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A Review on Advances in Process Automation in Various Stages of Different Casting Processes

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Abstract : *Casting is the marvelous art of metal forming in which a metal is liquefied and formed into any desired shape using a suitable mould cavity followed by solidification. Casting has been recognized as one of the essential operations in several manufacturing processes. It has been observed that the casting process forms the backbone of any manufacturing industry. As the demand for quantity, quality and variety of consumer goods is increasing rapidly, the need to integrate automation in every manufacturing aspect is growing. Automation is the science of using various control systems to operate various devices and machines with an objective to reduce human effort. The present study focuses to throw light on recent developments in the automation strategies employed in three major stages of the casting process namely: Melting the raw metal, pouring the molten metal into the mould cavity and Solidification. There is a need to automate casting operations in order to obtain better surface morphology, higher accuracy, precision and productivity and also to eliminate possible casting defects. The process of pouring the molten metal into the mould is very dangerous, most small castings are done with the help of human beings. Thereby highlighting the need for automation which will eliminate danger to the workers. Of the aforementioned operations, it has been found that solidification is the most critical stage in a casting process as a majority of defects get transferred into the final cast during this stage and it was also observed that the level of automation achieved in this stage is minimum as compared to the other stages.*

Keywords: *Casting, Automation, Solidification, Metal forming, Computer-aided Manufacturing.*

INTRODUCTION

Casting has been identified as the first and the foremost operation in almost any of the manufacturing processes [1]. Heine et al. [2] defines casting process as "The process of obtaining the desired metal object by allowing molten metal to solidify in a mold of specific shape." Some popular kinds of casting are Dry Sand Mould casting [3], Investment casting [4], and gravity die casting, continuous casting, centrifugal and slush casting [5]. Gravity die casting is the simplest and most commonly used casting process [1],[6]. It has also been observed that greatest level of automation has been achieved in continuous casting process also commonly known as bottomless casting.

A process is said to be automatically controlled if it is controlled with the application of mechanisms, electronic circuits, computer and computer software without continuous direct intervention of human beings. With the increasing demand of consumer goods such as fans, motors, utensils, automobiles etc., it has become very difficult for industries to manufacture large volumes of quality goods in a limited space manually with greater accuracy and precision [7]. Also the variety of goods demanded by the consumer is difficult to accommodate. Thus, it is becoming essential to automize different processes in manufacturing industries. Casting is a fundamental step in any manufacturing process. Moreover during the casting operation, the worker's operate in the close proximity of the molten metal which often proves to be hazardous [8]. Casting process is highly dependent on geometric parameters of the mould and also, the physical properties of the molten metal. It should also be ensured that the final casting obtained should be free of defects which severely affect the mechanical properties of the final casting. More issues experienced during casting process are spilling of molten metal on the shop floor, variable pouring rate causing formation of air bubbles, incomplete filling of mould cavity, improper solidification etc [9]. To overcome these issues, there arises a need to introduce numeric control in various stages of different casting processes [1].

Fig 1: Automated High pressure die Casting (Aluminium)

The continuous casting technology accounts for 94% of the world steel production. It is one of the fundamental technologies which is easier to automate as the output obtained in this casting process is continuous [10]. Another commonly used casting process is high pressure die casting which is widely used I, n telecommunication automotive and aerospace equipment manufacturing industries to manufacture aluminium components [11],[12]. In this process molten metal (aluminum) is injected with a die casting machine under force using considerable pressure into a steel mold or die to form final products [13]. As the demand for different products manufactured using these processes is increasing, the need for automating these processes has increased.

This paper attempts to address various automation strategies and practices prevailing in various stages namely melting, pouring and solidification of different casting processes which are widely being used in the casting industry to highlight the recent advances which would help in finding the research gaps and future scope in the area.

II. STAGE I: MELTING

Proper consideration must be given to factors such as gases in the metal, selection and control of scrap, flux, furnace and temperature in order to obtain a good, defect free casting. To achieve these objective it is required to plan and schedule the activities in the melt shop effectively. Xu et al. [14] introduced an innovative scheduling approach of a large scale integrated steel plant in order to improve its productivity and energy efficiency. The proposed a bi-level intersection coordination heuristic where the bottleneck-stages and the coupling between the stages are modelled at the upper-level coordinator (as a MILP) while the original distributed schedulers are solved at the lower level based on given coordination variables from the coordinator. It has also been observed that in a large scale automated steel plant, dynamic bulging, a variation of the magnitude and/or the shape of the bulges, may occur and lead to a fluctuation of the height of molten steel with serious consequences in terms of quality and damage. A steady growth of these fluctuations is called mold level hunting.

Passenbrunner et al. [15] utilised switching control strategies to address this issue and increase the throughput of such plants.

Casting Process is a distributed parameter system (DPS) defined on complex 3D definition domain. Modeling, simulation and evaluation of real-time experiments in this area is now widely accepted as an important tool in product design and process development to improve productivity and casting quality [16],[17]. Simulation methods have contributed since their origins to obtain a better knowledge related to the materials and the manufacturing processes [18], and as a consequence to improve the manufacturing methods [19].

Thompson [20] designed an adaptive microprocessor control for providing a low fire mode and high fire mode of the heating cycle as a function of current cycle. Resistance type induction furnaces are increasingly being used in melting and casting of metals as melting of metal requires an exact temperature and the operating conditions of these type of furnaces could be easily and automatically varied and adjusted to the desired temperature requirements [21].

In mass production of metal parts made through casting in permanent molds or die casting machines, it is required to supply a fixed amount of molten metal, free from slag, delivered to mold at specified temperature periodically within a short period of time. Mario invented a means of dispensing the required amount of molten metal automatically by applying equal pressure to the molten metal during periods of time increasing from one dispensing operation to the next in equal increments to compensate for the level decrease in the container during the preceding discharges.

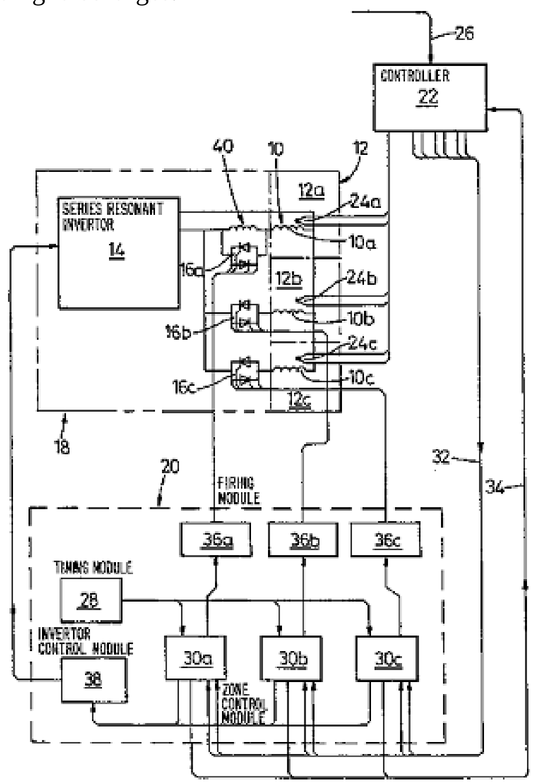

Fig 2: Multiple zone heating control in induction furnace [22]

Simcock [22] designed an Induction heating furnace which employs pulse width modulation to control temperature in multiple zones. As seen from figure 2, the furnace comprises of an induction coil divided into individual sections associated with respective zones. These zones are powered in parallel under regulation from controller.

Stringent environmental regulations and increased safety requirements are the major drivers for process automation in metal melting process [23]. Craig [24] in his research highlighted the importance of computer-aided design and simulation, use of controllers and instruments, computer-aided quality control etc. in order to achieve automation in mass production of steel. Matarazzo [25] devised a new control based using a cognitive decision making system to foster reduction of scrap in casting of superalloys for aerospace applications taking information from the measured values and the values obtained from sensors working on the principle of artificial neural network (ANN).

III. POURING

During the casting processes, molten metal was poured manually and is still done in many industries. This has a very deep impact on the castings as it results in defects in the final mold [26]. This is one of the main problems faced by many industries using manual method of pouring the metal in the mold. Therefore industries nowadays have started to apply automation in pouring using many different methods that provide better castings with lesser defects. This was a major breakthrough in the castings industry that helped helped improve the pouring efficiency of the metal into the mold.

Pouring of the metal into the mold in continuous castings can be regulated with the help of a tundish nozzle [27]. This nozzle could be used to regulate the flow of the molten metal into the mold. The nozzle helps in variably regulating the flow to help create better mould. This process involves measuring the amount of material present in the mold and then supplying the required amount using the tundish nozzle.

Fig 3: A Tundish nozzle [27]

Calculating the flow rate of the molten liquid in the mold is a very serious challenge. Conventional flow meters get ruined due to the hot molten metal [28]. Therefore other methods like an extended Kalman filter and Sensor Dynamics compensation are used for calculating the flow of the molten metal. These are very easy to construct. Therefore the issues faced due to the conventional flow meters are eliminated.

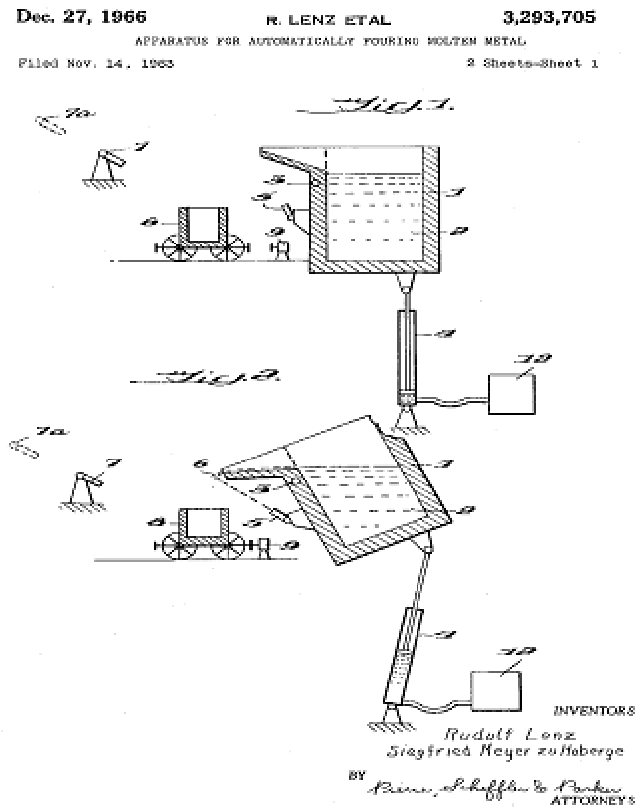

Fig 4: Apparatus for automatically pouring molten metal [30]

There are other methods of controlling technologies wherein an electromagnetic pump precisely pours a quantitative amount of molten liquid to the mold [29]. This electromagnetic pump easily pumps in the required amount of molten metal to the mold as per the requirement of the mold.

This is a very efficient method for mold formation. There are other methods like an automated pouring mechanism that has been designed that uses photoelectric cells which help in working as a switching mechanism. These sense only IR (Infrared) rays [30]. This prevents unwanted light rays from striking the photoelectric cell and causing a switching in the mechanism. The IR method provides a much better approach to sense the level of the molten metal in the mold. There has to be minimum supervision of the operators during pouring [31].

There is another design that involves a lot of components like the level detectors, the ladle tilting angle detector, a ladle tilting servomechanism, mold position detectors and a control device [32]. This control device is used to synchronize the signals of the level detectors and then maintains the tilt angle accordingly. The overall system is controlled perfectly to provide a much better pouring so as to get a very good mold. There is another technique where the pressure of a molten metal is controlled to achieve a better casting. There are not many methods that use this technique [33].

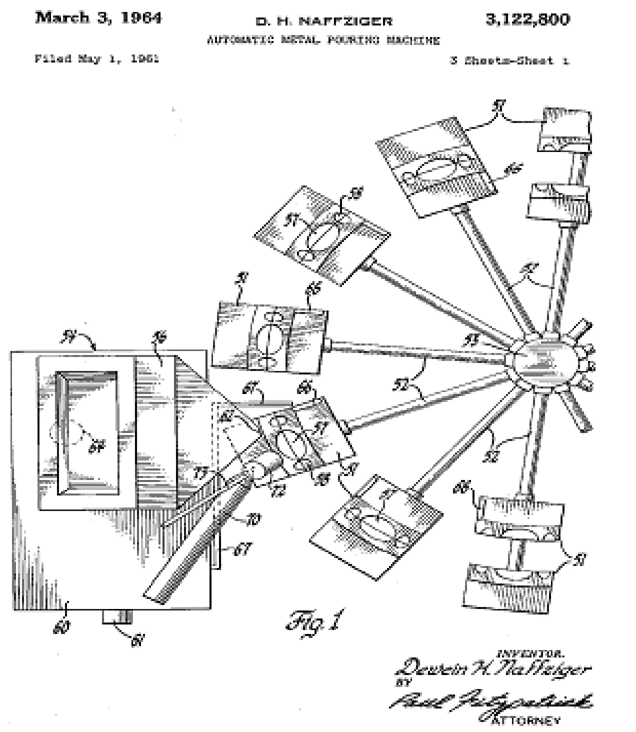

Fig 5: The tilt angle in automatic metal forming machine [32]

IV. SOLIDIFICATION

There have been only few studies on the solidification in a continuous casting process of copper tubes that caused failures due to the lack of control in the process. The basic casting process used nowadays is diffusion casting [34]. It is basically applicable to many ferrous and non-ferrous alloys.

There haven't been many studies on the automation of the solidification process. Only if the temperature is maintained throughout the mold can there be a proper casting with no defects. This is a very tedious process and requires an in-depth knowledge of the temperature distribution in the molten metal. There are studies done on copper tubes to prevent the defects from creeping in them [35].

One of the few Automation processes in solidification are using NN (Neural Networks) technology.The conventional processes were based on a static relationship between casting speed and water flow rate in each cooling zone. This does not consider a main element that is the dynamic surface temperature [36]. Usually such a parameter was not considered effectively in continuous casting process. Only when dynamic surface temperature is considered can we achieve a good slab quality.

Here the Neural Network is used to identify the non-linear behaviour heat transfer model in a continuous casting process. In this a dynamic heat transfer model was developed using dynamic heat balance. The Neural Network strategy is used to give a temperature which is stable and a PID is used.

The solidification feeding velocity and the ability of vacuum counter pressure casting technology depends on the magnitude of keeping pressure mainly [37]. The higher the keeping pressure the stronger the feeding velocity and ability are, the denser the microstructure.

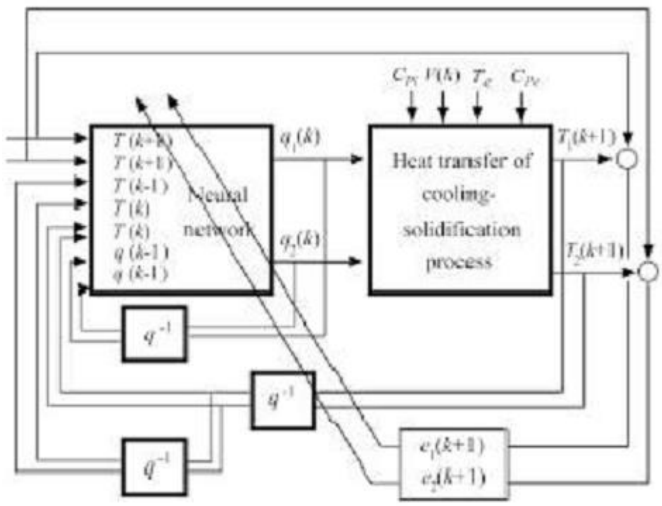

Fig 6: Structure of NN for Temperature Control [36]

In high pressure castings defects creep in due to high pressure and a technique was designed to prevent the defects from occurring in the molten metal. Due to pressing at high pressure during the casting process the surface of the product was rough. This process using GPC (Generalized Predictive Control) help create castings with better surface finish.

A switching control for suppressing the pressure of the press marks a very novel method for casting.

Computer aided analysis have been conducted to find out the thermal characteristics of various alloys during in-situ. Melting and solidification [38]. Numerical simulations have been conducted nowadays for detecting better castings. But the industrial application of such processes have not been very deeply impacted. The numerical analysis helps to check the various thermal characteristics undergoing during the process of solidification. This could help prevent direct impact on the product due to defects. Close monitoring could further reduce the aspect of defects in castings.

Using thermal analysis approach the behavior of the metal during solidification could be determined. This is a novel method for finding out the various imperfections that could occur in the mold after solidification. This is a very ideal process that should be used in industries but is not very commonly used. This could help in developing better castings with very little defects and could help sustain the life of castings to a longer period of time.

V. CONCLUSION

Thus, it can be concluded that casting forms such an important part of the manufacturing industries worldwide. It takes birth from a certain liquid metal and becomes a product with a lot of complex shapes and sizes. A metal is first melted then checked for fluidity using a certain standard testing apparatus and then poured into the mold, many parameters are taken care of and then solidification results in the final product. After studying about the three stages in castings we found out that automation has been applied in both melting and pouring to a commercial point of view as well. But automation in solidification is done on experimental basis and not commercially applied completely. This is one area where a lot of work could be done. Solidification is an important step to create a proper casting with desirable mechanical properties. The molten metal has to maintain a certain temperature to result in uniform cooling or else the castings will develop voids and various other defects. This could use automation to help prevent defects that could occur while handling the molten metal manually. Nowadays the very stringent environmental concerns are taken on prime importance hence automation is required to create a more environment friendly process. Another reason of using Automation is to prevent the dangers to the workers who handle the hot molten liquid and the heavy machinery during castings.

Various numerical simulations help analyse various defects that could occur in castings before the actual product is designed. These computerized approaches if used in real time monitoring of the mold and Neural Networks technology could create castings of better quality. These processes could be applied in castings to understand castings behaviour and take corrective actions for best quality castings.

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