

Development of a Robot Assisted Centrifugal Casting Machine for Manufacturing Multi-Layer Journal Bearing and High-Tech Machine Components

Mohammad Syed Ali Molla, Mohammed Azim, Mohammad Esharuzzaman

Abstract—Centrifugal-casting machine is used in manufacturing special machine components like multi-layer journal bearing used in all internal combustion engine, steam, gas turbine and air craft turbo-engine where isotropic properties and high precisions are desired. Moreover, this machine can be used in manufacturing thin wall high-tech machine components like cylinder liners and piston rings of IC engine and other machine parts like sleeves, and bushes. Heavy-duty machine component like railway wheel can also be prepared by centrifugal casting. A lot of technological developments are required in casting process for production of good casted machine body and machine parts. Usually defects like blowholes, surface roughness, chilled surface etc. are found in sand casted machine parts. But these can be removed by centrifugal casting machine using rotating metallic die. Moreover, die rotation, its temperature control, and good pouring practice can contribute to the quality of casting because of the fact that the soundness of a casting in large part depends upon how the metal enters into the mold or dies and solidifies. Poor pouring practice leads to variety of casting defects such as temperature loss, low quality casting, excessive turbulence, over pouring etc. Besides these, handling of molten metal is very unsecured and dangerous for the workers. In order to get rid of all these problems, the need of an automatic pouring device arises. In this research work, a robot assisted pouring device and a centrifugal casting machine are designed, developed constructed and tested experimentally which are found to work satisfactorily. The robot assisted pouring device is further modified and developed for using it in actual metal casting process. Lot of settings and tests are required to control the system and ultimately it can be used in automation of centrifugal casting machine to produce high-tech machine parts with desired precision.

Keywords—Casting, cylinder liners, journal bearing, robot.

I. INTRODUCTION

MOST of the of machine bodies and machine components are produced by melting ferrous and non-ferrous metals and casting them in sand molds or in metallic dies [1], [2]. Centrifugal casting is a metal casting technique where metallic die is rotated when the centrifugal forces generated for the rotation helps to distribute the molten material uniformly with certain centrifugal forces in the mold. Centrifugal casting or roto-casting is a casting technique that is typically used to cast thin-walled cylinder liners for the high quality of the

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results attainable, particularly for precise control of their metallurgy and crystal structure. Unlike other casting techniques, centrifugal casting is mainly used to manufacture stock materials in standard sizes for further machining, rather than shaped parts tailored to a particular end-use. Casting machines may be either horizontal or vertical-axis. Horizontal axis machines are preferred for long, thin wall cylinders, vertical machines for heavy railway wheel, rings. Centrifugal casting was the invention of Alfred Krupp in 1852, which used it to manufacture cast steel tires (wheels) for railway wheels [3].

Centrifugal casting can be widely used to manufacture cylinder liners. All combustion chambers of heavy duty engines are equipped with replaceable sleeves or cylinder liners. The cylinder liner, piston and piston ring prevent the leakage of blow by compressed gas in combustion chamber from escaping outside. It is necessary that a cylinder liner should have the properties like excellent wear-resistant in high temperature and high pressure in the cylinder. Thus, the development of the manufacturing process of IC engine and its spares is very necessary for the socio-economic development. It can be expected that this knowledge can be helpful in developing a cheap manufacturing process of the valuable parts of automobiles, aircrafts, steam turbines, gas turbines etc. in the long run.

The use of the robotic manipulator in various industrial purposes increases productivity, accuracy and efficiency. Manufacturing market analysts predicted that industrial robots will become increasingly viable in applications like assembly tasks which require more precision and sensory sophistication. During the last decade, the openness of control systems has been addressed in several ways by worldwide research projects both in the field of machine tools (i.e. OSEC/JOP, OMAC, OSACA) and in the field of robotics (i.e. OROCOS) [5], [6].

The robot architecture is conceived in order to obtain high flexibility and re-configurability in performing impedance-controlled manipulation tasks. The direct and inverse kinematics and dynamic models with special reference have their application in the control system.

F. Lange et al. and L.E. Bruzzone et al. established a sensor based control with different types of sensors and investigated for robots with a positional interface [7], [8]. Sensor data are used to build a representation of the desired path. This can be done by adding the sensed deviations between actual and desired path (given by the image information of a robot

mounted camera or sensor) to the actual position of the time instant of sensing. The prerequisites of this method are that the sensor has to be calibrated and that the time instant of sensing has to be known. In contrast to other approaches the amount of time-delays is of minor importance, even asynchronous sensing is possible.

H. Flordal et al. developed a method for automatic generation of collision free, blocking free and work cycle time optimized supervisions for industrial robot cells, has been implemented [9]. Finite automaton models of allocation and release of critical spatial volumes that the robots share, as well as models of the robots' possible movements are automatically extracted from a 3D simulation environment. This includes explicitly calculating the intersection between the robots' work envelopes, the spatial volumes where collisions may occur, and simulating the robots' collisions with these. Each robot's different sequences of operations of factorial complexity in the number of states are efficiently represented as a set of automation using a polynomial number of states.

II. CENTRIFUGAL CASTING PROCESS

In the centrifugal casting process, the metallic die is rotated at the required speed of 300 to 3000 rpm when the molten metal is poured into the die.

The designed speed of centrifugal casting rotor can be calculated by equalizing gravity forces of the casted metal with the centrifugal forces. Usually the metallic die is placed on four wheels where one wheel is for driving and the rest three wheels are idle wheels to support the rotating die as shown in Fig. 1. In the present investigation, the conventional die rotation by wheel power is modified by a motor and pulley driven shaft at designed speed as shown in Fig. 2. The main components of centrifugal casting machine are in Fig. 2.

Usually journal bearings are used as main and big-end bearing of all IC engine, and also used as the main bearing of steam turbine, gas turbine, and turbocharger, etc. These journal bearing are of multi-layer structure and thin wall cylinder liners are used in combustion chamber of IC engine shown in Fig. 3.

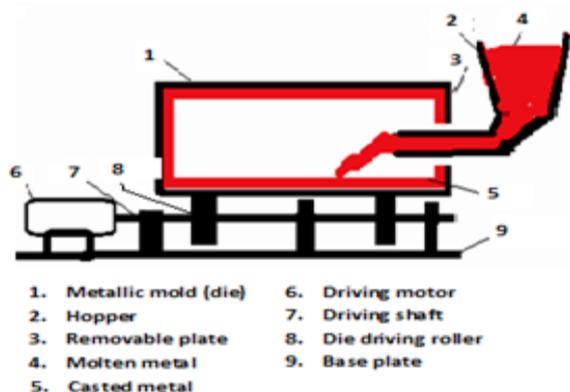


Fig. 1 Layout of a centrifugal casting machine

Generally, soft metal like white metal or gun metal is used in the inner lining and harder ferrous metal is used in the outer

shell of every journal bearing. The soft metal gives protection to the crankshaft or turbine shaft life and ferrous metal provides necessary strength to hold soft metal. In such case it necessary to cast ferrous molten metal in the rotating die first and later on white metal (Babbitt) or gun metal lining is casted over ferrous metal bearing outer shell in the die keeping in conformity with the required temperature control for better adhesion between outer layer and inner layer.

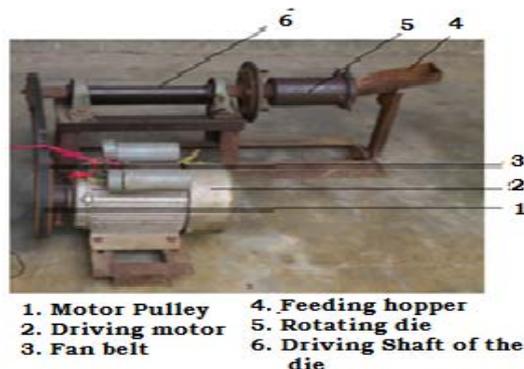


Fig. 2 Constructed centrifugal casting machine

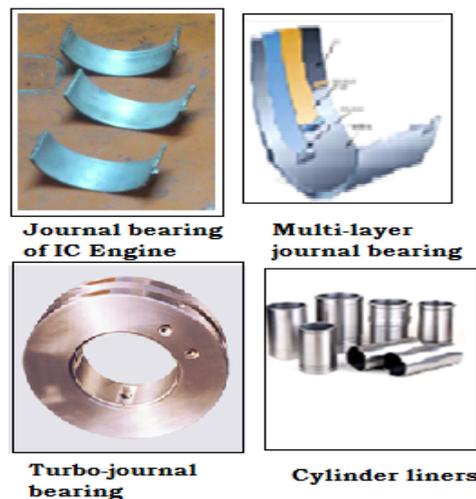


Fig. 3 Multilayer journal bearing and cylinder liners

At the beginning of this casting, a predetermined or measured quantity of molten metal is poured in the rotating die. The molten metal is centrifugally thrown towards the outward direction in the inside die and is gradually cooled and solidified. This casting is usually a fine-grained casting with a very fine grained outer diameter, owing to centrifugal effects and chilling against the mould surface. Impurities and inclusions are thrown to the surface of the inside diameter, which can be machined away later on before machining it to finish product. Most castings metals are solidified from the outside first. This may be used to encourage directional solidification of the casting and thus give useful metallurgical properties to it. Often the inner and outer layers are discarded and only the intermediary columnar zone is used [9].

Typical materials that can be cast with this process are iron, steel, stainless steels, glass, and alloys of aluminum,

copper and nickel.

III. METAL POURING PROCESS

The metal pouring process is defined as the transfer of molten metal in some fashion from the melting furnace into a mold in a way that will result in a sound, saleable casting.

- i. Provides a sound casting.
- ii. Reduces temperature loss.
- iii. Saves energy.
- iv. Reduces refractory wear.

There are three types of pouring process such as:

- i. Manual pouring process.
- ii. Mechanical pouring process.
- iii. Automatic pouring process.

A. Manual Pouring Process

In manual pouring operation the pourer carries the ladle of molten metal to and directs the stream of molten metal into the mold as shown in Fig. 4 (a).

The manual pouring process has various limitations such as:

- i. The amount of metal in each crucible/ ladle is dependent upon the strength of the pourers.
- ii. It limits the number of molds.
- iii. It limits the size of the casting.
- iv. It is suitable for only smaller casting.
- v. It is suitable for lower volume casting.

B. Mechanical Pouring Process

Mechanical pouring of molten metal is directed into the gating system by turning a hand wheel, a series of gears which tilt the ladle and allow the molten metal to flow. In other type of mechanical pouring process, the hand wheel and gearbox Fig. 4 (b) is not used where the ladle is carried to the pouring station by means of an overhead mono-rail system and metal is poured by motor and lever mechanism.



Fig.4(a) Manual casting

Fig.4(b) Mechanical casting

Fig. 4 Manual casting and mechanical casting

C. Limitations of Mechanical Pouring Process

Though the mechanical pouring process is better than manual pouring process, still the workers have to go close enough to the ladle to operate the hand wheel and gear box which is very dangerous to them because of the higher temperature of the molten metal [4].

D. Robot Assisted Pouring Process

The molten metal pouring operation is the most uncomfortable and risky jobs in the foundry. Automatic pouring process is defined as the process where the crucible/ladle is used to pour metal by automatic device without any human assistance. The need of an automatic pouring process or robot assisted pouring process arises because of the fact that the pouring process is required to avoid critical situation and producing quality casting.

Advantages of robot assisted pouring process

The advantages of automatic pouring process are many such as:

- i. It increases productivity.
- ii. It improves quality.
- iii. It saves labor cost.
- iv. It reduces scrap.
- v. It reduces production cost.
- vi. It reduces hazards and accident.

E. Automatic Pouring System Design

Crucible carrier has to be designed in such a way that it keeps the whole centrifugal casting system away from the furnace except for the crucible. The project design is inspired by crane and pulley system. Where a robotic arm or the crane act as a carrier for the crucible to move from one place to another and the pulley system act as tilting device to complete the pouring system.

F. Design and Construction of Robot Assisted Pouring Devices

For an initial test model, a robot assisted water pouring device is designed and constructed. The program and test model is found to work satisfactorily. The test model is further modified and developed to pour molten metal on a centrifugal casting machine so that it can work in actual foundry environments as shown in Fig. 5.

G. Program Controlling Unit of Robot Assisted Pouring Devices

The controlling unit consists of the following components

1. L298 Motor Driver,
2. Arduino Uno R3. Board,
3. IC of Arduino Uno R3.,
4. IR sensor,
5. Lm35 (Temperature sensor).

IV. OPERATION AND TEST

After construction, the device is tested for operation. When the power supply is given to the circuit the 1st motor starts rotating at the sensing the temperatures of the stationary die. As soon as the die is heated to preset temperature (500°C - 600°C) the die start rotating and crucible is loaded with molten metal with the help of designed mode. The robot starts the rotation with the crucible loaded with molten metal. The robot stops its rotation as the sensor detects its pouring position. The robot takes some designed delay time 200-500 ms as pre-set for starting tilting motor. The robot stops its tilting motor as

soon as it detects the completion of pouring in the rotating dies. The casted job is ejected as the metal is solidified and cooled.



Fig. 5 Experimental models for testing robot assisted pouring systems. 1. Robot control board. 2. Motor for the rotation of robot. 3. Base frame of the robot. 4. Crucible for metal pouring. 5. Motor for crucible tilting. 6. Vertical rotating shaft. 7. Robotic arm (manipulator)

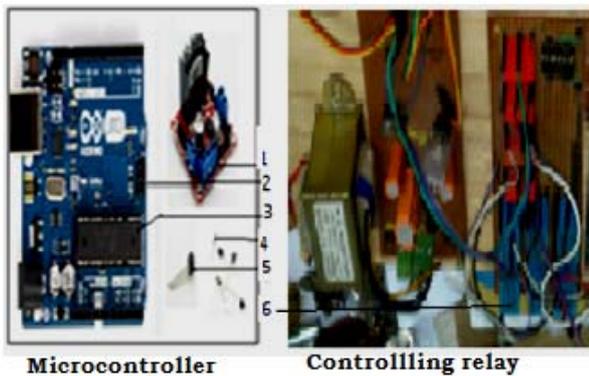


Fig. 6 Microcontroller unit and hardware

Safety is the primary concern in course of every invention. During the operation in casting process many difficulties may arise such as damage to the worker, damage to the properties of alloy due to temperature loss, excessive turbulence, over pouring etc. But by the proper application of this device, all of the problems mentioned earlier can be removed. By turning on the switch all the operations are done automatically without the need of close supervision of the workers. Not only that this device can also be used for covering a large distance between the furnace and pouring station. At first all the operational process is divided into different steps of work. Logic is build up accordingly to the step of work. Later on the required programming is done for the sequential operation. Depending on the operational condition the parameters can be changed in the program. After construction the device is tested for successful operation.

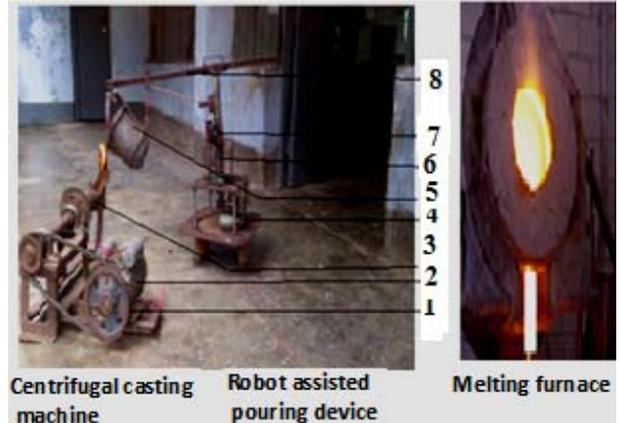


Fig. 7 Experimental set up for testing robot assisted centrifugal casting machine

V. CONCLUSION

Casting process is an art and science of building materials of required shape and size. But it is one of the most dangerous and uncomfortable job as well. This automated device makes it very easy, comfortable and safe by eliminating a lot of pouring problems. Thus, it can open and adds new dimensions in the casting process.

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REFERENCES

- [1] John Campbell, "Complete Casting Handbook", Butterworth-Heinemann, Langford Lane, Kidlington, Oxford OX5 1GB, UK, 1st Edition, 2011.
- [2] A.K. Chakrabarti, "Casting Technology and Cast Alloys", Prentice-Hall of India Pvt. Ltd., New Delhi- 110001, Edition- S2015.
- [3] Ernest P. De Garmo; J. T. Black.; Ronald A. Kohser (2003), "Materials and Processes in Manufacturing" (9th ed.), Wiley, p. 277, ISBN 0-471-65653-4.
- [4] E. Wernholt, "Multivariable Frequency Domain Identification of Industrial Robots", *Division of Automatic Control*; ISBN 978-91-85895-72-4 ISSN 0345-7524.
- [5] L.E. Bruzzone, R.M. Molfino, M. Zoppi, "Mechatronic design of a parallel robot for high-speed, impedance-controlled manipulation" *Proc. of the 11th Mediterranean Conference on Control and Automation*, June 18-20, 2003, Rhodes, Greece.
- [6] Academons; "Robotics", Written in 2002; Paper #027856.
- [7] F. Lange and G. Hirzinger, "Stability Preserving Sensor-Based Control for Robots with Positional Interface", *IEEE International Conference on Robots and Automation (ICRA2005)*, April 2005, Barcelona, Spain.
- [8] L.E. Bruzzone, R.M. Molfino, M. Zoppi, G. Zurlo, "Experimental tests on the prototype of an impedance controlled three-degree-of-freedom parallel robot" *Proceedings of RAAD' 03*, 12th International Workshop on Robotics in Alpe-Adria-Danube Region.
- [9] H. Flordal, D. Spensieri, K. Akesson, M. Fabian, "Supervision of multiple industrial robots: optimal and collision free work cycles" *Control Applications, 2004. Proceedings of the 2004 IEEE International*

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