Design and Implementation of Fuel Metering Unit for an Aero Engine

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Abstract - *In this novel we design a program using Labview software is designed and implemented on a FPGA system to control the fuel flow of an Aero engine. Fuel flow of an engine varies with an ambient condition such as temperature, pressure and the amount of fuel flow to the engine is different at various altitudes. Fuel system is one of the most important subsystems of aircraft and engine control unit which forms the base for fuel control. Our aim is to develop a closed loop control system which responds to the subsequent changes or disturbance in the system environment such as speed, temperature and pressure sensors are used to sense these ambient conditions, which is compared with the desired operating parameters and allow the user to set the desired operating state as a reference and also allow the control unit to control the Fuel system to the desired operating point with the help of NI based controller with FPGA processor.*

***Key Words*: FPGA, Fuel Flow Control, Stepper Motor, etc…**

I. INTRODUCTION

In this paper our main Aim is to design an Aero Engine Control System [2] for controlling Fuel Flow to the combustion chamber by using Stepper Motor, to control the speed of plane by monitoring critical Exhaust temperature and Compressor pressure. Stepper motor has many advantages then other types of motors, most important is rotates accurate angles or step based on command pulses. The speed of stepper motor can be readily controlled based on the pulse, enable stepping motor to achieve the variable speed synchronous movement of load is directly coupled to drive shaft of motor. For particular application of stepper motor and electromechanical actuator, the stepper motor size is selected and is determined by the nominal operating load range encountered.

The stepper motor is capable of receiving the digital signals and is to generate a corresponding angle variation in proportion to total number of pulses, the stepping motor is driven by an open loop without utilizing a feedback mechanism. Therefore, the stepping motor can be easily controlled when stepping motor is driven to achieve a rotational speed within acceptable range. For smooth functioning of engine, it is highly desirable to provide a reliable speed regulation and over speed protection mechanism of engine. Aero engine is extremely reliable when properly varied they can deliver years of safe light [1] Before Electronic Control Unit(ECU), air /fuel mixture, ignition timing and idle speed were mechanically set and dynamically controlled by mechanical and pneumatic means. An ECU commonly known as "Power train control module" (pcm), that controls a series of actuators on an internal combustion engine to ensure optimal engine performance. Depending upon the type of engine control system, its function may also include holding the engine speed at specific constant levels such as idle rpm or maximum/minimum speeds within a specific band or the entire range between idling and maximum speed [3].

II. METHODOLOGY

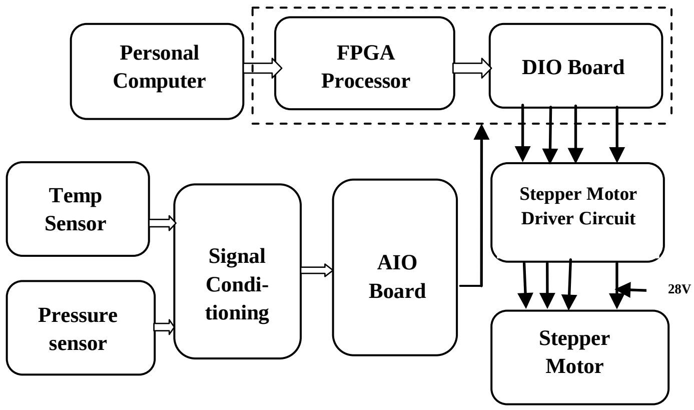

Fig-1: Block Diagram of the System

The Fig 1 consists of the following units

1. A Temperature sensor (thermocouples and RTD's) are used to measure the temperature of various parts of engine.
2. Pressure sensor is a device which senses pressure and converts it into an analog electric signal whose magnitude depends upon the pressure applied, since they convert pressure into an electrical signal, they are also called as pressure transducers.
3. A signal condition which manipulates the signal in a way that prepares it for the next stage of processing.
4. Fuel metering unit stepper motor is to control the speed by monitoring the incoming fuel to the engine. It consists of stepper motor and stepper motor is controlled by software control law's using labview.

5. Personal computer: A program is designed in labview software and dumped into FPGA using USB.
6. FPGA: Designed program is interfaced using FPGA processor. It is used for fast switching process. FPGA it belongs to the family of kintex-7, with the clock frequency of 50MHZ.It gives faster input output response time and specialized functionality.
7. Digital input output board: It is used for switching of the signals, In analog signals because of slope accurate value is not obtained so digital signals are used which has accurate value of 0-5v.
8. Base drive circuit Stepper motor requires large value of voltage to drive a circuit, so base drive circuit is used to obtain a required voltage of 28v.
9. Stepper motor Based on the demand it controls the fuel of aero engine which in turns controls the speed.

2.1 STEPPER MOTOR

Stepper motor or step motor is a brushless DC electric motor that divides a full rotation into a number of equal steps. The motor's position can then be commanded to move and hold at one of these steps without any feedback sensor an open-loop controller, as long as the motor is carefully sized to the application. Stepper motor is known by its important property to convert a train of input pulses i.e. a square wave pulse into a precisely defined increment in the shaft position. Each pulse moves the shaft through a fixed angle. Each rotation is called a step, with an integer number of steps making a full rotation. In this way, the motor can be turned by a precise angle.

2.2 STEPPER MOTOR DESCRIPTION AND FEATURES

The 3 phase stepper motors are extremely robust, maintenance free drives. They carry out step by step movements which are controlled by a positioning controller. The 3 phase stepper motors can be operated at very high resolutions with appropriate control electronics. Options such as rotation monitoring and holding brake with robust, low play, planetary gear extends the application options.

The 3 phase stepper motors are

1. **Powerful:** The optimized internal geometry of the motor offers a high power density i.e. up to 50% greater torque as compared to conventional stepper motors of comparable size.
2. **Silent:** The sine communication of the drive and the special mechanical design result in a very quiet and virtually resonance-free stepper motor.
3. **Versatile:** With a flexible modular system and modern variant management, a wide variety of motor types can be manufactured and delivered in a very short time.

2.3 SM POSITION AND CONNECTIONS

Stepper motor is placed inside the fuel pump of the engine. Fuel pump of the engine receives the fuel from fuel inlet and which is pumped from a low pressure to high pressure. Stepper motor rotating axis is connected a moving plate which covers the fuel inlet. This moving plate is known as camplate. When stepper motor is rotating in a clockwise direction camplate moves in a forward direction and vice versa. So opening and closing of the inlet depends on the direction of the stepper motor. Direction of the stepper motor depends upon signal it is receiving from the stepper motor drive circuit. Dependence of the direction of SM on drive circuit will be explained in the next part. And this drive circuit receives the command from a microcontroller which is in the processor of ECU. This controller takes the command from the pilot and compares it with the present values and gives command to the SM to either vary or to maintain a fuel supply. This gives the main implementation of the engine control.

2.4 STEPPER MOTOR SPECIFICATION

Stepper motor used here is a 3-phase stepper motor. General structure of winding inside this SM is shown in the Fig 2. The output voltage of this driver circuit is 3.3V. But for the FPGA to detect this signal is quite impossible since it needs much stronger signal for its proper working. Hence we design a driver circuit which gives around 28V as the output of this stepper motor.

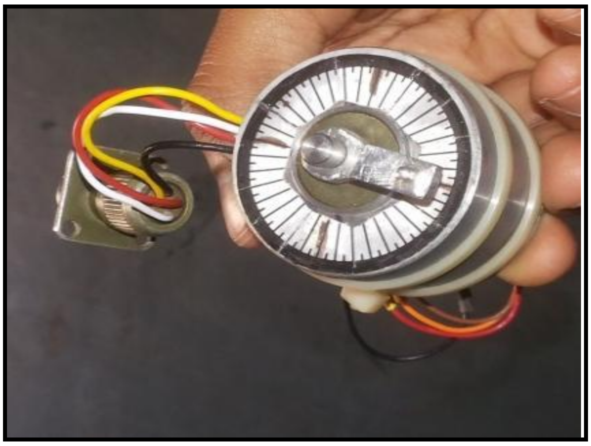

Fig-2: Stepper Motor

A TIP-122 transistor is used for driving the circuit, since they withstand high power loads. This transistor is driven by giving the base voltage of 5V. The stepper motor connections are given to the collector and the emitter is grounded. The three phases A, B and C are connected to SM-A, SM-B and SM-C as shown in the figure. This circuit gives 28V as the output. This is easily detected by the FPGA. Stepper motor can be operated in 2 modes, clockwise and counter clockwise [7].

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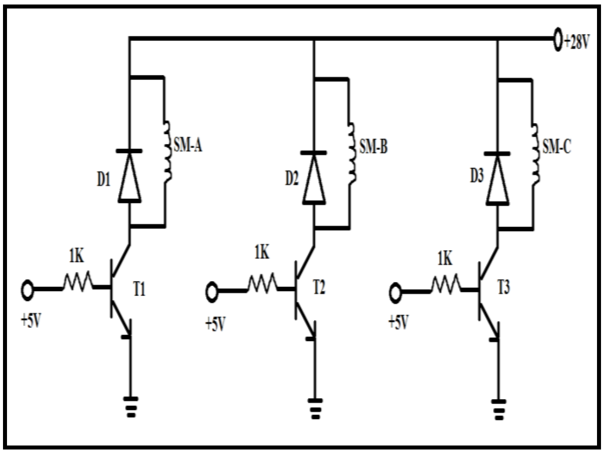

Fig-3: Stepper Motor Driver Circuit

Mode 1: Clockwise direction

The camplate moves in direction such that it increases the fuel supply which results in the increase of the frequency of engine.

Mode 2: Counter Clockwise direction

The camplate moves in direction such that it decreases the fuel supply which results in the decrease of the frequency of engine. By deciding the direction of stepper motor fuel supply can be varied accordingly. The table shows the sequence of the stepper motor in forward and reverse directions.

Then stepper motor rotates in counter clockwise direction. Thus the direction of rotation of stepper motor is determined by the status bits. The program for this is explained later. The stepper motor can withstand load up to 300kg N and maximum current capacity is 1A. The stepper motor used here first resets to 250 steps and then moves forward according to the feedback obtained, if the feedback is positive the stepper motor moves in forward direction; if the feedback is negative the stepper motor moves in reverse direction. 1 step = 0.8o The stepper motor maximum time consumption between each step is around 10msec, we have designed for this time limit. The RPM of the engine is found using the equation,

RPM = Number of cycles * 60 / Number of teeth

Table-1: Status Bit Diagram for Clockwise Direction

A	B	C	STEP
1	0	0	4
1	1	0	6
0	1	0	2
0	1	1	3
0	0	1	1
1	0	1	5

Table-2: Status Bit Diagram for Counter Direction

A	B	C	STEP
1	0	1	5
0	0	1	1
0	1	1	3
0	1	0	2
1	1	0	6
1	0	0	4

III FRONT END – LABVIEW

3.1 Reset Operation

1. The reset operation is performed in a while loop with I iterations and also a timer is added.
2. Initially the steps are compared with the overall steps (250 steps) if greater than 250 steps then the stepper motor will stop.
3. If a stop condition is given, then the stepper motor is forced to stop.
4. The iteration value is divided by 6 and the remainder is taken and multiplied by 3 since stepper motor needs 3 inputs to get activated at a time so the multiplied value is incremented and fed as an input to stepper motor to rotate to the 0th position.
5. The throttle valve in the engine determines the rate of flow of fuel, which is controlled by a stepper motor of 250 steps. These operations are done in a flat sequence, one after the other. The first part is to reset the stepper motor, and the second part is to initialize it to the first position.

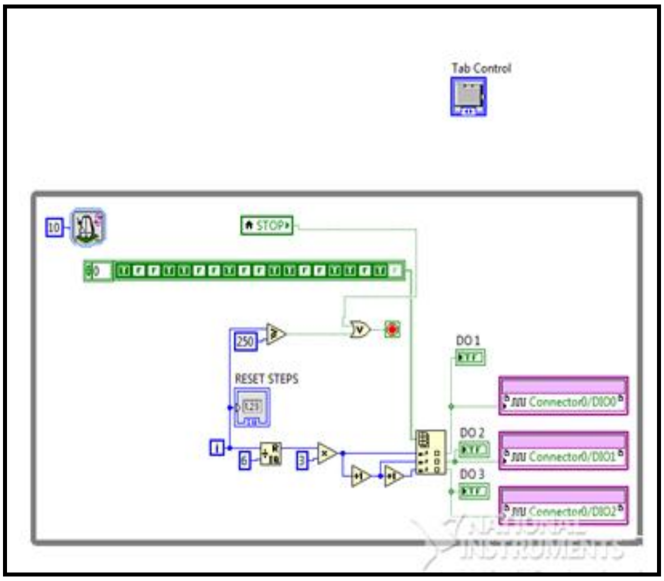

Fig-4: Front End- Labview Reset Operation

The stepper motor program is designed as shown above using LabVIEW software. The program has mainly two cases:
1. Resetting the Stepper Motor
2. Forward and Reverse rotation of Stepper Motor

RESETTING THE STEPPER MOTOR

The stepper motor first resets to 250 steps and then the demand is met according to the signals acquired by the acquisition system, the stepper motor sequence is given to index array where single step sequence is monitored, then the steps are given to the three phases of the stepper motor.

3.2 START COMMAND

Forward and Reverse Rotation:

The sequence is 4, 6, 2, 3, 1, and 5. When the demand is positive the stepper motor rotates in forward direction and moves according to the sequence mentioned above. The sequence is 5, 2, 1, 3, 6, and 4. When the demand is negative the stepper motor rotates in reverse direction and moves according to the sequence mentioned above. The demand here is met according to the signals acquired by the acquisition system, the original stepper motor sequence is first reversed and then the steps are given to the three phases of the stepper motor so that the stepper motor rotates in reverse direction. The start command from the pilot is used to control a case structure, which determines whether the demand as to be taken for further execution or not. These case structures are controlled by a Boolean variable.

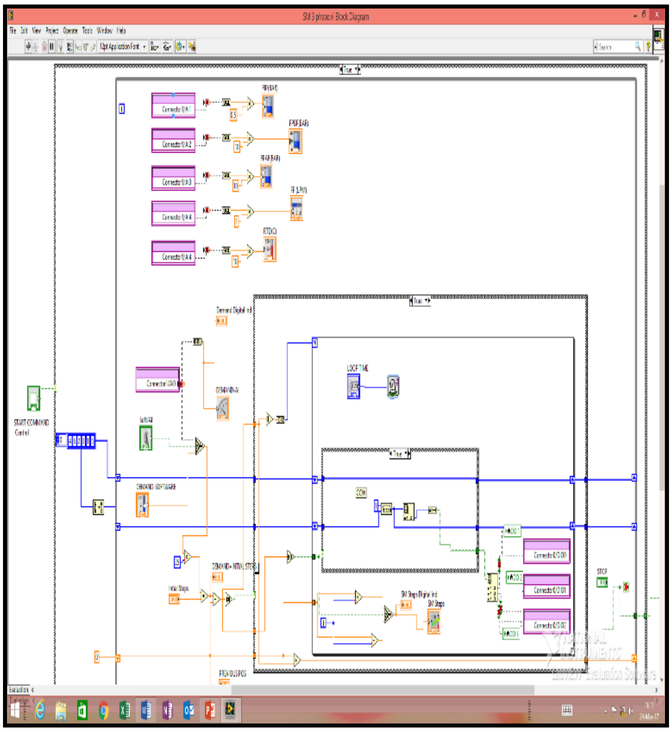

Fig-5: Overall Block of Start Command

IV SOFTWARE AND HARDWARE USED

4.1 Labview

Lab VIEW (short for Laboratory Virtual Instrument Engineering Workbench) is a System-design platform and development environment for a visual programming language from National Instruments. The graphical language is named "G" (not to be confused with G- code). Originally released for the apple Macintosh in 1986, Lab VIEW [5] is commonly used for data acquisition, instrument control, and industrial automation on a variety of platforms including Microsoft Windows, various versions of UNIX, Linux, and Mac OS X. The latest versions of Lab VIEW 2014, released in August2014.

4.2 FPGA: (Field Programmable Gate Array)

It is an integrated circuit designed to be configured by a customer or a designer after manufacturing - hence "FIELD PROGRAMMABLE" [6]. The FPGA configuration is generally specified using a Hardware description language (HDL), similar to that used for an Application-specific integrated circuit (ASIC).

FPGA's contain an array of programmable logic blocks, and a hierarchy of reconfigurable interconnects that allow the blocks to be "wired together" -, like many logic gates that can be interwired in different configurations. Logic blocks can be configured to perform complex combinational functions, or merely simple logic gates like AND and XOR. In most FPGAs, logic blocks also include memory elements, which may be simple flip-flops or more complete blocks of memory.

APPLICATIONS

1. Used for defence aircrafts
2. Used in civilian aircrafts
3. Used in marine applications
4. Same concept to other automobiles

ADVANTAGES

1. Efficient monitoring & control system
2. Real time transfer of data which helps in monitoring the parameters constantly & accurately
3. Cost effective
4. Time efficient
5. Easy to construct & install
6. Consumes less energy
7. Increase the overall efficiency of the system
8. Works at high speed
9. These systems there was no control unit, person present in the earth station use to guide the movement of an aircraft to the pilot, hence control systems are used in order to avoid limitation.

V RESULTS

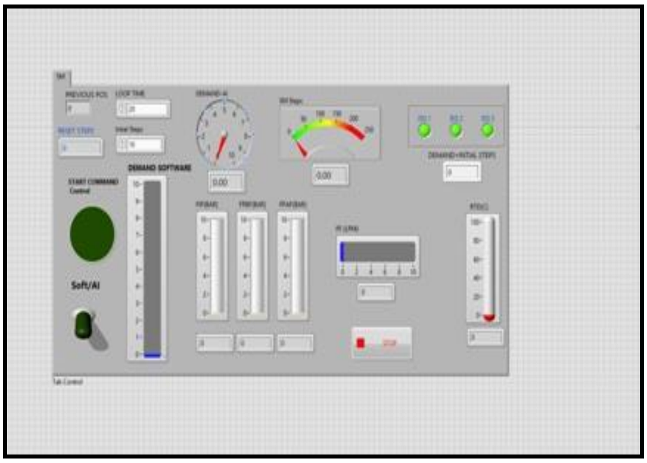

Fig-7: Front Panel of Stepper Motor

The above diagram depicts the final output of the FPGA where the Demand and the Feedback will be almost same. Various parameters such as Flow Meter, and Stepper Motor Steps is shown.

VI CONCLUSION

The program is developed in Labview and implemented it on a FPGA system to control the flow of the fuel into the engine of an aircraft. This system takes in the real time analog signal from the potentiometer and converts it to the corresponding number of steps to rotate the stepper motor so as to control the throttle valve of the fuel control unit. There are number of generally accepted stages in the design, development, manufacture and operation of aircraft, each with associated design methods and data requirements. The possibility of lowering the cost of fuel control systems for gas turbine engines is high and the main areas of research have also been determined regarding this. In general, the modern electric/electronic technology will be employed since there is no doubt that such systems will prevail in the future.

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