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BOOSTING THE SCIENTIFIC EXCELLENCE AND INNOVATION CAPACITY OF 3D PRINTING METHODS IN PANDEMIC PERIOD

MODULE 4

Flexible manufacturing systems

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1 Summary

The curriculum of this subject is composed of 5 main sections. The second section is oriented to introducing flexible manufacturing systems in general and in specific manufacturing environments – the medical application. The third section focused on robotic material handling, the specification of the industrial robot for medicine manufacturing. The fourth section concentrate on specific requirements for manufacturing devices in medical applications. The fifth section introduces various software solutions (platforms, systems) and explains their possible 3D modelling and CAM application.

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2 FLEXIBLE MANUFACTURING SYSTEMS

A flexible manufacturing system is designed so that it responds to and adapts to changes in the manufacturing process, including unanticipated problems. Since the 1970s, flexible manufacturing systems have aided businesses in rapidly developing products.

Fig. 1: Flexible welding line [1]

2.1 Description

Flexible manufacturing systems consistently improve the manufacturing process and provide two types of flexibility. We use the term "machine flexibility" to refer to a potential method of modifying the system to create new products. Additionally, there is a discussion of the system's ability to alter how the product operates.

The second classification is routing adaptability. It refers to a system's ability to perform the same operations on a given workpiece across multiple machines. Additionally, it relates to the system's capacity to adapt to quantity, capacity, or capability changes.

2.2 Disadvantages of a flexible production system

Flexible production systems also have their disadvantages. Users must keep these disadvantages in mind when implementing flexible manufacturing systems. Implementing FMS into the production process can be complicated and requires planning to the extent that some companies cannot implement without external assistance.

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Fig. 2: Industrial robot for material handling [1]

Highly qualified employees staff FMS. Also, due to the complexity of these systems, highly skilled maintenance and relatively expensive spare parts and consumables are required. Operation and maintenance costs will be high, but it will still be cheaper than shutting down the system due to a failure. Also, the purchase or modification of existing machinery will be expensive. For these reasons, FMS are currently available mainly to larger companies, which have sufficient funds for investment in the production system and its subsequent maintenance.

2.3 Advantages of a flexible production system

While the disadvantages of FMS may deter some potential users, it is essential to recognize that the long-term benefits outweigh the disadvantages.

These systems are challenging to implement in the first phase, but in the longer term, they will be beneficial, saving a large part of operating costs compared to conventional production. They reduce operating costs because they can adapt quickly to changes in production, thus preventing faulty products and thus wasting time and resources. Also, a smaller number of operators is usually needed to ensure the same or even higher production volume.

The most crucial benefit of FMS is that it helps the user become more efficient and flexible, especially in changing market requirements. In any change in the production process, they can quickly adapt and maintain the production flow. In this way, delays and production bottlenecks can be reduced or even completely avoided. The possibility of quick adaptation allows production with shorter production times, resulting in which it is a possible increase in customer satisfaction.

Flexible production systems have their disadvantages, especially in the initial phase of their deployment, but their deployment's advantages will bring, in the long run, eliminate these

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disadvantages. Though complex and expensive, flexible production systems enable businesses to create higher-quality products, improve their efficiency, and grow their revenue over time.

2.4 Division of flexible production systems

We know different types of FMS, which can be divided into several aspects. The most important and most used types of FMS are the following:

- Flexible manufacturing system - a functional configuration of manufacturing equipment based on material and information flow that enables efficient production of a small number of products.
- Unified manufacturing system - flexible configuration of compatible components and their relationships, expanded through innovation and the intention to change system parameters.
- Modular system - the ability to combine functional, logically integrated modules into a higher-level operational entity in a flexible manner.
- Reconfigurable system - a modular system with the ability to configure its modules in order to create an innovative manufacturing system.
- Self-configurable system – a reconfigurable system that can modify its module configuration independently in order to create an innovative manufacturing system.
- Metamorphic system - self-contained - reconfigurable
- The open fractal system is a reconfigurable system composed of proactive and active elements (fractals) whose structure repeats and monitors mutual objectives.

The following aspects are used to describe and classify different types of FMS based on its components:

Machine tools:

• General-purpose or specialized machine tools

• Automatic tool change option (increases flexibility) • In the case of tool magazines, the capacity and removability of the tool magazines are required for tool changes (affects flexibility).

System of material handling:

• Conveyor or one-way carousel; tow rope with wagons; network of wired cars; and stand-alone robotic cars are all examples.

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• Parts handling equipment: palletized or fixed parts

• Automated or manual tool delivery system.

Areas for storing the ongoing inventory:

• Central buffer storage • Decentralized buffer storage for all machine tools

• Decision mechanism: input order, priority, assigning a part to a cart, and controlling car traffic

• Component mixture control: periodic input, priority rule based on feedback

Fig. 3: Robotized flexible manufacturing system

We can categorize the described types of FMS according to their flexibilities. Advanced FMS classification is based on the properties of the mode and the four components defined above.

Type I FMS: Flexible machining cell

The Flexible Production Cell is the most straightforward and most adaptable type of FMS (FMC). It is comprised of a universal CNC machine tool and automated material handling. Provides raw or semi-finished parts for machining, loading, and unloading the machine tool from an input buffer. The container contains the buffers for the natural product area's input and output. The completed workpiece is moved to an output buffer, which is removed to its final destination. Occasionally, an articulated lever, robot, or pallet changer can load and unload raw material and finished parts.

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Given that the FMC consists of a single machine tool, one might question whether this assembly qualifies as a system. It does, however, contain all of the FMS components. Additionally, it is a critical component of the FMS. The smallest and most basic FMS is a machine tool with integrated loading, unloading, and storage capabilities.


Fig. 4: Automated, flexible manufacturing system

Type II FMS: Flexible production system

This type of FMS possesses the following characteristics: Online control of part production in real-time. It enables the production of multiple alternative parts routes with a low volume of each part and is composed of FMCs for various universal machine tools. Real-time control options can automatically allow for alternative ways for details, which complicates scheduling software. On the other hand, the actual design is more manageable with real-time control. For instance, a scheduling rule can direct execution to a random machine tool or the nearest available machine tool. The scheduling rule can be a dynamic feedback priority rule that is system-dependent. Occasionally, FMS will increase production by utilizing specialized machining tools, such as multi-spindle machining heads. The process does not determine the arrangement of machine tools. The type of parts to be machined by the FMS dictates the machine tools required. Type II FMS refers to a machine, process, and product flexibility.

Additionally, routing is highly flexible, as it adapts quickly and automatically to machine tools or other failures caused by grouping or duplicating operational tasks by machines. The various material handling options within the Type II category provides a subset of flexibility. Roller conveyors, top conveyors, pendulum conveyors, floor-mounted traction conveyors, and wire-guided wagons all contribute to the flexibility of material handling systems.

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Type III FMS: Flexible Transmission Line

The following characteristics characterize the third type of FMS. Each operation is assigned to a single machine and can only be performed on that machine. This approach results in each component having a fixed path through the system. The design is process-driven and, as a result, structured. Typically, the material handling system is a carousel or conveyor. Local storage is generally shared between computers. They may also include special-purpose machines, robots, and some specialized equipment. It is simpler to plan for machine load balancing. Because it is a dedicated transmission line, Type III FMS is easier to operate. The computer controls are more rudimentary, but the periodic input of components is realistic. After setup, it's simple to use and efficient. The distinction is in the frequency and speed of setup. Type III FMSs are less adaptable to changing processes and less capable of handling failures automatically. The system, however, can adapt by retooling and manually instructing the computer to route the components to the appropriate machine tool. This method takes longer than II. This type of FMS supports automatic redirection.

Type IV FMS: Flexible multicast transmission

The fourth type of FMS is formed by the joining of several Type III FMS. It combines the best features of Type II and Type III FMS without increasing the process's flexibility. Planning and control, like the Type III FMS, are relatively straightforward once the system is configured. The primary benefit is the redundancy it provides in the event of a routing flexibility failure.

2.5 Flexibility range

If all goes well, the Type II FMS works "flexibly" while the Type III works much more "constantly". These types provide extreme limits to, for example, flexibility. Of course, there is a range of flexibility between the two general types. However, these minor differences in flexibility can be defined as the versatility and capabilities of machine tools dictated by the specific application of FMS, i.e. the type of parts being processed. The kind of material handling devices also provide subgroups of flexibility. However, the overall flexibility depends on how the FMS works. It consists of several FACs, not all with the same device. Parts have a fixed path, but if an assembly cell stops, the parts that require it can be automatically routed to another assembly cell that contains the appropriate tools. Each FMS consists of similar components. The number and type of machine tools may vary. The flexibility of installation depends on how the whole production system works. The level of flexibility is an important strategic decision in developing and implementing an FMS.

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Historically, production costs were driven by mass production, which involved producing identical high-quality products at high speeds and in large volumes. Current prices are determined by mass customization, which means that the full range of products can meet the market's growing demands in increasing quantities. The goal of modern production is mass adaptation. This necessitates increased machine automation and intelligence levels, increasing costs and frequently slowing production. Flexible manufacturing systems (FMS) were developed to automate technological processes to address these issues. To accomplish this, businesses integrate FMS with Industry 4.0 technology.

2.6 Flexible production systems are part of Industry 4.0

FMS is primarily concerned with automating machine cells that serve as processing stations, automated material handling, and storage. The FMS is computer-controlled, enabling machines to identify and differentiate between different parts, quickly update manuals, and physically modify equipment. FMS is classified as having two types of flexibility: machine flexibility and material flow flexibility. The machine's versatility enables it to automatically control dozens of machine tools such as drills, milling machines, and lathes by combining various types of numerical control (CNC) devices. The CNC machine processes the semi-finished product (metal, plastic, wood, ceramic, or composite) by the CODE. The term "materials flow flexibility" refers to the movement of materials, parts, and finished goods from one machine to another during each production stage.

Fig. 5: Factory of Future

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CNC systems have advanced to new levels of automation in recent years, including the use of robots and cobots. Computer-aided design (CAD) advancements also contribute to enhancing FMS functionality. For instance, CAD software defines a machined part's geometric dimensions and mechanical properties and then converts them to manufacturing guidelines. Incorporating AI into the design phase via techniques such as generative design can significantly increase the product's productive capacity. [3]

2.7 Next stages for FMS

FMS is only the beginning of mass customization. Each machine can operate at peak efficiency thanks to tool selection and computer control customized to the FMS. They can, however, perform a limited number of functions once discovered. Finally, FMSs are complex systems that require a high initial investment and adjust a given set of process parameters using a combination of skilled labour and expensive robotics. When manufacturers decide, they are unwilling to incur the additional costs associated with significant changes. While this approach allows for greater flexibility, it still confines production to a set of predefined parameters. This image can be enhanced through digital transformation. For instance, we can use artificial intelligence to create models of machine decision-making.

Despite their automation, these plants offer a limited range of customization options within a single product family.

To begin, users can increase automation by adding a digital management layer (such as PLM) to an existing FMS system or by implementing new technologies that translate design parameters into manufacturing principles. 3D printing is an example of this transformation. When combined with digital design, component manufacturing, and the final product, 3D printing demonstrates inherent flexibility in many cases. However, this technology is approximately ten times more expensive per unit than the traditional approach and is intended for small-scale production rather than mass production. Producers should not stop at FMS in the face of these obstacles. Manufacturers must expand their FMS through digital transformation technologies (if necessary).

2.8 Modern Medical Device Manufacturing Trends of Today

Modernization is the driving force behind the manufacture of medical devices. Manufacturers continued to innovate in electronics, materials science, and engineering technology. The Internet of Things, artificial intelligence, and numerous new technologies are examples of current medical device development technologies.

Numerous trends, such as valuable diagnostic tools and wound healing solutions, drive new ideas, models, and tools for developing health services. Due to the multiple benefits, hospitals, clinics, and other healthcare institutions support this transformation in the medical device industry. Patients now have admission to various value-added services due to evolving trends in this field.

The following trends in healthcare industry production illustrate the industry's growth and potential for improvement.

2.9 Factory of future

The future factory is an intelligent and highly adaptable industrial environment that provides detailed real-time information to the plant's operations and management to maximize the value and efficiency of each machine and unit production.

Data networks connect the machine's components with integrated sensors and an intelligent control system using the device and plant-level communication architectures and a cloud-based solution. Advanced software collects, transforms, and processes data to illuminate production and provide valuable insights into bottlenecks, inefficient workflows, and equipment.

The potential benefits of applying this type of technology to the challenges faced by healthcare manufacturers are critical when the technology is involved systematically. The environment persuades manufacturers to expand their automated production systems and that their integration into a plant-wide network will automatically increase efficiency and improve process control.

To maximize the value of Factory of Future technology, medical appliances producers must consider several factors of their current production systems and manufacturing processes:

• The level of automation at the moment. How automated are your manufacturing processes, and is automation being used effectively? Many assembly processes are equally efficient and cost-effective for manual assembly systems, depending on the product being manufactured; the manufacturer can equip these workstations with various technologies to assist the i4.0 operator in connecting to intelligent transport systems. Numerous manufacturing sites employ a variety of machine combinations, ranging from legacy equipment that lacks intelligent control, internal sensors, and communication capabilities to state-of-the-art techniques that are fully equipped to support the future factory. To maximize your investment in I4.0, you should assess the health of your legacy systems and develop incremental upgrade strategies.

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• Fragile state. No Factory of the Future can repair actual waste and inefficient work processes. I4.0 can only be implemented successfully and perform optimally if manufacturers have a well-established culture and practice.

• The globalization process. Certain medical device manufacturers are expanding their global supply and manufacturing chains while maintaining the highest quality standards by alternating between older, more expensive manufacturing facilities and newer, less expensive manufacturing facilities capable of combining automation with automation. Manual assembly is time-consuming and can result in complications. I4.0 technology enables solutions [4], such as real-time cloud sharing and data analysis in production.


Fig. 6: Manufacturing system design

2.10 Smart Factory

Expanding product variants and decreasing order lead times – like a sheet metal processor, you require a strategy for the future. Downtime is not a viable option. Each production is unique.

Each production is unique, but one is identical in every way - production batches are shrinking. Simultaneously, required delivery times are decreasing.

Sheet metal processors frequently lack visibility into their orders, capacities, and utilization. Manual coordination and alignment are inherently complex and prone to error. Additionally, indirect processes must be optimized to operate more efficiently and shorten production times.

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We will collaborate with you to develop a flexible and permeable comprehensive system from the initial offer to the dispatch of parts.

2.10.1 Laser is the perfect tool for Industry 4.0

In Smart Factory, for example, workpieces are provided with a QR code. With it, the system can determine which direction the part is moving through the equipment and how it should be machined. Transport systems and machining stations are adhered to. For this to work, manufacturing needs a highly flexible, easy-to-use tool such as a laser. A marking laser generates the codes themselves: Unambiguously legible on all surfaces, with image processing supported by the camera during the writing process. The code contains all other information about all further machining and tracing.

Fig. 7: Laser cutting/marking

It is necessary to adapt your production step by step to the Industry 4.0 standard. At the very beginning of the list of works is often the standardization of processes and the introduction of appropriate control systems.

2.10.2 Mutual communication between machines in Industry 4.0

A standard language connects, this also involves to the appliances of the industrial Internet of Things. The easier they are to exchange information, the more efficient they are.

Therefore, the Association of German Machine Tool Manufacturers (VDW) has developed the umati (universal machine tool interface) system. It is a versatile interface that can safely, seamlessly, and effortlessly integrate machine tools and equipment into customer and user-specific IT ecosystems. The standard is not only for Germany but also for users around the world - for developing new potentials in the times of Industry 4.0.

Fig. 8: SMART manufacturing - automated manufacturing system

After an initial analysis of production in terms of Industry 4.0 (overview in production and identification of optimization potential in terms of Industry 4.0), further steps follow. With automated machines or autonomous production cells, you will achieve production growth step by step. Thanks to the right software, you will have software at hand, with which you will comprehensively digitally manage and administer all processes - from the customer's order to dispatch. Because automated and efficient processes increase productivity, they contribute to better material utilization and ensure efficient material flow.

In automated production, you will always have a complete overview of your production processes. Thanks to this, employees will be able to focus on their primary tasks, which increases

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motivation and, at the same time, the quality of parts. With automated production, you save space and make better use of your machines. You produce more economically and non-stop. On the other hand, your customers can rely on you as a reliable supplier. Overall, according to the principle: satisfied employees - satisfied customers.

With the help of an integrated production solution, it is possible to get the most out of production. It is necessary to ensure the optimal interplay of machines, automation and software components. To increase the flow of production in the production hall, increase your productivity and respond flexibly to new customer requirements. In addition, the Manufacturing Execution System (MES) constantly records all essential production data and thus contributes to the best possible overview in an intelligent plant. You can then use other applications to increase additional optimization potentials quickly.

Intelligently interconnected production components form a significant whole. This includes all sub-systems, from machines through automation to suppliers and customers. Intelligent material flow with automatic part localization enables higher productivity of all devices. Behind this is an integrated warehouse and logistics system that brings raw materials and parts to the right machining station at the right time. The machines report their production status to the central software. From there, you can track orders and automatically plan, manage, analyze and optimize your production.

2.10.3 Additive Manufacturing

The additive manufacturing process (AM, 3D printing) is critical in developing medical devices. According to SmarTech Publishing, approximately 3.2 million 3D-printed medical implants will be used globally by 2026. The widespread use of 3D printing technology creates tremendous opportunities for medical device manufacturers.

Additive manufacturing enables the medical industry to produce and transport customized medications. AM offers significant advantages over traditional methods of medical device manufacturing, such as casting, forging, or milling.

AM eliminates manufacturing constraints and barriers and introduces new features for patients and surgeons.

It assists medical device manufacturers in lowering their manufacturing costs.

It enables medical device manufacturers to create products in various sizes and designs within a single product line.

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AM enables the industry to create custom components while simultaneously developing multiple designs for a single product or series.

It enables the design of implants compatible with the body's mechanical properties.

2.10.4 Innovative materials and designs

Advances in related technologies are paving the way for medical device innovation and elevating material options and durability. The use of compact and durable cases improves the functional properties of medical facilities.

Medical appliance researchers and material suppliers constantly develop new solutions to previously unsolved problems. They identify valuable and novel materials that address healthcare organizations' current needs. Producers who incorporate this trend into their daily operations can easily position themselves in a crowded market.

Fig. 9: Examples of medic*al* devices [5]

2.10.5 Cloud solution

Medical device manufacturers have begun to embrace cloud technology, primarily in response to mounting pressure on healthcare providers to improve patient care while maintaining cost control. However, cloud solutions can provide numerous benefits, including the following:

• Lower costs while maintaining the same level of service.

• Low maintenance and ease of use;

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• Rapid collaboration between diverse product development networks.

In today's medical environment, cloud solution has proven to be more critical than ever. While cloud deployment is still in its infancy, it has benefited the medical appliance industry in numerous ways.

Fig. 10: Manual manufacturing in medicine production [4]

At first glance, peak increased productivity and near-error-free production appear to be mutually exclusive objectives. Businesses are increasingly investing in advanced plant automation systems and tools dubbed the Factory of the Future to accomplish this.

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3 Laser production

3.1 The physical principle of laser

From a physical point of view, a laser is a quantum-electronic amplifier of electromagnetic radiation. The laser is a source of intense monochromatic and temporally, and spatially coherent radiation. The principle is based on the stimulated emission of photons in the active environment of the laser.

Under normal conditions, most atoms, ions or molecules (particles) are in the lowest energy state. Suppose these particles are excited to higher energy states by the action of external energy sources, e.g. intense light flashes, discharge, immersion in a magnetic field, etc. In that case, they will emit incoherent light radiation during the jump to the original or lower energy state.

The action of external energy sources is called laser pumping. In the laser, these emitted photons move in the so-called resonator (optical), the technical design of which is a closed tube (cavity), which has metal mirrors parallel to each other at the ends, one of which is highly reflective and the other semipermeable, allowing the beam to exit. The current of photons thus obtained has an identical wavelength, direction and phase. Mirrors do not control photons that are not arranged by a resonator; the cavity will amplify only those photons that are correctly oriented.

The states and phases of laser amplification are:

- the active medium particles are in an unexploded state
- the initial state of spontaneous emission
- advanced state of spontaneous emission of excited particles by an external source to higher energy levels
- the initial state of the stimulated photon emission after the collision of the emitted photons
- amplification phase, multiple reflections of photons between mirrors
- a phase of a coherent beam emanating from a semipermeable mirror.

The process is permanent (it does not mean continuous) as long as the inverse population is secured. The inverse population is a necessary condition for laser operation.

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The unique properties of the laser are monochromaticity (monochromaticity, radiation at one frequency). In practice, laser light consists of several spectral lines of a minimal width (complete the picture from the manuscript). Monochromaticity is important in interferometry, holography, velocity and distance measurement, isotope separation, and communication and information technology. It is not essential for laser machining.

The spatial and temporal coherence shows the connection between the electrical and magnetic parts of an electromagnetic wave. If these components are all arranged in a row - the beam is coherent. (The analogy can be a group of marching soldiers when looking at the boards from the front, the arm is at the shoulder - spatial coherence, when looking at the group from the side, the distances do not change when the group moves - time coherence.

Bending is a phenomenon in which light bends around a sharp-edged object. The minimal scattering of laser light causes it to reach much further than regular light when reflecting. Divergent angle, e.g. The HeNe laser is 0.2 mR.

The luminosity of a light beam is essentially light output and is expressed in W / m 2 / steradian. A standard HeNe laser with an outcome of 1 mW has a radiance 100x of magnitude higher than the sun's surface. The radiance cannot be raised by optical manipulation, and it depends mainly on the construction of the cavity.

3.2 Essential elements of a laser

Each laser consists of three essential parts:

- An active amplification environment contains atoms, ions, or molecules capable of exiting emission energy levels and providing an inverse population.
- The source of energy that causes this excitation.
- Optical resonator, which ensures multiple reflections of photons from plane-parallel mirrors of the cavity.

Types of lasers

Lasers are most often divided according to the active environment (type of pumping):

solid-state lasers

- gas
- liquid
- chemical

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• semiconductor

according to the working value of the wavelength.

Virtually all lasers can operate in two-time modes:

• continuous-wave - the laser glows without interruption

• pulse mode - the laser glows periodically (intermittently).

Solid-state lasers use ions released into the crystal lattice. The active medium is formed by a specific type of crystals or glass doped with ions of one of the groups of transition elements of the periodic table (e.g. Cr ^{3}+ ions, rare earth metal ions, especially Nd 3+. Semiconductor lasers are solid-state lasers, are therefore considered as a separate group.

Ruby laser

The active medium consists of Al_2O_3 + Cr_3O_2 (Cr gives it a red colour) in the shape of a rod with ground plane-parallel surfaces at the ends around which the tube is wound as a xenon or selenium lamp as a source of pumping. The typical working wavelength is 694.3 nm, the average power does not exceed 1 W, the maximum capacity in the pulse mode of 1 ms is $10\text{-}10^{4}$ W with an efficiency of 0.1%. It is mainly used in holography and distance measurement.

Neodymium laser

The active environment of this type of laser is $Y_3Al_{15}O_{12}$ (laser is known as YAG), the typical wavelength is 1.06 μm, power in continuous mode is up to 150 W, maximum power in pulse mode up to about 2.10^{4} kW

Gas lasers

The active medium is a gas or a mixture of gases. A sufficiently intense electric discharge is usually sufficient to pump these types of lasers.

Depending on the composition of the laser medium, gas lasers are further split into groups:

a **gas neutral of atom**

He Ne (the most popular visible laser with a wavelength of 0.6328 μm) The required "avalanche" properties have the Ne-atom, the passage of electrons, and the presence of He initiates a discharge, the energy of which is transformed to Ne atoms in a low-pressure discharge tube. Energy efficiency does not exceed 0.1%, and the typical power is 50 mW. It is used in holography, scanning, stakeout, measurement, and fibre communication networks - wherever a low energy level is sufficient.

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An electric discharge starts the excitation process, which is accomplished in two ways: the gas is ionized, and the electrons are brought to an excited state. gas laser or ion laser. The ion laser makes use of ionized gas. such as Ar, Kr, Xe, which produce a laser beam with a wavelength of 0.5 - 1 µm. The resulting beam can reach a power of up to several watts. The application spectrum mainly includes spectroscopy and surgery.

- **Molecular** laser uses gas molecules as a laser medium. The molecules are excited to vibrational states. Photons provide transmissions between different vibrational states. Representatives of this type of laser are CO, HF and CO_2 lasers. The CO_2 laser is suitable for machining applications. In the far-infrared range of the electromagnetic spectrum, it emits light with a wavelength of 10.6 m. CO2, N, and He are all used in the laser medium.

The laser mechanism differs from previous types here. CO_2 molecules are not adequately excited until they collide with N molecules, which add energy to them (excitation is achieved by increasing the vibrational energy). For CO_2 molecules, the loss of light energy and heat during energy transfer is much less than other lasers. The energy efficiency of this type of laser is up to 10%.

They are designed depending on the discharge's geometric arrangement and the tube's gas flow for the power of several W to 15 kW. The application area of this type of laser is machining, welding, heat treatment, etc.

Type 1 If the gas flow is not controlled, the maximum power is about 50 W, and the life of the laser ends with the dissociation of CO_2 into $2CO + O_2$.

Type 2 of this laser is an axial flux laser. Axial flow makes it possible to replace "depleted" CO_2 with new ones. Typical power is up to 4 kW in continuous mode. Up to 1 kW, the intensity profile has a Gaussian distribution. These axial flux lasers can be further distinguished as low-speed lasers, where the power per standard meter of the tube is about 60 W. High-speed flux lasers (60 m / s) have a typical power of 600 W per tube meter with a total power of up to 6 kW. Due to the medium's fast flow, the resonator's thermal effect is relatively more minor than with the previous one, but it is also necessary to cool in this case.

A He, N 2, and CO2 gas flow perpendicular to the optical cavity in Type 3 CO2 lasers. 10kW / m is the typical power. Zinc selenide or gallium arsenide is used for the optics.

An excimer laser, for example, uses xenon Xe, fluorine F, and other rare gases as a laser medium. ArF, KrF, XeF, and others are examples of excimer complexes. When a noble gas is stimulated, these compounds form (in the excited electron state). Although strong, the bond only lasts a few nanoseconds. Each complex molecule decomposes into elementary compo-

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nents when the noble gas atom is no longer stimulated, releasing binding energy in the form of photons in the process.

Excimer lasers generate high-power pulsed beams with an average power of more than 100 W and a pulse rate of 1000 Hz. These lasers' material removal procedure differs from CO2 and Nd: YAG lasers in physics. It is a thermal transformation from solid to liquid instead of melting and evaporation, which removes the substance. Excimer lasers scan the material to convert it to a gaseous state via ablation, which disrupts the substance's chemical bonds and dissociates it into chemical components.

There is no formation of liquid or gaseous phases! Photons are absorbed by organic materials in a thin layer at the surface, breaking the connections between organic components. The capacity to focus the beam on a tiny area and cross the workpiece is another advantage of the excimer laser over CO2. These lasers generate a large-diameter beam focused on the workpiece using a lens after passing through a mask. (The contact will be utilized as a disguise.) the energy density of the unfocused excimer laser is 100-200 mJ per cm2. Most laser light is reflected by the lid, which is constructed of metal. For example, the excimer laser can drill 5,000 holes in a polyamide strip in 3 seconds versus 50 seconds for the CO2 laser.

Liquid lasers

The active medium of these lasers is a solution of a specific organic dye in water, methanol or ethanol. Lasers emit at wavelengths in the range of about 0.4 - 1 µm. Their typical feature is the possibility of returning. They are used in photochemistry, spectroscopy, etc.

Chemical lasers

The inverse population in these lasers is achieved through a chemical reaction. The representative of this group is, e.g. hydrogen fluoride laser. The output power level refers to CO2 lasers.

Semiconductor lasers

Operating conditions of lasers. A typical modern representative of a semiconductor laser is the GaAsAl laser used in computer, information and consumer electronics (CD, MD, DVD). Unlike other types of lasers, where the wave functions are related to a molecule or an atom, it is necessary to apply the wave functions to the crystal as a whole in semiconductor lasers. Apart from the wide range of possibilities for lasers, the knowledge in this section will be aimed at

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the industrial and especially production use of lasers. Some ideas in the following text agree with the fictitious installation of a high-performance laser workplace.

3.3 Laser power

There is a range of relevant, helpful laser power for a given application and material. As mentioned, the efficiency of lasers is in the field of 0.1 to 15%. When choosing the output power of the laser, the efficiency must be taken into account in terms of power dimensioning.

With the undersized selection, the process will be slow, and some machined materials, resp. their thicknesses, will be irrelevant to the choice. The highest continuous power is provided by CO_2 lasers, the highest pulsed power - Nd: YAG laser.

The level of required laser power is based on data of optical and thermal properties of the machined material, e.g. the ceramic material requires increased laser power due to the high latent heat typical of this type of material.

The optical properties of the material are manifested when the beam strikes the workpiece. The absorbency of the material has the most significant effect on the performance of the laser. Absorption determines the proportion of energy components absorbed and reflected into the environment. The absorption coefficient varies depending on the incident beam's wavelength, the machined surface's roughness, the temperature, and the possible type of coating on the workpiece surface. A specific correction is performed concerning the required thickness, shape and other parameters of the workpiece. E.g. Al and Cu and their alloys have low absorption for rays with a wavelength of about 10 μm (CO_2 laser) but much higher for beams with a wavelength of about 1 μm (Nd: YAG laser).

The laser time mode can be:

- continuous and
- intermittent.

The pumped energy is retained intermittently until a particular threshold is achieved, at which point the subsequent discharge triggers a beam pulse. Deeper holes may be drilled, more significant thicknesses can be cut, and the workpiece is subjected to less thermal stress (suitable for polymers). Continuous mode offers the advantage of a more acceptable machined surface and is applied where large removals are required.

The type of time mode depends mainly on the kind of laser medium. For gas lasers, a continuous mode is typical; for fixed lasers - a pulse mode.

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Spatial mode

A transverse electromagnetic mode can identify the beam profile (TEM). Because the frontal phase of the beam is uniform, the TEM 00 mode, which has a Gaussian spatial distribution, is regarded as the best mode for laser machining. There is slight bending during focusing, and the mode allows you to achieve the largest beam diameter possible. If you need to expose a broader region, you can use other modes (e.g. welding, heat treatment).

Size of the focused area

is of paramount importance in machining operations. A low-divergence laser beam can be focused on a smaller area than a high-divergence beam.

Practical use of laser in machining

Cutting, welding, marking, surface treatment - more and more experts in production technology appreciate the laser's flexibility, versatility, and cost-effectiveness as a tool.

3.3.1 Disk laser

The use of disk lasers is extensive. From the creation of hair-sized holes through the surface treatment of metals to the welding of ship panels. Whether a CW laser or an ultrashort pulse laser. Disc laser technology shows its advantages in every segment at high pulse energies and high medium powers.

The laser powers are from 1 to 16 kW.

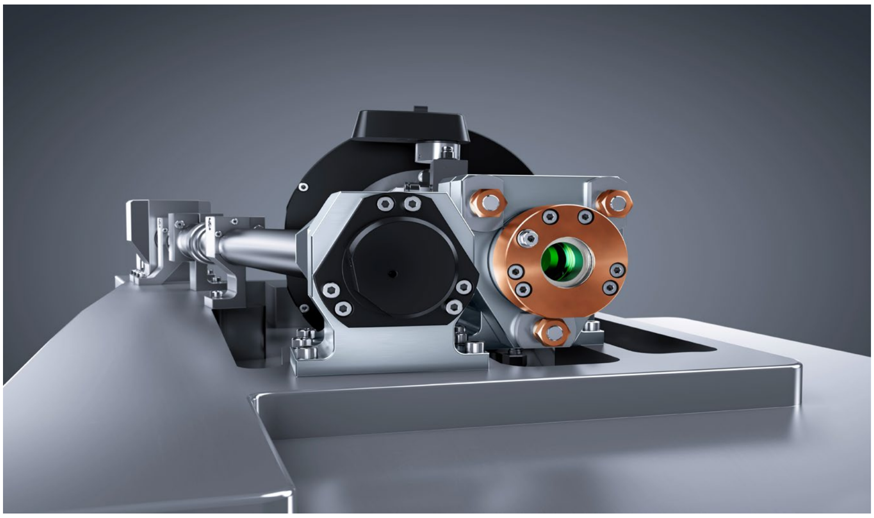

Fig. 11: Disc laser

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3.3.2 Fibre laser

As a durable "all-in-fibre" resonator design, it has a compact floor plan, a long service life, and outstanding single-mode (SM) beam quality of up to 2 kW or multi-mode (MM) power up to 6 kW. Our fibre lasers may also be smoothly incorporated into more extensive systems thanks to a 10 m long SM or up to a 20 m long MM transmission fibre and versatile laser communication and control options.

The solid-fibre fibre laser is a fine-work precision laser. It impresses with its Single Mode beam quality and the number of power classes available. While fibre lasers with lower power classes (up to 1 kW) are best for fine cutting and welding, those with higher power classes (beyond 1 kW) excel at frequency sweeping welding.

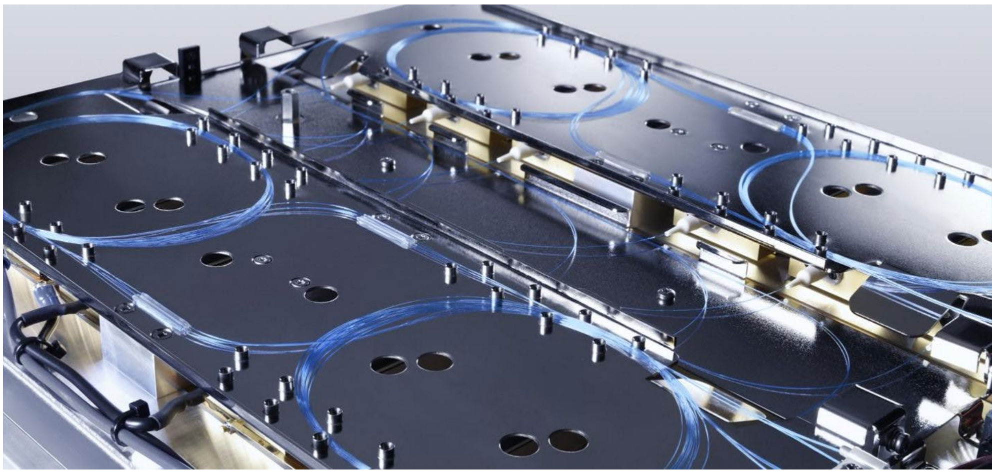

Fig. 12: Fibre laser

3.3.3 Diode laser

Diode lasers with high efficiency deliver optimal outcomes in low investment and operating costs in applications. Lasers can reliably deliver up to several kilowatts of laser power. Deep, heat-conducting, laser welding, and soldering and welding of polymers are typical applica-tions. Production running costs are reduced by up to 40% due to high efficiency. The lasers are tiny since no additional resonator design is required.

They consistently deliver up to 6 kW of laser power at the highest efficiency. These lasers have a higher readiness and longer life due to passive diode cooling.

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Fig. 13: Diode laser

3.3.4 Pulsed lasers

Pulsed lasers enable the generation of short, energetically intense pulses with high pulse power. Thanks to this, they are highly suitable for spot and stitch welding of almost all metal workpieces, with minimal thermal influence. Pulsed lasers are also used in the micromachining of material and laser marking. Pulsed lasers provide high durability and the possibility of modular construction.

Pulsed solid-state lasers cost-effectively weld a wide range of materials. Short pulses with a high kilowatt tip power are ideal for spot and stitch welding with low thermal effects. Pulse energy and laser beam guidance can be easily adapted to each application individually.

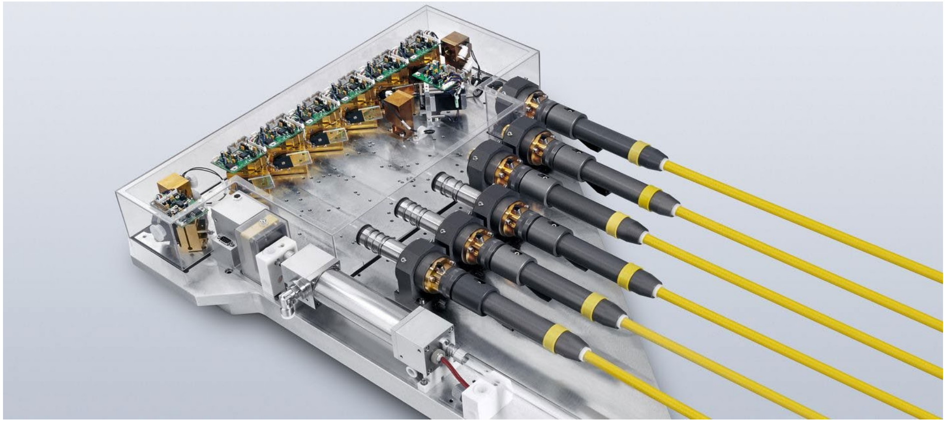

Fig. 14: Pulsed laser

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3.3.5 Laser with short and ultrashort pulses

Lasers with short/ultrashort pulses are helpful for the micromachining sector. They can be used for all types of standard machining on a wide range of materials, including cutting, drilling, removing material, and structuring. Nanosecond lasers (ns-lasers), ultrashort pulse lasers, picosecond lasers, and femtosecond lasers are examples of lasers (ps- and fs-lasers). These ps- and fs-lasers enable cold machining of the material with essentially little heat input to the workpiece even at moderate medium energies. Short and ultrashort pulse lasers have medium capabilities ranging from a few watts to several hundred watts.

Fibre-based ultrashort pulses have a compact and lightweight architecture. The integration of the laser is substantially more accessible thanks to hollow-core fibre technology. Soft, medium power combined with good beam quality offers new application possibilities, such as medical technology and film processing.

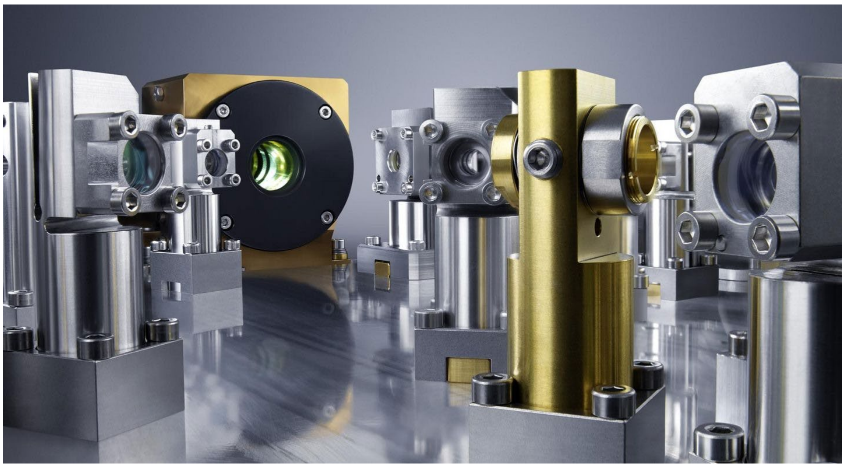

Fig. 15: Ultra short pulse laser

3.3.6 Marking laser

There is a large selection of marking lasers in various power classes and all standard wavelengths (infrared, green, ultraviolet). They are suitable for keeping engraving, material removal, tempering, marking, dyeing, and foaming. In addition to metals, marking lasers also machine many other materials such as plastics, glass, silicon, ceramics, and organic substances. All marking lasers are usually modular and can therefore be easily integrated into the system.

Fig. 16: Marking laser

CO_2 laser

Tens of thousands of CO_2 lasers are doing different cutting and welding operations in production halls worldwide. These lasers can be supplied in various powers from 2 to 20 kW. The wavelength of 10.6µm is very flexible for different types and thicknesses of material. Laser processes run stably, productively and without splashes. Thanks to its compact design, CO_2 lasers can be easily integrated into existing devices.

CO_2 lasers are suitable for efficient and cost-effective machining of a wide variety of materials. With the help of lasers, it is possible to cut and weld two and three-dimensional workpieces, or you can use them for surface treatment.

3.4 Additive method of laser production

There has been significant development of technologies and materials for additive manufacturing (AM - Additive Manufacturing). The use of additive technologies in medical applications is becoming more widespread and is part of the revolution in healthcare. It brings many benefits, especially the personalization of medical products, biomimetic principles, cost reduction, increased productivity, integration of appropriate geometry and material optimization.

In medicine, effective use of AM can be observed - in the production of joint replacements or precise and complex individual implants for various fields of medicine, such as neurosurgery, maxillofacial surgery, traumatology, thoracic surgery, dentistry, plastic and aesthetic surgery and the like. We describe the possibilities of metal additive production, its advantages over standard production technologies used in medicine, an overview of manufacturers of equipment and types used in medical applications, and a description of selected medical and dental applications.

Additive manufacturing includes technologies that create an object from three-dimensional (3D) data by making successive layers from the desired material. AM is commonly referred to as 3D printing, which uses computer-automated manufacturing (CAM) processes to produce physical 3D objects layer by layer from models using computer-aided design (CAD). Plastics, ceramics, metals, liquids, and living cells can all be employed in this technique, making it incredibly versatile. AM is relatively accurate and cost-effective, enabling reliable production of objects adapted to the user and the application. The share of AM in individual industries, with medical applications accounting for about 16%.

Polymeric materials are most commonly used in total AM production, accounting for up to 59% of the total output. Subsequently, the second most widely used material is metal - 32% of all applications. Initially, additive technologies were used to produce prototypes. Later, for piece production, today we can talk about small series production in various industries.

3.4.1 Overview of metal 3D printing in medical applications

Additive technologies have been used in medicine since 2000 when they were first used to manufacture dental implants and prosthetics. An excellent example of medical applications is individual implants, which are time-consuming and expensive when using traditional machining methods for production. Specialized or customized surgical instruments help shorten the operation time. Improving ergonomics or making the device easier to use helps the surgeon and reduces the risk of the implant not being fixed properly.

In medical applications, additive manufacturing methods are used, such as the direct sintering method of metal powder (DMLS), selective laser sintering/melting (SLS / SLM), direct printing from metal powder (DMP), the method of electron beam melting (EBM). These technologies use a powerful laser, resp. Electron beam melts the metal powder to create the desired geometry compared to casting technology, e.g. dental prostheses, custom porous implants, surgical guidance systems and many other medical devices.

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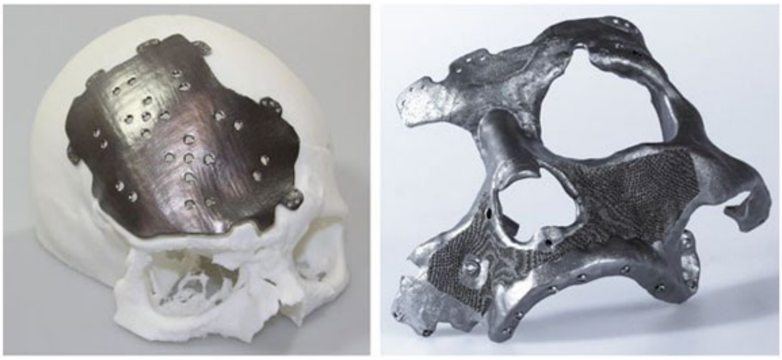

Fig. 17: Skull implants

The future in AM of tissue and organ replacements is the 3D printing of cells on the so-called carriers or structures to form scaffolds. Therefore, 3D printing of human cells and cell structures could help in drug testing and thus become an integral part of the pharmaceutical industry, where the ethical benefits of eliminating animal testing are invaluable. It is assumed that bio additive production will be part of manufacturing hospitals, where tissue and organ replacements will be designed and manufactured.

3.4.2 Additive metal production in implantology and dentistry

Implants and dental prostheses can be made in almost any conceivable geometry by transferring X-ray, MRI or CT scans to digital printable 3D file formats stl. AM is now commonly used in the manufacture of dental, spinal and lumbar serial implants and custom-made implants for various parts of the human body.

Corrosion resistance and especially biocompatibility. In medical AM, in addition to polymers, the use of metal alloys, mainly based on titanium (e.g. cp Ti, Ti-6Al-4V - Grade 5, Ti-6Al-4V ELI - Grade 23), is widespread due to their strength, stiffness, low weight. Titanium enables the production of a porous architecture with a defined geometry for fixation while reducing the resistance to stress arising from the implant's contact with the tissue (so-called stress-shielding effect). In addition to titanium, stainless steel and cobalt alloys are also used.

Cobalt chromium alloy (CoCr) is the most widely used material in the dental field, mainly due to its simple processing and relatively good biocompatibility. CoCr alloy is used in dentistry to produce removable partial dental prostheses and metal structures (crowns and bridges). Also, in the dental field, the focus is mostly on alloys of cobalt and titanium.

The production of dental prostheses and structures has been advancing rapidly over the last 30 years, mainly due to the development of simulation, digitization and implementation of additive technologies. The use of CAD / CAM systems in the dental field has led to the elimination of many manual activities, increased accuracy of dental prostheses and structures, and reduced production time. Additive technologies were developed as an alternative to subtractive technology for crowns and bridges (milling).

Additive technology offers many advantages over the subtractive or traditional method of making dental prostheses. The first advantage is the possibility of producing geometrically more complex elements and the controllability and speed of the production process. Other advantages are the possibility of production from different materials and optimization of mechanical properties. At present, a relatively wide selection of additive technologies is available for use in implantology and dentistry.

Introducing a new production technology requires experimental testing - verification to set the quality of processes and products in dentistry and implantology. It is essential to set up production in terms of new standards, which various institutions gradually require. US FDA.

The development of metal additive production in medical applications reduces funding in terms of costs for manufacturing companies or even patient care costs. Additive technologies allow the application of environmental principles to create optimized products using biomimetics (inspiration by nature, e.g. porous structures, biomechanical and mass optimization). However, there is still room for research and development in this area, especially in creating new materials (e.g. magnesium alloys, memory or intelligent materials), accelerating processes, and ensuring repeatability of production. Simplifying work with these production technologies.

Various geometries of workpieces Prototypes, one-of-a-kind items, small and huge series Like few other processes, additive manufacturing (3D printing) is forging the manufacturing industry's future. Using an additive manufacturing method, such as laser sintering or laser melting, it is possible to produce workpieces with the highest material requirements and create surface treatments or repairs. In contrast to typical, unorthodox manufacturing procedures like turning or milling, the design of an additive manufacturing method is defined by the manufacturing process itself, which is also known as "Design for Additive Manufacturing" (DfAM).

Over the previous 20 years, two laser methods of generative production have been put into practice, which can be used to quickly, flexibly and cost-effectively create demanding shapes and individual metal workpieces in layers of metal powder: Laser Metal Fusion (Laser Powder Melting) and Laser Metal Deposition (laser surfacing).

With the additive production method, there are no boundaries in the field of construction - it is even possible to integrate functions that cannot be implemented in the conventional production process or create complete structural groups in one go.

• With 3D printing, you can quickly and flexibly create customer-specific solutions and personalized workpieces - even in series production.

• Thanks to the high stability of complex structures and at the same time the minimal weight of additively manufactured parts, the process is desirable for light constructions.

• With 3D printing, the required workpieces and geometries are created in a targeted manner and only with the needed material.

• Since no tool is required with the additive production method, you work more cost-effectively and avoid wear and tear and installation time.

Examples of AM

• Individual skull implants or dental crowns and bridges (LMF)

• Additive technology for manufacturing heat exchangers with the most delicate lattice architectures (LMF)

• Corn Cutter Finishes to Improve Lifetime (LMD)

• Compressor blade repairs after wear (LMD)

Numerous versions, ever smaller production batches - the tendency is obvious in a wide variety of businesses.

Laser Metal Fusion (LMF) and Laser Metal Deposition (LMD) are two laser-based methods that address these issues, improving the industrial appeal of additive manufacturing (3D printing).

3.5 Laser Powder Melting (LMF)

Laser Metal Fusion (LMF) - - is a method of additive manufacturing in which a workpiece is created in stages within a powder bed. The laser melts the metal powder precisely in layers at the locations designated in the workpiece's CAD design files. As a result, this method is frequently referred to as 3D metal printing, and the industry also uses the terms laser sintering and laser melting interchangeably. The technology is optimum for the serial manufacture of geometrically complex objects with intricate internal channels and empty spaces that cannot be produced efficiently using standard turning or milling techniques. Industrial 3D printing produces high stability and low weight workpieces – especially advantageous for lightweight

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constructions or custom-made implants and prostheses. Additionally, laser melting of the powder is a more durable manufacturing process than material removal procedures since no chips are generated. As a result, surplus material is kept to a minimum.

• With LMF, users can directly create functional workpieces from 3D CAD models - e.g. flexible or rotating structures.

• With LMF, it is possible to produce workpieces with bypass cooling. These dissipate heat immediately from where it arises.

• Additive method of production allows the creation of detailed structures in a comprehensive design.

• Freedom of design: in 3D metal printing, the production of the workpiece is determined by the method - as opposed to conventional manufacturing processes.

• Almost no set-up times occur with 3D metal printing. Thanks to the Multilaser option and automation components, the efficiency of your production is further increased.

• Closed powder circulation contributes to a clean and safe production environment.

At the beginning of the laser powder melting process is a virtual 3D model of the workpiece. During data preparation, the design data is converted into machine-readable print program data. In doing so, the workpieces are adjusted on the base plate, and, if necessary, a support structure is placed. For the printing process, the workpieces will be broken down into several layers ("cuts") and the respective paths of the beam movement ("hatching") will be defined. The formation of the workpiece in layers is finally carried out on a base plate in a working chamber under shielding gas. The chambers are located next to each other on one axis: a cylindrical reservoir, a construction, and an overflowing cylinder. The applicator applies the powder from the roller hopper to the construction roller. Finally, the laser melts the first layer of powder according to the part's geometry cohesively to the layer below it. In the next step, the structural roller drops down one layer. The workpiece is produced in a so-called powder bed. Excess powder ends up in the overflowing cylinder. This process is repeated until the entire part is created. To increase productivity, it is possible to use multiple lasers that work simultaneously. We are talking about the so-called multilaser principle. The finished part is finally freed of metal powder in the unpacking station. Finally, the workpiece is separated from the plate, and the support structures are removed if they are part of the workpiece and, if necessary, the workpiece is finished.

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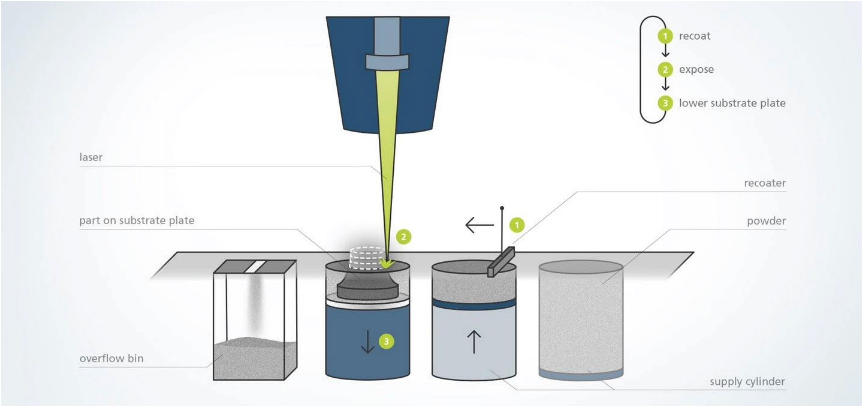

Fig.18: Laser Powder Melting (LMF)

3.6 Laser surfacing (LMD)

Laser surfacing is a generative manufacturing process for metals. It is mostly internationally referred to as "Laser Metal Deposition", or LMD for short. There is also talk of "Direct Metal Deposition" (DMD) or "Direct Energy Deposition" (DED). The process is explained: The laser creates a melt on the surface of the workpiece. The metal powder is fed automatically through the nozzle. Welded weld caterpillars are formed, which form structures on existing bodies or entire workpieces. The process is used in aerospace, energy technology, petrochemistry, automotive industry and medical technology. Thus, it is possible to combine laser welding technology (LMD) with laser welding or laser cutting.

• Coarse and very fine structures are created by laser welding, with high application rates compared to other generative processes.

• Numerous powder containers can be active during the process, from which your alloys can be created as needed.Thanks to the combination of different materials, layered structures are built.

• With the help of laser welding, it is possible to apply 3D structures to existing uneven surfaces and thus quickly implement changes in geometries.

• With laser welding, it is possible to change the material in one working process easily.

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Thanks to the generative process, workpieces are created only from powder and light in the 3D printing machine. 3D printing create the future of industrial production. Highly productive laser machine tools enable innovative operation in surface treatment and repairs thanks to laser welding.

For the industrialization of 3D printing, there are complete solutions for digitization, service and different production systems.

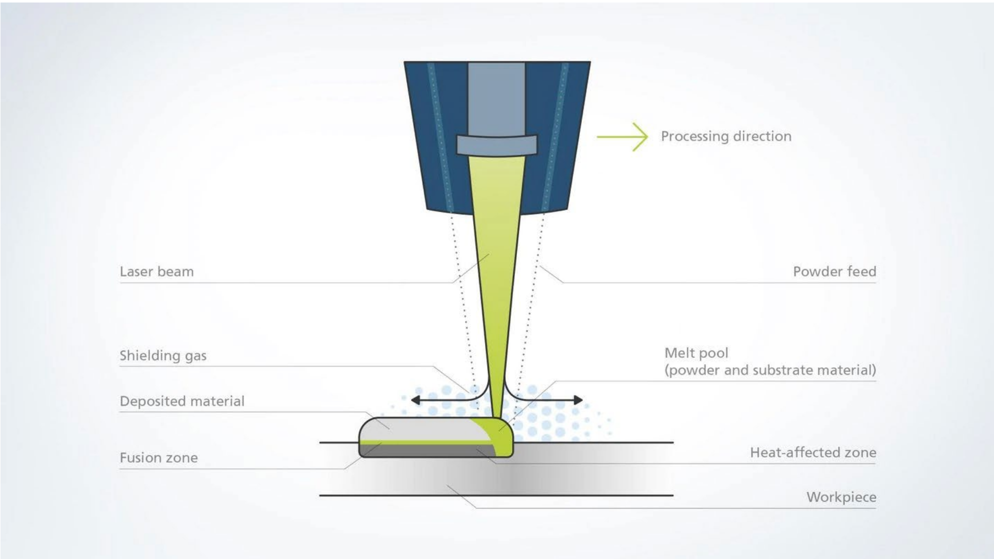

Fig.19: Laser Surfacing

3.7 Hybrid additive production: flexible 3D metal printing with

Conventional and subtractive technologies are still the standard in production halls. Complexly shaped components made of forgings and castings often have to be costly machined. Up to 90 % of the raw material is still used to produce high-performance and lightweight components in the aerospace industry. In contrast, in additive production, the pieces are arranged in layers. Not only are resources saved and production waste prevented, but production is also highly flexible.

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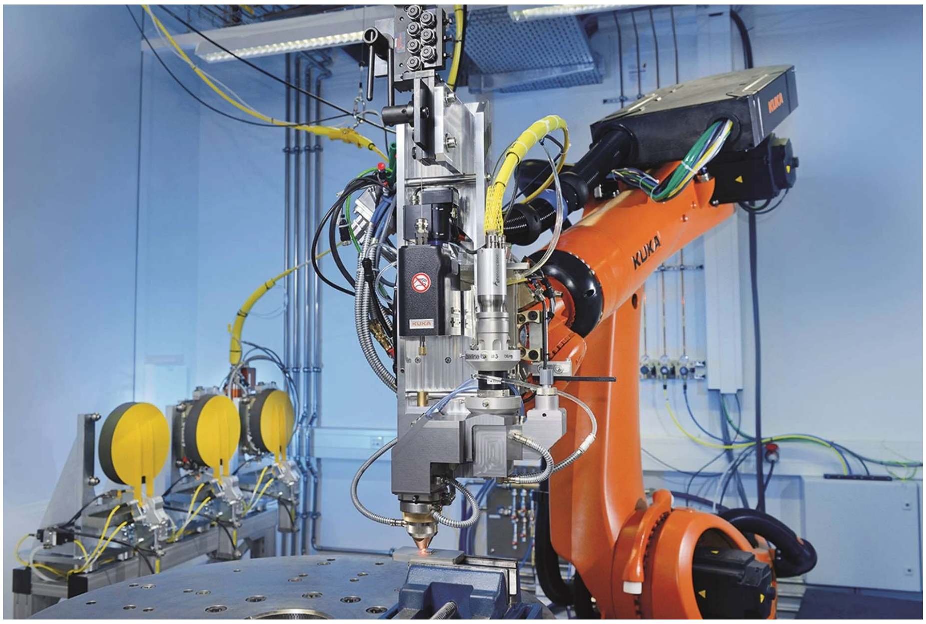

Fig. 20: Hybrid additive manufacturing by robot

A practical alternative to traditional methods is hybrid additive production. The raw parts are produced conventionally, for example, by forging or casting. Still, the different geometries are applied by an additive method, and the components thus acquire an individual dimension - e.g. using LMD laser surfacing. The advantage over other additive techniques is the high application rate. Possible to produce, for example, locally reinforced structures for aircraft or highly functional components for turbines. However, the widespread use of this technology is still often hampered by high costs and demanding processing conditions.

Various manufacturers are developing systems to use LMD technology, robust and efficient production and system technology in producing significant components. This system is intended to meet state-of-the-art production techniques and high safety requirements in industries such as aerospace. Standardized system technology based on industrial robots offers cost advantages. Thanks to the use of a fibre-based system, the robot remains almost indefinitely in its workspace. It is thus possible to flexibly consider the geometry and size of the components - even with small production batches.

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3.7.1 2D laser machining equipment

CO_2 and solid-state lasers are commonly used for these applications. Only the application decides which laser machine is suitable. Don't just look at clean cutting time. It is necessary to optimize the previous and next processes related to laser cutting.

Solid-state laser - With the help of a solid-state laser, you will cut quickly, especially in the area of thin sheets. It is possible due to radiated radiation with a wavelength of approximately 1.03 µm. The material more strongly absorbs the energy than at the 10.6 µm wavelength with the CO_2 laser. The laser supplies more power to the sheet so that we can be cut it faster.

CO_2 laser - The CO_2 laser is a proven industrial laser, durable and robust. The edges cut by this laser are of such high quality that you can usually avoid additional workpiece modifications. Reason: The wavelength of 10.6 µm contributes to the formation of edges with very low roughness - the workpieces are immediately ready for further processing.


Fig. 21: 2D Laser machining equipment

3.7.2 3D laser machining equipment

In case it is necessary to cut not only 2D but also 3D parts, profiles or tubes, in addition to beam sources and components for the laser beam path, there are also complete machines and systems in which all members are optimally coordinated with each other.

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Fig. 22: 3D Laser machining equipment

3.7.3 Laser welding equipment

Laser welding equipment is an ideal tool when it is necessary to accurately weld metals. At the same time, it is possible to optimally combine both materials with high melting temperatures and high thermal conductivities. Thanks to fast programming and simple operation, the arc welding cell allows easy entry into the world of automated welding.

With laser welding, you produce workpieces with almost no deformation with the highest accuracy. Visually demanding welds require virtually no subsequent modifications. At the same time, these devices offer highly productive processes for large numbers of pieces with high repeatability or flexibility for changing production batch volumes.

3.7.4 Laser pipe cutting machines

Pipes and profiles are used everywhere - from the manufacture of machinery and equipment to the furniture industry. At the same time, the laser opens up new possibilities for construction. Therefore, more and more designers are betting on the advantages of laser-cut pipes and profiles, which significantly increases the demand.

Solid-state laser With the help of a solid-state laser, it is possible to cut quickly, especially on thin sheets.

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The CO_2 laser is a proven industrial laser, durable and robust. The edges cut by this laser are of such high quality that you can usually avoid additional workpiece modifications. Reason: The wavelength of 10.6 µm contributes to the formation of edges with very low roughness - the workpieces are immediately ready for further processing.

Fig. 23: 3D Laser pipe cutting machine

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4 Robotized assembly and material handling

4.1 Description

We can characterize industrial robots and manipulators by their electromechanical system, which has a higher degree of integrated electronics while transferring objects, grasped, assembled, or possibly machined. These are universal automated mechanisms that can perform movements similar to the actions of the hand or human arm. Industrial robots differ from other machines by the following features: flexibility, programmability, target orientation, exchange of information with the environment, automatic operation, or mechanical action on the environment.

Current trends in development and research have enriched the definition of industrial robots with two new possibilities:

• the robot should have a consistent and intelligent structure and use it to implement and plan its activity,

• to carry out the successful automatic operation of an industrial robot even during changing environmental circumstances that he did not have to know.

The industrial robot is suitable for operations that require a fast and accurate sequence of functions without moving the worker around the robot.

The revised definition speaks of an industrial robot as an autonomous, complex, programmable, universally usable automatic device. Its task is to perform predetermined functions in mechanical interaction with the environment and the simultaneous exchange of information using targeted, flexible action. The robot may not know the surroundings changes. The robot should have a consistent and intelligent structure to carry out and plan its activity.

From a design point of view, industrial robots and manipulators are very complicated devices made of advanced elements, and therefore their classification is exceptionally complex and complex. Depending on the complexity of the structure, the uniqueness of the design, the interrelationships between the execution mechanism and the control system, we divide the handling equipment into:

• single-purpose manipulators,

• universal manipulators:

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  - synchronous manipulators:
    - teleoperators,
    - exoskeletons.
- programmable manipulators:
  - industrial robots of the 1st generation,
  - industrial robots II. generation,
  - industrial robots III. generation.

According to the tasks they perform, we divide them into:

- industrial handling robots,
- industrial, technological robots,
- specific industrial robots.

Industrial robots can also describe mechanical systems used to transmit forces and movements to guide an object along a specified route or convert a particular type of automatic movement into another. In the kinematic mechanism of PRaM, two parts can identify that fulfil different functional tasks. The technological or gripping output head defines orientation capability with its joint. The remaining part of the device affects the manoeuvrability of PRaM and the dimensions and shape of the functional space. In the construction of PRaM, kinematic pairs are usually present, characterized by one degree of freedom, either translational or rotational kinematic pairs.

The primary concepts of kinematics include:

- joint - technical construction of the binding,
- binding - restriction of mutual movement of two bodies,
- frame - the part that fixed, mostly merged with the ground,
- gripper - a part that manipulates tools or objects,
- kinematic pair (KD) - a pair of bodies that connected by a bond, representing two moving parts of the robot connected by a translational (sliding) kinematic bond T or a rotary (rotational) bond R,
- kinematic chain - represents a system of kinematic pairs,
- operating space - the space into which the robot enters any part of it during manipulation,

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• workspace - the set of all points into which can place the gripper.

• degree of freedom (DOF) - the object has as many degrees of freedom at a particular point as there are dimensions in the space where it can move at a specific position.

Industrial robots with serial kinematics

The following types of kinematic structures characterize the four groups of the most common robots in current practice

• three translational kinematic TTT pairs,

• one rotary and two RTT translation pairs,

• two rotaries and one translational pair RRT,

• three rotating RRR pairs.

The working space of the robot is determined by connecting kinematic pairs. The area that surrounds the robot arm reference point is called the workspace. Workspaces of basic types of kinematic structures can be:

• TTT - block (rectangular, Cartesian space),

• RTT - cylindrical space,

• RRT - spherical (spherical) space,

• RRR - angular space.

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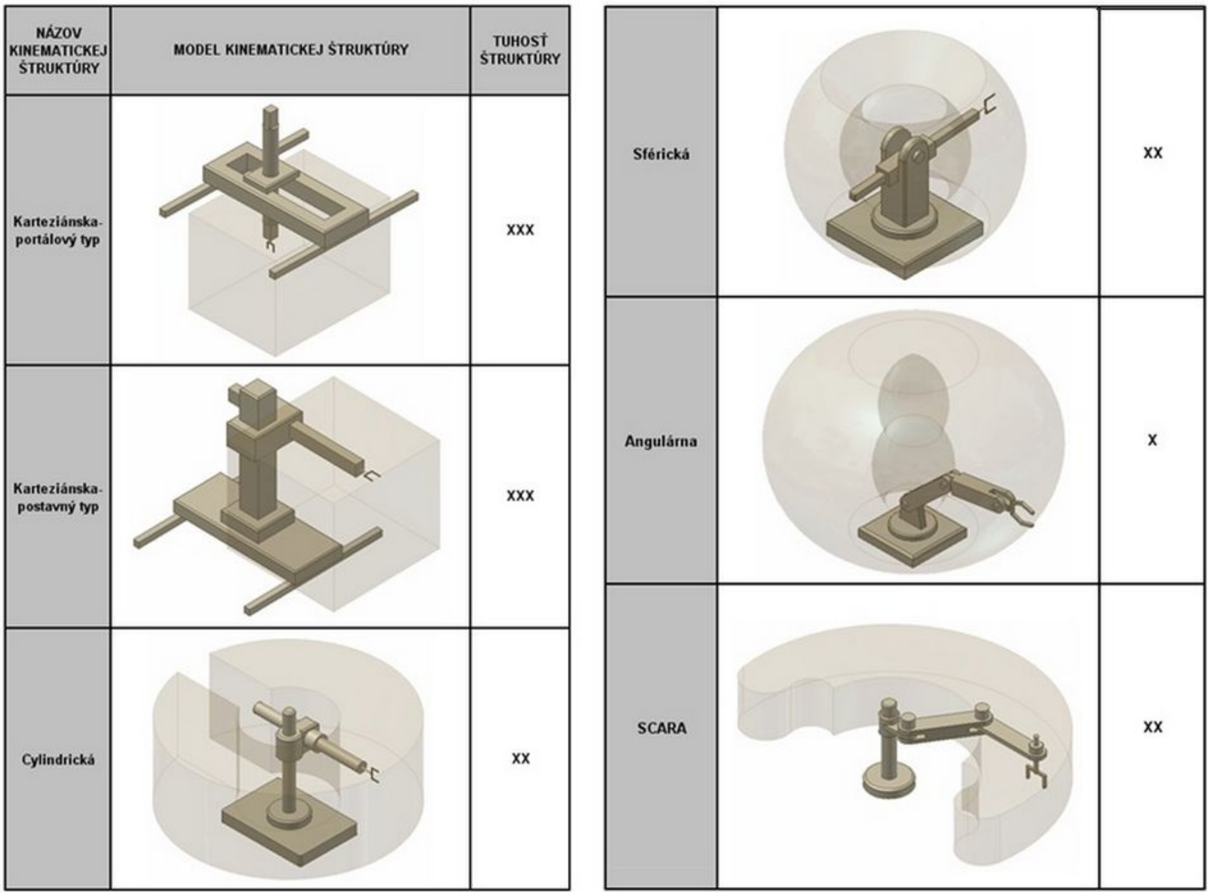

Fig. 24: Kinematic structures of industrial robots [1]

4.2 Robotic applications in industry

• the robot manipulates the specialized head, which acts on the workpiece (connected to a work table with its degrees of freedom if necessary - e.g., arc welding positioner) • the robot manipulates the workpiece (which places it in other technological devices, where the relevant technological operation realize over them)

• the robot's technological head is not in physical contact with the workpiece (arc welding, spraying, plasma cutting); • the robot operates independently of external sensors (workpieces to be machined must have the same shape, position, and orientation for high-quality machining);

• the robot operates adaptively and, based on information from external sensors, corrects the machine's path over the workpiece or the forces and moments of action on the workpiece.

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• the robot is cognitive, controlling the sequence and course of all technological operations based on data from external sensors.

Collaborative robot The advantage is safety and ease of programming, but a significant disadvantage is the lower speed and lower torque due to the lower payload. We must consider the tool's weight and the forces that will act on the joints during handling. It may be necessary to choose a larger robot than planned, which can significantly increase costs.

The design of the robot allows a wide selection of accessories for the robot's function itself, such as grippers, sensors, and camera systems, thanks to which the robot can quickly involve in the assembly process.

The robot can work safely in one environment with a human worker without endangering his health. The advantage is the fast integration and installation of the robotic arm in the workplace and the possibility of use in various applications. Programming the robot is possible using a touch tablet or moving the arm itself to the required position, then confirm this position, and the robot stores it in memory. The plastic body itself is relatively lightweight, and the working space is smaller.


Fig. 25: Colaborative robot [3]

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4.3 Robotic applications in medicine – medical technologies

Modern medical technology can significantly improve health, save lives, and enhance healthcare. The industry adds value to healthcare practitioners, society, and healthcare systems through advanced diagnostics and novel medical devices. Producers assist economic growth by creating jobs.

Medical technology allows people to live active lives by enhancing the rehabilitation and care of patients' health. Modern medical technology enables the accurate and quick identification of life-threatening health disorders and the improvement of treatment outcomes, and the possibility of early intervention. Medical advancements allow the repair, replacement, and maintenance of bodily systems, while telemedicine enables remote monitoring of patients' situations.

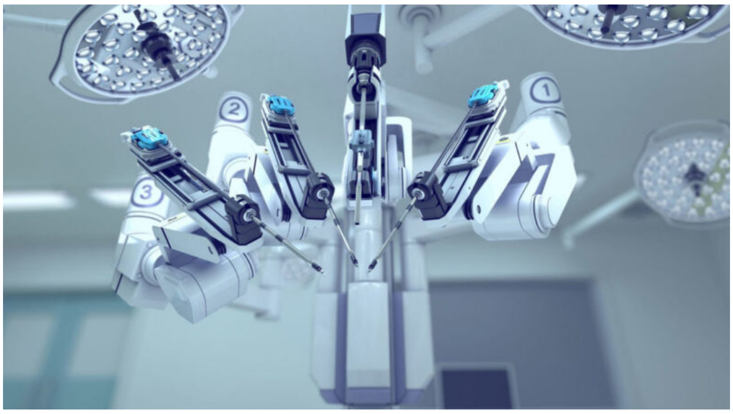

Fig. 26: Robotic surgery [4]

Early and accurate diagnosis enables healthcare professionals to make clinical decisions, which optimize patient outcomes. By minimizing patients' recovery time after complicated surgical procedures, medical technology can help alleviate the pressure on healthcare professionals.

Medical technology advancements increase efficiency and improve healthcare. It enables citizens to maintain economic and social activity, and by preventing serious complications, it can contribute value to healthcare and society. After completing their undergraduate courses, students can choose to continue their education and research to develop new technologies or seek employment in a variety of hospitals and medical establishments to maintain supportive technology, data interpretation, and installation of advanced medical equipment.

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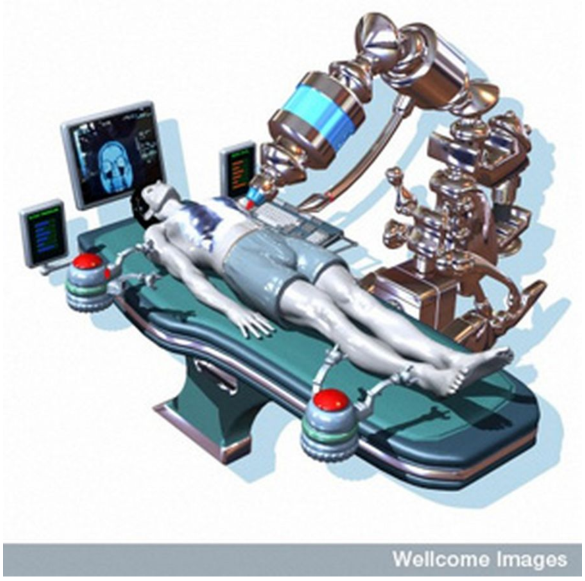

Fig. 27: Robotic surgery [7]


Fig. 28: Nursing robot [6]

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5 Specific requirements in medical applications

5.1 Description

Medical technology combines engineering sciences and a specialized field of medicine and creates an exceptional topic of focus in technology. The aim is to improve diagnosis, treatment, cure, care, rehabilitation, and quality of life. We characterize this sector mainly by the close interconnection of products and services and the high level of activities in research and development, extensive national and international standardization and various regulations at the state level, which present challenges.

Thanks to medical and technological progress, it is already possible to a large extent to restore greater independence, mobility, and thus the quality of life of people with disabilities. At present, we can adapt prostheses, orthoses, splints, and even wheelchairs to individual needs and unique environments. The correct heat treatment must take into account during the manufacture of the equipment to guarantee this adaptability and user orientation. Joints and all individual components should allow the final product to perform daily and leisure activities with the least possible restrictions.

5.2 Surface treating

The plasma generator is the heart of every device, as the name suggests, generates plasma. In addition to the solid, liquid, and gaseous states, we know plasma, usually referred to as the fourth state, is formed by adding a massive amount of energy to a gas. Plasma formation can achieve by heat, radiation or electrical voltage. The wall of the receiver serves as an anode, components as a cathode. Electrons collide with (process) gas molecules during the path from the cathode to the anode. This collision breaks the gas molecules and catapults the electrons from the mantle. While these repeatedly collide with other gas molecules and the cleavage process is repeated, the remaining ionized gas molecules migrate toward the component and initiate the atomization process.

Plasma generators mainly use in the following areas:

- Plasma nitriding (with or without subsequent oxidation)
- DLC coatings
- PVD coatings
- Plasma carburization

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- Magnetron spraying
- Plasma gentle cleaning and sterilization
- Plasma etching
- Pretreatment of plastics (plasma cleaning, plasma activation)
- Surface treatment of non-conductive materials using alternating pulse operation

5.3 Medicine tools

Scalpels, retractors, wound spreaders, and all other surgical instruments are exposed to particularly demanding conditions during use and, at the same time, must meet high-quality requirements in terms of hygiene and durability. The most important priorities are blood and acid resistance and excellent cleanability. The cleanability must brings high wear and corrosion resistance and tool life and, of course, adequate surface biocompatibility.

Preparation and dental tools withstand enormous wear. As well as surgical instruments, they are subject to strict hygiene standards and are resistant to blood and acids. The same applies to their components, such as angles and turbine heads, parts of dental drills, couplings, or FG shafts.

Vacuum hardening processes provide the individual components with the required core hardness, fatigue strength, and elemental wear resistance. If the parts to treatment require further heat treatment in the end layer, they are nitrided internally (plasma or gas nitriding). We can further improve in this way the surface wear properties.

Proper heat treatment of individual parts in these devices provides a competitive advantage. The basic requirements of every manufacturer of medical devices are protection against wear and corrosion, the possibility of effective disinfection or, ideally, the application of biocidal surfaces.

The layers of rigid material offer maximum resistance to wear and corrosion and perfect sliding properties. In addition, they can assign customer-specific colour schemes that allow the end-user to identify coated parts promptly and clearly.

The plasma-assisted chemical vapour deposition (PACVD) coatings are applied with plasma support by physical separation. The layers are based on carbon or titanium and offer in the DUPLEX process, i. j. they are pre-nitrided by plasma. This nitriding of the surfaces considerably improves the adhesion of the applied layer of hard material.

DLC Xtended® (Diamond-Like Carbon) is an amorphous carbon-based layer containing silicon and hydrogen. Their high chemical resistance guarantees the highest level of protection

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against corrosion and wear in all layers of rigid material and prevents the uptake of foreign substances on the surface. In addition, it impresses with a perfect feeling of touch and appearance with metallic shiny and clean surfaces. A surface can achieve a surface hardness of up to 1,500 HV in combination with the plasma nitriding process.

5.4 Cleanroom

used to capture particles 0.3 micrometres in size and larger in this way, reducing the number of particles in the air and being in the enclosure.

The cleanroom(s) contain very few particulates in a controlled environment, such as chemical vapours, aerosol particulates, dust, or airborne microbes. All air supplied to our cleanroom is filtered through an HVAC system and then through a high-efficiency particulate air (HEPA) filter, which captures particles 0.3 micrometres in diameter and larger, thereby reducing the number of particles in the air and within the enclosure.

Classification of cleanrooms is based on particle limits and sterility requirements. Many people associate cleanrooms with terms from the Federal Standard 209E and the International Standards Organization (ISO) TC209, which classified cleanrooms according to the quantity and size of particles permitted per air volume. Classifications such as "class 100" or "class 1000" refer to FED-STD-209 and indicate the maximum allowed the number of particles with a diameter of 0.5 m or greater per cubic foot of air in a defined space. ISO classifies cleanrooms into nine categories based on the cleanliness of the airborne particulates per cubic meter. A cleanroom meets the highest standard of ISO Class 1, whereas typical room air meets the ISO Class 9 standard. The Tape Lab operates a cleanroom certified to ISO Class 8. We frequently fabricate components for medical devices classified as Class I to Class 3. These devices pose little or no risk to the patient or the user.

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Fig. 29: Cleanroom manufacturing [6]

Applications involving cleanroom manufacturing and conversion:

- Die Cutting
- Rewind Slitting
- Packaging and Assembly

5.5 *Machinery and production of medical replacements*

In aeronautical and medical technology, the priority is the quality and thorough control of each manufactured piece, as any failure would directly endanger human lives and health.

The manufacturer's technicians found real help in the implementation in the possibility of 3- to 5-axis milling on Kovosvit machines. Here are representatives of products manufactured on MAS machines. The manufacturing machines also produce a world first, a unique implant for complicated fractures of the heel bone called C-Nail. This product requires precise 5-axis milling.

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Fig. 30: 5 *axis milling*

5.5.1 Wrist joint implant

This replacement helps patients with wrist osteoarthritis. The semi-finished product is a titanium alloy of cobalt and chromium.

The production background of the LAG manufacturer consists of six MCV machines, i.e., vertical milling centres. The oldest is the now discontinued MCV 32 from 1995, which corresponds to the later designation MCV 500. Gradually, from 1997 to 2006, five MCV 750s with a Heidenhain control system were purchased. The machines are equipped with a fourth axis or a rotary-tilting table from a quality manufacturer Walter from Germany. Spindle units with an ISO 40 taper with a maximum speed of 10,000 rpm and a maximum output of 17 kW ensure a sufficient technological range of roughing, especially drilling operations, threading, or even finishing operations, significantly shapes roundings, etc. Accessories such as a tank with automatic change, workpiece probes, central cooling, manual rinsing, and more are now the essential equipment of machines in this class.

At present, a total of over 2,500 MCV machines in various configurations produce. The machines gradually innovated with modern components and control systems. The portfolio of technologically more complex devices, especially multifunctional ones for the combination of milling and turning, is being supplemented. An example is the vertical portal centre MCU 630VT-5X, which excels in installed power and high spindle torque and overall rigidity, enabling very productive turning operations.

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