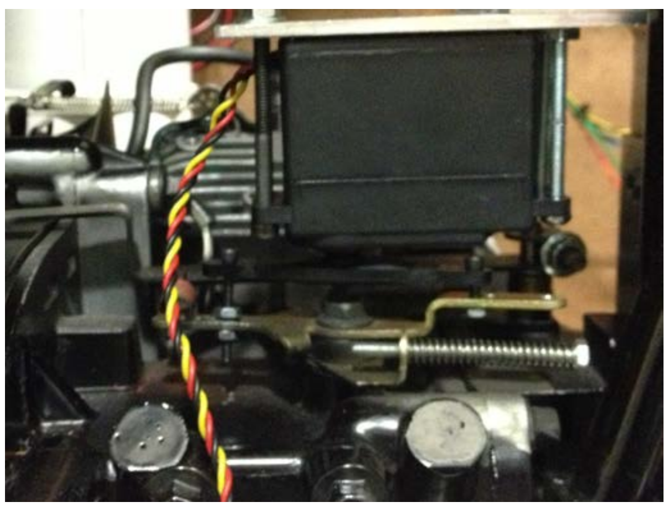

Figure 3 Throttle Servo attached to the Motor Control Arm

Remote Start

In order to reduce risks induced by pull starting the engine and to better enclose the test stand, a remote start procedure was added to the LabVIEW code. The code enables the choke, via solenoid, and powers the electric motor to turn the output shaft of the engine to start it.

Fuel Consumption Rate

The fuel consumption rate is calculated from analog measurements that are entered into the LabVIEW GUI. The user enters the starting fuel level and final level, measured from the bottom of the meniscus of the graduated cylinder. When you click the start test switch, the program prompts you to enter a fuel level.

Water Injection

The engine has been modified to accept an automotive fuel injector that is mounted in the air take and directed at the carburetor. The test stand holds a water reservoir with an automotive fuel pump to deliver water to the injector. The amount of water that is injected into the cylinder can be calculated by multiplying the injector flow rate by the amount of time the injector is open over the duration of the test. It is assumed that the customer will provide the high-pressure pump and water injector necessary for direct injection in the hybrid engine. The customer should calibrate the software via the test procedure outlined in the testing manual.

Figure 4 Water Fill Port

Figure 5 Water Injection System

Safety

In order to protect the customer, a number of safety precautions have been implemented on the test stand. There is a large and easily identified emergency stop button mounted on the top of the stand. Additionally, there is a circuit breaker for added current protection. Five of the six sides of the stand are enclosed to prevent the user from accidentally getting their clothing or hair caught in the rotating shaft, burning themselves and to protect them from electric shock. Warning Stickers have been placed on the test stand to further warn the customer.

Data Acquisition

A National Instruments NI-USB-6008 data acquisition module is used to interface LabVIEW with a number of sensors used for data logging. This specific model has a number of analog and digital I/Os with a 12VDC voltage swing. The data acquisition device has a sample rate of 10 Ksamples/second and 12-bit quantization.

Sensors

Thermocouples are used to measure temperature at key points that are useful in determining the efficiency of an internal combustion engine. They are located at the air intake, on the engine block, and at the exhaust port (upstream of muffler).

The National Instruments board is used to measure load current and voltage using the analog input pins. The analog inputs have 12-bits of resolution over a voltage range of 0-12VDC which comes out to a resolution of about 100 mV for measuring voltage and about 50 mA for measuring current using the designed voltage divider and current sensing circuits.

An encoder is used in conjunction with two photo interrupters to track crankshaft position of the engine under test and to trigger the water injection. The sensors selected output a TTL signal depending weather the line of sight between apertures is broken. This signal is converted to CMOS in the electronics box to be used for further processing.

The encoder disc has two clearings marked on it. One clearing spans 180° of the disc and allows the circuitry to know when the piston is traveling toward or away from TDC. A small circular clearing also exists on the disc to control the timing of the water injection.

Electronic Control Module

Although much of the control systems are done in LabVIEW it is not suitable for some of the more high speed controls that need to be carried out in near real-time. This means that signals such as water injection and electronic valve control needs to be controlled with hardware. The hardware is divided into two sections, analog and digital. The two best options for hardware design would be an embedded design for the digital board or to use discrete logic such as the 4000 series to construct the needed logic. The analog board would need to be made from discrete components either way.

It was decided to use the discrete implementation despite the obvious drawback of less flexibility in the design to changes because of the significantly reduced cost of implementation.

Power Generation

In planning stages, the project team was offered a 10 horsepower DC motor to use as the electric generator. It was discovered late in the design cycle that the motor was not a permanent magnet DC motor as assumed but a universal series DC motor. Permanent magnet DC motors are easily converted to generators by rotating the shaft and applying a load at the terminals but a universal series motor is not so easily converted. It must either be self excited or externally excited with a power source. The 10HP universal series motor could not provide enough power output in the self excited state (Lab2) and an external power source was unavailable.

A substitute PM DC motor was found to replace the series motor. A mounting plate was fabricated to interface the new motor to the test stand. The new motor has favorable specs because it operates at a higher voltage and lower RPM than the series motor. This means the PM motor has closer characteristics to the IC engine, which will optimize power transfer. Also, the resistive load used is designed for 120VAC. The higher output voltage of the PM motor significantly increases the power output at the load when compared with the 60VDC output from the series motor.

The transient response of the PM motor is considered when building in protective circuitry because PM DC motors tend to have poor control of output voltage during transient events, load removal for example.

Power Measurement

A .1Ω shunt resistor is placed in series with the load cell. The NI-USB-6008 DAQ measures the voltage drop across the resistor. The program then calculates the current draw and power output of the IC engine. The load cell dissipates the energy through four hot water heating elements that are water cooled with a steady flow of water from a garden hose.

Load Cell

Dissipating the large amount of electrical power that the system creates is a difficult task to do on a low budget. The test stand load cell utilizes water heater heating elements to reject energy from the system to flowing water. The constant flow of water prevents the water in the bucket from boiling and carries the heat to the environment. The user may further modify this bucket so that the injected water can be preheated.

Fabrication

Machining the components was much more difficult than anticipated. Both mechanical engineering students got a refresher on how to use the tools in the machine shop and without the help of the shop staff the fabrication would have been impossible.

Assembly

Design flaws were brought to attention during the assembly process. For example, the original design for the throttle servo bracket did not place the servomotor over the center point of the pivoting throttle control arm on the engine. The planned linkage did not allow the servo to actuate without creating large deflection in the throttle angle bracket. A new throttle angle bracket was created from a larger piece of aluminum that allowed more adjustability in the final position of the throttle servo plate so that the center points of the servo motor arm and throttle control arm coincided. These flaws could have been avoided and the parts made to an exact measure if an accurate 3D model of the engine were available. Unfortunately Kohler did not have a drawing available for use. Since the model could not be exactly created digitally most of the brackets were designed to be fabricated as they were integrated into the stand.

RESULTS AND DISCUSSION

The tests show that all engineering specifications have been met.

The engine shaft output power is used to measure the relative difference in power created between a test at a certain load and RPM with water injection and one without. Since the motor has the same mechanical and electrical losses at specific RPM values, as long as the tests for with injection and without injection are run at the same motor speed, the test stand will produce accurate results. The current motor is a proof of concept solution. A benefit analysis should be performs to determine whether it would be cheaper to excite the existing series motor or find a permanent magnet DC motor that could be spec'd and implemented with dimensions and mounting locations as the original series motor used by the stand.

Temperature readings were to be collected within 5% of actual temperatures. The thermocouples that are used are specified to have a tolerance of three percent. The water consumption of the test stand can be calculated based on the customer's choice of water pump and fuel injector. The graduated cylinder holds the gasoline and provides an easy way for the operator to gauge how much fuel has been consumed. The LabVIEW program prompts the operator to input the fuel level before and after each test session. Based on the two fuel level readings, fuel consumption is logged.

The LabVIEW program logs data and inputs it into an excel file for easy recollection. After the test of a hybrid gasoline/steam engine, the consumption of gasoline and water can be analyzed and compared to the power output of the engine. This analysis will provide the necessary information to determine whether or not a hybrid gasoline/steam engine is more efficient than a standard, unmodified engine.

The test stand itself was designed to fit through a standard size door and can be easily moved as it was built on four caster wheels. The Kohler CH5 engine is mounted on the stand via a mounting plate that has been set up for the mounting pattern of the engine. The engine is then interfaced with the electric motor via a flexible spider coupling. This coupling reduces vibrations transmitted from the engine to the motor in an effort to extend stand life. All the systems on the test stand are successfully powered by one single 120V 20A outlet.

Tests have shown that the gas engine can be started and throttled up and down with the LabVIEW program. Unfortunately the series motor could not be configured in a manner to generate more than 3 watts of power. The PM motor was tested to produce 2500 watts of power and confirm the operation of the test stand. This motor is not a permanent solution, it merely validates the stands ability to measure and dissipate power. The water injector and reservoir were tested independently to be controllable and work with the LabVIEW program.

CONCLUSIONS AND RECOMMENDATIONS

The results show that the test stand has met all of the engineering specifications. . In order to provide a better product, the following changes should be made.

Graduated Cylinder Material is rated for 7-30 days of continued exposure to gasoline (1). As such, it is important that all fuel be consumed after each test. It would be best to replace the graduated cylinder with a dedicated fuel tank and digital flow meter, connect it to the DAQ and edit the LabVIEW software to read and report it.

Add a thermocouple to the load cell that will shut the stand down if the load cell overheats.

If the load is disabled while the engine is still running, it will cause a significant voltage buildup in the relays. Although this is protected against happening in software, it would be ideal to implement a mechanism such as a large diode or a capacitor across switches so that it does not happen if the loads are physically turned off.

If it is possible, find any reported values for electrical efficiency of the motor to replace the PM servomotor. If the efficiencies are known at certain RPMs, it will be possible for the program to recognize what the electrical efficiency is at that moment in time and report a number more accurate to the engine's actual output shaft power.

If budget permits a torque sensor will produce more accurate results than electrical power created. This route was too costly for P13263 to implement.

REFERENCES

[1] "Chemical Resistance Chart." *Ted Pella, Inc.* N.p., n.d. Web. 15 Feb. 2013. <http://www.tedpella.com/company_html/chem-resistance.htm>.

[2] "DC Generators: shunt, series, and compounded." Mar. 2008. PDF file.

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