Journal of Physics: Conference Series



# Machine Design Modern Techniques and Innovative Technologies

To cite this article: Hussein Younus Razzaq *et al* 2021 *J. Phys.: Conf. Ser.* **1897** 012072

# Machine Design Modern Techniques and Innovative Technologies

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**Abstract**

The manufacturing sector is facing a challenge in this 21st century to continue developing their business by applying a new and innovative production technology and system. This is to help the novel ways of manufacturing process to move forward, where, the Machine Design will feature and compile the newest product line with an inventive technology to keep modernized techniques at the top of mind for our OEMs, end-users, integrators, and the entire supply community. This research paper will explore how the simulation derived model of Mechatronic could manage the most complex scheme of the machinery profile with a systematic approach by understanding the concept with precise machine design actions, dynamic behavior, and effective interaction with the various components of the machine. Mainly, the Mechatronic engineers will unite the mechanics, and electronics principles and compute them to generate more economical, a simpler, and reliable system.

**Keywords:** Machine Design, Innovative Machining Technologies, Mechatronic Engineers, Smart Machines

## 1. Introduction

There is a mounting demand for more complex systems, development of new product lines. The productivity of manufacturing machines, which have created a steady growth of technological significance, necessitates the new ideas with an appropriate application in the production and development process. The system offers better possibilities of optimizing and evaluating the dynamic movement, action and performance of the entire automated arrangement in the preliminary stages of the machine design process. The smart machines can take decisions regarding the manufacturing processes in real-time with sufficient adaptive controls. All the machine design simulations are based on Mechatronic model, which processes and implements complex structures and systems with a dynamic behavior, better understanding, and effective interactions of all the components (Wang & Li, 2010). Mechatronics, is a multidisciplinary engineering branch that focuses on both mechanical and electrical engineering systems, including the combination of telecommunications, computer systems, robotics, electronic control arrangements, and product engineering (Abed, Abdullah, & Dikhil, 2019). Their effective interaction influences different machine components and achieves precision machine dynamics to produce better quality components. There are distinguishing features of Mechatronic system that can be demonstrated by an intensive integration of all the systems (Yun & Li, 2011). It optimizes the entire manufacturing process and production line, by an effective machine component to interact and influence the complete control system, while machine component design process continues with the coordination of the frame structure of each component and feed drive (Huang & Tang, 2012).

## 2. Investigating the problem of modern techniques in Machine Design

Disruptive innovations in optimization of machine design are motivated by the modern, emerging trends. The computer science progress and improvements in mathematics have helped more elaborate optimization scenarios to include ever more features of physics. Previously, machine design was corresponding to magnetic performance, while the modern techniques involve synchronized investigation of mechanical and electrical engineering, together with power electronics, rotor dynamics, and control features are included (Aiyu Gu, et al., 2019). The engineering and material science have brought new dimensions to the impact of manufacturing in the optimization process, when the unavoidable tolerances are considered. As a result, improvements in multifaceted settings are analyzed in numerous fields that take effect. The academic and practicing engineers are forced to include the recent innovative developments, while taking into account the future trends (Abed, Fadhil, & Al-Yaseen, 2020). It includes the entire optimization scenarios, geometry specifications, target setting to illustrate comprehensively (Bramerdorfer, et al., 2018).

## 3. Importance of Machine Design and its modern techniques

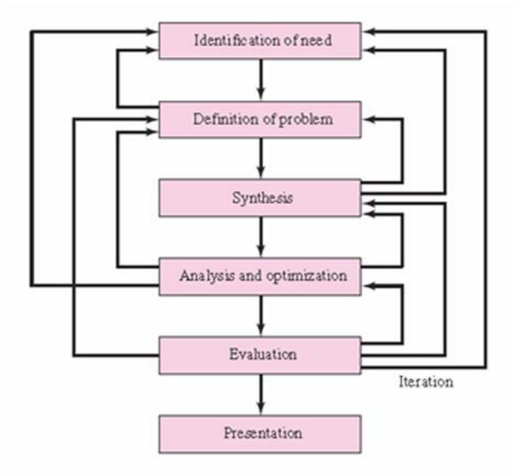


Figure 1: Machine design phases, an act of formalizing concepts and ideas into concrete information.

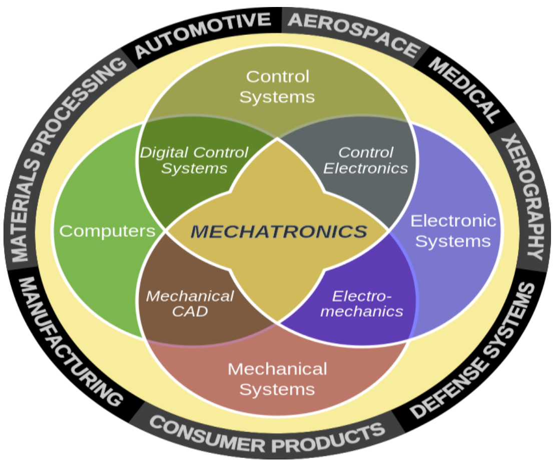


Figure 2: The Stages and Design Principles for Precision Mechanism of Mechatronics (Tang & Li, 2011; Bradley et al., 2015).

The design procedure initiates with identification of the need, defining the problems and their synthesis, analysis with optimization, Evaluation, of a decision to do something about the machine. After several iterations, the procedure ends with the presentation of the designed plans to satisfy the needs. Based on the nature and situation of the designing task, many stages can be repeated prior to finalization of the design. The entire design process can be expressed using Figure 1, showing design phases, processes and iterations (Sharma & Aggarwal, 2014).

## 4. Research Idea Transition towards Machine Design modern techniques

Research is the most powerful and essential tool that leads the man towards progress. No proper work can be done and no progress in work can be done without systematic work of research to perform the machine design, which the prerequisite of any machine production (Pandey & Pandey, 2015).

## 5. Aim and Objectives

- To understand the essentials of machine design in mechanical engineering to gain academic diligence by effective learning process;
- To investigate how the Mechatronic system functions in machine designs to foster and maintain better quality standards in industries and academia;
- To adopt responsible and ethical engineering practices and follow the procedure for lifelong learning;
- To encourage and develop sustainable machine design technologies for the advantage and assistance of global society;
- To explore how the State-of-the-art machine design and techniques can be formulated to facilitate quality machinery development and education.

## 6. The Concept and Purpose of Machine Design

In Mechanical Engineering, the Machine Design, is the very crucial branch of Engineering Design. For instance, the Car or vehicle gearbox helps in transmitting the motion, backward, neutral or forward movement and the power to the vehicle wheels. The gearbox (Figure 3) is normally bolted to the rear part of the engine, having the clutch between them (Tang & Li, 2011).

Figure 3: Precision gear box for power transmission (Alex Muir, 2020).

The gearbox is comprised of many gears, subjected to motion, and they have the load sustaining capacity of the vehicle. The gears help to move the vehicle at a desired speed, while taking desired loads. Hence, they are designed accordingly. Numerous calculations are performed while designing, considering loads, speeds and the materials of the gear of specific dimensions and thereafter, manufactured at the minimum cost to give optimum performance. In the same manner, all the parts and components including engine, of the vehicle are designed to meet the optimum functional requirements, with an innovative technology, at minimum possible cost. Such designing technology is known as mechanical design or machine design in mechanical engineering (Schreiber, et al., 2020).

Machine Designing is the dimensional drawing procedure by which the energy resources are converted into requisite mechanisms, to obtain a desired output yield from the machines in the required format as per the specified needs. Machine designing leads to creating the entirely new machine leading to innovations, improvement, up-gradation of the prevailing machine. For example, in case the present gearbox is very heavy or unable to sustain the requisite loads, the entire gearbox can be redesigned. However, in case the same gearbox carries the capability to lift higher loads, the up gradation with essential changes can be made in its design (Tang & Li, 2011).

## 7. The Machine Design Purpose

The Machine Design helps to understand the designing fundamentals of the most essential and commonly utilized components, elements, parts, and units of several machines. By assembling small machine components, they make a big machine. Therefore, the machine is the assembly of well designed individual components (Schreiber, et al., 2020).

The machine design knowledge helps the machine designers as below:

1. To select essential and proper components, and materials of the best suited shapes;
2. To perform calculations to obtain proper dimensions depending on the machine loads and load carrying capacity, as per the strength of the materials to be used;
3. Machine designs specify the process of manufacturing of the designed machine components of the entire machine (Tang & Li, 2011).

## 8. Problem Statement Fundamentals of Machine Design

While machine designing and designing its components, several things must be considered. However, the major concepts must stipulate the following fundamentals (Bhandari, 2007).

- Purpose or Goal: The design engineer must possess an intense and complete knowledge of every component of the machine, their application and processes;
- Mechanism: The design engineer must select a set of mechanisms, which can help to provide the machine with the desired function and applicable motion;
- Load Scrutiny and Analysis: When the design concept is finalized, it needs to be analyzed applying all the appropriate loads;
- Material Choice: Selecting the correct material has always been tricky and needs a special attention;
- The Design of every Element: A dynamic and static load analysis should be conducted on every member by evaluating the forces working and acting on every element;
- Modifications: Once the designing process of every element is completed, the modification of elements can be processed to optimize the design;
- Drawings: An elaborate drawing of every component must be developed and presented to process the design from its basic concept to manufacturing stage;
- Manufacturing Stage: Once the designing stage is successfully completed, the idea and concept developed on paper must be approved for further manufacturing. The designer should reliably evaluate the criteria applied to characterize the designs and the respective predicted performance (Benjamin Cheong, 2019).

## 9. Literature Review

### 9.1 Fundamentals of Machine Design in Mechanical Engineering

Mechanical engineering comprised of the design, development, construction, and operating processes of engines, power plants, and machines. They deal with most of the mechanisms that reposition and move . A common procedure of mechanical engineering categorization is by machine design or energy utilization, which involves the creation, distribution, and applications of heat in engines, boilers, refrigeration and air conditioning. Machine design relates to hardware components, that includes machinery using heat processes (Schreiber, et al., 2020). Presently, the new technology involves the fundamental concepts associating software skills in Autodesk software to operate while making machine designs. No product can be made or manufactured without designing it.

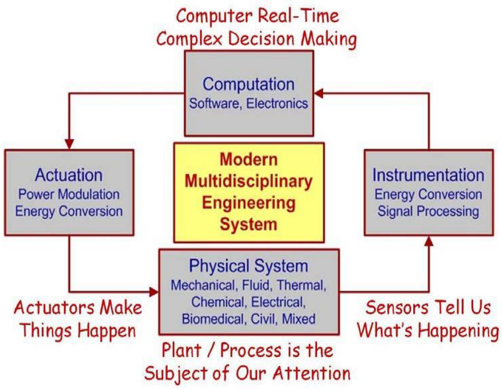

Figure 4: Fundamental Principles of Mechanical Design (Craig, 2010). Figure 5: Mechatronic system (Bradley et al., 2015).

- Precision machine designs are the most essential features of an industrial development.
- A precision machine and their meticulousness designs are the integrated processing methods, and they mostly rely on the each component attributes to locate the flaws and weaknesses of every other component;

- While the precise machine designs emphasize the structural and mechanical aspects of the machine components, their proper integration with control system, actuator, and the sensor will add value to optimize performance (Đorđe, Slobodan & Vukosavić, 2020).
- The machine designs help tremendously because they are the combination of creative visualization, thoughts, techniques and analysis;
- Good machine designs in mechanical engineering are done on the basis of excellent concepts together with proper, ingenious and creative designed details (Soemers, 2010).

### 9.2 Machine Design Principle Mechanisms and Functions

- Properly understand the concepts and associate images in the designs;
- By looking at the machine structure, the designer can observe the fundamental and basic principles of the machine in either action or they are missing in the design;
- By applying the intense knowledge concerning the fundamental principles, the designer can quickly create and apply strategies to apply in his design concepts to bring them into the greatest creativity and the biggest viability;
- By understanding the depth, fundamental cause and principles of machine designs, the designer can critically assess, measure and effectively evaluate the functions of every machine and its components (Schreiber, McCarthy & McGeough, 2020).

### 9.3 Design Essentials

The Organized method of design performance can be accredited to several essential factors.

A designers should reliably evaluate and maintain the essential criteria utilized to characterize the design features and their expected performance. The Machine Design should specify the main list of contents as the crucial decision making constituents (Lingaiah and Iyengar Commonly practiced surrogates, Data Handbook).

The Machine Design format is the comprehensive technical source for all the mechanical engineers. Machine design drawings provide all the technical essentials of the machinery to be produced along with operating instructions, advanced design of components for manufacturing. All the machinery manufacturing techniques are considered at the designing stage to obtain high-precision results (Schreiber, et al., 2020).

The designers always consider the designing process by taking into consideration the following points:

1. Selecting the structural material, which is insensitive to vibration and thermal displacement, while the deterioration process with age is nominal. For instance, the Granite stones are utilized for the precision measuring of surface plates as per the equipment image.
2. Making a very rigid structure for minimum deflection due to vibrations and self-weight.
3. The Structural design should allow effortless and precise adjustment at the time of machinery assembly; For instance, after the granite stone fine-polishing, there is a need to adjust the parallelism, perpendicularity, and surface flatness, using an ultra-precision machining process.

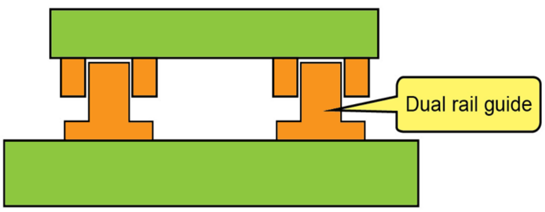


Figure 6: Dual rail guide for the compact drive table (Layosa, 2018).

4. Selecting the proper and inexpensive materials and components, which are compatible with the stated equipment design.

### 9.4 The prime Components of Decision Making

| Ingredient | Surrogate |
|---|---|
| Facts | Information and data |
| Knowledge | Advice received |
| Experience and Know-how | Ad Hoc experiments performed |
| Analysis and Scrutiny | Intuition and Insight |
| Judgment by finding | None |

Before the commencement of machine design, it is imperative to identify and recognize the two basic categories of the machines. (1) Fully automated; or (2) Semi Automated.

There are certain companies, which require completely manual machines, while many others may need fully automated or semi-automated. It is also very common for the industries and manufacturing plants to possess a combination of all three – fully automated, semi-automated and manual (Zienkiewicz, et al., 2013). For any semi-automated and fully automated machines, they are designed expecting certain human involvement and assistance, with three main elements:

a. Power to process and operate the system;
b. Instructions to stipulated program of specific instructions needed to direct the machining process;
c. Control System for actuating the instructions.

These major elements entirely depend on each other and are necessary to make the machinery and equipment to perform, be productive until the final process is reached. The element relationship is demonstrated in the below Figure 7.

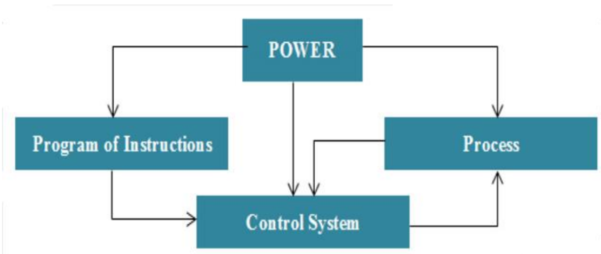


Figure 7: Automated Machine Basic Elements are Control System, Program of Instructions, Process and Power, and they provide the Final and Essential results (Jindal, 2010).

### 9.5 Machine Design Challenges

There are commercial challenges addressed for machine designers in the motion control industry. Due to commodity intensive marketplace, in the motion control, machine designers remain under pressure to design machines suitable for a large range of applications, like benchtop automation laboratory, material handling plant-floor, and construction vehicles for heavy-duty applications. Many OEM- original equipment manufacturers take the help of control component vendors, seeking additional functionality in a reduced space, with the fastest time of delivery. Also, in the case of prototypes of products, they expect more flexibility and control over price aspects and prefer seamless integration of all operations (Crawford, 2018).

The machine designers of the motion control industry are involved to perform and deliver new capabilities with added value. With the innovative techniques using Mechatronic system functions, they make a difference by properly responding to five main commercial challenges.

1. The small size product system designers intend to make products smaller so that the entire system becomes highly compact, easier to move, operate and store;
2. Prototyping Quickly. In this competitive environment, as the pressures mount, there is always a demand and quick delivery of all the personalized and specialized equipment;
3. Selection of holistic component, and integration. This is the most critical aspect of marketing when selecting the precise components and subsequently integrating them in the best possible manner for maximum accuracy, needs straightness, precision, maintaining the noise level, and various related performance characteristics. The motion control, optimization challenges are always complicated (Yun & Li, 2011);
4. Life cycle cost and Component cost. Even though the machine designers strive to obtain the supreme quality components for the equipment and systems, they do not prefer to make parts, which will outlive the entire machine. Therefore, they put a component like motion control, which is designed to last at least two decades into the system. It does not make a good engineering sense or business when the machine will turn obsolete within five years (Zienkiewicz, et al., 2013).

5. Bringing product value of the machine is the biggest commercial challenge all the OEM industries face and is the major share with the machinery component manufacturers.

They expect to produce what the market demands and the ways to differentiate in the process of delivering it. By connecting the product data in the cloud becomes the most promising opportunity to make a strategic difference (Crawford, 2018).

## 10. Method of Data analysis

### 10.1 Complex Structures Simulation with machine design

In Mechanical Engineering, Mechatronic system functions as a singular or in combination with other processes like electronics and computing in the designing stage and thereafter the technique is applied in the development of new product manufacturing. Several industries have delivered innovative ways with Mechatronic solutions to provide higher productivity in every section of their industry (Schreiber, et al., 2020).

Mechatronics methodology applies the optimal electromechanical design to develop products. Forty years ago, Mechatronics term was coined and the work was initiated in 1969. The engineer Tetsuro Mori used the combination of words “mechanical” and “electronics” to illustrate the electronically operated control system used by Yaskawa Electric and Electronic Corporation to build the equipment for the mechanical factory. Mechatronics provides the design philosophy, which integrates an engineering design approach as demonstrated in the below Figure 8. All these major factors and stages are involved in Mechatronics to cover the entire areas in the design process (Gurbuz, 2009). Simulating with interdisciplinary ideas, mechanisms and techniques, Mechatronics can provide an ideal situation to develop synergy, to provide catalytic effects to obtain new and better solutions to solve technically complicated issues. The Mechatronic device and system have crucial characteristic with built-in intelligence resulting in a precise combination of mechanical/electrical engineering with real-time programming system to integrate the design process. By using the precise combination of various parameters, the synergy can be developed; which means, the ultimate product created is better than the sum of all its parts. Therefore, the Mechatronic products display a special performance feature, which were previously not possible to achieve without the synergistic combination arrangement. Recently, certain Mechatronic applications were demonstrated on a helicopter, micro motion and robotic arm through various research articles (Tang & Li, 2011).

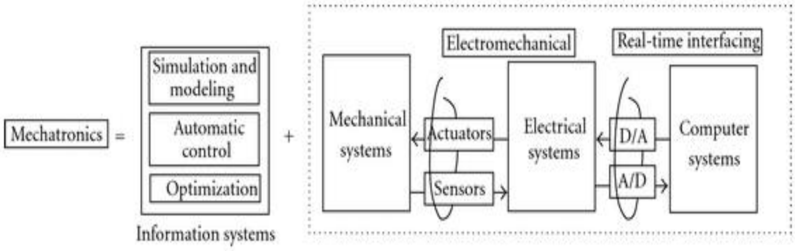


Figure 8: Mechatronics machine design process (Shetty, Manzione, & Ali, 2012).

A typical Mechatronic processed machine design (Cho & Kim, 2005) is shown below in Figure 9. Beginning with stage 5 to stage 9, the software tools are used to help the designer create the debugging (the process to identify and remove errors from the software and hardware systems of computers), in the mathematical procedure models. Certain tools, which are specifically useful can allow the machine designer to signify the system by generating a block diagram from an ordinary building blocks, like nonlinear switches, gain stages, integrating units and summing junctions. Certain instances of such tools are Simulink/Matlab, LabVIEW, SimPACK, Matrix-x, ACSL, VisSim and Hypersignal. The tools of graphical simulation can operate on generic platforms like desktop PC, which is compatible with Windows operating system. Using any one of these tools, the machine designer can generate a plant model so as to validate it against virtual measurements (as shown in the stage 5 of below figure 9). When the plant model gets validated, the designer will proceed with designing the control system to optimize it to obtain the exact response and that is achieved in the stages 6 and 7 (Shetty, Manzione, & Ali, 2012). In certain cases, entirely precise plant models are not possible to make. Hence, certain assumptions are made concerning the plant model, which is not possible to validate. In such cases, it becomes advantageous to examine and validate the control system in the prevailing plant environment, as indicated in stage 8. Sometimes, the process is mentioned as the simulation of hardware-in-the-loop, because of the certain actual hardware parts of mechanical and electrical specifications. They are used in the control loop system, which operate at the plant, to be controlled. The simulation of hardware-in-the-loop testing process provides the machine designer with encouragement and assurance that any kind of assumptions made previously regarding the plant model were accurate. In case of any incorrect assumptions, however, the machine designer can find the opportunity to improve, validate and optimize the design as shown in stage step 9, before finally committing for approval (Cho & Kim, 2005).

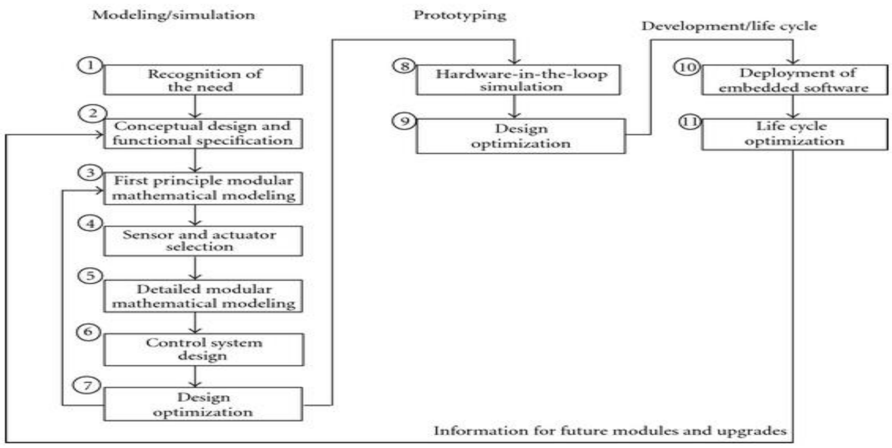


Figure 9: A Specific Mechatronic Machine Designing process (Cho & Kim, 2005).

**Using Mechatronics for Designing Smart Machine Components**

The Mechatronic technique is often used by the researchers for various applications, like smart machine tool type design (Erkorkmaz & Altintas, 1998). It elaborates the integrated CAx tool application for the conception of a virtual prototype to allow evaluation and further optimization of the motion dynamics of the entire machine tool in its early stages of the developmental course. Due to the machine design advance and drive technology, the latest numerically operated machine tools are mentioned extensively to a better extent as the main feature of complicated Mechatronic systems (Erkorkmaz & Altintas, 1998). The Mechatronic distinguishing features of the entire systems can be achieved by system functionality with an intensive electronic integration and information functions using a mechanical carrier (Reinhart & Weissenberger, 1999).

**10.2 Integrated Design Issues in Mechatronics**

The Mechatronic system integration can be developed by the combination of the software information processing system with hardware components. By integration of Hardware, it results in proper designing of the entire Mechatronic system, and bringing together the microcomputers, actuators, and sensors in the entire mechanical system. At the same time, the Software integration process is primarily depends on the advanced control functioning system (Gerd, Bramerdorfer, 2019).

## 11. Conclusion

The mounting demand for machine tool product and their increasing technological complexity bring challenges for improved and innovative methods in the product development procedures. The research study examined the integrated tool application to set up an effective prototype at the initial stages of the product development process. The Mechatronic designing procedure provides an open interactive modeling, architecture issues, and an essential prototyping, while Mechatronics is completely influenced by smart and intelligent devices for the real-time monitoring. It includes control and diagnosis of processes. The latest Mechatronic advances in smart manufacturing along with alterations and improvements to all the past conventional designs can be made with a new approach as discussed (Cho & Kim, 2005).

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