Development of a 10 RPM Engine as an Instructional Tool

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Thermodynamics can be a difficult topic for students to visualize. The interactions between pressure, temperature, and volume in gases cannot be seen directly, and realistic devices that can help are not readily available. With the help of the National Science Foundation, the authors are developing a small, table-top engine system specifically designed to operate at 30 RPM in a typical classroom setting. Under these conditions the system is being instrumented and monitored in such a way that both the thermodynamics of gases, as well as the operation of a realistic internal combustion engine can be more easily observed and understood by students in K-12 through college level classes.

The complete system consists of a 5 horsepower 4-stroke engine, coupled to a fractional horsepower AC electric motor to provide the mechanism for consistent speed under all power flow conditions. Instrumentation for measurement of pressures (2), temperatures (3), crankshaft position (1), and reaction torque are included at various locations and connected to a data acquisition system for automated collection and interpretation. The entire assembly fits within a 30 x 18 inch footprint suitable for table-top usage in virtually any classroom. Propane fuel can be supplied either by an on-board delivery system, or separately delivered from a typical supply system of the type found in many high school and college science laboratories (house systems terminating with hose-barb petcocks). See figure 1.

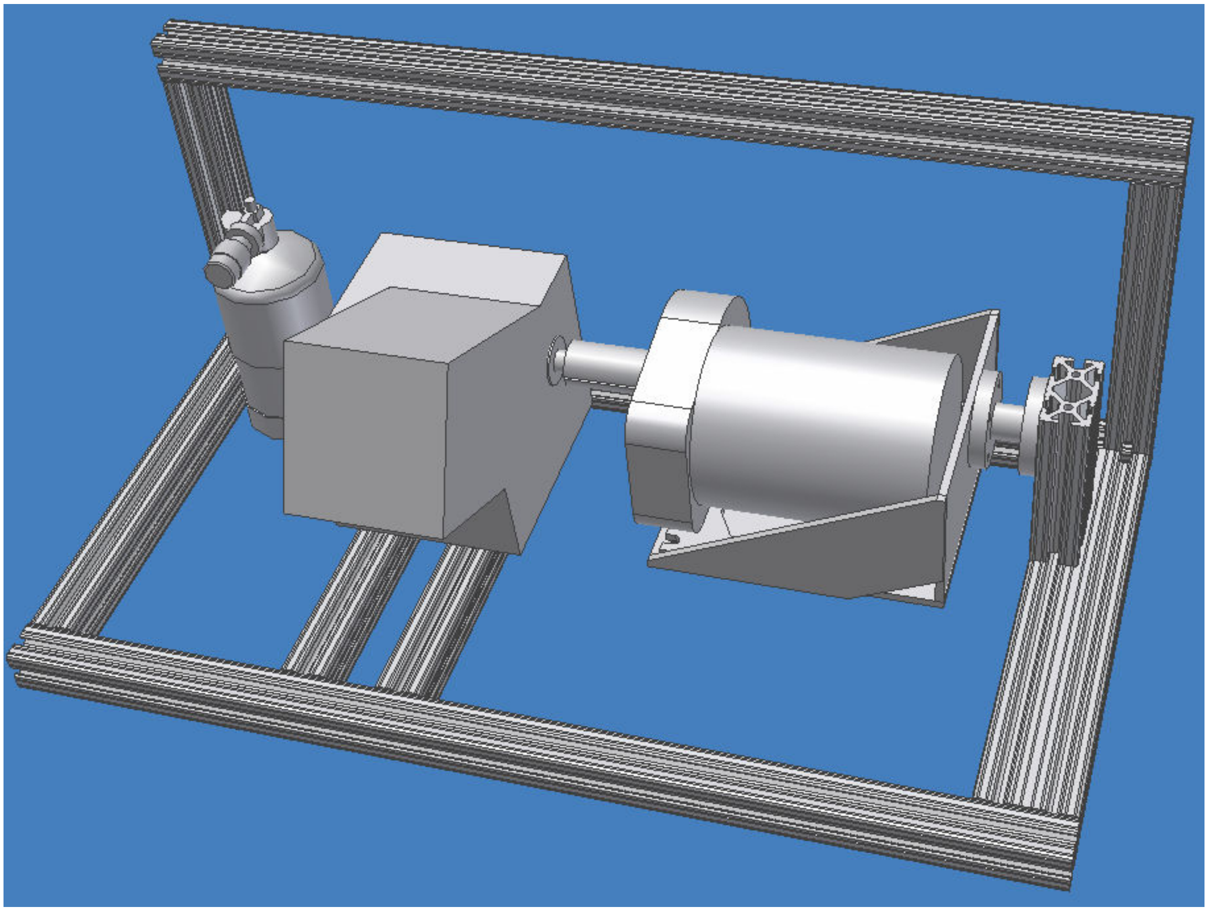

Figure 1. The Physical System

As development of this system has progressed, the authors have encountered several interesting challenges. These challenges have been divided into two categories; those involving mechanical aspects associated with operation of an internal combustion engine at speeds two orders of magnitude slower than originally designed, and those involving electrical and instrumentation aspects. While mechanical challenges are presented in another paper at the 2004 Proceedings of the American Society of Engineering Educators national conference, there are two significant electrical/instrumentation challenges the authors have encountered thus far. These challenges involve the design of effective spark ignition and instrumentation systems, and are presented below.

The Spark Ignition System

In the original engine design (from the factory), the spark ignition system consisted of a magneto-style coil and spark plug wire mounted to the block. A bar magnet, attached to the flywheel would generate the appropriate field through this coil with every revolution of the crankshaft. Two things were necessarily required for effective operation; a flywheel and sufficient speed to generate and collapse the magnetic field. Unfortunately for the authors, neither was present in the new design. The flywheel was no longer needed for conservation of momentum or fan-cooling purposes, plus the space it occupied was needed for other purposes.

Also, an engine speed of 30 rpm was now far too low for adequate magnetic field functionality. Therefore, a new spark ignition system was needed.

System Features

Two design features of the spark ignition system were deemed paramount. First, as opposed to the common spark generating systems, it was felt that multiple sparks would help insure ignition of the fuel/air mixture. Therefore, the system needed to continuously generate a spark for a predetermined, controllable amount of time (as measured in crankshaft degrees of rotation). The second design feature was the need to generate a consistently strong spark of known strength. This was done by reverting to an automotive-style system that used a 12 volt source to drive an automotive ignition coil. Together these two features would produce a strong spark pulse of any required duration across a spark plug gap that could theoretically be as large as the combustion chamber would allow.

Circuit Design

The spark circuit utilizes a reflective sensor, the Fairchild QRB-1134 for input from the crankshaft. A matte-black painted disc is attached to the crankshaft and on it is a piece of reflective tape set at approximately top-dead-center (TDC). This piece of reflective tape on the disc reflects light into the integral phototransistor of the reflective sensor causing it to conduct. The conduction of the phototransistor causes its emitter to exhibit approximately a 1 volt level. This low level on the Schmitt trigger inverter's input causes its output to go to a TTL high level of approximately 3.8 volts which causes Q2 to conduct, when Q2 conducts the base of Q3 is low keeping Q3 "off". As long as Q3 is "off" there is 12 volts supplied to the 555 timer that is configured in the astable mode. With the 12 volts present at the 555 its output will oscillate at approximately 1 kHz and 50% duty cycle. Both Q4 and Q5 serve as buffering stages for the switching transistor Q6. The output of the 555 drives the base of Q4 causing it to conduct when the 555 output is high. The operation of Q5 is inverse to Q4; when Q4 conducts, Q5 is "off" and when Q4 is "off" Q5 conducts. When Q4 is driven high by the 555 and conducts, Q5 is "off" and approximately 12 volts is present at the base resistor of Q6 driving it into saturation and causing current to flow through the primary of the ignition coil. When the 555 output goes low, Q6 is stops conducting and the Counter EMF (CEMF) is developed across the coil's primary, inducing voltage sufficient for spark in the coil's secondary. The process repeats at a rate of approximately 1k kHz as mentioned earlier, providing repeated sparking as long as the phototransistor of the reflective sensor is receiving sufficient light.

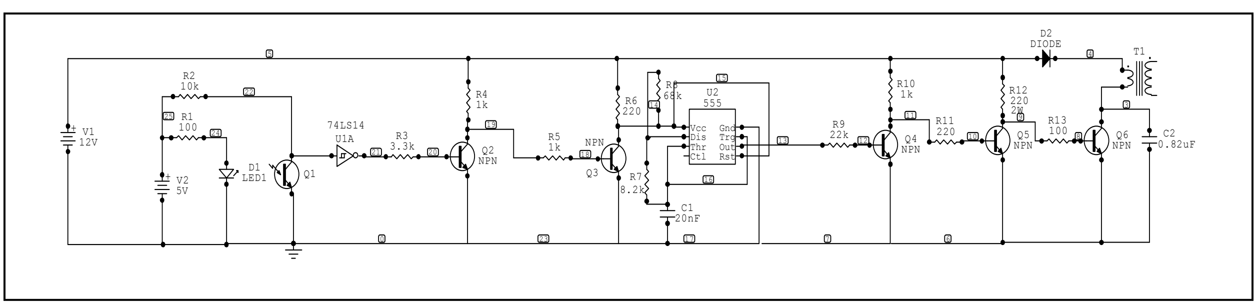

Figure 2. The Spark Circuit

Circuit Performance

The spark will continually occur at a frequency of approximately 1 kHz, with the duration of the sparking determined by the amount of time light is reflected to the sensor. So the duration of the sparking is determined by the target size and the angular velocity of the crankshaft. This circuit has been bench tested for hours and demonstrated reliable sparking. The spark is quite robust and it will jump as large a gap as the spark plug will allow.

Results to Date

The counter electromotive force (CEMF) developed by the coil put huge voltage spikes on the power supply bus and even the circuit common itself. A voltage spiking of +5volts to -5 volts was measured across the metal enclosure itself. A positive voltage spike 400 Volts was measured on the +12 volt bus. This monstrous voltage spike destroyed the reflective sensor and 74LS14 Schmitt trigger inverter twice. Once the cause of these circuit failures was discovered, the addition of components to suppress the voltage spike were added. A 1N4007 diode was added to the +12 volt bus just prior to the input to ignition coil's primary input. Also the collector to emitter junction was by-passed by a 0.82uF capacitor being placed across it in parallel. These modifications made the voltage spike only a few volts positive on the +12 volt bus and removed any voltage spikes from the circuit common. The multi-sparking circuit has given reliable ignition of fuel/air mixtures that appear to be well outside normal ranges.

The Instrumentation System

For the system to be effective as an instructional tool for thermodynamics and engines, it must be able to measure and display in real-time the important parameters at work in the system. The most important of these is the behavior of gases and/or combustibles in the cylinder. In addition, the torque required to compress and contain these gases or combustibles is important since this allows the concept of work, energy, and power to be correlated with the compression and expansion processes. Other meaningful measurements include; crankshaft angle for measurement of piston position, exhaust temperature, and intake pressure and temperature. Together, these parameters provide a relatively comprehensive picture of the phenomena present as the engine operates, regardless of whether it attempts to behave as an engine under power or as a simple compression/expansion chamber.

Instrumentation System Design

The device utilizes seven sensors in its present configuration. There is one torque sensor to measure the output during the power stroke, two pressure sensors, one on the combustion chamber to measure during the compression stroke and the second pressure sensor is to measure vacuum on the carburetor input. Additionally there are two thermocouples. One thermocouple is on the combustion chamber, and a second on the exhaust. The torque sensor and the pressure sensors require a DC drive voltage, this voltage may be anywhere from 9 to 30 volts. A 9.5 volt regulated DC input voltage is supplied via an LM317T adjustable voltage regulator. The voltage regulator is necessary to supply a regulated voltage to sensors for accurate and consistent output in addition to being necessary to supply attenuation of any voltage spikes that exist on the +12 volt bus. Each of the seven sensor inputs is connected to a data acquisition module that is controlled via LabView software. The system allows for the simultaneous monitoring and display of the seven sensor's characteristics. This capability is essential to the educational purpose of the trainer.

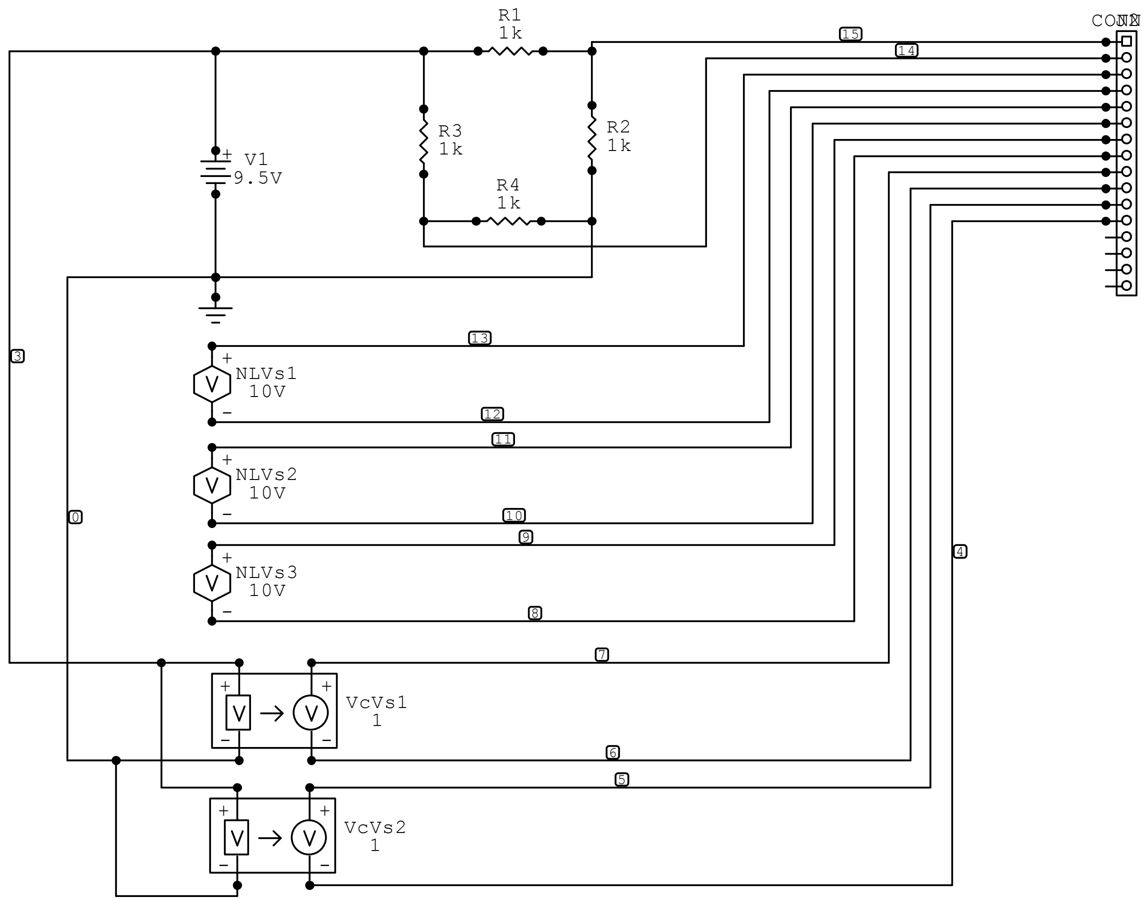

Figure 3. Sensor Circuit

System Performance

System performance has been reliable and the instrumentation system has experienced only minor noise generated by the ignition system. These problems have been dealt with by shortening and proper routing of sensor input wires and judicious grounding connections between the engine frame, the circuit enclosure and earth ground. The most significant and troubling noise to the sensors is generated by the computer and monitor, this interference source has not yet been defeated in this system.

BIOGRAPHY

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