

Photosensor Based Measuring System for Cutting the Bloom at Desired Volume Inspite of its Cross-Section Variation in Continuous Caster of Steel Plant

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(Received September 29, 2006)

Abstract: Inaccurate sized blooms generate Rail-scrap. For deciding the length of rail, the variation in cross section of bloom is more significant than variation in its length but this factor was not considered earlier. Conventional dimensional measuring systems like laser, charged-coupled devices, shaft encoder etc. were tried but they could not work satisfactorily in steel plant environment. Recently a very low cost photo-sensor based bloom dimensional measuring and feedback control system has been designed and tried for cutting the bloom at desired volume inspite of variation in its cross-section and casting speed. This undergoes a wide degree of in surface temperature of bloom fluctuates from 350°C to 900°C and have been tracked through silicon phototransistors (sensitive to above 550°C temperature range) by using method of light interruption. The cross-section of bloom has been measured with an accuracy of 1 mm² by using photo-transistors whose individual diameter itself is 6 mm. Arrays of light emitting diodes have been used for representing the length, width and height of moving / stationary blooms for operator guidance. Techno economic has been calculated only based on bloom length measurement and its control is in the generation of 18 extra rails per day from same amount of steel with a monetary gain of Rs 82 lakhs (\$ 0.16 million approximately).

Key words: photo sensor stack, accuracy, productivity, L.E.D. based dimensional display.

1. Introduction

USSR supplied bloom caster of Bhilai steel plant (India) continuously casts the molten steel into blooms (cross section 300 mm x 340 mm) at 15 meter height in four narrowly spaced strands as shown in Fig-1. After passing through accelerated water spray system, the blooms are gradually dragged and roll-down to ground level where they are cut into small pieces ranging from 5.4 m to 5.9 m long by means of gas cutting torches which are installed in the trolley. After completion of cutting current bloom, the gripping device releases it and the trolley returns to initial position for gripping /cutting the incoming bloom stream. These cut-blooms are sent to rail mill to roll for 84m long rail.

Problem: Due to wear and tear and other metallurgical and mechanical problems, the mould cross section changes by 1 mm^2 to 130 mm^2 , ultimately affects the rail length as shown in tables 1 and 2 respectively. Many a times trolley deviates from its reference point due to bouncing and affects the bloom cut length¹.

2. Comparison of other Dimensional Measuring System with Newly Developed System

Limitations of other dimensional measuring system are discussed below:

CCD camera: The system is unable to measure dimension of bloom precisely since its surface temperature varies from 350°C to 900°C . Its electronic components like shift registers, master clock etc are damaged due to minute interruption in its cooling. It needs obstruction free area to view but it is not possible in busy shop floor. It also needs 1:100/1000 scaling^{2,3} and needs wide gap between two pieces. The measuring error varies from 0.1 % to 0.3 %. The cost of the system is 10 lakhs (approximately).

Encoder (Incremental/ Absolute): Tear and wear of roll, non contact as well as slip between rolls and bloom, glitches and unmeasured impulses attribute error⁴. Failure of coupling, hydraulically pressed rolls need continuous adjustment and system needs cooling. The measuring error varies from 0.1% to more than 2%, which is dependent upon calibration. The cost of system is Rs 3 lakhs(approx).

Laser:

a. Pulse time of flight: The front cross section of bloom should be visible from the laser source, but in actual practice there is hardly any gap between two successive pieces⁵. It needs 0.001 nano-second timer. The accuracy varies from 0.01% to 0.3% and its price is Rs 4 lakhs (approx).

b. Doppler shift: Tilting and roughness of bloom causes system failure⁶. It needs continuous adjustment and it has complex circuitry to maintain. The cost of the system is Rs 1.5 crores (approx).

Photosensor based (New system) : It does not need calibration on span of time since it has 1:1 scaling between location of photosensors and tracking of front of bloom and it could be possible by putting them at 200 mm from hot bloom. Photosensor do not need external cooling and has simple circuit. The accuracy varies from 0 to 0.3 % and it depends upon least count. The cost of the system is only Rs 30,000/-.

3. Design of Bloom Dimension System

System has been designed as follows:

a. Bloom sensing b. Dimension accuracy

a. Bloom sensing:

(i) Fluctuation in bloom temperature: Factors like scale formation over bloom and fluctuation in casting speed vary the temperature of bloom surface ranging from 350°C to 1100°C . Germanium photo sensor is sensitive to low temperature radiation but it is unstable at higher environment temperature. While silicon photosensor is stable at higher operating temperature but its sensitivity is limited (in visible and higher intensity of infra red radiation region). The silicon photosensors are cheaper than Germanium photosensor⁷.

Phototransistor 14 LF-32 comprised of two bipolar phototransistors is intended to be responsive to radiant energy. Therefore an uninterrupted high intensity halogen light source (70 W, 24 V, 4 A, 2000 hours of continuous operation without cooling) has been focused over hot-bloom while its shadow has been sensed by silicon photosensors which are kept on the other side of bloom. The relative radiation of different light sources and the response of photosensors are depicted in Fig-2.

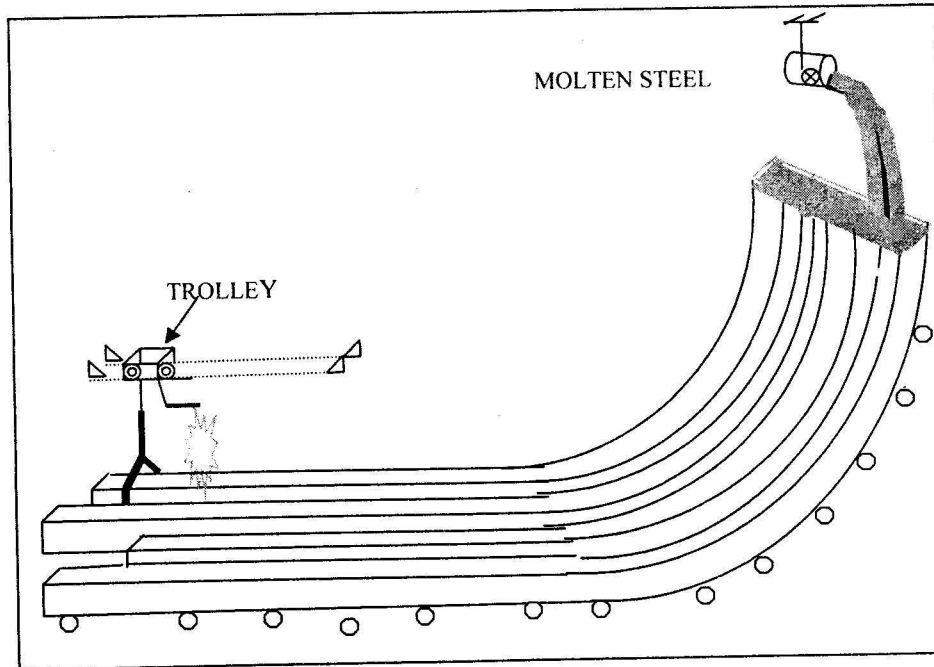


Fig 1: Four Standards Bloom Caster

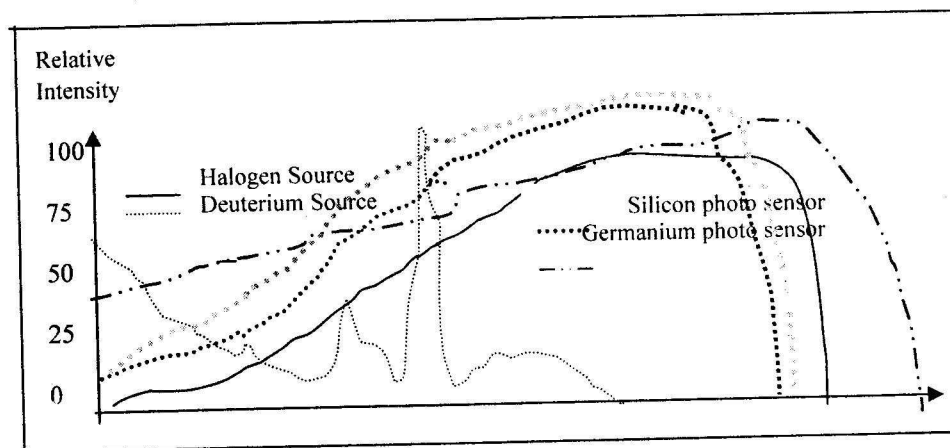


Fig 2: Radiation of Different Light Source & Response of Ge/ Si Photosensor

(ii) **Emission of thermal waves:** Intermittent emission of thermal waves of varying density from hot bloom creates problem in sensing and is overcome by providing narrow focusing hoods and individual clipping circuit to each signal channel of sensor stack, specially for height and width stack.

b. Dimensional accuracy: It has two sections

(i) Bloom volume measuring / controlling system

(ii) Measuring the reference position of gas cutting torch

Bloom volume measuring / controlling system: The relation of bloom volume and rail length is governed as follows.

Volume of bloom = Volume of 6 no. rails (each 13.1 m long) + front crop + back crop

$$(3.1) \quad (L_b \times W_b \times H_b) = L_R \times \text{cross section of rail} + FC + BC$$

where b and R denote bloom and rail respectively while L , W , H are the length, width and height. FC and BC are front crop and back crop of rail of standard lengths. The cross section of rail is maintained very precisely in order to avoid train accidents thereby only length of rail can be changed according to inaccurate sized bloom.

Bloom dimension measuring system consists of following 3 subsystems:

(i) Length sensor stack (ii) Height sensor stack (iii) Width sensor stack.

Location of their sensing unit is shown in Fig-3.

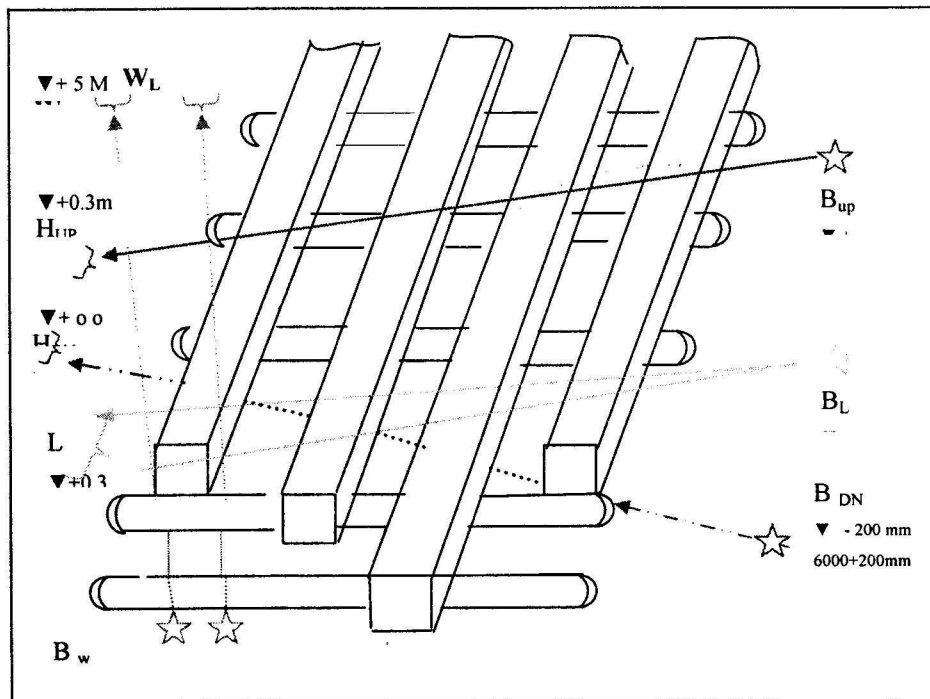


Fig 3: Location of Light Sources & Sensors for the Bloom Volume Measurement

(i) **Length sensor stack:** It consists of following two measuring systems:

(a) Tracking the initial position of trolley, (b) Tracking the bloom for cutting at different length.

(a) **Tracking the initial position of trolley:** To avoid the error due to bouncing of trolley at its initial position, the position of trolley is sensed with a accuracy in the range of 0 to 25 mm by concept of multi point tracking by using array of 11 numbers phototransistors while a bunch of L.E.D. is used as a light source for focusing the light over phototransistors. On blocking the light by reference metallic strip which is mounted on trolley. The location of trolley is displayed by means of LED in dimension display unit.

Table 1: Variation of height /width of bloom

Height		Width	
From	To	From	To
297 mm	307 mm	237 mm	347 mm

Table 2: Rail length due to variation in dimension of bloom

Variation in Bloom	affect on Rail Length by	
Length by 1 mm	13 mm	0.016%
Height by 1 mm	235 mm	0.29%
Width by 1 mm	266 mm	0.33%
Cross section by 1 mm ²	502 mm	0.629%

(b) **Tracking the bloom for cutting at different length:** It is clear from the Table-1 and Table-2 that the variation in height (H_B) and width (W_B) of bloom are 15 mm each. Due to this much cross section forces variation in bloom length of the order of 0.540 m and it generates huge rail scrap. Therefore for safer side, 550 mm variation in bloom length is covered by putting 23 number silicon photo transistors⁽⁸⁾ at a interval of 25 mm in a sensor stack as shown in Fig 4-A. Front end of moving bloom starts to block the light ray of particular light source (halogen type). The shadow gradually advances over photo transistor stack and same is indicated by glowing different light emitting diodes of length display unit after processing through operational amplifiers and filter circuit as shown in Fig-6. Each light emitting diodes and associate length selector switches meant for their respective length with reference to gas cutting torch. For minimum measuring error, the light source has been kept away from bloom while sensor stack should be nearer.

(ii) **Height sensor stack:** Top as well as bottom edges of bloom are continuously sensed by two sensor stacks which are placed on one side of bloom while other side, two independent light sources have been placed as shown in Fig-4-B and Fig-5-B. Each sensor stack consists of 11 phototransistors and kept side by side in a linear array. Stack can be rotated, tilted in all the three direction in order to get maximum light from light sources (top and bottom). The continuously varying shadow of bloom edges over sensor stacks translated into bloom dimension unit by means 22 L.E.D. The slope of sensor stack with respect to horizontal plane can be varied for varying the arm of sensor stack. The least count of the order of 1 mm in height is achieved.

$$(3.2) \quad \text{Height of bloom} = \left\{ \begin{array}{l} \text{no. of sensors under shadow in (Top + Bottom) stacks} \times \\ \text{least count} + \text{distance between sensor stacks} \end{array} \right\} \times 1/a$$

$$= \left\{ \text{Cosec } \theta_1 \times L_{H \text{ top}} / n_1 + \text{Cosec } \theta_2 \times L_{H \text{ bottom}} / n_2 + d \right\} 1/a$$

where n_1 and n_2 are number of sensors in top and bottom stack and $L_{H \text{ top}}$ and $L_{H \text{ bottom}}$ are length of sensor stacks and θ_1 and θ_2 their inclination with horizon respectively and d is distance between two sensor stacks and a is compression of shadow of bloom over sensor stacks.

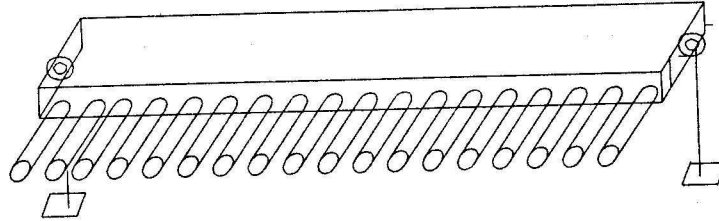


Fig 4A: Length Sensor

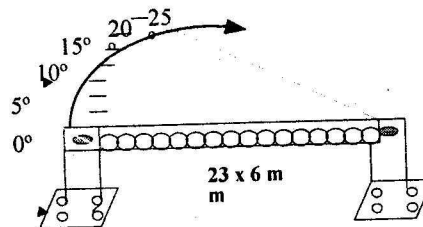


Fig 4B: Height/Width Sensor

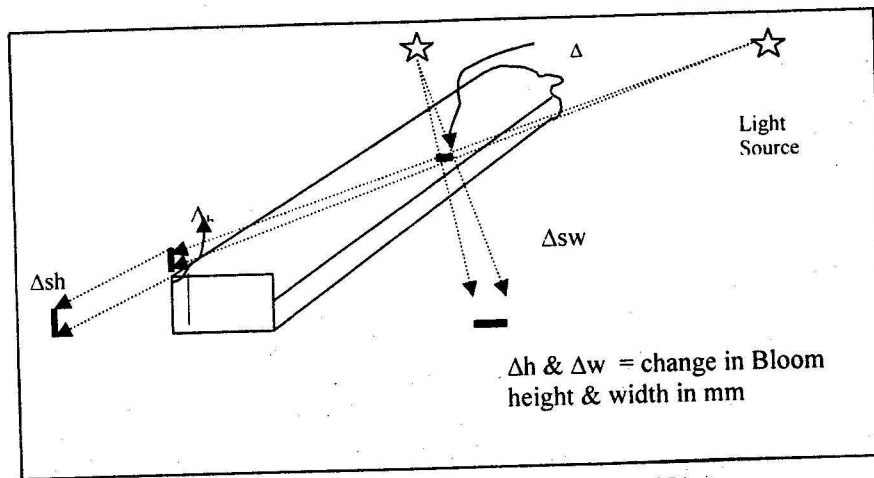


Fig 5A: Change in Shadow With Cross Section of Bloom

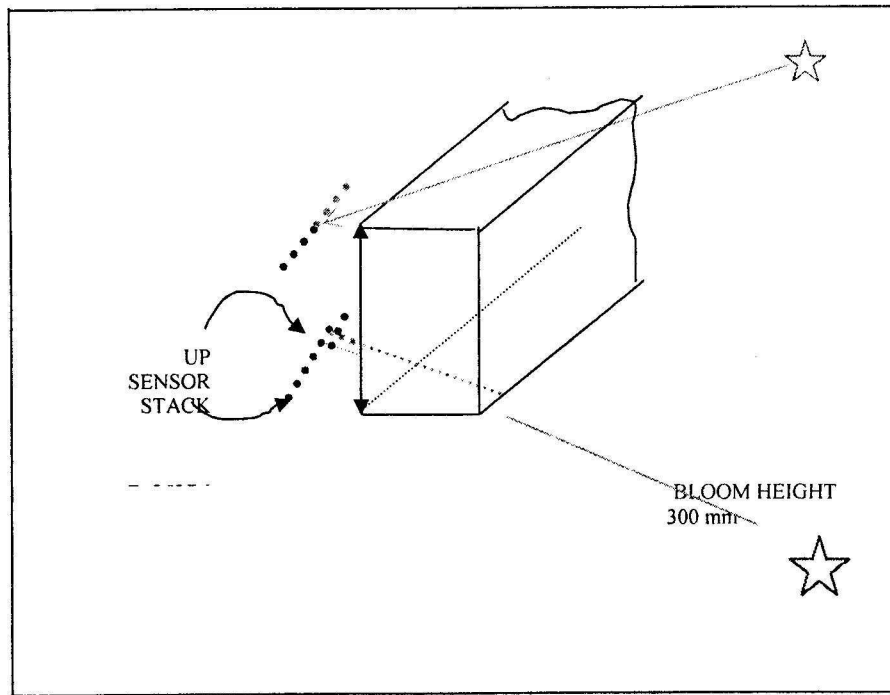


Fig 5B: Bloom Height Measurement

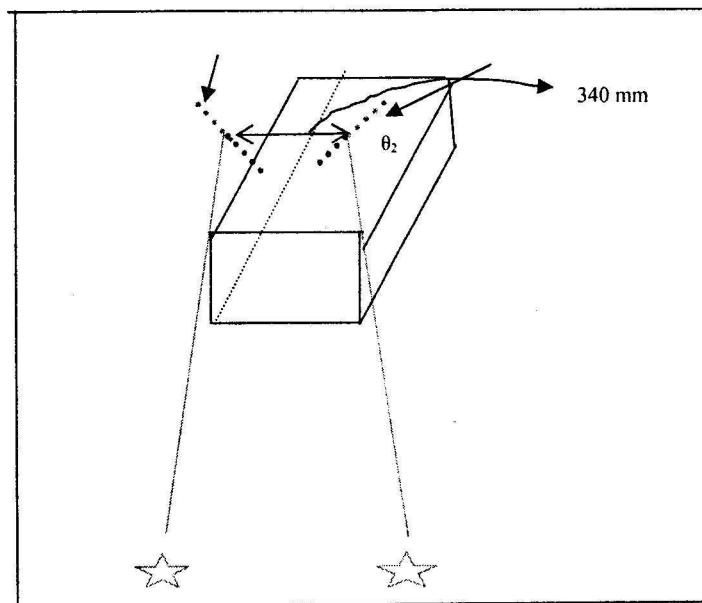


Fig 5C: Bloom Width Measurement

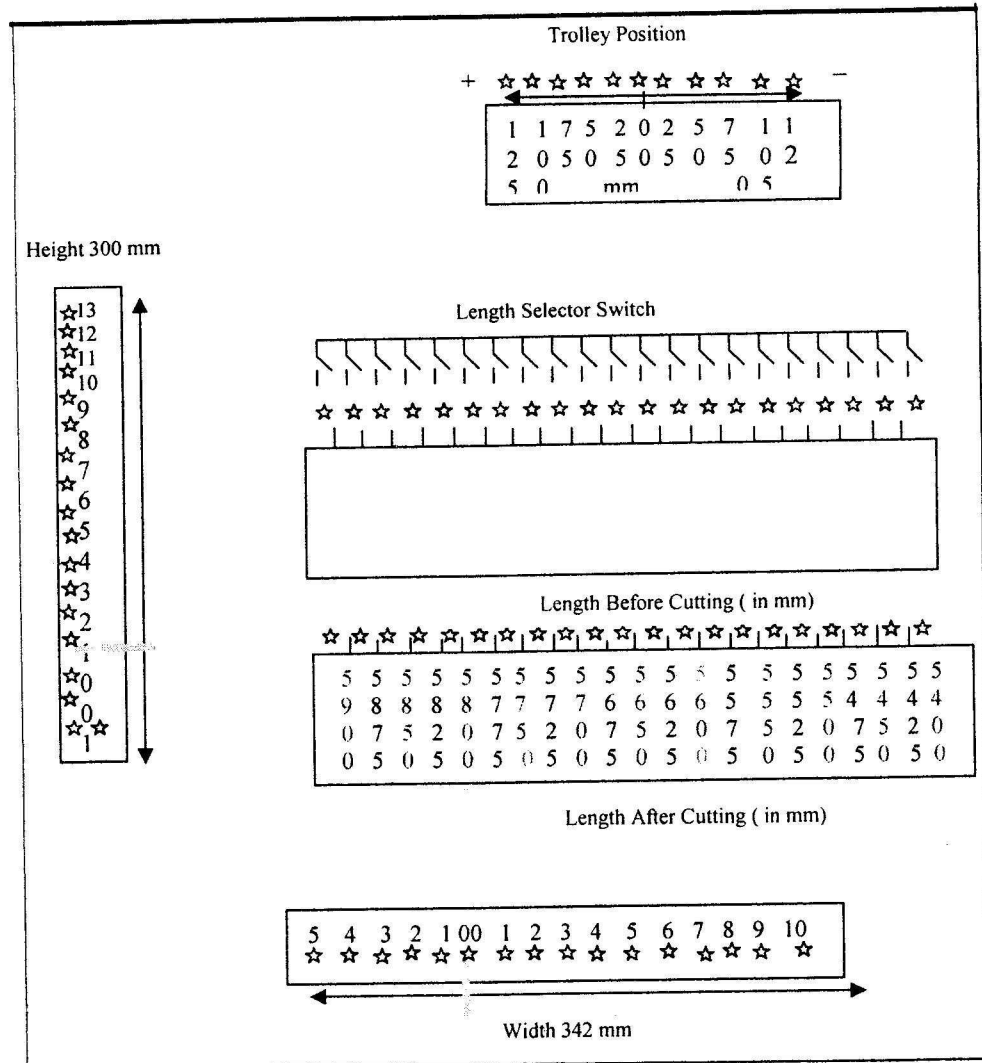


Fig 7: Bloom Volume Display

4. Bloom Volume Display

Electronic-display unit serves an important interface between operator and measuring system. The output of operational amplifier related to length, height, and width is fed to LED based bloom length display unit which is installed in the operator pulpit to guide the dimension of bloom as shown in Fig-7. Table-3: Cut length vs cross section, shows that the standard volume for generation of R-52Kg and R-60Kg rails is divided by current measurement of height and width of bloom and the resultant predicts the bloom length which is given in the Table-3. Thereafter operator selects the bloom length by means of selector switches. The close loop system for reducing the crop is depicted in Fig 8. The

bloom length L_{ij} is decided by the different height starting from H_i to H_n i.e. 297 mm to 307 mm and different width starting from W_i to W_n i.e. 337 mm to 347 mm.

$$(4.1) \quad L_{ij} = \begin{array}{c|c|c} H_i & & W_j \\ \hline - & \times & - \\ \hline - & & - \\ \hline - & & - \\ \hline H_n & & W_m \end{array}$$

Let us see the Table-4: Cut length vs casting speed: As casting speed varies from 0 to 1.2 m /min and affects the cut length as gripping of bloom takes 2-3 seconds and it contributes 40 mm to 60 mm error in bloom length and especially at the end of casting, the speed shoots up. In order to cut bloom at desired length the gripping device should be actuated in much advance (say 25 mm or 50 mm). Therefore a table has been put for guiding operator to cut the bloom at desired length by using the selector switch.

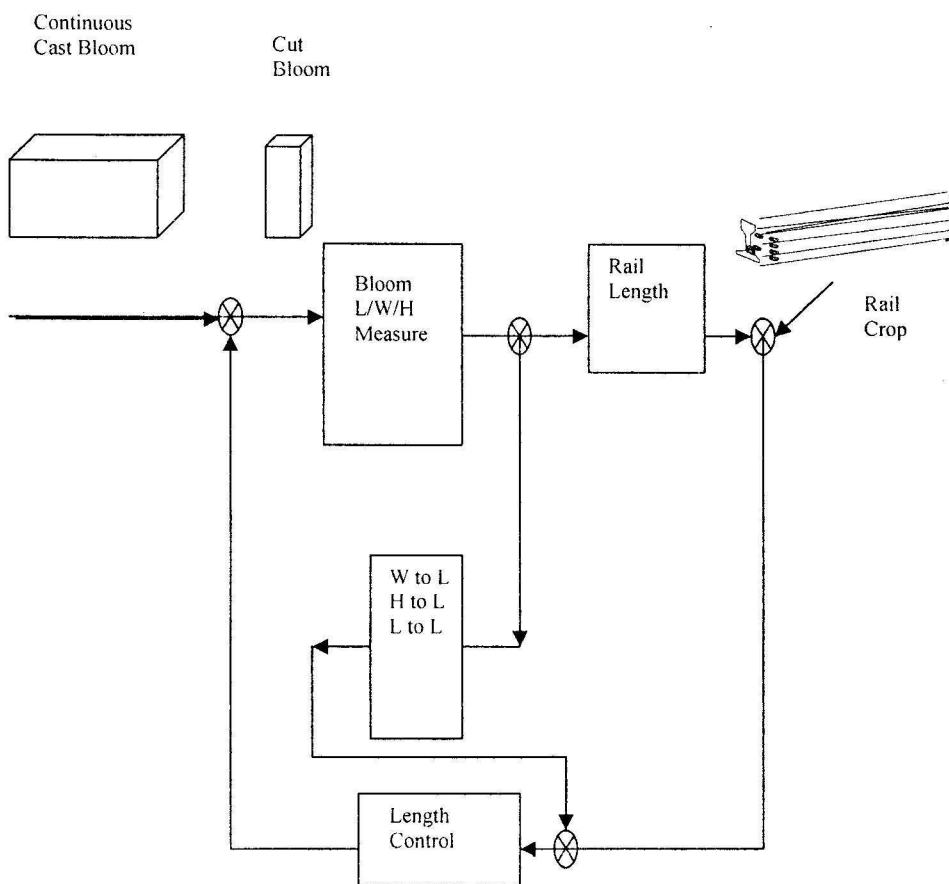


Fig 8: Close Loop System for Reducing the Crop

Table 3: Set length as per bloom cross section

Height	Width	Set-Length
297 mm	340 mm	5.556 mm
298 mm	340 mm	5574 mm
299 mm	340 mm	5582 mm
300 mm	340 mm	5600 mm
301 mm	340 mm	5.618 mm
302 mm	340mm	5.636 mm
303 mm	340 mm	5.654 mm
--	340 mm	--
307 mm	340 mm	--
297 mm	339 mm	--
--	339 mm	--
--	339 mm	--
307 mm	339 mm	--
--	--	--
--	--	--
--	--	--
297mm	--	--
--	346 mm	--
307 mm	347 mm	5.96 m

Table 4: Set length according to casting speed

Casting Speed	Correction In Set-Length
0-10 mm/sec	-25 mm
11-20	-50 mm
21-30	-75 mm
31-40	-100 mm
41-50	-125 mm

5. Conclusion

The system tried in one of the strand of continuous caster of Bhilai steel plant by tracking the blooms up to hot saw of rail mill. Techno economic has been calculated only based on bloom length measurement and its control and it generates 18 extra rails per day from same amount of bloom-steel with a monetary gain of Rs 82 lakhs (\$ 0.16million approximately) while cost of system is only Rs 1.2 lakhs (\$ 0.0024million approximately) and pay back period of the system is a week.

Future scope of work: The standard volume for generation of R-52Kg and R-60Kg grade of rails will be stored in the memory of computer Pentium-IV and it can be divided

by current measurement of height and width of bloom. In order to cut the bloom at constant volume irrespective its cross sectional variation, the length can be adjusted and same can be achieved by comparing the out put of computer (bloom length) in one of the 23 number AND gates with actual bloom length (length sensor stack) as shown in Fig 9. The selection of particular logic AND gate can be updated on the basis of casting speed and same can be measured by the time taken by front end of bloom to cover successive photo sensors. On arrival of front end of bloom before actuated AND gate, a 12 volts relay can be actuated for initiating the gripping/ cutting circuit of bloom. After the cutting of bloom, the length of cut bloom can be again sensed / checked. The developed software may display the volume of bloom and provide hard copy hour wise, shift wise, daily for management analysis.

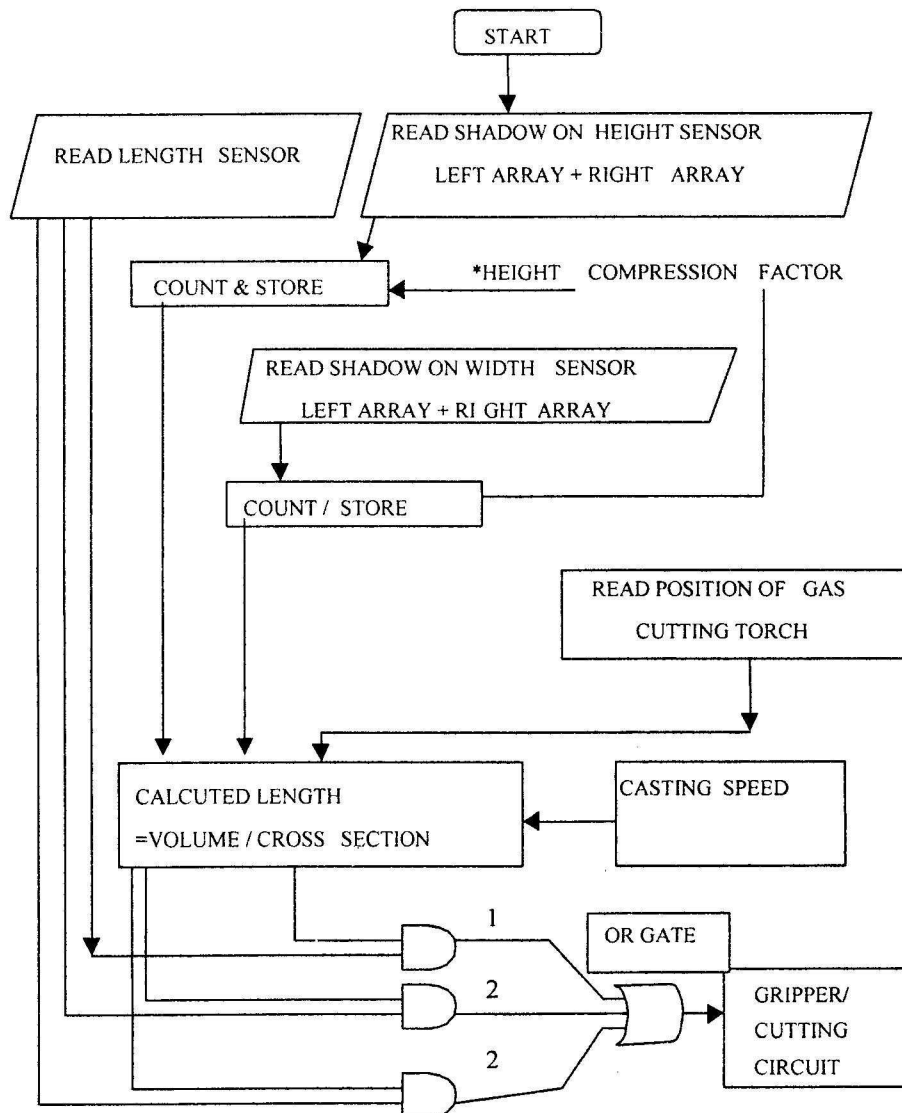


Fig. 9: Flow Chart Bloom Measurement and Control

9. Acknowledgements

Author is grateful to managements of R & D, Steel Authority of India Ltd, Ranchi and Bhilai Steel Plant for providing all the help for carrying out different experiments.

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