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Development of Fuzzy Logic based Ignition Control using Microcontroller

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ABSTRACT

The application of soft computing techniques for spark ignition (SI) engines improves the performance of the system. This paper presents the development of fuzzy logic based ignition control system for a single cylinder SI engine.The fuzzy logic controller (FLC) was designed and developed in Matlab. The inputs to the FLC are engine speed and throttle position and the output is spark angle value. The spark angle value obtained from the Matlab simulation for different engine speeds and throttle position conditions is found to be satisfactory.To validate the simulation results, the FLC is implemented in a microcontroller with ARM7TDMI core. It has been observed that the hardware results match the simulation results. As the control system is programmable, it could be used to enhance the performance of different engines.

Keywords: Electronic Ignition Control, Fuzzy logic controller, Microcontroller.*formatting, style, styling, insert* (key words)

I. INTRODUCTION

One of the research domains in automotive industries is the application of electronics and VLSI Technology for the enhancement of safety, performance, controllability and comfort. The automotive engines are controlled by Electronic Control Units (ECUs) to meet the two primary objectives namely emission standards and fuel economy [5]. The ECU controls the ignition timing based on different variables namely throttle position, engine rpm, and coolant temperature [5]. As in [4], the important factors namely, throttle position and engine rpmare considered in this paper. There is a certain crank angle in the compression stroke which gives maximum torque output when the air/fuel mix is ignited at that point. This angle is the optimal spark angle value. ECU decides this and accordingly fires the spark plugs.The spark timing orignition timing is adjusted by the ECU to enhancetorque and fuel economy [3].

Spark angle is measured in degrees before top dead center. The spark angleinfluences the exhaust emissions, fuel economy and torque [3, 5]. The engine torque is maximumat a particular spark angle. The operation of engine at this angle is desirable as it optimizes the performance. This optimal spark timing varies with engine speed and load. The spark angle has to be increased when the engine speed is high for a constant load. Likewise, the spark angle has to be decreased when the load is low for a given speed. The engine load is specified by the throttle position. The throttle position sensor(TPS) senses the wide open throttle as100 %, which corresponds to a heavy load. Considering these two basic factors, electronic ignition control system uses look-up table approach to obtain a desired spark angle value. If the input parameters do not match the fixed ranges of values, the spark angle value is extrapolated [3].

The different spark timing control techniques like Neural network, predictive control and fuzzy logic are available in the literature. Marin *et al.* applied the fuzzy logic for the computation of ignition time in a

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specific engine [4]. This paper focuses on developing a fuzzy logic controller for electronic ignition system for a single cylinder SI engine. The complete system is simulated in Matlab to obtain the spark angle values. To validate the simulation results, the fuzzy logic controller is implemented in an ARM7TDMI core microcontroller.

II. FUZZY LOGIC CONTROL

Fuzzy logic control is applicable to systems for which the development of mathematical model is complex. Based on the human expertise of a system, a fuzzy inference system is formulated. The decision made by the fuzzy logic depends on the rule base.

Engine Speed Sensor and Throttle Position Sensor are connected to a FLC. The FLC consists of fuzzifier, rule base and defuzzifier[2], [8]. The spark angle value is obtained as the output of defuzzifier. The input physical variable,speed is converted to linguistic variables namely VH(Very High), H(High), VL(Very Low), L(Low) and M(Medium). The next variable,TPS is converted to linguistic variables namely H(High), L(Low) and M(Medium). Fig. 1.a and 1.b show the triangular membership functions ofthe input variables. The speed has five subsets and the TPS has three subsets. A rule table is formulated based. A rule table with fifteen rules isshown in Table 1. The first rule is, if the TPS is L and the speed is VL, then the spark angle value would be VL.

Table I
Rules for electronic ignition control

TPS ↓	*RPM VL*	→ *L*	*M*	*H*	*VH*
L	VL	L	M	VH	VH
M	VL	M	H	H	H
H	VL	L	M	M	H

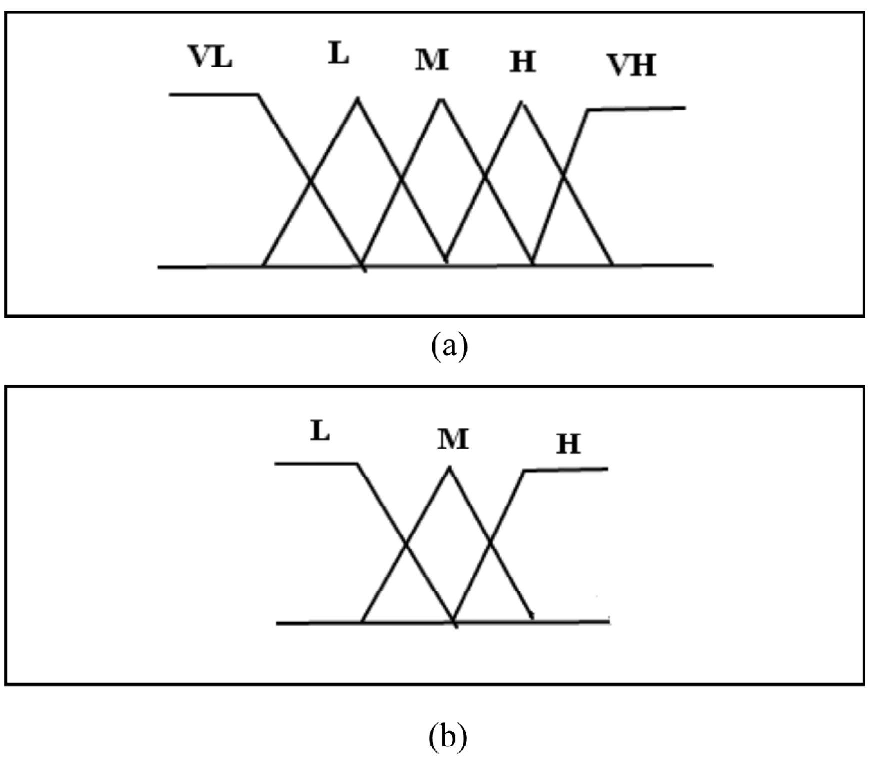

Figure 2: Membership functions for (a) speed and (b) TPS

III. SIMULATION RESULTS

Fig. 3 shows the simulated ignition control system in Matlab. The system has two inputs and one output variable. The system is developed based on Sugenotype fuzzy inference because of its simplicity. The range for engine speed is from 0 to 10000 RPM; the range for TPS is from 0 % to 100 % and it is from 8˚ to 47˚ for spark angle.

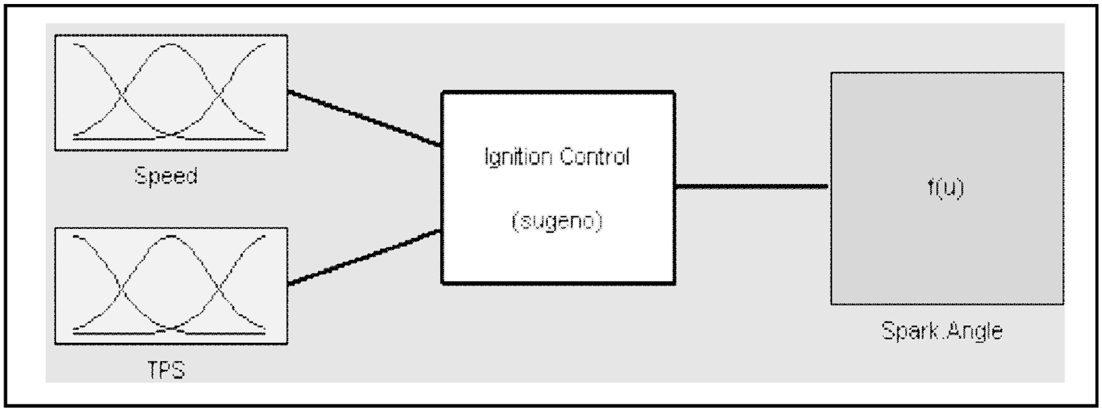

Figure 3: Simulation of Fuzzy logic controller in Matlab

The system is tested for various input variables and the output spark angle value is obtained. In Fig. 4, the spark angle value of 15.7˚ is obtained for Speed=1500 RPM and TPS=25 %. As the load is low, the spark angle value is also low as sufficient time is available for the burning of the air-fuel mixture. Fig.5 shows the spark angle value of 42.5˚ for Speed=8000 RPM and TPS=75 %. In this case, as the speed is high, the spark angle value is high as more time is required for the mixture. The surface plot for TPS, speed and spark angle is shown in Fig. 6. This could be used as ignition map for an engine.

The spark angle value obtained from the simulation meets the requirement specification of the system. Likewise, the system has been verified for various test cases and the result is found to be satisfactory.

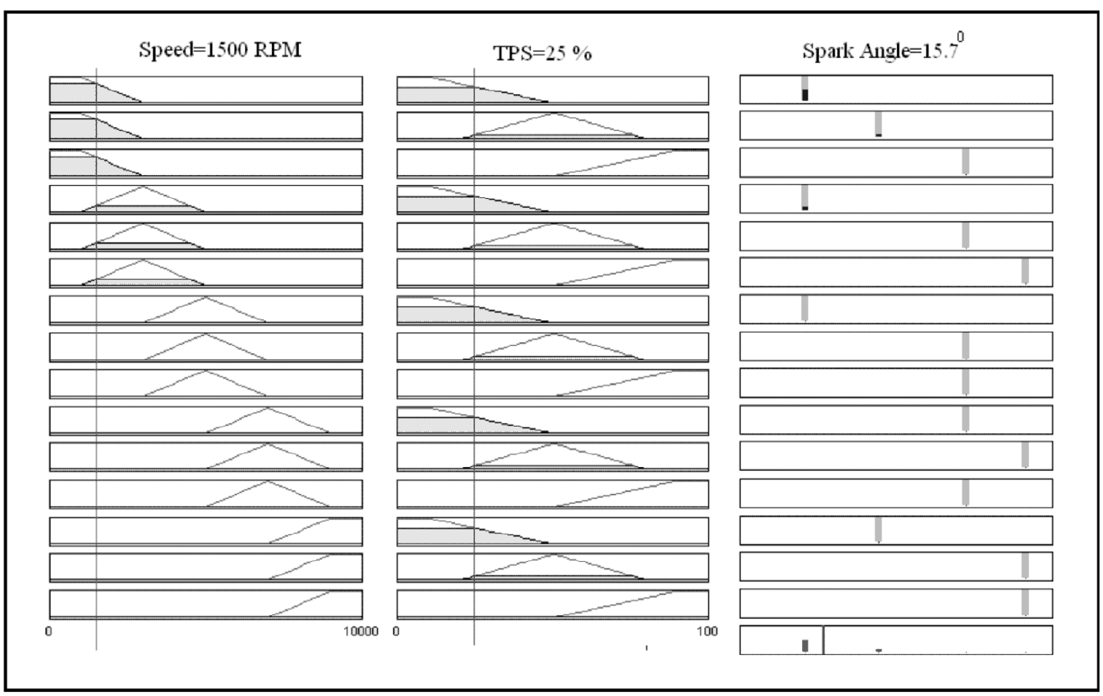

Figure 4: Spark angle value of 15.7˚ for Speed=1500 RPM and TPS=25 %

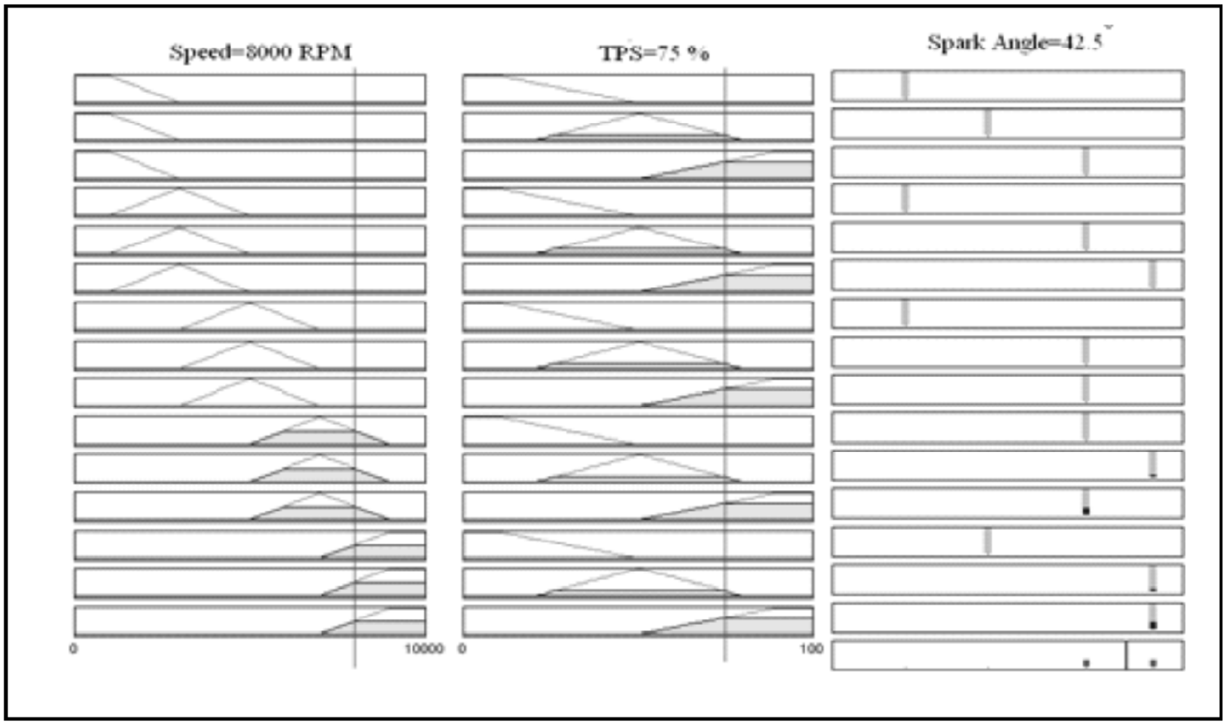

Figure 5: Spark angle value of 42.5° for Speed=8000 RPM and TPS=75 %

IV. HARDWARE IMPLEMENTATION

The fuzzy control algorithm is implemented on an ARM7TDMI based micro-controller. The peripherals that are required to realize the logic include Input/Output Ports, Timer, PWM and UART. The engine speed sensor is mimicked by a square wave generator. The peak value of the waveform is 3.3 V and the frequency can be varied from DC to 20 kHz. The square wave is fed to the capture pin of the microcontroller. The frequency of the waveform is calculated using input capture module and it is mapped to the engine speed in rpm. The throttle position sensor is mimicked by a potentiometer (POT). A value of 3.3 V from the POT corresponds to a wide open throttle and 0V to a closed throttle. The output terminal of the POT is fed to analog pin of the microcontroller. The digital value is scaled and mapped to throttle position in %.After fuzzification and de-fuzzification, the output of a FLC is the spark value, which is a mere number. The spark angle value is loaded to a duty cycle register of the microcontroller to generate a pulse-width modulated

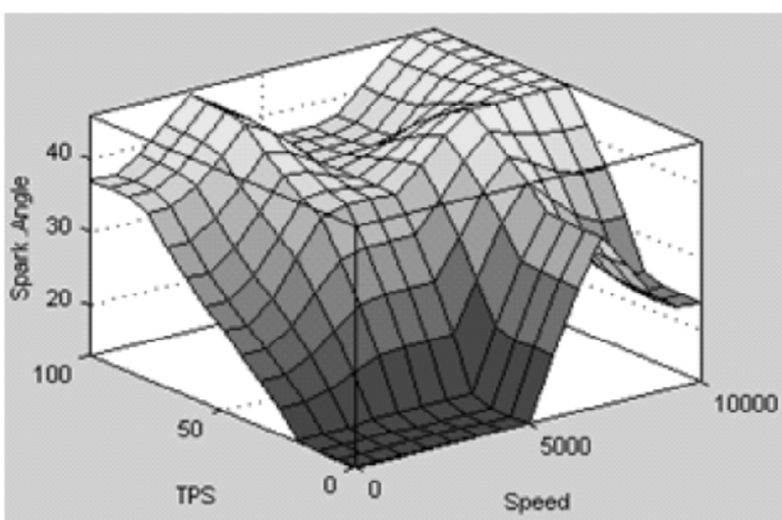

Figure 6: Surface plot for TPS, Speed and Spark angle

(PWM) waveform. This pulse has to be applied to the spark plug after amplification by an IGBT based driver circuit. The hardware setup is shown in the Fig. 7.

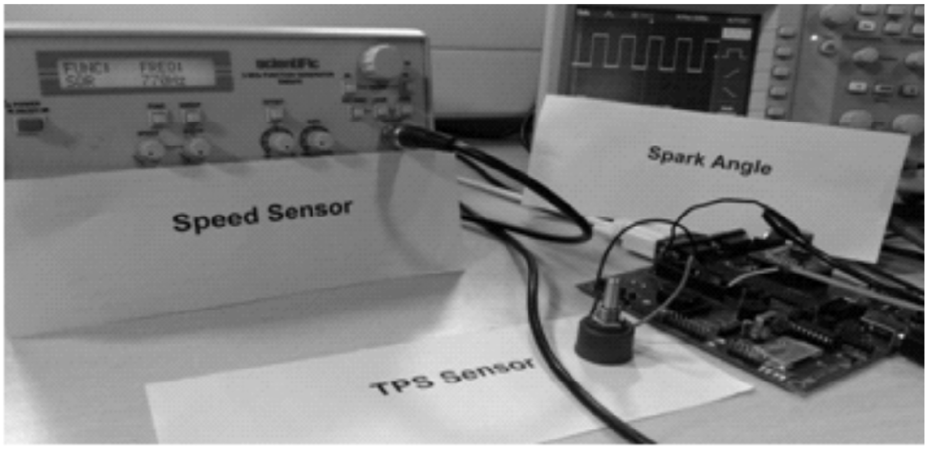

Figure 7: Hardware set up of spark ignition system

A software is developed in C to implement the fuzzy logic in the microcontroller. The Algorithm to implement the code is given below:

1. Compute speed in RPM using capture module
2. Compute the throttle position in % using analog to digital converter.
3. Fuzzify the input variables using functions
4. De-fuzzify the fuzzy variables using centre of gravity method
5. Conversion of the spark value to a duty cycle
6. Generate a PWM waveform that corresponds to ignition pulses
7. Goto step 1

Figure 8 shows the ignition pulses that are obtainedfrom the microcontroller. The results obtained matches with the simulation results.

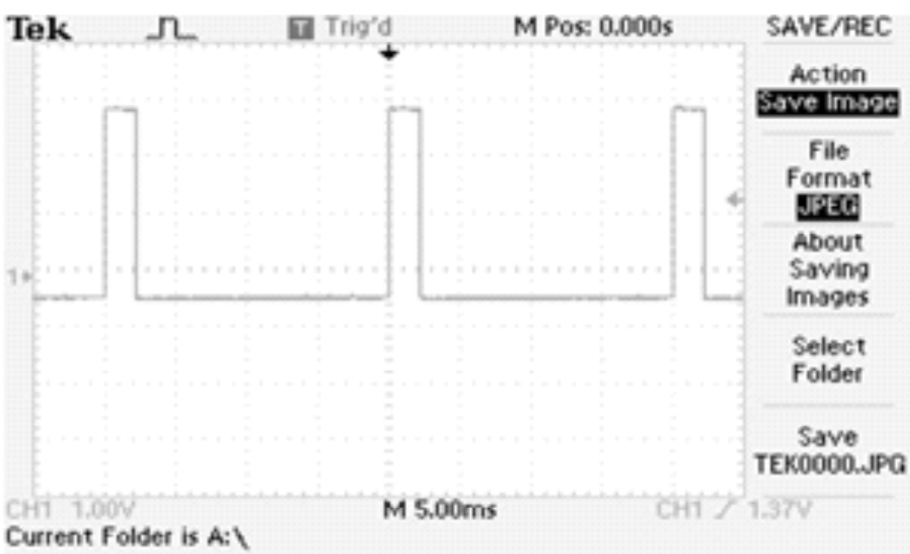

Figure 8: Ignition pulses from the microcontroller for the spark angle value of 42.5°

V. CONCLUSION

The application of soft computing techniques such as Fuzzy logic, Neural Network etc., for spark ignition (SI) engines improves the performance of the system. This paper presents the development of fuzzy logic based ignition control system for a single cylinder SI engine. The simulation has been carried out in Matlab for different engine speeds and throttle position conditions. The spark angle value is obtained from the fuzzy logic controller and it is found to be satisfactory. To validate the simulation results, the fuzzy logic algorithm is implemented in a microcontroller with ARM7TDMI core. It has been observed that the hardware results match the simulation results. The accuracy of the fuzzy logic system could be improved if more number of fuzzy subsets and rules is considered. As the control system is programmable, it could be used to enhance the performance of different engines.

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