Experiential Learning of System Design and Advanced Engine Cycles

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Abstract

Engineering students are admitted based on grades in courses such as physics and mathematics without regard for experience with mechanical systems. As a result, students struggle in courses due to lack of exposure to mechanical systems. As a remedy, the authors offer a course where students disassemble an internal combustion engine, and integrate an improved system into the engine. In the project, students convert an Otto cycle engine so it operates on a Miller cycle. In the Otto cycle, the intake valve is open for the same time each cycle, and airflow is controlled by the throttle. In the Miller cycle, the throttle is eliminated, and air is controlled by varying the intake valve period. Groups have worked with approaches that include an electronic valve actuator, a variable cam system, and variable control of the rocker arm. Success is measured by gains students make in their knowledge of the systems.

Keywords

Otto cycle, Miller cycle, electronic valve actuator, variable cam, variable rocker arm

Introduction

Students are typically admitted to engineering school based on performance in technical courses such as physics, mathematics, and chemistry. There is no requirement for "hands-on" experience with complex machines or systems. Design of such systems has become an important component of the undergraduate engineering curriculum, and most students struggle due to lack of exposure to traditional mechanical systems. To address this deficiency, the University of Florida now offers an elective course called "Re-Engineering Historic Machinery" in which students participate in "hands-on" mechanical projects.[1] The projects are individually tailored to the experience level of the students, and students are evaluated by how much more they actually learn about systems that they previously had little or no knowledge.

The faculty base their instruction in this course on a model described by Dennen and Burner called "cognitive apprenticeship".[2] In this model, students learn from an experienced mentor by way of cognitive and metacognitive skills and processes. In this context, cognition refers to the process by which knowledge and understanding is acquired, and metacognition refers to developing strategies to maximize one's potential to think and learn. The practical application of this involves assessing the abilities of each individual, and assigning tasks that slightly exceed the student's current ability, but gives the student an opportunity to achieve that task by researching the topic and determining how to accomplish the task. This method requires a great deal on one-on-one interaction between the student and faculty, but results in the student achieving much more complex skills than they would otherwise.

Course Description and Objectives

The course description for the university's undergraduate catalog is:

Study of a historic commercial machine or vehicle, including theory of operation, embedded engineering principles, and design. Re-engineering and design of enhancements. Laboratory includes disassembly, observation of characteristics and conditions, implementation of enhancements, and rebuilding.

The syllabus tells the students that the course objectives are:

Provide students with detailed understanding of machinery operation and design through hand-on disassembly and rebuild of historic machinery. Students will develop ability to measure and verify component design specifications. Custom design of replacement components and remanufacturing to bring components back to original design specifications may be required. Students will gain greater insight into manufacturing and maintenance aspects of machinery design.

There are no pre-requisites for this class other than permission of instruction. A list of available projects are shown to the class at the beginning of the semester, and students select projects that are of interest to them. There was a once-per-week lecture meeting in which the students were given guidelines and background and technical information. For example, there were lectures on engine disassembly, the Otto cycle, and the Miller cycle. Two instructors were used during the most recent offerings of the course, each having extensive "hands-on" experience in the subjects of their lectures. The lectures gave the students enough technical background so that they could perform the laboratory tasks and gain maximum knowledge benefit from what they were seeing during disassembly. Although nominally a lecture, the periods were conducted with interaction between the instructors and the students, including frequent questions from the students and contributions from the peers with more experience.

Otto Cycle vs Miller Cycle

A typical gasoline engine operates on the Otto cycle. In the Otto cycle, air is drawn into the intake manifold through a throttle and mixed with gasoline, and then the air/fuel mixture enters the combustion chamber (cylinder) through the intake valve. The air/fuel mixture is drawn into the cylinder by the suction created as the piston moves from top dead center (TDC) to bottom dead center (BDC). In the Otto cycle, the intake valve is open the entire time the piston is moving from TDC to BDC, and the amount of air is controlled by a butterfly valve in the throttle. Once the air/fuel mixture is drawn in, the intake valve closes, and the fuel/air mixture is compressed by the upward travel of the piston. As the piston approaches TDC, the spark plug fires and ignites the fuel/air mixture. Energy is released causing a rapid increase in pressure in the cylinder which pushes down on the piston which is connected to the crankshaft which is used to turn a drive shaft which can be used, for example, to turn the wheels on an automobile. The efficiency of the engine depends on the compression ratio of the engine which is the volume of the cylinder at BDC divided by the volume of the cylinder at TDC. An engine operating on the Otto cycle has a fixed compression ratio on both the compression and power strokes.

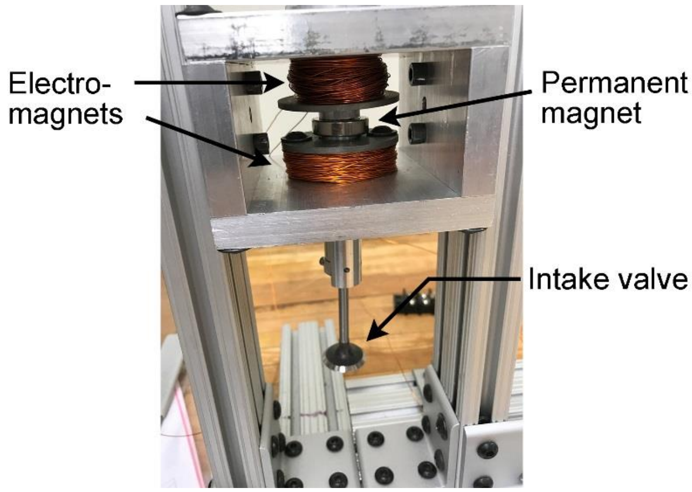
Unless the engine is operating at full throttle, there are “pumping” losses over the throttle. If a technique could be developed to eliminate the throttle and control the amount of air by controlling the amount of time the intake valve is open, the pumping losses could be eliminated. If the time the intake valves is variable, that will result in a variable compression ratio. This approach is called the Miller cycle. An increase in efficiency of about 5% can be obtained by having a variable compression ratio which is significant since most engines operate at about 35% efficiency. The Miller cycle was patented by Ralph Miller in 1957, but has never been widely implemented due to the complexity added to the engine.

Machine Selected for Current Offering

The project for the students was to convert an engine operating on the Otto cycle into one that operates on the Miller cycle. The engine selected for the most recent offerings of the course was the Honda GL 200 engine. This engine is found on many types of home maintenance equipment such as lawn mowers, generators, and pressure washers. It is not really a “historical” machine, but was selected because it was the most appropriate for the project since it only had a single cylinder which would be easier to convert than an engine with multiple cylinders. In the Otto cycle, the intake valve is controlled by a cam. The cam is open and closed for the same percent of time on each cycle of the engine, and the amount of air into the engine is controlled by the throttle. In the Miller cycle, the throttle is eliminated, and the amount of air into the engine is controlled by varying the amount of time the intake valve is open. There have been multiple groups working on the project, and each had a different approach for controlling the intake valve. The three most promising approaches have included an electronic valve actuator, a variable cam system, and a slip-and-recovering mechanism that provides a variable control of the rocker arm.

Approach 1 – Electronic Actuator

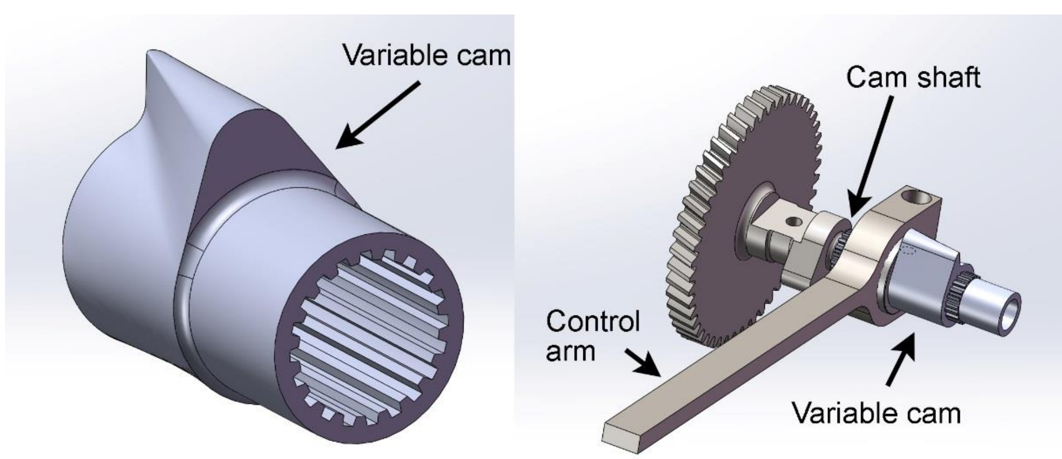
In this approach, the intake valve is removed from the normal mechanical cam that controls the position of the valve, and is attached to an electromagnet paired with a permanent magnet that cycles the valve up at down at a controlled rate and period of opening. Shown below is an image of the test stand that was built for developing and testing the actuator.



The permanent magnet at fixed to the shaft of the intake valve. The permanent magnets have reverse polarity, and are turned on and off by a signal from a computer that is synchronized to the engine speed. The electromagnets cause the permanent magnet to "pop off" the iron core of the electromagnets and move to the opposing side. The rpm and power of the engine is determined by how long the valve is open on the intake stroke of the engine.

Approach 2 – Variable Cam

In the original configuration of this engine, the intake valve was controlled by a fixed-shape cam that moved a pushrod connected to a rocker arm that was then connected to the valve. In the variable cam method, the shape of the cam is variable along the axis of the camshaft, and the cam rides on a splined shaft and can move. The shape of the cam determines when the valve is opened and how long it stays open. With the variable cam system, the timing can be varied by sliding the cam along the cam shaft.



As shown in the figure above, the variable cam slides along the splined cam shaft. In the figure above on the left, an enlarged view of the variable cam is seen.

Approach 3 – Slip and Recovering Mechanism – Variable Control of the Rocker Arm

In the slip and recovering mechanism, a two-piece rocker arm pivots about a center pin until the joint of the two links makes a contact with a separate "rod" (trigger mechanism), thus making the rocker arm collapse. With this method, an operator could control the position of the rod via a wheel to determine where the rocker will slip, thus adjusting the speed of the engine. A torsional spring is used at each end of the rocker arm to return the rocker arm to its initial state once the compression stroke begins to take place throughout the cycle.

Discussion

The purpose of this course is to give undergraduate students an opportunity for hands-on experience in sophisticated engineering applications. For most students, this is a new experience and they are not used to working independently since the typical engineering curriculum is highly structured. In the model used in this class, students are given a topic and are asked to research the topic and develop and implement a solution. The topics described in this paper are fairly difficult. If the implementation were successful, it could have a profound impact on the internal combustion engine industry. The industry is aware of the potential, but as of yet, has not discovered a successful implementation. Thus, there is little to go on for the students.

The authors have found that in the early stages of the project, intense mentoring is required. The instructors must work one-on-one for many hours in the lab to demonstrate even simple tasks such as using hand tools and how to acquire materials. In the three semesters the course has been offered, the authors have found that very little gets done in the first two months of the course, and then there is a flurry of activity in the last month.

Conclusion

The authors have been skeptical of the success of the course as the general feeling among the authors is there seems to be a lot of dead time as the students work independently. On the other hand, students have reported that this is the best class they have taken, and that they learned more in this class than any other. Several students have claimed that they got job offers based on what they did in this class. As a result of that feedback, the course will continue to be offered. In the next offering, we will continue to work on the projects described in this paper, but the instructors will spend a great deal of time mentoring the students at the beginning of the semester to get them over the hurdle of not being able to work independently.,

References

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