VDI 2206

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

The branch of engineering called systems engineering uses a concurrent approach for preliminary design. In a way, mechatronics is an extension of the system engineering approach, but it is supplemented with information systems to guide the design and is applied at all stages of design (not just the preliminary design step).

Mechatronics 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; 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.
Mechatronic system design supports the concepts of concurrent engineering.

In the designing of a mechatronic product, it is necessary that the knowledge and necessary information be coordinated amongst different expert groups.

Concurrent engineering is a design approach in which the design and manufacture of a product are merged in a special way. It is the idea that people can do a better job if they cooperate to achieve a common goal. It has been influenced partly by the recognition that many of the high costs in manufacturing are decided at the product design stage itself.
The characteristics of concurrent engineering are:

- Better definition of the product without late changes.
- Design for manufacturing and assembly undertaken in the early design stage.
- Process on how the product development is well defined.
- Better cost estimates.
- Decrease in the barriers between design and manufacturing.

However, the lack of a common interface language has made the information exchange in concurrent engineering difficult.

Successful implementation of concurrent engineering is possible by coordinating an adequate exchange of information and dealing with organizational barriers to cross-functional cooperation.

Using concurrent engineering principles as a guide, the designed product is likely to meet the basic requirements (High quality, Robustness, Low cost, Time to market, and Customer satisfaction)

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A major factor in the sequential approach (traditional) is the inherently complex nature of designing a multidisciplinary system. Essentially, mechatronics is an improvement upon existing lengthy and expensive design processes.

The mechatronic design process consists of three phases:
- modeling and simulation,
- prototyping,
- and deployment.
Mechatronics Design Process

Modeling/Simulation

- Recognition of the need
- Conceptual design and functional specification
- First principle modular mathematical modeling
- Sensor and actuator selection
- Detailed modular mathematical modeling
- Control system design
- Design optimization

Prototyping

- Hardware-in-the-loop simulation
- Design optimization

Deployment/Life cycle

- Deployment of embedded software
- Life cycle optimization

Information for future modules/upgrades
Innovative products require an interdisciplinary combination of mechanical engineering, electrical engineering and information technology. The term "mechatronics" is the expression of this. In view of this situation, a practical guideline for the systematic development of such products is necessary. The present guideline, VDI 2206, is intended to meet this requirement.
Mechatronics Design Process – VDI 2206

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"[Mechatronics is]... the synergetic integration of mechanical engineering with electronic and intelligent computer control in the design and manufacturing of industrial products and processes."\(^3\)

**Electro-mechanics** describes structures which are generally characterized by the interaction of electromagnetic fields with bodies affected by mass. Examples are relays, rotating electrical machines or linear drives, that is systems which convert electrical and mechanical energy.
**Mechatronics Design Process – VDI 2206**

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Diagram:

- **Information Processing**: Arrows indicating information flow.
- **Actors**: Connected to the information processing system.
- **Sensors**: Receiving input from the environment.
- **Basic System**: Central to the integration of various components.
- **Communication System**: Intermediary between information processing and man-machine interface.
- **Man-Machine Interface**: Connection to the human element.
- **Power Supply**: Input for the system.

**Legend**:
- Solid line: Necessary unit
- Dashed line: Optional unit
- Gray arrows: Material flow
- Gray solid arrows: Energy flow
- Gray dotted arrows: Information flow

**Fig. 2-2. Basic structure of a mechatronic system**

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The V model as a macro-cycle: A guide for the basic procedure is offered by the V model adopted from software development and adapted to the requirements of mechatronics; it describes the logical sequence of important substeps in the development of mechatronic systems [Brö95; FKM00].
VDI 2206 – Design Procedures

- Main procedures:
  - Requirements.
  - System design.
  - Domain specific design.
  - Modeling and model analysis.
  - System integration.
  - Assurance of properties.
Fig. 3-2. V model as a macro-cycle
Requirements: The starting point is formed by an actual development order. The defined object was specified more precisely and described in the form of requirements. These requirements at the same time form the measure against which the later product is to be assessed.

System design: The aim is to establish a cross-domain solution concept which describes the main physical and logical operating characteristics of the future product. For this purpose, the overall function of a system is broken down into main subfunctions. These subfunctions are assigned suitable operating principles or solution elements and the performance of the function is tested in the context of the system.
**VDI 2206 – Design Procedures**

**Domain-specific design:** On the basis of this jointly developed solution concept, further concretization usually takes place separately in the domains involved. More detailed interpretations and calculations are necessary to ensure the performance of the function, in particular in the case of critical functions.

**System integration:** The results from the individual domains are integrated to form an overall system, to allow the interaction to be investigated.
VDI 2206 – Design Procedures

System integration

- Integration of distributed components
- Modular integration
- Spatial integral
### VDI 2206 – Design Procedures

**Integration of distributed components**
- Components such as sensors and power actuators are connected to one another via signal and energy flows with the aid of communication systems, that of the energy flows via coupling and plug-in connectors.

**Modular integration**
- The overall system is made up of modules of defined functionality and standardized dimensions. The coupling takes place via unified interfaces such as for DIN plug and socket connection, standardized integral.

**Spatial integration**
- All components are spatially integrated and form a complex functional unit, for example integration of all elements of a drive system (controller, power actuator, motor, transfer element, operating element) into a housing.

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**VDI 2206 – Design Procedures**

*Hardware-in-the-loop (HIL)* is the integration of real components and system models in a common simulation environment. The HIL replication (simulation) of dynamic systems by physical and mathematical models must in this case take place in real time and with the physical loads replicated. An example is the simulation of an entire vehicle on a computer with the connection of a real control device and the actor technology for functional control to provide vehicle stability. A decisive advantage of HIL is the function test of the control device under real conditions while at the same time saving on time- and cost-intensive driving maneuvers.
Assurance of properties: The progress made with the design must be continually checked on the basis of the specified solution concept and the requirements. It must be ensured that the actual system properties coincide with the desired system properties.
Verification

• Verification means checking whether the way in which something is realized and whether it coincides with the specification.

• Verification is the answer to the question: Is a correct product being developed? For example, does a software program coincide with the deception of algorithms.

Validation

• Validation means testing whether the product is suitable for its intended purpose or achieves the desired value.

• Validation is the answer to the question: Is a right product being developed?
Modeling and model analysis: the phases described are flanked by the forming and investigating of the system properties with the aid of models and computer-aided tools for simulation.
VDI 2206 – Design Procedures

Modeling

- physical model
- Mathematical model
- Numerical model
### VDI 2206 – Design Procedures

<table>
<thead>
<tr>
<th>Physical model</th>
<th>Mathematical model</th>
<th>Numerical model</th>
</tr>
</thead>
<tbody>
<tr>
<td>- it is created from topological description ,</td>
<td>- it forms the basis of the behavioral description of the system .</td>
<td>- The Mathematical model is then prepared in such a way that it can be algorithmically handled and subjected to a computer aided process, for example simulation</td>
</tr>
<tr>
<td>- This representation is defined by system - adapted variables such as for example masses and lengths in case of mechanical systems or resistances and inductances in the case of electrical systems,</td>
<td>- the physical properties of the physical model are formulated with the aid of mathematical descriptions</td>
<td></td>
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<tr>
<td>- the physical model describes the system properties in a domain specific form .</td>
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VDI 2206 – Design Procedures

Fig. 3-9. Model abstraction levels in the modeling process
**Product:** The result of a continuous macro-cycle is the product. In this case, a product is understood as meaning not exclusively the finished, actually existing product but the increasing concretization of the future product (product maturity). Degrees of maturity are, for example, the laboratory specimen, the functional specimen, the pilot-run product, etc.

A complex mechatronic product is generally not produced within one macro-cycle. Rather, a number of cycles are required (Figure 3-3).
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Fig. 3-3. Running through a number of macro-cycles with increasing product maturity

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4.2 Design of the drive unit of a simple painting system

For painting mass-produced articles (kitchen appliances, audio and video equipment, aluminum wheel rims), painting systems in the form of continuous lines are often used. On these, the objects to be painted pass continuously through the system on a conveyor belt. The paint is applied by a number of spraying units, the oscillating movement of which runs either vertically (for the side surfaces of the object) or horizontally (for the upper side of the object) (Figure 4-11).
Fig. 4-11. Basic representation of the continuous line
**VDI 2206 – Example**

**System design**
- search for variants for converting a rotational movement into a translatory movement
- rough dimensioning to the mechanical and electrical drive elements (power, mass, rigidities, inductances, torque constant, etc.)
- assessment and selection of variants

**Modeling and system analysis**
- Modeling of the overall system (Matrix X/SystemBuild model)
- design of the controller structure or the control
- checking the realizable requirements in the simulation model

Fig. 4-10. Procedure for designing the drive unit of a simple painting system

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4.2.1 Selected requirements
Desired speed in \( x \) direction:
1 m/s
Distance at constant desired speed in \( x \) direction over the belt:
700 mm (ideally: 900 mm)
Maximum oscillating amplitudes in \( x \) direction in the range of constant desired speed:
\( \pm 3 \) mm (ideally: \( \pm 2 \) mm)
Electric drive
The geometrical requirements are summarized in Figure 4-12.
Fig. 4-12. Geometrical requirements
VDI 2206 – Example

Fig. 4-13. Solution variants of the system design.
A more precise assessment of the variants cannot be made within the scope of this guideline. However, it should be noted that variants of type 2 represent a solution that is customary in practice, but have great problems with mechanical loads and wear in the connecting link guide and also lead to inflexible kinematics in the returning area. Therefore, variant 5 with a brushless DC motor in combination with a toothed belt drive is to be considered by way of example.
VDI 2206 – Example

Modellvorstellung für den Ausleger: Eingespannter Krag balken/model idea for the boom: restrained cantilever beam

\[-m_1 \cdot \ddot{u}_1 - F_s = 0\]

\[F_s = F_k + F_d = k \cdot (u_1 - u_2) + d \cdot (\ddot{u}_1 - \ddot{u}_2)\]

\[u = \frac{F \cdot 1^3}{3EI} \quad \rightarrow k = \frac{3l}{1}\]

\[-m_2 \cdot \ddot{u}_2 + F_s + F_{\text{Motor}} - F_{\text{Reibung}} = 0\]

\[F_{\text{Motor}} = 2 \cdot M_{\text{el}} / d_{\text{Zahnscheibe}}\]

Figure 4-14. Formulating the differential equations for the simple mechanical substitute model
The DC motor used is described by its winding inductance and winding resistance and also two constant factors $k_i$ and $k_E$ with the equations

$$i = \frac{1}{L} \cdot (U_{\text{motor}} - R \cdot i - k_E \cdot \phi)$$

$$M_{\text{el}} = k_i \cdot i$$

The term $k_E \cdot \phi$ describes the mutual induction and couples the mechanical and electrical equation systems.
4.2.4 Control structure

The system is designed as a cascade control with three PID controllers. In the inner cascade, the current control ensures that the inductance of the motor winding which limits the rate of current rise is compensated by an increased motor voltage. The dynamic behavior of the motor is consequently idealized. The middle cascade comprises the speed control of the motor, while the outer cascade controls the position. The desired displacement is also additionally fed forward here as a precontrol. Furthermore, limitations both for the maximum motor current (43 A) and the maximum motor voltage (300 V) are integrated in the controller cascade. Figure 4-15 shows the overall system.
Fig. 4-15. Block diagram of the overall system
Fig. 4-16. Simulation results of the block diagram from Figure 4-15
Thank You For Your Attention!

Questions?