

# Research Journal of Pharmaceutical, Biological and Chemical Sciences

## Embedded High Speed Response Programmed Impulse Motor Drive for Continuous Casting Machines in Metallurgical Industry

Vandana Ilamchezian, and V Vijayakumar\*

<sup>1</sup>Department of Electronics and Communication Engineering, Sathyabama University, Chennai-600119, India

### ABSTRACT

In continuous casting metallurgical process, velocity controlled withdrawal mechanisms have to be interfaced with continuous caster pull-out drives where it is connected with a liquid metal pool. At present, hydraulic driven programmed cylinder operations are utilized in many industrial systems. In that case, a prominent 4-quadrant electric drive DC servo motor with flexibility of velocity control is required. In the present work, programmable velocity Vs time information is stored in an embedded array and it is controlled by the digital real-time velocity controller that drives the motor driven shaft with exact velocity profile. The rotation and movement of shaft is completely controlled with the programmed velocity profile. These programmed velocity control profiles in real time is generally referred in CAM data. The 4-quadrant DC servo amplifier has been utilized for control the actual rotational speed and closed loop control of the drive. This drive amplifier can accelerate the shaft with the CAM programmed acceleration profile in the first quadrant with coasting phase of constant velocity and deceleration period in the third quadrant section. The feedback velocity is a high speed response encoder of adequate pulse counter per revolution of the encoder shaft.

**Keywords:** Casting, velocity controller, CAM, coasting phase, Encoder

*\*Corresponding author*

## INTRODUCTION

Continuous casting is a prominent method of producing billets, slabs and blooms. The transfer of heat plays a vital role in quality and productivity of steel prior to rolling. Different kinds of internal and surface quality defects initiated from improper cooling practices [1, 2]. Continuous casting process required sensible control of secondary cooling process and efficient analysis of heat transfer. Various heat transfer models have been successfully developed and facilitated to simulate steady state casting process on both offline and online mode. Due to the economic and complex reasons, it is not opt to undertake more experimental trials while continuous casting operation to describe the influence of various operational parameters. Thus, the fast development of optimization and good process control is extensively depend upon simulations achieved with artificial intelligence techniques and heat transfer mathematical model [3-5].

Among different types of casting process, high pressure die casting (HPDC) is most prominent for mass production owing to its good surface finish and dimensional accuracy, higher productive efficiency, good mechanical properties and capacity of producing thin-walled and intricate shapes components [6].

Even though, flaw such as gas pores and shrinkage are often found in the cast parts. These types of defects not improve the mechanical properties of the casting components. Herein, many works have been performed to study the casting process with the application of CAD/CAE system, numerical simulation, etc [7-10].

Tuna et al. [11] proposed the corrosion resistance assessment of cobalt-chromium alloy frameworks synthesized by CAD/CAM milling, casting process and laser sintering. Over the past few decades, the metallic restorations have been systematically produced with the help of conventional casting and lost-wax technique. The prolonged and complicated procedures are involved various stage in conventional casting method. To rectify these limitations, novel techniques have been implemented [12]. One of these methods includes computer-aided manufacturing (CAM)/computer-aided design (CAD). The direct metal laser-sintering system (DMLS) is a more recent method is utilized for an additive metal fabrication technology [13-16]. In both techniques, investing, casting procedure and waxing are eliminated, therefore avoiding dental and clinical technician, preventing the distortion of frameworks, the working time also rapidly decreased. In spite of this, the high expensive equipment is a limitation of these techniques. Different studies have compared the internal fits, marginal [17, 18], fracture strengths [19] and metal-ceramic bond strengths of the metal frameworks manufactured by DMLS systems, CAD/CAM milling and conventional casting.

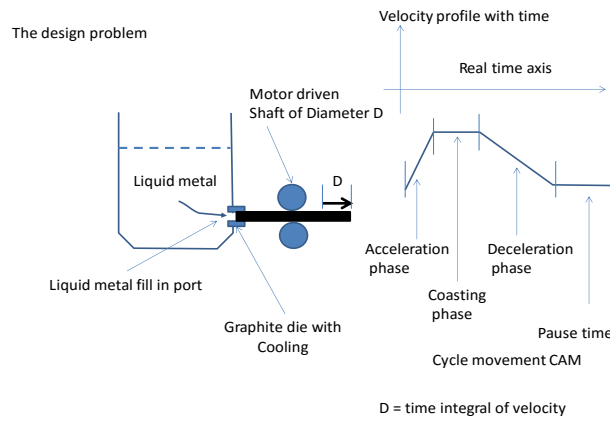
Continuous casting technology is an important process in which the heat transferring from liquid to solid billet. In addition to this process, the slab surface temperature is one of the most predominant parameters for controlling. Thus, it is compulsory to optimize casting speed and to analyse liquid depth and intensity of second cold [20]. It is directly examine the state of slab solidification and corresponding with slab defects such as surface cracks, internal cracks slab link changes and bulging slab, etc. Thus, the temperature of slab surface is a prominent parameter in the continuous casting. Moreover, the slab surface temperature not only related to cooling intensity and mold of the secondary cooling zone, this is also depends on the slab cross-section dimensions, casting speed, casting temperature, shell thickness with other influent factors. Skovranek et al. [21] proposed the fractional order control model of steel casting process. Junhong et al. [22] reported the slab surface temperature measurement of continuous casting process by CCD imaging. In the present work, velocity controlled withdrawal mechanism have been incorporated with the casting metallurgical process with continuous caster drives where it is interfaced with a liquid metal pool. In that case, a most suitable 4-quadrant electric drive DC servo motor with flexibility of velocity control is used. Moreover, the programmable velocity Vs time information is stored in an embedded array and it is regulated by the digital real-time velocity controller that drives the motor driven shaft with exact velocity profile. These programmed velocity control profiles in real time is referred in CAM data.

### Casting process

Making small diameter metal rods is a practiced art with rolling of higher diameter rods / sections, when the metal in contention is not malleable /ductile, rolling (hot / cold) is not feasible. Most high performance metals that have high nickel content (Stellite as a typical example) are so hard that rolling is not a

manufacturing option. Such materials, if needed as rods of a given diameter have to be directly cast in that needed diameter from a metal bath holding the liquid metal.

Figure 1 illustrates the casting process and how a withdrawal mechanism is used to pull out the cast rod in repeated small sections on a continuous basis such that each subsequent section welds to the previous section as the process continues.



**Fig 1. Casting process**

Figure 2 illustrates a picture of the continuous rod so manufactured the interface welds between each section formed during the casting is clearly visible in the figure.



**Fig 2. Continuous casting rod**

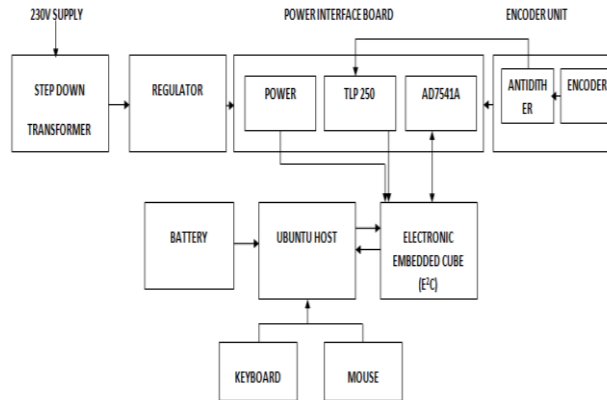
After solidification of the castor rod in the water cooled molds it is mechanically pulled away and cut into required lengths. In legendary systems these operations are controlled by a hydraulically driven programmed cylinder which controls the pulling motion; these hydraulic systems had poor response and poor repeatability of each stroke length that controls the pull.

**HARDWARE AND SOFTWARE DETAILS**

In order to achieve the high efficiency, improved quality, improved productivity, reduced labor and reduced capital investment, a system capable of rapid and controlled velocity pull-out mechanism should be interfaced with the castor pull-out connected to the liquid metal pool. An integrated automatic system designed to flexibly control the 4-Q DC servo motor supported with the necessary electrical and electronic equipment, instrumentation, process control and optimization is built as the interface. This system is controlled by a velocity CAM data (velocity vs time data) stored in an embedded system (embedded UBUNTU variant of linux) interfaced to a real-time velocity controller(Application Specific Integrated Circuit (ASIC) FPGA module) that drives the motor driven shaft by the exact velocity CAM profile.

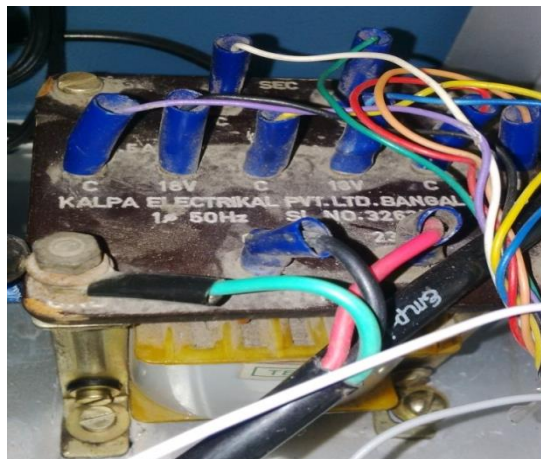
**RESULTS AND DISCUSSION**

The shaft rotates at a given rotational angle based on the CAM velocity profile. An optical encoder is used to monitor the speed and position of the shaft that the 4-Q DC servomotor drives. The optical encoder is an angular position sensor whose shaft is mechanically coupled direct to a motor drive shaft. The angular position of the motor drive is proportional to the electrical output of the encoder in digital form. When the rotational phase is not matched with the CAM velocity profile, the change in shaft movement  $\Delta d$ (error rate calculated based the desired distanced to be moved by the CAM) controlled by a feedback velocity through a high speed response encoder to an adequate angle of revolution which is calculated by the ASIC FPGA module. Figure 3 (a) refers the system hardware chart.



**Fig 3. (a) System hardware chart.**

A step down **transformer** is used to bring voltage down in an Electronic circuit as shown in Figure 3 (b). It reduces the 230V AC line voltage into 9V and 18V AC since the all the electronic components built in the system needs a voltage ranging between 0 to 15V DC.



**Fig 3. (b) step down transformer**

The power regulator module in the system consist of the full wave bridge rectifier (MIC W02) which is used for converting the Alternating current (AC) into a Direct current(DC). The main advantage of full wave bridge circuit is that it does not require a special centre tapped transformer, thereby reducing its size and cost. The single secondary winding is connected to one side of the diode bridge network and the load to the other side. It consist of voltage regulators **uA7805**, **uA7815**, **L78150**designed to automatically maintain a constant voltage level .The series of fixed-voltages +5V,E+5V,+15V,-15v integrated-circuit voltage Regulators stabilize the DC voltages used by the system.



Fig 3. (c) Power interface board

The power interface module in the system consist of the

- i. Four fixed input voltages(+15V, -15V,+5V,E+5V) & two input grounds (GNG,EGND),where E represents the Encoder.
- ii. TLP 250 is an **opto-isolator** also called an **optocoupler, photo coupler** is a component that transfers electrical signals between two isolated circuits by using light.
- iii. The Analog Devices AD7541A is a 12-bit monolithic multiplying digital-to-analog converter.

The series of fixed voltages from the regulator is given as the input to the power interface module using a jumper (JP5). These voltages are given as the input voltage to various devices in the power interface board such as AD7541A, opto-couplers, Anti-Dither unit, Encoder, LM358 as shown in Figure 3 (c).

An **Opto-coupler** is an electronic component that interconnects two separate electrical circuits by means of a light sensitive optical interface. The basic design of an Opto-coupler consists of an LED that produces infra-red light and a semiconductor photo-sensitive device that is used to detect the emitted infra-red beam. Both the LED and photo-sensitive device are enclosed in a light-tight body or package with metal legs for the electrical connections. It is galvanically isolated by giving a separate ground to prevent the transmission of light waves from current.

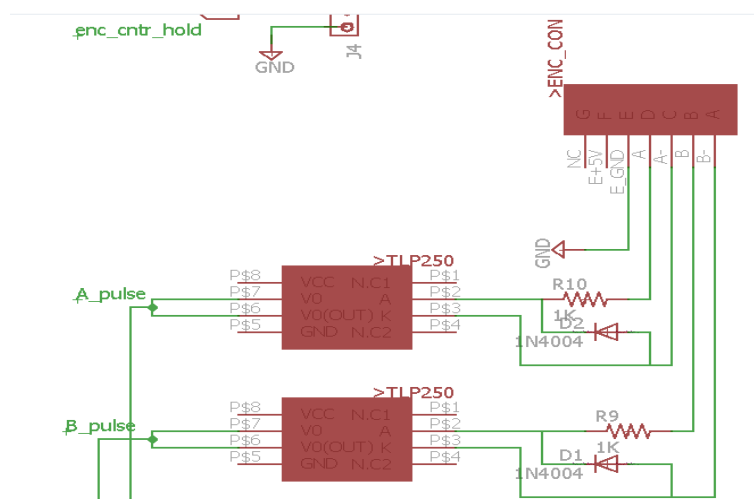


Fig 3. (d) A pulse and B pulse of the encoder TLP250

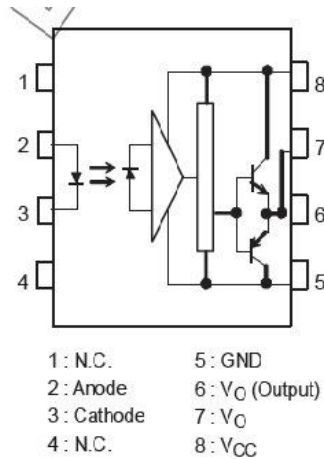


Fig 3. (e) Pin diagram of TLP250

The Figure 3(d) shows the Apulse and Bpulse of the Encoder is given as input to the Anode pin of TLP250 (refer the pin diagram of TLP250 ) as shown in Figure 3(e). The equivalent electrical signals are produced from the Vo pin. The output of Vo pin A\_pulse&B\_pulse are given to the ASIC FPGA module. TLP250 is used optically isolate digital input signal from the Encoder connected to the shaft of the 4Q DC servomotor drive located around the industrial condition which has electrically noisy environment.

**AD7541A** is a digital to analog converter which converts the digital signal into an analog signal as shown in Figure 3 (f).

It is fabricated using advanced, low noise, thin film on CMOS technology and is available in a standard 18-lead DIP and in 20-terminal surface mount packages.

The main function of AD7541A is

- i. To convert the 8bit digital output from the ASIC FPGA unit into the equivalent analog voltage. The corresponding DAC OUT voltage controls the 4Q DCservomotor action which controls the casting process.
- ii. The 12 bit Encoder value is given as input which is compared with then the error value of change in distance moved between each step by the CAM data is calculated by the ASIC FPGA module is given as digital input is given into AD7541A and the analog output is generated to make the stroke faster using the 4Q DC servomotor.

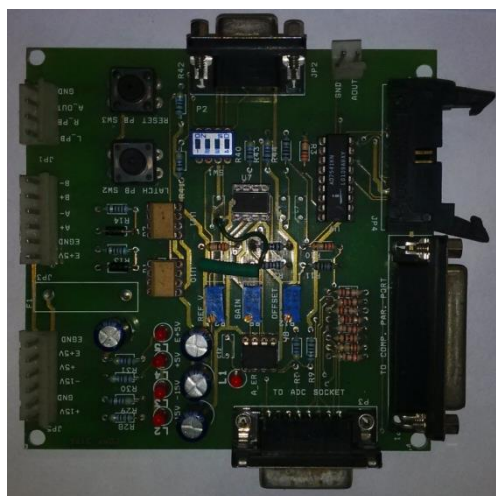
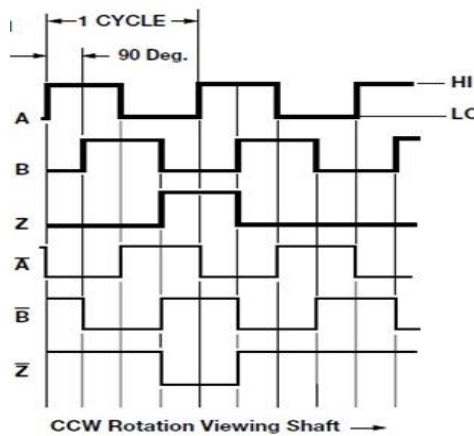


Fig 3. (f) Power interface board for AD7541A

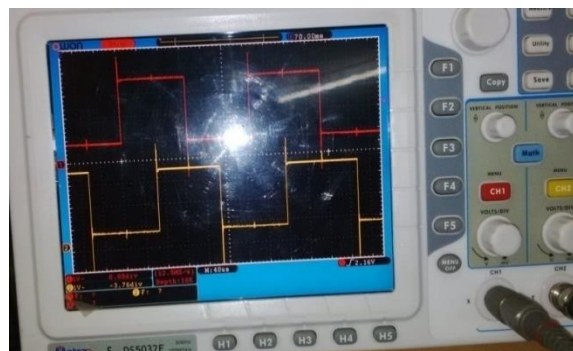
**ENCODER UNIT**

A digital optical encoder is a device that converts motion into a sequence of digital pulses. Encoders have both linear and rotary configurations, but the most common type is rotary. Rotary encoders are manufactured in two basic forms: the **absolute encoder** where a unique digital word corresponds to each rotational position of the shaft, and the **incremental encoder**, which produces digital pulses as the shaft rotates, allowing measurement of relative position of shaft i.e. 4Q DC servo motor.

HD25 is a rugged optical incremental shaft encoder designed for heavy-duty industrial applications. It monitors motor action in the automatic casting process and converts into sequence of digital pulses. HD25 consist of 4 pulses A,A/,B,B/ which are 90degree out of phase as refer in Figure 4. Each pulses produces 10,000 lines per revolution totally 40,000 pulses are produced.



**Fig 4. Pulses of H25 Encoder**



**Fig 5. CRO output of Apulse and Bpulse**

**Indicating the 90 deg out of phase A/ and B/ pulses are derived from A & B pulses using NOT function as displayed in Figure 5. The express encoder as shown in Figure 6.**

The total distance moved by the CAM

$$\sum_{i=0}^{n+m} N_i$$

Where i is the Encoder value accumulated in each time slot set from CAM. Total distance is given by

$$40,000 \text{ pulses} = 2\pi Dia$$

Hence the distance moved per stroke is given by

$$\left( \frac{\sum_{i=0}^{n+m} N_i}{40,000} \right)$$



Fig 6. Express Encoder

**Functionality:**

The CAM data is given to the DC servomotor which controls automatic production of casting rod. Encoder unit produce the digital pulses based on the movement of motor. This digital data is used for analysis of error value in case if the CAM value and motor action does not match.

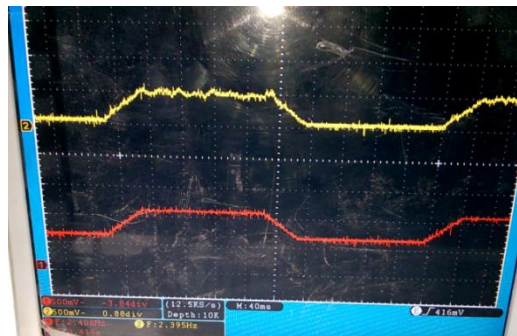


Fig 7. The rotation of motor faithfully following the CAM data.

At the faster speeds the no of strokes in the oscilloscope increases .Each trapezoidal pulse in the oscilloscope screen represents a stroke of a given length and more strokes per minute is for the faster withdrawal as shown in Figure 7. The time axis( X axis of the oscilloscope) provides the time base to find out the rising point of the trapezoid to the next trapezoid if the repeat period and the inverse of this is the strokes per sec and 60 times of this gives the stroke per minute. Typical normal speed is 100strokes per minute and faster strokes is about 160 strokes per minute,stroke length is constant for the given CAM. Depending on the material that is to be cast the stroke length and stroke per minute are varied. The CAM profile and the frequency information passed on to provide the changing strokes per minute.

**Anti-dither unit**

The main function of anti-dither is used to remove noise from the encoder pulses as shown in Figure 8. It is connected to the power interface module using the jumper 3.





Fig 8. Anti-Dither unit

**Smart fusion board:**

The SmartFusion2 Starter Kit (SF2-STARTER-KIT) provides designers with a prototyping platform for SmartFusion2 system-on-chip (SoC) FPGAs, which integrated with inherently reliable Flash-based FPGA fabric, a 166 MHz ARM Cortex-M3 processor, advanced security processing accelerators, DSP blocks, SRAM, eNVM and industry-required high-performance communication interfaces all on a single chip. The state diagram of ASIC-FPGA as shown in Figure 9. Table. 1 refers that the operation of state diagram by the module.

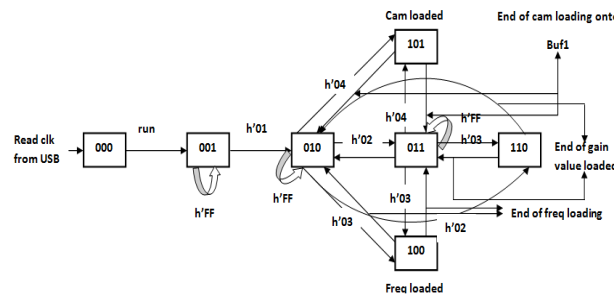


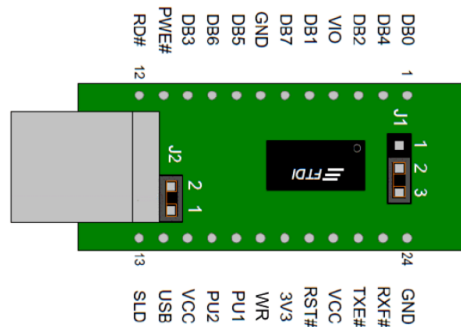
Fig 9. State diagram of ASIC-FPGA

Table 1: Operations of state diagram controlled by the module:

STATE	BIT	NAME	FUNCTION	CURRENT STATE	NEXT STATE
0	000	Read state	A clock pulse is given from the ubuntu through USB in order to send the Bit stream.	000	001
1	001	Initial state	Transition of state from initial state to reset state, in order reset the system.	001	010
2	010	Reset state	<ol style="list-style-type: none"> <li>1. There is a transition of state from reset state to freq in state.</li> <li>2. There is a transition of state from reset state to cycle data in state.</li> <li>3. There is a transition of state from reset state to gain set state.</li> <li>4. There is a transition of state from reset state to start state.</li> </ol>	010	100
3	011	Start state	<ol style="list-style-type: none"> <li>1. There is a transition of state from start state to freq state.</li> <li>2. There is a transition of state from start state to cycle data in state.</li> <li>3. There is a transition of state from start state to gain set state.</li> </ol>	011	100
4	100	Freq in state	<ol style="list-style-type: none"> <li>1. The freq is loaded (ranging 0 to 99) and returns to the prev state.</li> <li>2. The freq is loaded (ranging 0 to 99) and returns to the prev state.</li> </ol>	100	011
5	101	Cycle data in state	<ol style="list-style-type: none"> <li>1. The cam file is loaded and returns to the prev state.</li> <li>2. The cam file is loaded and returns to the prev state.</li> </ol>	101	011
6	110	Gain set state	<ol style="list-style-type: none"> <li>1. The cam file is loaded and returns to the prev state.</li> <li>2. The cam file is loaded and returns to the prev state.</li> </ol>	110	011

**Ubuntu host:**

**Ubuntu** is a Debian-based Linux operating system and distribution, with Unity as its default desktop environment . Ubuntu also runs network servers a free software with python programming language. The ubuntu version 14.04 LTE is interfaced with the linux SMARTFUSION II Emcraft sytem. The commands from the ubuntu is given through the USB module called UM254R. UM254R consist of the unique number (the FTDIChip-ID™) is burnt into the device during manufacture and is readable over USB, thus forming the basis of a security dongle which can be used to protect customer application software from being copied. Pin diagram of UM254R as shown in Figure 10. Table 2 shows the details of pins has used to communicate Embedded board.



**Fig 10. Pin diagram of UM254R**

**Table 2: Pins used to communicate Embedded board**

Pin No.	Name	Description	Function
1	DB0	FIFO Data Bus Bit 0*	Bit0 of cam data
2	DB4	FIFO Data Bus Bit 4*	Bit4 of cam data
3	DB2	FIFO Data Bus Bit 2*	Bit2 of cam data
5	DB1	FIFO Data Bus Bit 1*	Bit1 of cam data
6	DB7	FIFO Data Bus Bit 7*	Bit7 of cam data
8	DB5	FIFO Data Bus Bit 5*	Bit5 of cam data
9	DB6	FIFO Data Bus Bit 6*	Bit6 of cam data
10	DB3	FIFO Data Bus Bit 3*	Bit3 of cam data
23	RXF#	When high, do not read data from the FIFO. When low, there is data available in the FIFO which can be read by strobing RD# low, then high again.	It is used to receive the data from the embedded board
22	TXE#	When high, do not write data into the FIFO. When low, data can be written into the FIFO by strobing WR high, then low.	It is used to transmit the cam data to the embedded board.
24	GND	Module ground supply pins	Ground connection

**LCD display:**

LCD display is the type of **graphical user interface** or **GUI** that allows users to interact with electronic devices through graphical icons .

GUIs is used as a command-line interface(CLI), through which the commands are typed to control the process of casting rods.It is connected to the CPU through the USB.

**Keyboards and Mouse**

The Mouse and keyboard is the input device of the Ubuntu host. The QWERTY keyboard is used to enter the commands in command-line interface.

## Python commands to control the Smartfusion II

The following commands are given to control the automatic casting process

**STEP1:** Switch ON the power supply and login to User by typing the password “**User\_123**”and press Enter.

**STEP2:** In the Home screen or Desktop click “**ctrl+alt+t**” or click on the “**Dash**” to open the Terminal.

The Terminal window opens displaying “**user@ramcomp:~\$**”

**STEP3:** Type “**user@ramcomp:~\$ cd Desktop/SmartCast/**” and press Enter to open the folder which has CAM program.

**STEP4:**Type “**user@ramcomp:~/Desktop/SmartCast\$ ls**” and press Enter to display (or *lists*) information about files

List of files inside the folder **SmartCast**

**STEP5**Type“**user@ramcomp:~/Desktop/SmartCast\$ sudo ./smartcast\_02Dec2015** ” and press Enter to open the program to run CAM.

**STEP6:**Type “[sudo] password for user :**User\_123**” .The password for user → User\_123 is invisible and press Enter

**STEP7:** Type “Enter password :**RamB505-347E**” and press Enter.

**STEP8:**Type “Enter the command (Reset/Igainset/Freq/Cycle):**Reset** ” to reset the system as well as the previously entered CAM files will be resetted.

**STEP9:** Type “Enter the command (Reset/Igainset/Freq/Cycle):**Freq** ” and press Enter

“**Enter a value (ranging 0 to 99) : 25**”(example) and press Enter To make the CAM to run at the required frequency.

**STEP10:** Type “Enter the command (Reset/Igainset/Freq/Cycle):**Cycle** ” and press Enter.

“**Enter the name of the cam file to read : cam04.txt**”(Example) and press Enter. To make motor drive to run at the precise response.

**STEP11:** Type “Enter the command (Reset/Igainset/Freq/Cycle):**Start** ” and press Enter. To rotate the drive with the inputted CAM data and freq in data loaded.

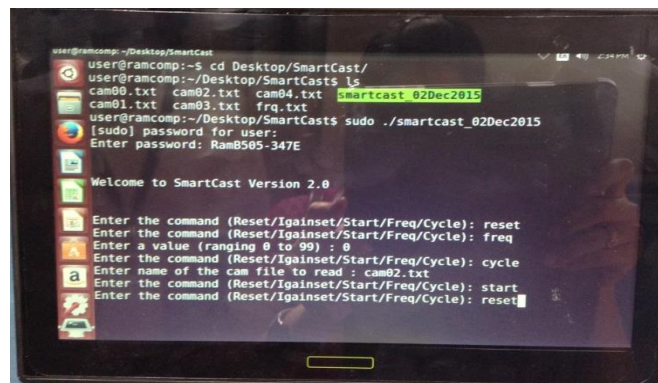
**STEP 12:** Type “Enter the command (Reset/Igainset/Freq/Cycle):**Igainset**” and press Enter.

**Enter a Igainsetvalue(ranging 0 to 15) : 10**”(Example) and press Enter. To increase the response of the encoder.

**STEP13:** Inorder to change the freq of the CAM repeat the **STEP 10**

**STEP14:**Inorder to change the CAM file repeat the **STEP 9**

**STEP15:**Inorder to reset the system repeat the **STEP 8**.



```

user@ramcomp:~/Desktop/SmartCast
user@ramcomp:~$ cd Desktop/SmartCast/
user@ramcomp:~/Desktop/SmartCast$ ls
cam00.txt  cam02.txt  cam04.txt  smartcast_02Dec2015
cam01.txt  cam03.txt  freq.txt
user@ramcomp:~/Desktop/SmartCast$ sudo ./smartcast_02Dec2015
[sudo] password for user:
Enter password: RamB505-347E
Welcome to SmartCast Version 2.0
Enter the command (Reset/Igainset/Start/Freq/Cycle): reset
Enter the command (Reset/Igainset/Start/Freq/Cycle): freq
Enter a value (ranging 0 to 99) : 0
Enter the command (Reset/Igainset/Start/Freq/Cycle): cycle
Enter name of the cam file to read : cam02.txt
Enter the command (Reset/Igainset/Start/Freq/Cycle): start
Enter the command (Reset/Igainset/Start/Freq/Cycle): reset

```

**Fig 11. Ubuntu Terminal window for Enter the commands Working**

The power supply is given power interface board, Electronic Embedded Cube is powered. The ubuntu system is switched ON as shown in Figure 11.

The GUI command line interface is opened (Terminal). Using the keyboard the program to run the 4Q DC servomotor is CALLED,the reset command is given to reset the system,the freq is given and CAM file is opened based on which the motor rotates, the start command runs the 4Q DC servo motor. The commands given in the ubuntu host is interfaced to the E<sup>2</sup>C using UM254R. The digital signal corresponding to the CAM data is given to the interface board(AD7541A) .PIB generates the analog voltage (DAC OUT) connected to the 4QDC servo Motor.Encoder unit generates the digital pulses with respect to the 4Q DC servo motor rotations.

This digital signal is given as the input to the E<sup>2</sup>C through which the error value to make the stroke faster is generated. Based on the 4Q DC servo motor rotations the rods of a given diameter have to be directly cast in that needed diameter from a metal bath holding the liquid metal which has high nickel content. The outcome of the present work has merely matched with the working industrial condition as shown in Figure 12.



Fig 12. Working Industrial condition

### CONCLUSION

In conclusion, the programmable velocity Vs time data has been stored in an embedded array and controlled by the real time velocity controller that also derived the motor driven shaft with exact velocity profile. Both hardware and software were used in this proposed work are explained precisely with pin as well as block diagram. The rotation and movement of shaft is completely optimized and controlled with the programmed velocity profile. The rotational speed and closed loop control of the drive is controlled by 4-quadrant DC servo amplifier. The system for continuous casting is designed built programmed to produce the continuous casting rod of variable diameter and tested in the industrial condition.

### REFERENCES

- [1] Savage J, Pritchard WH, Iron Steel Inst. 1954; 178 (11): 269–277.
- [2] Thomas BG, Samarasekera IV, Brimacombe JK, Metall. Mater. Trans. B 1984;15 (2): 307–318.
- [3] Ha JS, Cho JR, Lee BY, Ha MY, J. Mater. Processing Technol. 2001; 113 (1–3): 257–261.
- [4] Nozaki T, Matsuno J, Murata K, Ooi H, Kodama M, Trans. ISIJ 1978; 18 (6): 330–338.
- [5] Hardin RA, Liu K, Kapoor A, Beckermann CA, Metall. Mater. Trans. B 2003; 34B (3): 297–306.
- [6] Ji S, Yan F, Fan Z, Mater. Sci. Eng. A 2015; 626: 165-174.
- [7] El-Mahallawy N, J. Mater. Process. Technol. 1998; 73(1): 125-138.
- [8] Jia L, Xiong S, Liu B, J. Mater. Sci. Technol. 2000; 16: 269-272.
- [9] Zhang W, Xiong S, Liu B, J. Mater. Process. Technol. 1997; 63: 707-711.
- [10] Wu M, Xiong S, Acta Metall. Sin. 2010; 46: 1534-1542.
- [11] Tuna S H, Pekmez NO, Kürkçüoğlu I, J Prosthet Dent 2015;114:725-734.
- [12] Kellerhoff RK, Fischer J., J Prosthet Dent 2007;97:209-15.
- [13] Kim KB, Kim WC, Kim HY, Kim JH, Dent Mater 2013;29:e91-6.
- [14] Akova T, Ucar Y, Tukay A, Balkaya MC, Brantley W, Dent Mater 2008;24:1400-4.
- [15] Ucar Y, Akova T, Akyil MS, Brantley WA, J Prosthet Dent 2009;102:253-9.
- [16] Strub JR, Rekow ED, Witkowski S, J Am Dent Assoc 2006;137:1289-96.
- [17] Örtorp A, Jönsson D, Mouhsen A, Vult von Steyern P, Dent Mater 2011;27: 356-63.
- [18] Castillo-Oyagüe R, Lynch CD, Turrión AS, López-Lozano JF, Torres- Lagares D, Suárez-García MJ, J Dent 2013;41:90-6.
- [19] Suleiman SH, Vult von Steyern P, Acta Odontol Scand 2013;71:1280-9.
- [20] IGNACIO A, JORGE M. Industrial online surface defects detection in continuous casting hot slabs[J]. Optical Measurement Systems for Industrial Inspection VI,2009,6.
- [21] Tomas Skovranek, Jan Kukurugya, Igor Podlubny, Jan Terpak, "Fractional order control model of steel casting process", 2011 12th International Carpathian Control Conference (ICCC).
- [22] Yan Junhong Bai Xiaoqing, Baotou Iron and Steel Institute, "Research on Slab Surface Temperature-measurement of Continuous Casting Based on CCD Imaging", ICEMI'2011The Tenth International Conference on Electronic Measurement & Instruments.