Standard Industrial Guideline for Mechatronic Product Design

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Modern products are comprehensive mechanical systems with fully integrated electronics and information technology (IT). Such products, which are considered mechatronic products, demand another approach for efficient development as pure mechanical, electronic/electric and IT products. Industrial and scientific evolutions of mechatronic products have led to substantial experience and as a natural consequence industrial guideline have emerged for the product design of mechatronic products. Widely accepted industrial guidelines proposed crucial steps and measures to finalize efficient and cost-efficient mechatronic products. Aside from the presentation of and comments on such industrial guidelines, some examples for practical application are also given – washing machines.

Keywords: *mechatronics, product design, industrial guideline, washing machine, VDI 2206.*

1. INTRODUCTION

There are many definitions of mechatronics as a scientific discipline, but one of the most accurate definitions could be – *the synergistic integration of mechanical engineering with electronics and intelligent computer control in the design and manufacturing of industrial products and processes* [1].

Regardless of the definition, mechatronics integrates the following disciplines [2]:

- **mechanical systems** – mechanical elements, machines, precision mechanics;
- **electronic systems** – microelectronics, power electronics, sensor and actuator technology and
- **information technology** – systems theory, automation, software engineering, artificial intelligence.

A more detailed description of such mechatronic, multidisciplinary product design is presented in the diagrams below, Fig. 1.

The word "mechatronics" was born in the middle of 1970s. Since the word "mechatronics" can be pronounced easily with good sound, it came to be used widely in magazines, papers and other publications. In February of 1976, a magazine whose name is "Mechatronics" was published by an institute that surveys the condition of Japanese industry. Mechatronics of 1970s meant the design concept for making, machines of which mechanisms are simplified and of which ability is raised by using the electronic circuits. Mechatronic design decreases the weight and cost of products, increases their reliability and raises their ability. Therefore, this design concept spread widely and rapidly [5].

The field in the 60s was dominated by mechanical systems with increasingly automatic control and some digital and process computers emerged. The following decades saw accelerated application with miniaturization and integration of the process and micro computers [2,6].

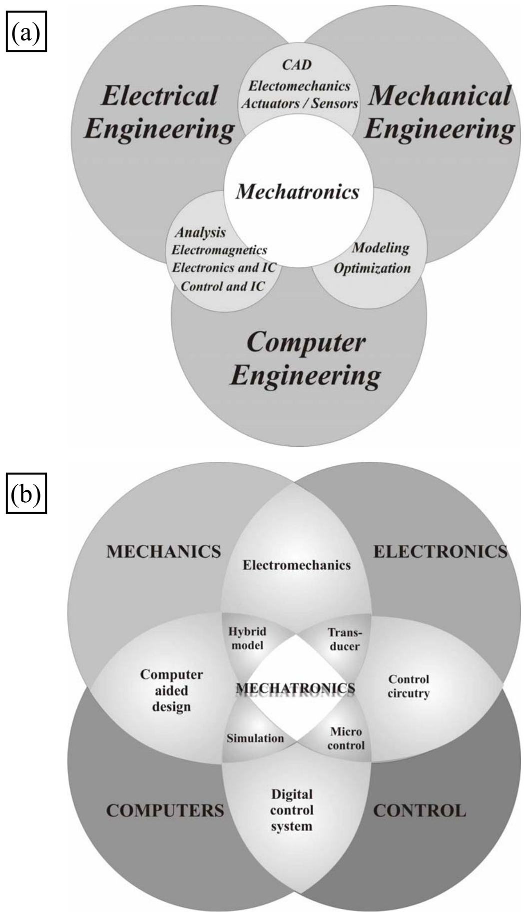

Figure 1. Mechatronics: (a) general and (b) detail definition of multidisciplinary product design [3,4]

The application domain of mechatronics was enlarged with the advances of a technological basis for IT and decision making, which led to modern smart products. But even the integration of different fundamental domains caused the field of mechatronics systems to differentiate into the conventional

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mechatronic and microelectromechanical-micro-mechatronic systems – MEMS (deals with classical mechanics and electromechanics) and nano-electromechanical-nanomechatronic systems – NEMS (deals with quantum theory and nanoelec-ctromechanics) [3].

2. MECHATRONICS AND PRODUCT DEVELOPMENT

2.1 Mechatronic – basic approach

Regardless of the type of mechatronic system, there is a need to understand the fundamental working principles of mechatronic systems before approaching the design procedure of a mechatronic product. The general scheme (Fig. 2) is an example of a mechanical system which is a power-producing or power-generating machine.

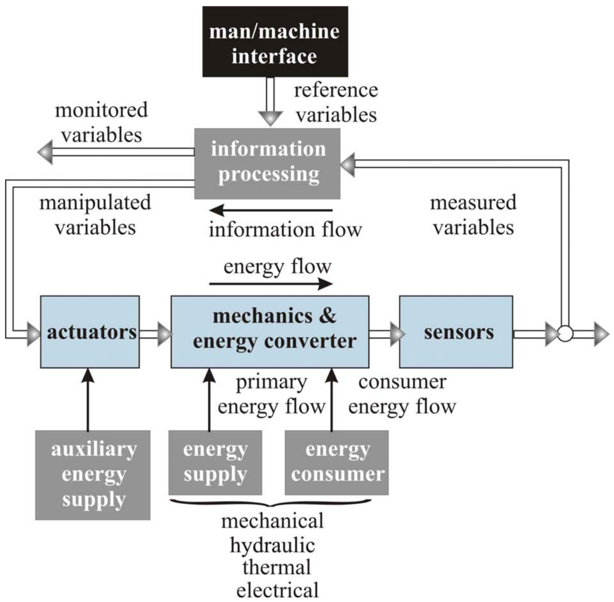

Figure 2. Mechatronics – working principle of mechatronic products auxiliary [2]

A description of the working principle could be correlated with the washing machine working principle. The basis of many mechatronic systems is the mechanical part, which converts or transmits the mechanical process (e.g. the drum of washing machine for laundry washing). Information on the state of the mechanical process has to be obtained by measuring generalized flows (e.g. speed, mass flow) or electrical current/potentials (e.g temperature of water). Together with the reference variables, the measured variables are the inputs for an information flow, which the digital electronics convert into manipulated variables for the actuators (e.g. hydrostat) or for monitored variables to display. The addition and integration of feedback information flow to a feed forward energy flow in the mechanical system (e.g. motor drive, drainage pump) is one of the characteristics of many mechatronic systems. When auxiliary energy is required to change the fixed properties of formerly passive mechanical systems by feedforward or feedback control, these systems are sometimes also called active mechanical systems [2].

Interactions of man and (washing) machine have been profoundly enhanced by the development of electronics and IT technologies (e.g. SMS, voice control) and interactions have become more versatile and user-friendly. The potential benefits of mechatronics come from the innovation potential of the technologies and the functional and spatial integration of the technologies.

Many of these potentials for market success could be divided into technical and commercial parts, which are coupled and presented in the graphs below (Fig. 3).

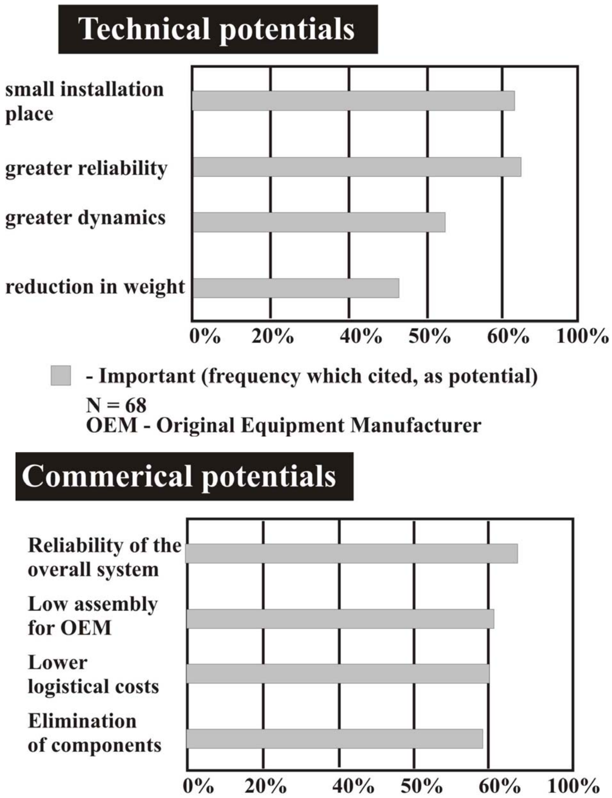

Figure 3. Mechatronics – technical and commercial potential of mechatronic products [7]

Despite many obvious advantages of mechatronics, the product designer also has to face some drawbacks. The main disadvantages are the higher costs of spare parts in the case of repair, a lack of experience with the use of new production and testing technologies and also the use of pioneering technologies in the construction and connection technologies [7,8].

Approaching the procedure of mechatronic product design, we have guidelines available for self-standing and independent mechanical, electronic and software products [9-14]. The main steps for product design by each mechatronic domain are presented in the graph below (Fig. 4).

There is still the open question of how to efficiently approach mechatronic product design and implement the advanced product procedure in reality.

2.2 Some aspects of industrial guideline for mechatronic product design

The proposed industrial solution for the development of mechatronic products is presented as V model with the industrial guideline – VDI 2206, Fig. 5.

The primary purpose is to overcome classical sequential product design procedures and domain

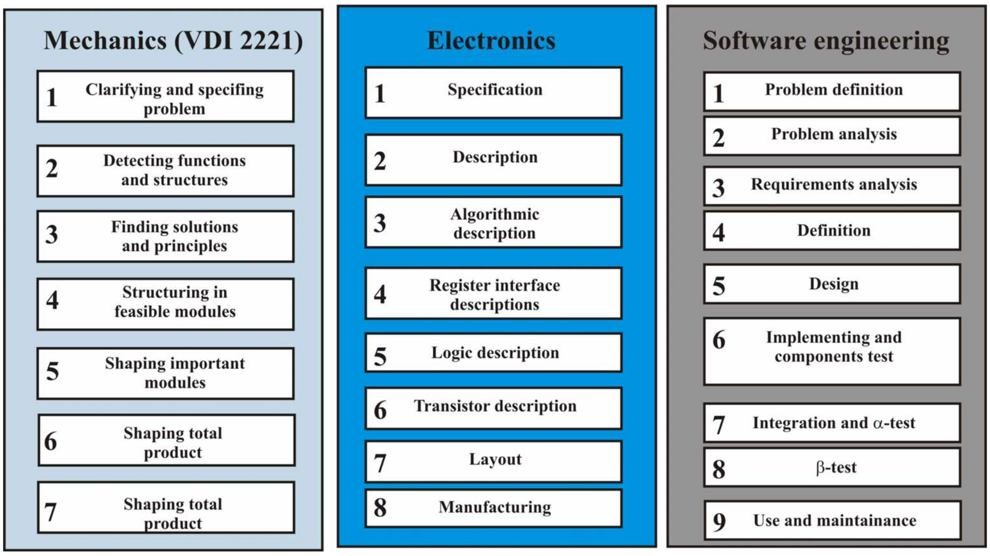

Figure 4. Product development guideline for mechanical, electronic and IT product [15]

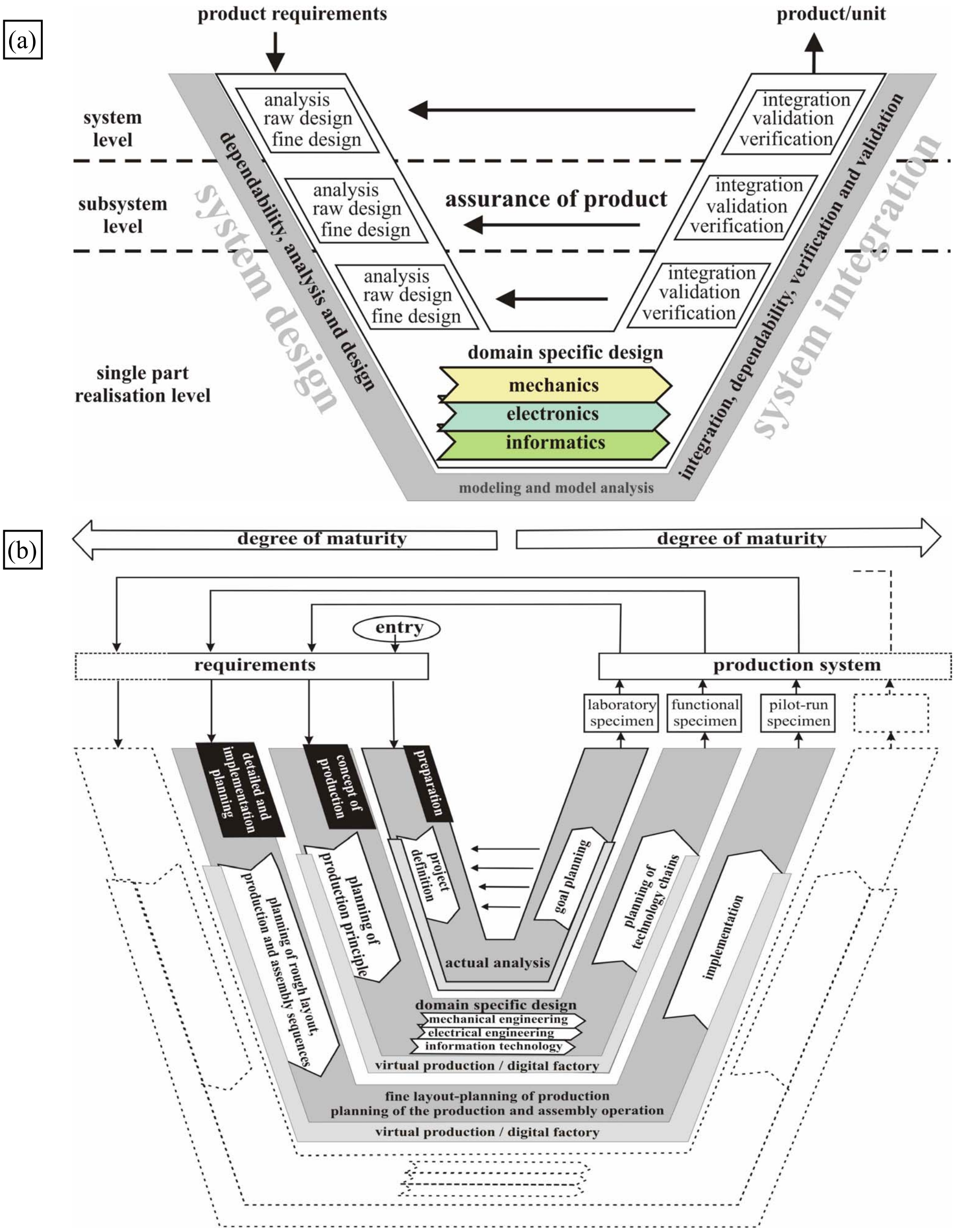

Figure 5. Proposed industrial guideline for mechatronic product design: (a) basic principle and (b) mechatronic product design and degree of product maturity [7,16]

isolated product development (s.c. over-the-wall-syndrome) with substantial cost and time reduction. The goal of this new guideline is not to replace other existing, well-established domain-specific methods, but to integrate them into a methodology for complex mechanical products in a holistic way. This guideline promotes concurrent engineering and actually consists of three main parts – micro cycle, macro cycle and process module [15].

After a general problem solving procedure on the micro level and the determination of all necessary requirements, there is need to enter s.c. V model. The proposed V model has been adopted from software engineering and adapted for mechatronics requirements, which are distinct from case to case. The aim is to establish a cross-domain solution concept which describes the main physical and logical operating characteristics of the future product, Fig. 5a.

Naturally, the overall function of the system is broken down into subsystems or even components to which suitable operating principles or solution principles are assigned. When using this model in practice, sometimes the time sequence of the sub-steps deviates from the logical sequence. This means that we have to bring critical subsystems almost up to readiness for mass production before commencing development of the complex overall system [7].

Domain-specific design, system integration and properties assurance has to be accompanied with modeling and model analysis. This means forming and investigating the system properties with the aid of models and computer-aided tools, Fig. 5a.

A complex mechatronic product is generally not produced within one-macro cycle, but within many macro cycles as a continuous macro cycle -Figure 5b. The term “end product” means not only the finished product, but increasing concreteness of the future product in terms of product maturity e.g. laboratory specimen, functional specimen and pilot-run product. These products represent a certain degree of product maturity, which need to be interacted and adjusted among themselves.

In the end, part of process module is made out of system design, modeling and model analysis, domain-specific design, system integration and assurance of properties. The ultimate goal is making the process more concrete and forming solution variants into the principle. Since the ideas worked out for solution are usually not concrete enough to stipulate the final cross-domain concept, instead other issues have to be taken into account – e.g. fault susceptibility, weight, service life. The final assessment of end-solution variants are always subjected to technical and commercial criteria.

A practical example for the development of mechatronic products is presented for the washing machine and domain-specific solution – dynamics of multi-body systems and stability. The primary function of washing machine is to produce a satisfying washing effect (clean clothes) in the shortest time with the minimum consumption of water, energy and detergent. At the same time, this system has to perform with low levels of vibration and noise, which have almost the same relevance for the customer as the washing effect. All relevant product data for customer are anyway quoted on the energy label, which is accepted world-wide as a product description in the white goods industry [17].

2.3 Practical example – washing machine

Based on well-defined product requirements, there is a need to design the model of mechatronic products for further parametric analysis and optimization. A model of the mechatronic product is a substitute model of the real system, which is based on the mathematical procedure to describe behavior with a certain accuracy. Then the results of such model could be realistically transferred to reality. This approach is actually very common for the area of computational dynamics and related multibody system dynamic simulations [18-20].

The proposed procedure to form accurate and relevant models of mechatronic products is presented in the diagram below, Fig. 6.

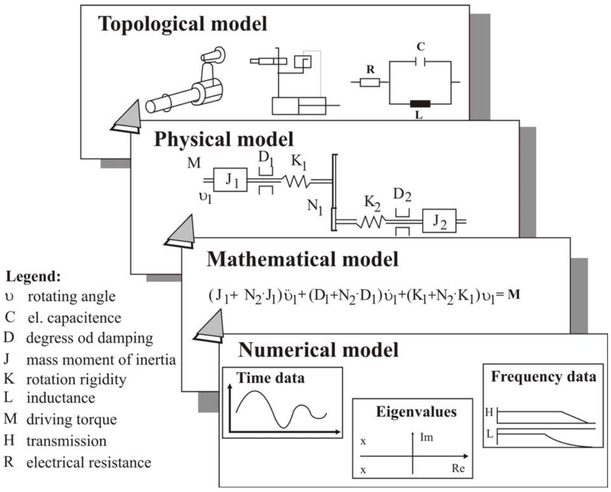

Figure 6. Mechatronic product – model abstraction levels in the modeling process [7]

The topological model describes and interlinks the function-performing elements, where the element represents three basic functions [7]:

- kinematic (e.g. number of kinematic joints, position of robot’s joints),
- dynamic (e.g. movement of masses due forces) and
- mechatronic function (e.g. control, monitoring).

Topology of mechanical elements could be presented in various ways (e.g. graphs, free-body diagrams, tree-structure) and essentially determines the kinematics of mechatronic systems.

Based on topology descriptions, a physical model is created and describes system properties in system-adapted variables – e.g. masses and length for mechanical systems [7]. Regarding the mathematical model with applied physical principles, parametric theoretical modeling results can be achieved through numerical or analytical methods.

Such mathematical models are often too complex to be solved in an analytical way and therefore numerical methods are applied (e.g. Runge-Kutta).

The natural follow up is to initially verify the set up theoretical model experimentally – with measurements on a real system (model and prototype). Otherwise it is also necessary to determine unknown parameters by adjustment with the real system. This approach is already known and well-accepted in the white goods industry, where it is performed with the numerical tools or with advanced CAE tools [21].

Similar to the multibody structure for the car's suspension modeling, it is possible to write down in a similar way the multibody structure of the washing machine and its suspension, Fig. 7.

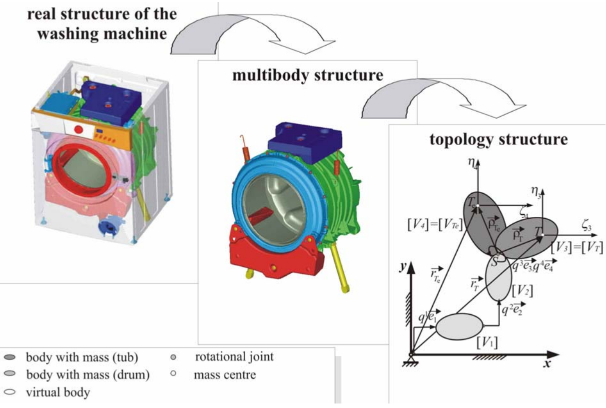

Figure 7. Mechatronic design approach and washing machine model as multibody system [22]

Multi-body dynamics is based on analytical mechanics and comprises a relatively new branch within mechanics, closely related to control design, computer methods and vibration theory [23].

Multibody dynamic analysis of washing machines could be treated either as rigid or flexible (elasto-plastic) multibody systems with contacts. Such model analysis has the purpose of enabling analysis for establishing the actual state or analysis of possible behavior.

This means that the merits and limits of such a multibody system (washing machine) is parametrically evaluated regarding the system's response (e.g. stability, frequency analysis). Parametric evaluation means the numeric simulation of the system for different components' properties (e.g. mass, geometry, friction) upon different stimuli in the form of energy input (e.g. drive motor characteristics).

In case of washing machines passive mechanical system could be converted into active mechanical systems with adaptive (magnetorhelogical) dampers, which could provide optimization of system stability and suspension with adaptive damping properties [24].

The results of this product development phase (mechanics) serve for other domain – optimizing the newly designed overall controlled system s.c. washing program (electronics and IT).

Very important goal is therefore creating a multi-body dynamic mechanical model to enable designer parametric solutions for different combinations of washing machines in order to accommodate varying functionality demands (e.g. less power and water consumption, lower noise).

Three vital phases in the design of dynamic systems must be considered: modeling, experimental validation and parameter optimization. Such techniques are already in use in the appliance industry and development time has been cut and reliability was increased with respect to the numerous constraining factors [25].

Practical approach to the analysis of mechatronic system is also conducted at Faculty of Mechanical Engineering, Department of Mechanics within Mechatronic laboratory, Fig. 8.

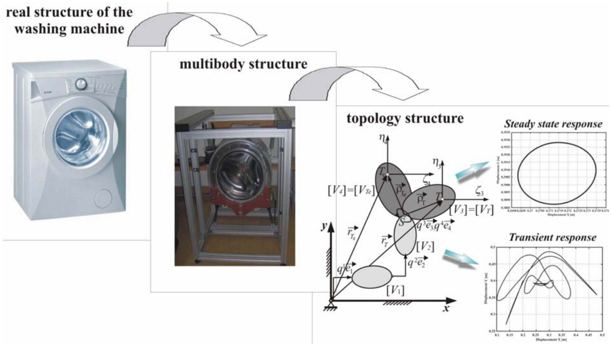

Figure 8. Analysis of mechatronic system – washing machine [26-28]

3. CONCLUSION

The advanced mechatronic product design approach enables the development of modern, technically and economically competitive products. With the science and technology evolution this approach becomes not only present in official standards and guidelines, but also more and more implemented in the daily industrial environment and education. Nowadays even normal white goods products such as washing machines can be treated as mechatronic products, because of the unavoidable integration of mechanical components with electronics and IT tools. Based on the clearly defined end product requirements and related functionality, it is necessary first to define mechanical parts with respect to the fundamental laws of mechanics. In other words, it is necessary to form such a mechanical/mathematical model of mechatronic systems, which can easily be parametrically analyzed and optimized. From the practical example of washing machines, this is made upon the mathematical model of multibody systems and related systems' stability as well as frequency response. Upon this parametric analysis of mechanic systems, there is an easier and more transparent way to integrate electronics (sensors, actuators) and related IT with control software program.

In other words, even simple products are not any more to be underestimated and, with the presence of integration electronics and IT, higher demands are set for product designers.

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СТАНДАРДНА ИНДУСТРИЈСКА УПУСТВА ЗА МЕХАТРОНИЧКО ПРОЈЕКТОВАЊЕ ПРОИЗВОДА

Василије Васић, Михаило Лазаревић

Данас, модерни производи представљају свеобухватне механичке системе са комплетном интегрисаном електроником и информационом технологијом (ИТ). Такви производи, који се сматрају мехатроничким производима, захтевају други приступ за ефикасан развој као чисто механички, електронски-електрични или ИТ производи. Индустријски и научни развој мехатроничких производа доводе до значајног искуства и као природна последица примене индустријских упутстава појављује се у пројектовању производа као што су мехатронички производи. Широко прихваћена индустријска упутства предлажу важне кораке и мере са циљем ефикасног финализирања и са ценом прихватљивих мехатроничких производа. На крају, поред презентације и коментара на представљена индустријска упутства, илустрована је практична примена на примеру веш машина.