Speed Referencing For Continuous Hot Rolling Mill Using FPGA Controllers

S.Dinesh Kumar[1], A.Mohankumar[2], G P Nathan[3], R.Sathish[4]

[1]UG Scholar, [2] UG Scholar, [3] UG Scholar, [4]Assistant Professor

Dept. of Electrical and Electronics Engineering, Angel College of Engineering and Technolgy, Tiruppur, TamilNadu, India.

Abstract- The increasing need to save energy and minimize scrap together with requirements on the accuracy and quality of operation in continuous rolling mills has necessitated the development of an intelligent controller for continuous hot rolling mills. The cascade speed reference controller is the main application in wire rod mill for reducing the size of the bar. Effective control of the speed should be done for getting the optimum response required for the rolling. The control of speed is being realized by using FPGA controller. The cost of the designed circuit is low when compared to the PLC based industrial controllers presently used as high end part of a large automation system. When addressing a compact automation system like the cascade speed reference controller, the proposed system needs to be very effective and economical. 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.

Index Terms—Industrial Controllers, Operation of Hot Rolling mills, Control Philosophy, Cascaded Speed reference controller.

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

A.EXISTING 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].

B.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.. FPGA-s on the other hand operates with a different technology and provides very fast computational speeds.

The producing speed reference signal for continuous hot rolling mill is taken, since this application is quite complex but at the same time compact. Looper and tension control is important in hot strip mills because it affects the strip quality as well as strip threading. Here a sophisticated control algorithm is developed and implemented in FPGA controllers for cascade speed referencing system and the Looper and tension control in hot rolling mill. The speed of the various dc drives involved in the hot rolling mill is controlled according to the loop angle in case of abnormal condition. When disturbance occur due to several sources the tension of the billet increases between the stand. As a result of it loop is formed between the stand. In such a case the loop height is measured and adjusted by controlling speed of that stand until the loop height measured is equal to the set value. The FPGA controller is used to produce the signal, to correct the speed according to error signal and its performance is improved.

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 speed reference at any instance is represented as a fixed point value inside the FPGA.

2. OPERATION OF HOT ROLLING MILLS

2.1. LAYOUT OF HOT ROLLING MILL

The process areas in HRM comprises of various part as shown in fig2.1 like Reheating Furnace, Roughing Mill, Steckel Mill and the down Coiler .The slabs are continuously charged in to the reheating furnace which is LPG fired and heated to around 1100°c to 1300°c for 6 to 8 hours depending upon the input steel. The slabs are moved from charging pit to outlet of furnace by walking beam conveyor. The roughing mill is a single stand four high reversing mill with attached vertical edger and a screw down for the roll gap adjustment. Hot slab of initial thickness is rolled down to 25mm in about seven to nine passes. The transfer bar is then transported to the Steckel-Finishing Mill. The finishing mill comprises a single 4 high -reversing stand with a furnace coiler on either side. A pinch roll unit is also located between the stand and the coiler to assist the strip to feed in to the furnace and to the roll gap at the time of threading. The furnace for the coilers is used for maintaining the temperature of the strip (700°c to 800°c) during rolling process.

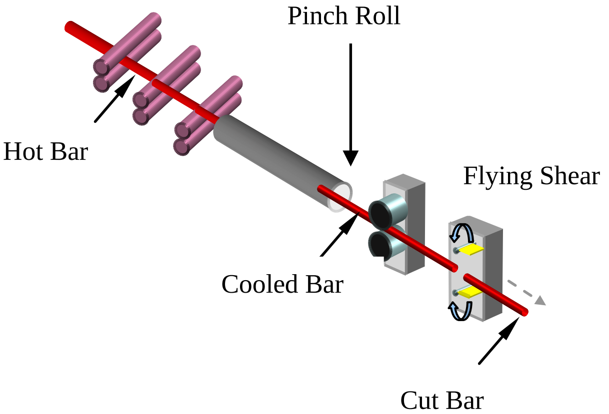

Figure 2.1 Layout of hot rolling mill

The automatic steckel mill has been provided with all technological features like AGC, CVC and width control in order to produce good surface profile and close strip gauge tolerances. The transfer bar received from the roughing mill is first cropped by a drum type shear located ahead of the steckel mill. The material here is rolled in to strip for the required thickness of 2 to 8 mm in about seven reversible passes. When the final required thickness is achieved in the steckel mill, the strip is transported to the down coiler with the help of run out tables.

2.2 BASIC LAWS OF ROLLING MILL

The real time inputs are reduction ratio of each stand and the linear speed of the last stand (reference signal) which is the desired speed of mill. The desired motor speed in rpm can be calculated based upon the desired linear speed in m/s, effective roll groove diameter in meter and gearbox ratio of the rolling stand. There are various ways to achieve the speed reference generation for the wire rod mills; to properly synchronies the linear speeds of all the rolling stands. Synchronization of the linear speeds for the stands is required to adjust or control the linear speeds of the stands, to achieve tension free rolling of the bar.

2.2.1 REDUCTION RATIO

The reduction ratio is defined as the ratio between cross sectional areas of the product existing stands N and N+1. However the measurement of areas cannot be dynamically done; the same is indirectly calculated as the inverse ratio of their corresponding exit speeds. This is due to the principle of constancy of volume exiting per unit time.

The above law provides the 'mechanism' with which it is possible to perform roll pass design in continuous bar mills.

2.2.2 LINEAR SPEED

The linear speed of an object is a measure of how long it takes the object to get from point A to point B. linear speed is usually given in a form such as meters per second (m/s).

2.2.3 ANGULAR (ROTATIONAL) SPEED

The angular speed of a rotating object is a measurement of how long it takes a given point on the object to make one complete revolution from its starting point. Angular speed is generally given in revolutions per minute (RPM). An object that makes ten complete revolutions in one minute, for example, has a speed of 10 RPM.

The angular speed is measured using tachogenerators and the same is related to the linear speed by the equation (2.1)

$$V = \frac{2\pi N}{60} x \text{radius of the work roller} \ldots\ldots\ldots\ldots (2.1)$$

The cascade speed reference system calculates the rotational speed as per the actual linear velocity and the individual roll diameters. It provides the correct rotational speed references to the individual motor drives, to achieve the end requirement that is tension- free rolling.

The above calculations are being done through PLC based larger automation system. The purpose of this project is to achieve the above functionalities using a simple dedicated FPGA Controller.

3.1PRINCIPLE OF THE CASCADE SPEED REFERENCE CONTROLLER

The arrangement of cascade speed reference controller is shown in Figure 3.1. The Wire Rod Mill is used for producing the round shaped bars of various sizes. For getting various linear speeds for various roll diameter set ups, the motors are used, with the thyristor converters for getting the optimum response required for the rolling. The converter-motor combination can be tuned to offer best recovery upon the impact speed drop, when the bar bites the roll stand. The various motor drives use appropriate power modulator. Because of the fast correction because of the digital controller, the speed drop is limited, and the recovery to the required speed is within shortest possible time.

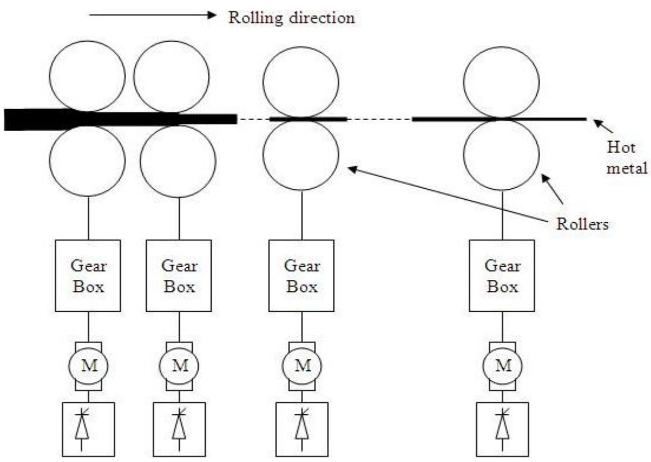

Figure 3.1 Arrangement of cascade speed reference controller

The speed referencing system adopted here is based on the law of volume flow constancy per unit time. The overall mass at the entry is same as that of the mass at the delivery. This means the linear speed at the delivery shall be more as compared to that at the entry, and the length of the bar shall be more, at the delivery, as compared with that of at the entry. The speed reference for each stand is calculated depending upon the schedule reduction ratios of each stand.

3.2 CONTROL PHILOSOPHY

The Speed Referencing System adopted here is based on the law of volume constancy the Entry cross-section area (A_i) and Exit

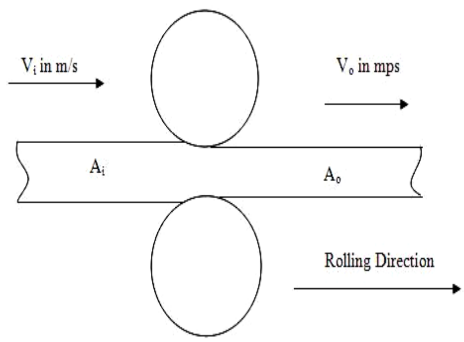

Figure 3.2 Details of linear speed and Reduction at a particular stand of the Wire Rod Mill

cross-section area (A_o) are mutually linked to the Entry Speed (V_i) and Exit Speed (V_o). With reference to the Figure 3.2 following parameters can be defined –

A_i = Area of the cross section of the bar before it enters the

rolling stand

A_o = Area of the cross section of the bar after it is delivered

from the rolling stand

V_i = Linear speed of the bar at the entry in m/s

V_o = Linear speed of the bar at the delivery of the stand in

m/s

The formula derived out of this can be written as –

$$\frac{\text{Ao in meter square}}{\text{Ai in meter square}} = \frac{\text{Vo in m/s}}{\text{Vi in m/s}} \quad \text{…………} (3.1)$$

The ratio of the cross sectional area of the bar at delivery to the cross sectional area of bar at entry is the Reduction Ratio (RR) for the rolling stand. To achieve desired Reduction Ratio by monitoring and maintaining the linear speed ratios, the angular speed to be compared for diameter variation.

3. 3 SCHEDULING

As a part of automation to have online coordinated distribution of real time parameters among Distributed Control Systems, numbers of schedules are required for the products to be produced.

For the rolling process, the same is called as rolling schedule which provide the relationship between various parameters such as

1. Input billet area and length
2. Output product dimension and the desire

   Production speed.

   No. of passes.

1. Individual pass reduction ratios (or equivalent speed ratios).
2. Individual pass roll diameter.

These are proposed and stored in the HMI with certain product code numbers and called upon when that product is to be produced. Whenever a particular output from a particular input is required, for e.g. from 80 mm^2 billet to 10mm round bars, that particular schedule to the controller should be downloaded by the operator. Depending on the schedule selected the correct output of the mill is taken out .The required condition for this is that the mill should be offline and all contacts should be open. As the billet goes down the mill the length of the material increases, reducing the total area of the material. The mill works on the principle that the volume flow of the material / unit time remains the same increasing the length factor. As the length of the material increases, to keep the tension constant the speed of the material is increased.

3. 4 CASCADE SPEED REFERENCE CONTROL

The Wire Rod Mill is used for producing the round shaped bars of various sizes. The heated bar is very soft. When this bar enters into the rolling stands, the linear speeds of adjacent stands are required to be kept within precise limits, so as to ensure that the bar is not subjected to tension. Consider, if a stand is running at a higher linear speed, compared to its required linear speed, then the bar is subjected to tension and can deform. To remove the tension because of the higher speed of this stand, the linear speed of the preceding stand can be increased. But then the tension shall be shifted to the preceding section. The formation of loop is shown in Figure 3.3.

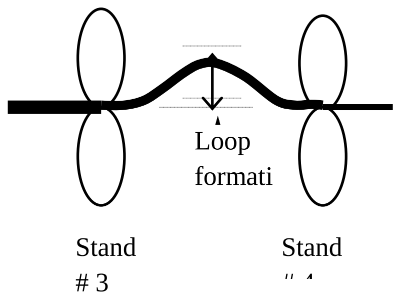

Figure 3.3 Formation of Loop

To avoid this from happening, the linear speed of all the preceding stands need to be adjusted in their proportion of the reduction ratios. Normally, the mill has number of stands in which the material is passed to reduce the size. The maximum delivery speed of the mill in m/s is given by the Rolling Schedule. This speed is decided depending upon the metal grade and section being rolled. The line speed of subsequent individual stand is calculated by using the speed reference of previous stand and its schedule reduction ratio. The schedule reduction ratios will be given by Rolling Schedule and is calculated from the entry cross-section area and exit cross-section area of each stand.

This is illustrated as under –

Consider if there are 22 stands in a mill. If Stand-22 is finishing stand, then the line speed reference for Stand-21 is derived as follows:-

$$V21 = \frac{V22}{Rf22} \quad \text{………….. (3.6)}$$

Where V_{21} = Line speed reference for Stand-21.

V_{22} = Line speed reference for Stand-22 (Mill Delivery

Speed)

Rf_{22} = Reduction factor for Stand-22

$Rf_{22} = Ain_{22} / Aout_{22}$

Ain_{22} = Entry cross-section area of stand 22.

$Aout_{22}$ = Exit cross-section area of stand 22.

Thus for N^{th} stand the Line Speed reference is derived as follows: -

$$V_N = \frac{VN+1}{RfN+1} \quad \text{……………. (3.7)}$$

The reduction ratio of the each stand and the desired speed of the mill are given as input to the controller.

The basic block diagram is shown in the Figure 4.1.

4. FUNCTIONAL BLOCK DESCRIPTION

The block diagram of the controller unit with specification of input and output is shown in Figure 4.1.

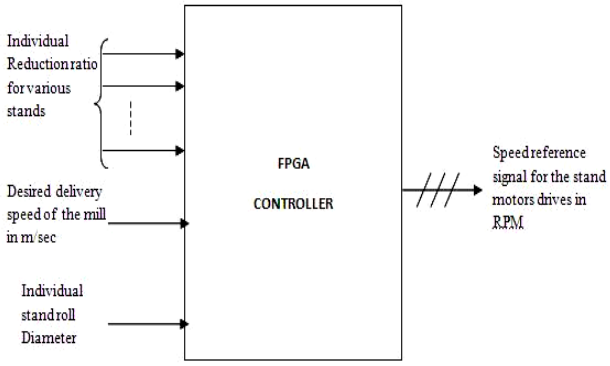

Figure 4.1The block diagram of the controller unit with specification of input and output

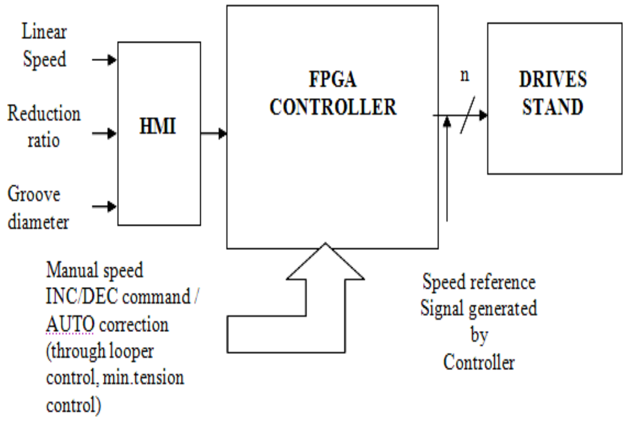

Figure 4.2 Input and Output Block Diagram

Wire Rod Rolling is selected, the delivery speed of last stand is taken as a reference .i.e. the linear speed reference is set in the last delivery stand drive regulator. This linear speed reference is multiplied with the reduction ratio for that stand. This becomes the linear speed reference for the preceding stand drive. The linear speeds of the stands is required to be adjusted to correct the tension developed in the bar. The speed can be adjusted manually or automatically. The manual control is done when the speed is small (during first stages). The AUTO control is used when the mill speed is large (during last stage).

In manual tuning, the stand which is to be adjusted is called as the anchor stand and the command INC/DEC is given to that particular stand. It will be incremented or decremented as per the INCRATE /DECRATE command so as to maintain the reduction ratio or inter stand ratio between two stands. The correction is done in upstream direction which is opposite to the rolling direction.

- Slow increment / decrement rate is 0.1% /sec of the actual value.
- Fast increment / decrement rate is 0.5% /sec of the actual value.

In auto tuning, the speed is controlled by tension control and loop control. Figure 4.2 shows the block diagram for calculating A- factor (Reduction Ratio).

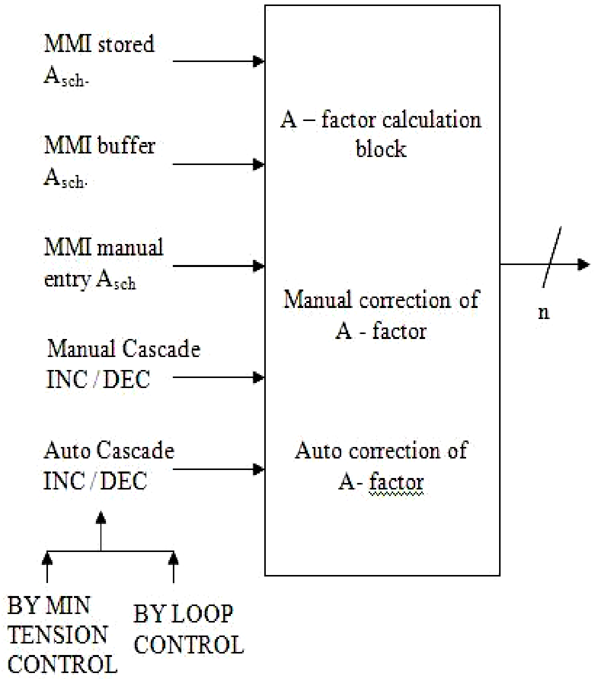

Figure 4.3 Block Diagram for Calculating Reduction Ratio

Where A_{sch} --- desired reduction factor

n --- Number of stands

The adjustment of the linear speed can be implemented as indicated in the Figure 4.4. The speed set point introduced in between the frequency input block and the multiplier block facilitates the entry of the correction signal to the main cascade speed reference signal. The speed set point block develops a small speed reference, when the input joystick switch is changed to increase or decrease position. This correction signal is added or subtracted into the main cascade linear speed reference of the drive as shown in the Figure 4.4. This change is automatically reflected to all the preceding stand drives, because of the cascading chain of the linear speed reference signal.

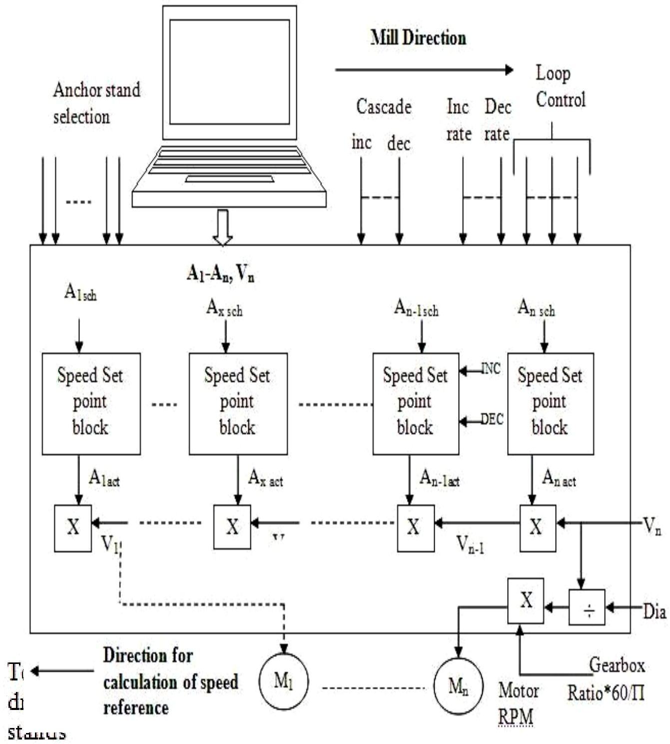

Fig. 4.4 Cascade Linear Speed Reference Block

Where A_{act} --- modified reduction factor

A_{sch} --- desired reduction factor

V_1-V_n –linear speed

A_1-A_n – reduction factor

$$Asch = \frac{\text{Exit area as per schedule}}{\text{Entry area as per schedule}} \quad \ldots\ldots (3.9)$$

$$Aact = \frac{\text{Entry speed (m/s)}}{\text{Exit speed (m/s)}} \quad \ldots\ldots\ldots\ldots\ldots (4.0)$$

The linear speed and the reduction ratio are given from the HMI.

V_n is the desired delivery speed of mill in m/s. Loop control is done by auto tuning. This also includes auto INC/DEC as shown in Figure 4.8. Anchor stand selection, the cascade INC/DEC and INCRATE/DECRATE are done by manual tuning. The speed reference is calculated to the opposite direction of mill. The motor angular speed reference is calculated finally from the effective roll groove diameter, the gearbox ratio and the linear speed reference for that stand as derived above and it computes the angular speed reference for the motor in terms of the rpm.

5. CONCLUSION

Field programmable gate array developed in the past few years are frequently used in motion controller applications because they contain several features optimized for such uses. FPGA Controllers are used to build a block constituting a total mill automation system. It provides basis for a truly distributed control system. Hence this project is a low cost method to control the coordinated drives. The generated signal can be fed to the drive controller operating in the rolling mill. Before giving this signal to the drive controller, it should be modified according to the drive controller employed in the hot rolling mill. 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, 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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