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INCREASE OF THE OPERATING LIFE OF A MOULD DURING THE CASTING PROCESS OF FLOTATION BALLS WITH THE AID OF TRIZ METHOD

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Vojislav Miltenović[1#], Nedeljko Dučić[2], Radomir Slavković[2], Snežana Radonjić[2], Nikola Bošković[2]

[1]Faculty of Mechanical Engineering, Niš, Serbia,
[2]Technical Faculty, Čačak, Serbia
[#]E-mail: vojamiltenovic@yahoo.com

Abstract. *This paper presents the use of the TRIZ method in the casting process as a problem-solving methodology which relies on a systematic and logical approach based on the study of many patents. The wear of casting tools affects the effectiveness of the casting process and, for this reason, the tool wear should be reduced. The paper also presents the possibility of tools protection by applying the methods based on the Altshuller's matrix.*

Key words: *Casting, TRIZ Method, Wear, Automatization*

1. INTRODUCTION

The casting process has remained unaltered for centuries. However, the equipment used for casting has been undergoing changes thus affecting casting quality. Products of casting are brought to perfection. Casting or liquid metals processing includes a series of processes or operations aiming at obtaining the castings (parts of certain size and shape) after cooling the fused metal which is poured into an appropriate mould hollow. Generally, casting can be considered as the basic stage of modulation of any raw metal, which needs to be processed further. In casting technology, which is today applied successfully, metal pouring may be either manual or mechanized, or it may be done by casting machines using gravity, pressure or centrifugation. Pouring of metal into a mould hollow by using gravity (as in the case of flotation balls casting) is applied to all metals and alloys. It can be said that this is one of the technological methods that will be used in future, although it dates back to the Stone Age. This casting method ensures a good surface, high quality of products, low price of production and good working conditions in the foundry in terms of sanitary and technical protection. Casting in moulds is especially convenient for small and simple castings which have balanced wall thickness. More balanced castings

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can be obtained by casting into moulds (with narrow tolerances, better surface quality and better mechanical characteristics) than by sand casting. Considering the requirements related to productivity, the quality of castings and consumption of moulds per 1 kg of castings, it is necessary to improve the casting process in terms of increasing the operating life of moulds, i.e. reducing mould wear which is directly related to the quality of casting products.

2. Analysis of Technical System and Flotation Balls Casting Process

In the industrial combine "Guča", flotation balls of low-chromium white cast iron are obtained by casting in moulds. Hard cast iron is an alloy whose carbon is all tied up in cementite (Fe3C) or most of the carbon is tied up in cementite while a small portion of carbon is isolated in the form of graphite. This can be achieved by an appropriate chemical composition of cast iron and faster cooling. The chemical composition of hard cast iron ranges within 2.2 - 4% carbon, 0.3 - 1.5% silicon and 0.4 - 1.5% manganese. The content of silicon in hard cast iron is small. A higher cooling rate, which also prevents cementite decomposition, is obtained by casting in metal moulds and moulds with built-in cooling devices. Regarding the structure and appearance of the fracture, there are two types of hard cast iron:

- white hard cast iron, and
- hard cast iron.

White hard cast iron is used for producing castings that are exposed to wear like parts of crashing mills, mill balls (flotation balls), nozzles for sand, etc.

Table 1 Chemical composition of low-chromium white cast iron

C, %	Si %	Mn %	Cr %	S %	P %	Others %
3.4 – 3.7	0.6 – 0.8	0.6 – 0.8	2.3 – 2.6	Max. 0.1	Max. 0.1	Within the limits

Obtained balls are used for copper ore milling (a ball with 2.5 % Cr). Metal cartridge is made of carbon steel and low-alloyed steel, which, after melting, is alloyed with chromium, manganese and carbon on the required chemical composition. For the sake of production optimization, cost reduction and better quality balls, it is necessary to add high alloyed steel scrap, alloyed with Cr, Mo, Nb, Ni, W, Ti, to the composition of metal cartridge (with waste material). The addition of materials (blacksmith waste materials) with good mechanical properties enables an increase of flotation balls hardness from 54 HRC to 56 HRC. For mass production, such as the production of flotation balls in IC "Guča", for opening and closing of moulds (tools), hydraulic cylinders (machines with hydraulic opening) are used, as shown in Fig. 1.

Fig. 1 Tool during the casting process

A drawing of a completed part (flotation ball), i.e. drawing of a casting, serves as a basis for the construction of a casting mould. The drawing must be carefully analyzed before making the final technical solution to the mould (Figs. 2 and 3).

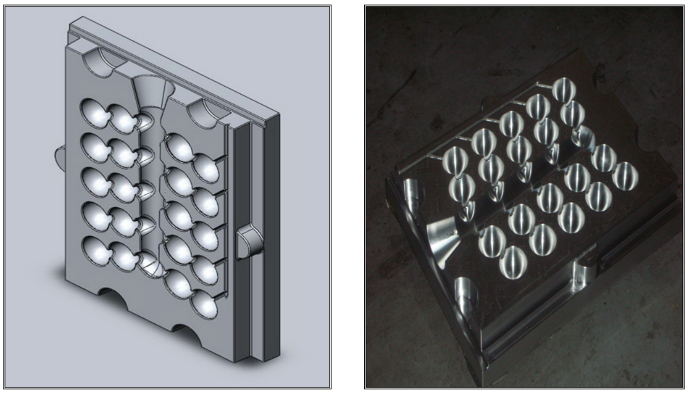

Fig. 2 a) Drawing of the tool for balls casting;
b) The tools for balls (mould) casting after processing by CNC milling machine

Metal is poured from above, thus filling the lower cavities first and the upper cavities afterwards (Fig. 3a). When constructing the mould, one should also provide for the surroundings of the casting.

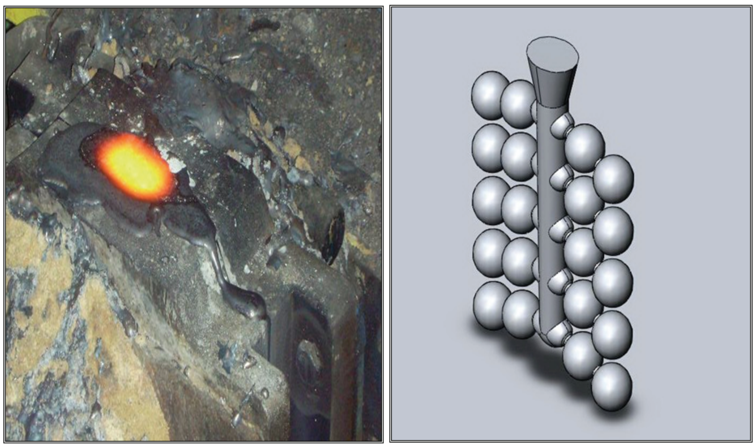

Fig. 3 a) Pouring of cast iron into the tool; b) "balls in a cluster" after being taken out of the tools

Casting temperature must remain within the range of 1350–1450°C. When constructing the mould, one should also provide for the space for a tundish around the casting. Because of the transport and period envisaged for pouring of metal into the mould. Casting temperature for this alloy is 1340°C. From the furnace located at the foundry, cast iron is poured into a one-ton ladle and transported by a lorry to the balls line. Cast iron is poured from the big ladle (1 ton) to a small ladle of 180 kg, and then, into the mould. Six discharges are necessary for emptying the large ladle in a time interval of 20 - 30 minutes. After this, the castings are "drummed", and they are now ready for use, as shown in Fig. 4.

Fig. 4 The balls ready for flotation

3. Development of a Partial Functions Model of Flotation Balls Casting Process

The development of a function model with the aid of TRIZ method is used to address the analyzed technical problem quickly. A proper definition of the problem is actually the first step in solving it. The proper definition of the problem by using the Altshuller's matrices yields technical parameters that can be improved, without having a negative effect on the other parameters of the system. This problem is overcome by using 40 principles for eliminating technical contradictions. The casting process can be broken down into several interrelated sub-functions. Fig. 5 presents a graphical display of the function model.

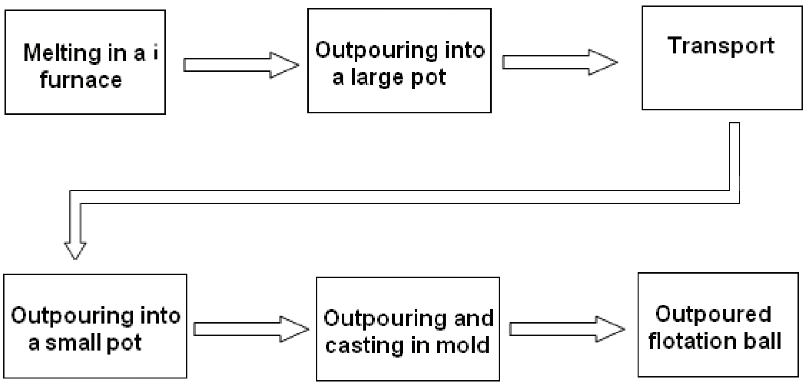

Fig. 5 Graphical display of the function model

A useful function of flotation balls casting is to obtain the balls with desired properties. This function depends, for its realization, on other useful functions such as:

- Melting in the furnace,
- Pouring of cast iron into the big ladle,
- Transport of cast iron,
- Pouring of cast iron into the small ladle,
- Pouring of cast iron into the mould and casting, and
- Storage of flotation balls.

An analysis of "mould casting" reveals the occurrence of a negative characteristic – mould wear, which is due to the fact that liquid metal causes the mould corrosion. The service life of a mould depends on the types of cast iron, casting methods and complexity of casting. The moulds used for casting white cast iron have a much shorter service life than those used for casting light and non-ferrous metals. Therefore, the negative characteristic that should be reduced is mould wear during the casting process.

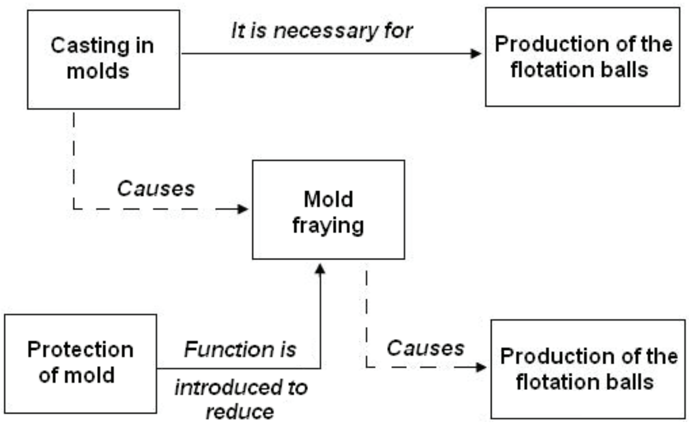

Fig. 6 Graphical display of useful and harmful functions of the system

4. Elimination of Technical Contradictions by Applying the TRIZ Method

Definition of technical contradictions

TC – 1: If the characteristic (mould wear) is reduced by using the appropriate liner, the "complexity" of the system will get worse.

Harmful factors that are induced in the very object / Device complexity

TC – 2: If the characteristic (mould wear) is reduced by using the appropriate liner, then the "mass" of the system will get worse.

Harmful factors that are induced in the very object / The mass of immovable objects

TC – 3: Exceeding the time of keeping the balls in the mould can also be the cause of mould wear. Furthermore, it can also have a negative effect on the casting characteristics.

Therefore, it is necessary to influence the improvement of the level of automatization of the process of keeping the balls in moulds. Balls of different diameter require different periods during which they are kept in the mould (Φ50 – 150s, Φ60 – 180s, Φ80 – 360s).

The degree of automatization / Complexity of the device

Table 2 Altshuller's matrix of contradictions

Characteristics that need to be improved or whose harmful effects must be reduced		Characteristics of the system that are getting worse (unauthorized change)			
		1.	2. The mass of immovable objects	...	36. The complexity of the device
31.	Harmful factors that are induced in the object		1, 22, 35, 39		1, 31, 19
...					
38.	The degree of automatization				15, 24, 10
...					

Solving technical contradictions

The first contradiction:
Harmful factors that are induced in the object/complexity of the device

The principles obtained for these contradictions are: 1, 31 and 19.
The method used is 31a: *Make the object porous or use some additional elements* (*liners, covers)*

Principle 31a – It is possible to insert a liner (cover) in the object (mould). It would serve as a barrier between the liquid metal and the mould and, thus, extend the service life of the mould by reducing a thermal shock and corrosion of the mould caused by liquid metal.

The second contradiction:
Harmful factors that are induced in the object/the mass of immovable objects

The principles obtained for these contradictions are: 1, 22, 35 and 39.
The methods used are 35a and 39b. 35a: *Change the state of aggregation of the object*; 39b: *Introduce some neutral substances or additives into the object*;

Principle 35a – It is recommended to change the physical state of the liner, i.e. transform it into liquid state. It is suggested to transform the liner into liquid state.

Principle 39b – This principle, in combination with 35a principle, provides a solution to the problem. It is recommended to use the coating added to the inner surface of the mould to serve as a barrier between liquid metal and mould, i.e. between mould and the surface of the casting.

The third contradiction:
The degree of automatization / Complexity of the device

The principles obtained for these contradictions are: 15, 24 and 10.
The method used is 15a. Ensure (or design) the characteristics of an object, surroundings or process so that they can be changed in an optimal way, or that they are present under the optimal working conditions.

Principle 15a - The characteristics of the object must be changed in order to be optimal during the process. For this system, it means that the period during which cast iron is kept in the tool needs to be adjusted to the corresponding parameters. A software system that would have control over parameters and manage the process could contribute to the reduction of mould wear and improvement of the casting quality. It means that the improvement of automatic management of hydraulic cylinders used for opening and closing of the moulds ensures a precise control of the period during which iron cast is kept in the tool. Flotation balls casting in IC "Guča" involves the system of ten moulds managed by contactor equipment which includes circuit breakers, time relays and switches (Fig. 7). Management of the process is manual and it involves following operations: the operator opens and closes the moulds by pressing the keys, while the period during which cast iron is kept in the tool is not programmed.

Fig. 7 Cabinet with contactor equipment

A solution for the new system for managing the casting process involves the use of a PLC controller (with logic circuits, time circuits, arithmetic circuits, etc.) and touch panels (one for each tool) which serve for regulating the opening and closing of the moulds and the period during which cast iron is kept in the tool. The hydraulic scheme of process management (Figs. 8 and 9) includes: a hydraulic valve 4/3 with electromagnets that switch on the appropriate positions, a two-way hydraulic cylinder, a hydraulic irreversible valve pilot, as well as inductive limit switches that limit the piston rod movement.

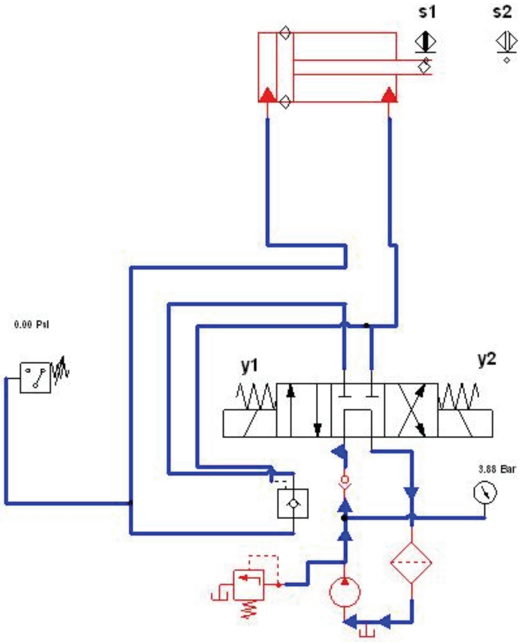

Fig. 8 Hydraulic scheme - opened tool

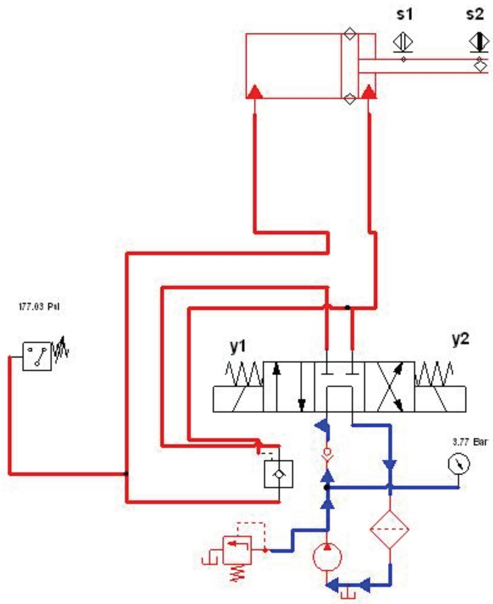

Fig. 9 Hydraulic scheme - closed tool

The program presented by the Ladder diagram (Fig. 10) contains three timer blocks set to different time intervals that correspond to the time intervals necessary for the casting of flotation balls of particular diameters. The mould is closed by pressing the **START** key, which results in the activation of **T0** output. This excites electromagnet **y1** which leads the distributor into the left position. The piston rod is pulled out, thus closing the tool, which is closed when the inductive switch **s2** is activated. Then the operator pours cast iron from the small ladle into the tool after which he specifies the time necessary for keeping cast iron in the tool by pressing the appropriate button (**diameter 1, diameter 2, diameter 3**). After the time necessary for keeping cast iron in the tool is over, **T1** output turns on and excites electromagnet **y2**. The right position of the distributor is activated, the tool is opened and the casting falls down on the continuous conveyor belt. The tool is opened until the switch **s1** is activated.

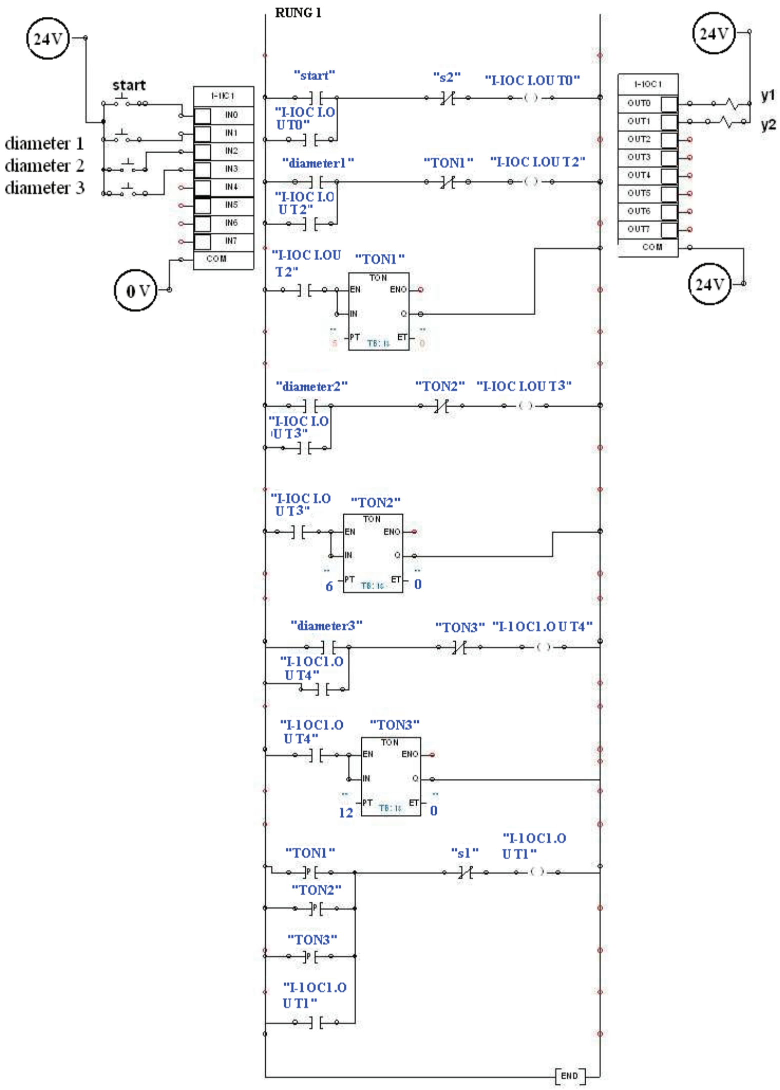

Fig. 10 Managing the process by Ladder diagram

5. CONCLUSION

Nowadays, the casting process is facing many challenges. Producers of casting products must meet the ever rising customer expectations (high level of quality, shorter time for product realization, lower and more competitive prices). The increase of the operating life is one of important segments of increased efficiency and economy of casting process of flotation balls. Based on the analysis of possibilities for increasing the operating life, the following can be concluded:

- The quality of casting process can be improved by automation of the process,
- Thermal damage can be reduced by using appropriate coating after pouring of liquid metal,
- Using of coating prevents damaging of mould by liquid metal,
- The operating life of a mould is extended by using coating. The capacity of the mould which is protected by coating is the casting process of 12 tons of liquid metal, while the capacity of the mould which is not protected by coating is the casting process of 5 tons.

Based on this paper, it can be concluded that the application of the TRIZ method led to the solving of technical problems in practice.

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POVEĆANJE RADNOG VEKA KOKILE U PROCESU LIVENJA FLOTACIJSKIH KUGLI PRIMENOM TRIZ METODE

Vojislav Miltenović, Nedeljko Dučić, Radomir Slavković, Snežana Radonjić, Nikola Bošković

U radu je predstavljena primena TRIZ metode u oblasti livarstva, kao metodologija rešavanja problema koja počiva na sistematičnom i logičkom pristupu razvijenom na osnovu studioznog izučavanja velikog broja patenata. Jedan od faktora koji utiču na efektivnost procesa livenja flotacijskih kugli je habanje alata za livenje kugli (kokila). Kao karakteristika sistema koju treba umanjiti ističe se smanjenje habanja alata. Funkcija koja se uvodi je zaštita alata, koja se sprovodi na načine dobijene korišćenjem Alštulerove matrice.

Ključne reči: *livenje, TRIZ metoda, habanje, automatizacija*