FPGA Based Optimal Position Control For Flying Shear In Hot Rolling Mills

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Abstract- **The increasing need to save energy and minimize scrap together with requirements on the accuracy and quality of cutting operations in continuous rolling mills have necessitated the development of a concept of flying shear control. Sophisticated position control algorithms based on optimal positioning with a moving target are described. Effort to replace the existing higher end and high cost real time controllers by the state of the art high performance, economical FPGA based industrial controllers. This controller will be flexible for engineering a specific real time application with limited inputs and outputs rather than being part of a large automation system. Theoretical considerations are supported by digital simulation and verify the validity of the concept. The implemented flying shear control system proved highly efficient in operation.**

Index Terms—Industrial Controllers, Operation of Shear, Speed reference blocks, H-bridge, Simulation results.

1. INTRODUCTION

Real time industrial automation means the ability to do any control function as it is required without any time delay. Industrial Automation commonly uses high speed computers with central processor, adequate memory and the inputs and outputs for control applications. With successively improving reliability and performance of digital control techniques have predominant over other analog counter parts [1-2].

The advantages of digital controllers are

1. Reconfigurability
2. Power saving options
3. Less external passive components
4. Less sensitive to temperature variations

1.1EXISTING TECHNIQUE

Digital signal processors (DSPs), Microprocessors and Microcontrollers are normally used for digital control applications. Micro-processor based control schemes have the advantage of flexibility, higher reliability and lower cost [3], but the demanding control requirements of modern power conditioning systems will overload most of general purpose microprocessors and the computing speed of microprocessor limits the use of microprocessor in complex algorithms. DSPs and Microcontrollers `can no longer keep pace with the new generation of application, that requires higher performance and more flexible to accomplish the same task. In spite of the increasing popularity, the design of digitally controlled industrial controllers are affected by several problems among them, software portability/ re-usability is of strict concern in fact though in most cases high level language is the programming choice, each program is strictly tied to the particular architecture, being I/O pins, peripherals and register settings specific for each Microprocessors [4].

Therefore any change of the Microprocessor, imposed by the introduction of new features or the need of better performance or the availability of cheaper components, requires a huge revision of the project in order to fit with the new system such an operation is time consuming, expensive and sometimes unsuccessful[5]. Moreover Microcontrollers and DSPs are sequential machines that mean tasks are executed sequentially which takes longer processing time to accomplish the same task [6]. These results in time delay or switching delay between the initiation of the command and the actual execution [7]. The efficient control of industrial drives systems should involve fast computational units and the better energy control [8].

1.2 PROPOSED TECHNIQUE

In recent years programmable logic devices have developed rapidly especially the Field Programmable Gate Arrays (FPGA) it has low power consumption, flexible programming, shorter development cycle, easier to transplant [9]. In FPGA multiple operations can be executed in parallel so that algorithm can run much faster which are required by control system [10]. The high speed hard wired logic can enhance the computation capability. The ASIC based technology provides a rapid and low cost solution for special application with large market. Owing to the progress of technology, the life cycle of the most modern electronic products becomes shorter than their design cycle [11]. The emergence of FPGA has drawn much attention due to its shorter design cycle, lower cost and higher density. The simplicity and programmability of FPGA make it the most favorable choice for prototyping digital systems. Additionally, they almost eliminate the code portability problem as VHDL, the main hardware description language, and several development tools are almost device independent [12-13]. The proposed FPGA based real time controller takes care of these problems with different architecture of the controller. FPGA-s on the other hand operates with a different technology and provides very fast computational speeds.

The control of flying shear in a hot rolling mill is taken, since this application is quite complex but at the same time compact. The flying shear is the common application in hot rolling mills for cutting the moving steel bar. Effective control of the shear should be done for ensuring accurate cut under different metal size and speed. This control of shear is being realized by using FPGA. An FPGA is the ideal means of implementing a large amount of logic in a very small space with a large degree of flexibility. An FPGA is reprogrammable and this allows modifications to the switching controller to be made internally without any changes to the printed circuit board. The re-programmability decreases the number of required prototype re-designing rounds [12-13]. All decisions are made digitally and the current reference at any instance is represented as a fixed point value inside the FPGA.

2. OPERATION OF SHEAR

2.1. PRINCIPLE OF SHEAR

The flying shear employed in hot rolling mill is used for cutting the rod. Either front end or tail end trimming or cutting process is shown in the figure 1. Hot Billet is the raw material to the rolling mill. The steel bar in the rolling mill moves with a constant velocity Vdel. The distance between the hot metal detector and the center of the shear is fixed LS and LC is the length to cut. Initially the shear may be at rest. TC is time duration between the detection of rod by HMD and acceleration of the shear. At time TC, if the shear is commanded to accelerate, the shear blades will cut the material at an appropriate instant and the desired cut length is achieved. The shear blades and the material should move in approximate synchronism during the separation but a slightly higher velocity of the blades should be specified for separating the material [14-15-16]. Following the cut, the shear is decelerated and is finally parked at rest at the selected park position. It is to be noted that the accelerating and decelerating phases must be completed in less than one revolution of the shear roll. The metal is rolled in number of stands. The stands in the beginning of rolling are called roughing stands, followed by intermediate stands and then the finishing stands. The shear for trimming the ends or crop shear is located between the roughing and intermediate stands and between the intermediate and finishing stands. A typical location of shear is as shown in the Figure 1.The input material to the shear may travel with a linear velocity Vdel depending upon the size.

2.2 FLYING SHEAR CONTROL:

The name flying shear implies that the bar is cut while it is on move, without stopping it. This is called as "Cutting on the fly". The flying shear drive accelerates the shear rolls to synchronize with the line speed. At some point of time, the cutting blade comes in contact with the hot bar and shears it, when moving with the speed of the bar speed plus additional set lead speed. The shear rolls then decelerate and return to its original position ready to cut again. Such an application as above requires 'Real Time Controller' without any time delays. Bar mill contains digital drives for stand drives, shears, braking pinch rolls, special duty shear motors, main supply transformers, controllers, motor control centers for water pumps, operators control desks and posts. Sensors like hot metal detectors, pyrometers, water level sensors, pressure transducers, instrumentation panels, pulse encoders, proximity switches. The drive is configured using real engineering units such as mm or inches. Operator interface is made by entering parameters directly on the drive.

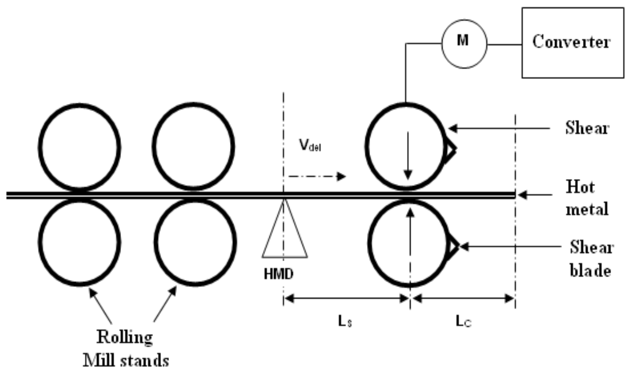

Figure 1 Principle of Operation of Shear

The flying shear control is split into three portions: [15]

1. Generating the shear speed reference and initiate the acceleration of the same at the right instant
2. Generating the cut command and initiate the deceleration for stopping
3. Initiate the parking control to bring blades back into parking position.

The generated speed reference signal has five parts.

1. Calculate the time to give cut command (T_C)
2. Accelerating period (T_1)
3. Constant speed period (T_2)
4. Deceleration period (T_1)

5. Finally generating speed reference for position control.

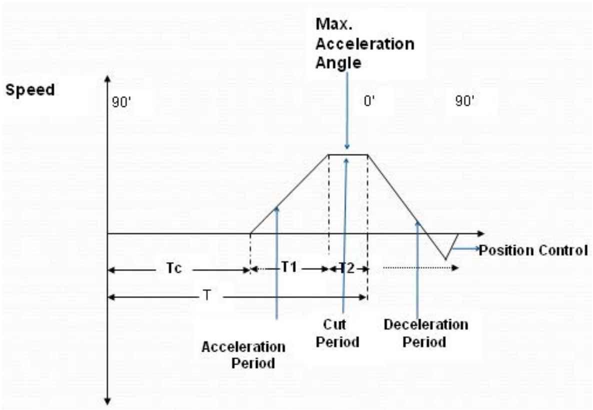

Figure 2 Speed Time Characteristics of Start-Stop Shear

2.3. TYPICAL CALCULATIONS TO BE IMPLEMENTED IN THE SHEAR CONTROLLER

Delivery speed is the input which can be calculated from the speed of the rollers [14].

$$V_{del=} (2\pi rN/60) \quad (1)$$

Where, Vdel - the delivery speed of metal bar

r - (D/2) the radius of the roller

N - the motor rpm

- The distance between the Hot Metal Detector and the shear is fixed = L_S
- The desired cut length = $L_{C.}$
- Shear blade has to accelerate to a peripheral velocity 1.1 $V_{del.}$
- Shear blade is normally placed at 90 degree.
- HMD detects the front end as well as tail end or each billet and initiates the shear.
- Shear blade will be given a command at time T_C (instance for giving cut command).
- The time taken for the blade to travel from 90 degree position to the cutting angle depends on the thickness of the metal.
- Shear has to accelerate from 0 speeds to the maximum speed within the time $T_{1.}$
- The time taken for the blade to travel from 330 degree to 360/0 degree is $T_{2.}$

The various timings like Tc, T_1 and T_2 are given by

$$T_C = [(L_S + L_C) / Vdel] – (T_1 + T_2) \quad (2)$$

$$T_1 = 2 π r (2/3) (2/1.1 Vdel) \quad (3)$$

$$T_2 = 2 π r (1/12) (1/1.1 Vdel) \quad (4)$$

The equations (3) & (4) are based on a certain bar thickness and may undergo changes for other thicknesses.

3. FUNCTIONAL BLOCK DESCRIPTION

Key Pad here seems to be HMI used enter the values like material speed in m/sec, Cut length of the rods in meter, radius of the shear blade, LCD is to display the input values given to FPGA controller. The key pad and LCD can be interfaced to the FPGA by the interface program [17].This is shown in the figure 3. Hot Metal Detector is to detect the front end as well as tail end or each billet and initiates the shear. FPGA controller takes the input values and performs all calculations and finds the timings like TC, T1, and T2. According to these timings the FPGA controller will produce speed reference signal to the shear drive. The speed reference signal produced by the FPGA is the digital control pluses produced to the drive. Shear motor is connected to the shear drive, as per the pulses produced by the shear drive shear motor is operated.

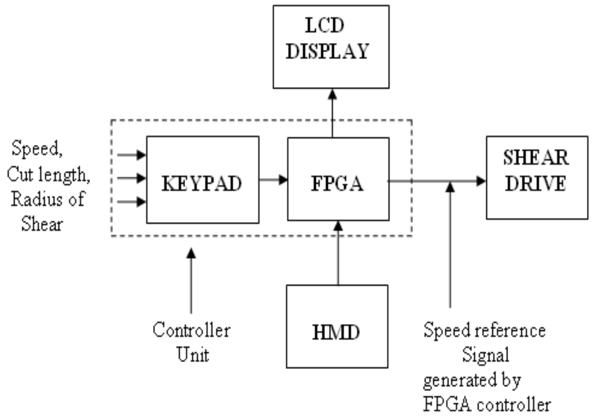

Figure 3. Functional Block Diagram

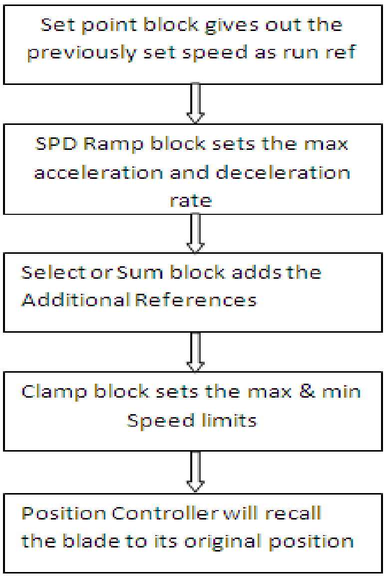

Figure 4.Speed Reference Block

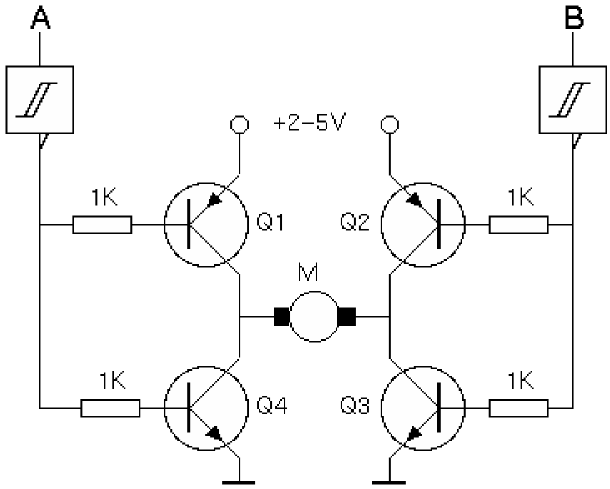

Figure.5.Arrangement of H-Bridge

Figure 4 explains the various functions of speed reference blocks. A set point block for setting up the required operating speed and saving the same for subsequent start-ups.The set point block bit inputs receives increase or decrease commands from external operator devices like push buttons. A ramp block for setting up the acceleration and deceleration rates. A select or sum block to select or add more than one additional references. These additional references can be some internal values or external operator set values. A clamp block for fixing the maximum or minimum speed references finally given to the process with settable limits through calibration Finally the position controller will produce signal to drive for recalling the blade to its original position. These Speed Reference Blocks come in to operation when the FPGA gives the Drive ON Signal and also these kinds of speed reference blocks normally employed in the microcontrollers now here implemented the same in the FPGA.

4. H-BRIDGE BASED SHEAR ON-OFF FUNCTION

H-Bridge is an electronic circuit which will control the mechanical operation. The H-Bridge is the link between digital circuitry and mechanical action. The computer sends out binary commands, and high powered actuators do stuff. Most often H-bridges are used to control rotational direction of DC motors. In H-bridge there used Four MOSFETS.So to operate MOSFET voltage is applied to the gate (from FPGA), and suddenly a current of electrons passes through the other two pins [18]. Connect a motor (M) in line with one of the pins then motor is set to go. In the Figure 5 shown below the letters A and B are the two control lines in which the control logic should be applied. Since there are two pins, and only a binary control, there are four possible things that can happen.

A=**0** B=**0**: Nothing happens, the motor is turned off.
A=**1** B=**0**: Motor rotates clockwise.
A=**0** B=**1**: Motor rotates counterclockwise.
A=**1** B=**1**: Motor stops.

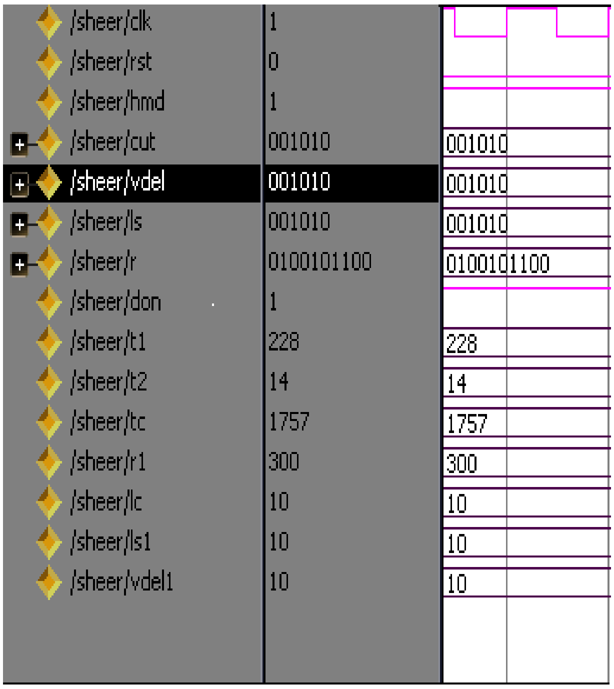

Figure.6 Simulation Result for Shear On and Off Time Calculation

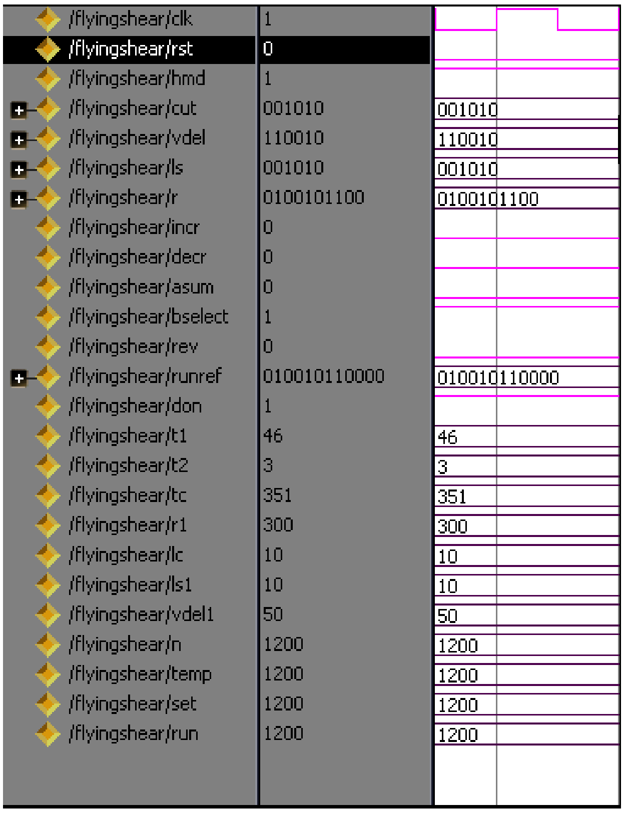

Figure.7 Simulation Result for Speed Reference Blocks

So with this concept we can ON and OFF the shear with respect the following time periods.

1. Time to give cut command (Tc) here **A**=0 **B**=0.

2. Accelerating period (T_1) here **A**=1 **B**=0: Motor rotates clockwise.

3. Constant speed period (T_2) here **A**=1 **B**=0: Motor rotates clockwise.

4. Deceleration period (T_1) here A=0 **B**=0: Nothing happens, the motor is turned off and the brake is applied for the fast stopping.

5. Parking period here **A**=0 **B**=1: Motor rotates Anti-clockwise for some period and decelerates and stopped in the final park position.

The code is written in VHDL and simulated using Modelsim and then downloaded into XILINX SPARTAN 3E. The simulation result showed in the figure 6 shows the shear ON and OFF time calculation for the various input parameters and the simulation result shown in figure 7 shows functional speed reference blocks according to fixed process loaded in the speed reference blocks it will operate the drive and then FPGA will produce gate pulse to the H-Bridge. The position control is optimal in the sense that the flying shear drive accelerates/decelerates with the fixed timings which has been according to the various input parameters.

5. CONCLUSION

An optimal position control for flying shear based on a moving target has been presented. The developed and implemented position control algorithms, with appropriately selected parameters and with a corresponding correction signal added to the blade velocity reference, ensure high cutting accuracy. The algorithms also allow automatic transition from one mode to the other, thereby permitting on-line scrap minimization by computing the optimal combination of different custom length sections. The presented FPGA-based flying shear control system has been put into operation. We can get the reduced cycle time of 10 to 15 msec when compared to other sequential processing machines. The significant economic effects of its operation are due to high reliability, high quality and accuracy of cutting, energy savings and especially scrap reduction. With appropriate modifications, the described algorithms can also be used in the automation of metal-processing plants and various manipulators, the control of which is based on the positioning.

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