DESIGN AND DEVELOPMENT OF A CENTRIFUGAL CASTING MACHINE FOR PISTONS PRODUCTION

Eurico Seabra
Joaquim Barbosa
Hélder Puga

Mechanical Engineering Department, Engineering School, University of Minho.

Abstract

This presentation concerns to the development of a centrifugal casting equipment to produce engine pistons with gradient of properties. Pistons require different properties in different areas of their body, such as high thermal fatigue resistance in the top, high wear resistance in the pin-bore area and low weight in the skirt. Reliable processing techniques for that purpose have not been established yet, and results obtained so far reveal sharp and undesirable interfaces. A possible solution might be a well controlled sequential pouring technique of different materials that lead to a smooth gradient of composition/properties between different piston functional areas, using centrifugal casting. For this purpose a special design of a vertical axis centrifugal casting machine was developed. A detailed study of the centrifugal pouring process and the inherent fluid dynamics was performed to develop a conceptual design and operation parameters and input/output system variables were established. A sketch of the equipment was developed and established the main components and interconnections. Finally, the design and selection of the system’s components was done accordingly to the main goals of this work. This paper analyses and discusses all of the referred design phases, including selection and prototype implementation of the necessary actuators.

Keywords: Mechanical design, Engine pistons; Castings: Functionally graded materials

1. Introduction

The development of the automotive industry strongly depends on two main issues: increased fuel-efficiency in order to accomplish the ever more stringent regulations on gas emission control and improved automobile performance [1, 2]. To achieve such goals, the use of advanced materials to improve the quality of car components and significant weight reduction are crucial [3, 4], and new engine pistons concept is a good example of the required evolution.

Pistons require different properties in different areas of their body, such as high thermal fatigue resistance in the top, high wear resistance in the pin-bore area and low weight in the skirt. On our days, pistons with composition gradient are still not available. They are usually produced using a single alloy with homogeneous composition. For some very particular applications, incorporation of another material can occur, to improve the mechanical characteristics in specific regions (as for instance in the grooves for the segments).

Pistons are typically cast in metallic moulds and machined afterwards. However, in special cases where cost is not crucial (like racing engines for example), pistons are manufactured by forging to increase their mechanical properties.

In what concerns to centrifugal casting, this technique has been mainly used for obtaining cylindrical parts. There are essentially two basic types of centrifugal casting machines: horizontal and vertical axis, according to the spatial position of the rotation axis (see figure 1), either of them for different application and with different capabilities.
Horizontal centrifugal casting machines are generally used to make pipe, tube, bushing, cylinder sleeves (liners), and cylindrical or tubular casting that are simple in shape. The range of application of vertical centrifugal casting machines is considerably wider: gear blanks, pulley sheaves, wheels, impellers, electric motor rotors, valve bodies, plugs, yokes, brackets [5]. Casting that are not cylindrical, or even symmetrical, can be made using vertical centrifugal casting. Centrifugally cast parts have a high degree of metallurgical cleanliness and homogeneous microstructures, and they do not exhibit the anisotropy of mechanical properties evident in rolled/welded or forged parts [6, 7].

Due to the potential of this casting process, a possible solution to produce pistons with gradient of composition might be a well controlled sequential pouring technique of different materials that lead to a smooth gradient of composition/properties between different piston functional areas, using centrifugal casting. This paper presents the special design of a vertical axis centrifugal casting machine developed for that purpose.

The motivation for this project arises from the needs of the casting research group of the Mechanical Engineering Department to obtain Functionally Graded Materials for practical applications in order to characterize their mechanical and metallurgical properties, as well as to identify relevant processing parameters.

Bearing in mind the main project goals design specifications were firstly established, upon the opinion and needs of future users. Then, the state of the art in what concerns to available centrifugal casting machines was characterized. Afterwards, the conceptual design was developed, based on the operation parameters and every output and input envisaged system variables. At this project stage, a sketch of the equipment was made, identified and specified the main components as well as their interconnections. Finally, the design and selection of the system’s components was performed according to the established requirements.

This paper is organized as follows: Section 1 provides a brief overview of the thematic literature related to the state of the art of centrifugal casting. Then, section 2 presents the conceptual design developed for the centrifugal casting machine. Section 3 presents and discusses the equipment design main details. Finally, in section 4 the main project conclusions are presented and some future work perspectives are outlined.

2. Conceptual design

The main objective of this research work is the design and development of suitable equipment for engine pistons die casting. Figure 2 shows the piston virtual model that is our intention to produce.
The piston base geometry and the pin hole will be obtained by casting and surface finishing and rings grooves will be obtained by suitable machining operations.

It is specification of this work that casting should take place in a metallic mould, using a vertical axis centrifugal pouring machine with central pouring. Concerning the centrifugal equipment, it should allow a variable rotation speed between 300 and 2000 rpm.

The conception and design of the envisaged equipment includes two main sections: the centrifugal equipment itself and the metallic mould.

- The centrifugal equipment itself;
- The metallic mould.

The operation principle of the developed equipment is schematized in the figure 3. It consists of a metallic mould that it is put in rotation using a motor and a belt. During the rotation movement the different alloys are poured, in a sequential way, which will create different composition in the piston functional areas. In the moment shown in the figure are poured in simultaneous two alloys. This situation corresponds to the transition phase among the materials, in way to create a composition gradient.

When poured into a mould in rotation the liquid metal is subjected to centrifugal force that originates a pressure increase impelling the metal against the mould walls, where it solidifies. Attaching the casting mould to the centrifugal equipment a machine capable to carry out the centrifugal pouring is obtained.

2.1 Mould

The mould is one of the most important machine components, thus its design is crucial to obtain a good result during the liquid melt pouring. Results will be evaluated by the quality of the obtained pieces – presence of traditional pouring and solidification defects like porosity,

Fig 3 - Schematic representation of the pistons production principle proposed by centrifugal casting.
chemical heterogeneity as well as geometrical and dimensional inaccuracy. This way, the mould design involves the development of the mould geometry, cores conception/positioning, and pouring system. The mould and cores geometries determine the final shape and accuracy of the poured pieces. The pouring system is responsible for the casting metallurgical sanity and the envisaged composition gradient, so it must guarantee the ideal conditions for metal pouring and filling of the mould cavity.

2.2 Centrifugation equipment

The main function of the centrifugal equipment is to induce rotation in the mould. However, given the intended rotation speed range and mainly the involved mass, this system has to accomplish important safety and stability conditions, to guarantee its effectiveness. Thus, the centrifugal equipment design must attend to the following parts, among many others:

- Engine;
- Mechanical transmission;
- Mould attaching;
- Bearings units;
- Anti-vibration systems;
- Framework (support machine structure).

2.3 Alternatives proposed for the conceptual solution

Initially, attending to the design requirements and specifications and to the state of the art, some alternatives have been proposed for the conceptual solution. Figure 4 shows several hypotheses that were considered during the initial design phase.

In the first case, figure 4a), it was proposed a direct connection between the motor and the plate that hold the mould. In the second case, figure 4b), a gear transmission and in the last case, figure 4c), a belt transmission.

![Figure 4. Alternatives considered for the conceptual solution.](image)

Table 1 synthesizes the main advantages and disadvantages of the three referred solutions.

<table>
<thead>
<tr>
<th></th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
</table>
| Solution 1 | - Less components  
- Compact                   | - High vibration in the shaft                    |
| Solution 2 | - Structural rigidity  
- Inexistence of flexible elements | - High noise  
- Difficulty in absorbing vibrations |
| Solution 3 | - Low vibrations  
- Larger stability in the movement | - Belt maintenance                               |

Table 1 – Main specifications analysis for the different solutions.

“Selected Proceedings from the 13th International Congress on Project Engineering”.  
(Badajoz, July 2009)
In agreement with a specifications optimization process, solution 3 (belt transmission) was selected for the vertical centrifugal casting equipment.

3. Detail design

The final solution, which was obtained after considering several design iterations, is represented in figure 5, where the main equipment components can be identified. These components will be described in the next topics.

The equipment operation principle can be briefly described as follows: The mould is attached to a metallic plate using M6 screws. The rotation of the plate is obtained through the shaft that is attached to a transmission system that includes a motor, two pulleys and a transmission belt.

The plate motion stability is assured by two bearings placed in the shaft (enclosed by a metallic cylinder) and by the anti-vibration base. A structure shell is the housing for the overall equipment, using a tube and a metallic sheet, to guarantee the safety of the equipment.

Mould – The mould (figure 6) has a parallelepiped form with capacity to pour two pistons. It is divided in two half parts, and it has in its interior two cores. The cores are fixed by trunk-conics pins and for the mould. Each piston (oriented outside) is filled through the skirt through two channels of square section. In the superior part a thermoplastic sand cup is used to allow the sprue cutting when the piece is removed.

Figure 5. Schematic representation of the adopted solution.

Figure 6. Casting mould.
Transmission (off the shelf) - The transmission (figure 7) includes a 3-phase motor, two pulleys and a belt. To allow the regulation of the motor rotation speed an inverter is used. The movement transmission between the moving pulley and the machine shaft is carry out by a key.

Figure 7. Motor, pulleys, belt and inverter.

Plate – A key assures the movement transmission between the shaft and an aluminium plate (figure 8) where the mould is attached and fixed through thread holes. The plate geometry was design in order to minimize its mass.

Isolation joint (off the shelf) – The isolation joint (figure 9) is made of rock wool material. It is positioned between the mould and the plate, and its function is to minimize heat transfer between the mould and the other equipment components, in order make mould temperature control easier, and to avoid damaging some equipment components, like the belt for example.

Shaft - The shaft (figure 10) it is the most complex piece of the whole equipment, once it is composed by three parts: the superior and inferior sections and the thread union. The superior section serves as a guide and movement transmission for the pulley and the plate. On the other hand, the inferior section, guarantees stability to the system during rotation, and it is where bearings are attached. The union between the sections is made by a thread cover, as shown in the same figure.

Figure 8. Plate.  Figure 9. Isolating joint.  Figure 10. Shaft.

Bearings (off the shelf) - Bearings (figure 11) were used to allow the relative movement between the rotative group and the machine support. Two bearings were used - one of deep groove ball type and another of taper roller type (supports radial and axial strengths). Bearings assembly is made by tightening between the shaft and the metallic cylinder.

Anti-vibration system (off the shelf) – Outside, bearings are surrounded by a metallic cylinder. This cylinder is independent of the rigid structure of the machine, with a small gap between them, which allows the placement of the anti-vibration systems. These systems have the function to absorb shocks originated by the shaft and, this way, to avoid vibrations propagation to the machine structure. The anti-vibratory system is constituted by anti-vibratory bases (figure 12) and a foam blanket of high density (figure 13) located in the base.
Machine structure - The machine structure has two main functions: to serve as mechanical support of the machine, and to promote operator safety and equipment protection. The support function is guaranteed by some supports in steel, as can be seen in the figure 5. On the other hand, the protection function is obtained by a suitable cover box made of square section tubes and sheets that cover the whole machine. The structure still has a service hatchway that allows the access to the mould.

4. Conclusions

The design and development of a centrifugal casting machine to produce engine pistons has been presented and discussed throughout this work. It consists of simple equipment of feasible construction, adaptable to different conditions, fulfilling the safety standards.

The main merit of this project is its innovative equipment concept, when compared to those available in the market with special interest for the Functionally Graded Materials (FGMs) research field and constitute a fundamental and important contribution for the research and development of new pioneering centrifugal casting products.

This paper highlighted the design phase carried out so far, and future work will focus the detail design validation, as well as the implementation of the overall (electronics hardware and software) systems architecture to monitor and control the testing apparatus.

References


Correspondence (For additional information contact with):
Prof. Eurico Augusto R. Seabra
Mechanical Engineering Department - Engineering School - University of Minho
4800-058 GUIMARÃES (Portugal)
Telefone: +351 253 51 02 20
FAX +351 253 51 60 07
E-mail: eseabra@dem.uminho.pt
URL: http://www.dem.uminho.pt