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SYSTEMY MECHATRONICZNE

Streszczenie: Celem artykułu jest przedstawienie przeglądu zastosowań systemów mechatronicznych w różnych dziedzinach przemysłu. Podsumowano najnowszą wiedzę oraz zastosowania w konkretnych obszarach, takich jak projektowanie obrabiarek CNC, robotyka przemysłowa, mobilna i współpracująca, przemysł wojskowy, systemy transportowe i logistyczne, zautomatyzowane linie i komórki produkcyjne, systemy dla technologii życia wspomaganego przez otoczenie itp.

Słowa kluczowe: systemy mechatroniczne, maszyny CNC, roboty

MECHATRONIC SYSTEMS

Summary: The main aim of the article is to present an overview about mechatronic systems application in various areas of industry. There are summarized the latest knowledge as well as applications in specific areas as CNC machine tools design, industrial, mobile and collaborative robotics, military industry, transport and logistic systems, automated production lines and cells, systems for Ambient assisted living technology, etc.

Keywords: mechatronic systems, CNC machines, robots

1. Introduction

Mechatronics is a modern scientific and technical department including selected mechanical, electrical, informatics and cybernetic disciplines. It brings more than just a combination of them, it's new a comprehensive view of the problem and its solution. At present, great emphasis is placed on automation of mechanical engineering, mechanical engineering, machines and engineering products whose main occupation the activity is based on mechanical principles [1]. Human work is being replaced by automation different production processes where to produce implement automatic production lines, industrial robots and manipulators, which contributes to increasing

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the efficiency and quality of products [2-4]. These the devices are able to operate without interruption and automatically. One is not able to work without breaks, mostly used to operate the equipment, thus its role is facilitated compared to machines.
Among the important elements used in industrial automation includes sensors. Their job is monitoring of various physical quantities and creation of data for control processing. Equally important can be action members. They carry out the instructions issued by the controller system [5,6]. The computer has gradually started since its inception apply also in the field of engineering and between one the most important areas of application include robots and numerically controlled machines (CNC).
The task of robots is to perform assembly work, inspection, surface treatment of workpieces, but they are capable of very precise and precise work, therefore they are used e.g. during surgical operations. Between their advantages over human strength include the ability to work mentally and emotionally unencumbered.

2. Mechatronic products and systems

Mechatronic products are the results of procedures according to the principles of mechatronics [7-9]. They are made using advanced materials, the latest technological procedures, top features and purposeful machine intelligence [10]. Autonomous action or rational integration into a superior control system is made possible by the intelligence embedded in the mechatronic system.

Areas of application of mechatronics and mechatronic systems:

- CNC machines and robots,
- automated production lines,
- mobile machines and equipment,
- means of transport and handling,
- medical and special equipment,
- military equipment.

3. Division of mechatronic systems

Mechatronic systems are characterized by a certain degree of "intelligence". They are programmable, provide advice to users, have their own fault diagnosis, are corrected using their own reconfiguration and work with other intelligent machines.

A. Mechatronic systems in the military

Soldiers do not have it easy at all, in addition to deploying their lives in the service, they often have to carry weights weighing about 50 kg in difficult terrain for up to several hours without a break and over a very long distance [11,12]. It is exhausting and such a burden has a negative impact on the soldiers' torso and legs. Therefore, scientists are trying to lighten the burden on soldiers as much as possible and at the same time increase their safety.
The robotic mule is being developed by the US Agency for Research in Advanced Defense Technologies. It is a mobile, partially independent robot called LS3 (Legged

Squad Support System), which in translation means a support system with legs and a shape resembling a giant dog or a mule (Fig. 1). Its main goal is to support US Marines. The prototype of an ammunition carrier, a weapon, has had its first successful outings. They have shown that the control sensors are able to distinguish trees, boulders or obstacles in the field from people, and so the current form of the robotic mule is no longer expected by any drastic changes. The robotic helper manages to transfer 200 kg of load to a distance of up to 20 km in 24 hours, while the filling of one tank is enough for the entire journey.

Figure 1. Robotic mule in the field (http: //21století.cz)

An unmanned aerial vehicle (UAV) is an aircraft without human presence on board that can be operated remotely or fly using a programmed flight path. Such aircraft are used in the military for reconnaissance, monitoring, espionage and attack flights. Radio-controlled models or replicas of aircraft are also considered to be unmanned aircraft [13,14]. The best known unmanned reconnaissance vehicle developed by the US military is the MQ-1 Predator (Fig. 2).

Figure 2. MQ-1 Predator (http://www.brokerske-centrum.sk)

B. Mechatronic systems in healthcare

The aim of the health research program and the application of advanced technologies is to improve, enhance and prolong the human life of citizens. Mechatronic systems

make life easier, not only for people with disabilities, but also for healthcare professionals and also for those with no disabilities.
An electric wheelchair is a compensatory aid intended for people who have good upper limb function. The trolleys can be used indoors and outdoors. Simple operation allows people to easily integrate into everyday life and provide everything they need on their own. The trolleys can be equipped according to customer requirements [15]. In (Fig. 3) is an electric wheelchair equipped with a telescopic post which lifts a seated person to a desired height.

Figure 3. Electric wheelchair (http://partnerstvi-energetiky.msek.cz)

Genium is an intelligent system of lower limb prostheses (Fig. 4) based on many years of experience. With the Genium joint, everything happens in real time, almost the same as with natural walking. The optimized physiological gait of the system makes it possible to almost naturally copy natural gait, including walking backwards, walking up stairs, while the movements are smooth.

Figure 4. Lower limb prosthesis (http://www.neoprot.sk)

C. Mechatronic systems in the civil sphere

The role of mechatronic systems is not to improve or facilitate the work and life of professionals, scientists, but also ordinary people. Today, mechatronic systems are all around us [16]. Many are not even aware of this, but we use systems working on the mechatronic principle many times a day.
The robotic vacuum cleaner uses efficient movement and a whole set of sensors to thoroughly cover the area. With the help of visual localization, he can orient himself throughout the household. It creates landmarks in its map of space, so it knows exactly where it has been and where it still needs to be vacuumed. Fully charged, it can vacuum for up to two hours, then automatically return to the charging station. On carpets and rugs, it automatically increases engine power up to 10 times. You can start vacuuming via the application.
Automatic car braking uses camera or radar sensors that sense the distance from other vehicles, as you can see in Fig. 5. If you approach the vehicle, the system will warn you or start braking immediately, depending on the current situation. Current systems can reduce the speed of an impact or completely prevent an accident. With automatic brakes, the number of injuries has been reduced by 42% because the speed of the computer's response is significantly higher than the human's response

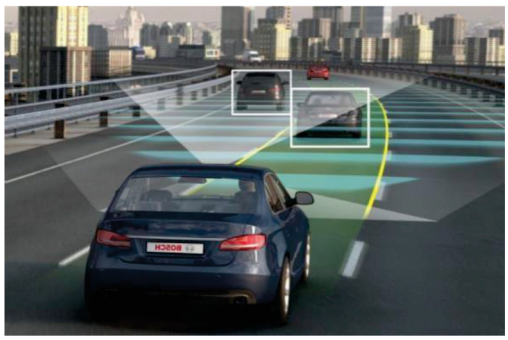

Figure 5. Sensors in the car (http://www.topspeed.sk)

D. Mechatronic systems in space research

Applications of systems in space have made it possible to observe processes taking place outside our reach. They broadened their horizons of functioning outside our Earth. In addition to space flights, they have also helped to improve the lives of ordinary people. Thanks to them, we can make phone calls to the other end of the world, or use navigation to guide us in the right direction. A spacecraft is an unmanned spacecraft launched to the moon or to escape from the earth's gravitational field [17]. Their task is to research the properties of the space through which they fly, or the bodies of the solar system to which they approach.

4. Mechatronic systems in Engineering

Resolving conflicts between the requirements for manufacturing accuracy in large machine workspaces and flexible and reliable production requires the construction of

machines with a universal system architecture and properties typical of mechatronic systems.

CNC stands for Computerized Numerical Control. They contain a control computer, which is part of the NC machine and controls the work tasks. The advantages of CNC machines are the reduction of the production of failures and the increase of accuracy by using data from sensors. The program can be modified. The production machine's own drives are controlled with model support to correct process errors. In today's modern NC machines, all machining operations, even with the setting of cutting conditions, are performed automatically. Human intervention is limited to clamping the workpiece, removing the workpiece and starting automatic operation.

Division of CNC machines:
- CNC lathes (Fig. 6),
- CNC milling machines and CNC grinders,
- CNC machine tools for the production of gears,
- CNC machining centers,
- CNC machines for unconventional machining methods (electrospark machine tools),
- CNC burning machines (laser, water jet, plasma, oxygen-acetylene flame)

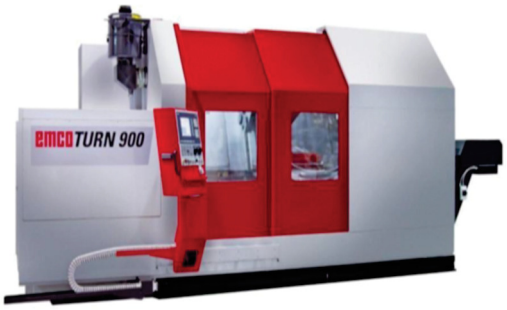

Figure 6. CNC lathe (http://www.kovo-stroje.sk)

We can write the NC program in a text editor or create it using CAD / CAM systems. These systems include a simulation to check the accuracy and functionality of the program. Then we transfer the program to the control system and we do not have to stand at the machine and write NC codes directly. Most often, the program is transferred using a USB key, but currently it is possible to connect CNC machines to computer networks. Each NC program starts with a header. Which is actually a command line that clearly characterizes the type of CNC control system and how to execute the program. Further in the header, there are default modal G-codes and auxiliary M-codes [18]. Modal means that they do not apply only to one command line, but that they are active up to the line where they are changed by another code. G-code is the language used to control the machine and M-codes take care of controlling its mechanisms. (http://www.strojnet.cz)

A special group of CNC machine tools consists of CNC machining centers. They belong to the group of multi-professional machines. It is possible to perform various technological operations on them (turning, milling, drilling, etc.). In Fig. 7 is a vertical machining center for machining parts in five controlled axes, used in small and

medium-sized enterprises. MAXXMILL 500 machines parts with maximum dimensions of 500 x 500 x 475 mm and is designed as a cantilever milling machine.

Figure 7. Machining center MAXXMILL 500 (http://www.kovo-stroje.sk)

The DMG MORI virtual machine is software developed for the most economical machining possible in order to optimize the production process and the quality of workpieces. This software enables accurate computer simulation of the actual machining in an accurate 1:1 display. Airbus Defense and Space has decided to use the DMG MORI software in its modern 5-axis DMC 125 FD duoBLOCK machining center (Fig. 8). Due to the water-cooled feed drive, accuracy has increased by 30%, while consumption has been reduced by 30%. The magazine can contain up to 243 tools, which the feeder is able to replace in 0.5 s. The model is equipped with a tilting rotary table with direct drive, while providing milling and turning.

The DMG MORI virtual machine displays production processes, including tool changes. In addition to machines in real size on a computer, it can also display their geometry and kinematics with the original control and the actual PLC [19]. It is used to simulate the machining of expensive components on a computer and verification in terms of feasibility or possible collisions. A measuring probe is integrated into the simulation, which performs measurements in real time, similar to real machines

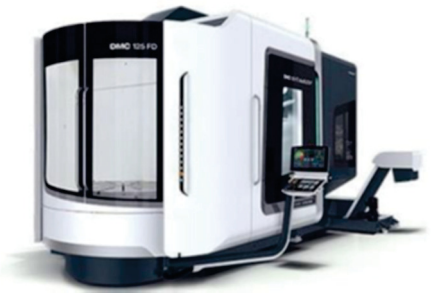

Figure 8. DMC 125 duoBLOCK machine (aimagazine, 2016)

The accuracy of the software is sufficient to be able to see on the computer whether the machining process meets our expectations. New professional staff can also be

trained in this virtual environment. In Fig. 9 we see a complete integration of control and an accurate representation of machine geometry and kinematics. Potential collisions and programming errors are identified immediately.

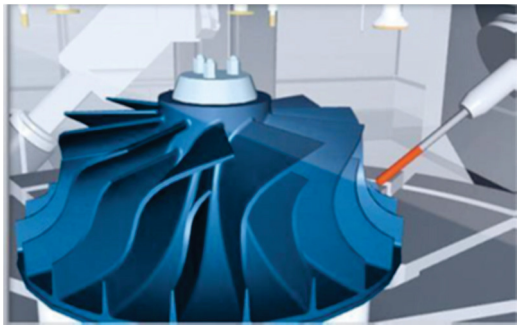

Figure 9. Check geometry (http://dmgmori.com)

A. Intelligent and mechatronic systems

Manufacturers of production equipment no longer try to distinguish not only by the mechanical construction and design of machines, but also by the implementation of a range of intelligent accessories that increase the functionality and accuracy of the equipment produced.

B. Integrated machine condition evaluation systems

Microcut is a Taiwanese manufacturer of CNC machines that has developed several advanced systems designed to monitor the condition of the machine. Axial Accuracy control is a system designed to reconstruct the thermal deformation of the machine based on temperature measurement and mathematical model. If the machine temperature is too high, where the temperature deformation is too high and the calculated correction would not be accurate enough, this system automatically adjusts the spindle speed and motion axes. One of the other systems called Straightness Compensation Technology (Fig.10) is used to compensate for the deflection of the retractable slider of horizontal machines. It uses a compensating rod, which is led from the front part of the slider to its rear part [20]. In this part it is connected to a hydraulic cylinder with a pressure sensor. When the slider is extended, the pressure in the cylinder is monitored and compared with the value stored in the PLC. If these values deviate outside the tolerance field, the pressure in the cylinder will be adjusted

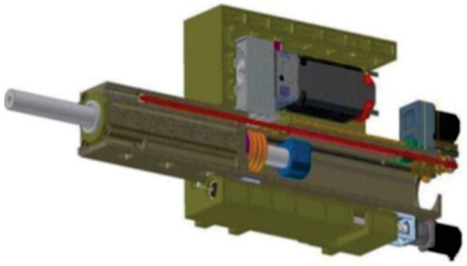

Figure 10. Straightness Compensation Technology slider [5]

Montronix is a company manufacturing measuring and evaluation systems for production machines. One of their collision monitoring systems is based on monitoring the acceleration of individual machine parts (Fig. 11). The decision on the collision is issued in less than 1ms.

Figure 11. Collision monitoring system [2]

C. Measuring systems for machine tools

Etalon has developed the Absolute Multiline Technology system, which is a new distance measuring technology with the possibility of interrupting and resuming the laser beam. The principle is based on the comparison of the wavelength of the measuring and the reference beam. The reference beam is created in a separate circuit inside the control panel. The parameters that are compared are the intensity and phase of both rays, which are evaluated by a mathematical apparatus. The advantage of this technology is the very small dimensions of the measuring optics. The beam from the control panel can be guided with an optical cable up to several kilometers, therefore it is possible to measure even large machine structures (Fig. 12).

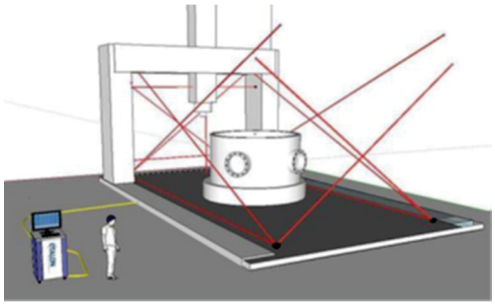

Figure 12. Etalon Absolute Multiline Technology [5]

LaserTRACER is a measuring device used for small spaces. The MultiTrace system represents a new way of using this device. It includes the use of several TRACERS working on the principle of GPS (Fig.13). This system is able to calibrate itself and achieves high accuracy by measuring with four interferometers. It enables, for example, dynamic recording of spatial trajectory in large workspaces with high accuracy or scanning of large surfaces.

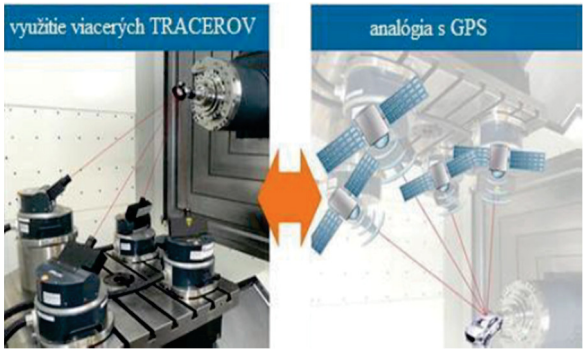

Figure 13. Standard Multitrace [5]

D. Intelligent elements of control systems

The HEIDENHAIN system includes the Adaptive Feed Control tool designed to increase the dynamic stability of machine tools. Actively controls the feed rate depending on the machine load. In cases where a smaller material removal is recorded, the feed rate is automatically increased (Fig. 14), thus reducing the machining time.

OKUMA has the Collision Avoidance System at its disposal, which evaluates the risk of collision in real time based on 3D models of workpieces, tools, fixtures, turrets and tailstocks. The simulation takes place simultaneously with the machining process in automatic mode. The machine stops moving before the program block that contains the collision instruction

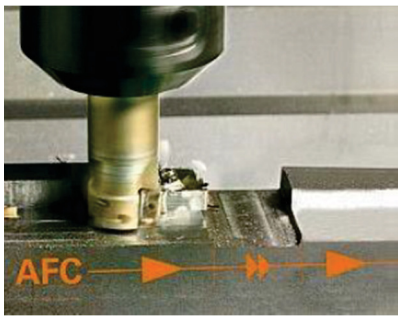

Figure 14. Etalon Multitrace [2]

E. Vibration suppression systems

Trimill has developed the VU 3014 machine (Fig. 15), on which a passive dynamic damper shown in green is placed on the slider to suppress vibrations. It is a ring in which the dominant mass is placed and smaller masses are hung on it. This damper is designed to suppress vibrations in the cutting process

Figure 15. Trimill VU 3014 [2]

INA designed and implemented a hydrostatic line that can be equipped with a vibration suppression system (Fig. 16). The hydrostatic gap of the nest is connected to the tank with hydraulic oil and the energy of the vibrations is converted into the potential energy of the fluid in the tank.

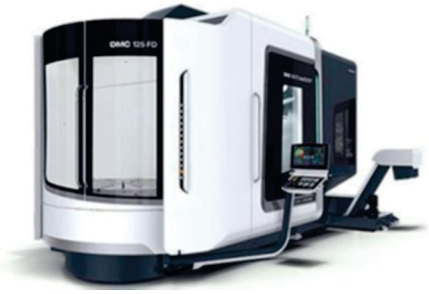

Figure 16. Hydrodynamic damper principle [5].

5. Robots

The robot is a controlled mechanism programmable in three or more axes. It is characterized by a certain degree of autonomy and moves within its environment to perform the assigned tasks. The main features of robots include high handling ability, versatility, adaptability and autonomy, the ability to make intelligent decisions. Robots together with CNC machines represent the basic representatives of mechatronic devices.

Distribution of robots by:

Application determination
- manipulative - manipulation with the object,
- technological - performing technological activities (welding, sheet metal bending, etc.),
- special - work in a special environment (research laboratories, outer space, underwater, in a radioactive environment, etc.).

Mobility
- stationary (industrial robots),
- mobile (service robots).

Construction arrangement
- with serial kinematic structure (Cartesian, cylindrical, spherical, SCARA and angular),
- with a parallel kinematic structure,
- with a hybrid kinematic structure.

A. Mobile robots

Mobile robots are equipped with a mobile device and represent a new category of robots. The classic robot acquires a new technical characteristic, namely mobility. They make it possible to increase the level of production automation. They are used mainly in the logistics chain in manufacturing, but also in non-manufacturing industries. KUKA's YOUBOT is one of the latest innovations in the field of mobile robots. (Fig. 17). It consists of a mobile platform on which a five-axis robotic arm with double-jaw grippers is installed. The arm and the mobile platform can also be used separately

The accuracy of the software is sufficient to be able to measurements in real time, similar to real machines.

Figure 17. Mobile KUKA YOUBOT (www.atpjournal.sk)

B. Collaborating robots

Human cooperation with an industrial robot is not an unknown concept and is currently gaining in importance mainly due to growing customer requirements or increasing competitiveness. The deployment of collaborative workplaces also has its application in shortening innovation cycles and a more flexible response to difficult-to-predict market requirements, while a necessary element is the protection of persons entering the process with a fast-moving robot. The main task of the advent of intelligent human-industrial cooperation is to facilitate the repetitive, often very demanding and dangerous human work. The only cooperating robot in the world with a payload of 35 kg is the CR-35iA from FANUC, which is shown in Fig. 18. It is suitable for almost all manual processes. The operator is out of danger thanks to the force sensors and the soft rubber skin of the robot, while the robot is able to work with or next to a human. The operator can guide, teach or simply push him away when he needs space.

Figure 18. Collaborating robot FANUC CR-35iA (www.fanuc.com)

C. Serial and parallel robots

Serial robots have the shape of the workspace determined by the relative movement of the TCP (Tool Center Point) endpoint by movements in the direction of the coordinate axes. The shape of the workspace is determined by the movement of the endpoint. We know a straight line (Fig. 19a) or a rotary (Fig. 19b) line of serial robots.

Parallel robots have an end point position determined by the movements of a number of active and passive linear guides or rotating members.

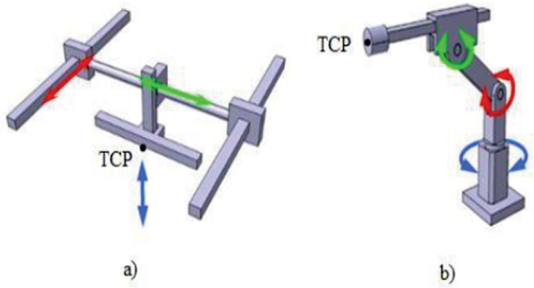

Figure 19. Serial kinematic structures (www.sjf.tuke.sk)

An interesting mechanism belonging to the group of structures with parallel kinematics used in industry, especially in the field of handling and assembly, is the Delta robot. In FIG. 20. is a FANUC M-3iA robot with a payload of up to 6 kg. It has the largest working space compared to other robots in its class (1350mm x 500 mm). It is available in four or six programmable axes.

Figure 20. Delta robot FANUC M-3iA (http://robot.fanucamerica.com)

Humanoid robots are reminiscent of the human body in construction and appearance. They have a torso, upper, lower limbs and a head. Today's humanoid robots can sing, recognize several hundred voice commands, dance, help the elderly, they can even imitate human facial expressions, or recognize your mood. Honda has designed a humanoid robot called the Asimo. Asimo is one of the leaders in robotics, especially when it comes to the way we walk. It is 130 centimeters high and its technical sophistication surpasses current humanoid robots. He communicates in foreign languages on any topic, the problem for him is not even walking up the stairs or dancing and football movements.

6. Conclusion

The content of the article is focused on an overview of the current state and clarification of the basic principles of mechatronic systems in various fields, especially in mechanical engineering.
In the introduction, the term mechatronics is described from its inception, development to applications in various industries. Sensors and actuators play a very important role in mechatronic systems.
Some of the latest knowledge and applications with their use for CNC machines and machining centres are presented. These are integrated systems for evaluating the condition of the machine, systems for suppressing machine vibrations, measuring systems for machines and the deployment of modern intelligent mechatronic systems in the field of mechanical engineering. Next, the problem of robots is presented, while the division is processed on the basis of their design, abilities and properties. An example is the increasingly used robots with parallel kinematics, referred to as Delta robots

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