

Aircraft Structural Testing Based on Digital PID Controller

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Abstract

Structural testing of aircraft components involves extensive use of electro hydraulic actuators. Electro hydraulic actuators can be operated in either load or position control modes. For precise control of load and position, feedback elements such as a load cell and potentiometer are used respectively. Structural testing of aircraft structural components mainly involves the simulation of aerodynamic loads. Aerodynamic loads are applied using Electro-hydraulic servo actuators.

Keywords: Data Acquisition; SCADA, remote monitoring

INTRODUCTION

The operation of closed-loop servo system is the most common type in the Navy today. It is normally made up of electromechanical

parts and consists basically of a synchro-control system, servo amplifier, servo motor, and some form of feedback (response) as shown in figure 1.

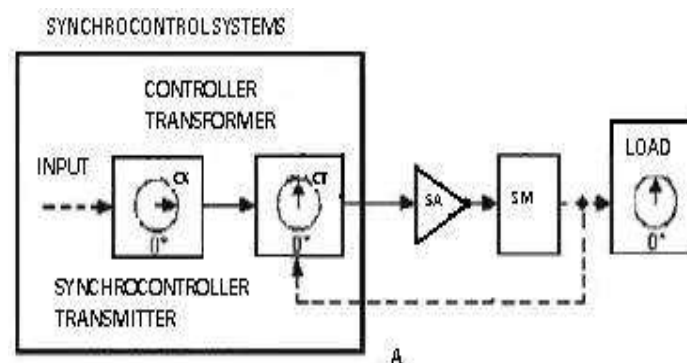


Figure 1. Basic servo system

Servo control, which is also referred to as "motion control" or "robotics" is used in industrial processes to move a specific load in a controlled fashion. These systems can use pneumatic, hydraulic, or electromechanical actuation technology. The choice of the actuator type (i.e. the device that provides the energy to move the load) is based on power, speed, precision, and cost requirements. Electromechanical systems are typically used in high precision, low to medium power, and high-speed applications. These systems are flexible, efficient, and cost-effective. Motors are the actuators used in electromechanical systems. Through the interaction of electromagnetic fields, they generate power.

This type of system is a feedback system, which is used to control position, velocity, and/or acceleration. The controller and some of our digital drives contain the algorithms to close the desired loop (typically position or velocity) and also handle machine interfacing with inputs/outputs, terminals, etc. The drive or amplifier closes another loop (typically velocity or current) and represents the electrical power converter that drives the motor according to the controller reference signals. The motor can be of the brushed

or brushless type, rotary or linear. The motor is the actual electromagnetic actuator, which generates the forces required to move the load. Feedback elements such as tachometers, lvdts, encoders and resolvers, are mounted on the motor and/or load in order to close the various servo loops.

The paper proposes to design a digital PID controller for aircraft structural testing. This system is made specifically for load and position control of aircraft structures by incorporating the PID control mode.

PROBLEM ANALYSIS

Many of the analog industrial controllers commercially available today realize the following interacting (the controller have derivative and integral action applied serially to the controlled variable) resulting in interaction between them although proportional gain affects all the three modes. As there is no extra cost in programming all the three models of control, most computer based algorithms contain all the three and then we use flags and logic to allow the process engineer to specify any signal mode or a combination of two or the modes. Many computer controllers use the non interacting version of PID control and some allow the option of either non interacting or

interacting version of PID control.

A digital control system is comprised of a digital controller, the controlled plant (or system), and the necessary input/output devices. There are several advantages of using a digital controller implementation instead of an analog one. In the case of digital controllers, complex control algorithms can be implemented in software or firmware rather than in special hardware. Digital controller designs and parameters can be changed without affecting the hardware. In digital control systems increased noise immunity is guaranteed and parameter drift is eliminated. Such systems are more reliable, maintainable, and testable. Finally, digital control systems feature reduced size, power, weight and costs.

RELATED THEORY

Aircraft structures are high performance structures designed to have finite life. Based on their application, aircraft structures are classified as:

- 1) Transport aircrafts are used to carry passengers and cargo.
- 2) Fighter aircraft are used for military applications.

Typical transport aircraft is as shown in Fig and it consists of following parts.

- a) Fuselage (body).
- b) Wing (airfoil).
- c) Empennage (tail).
- d) Landing gear.
- e) Power plant

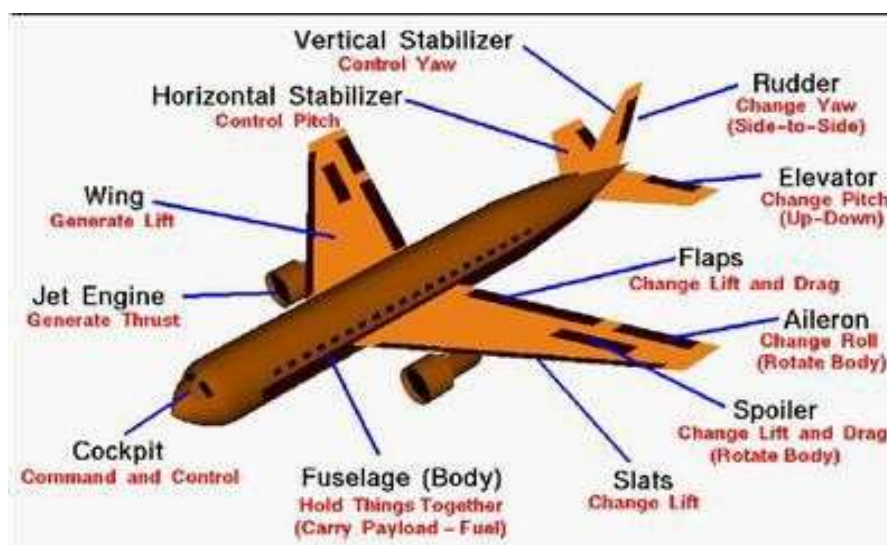


Figure 2. Typical Aircraft Structures

The fuselage includes the cabin and/or cockpit, which contains seats for the occupants and the controls for the airplane. In addition, the fuselage may also provide room for cargo and attachment points for the other major airplane components. The wings are airfoils attached to each side of the fuselage and are the main lifting surfaces that support the airplane in flight. There are numerous wing designs, sizes, and shapes used by the various manufacturers. Wings may be attached at the top, middle, or lower portion of the fuselage. These designs are referred to as high-, mid-, and low-wing, respectively.

The correct name for the tail section of an airplane is empennage. The empennage includes the entire tail group, consisting of fixed surfaces such as the vertical stabilizer and the horizontal stabilizer. The landing gear is the principle support of the airplane when parked, taxiing, taking off, or when landing. The most common type of landing gear consists of wheels, but airplanes can also be equipped with floats for water operations, or skis for landing on snow. The power plant usually includes both the engine and the propeller. The primary function of the engine is to provide the power to turn the propeller. It

also generates electrical power, provides a vacuum source for some flight instruments, and in most single-engine airplanes, provides a source of heat for the pilot and passengers.

BLOCK DIAGRAM DESCRIPTION

A typical load controlled hydraulic system consists of a power supply, flow control valve, linear actuator and electronic servo-controller. Input command is obtained from the function generator and given to the microcontroller. The servo controller compares the signal from the feedback load cell with an input demand to determine the load error, and produces a command signal to drive the flow control valve.

The control valve adjusts the flow of pressurized oil to move the actuator until the desired load is attained: a condition indicated by the error signal falling to zero.

A position controlled hydraulic system operates in a similar way, except that the oil flow is adjusted to achieve an output position, measured by a suitable displacement transducer.

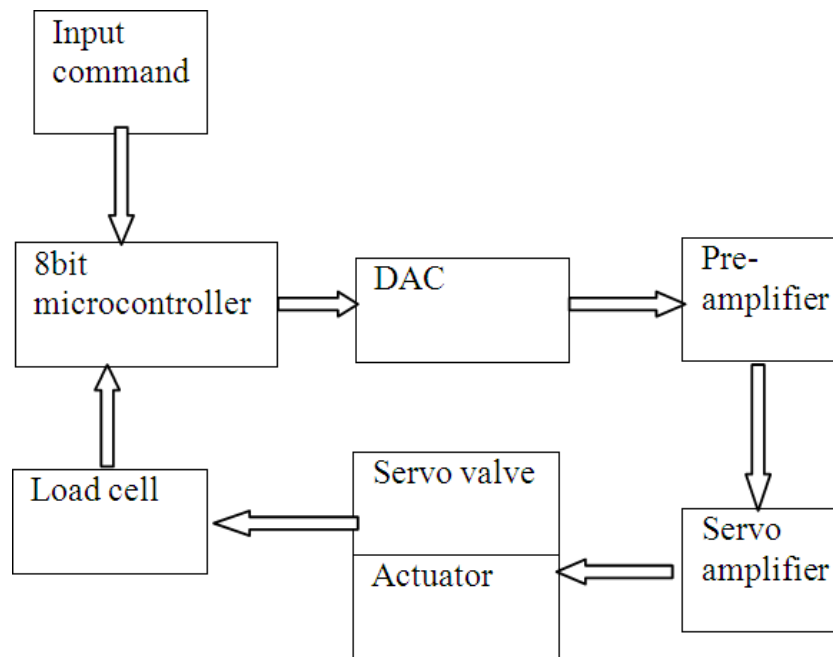


Fig. 3.Functional Block Diagram

A. AT mega 32 Micro-controller Features

- High-performance, Low-power Atmel®AVR® 8-bit Microcontroller
- Advanced RISC Architecture
- High Endurance Non-volatile Memory segments
- In-System Programming by On-chip Boot Program
- True Read-While-Write Operation
- 8 Single-ended Channels
- I/O and Packages
- 32 Programmable I/O Lines

- 40-pin PDIP, 44-lead TQFP, and 44-pad QFN/MLF
- Operating Voltages
 - 2.7V to 5.5V for ATmega32L
 - 4.5V to 5.5V for ATmega32
- Speed Grades
 - 0 to 8MHz for ATmega32L
 - 0 to16MHz for ATmega32
- Power Consumption at 1MHz, 3V, 25°C
 - Active: 1.1mA
 - Idle Mode: 0.35mA

Power-down Mode: < 1µA

B. Digital To Analog Converter (DAC)-0808

The DAC0808 series is an 8-bit monolithic digital-to-analog converter (DAC) featuring a full scale output current settling time of 150 ns while dissipating only 33 mW with 5V supplies. No reference current (I_{REF}) trimming is required for most applications since the full scale output current is typically 1 LSB of 255 I_{REF}/ 256. Relative accuracies of better than 0.19% assure 8-bit monotonicity and linearity while zero level output current of less than 4 mA provides 8-bit zero accuracy for I_{REF} 2 mA.

The power supply currents of the DAC0808 series are independent of bit codes, and exhibits essentially constant device characteristics over the entire supply voltage range. The DAC0808 will interface directly with popular TTL, DTL or CMOS logic levels, and is a direct replacement for the MC1508/MC1408

C. Pre-Amplifier and Servo-Amplifier

The servo-valve is driven by a composite signal. This voltage signal needs conversion to an analogous current signal as the valve is current driven. Hence the valve is basically a transconductance amplifier. The servo valve coil takes a current input

in the range of -50mA to +50mA. The error voltage at the input has to be converted into a proportional current at the output of the driver. Since input to the driver is a voltage varying according to the command signal the driver circuit should be able to convert the varying voltage into proportionally varying current.

For a varying voltage say a step voltage input, the current can only rise very slowly and if there is a variation in the input voltage when the current is just reaching the current level for the previous voltage input, follows the new voltage input. To avoid this, the current is stepped up through a differential amplifier. An op-amp can deliver only a limited amount of current where as the requirement is 50mA. So a transistor circuit is used to boost the current level to the required 50mA.

Transistor Q1 and Q2 are used. When the input is positive Q1 boost the current level and the voltage is negative Q2 take care of current boosting. The output current is converted into voltage and fed back to the non-inverting terminal of the differential amplifier. The amplifier amplifies the differential voltage and the output current changes accordingly towards the required level. Freewheeling diodes are used to prevent any damage to

the circuit when the current changes direction and flows in to the circuit. The servo valve is connected between the current output and the feedback points.

D. Servo-Valve

In the context of hydraulic servo-systems, flow control valves fall broadly into two main categories: proportional valves and servo-valves.

- 1) Proportional valves use direct actuation of the spool from an electrical solenoid or torque motor
- 2) Servo-valves use at least one intermediate hydraulic amplifier stage between the electrical torque motor and the spool.

A major advantage of proportional valves is that they are largely unaffected by changes in supply pressure and oil viscosity. However, the relatively large armature mass and large time constant associated with the coil means that these valves generally have poorer dynamic performance compared with servo-valves of equivalent flow characteristics. The basic servo-valve produces a control flow proportional to input current for a constant load. While the dynamic performance of a servo-valve is influenced somewhat by

operating conditions (supply pressure, input signal level, fluid and ambient temperature and so on) a major advantage is that load dynamics do not affect stability, unlike single stage proportional valves.

Servo valves usually have superior dynamic response, although their close internal machining tolerances make them relatively expensive and susceptible to contamination of the hydraulic fluid. Two stage servo- valves may be further divided into nozzle- flapper and jet pipe types. Both use a similar design of electromagnetic torque motor, but the hydraulic amplifier circuits are radically different. Nozzle-flapper type servo-valves are currently by far the most common in high performance servo applications.

E. Linear Hydraulic Actuator

A hydraulic actuator is a device which converts hydraulic energy into mechanical force or motion. Actuators may be divided into those with linear movement (sometimes called rams, cylinders or jacks), and those with rotary movement (rotary actuators and motors). Linear actuators may be further sub-divided into those in which hydraulic pressure is applied to one side of the piston only (single acting) and are capable of

movement only in one direction, and those in which pressure is applied to both sides of the piston (double acting) and are therefore capable of controlled movement in both directions

LOAD CELL

A load cell is a transducer that is used to convert a force into electrical signal. The most common type is a strain gauge load cell. A strain gauge is a device used to measure strain of an object. The most common type of strain gauge consists of an insulating flexible backing which supports a metallic foil pattern. The gauge is attached to the object by a suitable adhesive.

As the object is deformed, the foil is deformed, causing its electrical resistance to change. The resistance change is commonly measured using a Wheatstone bridge.

A Wheatstone Bridge is an electrical circuit. Used in a load cell to measure an overall change in resistance. Increases sensitivity and reduces the affects of temperature The output obtained from the load cell is an analog output measured in terms of voltage. And the voltage varies from 0-5V. And this voltage is feedback to the ADC of ATmega32 microcontroller

THE PID CONTROLLER

A feedback controller is designed to generate an output that causes some corrective effort to be applied to a process so as to drive a measurable process variable, $y(t)$, towards a desired value, known as the set- point or reference, here noted $r(t)$. The concept is based, as shown in on the re- input of the system own output according to certain laws (hence the name 'feedback'). It is desired for the system output to follow the reference $r(t)$. All feedback controllers determine their output by observing the difference, called error, here noted $e(t)$, between the set point and the actual process variable measurement. This theory is valid for a wide class of systems, which include, but is not restricted to, linear systems.

For the class of the linear systems, a very widely used controller is the PID (Proportional Integral Differential). The PID looks at (a) the current value of the error, (b) the integral of the error over a recent time interval, and (c) the current derivative of the error signal to determine not only how much of a correction to apply, but for how long. Each of those three quantities are multiplied by a 'tuning constant' and added together [1]. Thus the PID output, $c(t)$, is a weighted sum as shown in figure 6

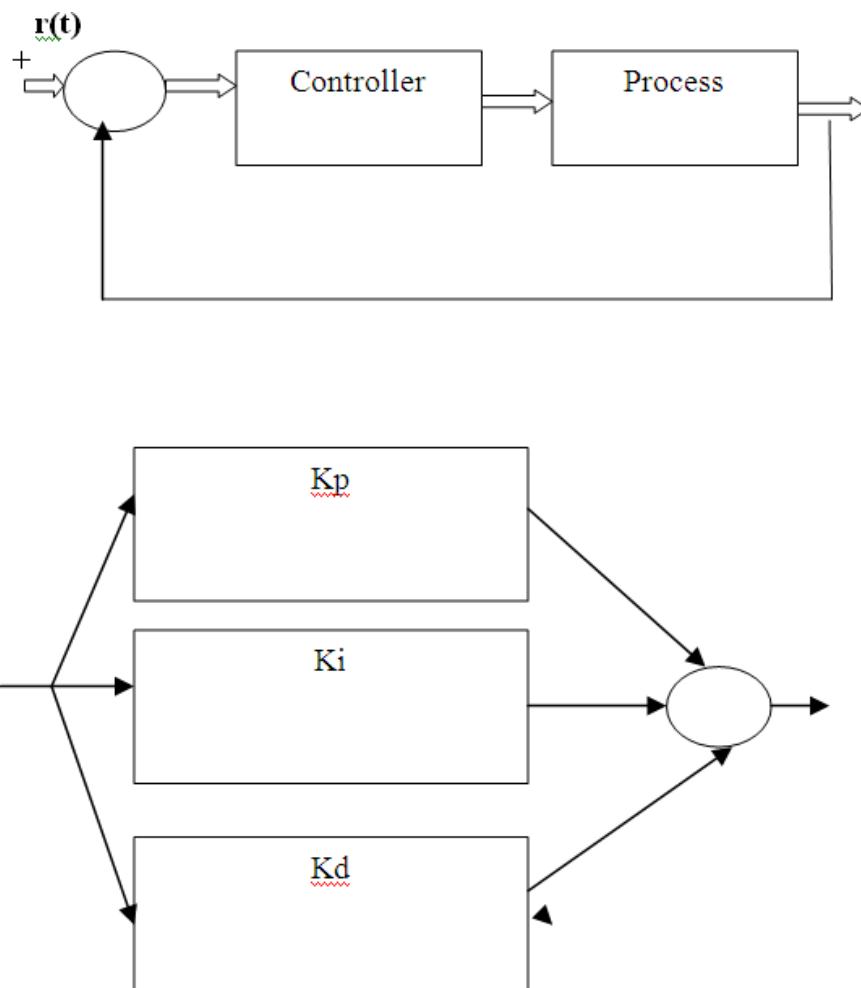


Fig 4.

Depending on the application one may want a faster convergence speed or a lower overshoot. By adjusting the weighting constants, k_p , k_i and k_d , the PID is set to give the most desired performance

SOFTWARE IMPLEMENTATION

In the beginning of the main program, the controller parameters are initialized. The program consists of the functions Initialize_Timer, Initialize_Read_ADC,

and the interrupt service routine (ISR). The timer is initialized in such a way that it interrupts every 10 ms. As ISR routine is entered, it is first checked if 10 interrupts are over i.e. 100ms is lapsed (ensuring that controller sample time is 100ms) and then the Initialize_Read_ADC function is called which initializes the ADC and reads the analog i/p from the load cell and after converting it to digital value stores it in variable y_k . The error e_k is then calculated

and the PID algorithm is then implemented. The controller output u_k is sent to the DAC by enabling the DAC and also taking into consideration that the D/A converter is limited to full scale, i.e. 255. After sending an output to D/A, the DAC

is disabled to latch the current value so that it doesn't change accidentally. The variables are then updated and at the end the ISR routine re-enables the timer interrupts and the program waits for the occurrence of the next interrupt.

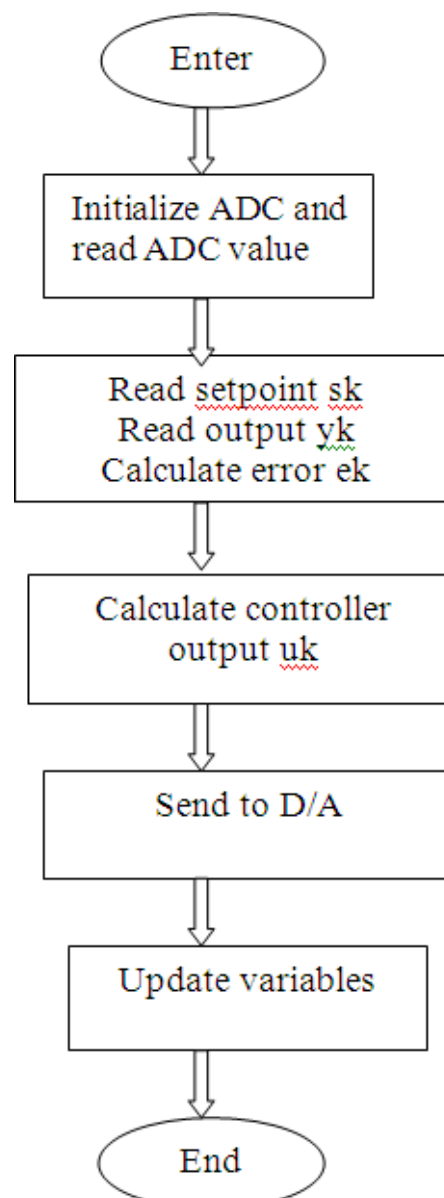
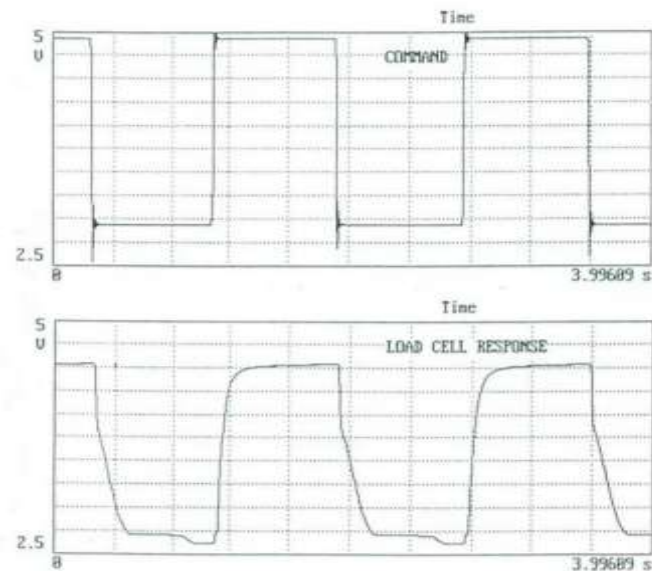


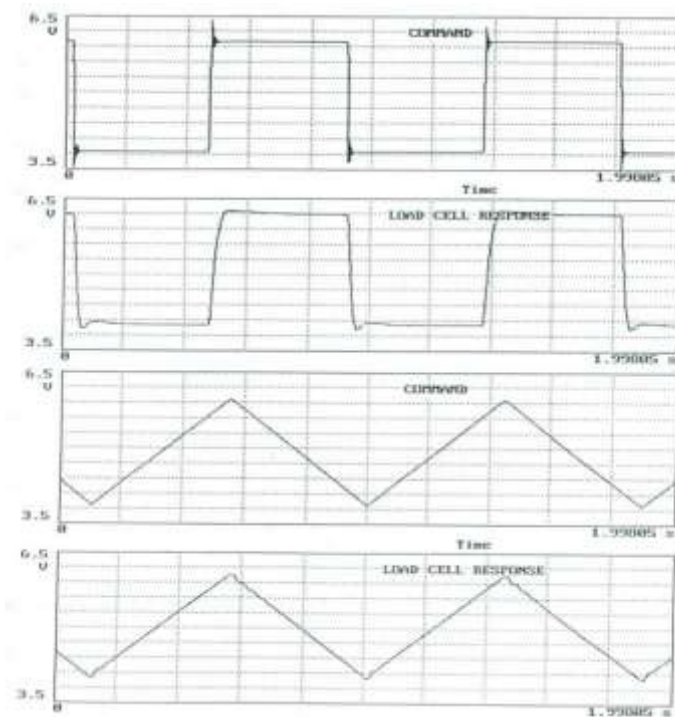
Fig 5 Flowchart for discrete PID algorithm

SIMULATION RESULTS

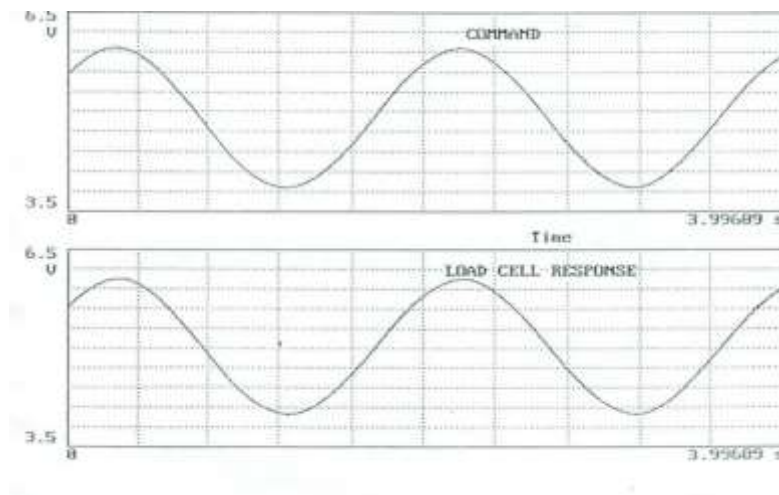


Response without PID gain

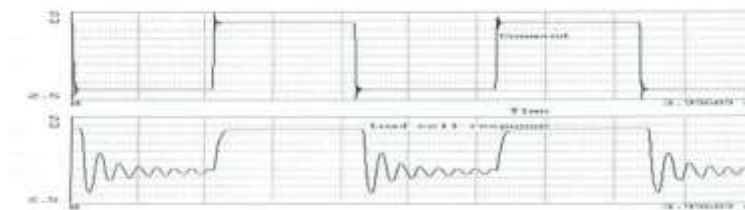
Fig 6 Load cell response for a square wave without PID gain



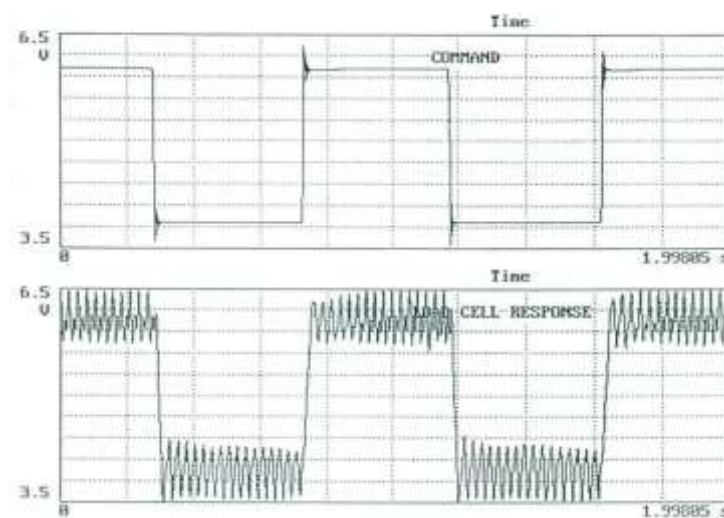
Response with high P gain



Response with appropriate PID gain



Response with high PD gain



Response with High PID gain

CONCLUSION AND FUTURE SCOPE

The digital PID controller system has been successfully designed, assembled and tested. As mentioned earlier many parameters such as position load can be measured and controlled by the same system thus providing to be economical and versatile, For testing purpose the PID controller was employed in order to control load on the test specimen, an angled beam, load cell which is an electromechanical sensor, was employed to measure load and give a corresponding feedback. The system was tested for varying command signals and the results were found satisfactory.

PID controller will be required for simulation of precise aerodynamic load. Structural testing of aircraft structural components mainly involves simulation of aerodynamic loads. Aerodynamic loads are applied using electro-hydraulic servo actuators. Thus the digital PID controller can be realized using 32 bit ARM 7 microcontroller. The above system is a design of a single channel servo control system which is a SISO (single input and single output) system. This system can be implemented to 4 channels and further multiple channelled servo control system which is a MIMO (multiple input and multiple output) system. Where

several single channelled servo controllers can be synchronized to form a multi channelled system. By varying PID gains for different input commands and the feedback signal coming from the load cell, the error signal can be minimized and this leads to a stable system.

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