DESIGN AND DEVELOPMENT OF A CENTRIFUGAL CASTING MACHINE FOR PISTONS PRODUCTION

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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, Motor pistons; Castings; Functionally materials

Resumo

Neste trabalho é apresentado o projecto e desenvolvimento de um equipamento de fundição centrífuga para produzir pistões de motor com gradiente de propriedades. Os pistões nas várias áreas do seu corpo requerem propriedades diferentes, elevada resistência à fadiga no topo, elevada resistência ao desgaste na área dos segmentos e reduzido peso na saia. Para este propósito, até a presente data, não foram encontradas técnicas de produção fiáveis, com os resultados obtidos a revelarem zonas afiadas e indesejáveis. Uma possível solução pode ser uma técnica bem controlada de fundição sequencial de materiais diferentes, que utilizando a fundição centrífuga, permita um gradiente de composição/propriedades nas diferentes áreas funcionais do pistão. Para este propósito foi desenvolvido um projecto de uma máquina de fundição centrífuga de eixo vertical. Para desenvolver o projecto conceptual foi realizado um estudo detalhado do processo de fundição centrífuga e da dinâmica dos fluidos envolvida e estabelecidos os parâmetros de operação e as variáveis de entrada e saída do sistema. Seguidamente, foi obtido um primeiro esboço do equipamento com a designação dos seus componentes principais e interligações. Por fim, foi realizado o

projecto de detalhe com a selecção dos componentes do sistema mais apropriados relativamente às especificações do projecto. Neste artigo são apresentadas e discutidas as fases de projecto referidas, inclusive a selecção e a implementação no protótipo dos actuadores necessários.

Palavras-chave: Projecto mecânico; Pistões de motor; Fundição; Materiais funcionais.

1. Introduction

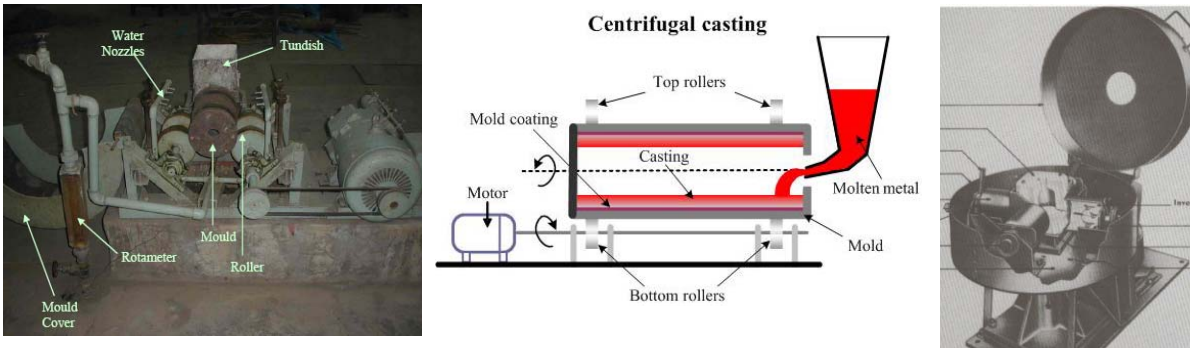
The development of the automotive industry strongly depends on two main issues: increased fuel-efficiency in order to accomplish the ever more stringent regulations on gas emission control and improved automobile performance [1, 2]. To achieve such goals, the use of advanced materials to improve the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

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, they are not pistons with composition gradient. The pistons are usually produced with homogeneous composition, in one alloy, existing in some cases incorporations of another material, to improve the mechanical characteristics in certain area (as for instance in the grooves for the segments).

The pistons are typically produced by gravity casting, in metallic mould and afterwards machined. However, in special cases, pistons are manufactured by forging to increase their mechanical properties.

Relatively to the centrifugal casting, this technique has been mainly used for obtaining cylindrical parts. There are essentially two basic types of centrifugal casting machines: the horizontal types, which rotate about horizontal axis, and the vertical type, which rotates about a vertical axis (see figure 1).

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].



a) b)

Figure 1. Centrifugal casting types: (a) horizontal axis and (b) vertical axis [8 ,9].

Due to the referred advantages of this process, a possible solution for the pistons production 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 shows the special design performed to develop a vertical axis centrifugal casting machine for that purpose.

The motivation for this project comes from the necessity of the casting research group of the Department of Mechanical Engineering to obtain Functionalized Graded Materials and characterize their mechanical and metallurgical properties.

With the purpose to achieve the project goals, the design specifications were firstly established, based on the opinion of the futures users. Then a detailed study to characterize the state of the art of centrifugal casting machines was carried out. Afterwards, the conceptual design was performed, established the operation parameters, as well as, the input and output system variables. In this phase of the project, a sketch of the equipment was made with the definition of the main components and their interconnections. Finally, the design and selection of the system's components was performed accordingly.

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, in section 2, the conceptual design developed for the centrifugal casting machine for pistons is presented. Section 3 presents and discusses the design details, independently for each main component of the developed equipment. Finally, in section 4 the main work conclusions are presented and some future work perspectives are outlined.

2. Conceptual design

The main objective of this work is the design and development of an equipment capable to perform the permanent casting of pistons with gradient of composition. Figure 2 shows the piston virtual model that it is intended to produce.

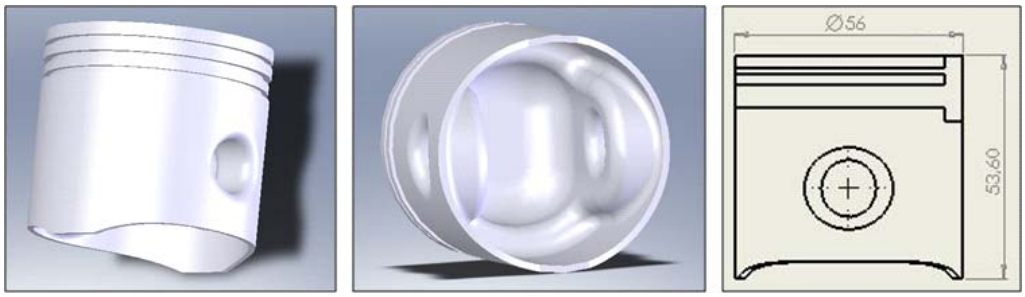


Figure 2. Motor piston geometry.

The piston base geometry and the pin hole will be obtained by casting and the final surface finishing and the rings grooves will be made using traditional machining processes.

It is specification of this work that the castings should be obtained in a metallic mould, using the vertical axis centrifugal casting technique. In what concerns to the centrifugal equipment, it must guarantee a variable rotation speed between 300 and 2000 rpm.

This way, the goals of this equipment design appear as twofold:

- Design of the centrifugal equipment;
- Design of the metallic mould.

The operation principle of the developed equipment is schematized in the figure 3. It consists in a metallic mould that it is put into 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 precise moment shown in the figure two alloys are being simultaneous poured. This situation corresponds to the transition phase among the materials, in order to create the composition gradient.

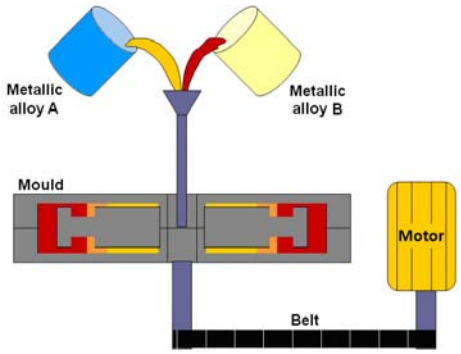


Figure 3. Schematic representation of the proposed pistons production device.

The liquid metal, when being poured in a mould in rotation, is submitted to a centrifugal force that originates a pressure increase, which impels the metal against the mould walls, where it solidifies.

By attaching the casting mould to the centrifugation equipment a machine capable to carry out the centrifugal pouring is obtained.

2.1 Mould

Being one of the most important machine components, the mould design is crucial to reach a good result during the liquid melt pouring. This result will be evaluated by the quality of the obtained pieces, namely the presence of defects occurred during pouring and solidification, and for the ability to handle the mould and the poured pieces. This way, the mould design involves the development of the mould geometry, cores, and pouring system.

The mould geometry and the cores determine the final geometry of the poured pieces. Concerning the pouring system, it is designed with the purpose to create the ideal conditions for the metal pouring and filling of the mould cavity, in order to obtain sound pieces with the desired composition gradient.

2.2 Centrifugation equipment

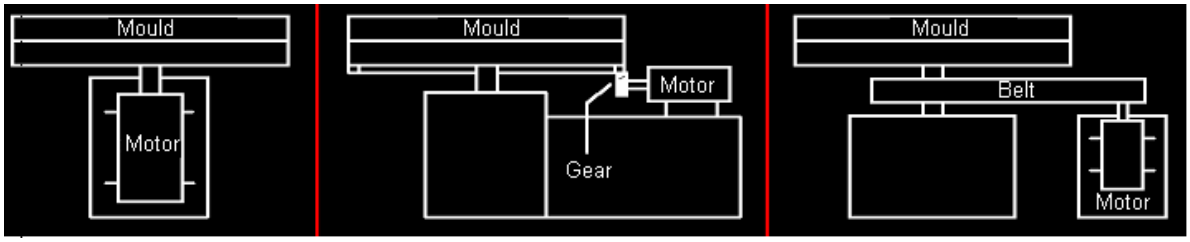
The main function of the centrifugation equipment is to supply rotation movement to the mould. However, given the intended rotation speed range and mainly the involved mass, this system has to accomplish certain safety and stability conditions, to guarantee its effectiveness. Thus, the centrifugation equipment design must attend to the following parts:

- Motor;
- Mechanical transmission;
- Mould attaching;
- Bearings units;
- Anti-vibration systems;
- Machine support 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 for the conceptual solution were proposed. Figure 4 shows the 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 holds the mould. In the second case, figure 4b), a gears transmission and in the last case, figure 4c), a belt transmission.



a) b) c)

Figure 4. Alternatives considered for the conceptual solution.

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

	Advantages	Disadvantages
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.

In agreement with a specifications optimization process, the solution 3 (belt transmission) was selected for the vertical axis centrifugal casting equipment.

3. Detail design

The final solution, which was obtained after considering several design iterations, is presented 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.

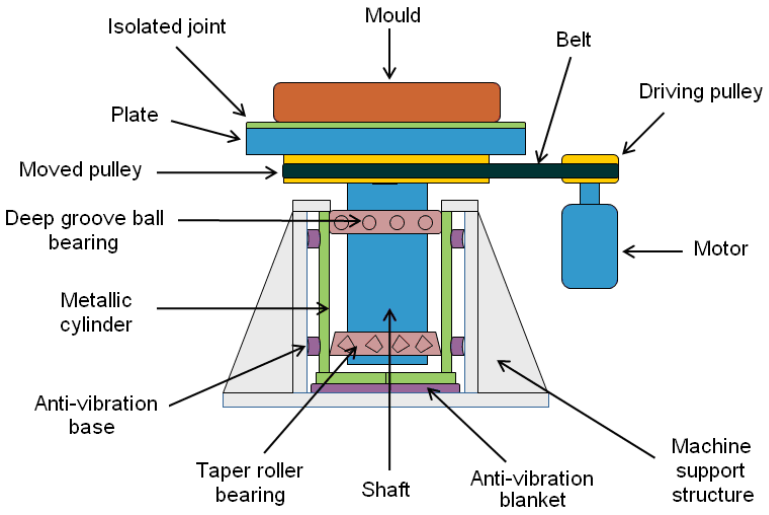


Figure 5. Squematic representation of the adopted solution.

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 pins trunk-conics and for the mould. Each piston (oriented outside) is poured through the skirt using two pouring channels of square section. In the superior half-die a pouring basin made of thermo set sand is used to allow the cut of the sprue when the piece is removed.

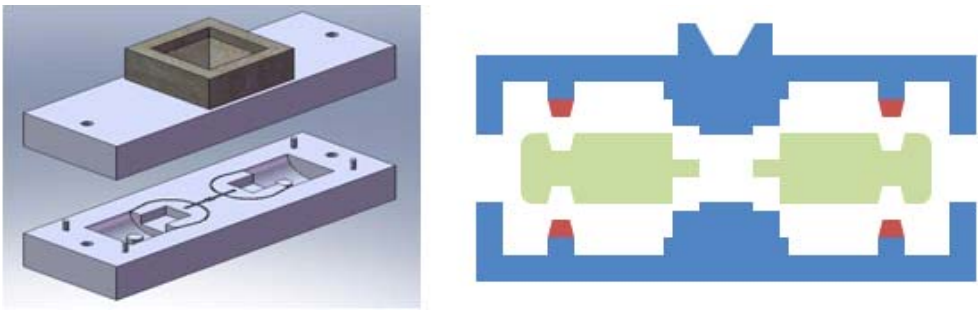


Figure 6. Casting mould.

Transmission (off the shelf) - The transmission (figure 7) includes a 3-phases motor, two pulleys and a belt. An inverter is used to allow the regulation of the motor rotation speed. The movement transmission between the moved 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 the plate. This plate (figure 8) is the component where the mould is attached; it has thread holes for its fixation. Finally, the plate geometry was design in order to minimize its mass/weight.

Isolated joint (off the shelf) – The isolated joint (figure 9) is made in rockwool material. It is located between the mould and the plate to minimize the heat transfer between the mould and the other equipment components, since high temperatures could damage them, namely the belt.

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 both sections is made by a thread cover, as shown in the same figure.

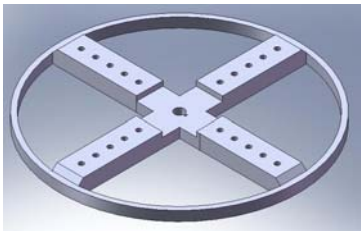


Figure 8. Plate.

Figure 9. Isolated joint.

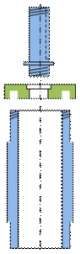


Figure 10. Shaft.

Bearings (off the shelf) - Bearings (figure 11) were used to allow the relative movement between the rotative group and the machine support. Two bearings types are used; one of deep groove ball type and another of taper roller type (supports radial and axial strengths). Bearings assembly is made by tighten 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. There is a small space among both, that allows the placement of the anti-vibration systems. These systems have the function to absorb those shocks originated by the shaft and to avoid, this way, the vibrations propagation into 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.

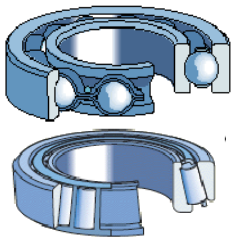


Figure 11. Bearings.

Figure 12. Anti-vibration base.

Figure 13. Anti-vibration blanket.

Machine structure - The structure has two fundamental functions: to serve as support to the machine, to promote the operator safety and the equipment protection. The support function

is guaranteed by some supports in steel, as can be see in the figure 5. On the other hand, the protection function is obtained with 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 motor pistons has been presented and discussed throughout this work. A simple equipment of feasible construction, adaptable to different processing conditions was obtained, fulfilling the initial specifications and 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 Functionalized 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 be focused on the detail design validation, as well as to the implementation of the overall (electronics hardware and software) systems architecture to monitor and control the testing apparatus.

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