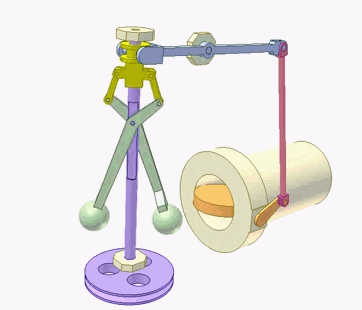
A Low-Power Embedded Controller for Small Engine Governor

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[[1]](#footnote-1)

***Abstract*—** **Many internal combustion engines are designed to run continuously at a given revolutions per minute (RPM) value. This is seen in industrial applications as well as consumer-grade products like lawnmowers, generators, etc. In these applications, having the engine run at a fixed speed is often integral to the proper function of the powered device. For example, the engine’s speed determines the output voltage in a traditional gasoline AC generator. The engine’s speed must be properly regulated in these applications. This can be achieved by using a governor. A governor is a mechanical or electronic device that monitors the speed of an engine and adjusts the throttle accordingly. One of the simplest and most prevalent governor mechanisms is the centrifugal governor. This is a purely mechanical device that regulates an engine’s throttle through proportional control. These systems are commonly found on small engines, due to their low cost and lack of complexity. However, many internal combustion engines have become dependent on computerized control; this allows for the use of electronic governor systems. This project seeks to test the potential advantages of an electronic governor and detail the process of implementing an electronic governor system. Experiments were conducted on a 5000-watt gasoline AC generator, and the performance results after 120 trials (12 experiments with ten trials each) between the mechanical and electrical governors are presented.**

**Fig 1:** Centrifugal Governor Animation

***Index Terms*—embedded controller, automation, programmable governor**

# I. INTRODUCTION

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his project will document the process of designing and fabricating an electronic governor system for a small engine and compare its performance to the original mechanical governor system.

### Generator: The engine testbed for this project is a Coleman Powermate PM0435001 generator. It outputs 120 and 240 VAC single phase, supplying a maximum of 5000 watts continuous power. The generator features a 9 HP Subaru Robin EX30 engine. This is an air-cooled, single-cylinder, overhead camshaft, four-stroke gasoline engine, displacing 287cc. It features a side draft carburetor and a centrifugal governor; it is designed to run at a constant rate of 3600 RPM.

### Operation of a Throttle A throttle regulates the speed of a gasoline engine by metering the amount of fuel and air which is supplied to the engine. The amount of fuel and air supplied to an engine determines the amount of energy which can be released though combustion, thereby determining how much power the engine outputs. A governor manipulates an engine’s throttle to regulate its speed.

# II. Mechanical Governor Overview

Centrifugal governors use the inertial forces affecting a rotating apparatus to actuate an engine’s throttle. This apparatus is driven by the engine, and its rotational speed changes along with the engine’s speed. As the apparatus rotates, a pair of flyweights change their position and manipulate a throttle linkage. As the apparatus increases in speed, the flyweights move outward, acting on the linkage, and decreasing the throttle. As the apparatus decreases in speed, the flyweights move inward, acting on the linkage, and decreasing the throttle. Figure 1 shows an illustration of a centrifugal governor. Many different governor designs utilize these basic principles.

These systems rely on proportional control. They make throttle adjustments based on the difference between the current engine RPM and the desired RPM.

# III. Microcontroller Governor Overview

A microcontroller electronic governor features a few key components, namely a speed sensor, a throttle actuator, and the microcontroller itself. The speed sensor serves as the governor’s input; it may take the form of a Hall Effect, variable reluctance, or optical sensor, among others. The sensor provides a signal(s) to the microcontroller each time the engine rotates, allowing the microcontroller to accurately calculate the engine speed. The throttle actuator serves as the governor’s output; commonly this is either a servo or stepper motor. This actuator manipulates the throttle valve, allowing the microcontroller to change the engine speed.

Electronic governors are not limited to proportional control. They can use a wide variety of algorithms to adjust the throttle, considering many factors. Electronic governors often account for the RPM rate of change, in addition to proportional control.

# IV. EMBEDDED CONTROLLER DESIGN

## A. Stepper Motor Carburetor Assembly

The EX30 engine uses a side-draft carburetor with a butterfly valve to control its throttle. The governor will actuate this butterfly valve to regulate the engine’s speed. A pair of identical, new carburetors were purchased for this project; one was modified for use with the electronic governor, the other was left unmodified and used with the mechanical governor.

The electronic governor uses a 28BYJ-48 4-pole stepper motor with a 64:1 gear reduction. This allows for precise throttle adjustment; in practice, the stepper motor has approximately 1200 positions between fully closed and wide-open throttle.

The carburetor features a pair of unused M6 x screw holes on either side of the fuel inlet. These screw holes allowed a custom bracket to be mounted on the side of the carburetor. The stepper motor is mounted to this bracket such that its output shaft rotates on the same plane as the throttle butterfly valve. A ball-joint linkage then connects the stepper motor’s output shaft to the butterfly valve. Figure 2 shows the modified carburetor.



**Fig. 2.** Stepper Motor Carburetor Assembly

## B. Hall Effect Sensor

The governor uses an NJK-5002C normally open Hall Effect sensor as the engine speed sensor; this sensor monitors the speed of the engine’s flywheel. The EX30 engine uses a simple magneto-based ignition system; it features a single permanent magnet located on the engine’s flywheel. For each revolution of the engine, this magnet passes by the ignition coil and generates an electric current, providing spark to the engine.

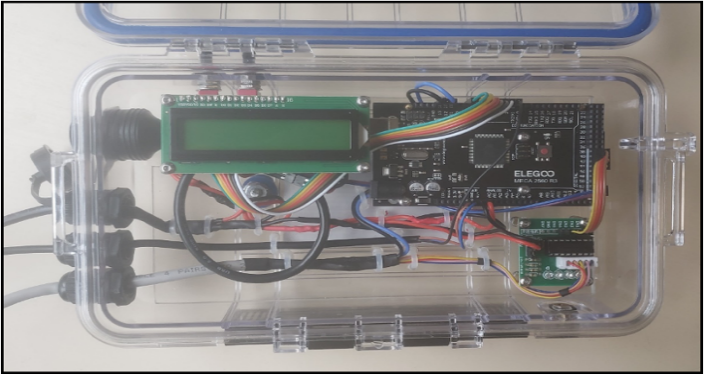
A Hall-Effect sensor is used in conjunction with this existing magnet on the flywheel to calculate the RPM. Each time that the magnet passes in front of the sensor, its normally open contact closes. This provides a consistent, discrete signal to the Arduino. The Arduino records the time elapsed between each pulse and calculates the engine RPM. For example, the sensor will generate a pulse every 16.67 milliseconds when the engine is running at 3600 RPM. The sensor is mounted via a hole in the engine flywheel cover. The end of the sensor rests a few millimeters from the edge of the flywheel.

## C. Electronics Enclosure

The governor relies on sensitive electronic components, all of which are housed in a weatherproof enclosure attached to the side of the generator. An Arduino Mega 2560 microcontroller performs all the calculations required for the governor system to function. It calculates the current RPM and commands the stepper motor to adjust the throttle as needed. Additionally, the Arduino is configured to output data logging info via serial.

An HD44780-based 16 character, 2 row LCD is controlled by the Arduino. It displays the desired RPM and the current RPM, updating the current RPM every 400 milliseconds. A ULN2003 stepper motor driver takes in a signal from the Arduino and then provides additional current to the necessary poles in the stepper motor.

Shown in figure 3 is a photo of the enclosure. It is made of transparent plastic, allowing the LCD to remain visible from the outside. All power/data cables exit through cable glands; these cables then connect to the throttle assembly and Hall-Effect sensor using weatherproof connectors. There is also a USB passthrough which allows the serial data to be collected from the Arduino without removing it from the enclosure. On top of the enclosure, there are a pair of switches; one switch controls power to the system, and the other enables/disables the stepper motor.



**Fig. 3.** Embedded Controller for the Governor

## D. Software Design

This section will detail the Arduino code which was written for this project. It will provide a high-level overview of how the program functions. The program is built around a loop that continuously cycles while the Arduino is powered on. During each cycle of this loop, the program performs the following checks.

**Fig. 4.** Software Flowchart

Throughout this process, the program is also waiting to receive an interrupt signal from the Hall-Effect sensor. Whenever the Arduino receives this signal, it will pause whatever code is currently being executed and record that it has received a pulse from the sensor.

If the program determines that the RPM is out of range, it will adjust the throttle using proportional derivative (PD) control. This is a two-part control algorithm. The proportional control is determined by the difference between the current RPM and the desired RPM. The derivative control is determined by the RPM rate of change.

This PD algorithm provides the electronic governor with a more complex control system than the mechanical governor, which relies solely on proportional control.

# IV. IMPLEMENTATION AND VALIDATION

The experiments were designed to test the mechanical and microcontroller governors' performance characteristics. These tests measure how each governor performs at a constant engine load and a variable engine load, measuring average RPM, RPM deviation, etc. The testing environment is given in Figure 5.

A picture containing floor

Description automatically generated

**Fig. 5.** Experimental setup for embedded governor

## A. Experimental Setup

The generator was tested under five different conditions: 1. No Engine Load, 2. Constant Engine Load, 3. Abrupt Load Decrease, 4. Abrupt Load Increase (Initially No Load), 5. Abrupt Load Increase (Initially Constant Load). Ten trials were completed for each test with each governor. These tests should provide insight into each governor’s performance over various engine operating conditions.

Additionally, two control experiments were completed during the No Engine Load and Constant Engine Load tests. During these experiments, the throttle was locked in place; no governor was used. These tests will provide a control which the governors can be compared to.

Results were gathered via a laptop receiving serial data from the Arduino during each experiment. This data was received every 50 milliseconds. This data is in the form of comma-separated values (CSV) and was later imported into Microsoft Excel for analysis. The data includes the total time elapsed in milliseconds, the current RPM, the number of stepper motor steps remaining, the current PD calculations, the change in RPM since the last measurement, and the total number of steps commanded by the PD calculations.

During the experiments, an electrical load was placed on the generator. This was done with a 1500-watt Comfort Zone DQ2016 space heater and an 1800-watt watt Ridg*i*d CM14500 Abrasive Cut-Off machine. The space heater was used as a constant load; in practice, it pulled approximately 1460 watts. The abrasive cutoff machine was used as an abrupt load. It was not easy to measure its initial startup draw; it is estimated that it pulled between 2000 and 3000 watts. Once it was running, it pulled approximately 750 watts. The current draw of each device was measured with a P3 P4400 Kill-a-Watt electricity usage monitor

The ambient temperature varied between 76- and 98-degrees Fahrenheit during these experiments. At the start of each day of testing, the generator was run for several minutes, until the cylinder head reached at least 180-degrees Fahrenheit, ensuring that the engine had reached operating temperature. The ambient and cylinder head temperatures were recorded during each experiment trial.

Before these experiments were conducted, general maintenance was performed on the generator. A new air filter was installed, and a new NGK BR6HS spark plug was gapped and installed. Two oil changes were performed, ensuring that any old oil had been flushed from the engine; during the experiments, the engine used Shell Rotella T4, conventional 15W40 motor oil. The engine was run on regular 87-octane gasoline with up to 10% ethanol.

## B. EVALUATION METRICS

The following sections will present data collected from the experiments. Each section presents a table summarizing the data from that experiment. This data is taken from ten trials. Some data represent an average from those ten trials, and some represent the maximum and minimum values taken. When data includes “TRIMMEAN: 20%” in the title, this data is an average that excludes the highest and lowest values from the ten trials. Following is an explanation of some of the specialized values included in the data.

### 1. Dev from Setpoint: Similar to the standard deviation, this value represents the RPM deviation from the 3600 RPM setpoint. This is the average of how far each RPM value deviates from the 3600 RPM setpoint.

### 2. Overshoot Time: This value represents how long, in milliseconds, the engine RPM is more than 100 RPM over the 3600 RPM setpoint. This typically occurs when the engine first starts up or when the load suddenly decreases.

### 3. Undershoot Time This value represents how long, in milliseconds, the engine RPM is more than 100 RPM below the 3600 RPM setpoint. This typically occurs when the load suddenly increases.

## Experiment Results

This section analyzes a portion of the experiment results to assess the performance of the mechanical and electronic governor systems. For brevity, the Abrupt Load Increase (Initially No Load) experiment has been omitted. Its results were similar to the Abrupt Load Increase (Initially Constant Load) experiment.

## Experiment Results – No Engine Load

This experiment provided a performance baseline. The engine was idling without an electrical load. The results demonstrate that there is noticeable RPM deviation, even with No Throttle Input. This may possibly be caused by poor tolerances in the throttle assembly or a lack of ignition timing control.

It is worth noting that the electronic governor achieves the best average RPM value, despite considerable RPM deviation.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **No Engine Load - Average of Results (TRIMMEAN: 20%) - 20 sec to 60 sec** | | | | | |
| **Control - No Throttle Input** | | **Mechanical Gov** | | **Microcontroller Gov** | |
| **Avg RPM** | **Std Dev** | **Avg RPM** | **Std Dev** | **Avg RPM** | **Std Dev** |
| 3614.759 | 32.5114 | 3623.146 | 33.207 | 3595.783 | 47.171 |
| **Setpoint Dev** | **RPM Range** | **Setpoint Dev** | **RPM Range** | **Setpoint Dev** | **RPM Range** |
| 36.823 | 227.343 | 32.628 | 396.280 | 36.410 | 344.931 |

**Fig. 6.** Experiment results, No Engine Load

## Experiment Results – Constant Engine Load

This experiment shows how the engine performed when placed under a constant load, via the 1500-watt space heater. The results show that the RPM deviation is smaller than in the No Engine Load test. This illustrates that the general engine behavior becomes more stable when under load. Also notice how the mechanical governor average RPM increased compared to the no load test. This shows how the mechanical system performs differently depending on engine load.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Constant Engine Load - Average of Results (TRIMMEAN: 20%) - 20 sec to 60 sec** | | | | | |
| **Control - No Throttle Input** | | **Mechanical Gov** | | **Microcontroller Gov** | |
| **Avg RPM** | **Std Dev** | **Avg RPM** | **Std Dev** | **Avg RPM** | **Std Dev** |
| 3601.538 | 28.494 | 3591.019 | 28.384 | 3591.168 | 39.048 |
| **Setpoint Dev** | **RPM Range** | **Setpoint Dev** | **RPM Range** | **Setpoint Dev** | **RPM Range** |
| 26.741 | 193.021 | 22.602 | 405.901 | 31.222 | 343.395 |

**Fig. 7.** Experiment results, Constant Engine Load

## Experiment Results – Abrupt Load Decrease

This experiment shows how the engine performed when a constant load (1500-watt space heater) is removed. This causes the engine RPM to increase. This experiment illustrates the performance weaknesses of the electronic governor. It is slower to respond to changes in engine load, causing a higher max RPM value and a significantly longer overshoot time. However, the electronic governor does maintain a better average RPM.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Load Decrease (1500 W) - Average of Results (TRIMMEAN: 20%) - 35 sec - 45 sec** | | | | | |
| **Mechanical Gov** | | | **Microcontroller Gov** | | |
| **Avg RPM** | **Std Dev** | **Max RPM** | **Avg RPM** | **Std Dev** | **Max RPM** |
| 3610.306 | 37.682 | 3792.775 | 3601.604 | 74.247 | 3875.169 |
| **Undershoot Time (ms)** | **Overshoot Time (ms)** | **Setpoint Dev** | **Undershoot Time (ms)** | **Overshoot Time (ms)** | **Setpoint Dev** |
| N/A | 50.000 | 29.632 | 377.778 | 656.250 | 52.387 |

**Fig. 8.** Experiment results, Engine Load Decrease

## Experiment Results – Load Increase (Initially Constant Load)

This experiment shows how the engine performed when an abrupt load is placed on the engine, via the 1800-watt abrasive cut-off machine. This experiment also illustrates the performance weaknesses of the electronic governor. It is slower to respond to changes in engine load, causing a higher max RPM value and significantly longer undershoot and overshoot times. Figure 9 illustrates the slower response time of the microcontroller governor, compared to the mechanical governor.

**Fig. 9.** Experiment Graph, Load Increase (Initially Constant)

V. Conclusion

This project has detailed the process of implementing a microcontroller-based governor system on a small gasoline engine. This electronic governor functions as intended, and it is able to keep an engine running at a constant RPM. However, the electronic system was unable to consistently match the performance of the original mechanical governor. Future research will likely involve improving the control algorithm in an attempt to improve the governor’s performance.

# References and Footnotes

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