MECHATRONICS AND CONCURRENT ENGINEERING

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Rezumat. *Acest articol își propune să exploreze legăturile dintre MECATRONICĂ (M) și INGINERIE CONCURENTĂ (IC), cea mai semnificativă tendință contemporană în dezvoltarea noii producții industriale. M este o IC văzută ca proiectare automată. Autorul definește ce sunt M și IC, subliniază legăturile existente între aceste două concepte și prezintă căile de integrare în M și IC. Concluzia principală a acestui articol este că ambele concepte au fost dezvoltate în anii 1980, când Informația și Tehnologiile Informației și Comunicării (TIC) erau în plină dezvoltare. Influența TIC este de netăgăduit. Dar există o diferență. Dacă M nu poate fi implementată în absența TIC, IC a fost mult influențată de TIC, dar tehnologiile de calcul și de comunicare nu erau strict necesare implementării IC.*

Abstract. *This paper aims to explore the connections between MECHATRONICS (M) and CONCURRENT ENGINEERING (CE), the most significant contemporary trends in new industrial product development. M is a CE view on machine design. The author defines what M and CE are, emphasizing the existing connections between these two concepts and presents the ways of integration in M and CE. The main conclusion of this paper is that both these concepts were developed in the 1980's, when Information and Communication Technologies (ICT) were in full swing. The influence of ICT is undoubted. But there is a difference. If M could not be implemented in the absence of ICT, CE was well-influenced by ICT, but communication and computational technologies were not strictly necessary for the implementation of CE.*

Keywords: Mechatronics; Concurrent engineering; Electromechanical engineering; Information and Communication Technologies

1. Introduction

In the real world, mechanical engineering and electrical engineering are inextricably entwined. Every electrical device is a mechanical device designed for its electrical properties and manufactured in a factory of mechanical machines. Many mechanical devices are partly electrical and most of them are made by machines that are electrically powered and electrically controlled.

Multi-disciplinary systems are not new. They have been successfully designed and used for many years. One of the most common multi-disciplinary systems is the electromechanical system, which often uses a computer algorithm to modify the behaviour of a mechanical system.

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Electronics is used for transmitting the information from computer science to the mechanical disciplines, after having been properly adapted.

Electromechanical **(EM)** engineering is interdisciplinary and deals with devices and systems combining the electrical and mechanical phenomena. The art of (**EM)** has been developed for over a century, but only recently, less than 40 years ago, under the impact of Information and Communication Technologies **(ICT),** it received a new name: **Mechatronics.**

Concurrent engineering is the relatively recent term applied to the engineering design philosophy of cross-functional co-operation in order to create products that are better, cheaper and brought to the market more quickly.

Concurrent Engineering (**CE)** and Mechatronics **(M)** represent the most significant contemporary trends in new product development and the present paper aims to explore the connections between **(M)** and (**CE)**.

Lately, several well-established industrial paradigms are undergoing dramatic shifts:

<u>A first paradigm shift</u> has been taking place from traditional sequential engineering to what has been called concurrent engineering. From the very beginning of the design cycle, all the functional aspects of a product (a component, a machine or a machine system for our purposes) have to be simultaneously considered and confronted with the capabilities offered by the different engineering and economic considerations and their interactions.

<u>The second paradigm shift</u> in interest from this paper has to do with how the meta-product i.e., the production machinery, is evolving. In order to cope with customers' too fast changing tastes, present day products are increasingly personalized**:**

The lot sizes per product variant are shrinking and the number of product variants to be produced is exploding; the production infrastructure must be increasingly flexible**,** flexibility being the key issue in present-day product and Meta product design.

This problem may be solved by designing and building products and meta-products in terms of plug & play compatible modules.

The mechatronics framework can be a guide to optimize the design of the modules and to provide suitable interfaces at all levels**,** as well as between the modules or the machines and the outside world (task programming, man-machine interface).

Mechatronics is proposed by its advocates as the ultimate solution for a large array of problems associated with designing complex artefacts. Others find mechatronics an attractive wrapping of old concepts. In my opinion, both are probably right (Iancu St., 1994).

2. What are Mechatronics and Concurrent Engineering?

Although there are no well accepted definitions**,** most authorities would probably concur that: Mechatronics**,** synergistically and inventively combines hard and soft knowledge and technology in order to conceive a product and/or a technological process whose compounding elements have intelligently controlled movements or developments (Iancu St., 2000).

Mechatronics is a methodology used for the optimal design of electromechanical design and for the integration of the electronic control systems in mechanical engineering (Devdas Shetty, 1997).

The term "Mechatronics" was first introduced in Japan by a Yaskawa Electric engineer in 1969 and Trademark rights were granted for this term in **1972**[1]. The term **(M)** became soon too popular and its use became widespread. For this purpose, in 1982 Yaskawa Electric released all rights pertaining to this trademark. In the early 1970's, **(M)** was viewed as the combination between mechanics and electronics**,** meaning that, in the beginning, **(M)** was more of an **(EM)** engineering.

Mechanics is a much older art - several thousand years old, if we go to its beginnings. Therefore its achievements are taken for granted and it has made no recent breakthroughs comparable to those of electronics. Although Electronics is a younger art, it has superseded the older art of mechanics in computing, in most information handling, in sound reproduction, and in controlling mechanical actions. Electrical and mechanical things are both simple and complicated in different ways.

All electrical circuits (but not fields) can be fully represented by diagrams in a single plan. But most electrical physical embodiments lie in a small number of planes with fewer connections from plane to plane than within each plane. These embodiments include printed circuits, panel boards and the integrated circuits which are the most complex artefacts ever made by humankind. Somebody can consider an internal combustion engine trivially simple in comparison with such electrical embodiments.

Most mechanical devices are three-dimensional and need three/dimensional parts and features to work. The art of mechanical drafting is the art of representing three-dimensional subjects on two-dimensional paper. Little can it be learned about an electrical circuit just by looking at the physical hardware**;** it is mysterious unless studied. Mechanical devices are superficially obvious**;** it is their subtleties that require study. This superficial "obviousness" leads some to condescend to mechanical engineering as an inferior art. (Iancu St., 1999).

[1]Japan Trademark Registration, no. 946594, Jan. 1972.

A case in point is competition between electronics and mechanics and it is up to people to use both branches in the best way. The combination of the two arts in the **(EM)** engineering has resulted in the manufacturing of disk memories, servos and guidance systems; more electronic technology helps mechanisms produce non-electronic effects, such as music reproduction and mechanical positioning. Based on mechanical technology, usually electronically controlled, there are manufactured electronic components; these components as integrated circuits and several mechanic components are included in the electronic systems, for instance computers and antennas.

3. How did Mechatronics and Concurrent Engineering appear and evolve?

Mechatronics: In the 1970's **(M),** particularly, was concerned with servo technology and was rather simple but it was also the dawn of advanced control methods. In the 1980's information technology **(IT)** started to be used in the industrial production and microprocessors enhanced its capacities and subsequently they were introduced into more sophisticated mechatronics products to improve their performance. Most mechanical systems were utilizing data base-driven systems and intelligent control was viewed as an advanced control tool, which looked more intelligent than expected in an average performance. Systematic design methods were sought for **(M)** and so the aspect of modelling and system integration was becoming more important. Optics emerged with **(M)** so that a new optomechatronics field was born.

Starting with the 1990's, the field of mechatronics introduced communication technology that stood alone among conventional mechatronics products which were connected by a communication network. And so, the machine could be controlled remotely, like the tele-operation in robotic systems. Computer controlled networking mechatronics is getting more and more popular, being often closely related to virtual reality and multimedia technologies.

Concurrent engineering integrates the new product development process to allow participants making upstream decisions to consider downstream and external requirements. Product design exists as long as mass production exists. Early on, there arose a division between intellectual labour (the designer was responsible for producing the design) and manufacturer labour (the worker was responsible for making the physical product).

All products should incorporate constraints imposed by the manufacturing process. The failure to account for these concerns is often due to a functional barrier within an organization between design and manufacturing**.** Another important functional barrier is the separation between the engineering designer and the customer**.** The designer has to become more responsive to customer desires and thereby to create a more successful product. Lead time has proved to be a significant facet of modern competition. By reducing the development lead time, a firm is able to respond more rapidly to market trends or to incorporate new technologies. A shortened lead time creates a market advantage for those firms that are able to rapidly produce products. All these ideas, which are fundamental to concurrent engineering, have been discussed in the literature for many years before the emergence of the **(CE)** movement. **(CE)** is a term that has been applying since the 1980's to the product development process where, typically:

- A product design and its manufacturing process are developed simultaneously;
- Cross-functional groups are used to accomplish integration;
- The voice of the customer is included in the product development process;
- The lead time, between product conception and market place, is used as a source of competitive advantage.

(CE) integrates the new product development process to allow participants making upstream decisions to consider downstream and external requirements.

The first paper in the literature on the management of the mechanical design process that I know of is from 1904. It focused not only on the relationship between the design department and the manufacturing department but also on the other functions, considered to be essential functions of engineering design. "Far too little attention has been given to the relations between the drafting department and the shop, among shop departments and among individuals, from the highest to the lowest, as a factor in the economic shop management". (L.D. Burlingame, 1904). The papers published later on[1] (W. Rauten Strauch, 1941) pointed out that some of the ideas had been used in pre-war projects by some companies and the ways in which **(CE)** ideas were applied during the World War II**. (**M.C. Ziemke, 1993) They also claimed that once the war was over the application of **(CE)** ideas became significantly less prevalent until rediscovered during the late 1970's – early 1980's. I consider that the ideas of (**CE)** are continuously traceable from the beginning of the 20th century till now**.** My belief is that these ideas have existed all along and have always been applied by companies that were using a sophisticated approach to product development.

It is possible to offer a number of conjectures as to why **(CE)** did not become the dominant product development strategy earlier than 1980's (Special Issue on Concurrent Engineering, 1996)

Conjecture One: New manufacturing processes make cooperation between manufacturing process development and product development more necessary than under previous manufacturing technology.

[1]*** Principles of Interchangeable Manufacturing, New York Industrial, 1921.

Conjecture Two: Current communication and other enabling computation technologies have lowered the costs of cross-functional cooperation, thereby encouraging such behaviour.

Cross-functional groups are used to accomplish integration, the customer requirements being considered in the product development, and the total duration time from product conception to market launch is used as a source of competitive advantage.

The new **(ICT)** enable the rapid exchange of information and the application of a range of analytical frameworks that are necessary in cross/functional design work. At the same time, it's a reality that a number of firms that applied **(CE)** before have had the satisfaction of using modern technologies.

Conjecture Three: A functionally separated organization makes it difficult to implement **(CE)** mechanisms. Changing to **(CE)** involves changing the organizational culture, which is an inherently difficult process. Changes that reduce the power base of existing functional managers are likely to be resisted by those managers.

There are several difficulties that might have caused hierarchical functional organizations to discourage the types of cross-functional cooperation associated with **(CE).** These may have led to the lack of adoption, perhaps by default, of a **(CE)** approach. In an organization that encourages cross-functional work the lines of control may become blurred.

More communications and coordination work becomes necessary. This has the potential of distracting employees' attention from their fundamental (technical) work.

Conjecture Four: Engineers have been under trained in product development, and therefore they did not learn about best practice, so best practice did not spread even though it had been developed. The educational and training systems of this century may have foiled the earlier development and spread of **(CE)** ideas in many ways. If during the first half of the 20th century, engineering education focused on engineering practice**,** which should have focused students' attitudes on product development issues, in the second half of the 20th century, it strongly emphasized engineering science rather than applied fields such as product development and manufacturing.

Conjecture Five: Competition increasingly focuses on lead time, which leads to increased benefits for **(CE)** organizations. There may have been changes in the strategic environment that have led to an increased need for and acceptance of **(CE)** ideas in recent years. But, there is little reason to believe that present times are more competitive than the previous eras.

4. Connections between Mechatronics and Concurrent Engineering

The difference between a mechatronic system and a multi-disciplinary system does not lie in the constituents, but rather in the order in which they are designed. Historically, multi-disciplinary system design has employed a sequential design-by-discipline approach. For example, the design of an electromechanical system is often accomplished in three steps beginning with the mechanical design. When the mechanical design is complete, the power and microelectronics are designed followed by the control algorithm design and its implementation. Sequential design generates new constraints on the point-to-point design. These constraints should primarily be created and then applied in the new discipline. This represents the major drawback of the design-by-discipline approach.

We have to think that, in the past, machine and product design had, almost exclusively, been the preoccupation of mechanical engineers (Fig. 1.). Solutions to controlling and programming problems were added by control and software engineers, after the machine had been already designed and built by mechanical engineers.

This sequential-engineering approach invariably resulted in sub-optimal designs. Under the impact of the influence of **(ICT)**, machine design has been profoundly influenced by the evolution of microelectronics, control engineering and computer science**.**

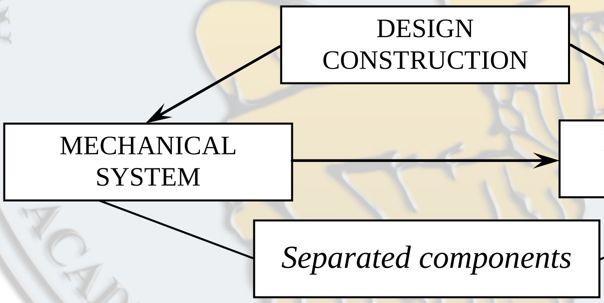


Fig. 1.

The hype created around these new mechatronic work procedures has provoked an overshoot in the opposite direction. Mechanics was no longer important**,** and every problem – also inadequate mechanics, one thought - could be solved by smart control algorithms and software. In my opinion, even today, one cannot turn poor mechanics into a good machine, irrespective of the power of control engineering and **(ICT)**.

The branch of engineering called systems engineering uses a concurrent approach for preliminary design. In a way, mechatronics is an extension of the systems engineering approach, but it is supplemented with information systems to guide the design and it is applied at all stages of design, not just the preliminary design step, making it more comprehensive. There is a synergy in the integration of mechanical, electrical, and computer systems with information systems for the design and manufacture of products and processes. The synergy is generated by the right combination of parameters; that is, the final product can be better than just the sum of its parts. Mechatronic products exhibit performance characteristics that were previously difficult to achieve without the synergistic combination. The key elements of the mechatronics approach are presented in Fig. 2.

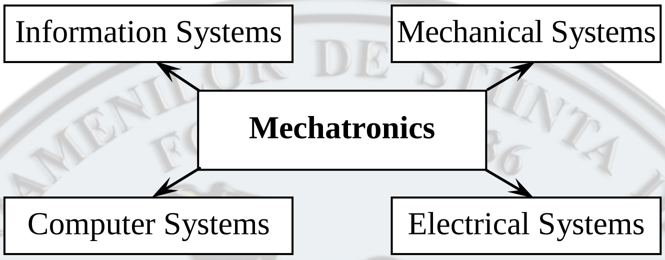


Fig. 2.

The mechatronic design methodology is based on a concurrent, instead of sequential, approach to discipline design, resulting in products with more synergy. (Fig.3.)

A synergetic cross-fertilisation between the different engineering disciplines involved (mechanical engineering; control engineering; computer science, microelectronics) is needed as a solid basis for designing high performance machines. This is exactly what mechatronics is aiming at.

The mechatronic design process starts with a customer's or client's announced need and it can be considered to be composed of the following stages (Bolton W, 1995):

- The first stage in developing a design process is to find out the true nature of the problem, i.e. analysing it.
- After the analysis, a specification of the requirements can be prepared. It will state the problem, any constraints placed on the solutions and the criteria which may be used to judge the quality of the design.
- Generation of possible solutions and selection of the best solution.
- Drawing a detailed design, and, if necessary, making a prototype in order to determine the optimum details of a design.
- The selected design is then transformed into working drawings, circuit diagrams, etc. so that the mechatronic system can be produced.

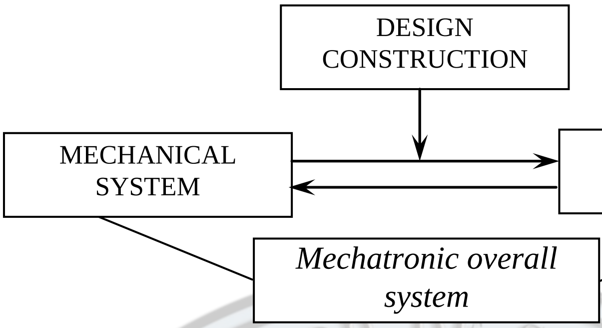


Fig. 3.

Mechatronics is a concurrent engineering view on machine design.

5. Ways of integration in Mechatronics and Concurrent Engineering

The integration within a mechatronic system can be performed in two ways: through the integration of components and through the integration by information processing (Isermann Rolf , 1996):

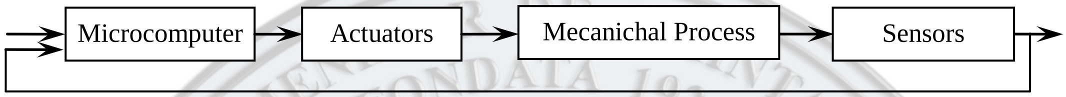
- The integration of components (hardware integration) results from designing the mechatronic system as an overall system and imbedding the sensors, actuators and microcomputers into the mechanical process (Fig.4.b.). This spatial integration may be limited to the process and sensor or to the process and actuator. The microcomputer can be integrated with the actuator, the process or sensor or it can be arranged in several places.
- The integration by information processing (software integration) is mostly based on advanced functions. (Fig.4.c.) shows that besides a basic feedback, an additional influence may take place through process knowledge and corresponding information processing. This means a processing of the signals available at higher levels and includes the solutions of certain tasks such as supervision with fault diagnosis, optimization, and general process management. Software integration supposes that, besides a basic feedback, an additional influence may take place through process knowledge and corresponding information processing.

The relevant solutions result in real-time algorithms, which must be adapted to the mechanical process properties and which can be expressed, for instance, by mathematical models in the form of static characteristics differential equation, etc.

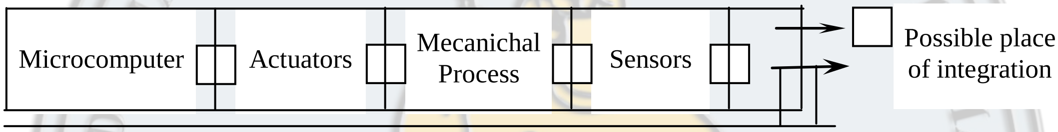
The mechanical parts are governed in various ways through higher level information processing with intelligent properties, possibly including learning, thus forming integration with process/adapted software

In concurrent engineering, several organisational methods have been proposed to accomplish the integration in the following organisational ways (Iancu St., 2007):

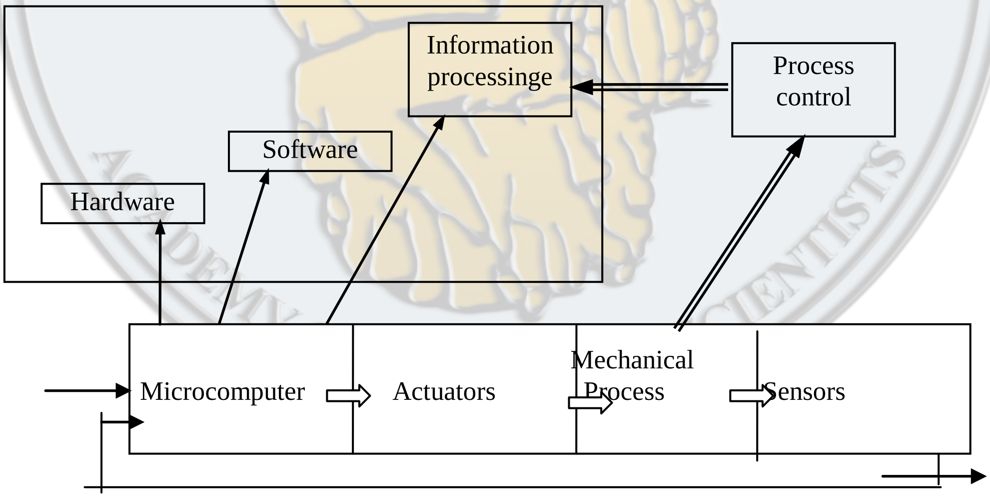
- Requiring approval of other departments;
- Establishing a liaison department that is responsible for co-ordinating the activities of other departments;
- Joining all interested parties into one cross-functional team;
- Using job rotation to ensure that functional cross-pollination occurs



a. Generation scheme of a (classical) mechanical-electronic system;



b. Integration of components (hardware integration);



c. Integration of information processing (software integration) is mostly based on advanced control functions.

Fig. 4.

Conclusions

a. Both the (**M)** and the **(CE)** were developed in 1980's, when **(ICT)** were rapidly developing. The influence of **(ICT)** is undoubted.

But there is a difference: If (**M) c**ould not be implemented in the absence of **(ICT), (CE)** was well-influenced by (**ICT)**, which included CAD/CAM[1] systems, integrated database, electronic communication tools etc.

But communication and computational technologies were not strictly necessary for the implementation of (**CE).** If the manufacturing plant and the designers were near to each other, and suppliers were also within a short distance, then the telephone and other communications technologies available earlier could have been sufficient to co-ordinate plans**,** have cross-functional groups, establish and implement DFM/DFA[2] rules, and accomplish much of the structure of (**CE)** practice.

In my opinion**,** the new technologies are neither necessary nor sufficient for cross-functional co-operation, but do serve to lower barriers against the adoption of such co-operation and have fostered the types of communication and analysis that occur in the product development process.

b. The ways of integration in (**M)** and (**CE)** are different. With respect to (**M)** these ways are technical (hard or soft) while with respect to (**CE),** they are organisational;

c. (**M)** is emerging as a (**CE)** thinking framework in the process of designing complex machines. It has a bright future and it will grow steadily into the 21st century.

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