CHAPTER 6

LABLT DRIVE ELECTRONICS

6.1 INTRODUCTION

Drive electronics for the Limited Angle Brushless Torque motor (LABLT) in Scan mirror mechanism is developed based on the requirement specifications given in chapter 3. The developed drive electronics should provide a position accuracy of 0.75 degree for six selectable angles within the constant torque region of +/- 20 degree mechanical. The rotor should move to the required position with the following rates 1 deg/sec, 2 deg/sec and 3 deg/sec.

The position information of the rotor is obtained by a 10 bit absolute encoder coupled to the motor shaft. The digital output of the encoder is given to the processor of control drive electronics for processing the present rotor position. The LABLT drive electronics is designed with the PIC18F4455, 8-bit microcontroller as processor. The function of the microcontroller is to read the set rate and to regulate the required current to the LAT to follow the set rate. The Proportional Integral Derivative (PID) controller is implemented with the processor to compute the required current (Low et al 1992) to drive the motor.

Drive electronics is interfaced with PC for giving the required position and rate input. Present position, rate and direction of movement of rotor information is available on the PC monitor via RS232 interface. The
LABLT values obtained are presented with a developed GUI for easy monitoring. The data are logged in the PC as notepad file for future reference and analysis.

6.2 FUNCTIONAL BLOCK DIAGRAM

The drive Electronics for LABLT is designed using a PIC18F4455 Microcontroller. The functional block diagram of LABLT Electronics is given in Figure 6.1. At every sampling interval of 10ms, the set input rate as well as absolute LABLT position is read in the PIC Microcontroller. The LABLT rate is measured by subtracting with the previous LABLT position.

\[
\text{Measured LABLT Rate} = \left( \text{LABLT}_{\text{present position}} - \text{LABLT}_{\text{previous position}} \right) \times \text{const} \tag{6.1}
\]

The Error rate is computed by subtracting the measured LABLT rate from the set input rate. This error rate will be input to the PID controller. The controller computes the output for the given error rate. The controller output is transferred to 10-bit Digital to Analog Converter (DAC) to regulate the LABLT coil current. The DAC output will be amplified by an analog power amplifier, which feeds the actual current to the LABLT coil. The motor torque is proportional to the current supplied to the LABLT coil.

![Figure 6.1 LABLT drive block diagram](image-url)
6.3 PID CONTROLLER IMPLEMENTATION

A Proportional–Integral–Derivative (PID) controller is a generic control loop feedback mechanism widely used in industrial control systems. PID controller calculates an error value as the difference between a measured process variable and a desired set point. The controller attempts to minimize the error by adjusting the process control inputs.

The PID controller calculation algorithm involves three separate constant parameters, and is accordingly sometimes called three-term control the proportional, the integral and derivative values, denoted P, I, and D. Heuristically, these values can be interpreted in terms of time: P depends on the present error, I on the accumulation of past errors, and D is a prediction of future errors, based on current rate of change. The weighted sum of these three actions is used to adjust the process via a control element such as the position of a control valve, or the power supplied to a heating element.

In the absence of knowledge of the underlying process, a PID controller has historically been considered to be the best controller. By tuning the three parameters in the PID controller algorithm, the controller can provide control action designed for specific process requirements. The response of the controller can be described in terms of the responsiveness of the controller to an error, the degree to which the controller overshoots the set point and the degree of system oscillation.

The PID control scheme is named after its three correcting terms, whose sum constitutes the Manipulated Variable (MV). The proportional, integral, and derivative terms are summed to calculate the output of the PID controller. Defining \( u(t) \) as the controller output, the final form of the PID algorithm is

\[
u(t) = MV(t) = K_p e(t) + K_i \int_0^t e(t) \, dt + K_d \frac{d}{dt} e(t)
\] (6.2)
where,

\[ K_p = \text{Proportional gain, a tuning parameter} \]

\[ K_i = \text{Integral gain, a tuning parameter} \]

\[ K_d = \text{Derivative gain, a tuning parameter} \]

\[ e = \text{Error } SP - PV \]

\[ t = \text{Time or instantaneous time} \]

6.4 DISCRETE PID IMPLEMENTATION

The analysis for designing a digital implementation of a PID controller in a Microcontroller or FPGA device requires the standard form of the PID controller to be discretised. Approximations for first-order derivatives are made by backward finite differences (Piyush & Emadi 2005). The integral term is discretised, with a sampling time \( \Delta t \), as follows

\[ \int_0^{t_k} e(\tau) \, d\tau = \sum_{i=1}^{k} e(t_i) \Delta t \quad (6.3) \]

The derivative term is approximated as,

\[ \frac{de(t_k)}{dt} = \frac{e(t_k) - e(t_k - 1)}{\Delta t} \quad (6.4) \]

Thus, a velocity algorithm for implementation of the discretised PID controller in a microcontroller is obtained by differentiating \( u(t) \) in Equation (6.2) using the numerical definitions of the first and second derivative and solving for \( u(t_k) \) and finally obtaining

\[ u(t_k) = u(t_{k-1}) + k_p \left[ 1 + \frac{\Delta t}{T_i} + \frac{T_d}{\Delta t} \right] e(t_k) + \left( -1 + \frac{2T_d}{\Delta t} \right) e(t_{k-1}) + \frac{T_d}{\Delta t} e(t_{k-2}) \quad (6.5) \]
At every sampling interval, the error value $e(t_k)$ will be computed and substituted in the above equation to compute the controller output (Rao & Ram 2009, Rodriguez & Emadi 2007). The controller output is scaled to suitable gain and transferred to DAC to adjust the LABLT current.

6.5 CIRCUIT SCHEMATIC

The Circuit consists of PIC18F4455 Microcontroller, a Serial 10-bit DAC, DAC signal conditioning circuit and an analog power amplifier. In addition, it has the provision to read the user input as well as 10 bit parallel Encoder interface to read LABLT absolute position. Each sub block is dealt in detail in the following sections.

6.5.1 PIC Controller Module

![PIC controller block diagram]

Figure 6.2 PIC controller block
The PIC18F4455 is a high performance 8-bit microcontroller with rich set of peripherals such as 13 channel analog to digital converter, general purpose timers/counters, Serial Peripherals Interconnect (SPI) port, Inter- Interface controller (I²C) port, communication block, FLASH programming memory and user RAM. Additional features for robust operation like fail safe clock operation and two speed start up are available. These rich set of resources will minimize the target hardware size and power.

The microcontroller power, reset and clock interface are given as per the datasheet of the controller. A quartz crystal 12 MHz to be connected to the oscillator inputs of PIC for clock generation. The oscillator circuits are built inside the microcontroller. A simple RC circuit to MCU pin will serve as reset for the microcontroller. A regulated +5V to VDD and GND to the microcontroller is adequate for the PIC18F4455 operation. After the power on reset, it will start executing from the reset vector. The rate input selection switches and status LEDs are interfaced to microcontroller in PORT B GPIO.

### 6.5.2 Digital to Analog Converter

![Digital to Analog Converter Diagram](image)

**Figure 6.3** Digital to analog converter
The PIC microcontroller does not have a Digital to Analog Converter (DAC) in it, hence an external serial DAC (MCP4811) is interfaced with PIC. The DAC is 10-bit resolution and can be operated with +5V supply. The DAC has internal voltage reference of 2.048V with a thermal stability of 50ppm/°C. The DAC output updated is step change in nature with each step of 2.048/1024. In order to minimize this stepping noise, a single pole RC filter with 1K resistor and 0.47μf is connected across the DAC output.

6.5.3 Level Shifter

![Figure 6.4 Level shifter](image)

The motor coil requires positive and negative currents for rotation in forward and reverse direction respectively. Since the DAC polarity is positive (0V to 2.048V), a level shifter and gain stage is required to convert the positive DAC output voltage to bidirectional output (-7.42V to +8.57V). The level shifter and gain stage are designed using LM324 operational amplifier (opamp).
6.5.4 Analog Power Amplifier and Current Controller

The LM675 is an analog power operational amplifier which will deliver up to 3Amp current to the load. This is an internally compensated

Figure 6.5 Analog power amplifier and controller

From level shifter output
opamp which supports high bandwidth operations. This opamp has 8V/µs slew rate, which provides excellent response to source or sink the current to the motor. In addition, the operation voltage can go as high as 60V. In order to control the coil more effectively, a push-pull power configuration is selected. This will provide additional amplification factor of 2. In this configuration, one end of the motor coil is connected to buffer power amplifier output, whereas the other end is connected to inverted power amplifier. If the buffer amplifier is sourcing, the inverting amplifier is sinking the current from the coil. In this way, the additional amplification factor 2 is achieved.

Peak torque demand of 2.5 Nm is controlled within limits with the help of current controller circuit. Two parallel resistors of 0.2Ω/2W each are put in series with the motor coil, to sense the motor current as shown (R34 and R35) in the Figure 6.5.

The equivalent voltage thus obtained in proportion to the load current is conditioned by LM324 and given to PIC microcontroller for manipulating control signals.

6.5.5 Encoder Interface

A 10-bit absolute encoder of EP58 series, Autonics make as shown in the Figure 6.6(a) is used for LABLT rotor position measurement. The encoder requires +5V for its operation. The outputs are parallel 10-bit with PNP open collector. The output is 10-bit binary format with a resolution of 0.35 degrees. A detailed specification of the encoder used is given in appendix. The PIC Digital I/O ports (PORT D and PORT B) are configured as input port to read the encoder data. The encoder output PNP transistor’s open collectors are terminated with 10KΩ resistors as shown in Figure 6.6(b).
After finalizing the components of each functional block by simulation, the LABLT motor control electronics PCB layout is made from the schematic. The PCB is designed for the required dimensions as multilayer single sided. PCB is fabricated and tested for proper insulation, component pads and tracks. A proper inspection of PCB is made before soldering the components to it to overcome the errors of track and component pads if any. All the components are chosen to be of Punch Through Hole (PTH) type and it is assembled and soldered in the PCB. The soldered PCB is thoroughly cleaned with IPA solution to prevent the corrosion of solder joints from moisture. Finished PCB with wired components as shown in the Figure 6.7 is then fixed to the chassis of a controller module to give mechanical strength.
and protection to PCB with components and to have a proper thermal conduction in power switches of the controller circuit.

Figure 6.7 Fabricated LABLT drive board

6.6 CONTROL SOFTWARE DESIGN

The software is designed using PIC cross compiler, which is a C compiler for PIC18 series devices. The software is a single monolithic code which starts execution after the reset exception occurred. The detailed program flow is shown in Figure 6.8.
Once the power on reset is asserted, the PIC microcontroller will initialize its internal special function registers. This special purpose register initialization configures the port, timer and other peripherals. After the initialization, the timer 0 is initialized as sampling timer for an interval of 10msec. At every timer 0 overflow interval, a timer overflow bit will set.

The software will wait for the timer overflow bit set and if the bit is set, it will enter the control program, else this will keep checking for the overflow bit. In the control program, the timer overflow bit is cleared and proceeded for control function.

As shown in the flow chart, the set rate will be read first and followed by encoder angle read. The encoder rate is computed by subtracting the present angle position with the previous sample interval encoder position. The controller error is computed by subtracting the measured rate from the set rate. The computed error will serve as input to the PID controller.

Once an error rate computation is completed, the discrete PID equations are obtained to compute the correction required. The controller output is scaled to suit DAC 10-bit and transferred to the serial DAC, which in turn controls the current flowing to the LABLT coils. The same control program is repeated for every sample interval.
Figure 6.8 LABLT control program flow
6.7 PC INTERFACE AND DATA LOGGER

PC interface is accomplished through RS232 COM port. The input/output is presented by GUI front end as shown in Figure 6.9. The instantaneous data about present position of the motor is logged in the text file (logfile1.txt).

![Figure 6.9 LABLT drive command software GUI](image)

The following features are provided in the front end design of Graphical User Interface (GUI) in LABLT control software.

i. Port address represents the port of PC to which the LABLT drive electronics is connected.

ii. 9 preset position selectable command input between +20 deg and -20 deg are offered.
iii. Three rate input selection command for 1deg/sec, 2 deg/sec and 3 deg/sec

iv. Hex value of +30 deg and -30 deg input can be given to the program by clicking the XSend and YSend buttons.

v. Present position of LABLT rotor is given in degrees.

6.8 INTERFACE DETAILS

Figure 6.10 shows the drive electronics package and provides the overall size and mechanical interface details.

![Figure 6.10 LABLT drive package](image)
Figure 6.11 gives the details of the interface connectors in the drive electronics module. The 5 pin D connector is used for connecting PC with drive electronics and 9 pin D – connector is used for connecting the drive electronics with encoder. The power connector is used to interface the LABLT motor armature terminals and the power supply with the module.

![Encoder and PC Connector Diagram]

**Figure 6.11 Interface connector pin configuration**

### SUMMARY

Drive electronics for control of LABLT to the required position and rate is developed. The discrete PID controller is implemented in the PIC18F4455, 8-bit microcontroller of LABLT drive electronics. Further the microcontroller reads the set rate and regulates the required current to the LABLT motor to follow the set rate. DAC, Level shifter and analog power
amplifier circuits are soldered to PCB. Proper heat sink is provided for thermal protection of power switches. As per the mechanical interface details, the PCB is mounted and interface is connected in the periphery of the module. A 15 pin D connector is provided in the PCB for interfacing absolute position encoder digital output with the control circuit. An RS232 interface provision is given in the drive electronics PCB for interfacing the LABLT drive electronics with PC for data logging and commanding the motor for the required rate and position.