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***Review Paper***

# Automation in steel making and its application for making quality steel like rimming steel

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## Abstract

*In today's world of cut-throat competition where companies are vying to win over customers so as to maximise their hold on markets, anyone who fails to evolve will be left behind and is doomed to fail. Therefore, to achieve their objective it has become imperative to continuously remain updated with the modern trends in technology. Implementation of automation in the manufacturing process has become unavoidable for manufacturing companies to remain competitive. Having this in mind, companies are undergoing paradigm shift in their manufacturing techniques by incorporating automation in their production process.*

**Keywords:** Automation, manufacturing, level of automation, rimming steel, steel making.

## Introduction

In today's world, manufacturing units and automation are inextricably linked to each other. Advantages of employing automation for production are manifold[1]. i. Better control over the production process. ii. Improvement in the productivity. iii. Reduction in the specific consumption of materials as well as energy. iv. Ensures an improvement in the quality of products. v. Reduction in the cost of production. vi. Improvement in the health of equipment. vii. Safety of operators and equipment.

Every sector viz. automotive sector, power sector, metal and mining sector, is gradually shifting from the manual mode of operation towards the automation mode. In Figure-1, which shows the assembly line of a car making company, the entire assembly line is automated by the application of robots. Likewise, many different companies have started to prefer the use of machines and software in their production units to reduce their dependency on humans.

Steel companies are not untouched from this paradigm shift of supplanting humans with machines which gives them an edge over their competitors of decreasing the cost of production with reduced man power cost. Because of the tremendous requirement of manpower to run various units in an integrated steel plant, a steel industry is known as a labour intensive industry. Reducing the cost of production is the need of the hour for steel companies in order to survive and thrive in this tough time. Therefore, it has become imperative to recognize the role of automation, along with other factors, in countering the present challenges and challenges that lie ahead in future.

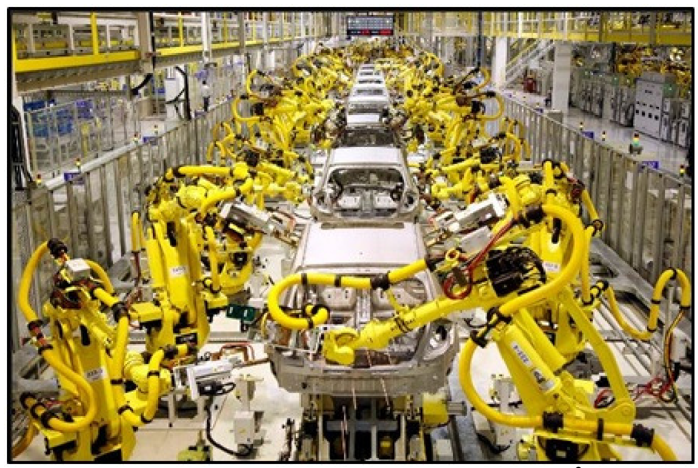

**Figure-1:** An automatized car assembly line[2].

## Industrial Automation

**Definition of Automation:** Industrial automation can be defined as a bundle of technologies that makes the industrial machines and system operational without substantial human interference/intervention those results in performance better than manual operation[3].

**Levels of automation:** Automation can be divided into five levels as explained below:

Level 0 – This level of automation means the absence of automation or negligible automation. All equipment is controlled manually. This level is characterised by the use of *actuators and sensors*, hence also known as sensor/actuator level[4].

With the help of sensors, parameters in the real time like pressures, temperature etc. is converted into electrical signals which are fed to the controller. Thermocouples, RTDs, proximity sensors, flow meters, etc are some examples of sensors commonly used in industries.

Whereas, actuators are used for the conversion of electrical signals (from the controllers) into mechanical motion to man oeuvre the processes. Actuators include devices such as flow control valves, servo motors, pneumatic actuators, DC motors, solenoid valves and relays.

Level 1 – The level 0 and level 1 automations take care of the automation of the production process only. The level 1 automation covers the control of equipment used for production. This level of automation is characterised by *automatic controllers* and comprises of different types of automation devices such as PLCs, CNC machines, etc.

PLC or programmable logic controller are the most famous controllers for industrial automation. Fundamental role of PLC is to get data from field input devices through the input interfaces, implement the user program stored in application memory, after that, based on the programmed control scheme by the user, takes action on the field output devices, or executes necessary control for the process application.

Programmable logical controller was discovered to replace relay controller. There are several advantages associated with the use of PLC: i. PLCs are modular in nature so that the removal of sub-assemblies becomes easier to facilitate repair or replacement. ii. Passing of data collection to a central system is possible. iii. Reusability of the system. iv. Simple programming of controller, so that it is easier for the plant personnel to understand.

Modern field instruments and graphical interfaces are utilized in this automation level. Complex multi input and multi output systems can be handles by level 1 control systems.

Level 2 – This level of automation is characterised by *process modelling* which carries out supervisory functions. This level is also known as Supervisory Control Layer. In this level, controllers are fed with targets/goals beforehand so that it makes it possible for the level to drive the automatic control system. Management information functions and production scheduling are combined with the process control functions by this level. It also includes process models. It utilizes physical process models to supplement the level 1 control giving calculated set-values to level 1 process control.

Level 3 – This level of automation is characterised by *production planning and production control* features. The most striking feature of level 3 automation is the use of enterprise resource planning (ERP) software. Scheduling and delivery status monitoring features, Maintenance planning and analysis of data are also parts of this automation level. In this automation level, operation in-charge, who is stationed remotely, can view all the data.

Level 4 – In this level of automation control over systems can be exercised remotely with the help of satellite. Apart from this, this level of automation is almost similar to the level 3 automation. This level connects orders from customers and material and manages capacity allocation to production. The complete order-supply-chain follow-up and documentation is managed by the ERP-system.

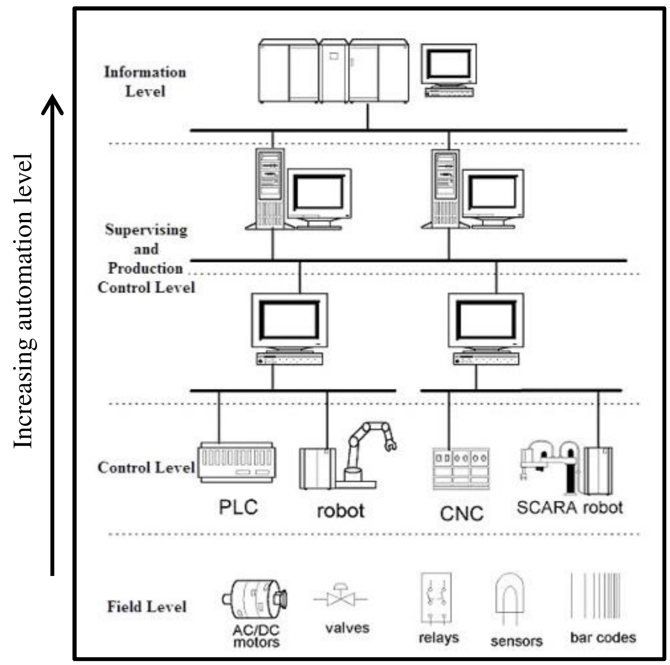


**Figure-2:** Different levels of automation[3].

## The role of automation in an integrated steel plant

As with any other manufacturing process, the steelmaking process has also evolved from Bessemer's process of steelmaking to the twin hearth process to the modern basic oxygen furnace steelmaking. The casting technique has also changed from ingot casting to continuous casting. The making of rimming steels through the THF-ingot casting route is a typical example of the obsolete route of steelmaking in which most of the works were done manually such as tap hole opening and closing, ferroalloy addition during tapping, ingot stripping etc. Such manual processes take its toll on the quality of rimming steel made through this route such as scab formation, high yield loss etc. The modern methods of steelmaking has made it possible to make this electrode quality steel by exercising strict control over the chemistry and the production process with the aid of automation thus resulting in lesser rejection than before.

In an integrated steel plant, automation has come a long way in making the job of steel production easier. In context of a steel melting shop, the introduction of level 1 and level 2 automation has made it possible the pre calculation and simulation of heats, has helped in improving the hitting rate for steel bath temperature and carbon content, enhanced process visualization and tracking, fine-tuning of operations and reduction of production costs, reduction of reblows, lower refractory consumption, lower rephosphorization rate, automatic slag detection and actuation of slag stopper etc.

**Figure-3:** Converter tilting drive[5].

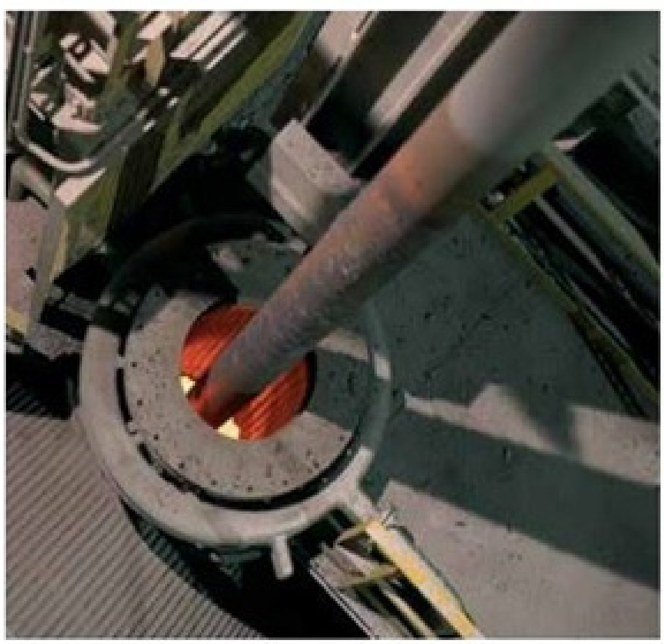

**Figure-4:** Sublance measuring system[5].

**Figure-5:** Slag stopper[5].

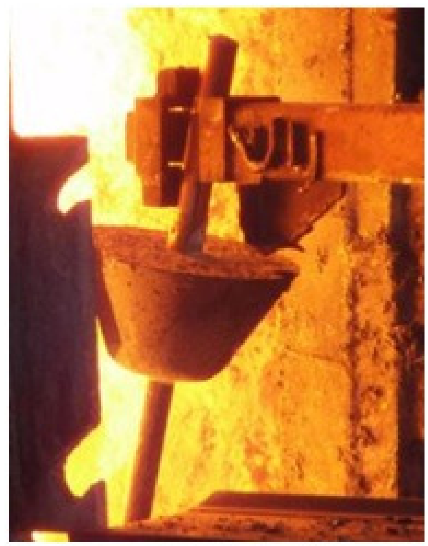

**Figure-6:** Darts used for plugging tap[6] holes.

## Automatic slag detection system

There are various units in an integrated steel plant, such as, coke ovens, agglomeration units, blast furnaces, steel melting shops, rolling mills etc. Therefore, there is a huge scope of the application of automation to enhance the performance of these units by exercising precise control over them.

Converters are used to convert hot metal from a blast furnace into steel by oxidising the impurities present in liquid steel. During this process, phosphorus, which is one of the impurities, is converted in $P_2O_5$ and becomes a part of slag. However, during tapping of liquid steel into a ladle, some slag also falls into the ladle which has to be prevented as this carry over slag results into phosphorus reversal, due to which, to some extent, phosphorus again enters the liquid steel as elemental phosphorus. This phosphorus is undesirable in the final product as it leads to cold shortness during rolling. Therefore, to prevent the slag from falling into the ladle, current practice is to use darts, which is put inside the converter by an operator who operates a dart gun for this. In spite of this, some slag goes in the ladle at the end of tapping.

To overcome the aforementioned problem, there are devices known as slag detection and slag cut off devices which work on the basis of stream identification. The slag detection system consists of a thermal camera inside a protective covering, an application dedicated imaging software for data acquisition, evaluation and system control, a database for the storage of all process-relevant data, and a web based user-friendly operator interface and devices for indicating the system status.

The thermal imaging camera continuously monitors the stream. As soon as the camera encounters a change in the radiation property of the stream, all important and relevant data are displayed on the screen continuously which comprises ofthe live thermal image, the slag carryover vs. tap time, the preset alarm threshold for the slag content and the alarm status. Due to the substantial contrast in the slag stream and the metal stream, the system easily identifies the advent of slag stream and if the percentage of the slag stream exceeds a threshold value then alarm is set off.

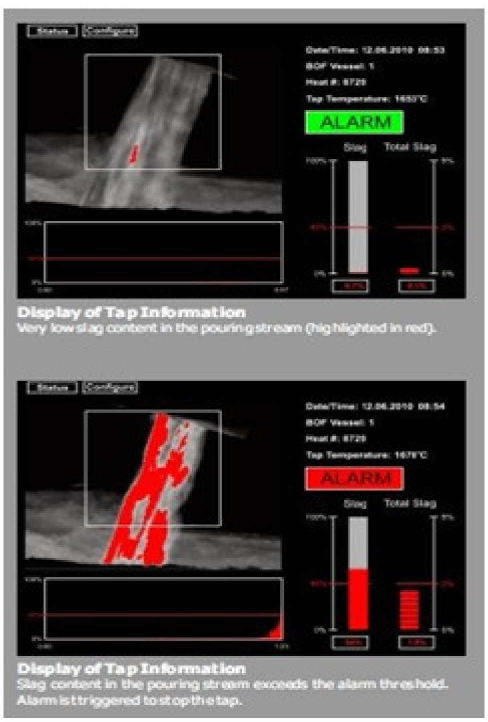


**Figure-7:** HMI snapshots of automatic slag detection system[7].

## Advanced ladle tracking system

In order to prevent the mismanagement of ladles, slag pots, tundish and scrap chutes and to ensure their timely availability where and when they are needed, Advanced Tracking System is a reliable position tracking system of such metallurgical vessels throughout a steel plant. It is based on a well-established industrial standard long range UHF-RFID-technology.

An RFID tag is installed on the vessel to be tracked in order to trace its location. The tag is a passive, heat resistant unit which is detected by the antennas. The antennas are placed on each location where the vessel should be tracked.

**Figure-8:** RFID tag[8].

## Sublance measuring system

Even without interrupting the oxygen blowing process in an LD converter, the measurements of temperature, carbon content, oxygen activity of the steel bath and taking steel samples from the bath can be done with the help of sublance system. Instrumentation and drives ensure excellent position accuracy and operational safety. Fully automatic in-blow or end-of-blow measurements are ensured by the closed loop process control of the sublance. The oxygen blowing process is supervised and controlled by the process optimization model by taking help of the in-blow measurements.

**Level – 2 automation in Steel Melting Shop (SMS):** As mentioned before, the level – 2 automation revolves around process modelling of various physical processes that govern the production process. In context of a steel melting shop, the Level-2 automation comprises of various models, some of which are enumerated below: i. Automatic Oxygen Blowing model in BOF, ii. Model for Charge Calculation for BOF, iii. Model for the prediction of Ferro Alloy addition, iv. Models for heating and alloying during secondary refining treatment, v. Model for the secondary cooling of casters, vi. Model for the quality control of cast blooms, vii. Tracking systems for ladles, viii. Lab automation systems.

## Model for addition of ferro alloy addition in rimming steel heats through automation

The production of rimming steels is always done through the THF-ingot casting route. The recovery of Mn in liquid metal gets affected by the residual oxygen in ladle. To reduce the excess oxygen in ladle some deoxidizer is added in it. The addition of deoxidizer should be such that it should not decrease the oxygen level below a certain limit since the rimming behaviour and rim thickness significantly depends on the oxygen level in ladle. Also the addition of ferromanganese (FeMn) should be such that Mn should come within the aforementioned range, because it is also a parameter whose recovery gets affected by the oxygen content in liquid metal. The residual oxygen and the Manganese percentage are the two major factors that affect the Rimming duration and Rim thickness and therefore the quality of rimming grade steel.

The uncertainty of Mn recovery and the thickness of the Rim formed were causing maximum rejection of rimming steel to lower grades. An experiment was conducted in which some practical data at different steel making stages have been collected and correlated with each other and mathematical models have been developed to predict various parameters and their effect on quality of rimming steel with the help of MATLAB software.

The outcome of the experiment is shown below:
Regression model: $y = 0.0489*z^{10} - 0.509*z^9 + 0.739*z^8 + 2.95*z^7 - 5.92*z^6 - 5.37*z^5 + 12.7*z^4 + 4.01*z^3 - 8.74*z^2 - 2.52*z + 48.6$

Where $z = (x - 0.456)/0.0451$

From Rim thickness vsMn % curve, it is possible to have an idea of the final Mn % in the steel for achieving a particular rim thickness and therefore addition of FeMn can be done accordingly with the help of the following formula.

$$\text{Amt. of FeMn added} = \frac{(\%\text{ increase of Mn})*(\text{Heat Size})}{(\%\text{Mn in FeMn})*(\text{Recovery})}$$

Another important piece of information that can be deduced from the curve is that if we know the final Mn % of steel then it is possible to have an idea of approximate rim thickness and therefore capping action can be done accordingly to control the thickness of rim.

The models developed with the help of this study have been incorporated in the systems of the shop, which have helped in eliminating human errors associated with the ferroalloy addition (FeMn), thus, reducing the percentage of rejections.

The entire process of ferroalloy addition has been automated by feeding the above model in PLC by programming. Vibro feeder which is controlled by PLC acts according to the fed model in the PLC. Therefore, in order to make rimming rimming heats, the only input is rim thickness, based on which, the final Mn % and FeMn required to achieve this level of Mn are automatically calculated and conveyed to the vibro feeder and the requisite amount of FeMn is fed to the heat by the feeder.

## Conclusion

Over the years, industrial automation has evolved from one level to another level, gradually decreasing human interventions in the manufacturing process. Adopting automation offers numerous advantages that cannot be overlooked. However, as with any other thing, there is a flip side to the adoption of automation as well. Automation leads to an increase in unemployment due to machines replacing humans, large initial investment is needed for the installation of various machines, more pollution than before as machines run by burning fuels, inability to perform non-repetitive task etc. However, switching over to automation by more and more companies is the manifestation of the fact that the advantages of automation are outweighing its disadvantages.

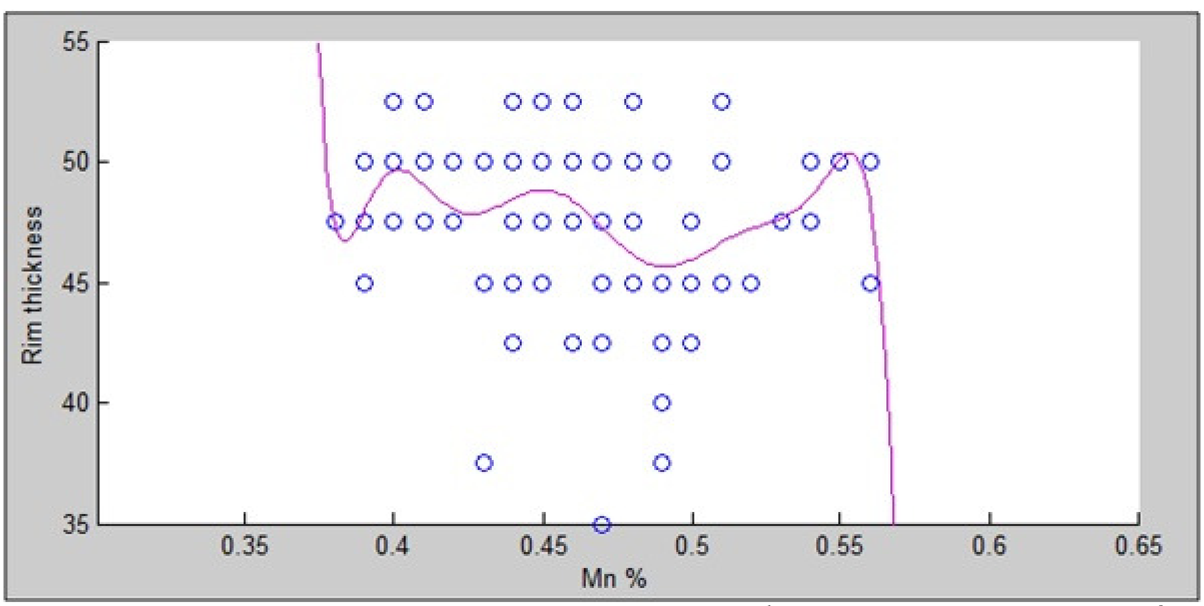


**Figure-9:** Scatter plot of Rim thickness vs final Mn content, with 10th degree polynomial curve of best fit[9].

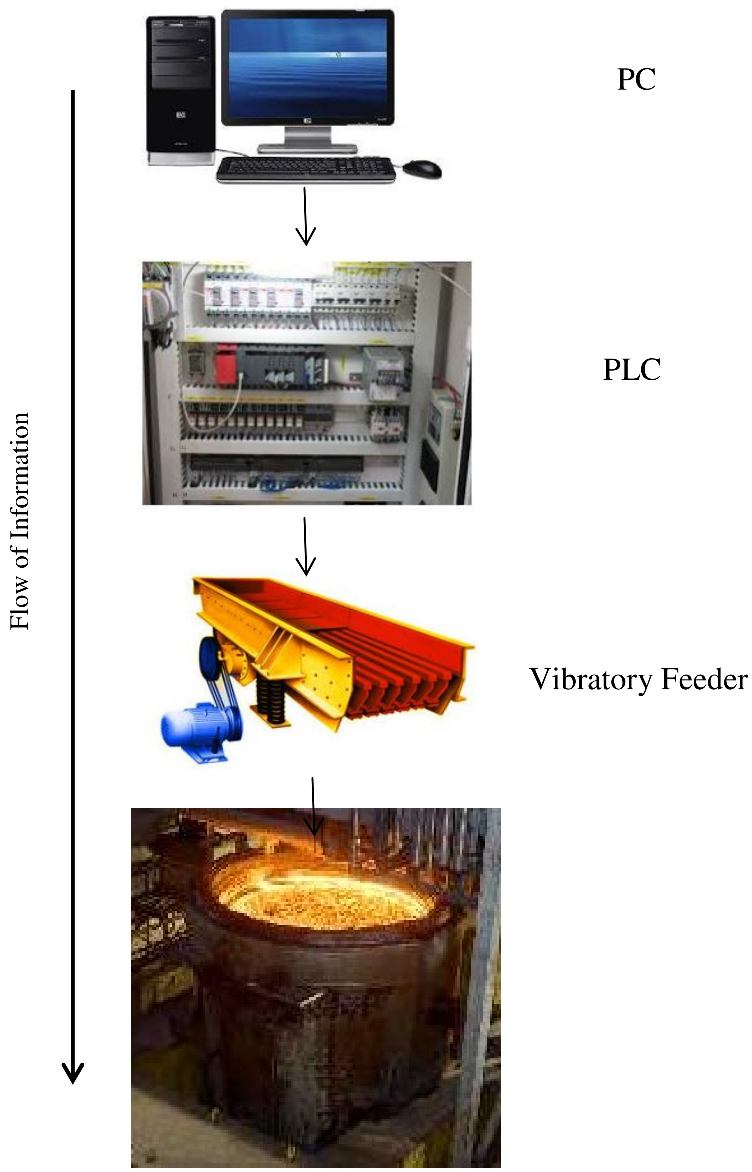


**Figure-10:** Scheme for adding Ferro-alloys in rimming steel making through automation.

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