Classification of parts used in mechatronic products and produced by permanent-mold casting methods

V Zaharinov, I Malakov, S Nikolov, R Dimitrova and G Stambolov
Technical University Sofia, blvd. Kliment Ohridski 8, Sofia, Bulgaria

vzaharinov@tu-sofia.bg

Abstract. The paper presents the results from a research on parts used in mechatronic products and produced by the permanent-mold casting methods of gravity die casting and die casting. An overview and analysis of different definitions for mechatronic systems and examples of mechatronic products is made. As a result, a new definition for a mechatronic product is proposed. Various classifications of mechatronic products are analysed and deemed too general for the purposes of the current research. Permanent-mold casting methods are analysed and their advantages and disadvantages are pointed out. Arguments as to why these methods are suitable for producing mechatronic product parts are given. Based on the proposed definition for mechatronic product, the analysed classifications, and the overview of the permanent-mold casting methods a new classification is proposed. The classification is used for classifying permanent-mold cast parts used in mechatronic products. The parts are classified in six groups with regard to their application in the mechatronic product. In addition, the classification gives information regarding permanent-mold casting method used, material, and mechatronic product that includes the part.

1. Introduction

According to the first definition of mechatronics, proposed by an engineer at Yaskawa Electric Corporation, called Tetsuro Mori [1], and the definitions that were brought up later [2, 3, 4, 5, 6, 7], a great deal of the engineering products designed and manufactured in the last forty years, that integrate mechanical and electrical systems, may be classified as mechatronic systems. Some examples of such systems are industrial robots, CNC processing machines, car control systems like ABS, ESP, automated measuring systems, etc. [4, 6, 7, 8, 9].

Before classifying anything related to mechatronic products it must be clarified what is a "mechatronic product". There are a number of publications [6, 7, 10, 11] that give definitions for a "mechatronic system", and use the term interchangeably with "mechatronic product". There are authors [4] that make distinction between a "mechatronic system" and a "mechatronic product", but do not give a clear definition of the latter. Therefore, due to this discrepancy, there is a need for clarification and definition of the term.

The choice of a new product for manufacturing, the choice of a test object for research in a particular manufacturing process, or starting a business of offering manufacturing services, is related to an extensive research on the process itself, the parts that are suitable for production with said process, and the products in which these parts are used as components. One tool for directing such searches is existing classifications of the types of parts, types of products, and the manufacturing processes used. Surprisingly enough, although mechatronic products today are widely used, and mechatronic design is
a strong tendency in engineering design, there are relatively small number of classifications proposing some kind of taxonomy of mechatronic systems [4, 12, 13, 14]. In addition, to the authors' knowledge there are no existing classifications aiding in the search of parts used in mechatronic products and produced by gravity die casting and/or die casting. The development of such a classification will aid future searches in the area of permanent-mold cast parts and mechatronic product components.

The aim of the current paper is to present the results from a research on permanent-mold cast parts used as mechatronic product components. To that end, a definition for the term "mechatronic product" is proposed, existing classifications of mechatronic products are analyzed, an overview of gravity die casting and die casting processes is made, and an open classification scheme summarizing the research, and enabling future expansion is developed. The presented work is part (subtask) of a larger research effort for the development of optimization methods and algorithms for automated permanent-mold casting processes through optimization of the robotic servicing of a permanent-mold casting machine.

2. Definition of a mechatronic product
Despite the variety of definitions for mechatronics, their analysis shows, that the authors agree in one thing: mechatronics unite at least several scientific and/or engineering fields. Because the nature of mechatronics is interdisciplinary, finding a widely accepted answer to the question "Which product is mechatronic?" is difficult.

At first, mechatronics referred to systems including only mechanical and electrical components - no computational system was included. Examples of such systems are: automated sliding door, vending machines, and automated garage doors. Nowadays, practically all mechanical devices include electronic components and some kind of computer monitoring or control. Therefore, the term "mechatronic" encompasses a huge number of devices and systems [15].

The term "mechatronic product" very often [6, 7, 10, 11] is used together with "mechatronic system" interchangeably, without clarification as to why. The authors [5, 7, 15, 16] instead of giving definitions for a "mechatronic product", prefer to give examples of mechatronic systems. In [7] a block diagram is proposed of a typical mechatronic system, including the following main components: user interface; controller; drive circuits; actuators; mechanical system; sensors; signal conditioning. In [15] also a schematic of the main components of a mechatronic systems is proposed which agrees with the previously mentioned components.

The mechatronic systems are characterized by the following features [4]: integration of mechanical and electronic components; software that defines functions; new design instruments for concurrent design; synergistic effects.

Some authors [4] suggest a certain degree of nuance between a mechatronic system and a mechatronic product: "While not a mechatronic product on the order of a camcorder, it is (home/office heating/cooling system) a mechatronic system because of its combination of mechanical, electrical, and computer components."

In an attempt to clarify the term "mechatronic product", and for the purposes of the paper, a definition of a "mechatronic product" is proposed, as follows: mechatronic is a product, that realizes full integration of mechanical systems, drive systems, and control systems into one aggregate technical system through the synergistic interaction between two main flows - energetic and informational.

3. Classifications of mechatronic products
For the systematic study of mechatronic products that include parts produced by permanent-mold casting methods, the study of existing classifications of mechatronic products is beneficial.

The rarity of mechatronic products' classifications in the specialized literature could be explained, to some extent, with the great variety of applications in which mechatronic products are used.

In [12] maybe one of the first classifications of mechatronic products is presented, developed in the late seventies of the twentieth century. The classification divides the mechatronic products in four classes:
- Class I: mainly mechanical products with included electronics for increased functionality. Examples are NC machines and velocity control drives in processing machines;
- Class II: traditionally mechanical systems with considerably modernized structure which includes electronics. The user interface is not changed. Examples are modern sewing machines and automated production systems.
- Class III: systems that keep the functionality of traditional mechanical systems but their components are replaced with electronics. The example given is a digital watch;
- Class IV: products designed with mechanical and electronic systems through synergistic integration. Examples are photocopiers, intelligent washing machines and dryers, automated cooking appliances and automated ovens.

According to [4], mechatronic products can be divided into mechatronic systems, mechatronic machines, mechatronic vehicles, precision mechatronics, and micro mechatronics.

In [13], examples are proposed of various mechatronic systems, which are divided into separate groups as follows: mechatronic machine components, mechatronic motion generators, mechatronic power producing machines, mechatronic power consuming machines, mechatronic automobiles, mechatronic trains.

In [14], the mechatronic systems are divided into conventional mechatronic systems, micromechatronic systems, and nanomechatronic systems.

These classifications, although some [12, 13] give examples of classified products, are very general and hardly can be used when searching for particular mechatronic products, their main components or manufacturing processes used. For the aims of the research laid out in the current paper, these classifications do not give enough information, and do not aid significantly the information search process.

4. Gravity die casting and die casting as processes for production of parts for mechatronic products

Some authors [4] point out, as a reason for the advent of mechatronic products, the desire for increasing the ratio of performance over costs, and the creation of new products, situated at the intersection point of the traditional engineering disciplines, informatics, and the natural sciences. A lot of today's mechatronic products are integrated systems from which high performance parameters are expected. Obtaining high performance parameters and enhanced functions puts a lot of pressure on the design of such products, and the use of new and complex methods for design optimization becomes mandatory. Advanced optimization techniques like shape and topology optimization generate complex geometric structures, that can be produced with economic benefit only through casting processes and/or 3D printing. As application of metal 3D printed parts outside the prototyping field gets more and more common [17], still the majority of metal parts with high importance to system performance and with complex shape are produced through casting processes. Moreover, 3D printer technology cannot provide the production rate that a casting process can. Some of the advantages of the metal casting processes, such as [18]: creation of complex external and internal geometry, and part production without the necessity of additional processing for obtaining the end product geometry and dimensions, also make them suitable for the production of mechatronic system components.

Gravity die casting, and die casting, are metal casting processes that use permanent-molds (metallic molds or a combination of metallic molds and sand cores) [18, 19]. Furthermore die casting is performed in two types of technological processes: hot-chamber die casting, and cold chamber die casting.

The main advantages of permanent-mold casting are [18]: good part surface quality; high precision; due to the faster solidification when using metal molds, structure with finer granularity is produced, leading to better strength characteristics compared to expendable-mold casting processes. Additionally, both gravity die casting and die casting have the following advantages [20, 21]: suitable for mass production; high precision of the dimensions (higher for die casting); good quality and details of the part surface (excellent for die casting); high production rates.
The main disadvantages of permanent-mold casting are [18]: the process is limited to metals with lower melting temperatures; simpler geometry compared to expendable-mold castings, due to the need for opening the mold; price of the mold. Additionally, both gravity die casting and die casting have the following disadvantages [20, 21]: not suitable for large castings; high surface hardness and internal stresses of the casting due to fast cooling; not suitable for small production quantities.

Both processes, gravity die casting and die casting, are mainly used for casting of non-ferrous metals like aluminium, zinc, magnesium, copper, lead, and low melting point alloys of said metals [18, 19, 22]. Some example parts produced with these processes are: carburettors housings, pump housings, connecting rods, internal combustion engine pistons, hydraulic break cylinders, parts for fridges and washing machines, gears and gear housings, parts for aircraft and rocket projectiles.

5. Classification of parts used in mechatronic products and produced by gravity die casting and die casting

A classification of parts produced by gravity die casting and die casting, and used as mechatronic product components is proposed. The classification divides the parts by their application in the mechatronic product in six groups, as follows: mechanical system, optical system, sensors, actuators, control system, and user interface (figure 1). These groups account for the main components of the mechatronic product with the addition of the optical system, which accounts for opto-mechatronic products [23].

![Figure 1. Classification groups](image)

The classified parts in each group are shown in figure 2, figure 3, figure 4, figure 5, figure 6, and figure 7. Additionally, for each part classified, information regarding the manufacturing process and material used is given. These are noted on the left and right sides of the block for the part accordingly, where DC means die cast; GC - gravity die casting; Al - aluminium; Zn - zinc; Mg - magnesium; Br - bronze. More than one manufacturing method, and more than one material can be utilized (attached to the block of a part) for the production of the same part. Under each part's box are given examples of mechatronic products in which it is used.

Twenty-nine parts are classified in the shown classification. From the parts included in the latter it can be seen that the gravity die casting and die casting manufacturing processes are used mainly for parts that function as housings for components. In addition, from the classification can be seen that a large number of the parts are made from aluminium and its alloys, although zinc and zinc alloy parts are also commonly used.

As noted before, mechatronic products encompass a huge number of devices and systems, and the classification of all existing parts by the classification criteria given, is a labour intensive and long process. Therefore, the classified 29 parts shown here do not make by any means an exhaustive list. There are also the space limitation constraints for the paper to be considered.

The given classification is just a beginning and gives a base that one can build upon. That is why the classification scheme is open, and easy to expand.
The proposed classification can be used as a tool in aiding the search for: mechatronic products, parts that build mechatronic products, permanent-mold processes used in manufacturing parts for mechatronic products, and commonly used materials for these parts.

Figure 2. User interface group

Figure 3. Control system group

Figure 4. Optical system group
Figure 5. Actuators group

Figure 6. Mechanical system group
6. Conclusion

From the research laid out in the paper the following important results are obtained:

- A definition of mechatronic product is proposed;
- An open classification scheme for parts used in mechatronic products and produced by gravity die casting and die casting is developed;
- Twenty-nine parts conforming to the classification scheme criteria are classified, showing how the proposed classification is built, and how it can be used for classification of parts;
- The most of the classified parts are used as housings;
- Out of the classified parts, the most commonly used materials are aluminium/aluminium alloys, and zinc/zinc alloys;
- Examples are given of mechatronic products in which the classified parts are used.

The proposed definition for mechatronic product is based on definitions from literature for mechatronic systems and it helps clarify the relation between a mechatronic product and a mechatronic system.

The developed classification can be used as a research aid tool, when information is sought regarding parts, processes, and materials used for manufacturing of mechatronic product parts.

The classification uses an open scheme which allows for expansion, and thus further development of the classification is related to adding more classified parts to it and/or adding more classification groups. Additionally, as the presented research is a part of a larger scope research, the classification will be used in the development of design and optimization methods for two automated robotic systems servicing a die casting and a low-pressure casting machine.

Acknowledgments

This work was supported by the European Regional Development Fund within the Operational Programme “Science and Education for Smart Growth 2014 - 2020” under the Project CoE “National center of mechatronics and clean technologies” BG05M2OP001-1.001-0008

References

[1] Mori T 1969 "Mechatronics, Yasakawa Internal Trademark Application Memo 21.131.01"
[2] Harashima F, Tomizuka M and Fukuda T 1996 IEEE/ASME Transactions on Mechatronics 1 1-
4 ISSN 1941-014X

[3] Auslander D M 1996 *IEEE/ASME Transactions on Mechatronics* 1 5-9 ISSN 1941-014X

[4] Bishop R 2002 *The Mechatronics Handbook - 2 Volume Set* Mechatronics Handbook 2e (CRC Press) ISBN 9781420042450

[5] Onwubolu G 2005 *Mechatronics Principles and Applications* (Butterworth-Heinemann) ISBN 9780750663793

[6] Shetty D and Kolk R A 2010 *Mechatronic System Design* (Cengage Learning) ISBN 143906198X

[7] Jouaneh M 2013 *Fundamentals of Mechatronics* (Cengage Learning) ISBN 9781111569013

[8] Karastoyanov D, Stoimenov N and Gyoshev S 2019 *IFAC-PapersOnLine* 52 539-542 ISSN 2405-8963 19th IFAC Conference on Technology, Culture and International Stability TECIS 2019

[9] Dichev D, Koev H, Diakov D, Panchev N, Miteva R and Nikolova H 2017 *Proceedings Elmar – International Symposium Electronics in Marine* 2017-September 219-224

[10] Bolton W 2015 *Mechatronics: Electrical Control Systems in Mechanical and Electrical Engineering* (Pearson) ISBN 9781292076683

[11] Isermann R 2005 *Mechatronic Systems: Fundamentals* (Springer-Verlag London) ISBN 9781852339302

[12] Kyura N and Oho H 1996 *IEEE/ASME Transactions on Mechatronics* 1 10-15 ISSN 1941-014X

[13] Isermann R 2008 *Control Engineering Practice* 16 14-29 ISSN 0967-0661 URL http://www.sciencedirect.com/science/article/pii/S0967066107000603

[14] Zambare A, Lande P, Walke P, Soudagar S and Gawali R 2016 *IJRASET* 4 49-54 ISSN 2321-9653

[15] Alciatore G D and Histand M B 2012 *Introduction to Mechatronics and Measurement Systems* (McGraw-Hill) ISBN 9780073380230

[16] Billingsley J 2006 *Essentials of Mechatronics* (John Wiley and Sons) ISBN 9780471723417

[17] Savov I, Todorov G, Sofronov Y and Kamberov K 2019 *IUTAM Bookseries* 33 149-163

[18] Groover M P 2010 *Fundamentals of Modern Manufacturing: Materials, Processes, and Systems* (John Wiley and Sons) ISBN 9780470467008

[19] Frolov K V et al. 2005 *Machines and Equipment used in the Forging, Stamping, and Casting Manufacturing* (Russian) (Mechanical Engineering. Encyclopedia in 40 volumes vol IV-4) (Mashinostroenie) ISBN 521702416X

[20] Singh R 2006 *Introduction to Basic Manufacturing Processes and Workshop Technology* (New Age International) ISBN 9788122423167

[21] Gupta H, Gupta R and Mittal A 2009 *Manufacturing Processes* (New Age International) ISBN 9788122428445

[22] Tonchev N 2005 Technology of metal materials (bulgarian) (*Preprint* www.castingarea.com)

[23] Cho H et al. 2003 *Opto-mechatronic systems handbook: techniques and applications* (CRC Press) ISBN 0849311624