Mechatronics

The term "mechatronics" came about as a made-up word from mechanics and electronics, where electronics means "hardware" and "software", and mechanics is the generic term for the disciplines of "mechanical engineering" and "hydraulics". It is not a question of replacing mechanical engineering by "electronification", but of a synergistic approach and design methodology. The aim is to achieve a synergistic optimization of mechanical engineering, electronic hardware and software in order to project more functions at lower cost, less weight and installation space, and better quality. The successful use of mechatronics in a problem solution is dependent upon an overall examination of disciplines that were previously kept separate.

Mechatronic systems and components

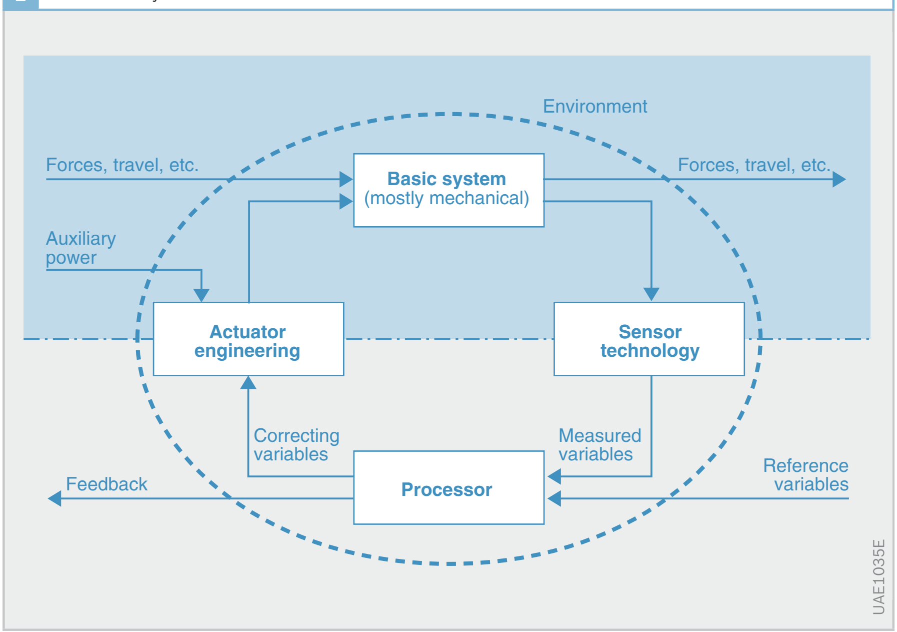
Applications

Mechatronic systems and components are now present throughout almost the entire vehicle: starting with engine-management systems and injection systems for gasoline and diesel engines to transmission control systems, electrical and thermal energy management systems, through to a wide variety of brake and driving dynamics systems. It even includes communication and information systems, with many different requirements when it comes to operability. Besides systems and components, mechatronics are also playing an increasingly vital role in the field of micromechanics.

Examples at system level

A general trend is emerging in the further development of systems for fully automatic vehicle handling and steering: more and more mechanical systems will be replaced by "X-by-wire" systems in future.

1 Mechatronic system



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A system that was implemented long ago is the "Drive-by-wire" system, i.e. electronic throttle control.

"Brake-by-wire" replaces the hydromechanical connection between the brake pedal and the wheel brake. Sensors record the driver's braking request and transmit this information to an electronic control unit. The unit then generates the required braking effect at the wheels by means of actuators.

One implementation option for "Brake-by-wire" is the electrohydraulic brake (SBC, Sensotronic Brake Control). When the brake is operated or in the event of brake stabilization intervention by the electronic stability program (ESP), the SBC electronic control unit calculates the required brake pressure setpoints at the individual wheels. Since the unit calculates the required braking pressures separately for each wheel and collects the actual values separately, it can also regulate the brake pressure to each wheel via the wheel-pressure modulators. The four pressure modulators each consist of an inlet and an outlet valve controlled by electronic output stages which together produce a finely metered pressure regulation.

Pressure generation and injection are decoupled in the Common Rail System. A high-pressure rail, i.e. the common rail, serves as a high-pressure accumulator, constantly providing the fuel pressure required for each of the engine's operating states. A solenoid-controlled injector with a built-in injection nozzle injects fuel directly into the combustion chamber for each cylinder. The engine electronics request data on accelerator pedal position, rotational speed, operating temperature, fresh-air intake flow, and rail pressure in order to optimize the control of fuel metering as a function of the operating conditions.

Examples at component level

Fuel injectors are crucial components in determining the future potential of Diesel-engine technology. Common-rail injectors are an excellent example of the fact that an extremely high degree of functionality and, ultimately, customer utility can only be achieved by controlling all the physical domains (electrodynamics, mechanical engineering, fluid dynamics) to which these components are subjected.

In-vehicle CD drives are exposed to particularly tough conditions. Apart from wide temperature ranges, they must in particular withstand vibrations that have a critical impact on such precision-engineered systems.

In order to keep vehicle vibration away from the actual player during mobile deployment, the drives normally have a spring damping system. Considerations about reducing the weight and installation space of CD drives immediately raise questions concerning these spring-damper systems. In CD drives without a damper system, the emphasis is on designing a mechanical system with zero clearances and producing additional reinforcement for the focus and tracking controllers at high frequencies.

Only by combining both measures mechatronically is it possible to achieve good vibration resistance in driving mode. As well as reducing the weight by approx. 15 %, the overall height is also reduced by approx. 20 %.

The new mechatronic system for electrically operated refrigerant motors is based on brushless, electronically commutated DC motors (BLDC's). Initially, they are more expensive (motor with electronics) than previous DC motors equipped with brushes. However, the overall optimization approach brings benefits: BLDC motors can be used as "wet rotors" with a much simpler design. The number of separate parts is therefore reduced by approx. 60 %.

In terms of comparable cost, this more robust design doubles the service life, reduces the weight by almost half and reduces the overall length by approx. 40 %.

Examples in the field of micromechanics

Another application for mechatronics is the area of micromechanical sensor systems, with noteworthy examples such as hot-film air-mass meters and yaw-rate sensors.

Because the subsystems are so closely coupled, microsystems design also requires an interdisciplinary procedure that takes the individual disciplines of mechanical components, electrostatics and possibly fluid dynamics and electronics into consideration.

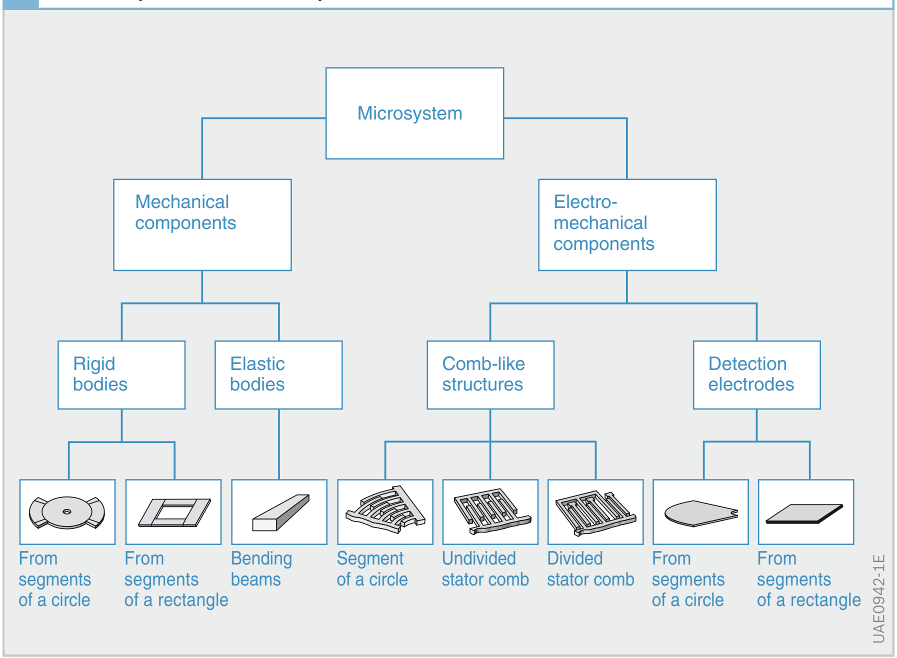
Development methods

Simulation

The special challenges that designers face when developing mechatronic systems are the ever shorter development times and the increasing complexity of the systems. At the same time, it is vital to ensure that the developments will result in useful products.

Complex mechatronic systems consist of a large number of components from different physical domains: hydraulic components, mechanical components and electronic components. The interaction between these domains is a decisive factor governing the function and performance of the overall system. Simulation models are required to review key design decisions, especially in the early development stages when there is no prototype available.

2 Model library for a micromechanical yaw-rate sensor



Basic issues can often be clarified by producing relatively simple models of the components. If more detail is required, more refined component models are needed. The detailed models focus mainly on a specific physical domain:

- This means that detailed hydraulic models of common rail injectors are available, for example. These can be simulated using special programs with numeric calculation methods that are exactly tailored to hydraulic systems. Cavitation phenomena have to be taken into consideration, among other things.
- Detailed models are also needed to design the power electronics that trigger the injector. Again, this involves the use of simulation tools which must be developed specifically to design electronic circuits.
- The development and simulation of the software that controls the high-pressure pump and the power electronics in the control unit with the aid of the sensor signals also takes place using tools that are specially designed for this area of the overall system.

As the components in the overall system interact with each other, it is not sufficient to consider specific detailed models of the components in isolation. The optimum solution is also to take into account the models of other system components. In most cases, these components can be represented by simpler models. For example, the system simulation that is focussed on the hydraulic components only requires a simple model of the power electronics.

The application of various domain-specific simulation tools during the development of mechatronic systems is only efficient if there is some sort of support for exchanging models and parameters between the simulation tools. The direct exchange of models is highly problematic due to the specific languages used for describing the models of each of the tools.

However, an analysis of the typical components in mechatronic systems shows that they can be composed of a few simple elements specific to the domains. These standard elements are, for example:

- In the hydraulic system: throttle, valve or electric line
- In the electronic system: resistor, capacitor or transistor
- In the mechanical system: ground with friction, transmission or clutch (or the equivalent for micromechanics)

The preferable solution is that these elements should be stored in a central standard model library that is also decentrally accessible to product development. The essence of the standard model library is a documentation of all the standard elements. For each element, this comprises:

- Description of physical behavior in words
- The physical equations, parameters (e.g. conductivity or permeability), state variables (e.g. current, voltage, magnetic flux, pressure) and
- The description of the associated interfaces

In addition, a major part of the environment is a reference model written in a modeling language that is independent of the tool. Overall, the library includes reference models from the mechanical, hydraulic, electronic, electrodynamic and software areas.

V model
The dependencies of the different product development phases are illustrated in the "V model": from requirement analysis to development, implementation, testing and system deployment. A project passes through three "top-down" levels during the development stage:

- Customer-specific functions
- Systems and
- Components

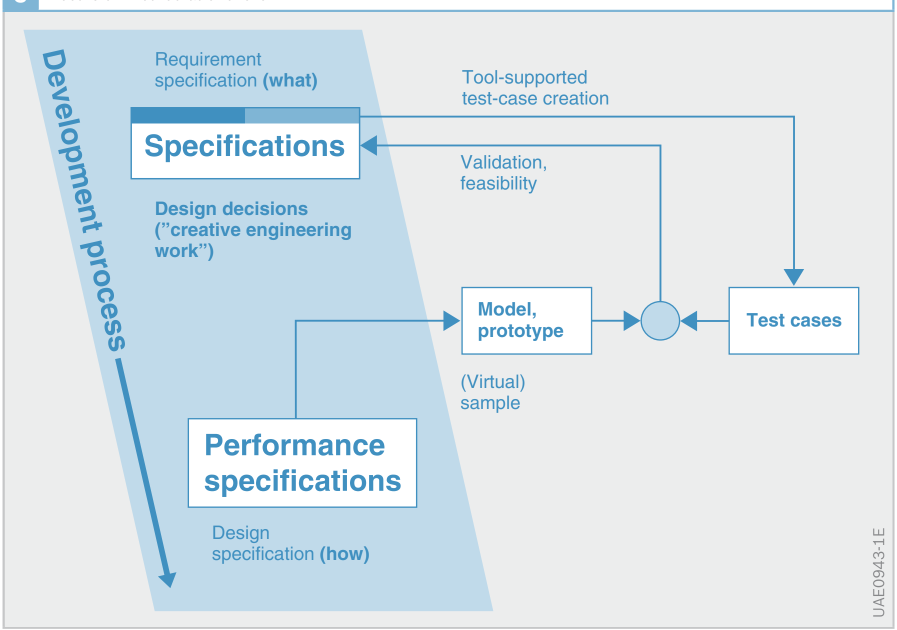
A requirements specification (what) must first be produced at each level in the form of specifications. This results in the design specification, which is drawn up on the basis of design decisions (the actual creative engineering work). The performance specifications describe how a requirement can be met. The performance specs form the basis for a model description which allows a review (i.e. validation) of the correctness of each design stage together with previously defined test cases. This procedure passes through each of three stages, and, depending on the technologies applied, for each of the associated domains (mechanical engineering, hydraulics, fluid dynamics, electrics, electronics, and software).

Recursions at each of the design levels shorten the development stages significantly. Simulations, rapid prototyping, and simultaneous engineering are tools that allow rapid verification, and they create the conditions for shortening product cycles.

Outlook

The major driving force behind mechatronics is continuous progress in the field of microelectronics. Mechatronics benefits from computer technology in the form of ever more powerful integrated computers in standard applications. Accordingly, there is a huge potential for further increases in safety and convenience in motor vehicles, accompanied by further

3 Recursion method at one level



reductions in exhaust emissions and fuel consumption. On the other hand, new challenges are emerging with regard to the technical mastery of these systems.

However, future “X-by-wire” systems without the mechanical/hydraulic fall-back level must also provide the prescribed functionality in the event of a problem. The condition for their implementation is a high-reliability and high-availability mechatronic architecture which requires a “simple” proof of safety. This affects both single components as well as energy and signal transmissions.

As well as “X-by-wire” systems, driver-assistance systems and the associated man/machine interfaces represent another area in which the consistent implementation of mechatronic systems could achieve significant progress for both users and vehicle manufacturers.

The design approaches of mechatronic systems should strive toward continuity in several aspects:

- Vertical:
  “Top-down” from system simulation, with the objective of overall optimization, through to finite element simulation to achieve a detailed understanding, and “bottom-up” design engineering from component testing through to system testing
- Horizontal:
  “Simultaneous engineering” across several disciplines in order to deal with all product-related aspects at the same time
- Beyond company boundaries:
  Step by step, the idea a “virtual sample” is nearing our grasp

Another challenge is training in order to further an interdisciplinary mindset and develop suitable SE processes and forms of organization and communication.

4 V-model general overview