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Introducing a Real Production Case of an Automated Process Leads to the Understanding of the Theoretical Bases and Complexity of the Production Systems for Vocational College Students of Mechatronics

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Abstract: The case study presented in this paper represents an optimized process time flow of die production operations. Die production is usually organized within small production organizations that employ around 50 people. Hence their products are intended for mass production, which increases the importance of die and tool production. Die production includes CAD/CAM design of a tool, which usually requires customer cooperation. The CAD/CAM design is followed by the process of machining. The next stage is quality control protocol. The automated process continues with EDM machining, which is intended for the finishing of special details, textures and the required quality of the surfaces. The last stage in the process is the final quality control protocol. Presenting the optimisation case of the technological process enables the teachers to present numerous optimisation methods that are used in production processes within different industries. Within the case of smart industry these concepts can be introduced, as well, with an emphasis on the economic benefits. Students learn about lean production, KAIZEN, 5S, cost/effect as well as CSI aspects. Today we must discuss sensing, efficient data collection, device-to-device communication, high-speed communication, simulation, statistical models and artificial intelligence. This case enables the students to learn about how the new production environment creates new value through 3 zones of improvement, which are productivity, quality and safety.

The case presented here teaches vocational college students of mechatronics that, together with a systematic and analytical approach, a creative approach to die tool design is required, as well, since it considers lean production principles and the benefits from production as well as the process-simulation software, based on smart industry concepts and results in high ROI and OEE. All the technical knowledge combined with the flipped-classroom approach generates a higher level of knowledge for the students and a higher level of satisfaction for the teacher.

Key words: tool and die production, smart industry, lean production, RFID identification, flipped classroom

1. Introduction

The idea behind this paper lies in the paper presented at the 4th International Congress on Education Sciences and Learning Technology held in Budapest in November 2018. The paper “Introduction of Smart Industry

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Concepts to Vocational College Students of Mechatronics with Emphasis on Economic Effects" presented a real production example of integrating two CNC machines and a robot cell in order to achieve the main goal of ensuring the machining process that costs 150 €/hour and more to run without interruptions and with shorter setup times (Helena Mladenović Jerman, 2018). High-speed milling machine and die sinking spark erosion machine (die sinker EDM) are connected with a tool- and workpiece magazine. The robotic feeder is a robotic cell that places workpieces and the appropriate tools into a CNC machine. Once the RFID tags are in place and the work pieces and tools are identified, the automated work starts. For every work piece a measurement protocol is prepared for when the high-speed machining is finished. Data is automatically transported to the die sinker EDM so that the final machining can be executed.

A complex production case such as the integration of two CNC machines offers us a large amount of knowledge, which can be fragmented into smaller chapters and presented to students as such. Every real-life production case represents theoretical and practical knowledge that is used for making a machine or building a process, so students can relate and understand the significance of learning the theory better. When mixed with modern didactical approaches, such as the flipped classroom[1], the learning process really intensifies, and the teaching process becomes more enjoyable as well, since it results in a higher level of student knowledge and a higher level of student competences.

The main emphasis of the project is on lean manufacturing since it is a methodology that focuses on minimizing waste within manufacturing systems while simultaneously maximizing productivity. Lean production has a very extensive collection of tools and concepts in order to prevent any of the following incidents: unnecessary transportation, excess inventory, unnecessary motion of people, equipment or machinery, waiting (whether it is people waiting or idle equipment), over-production of a product, over-processing or putting more time into a product than a customer really needs (such as designs that require high-tech machinery for unnecessary features and defects, which require effort and cost for corrections). In tool die production, the principles of lean production are important, since the costs of machining are very high. Therefore, setup times and corrections of defects must be avoided. Tool machining times can be very long (several hours) or very short (25 min). It is important to prepare the tools and the workpieces in advance, so lead times are shortened. One of the most appropriate tools of lean production is the so-called Andon [4]. Andon is a visual-feedback system for the plant floor that indicates production status, alerts when assistance is needed, and enables the operators to stop the production process. Andon offers a real-time communication tool for the plant floor that brings immediate attention to problems as soon as they occur — so they can be instantly addressed. A systematically organized workplace is also very important. When applying 5S (6th S is for safety) to lean production, it turns out that it is an appropriate tool for organizing the work area. Another appropriate tool is Kaizen, which is the concept of continuous improvement. Kaizen can be defined as a strategy where employees work proactively together to achieve regular, incremental improvements in the manufacturing process. Kaizen combines the collective talents of a company to create an engine for continually eliminating waste from the manufacturing processes. Lean production also includes Key Performance Indicator, which is metrics designed to track and encourage the progress towards critical goals of the organization. Strongly promoted KPIs can be extremely powerful drivers of behaviour, so it is important to carefully select KPIs that will drive the desired behaviour. The best manufacturing KPIs are aligned with top-level strategic goals (and thus helping to achieve those goals). They are also effective at

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[1] https://www.teachthought.com/learning/the-definition-of-the-flipped-classroom.

exposing and quantifying waste (OEE is a good example) and are readily influenced by plant floor employees (so they can achieve the desired results). OEE (Overall Equipment Effectiveness) is the standard for measuring the manufacturing productivity. An OEE score of 100% means only the good parts are being measured, as fast as possible, with no stop time. In the language of OEE that means 100% quality (only good parts), 100% performance (as fast as possible), and 100% availability (no stop time). Single-Minute Exchange of Dies (SMED) reduces setup (changeover) time to less than 10 minutes. Techniques include converted setup steps to be external (performed while the process is running), simplify internal setup (e.g., replace bolts with knobs and levers), eliminate non-essential operations, and create standardized work instructions. Single-Minute Exchange of Dies enables manufacturing in smaller lots, reduces inventory, and improves customer responsiveness. Total Productive Maintenance (TPM) is a holistic approach to equipment maintenance that strives to achieve the perfect production[2]:

- no breakdowns
- no small stops or slow running
- no defects

In addition, it values a safe working environment:

- no accidents.

TPM emphasizes proactive and preventive maintenance to maximize the operational efficiency of equipment. It blurs the distinction between the roles of production and maintenance by placing a strong emphasis on empowering operators to help maintain their equipment. The implementation of a TPM program creates a shared responsibility for equipment that encourages greater involvement by plant floor workers. In the right environment this can be very effective in improving productivity (increasing up time, reducing cycle times, and eliminating defects).

All the approaches can be found in our production case. Some of them were executed and some of them were suggested and are awaiting management approval.

2. Methodology

In a production case we can find several topics that we can cover, starting with basic engineering, which covers statics and dynamics of mechanical components. At first stage the students can be taught all about the materials used as well as about the technological processes. Mechatronics as a science can contribute to the optimization processes, since all of them require control functions and sensor systems of some sort. Robotics is almost always present, as well, when discussing the automatization of processes.

2.1 Basic Engineering

2.1.1 Machine Elements and Components

Every machine is built from machine elements and components. Every work piece must be submitted to the basic calculations, as well. Therefore, statics and dynamics can be applied to every real production case in order to calculate the hardness and yield stress, as well as wear and friction problems of the material. Basic machine elements can be presented in their use: from shafts and supports, bolts and pins, gears, belt- and chain drives, roller- and plain bearings, elastic springs, adhesive and welded joints, linear technology, pneumatics, hydraulics

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[2] http://www.allaboutlean.com.

and others.

2.1.2 Technological Processes

The technological process starts with CAD modelling. If the product that is being designed is a mold insert for relays, we must prepare the CAD documentation for the workpiece as well as the tools that are required. The correct separation of the electrodes is the basis of high-accuracy machining[3].

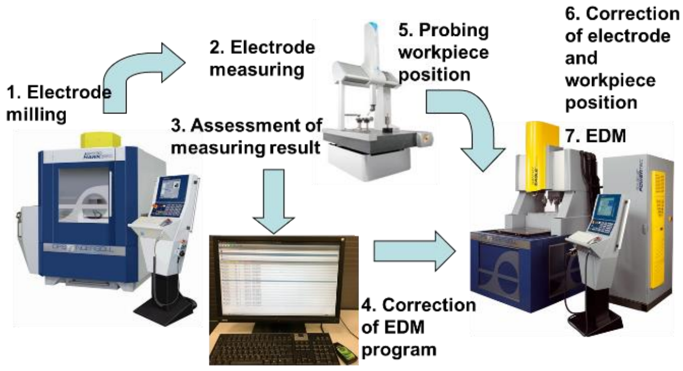

Figure 1 CNC Machines With Automatized Magazine for Tools and Workpieces and Quality Control System

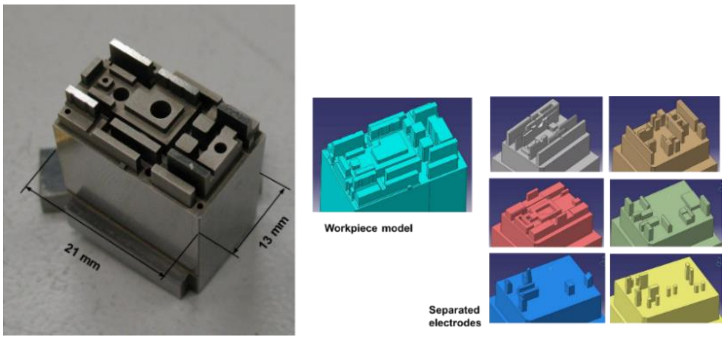

Figure 2 Mold Insert for Relays and Its CAD Model

When talking about high accuracy, it is important to realise what exactly one nanometer is, since one nanometer is the required accuracy for mold insert for relays.

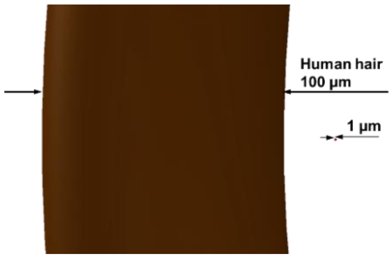

Figure 3 Representation of Nanometer

Keeping a tight tolerance in electrode production is a tough job and it is represented in high tolerances required for the machining process.

The two main processes are high-speed cutting and EDM erosion process. The first of the CNC machines is a dynamic, high-speed 5-axis milling machine that achieves a maximum speed of 30 m/s and can accelerate up to

[3] https://www.ops-ingersoll.de/produkte/download-26.html.

15 m/s. The high-speed milling machine uses a high-speed spindle with up to 42,000 rpm that allows the use of extremely small cutters. Therefore, the machine is most suitable to produce finite shapes, and can also be used after the hardening of steel, where the hardness of the material reaches 65 HRC. High quality cutters have small tolerances in diameter, low wear and uniform quality, but still an obvious shape deviation (Kris Alatič, 2018).

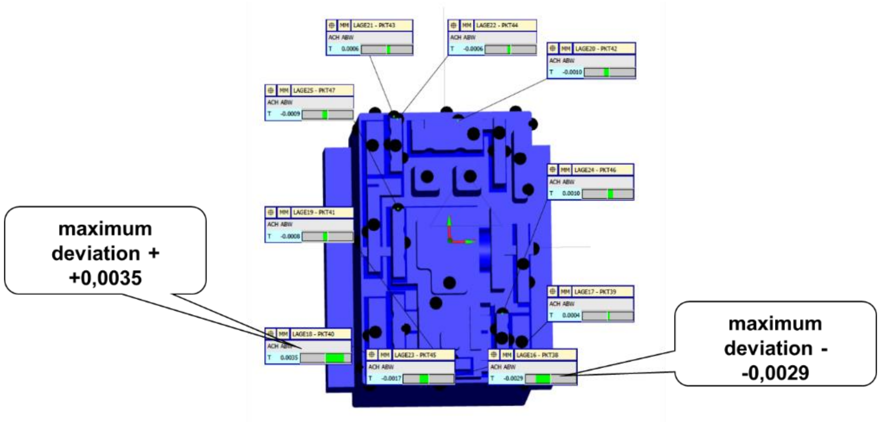

Figure 4 Measured Accuracy of the Workpiece

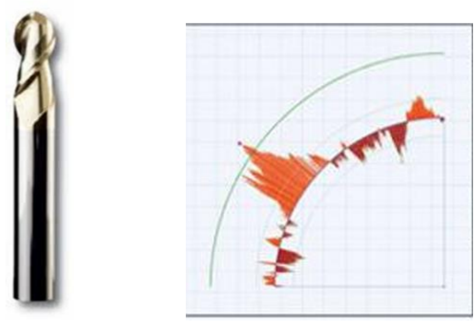

Figure 5 High-Speed Cutting Tool and Shape Deviation

The other machine is a CNC die sinking EDM, which is basically a 3-axis machine. The die sinker EDM consists of a control part of the machine, the electrical and the mechanical part. The electrical part is a generator that generates and controls electric impulses. Electric impulses are present during the treatment process and are released between the electrode and the work piece. When it comes to graphite electrodes, several important guidelines must be taken into consideration:

- use only high-quality cutters,
- control of cutter diameter with each cutter,
- posting of all programs with real cutter diameter,
- if necessary, posting with real cutter shape,
- for each workpiece, a new set of cutters must be used.

2.2 The optimization of the Process From Design to Recycle and Reusage

2.2.1 Lean Manufacturing

All the tools mentioned in our example have the potential to increase productivity and decrease lead times. When the preparation of tools and workpieces can be done outside the cutting process, shorter lead times are achievable. The operator measures all the workpieces manually to determine the starting point. The last manual process includes tagging the tools in the tool magazine and the workpieces with RFID tags. The operator assigns a starting point to every workpiece. In order for the automatization process to run without interruptions, the transport system between the two machines is required. In our case, we used a 6-axis robot programmed to transport work pieces and electrode tools. The robot inserts the work piece into the machine and places it on the grip system. The main problem is the wear of the electrodes that requires adjustments.

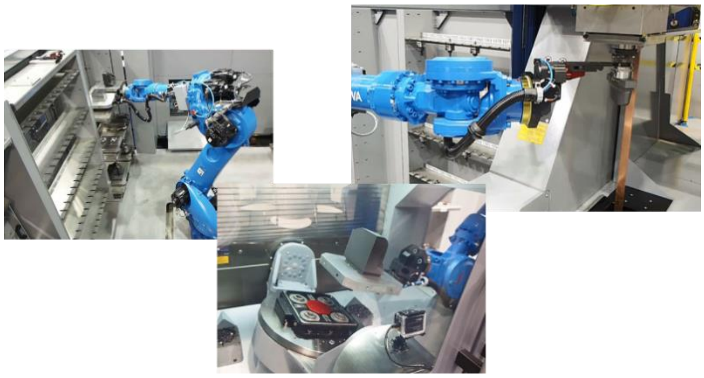

Figure 6 Optimizing the Tool and the Workpiece Transport

2.2.2 Productivity and Efficiency

The productivity increases with shorter lead time. One pallet/one clamping for the machining process allows tools and workpieces to be positioned and processed so there are fewer defects, which increases efficiency (Kris Alatič, 2018).

Figure 7 Adapter Pallet

Another optimization is achieved with the automatic loading of pallets into CNC machines.

Figure 8 Automatized Loading of Pallets

The designed automatized process concurs with the principles of lean production since it has:

- magazine positions for workpieces and electrodes,
- magazine is modular and extendable,
- swivelling unit for rotating electrodes,

- automatic gripper change,
- RFID chip identification,
- MultiProg allows communication not only between two machines and a robot but also from and to MES.

2.2.3 Upgrading the System

Upgrading the system will require an investment in IT technology. The experience has showed us that more work done in the preparation time directly means fewer disruptions during machining. Therefore, production simulation (digital twin, shadow production, robotized transport, smart maintenance) will be considered in the future. The cyber-physical system principle is achieved with M2M communication and with the communication between machines and MES system. IIOT offers additional opportunities for upgrading the system, since it will allow for a distributed control of systems. Quality control upgrade is possible with an augmented-reality system that will enable even shorter process times. However, all managed and structured production data will provide the possibility of establishing an AI manufacturing system.

3. Results

Our example shows that automatization and accuracy require optimized organization and stable production environment as well as state-of-the-art machines and equipment. Without automatization high precision can be achieved only with a lot of hard work. But automatization alone will not guarantee best accuracy. Setting a production isle that runs according to principles of industry 4.0 there is an investment that is required. The investment does represent financial challenge for the company. Also required are IT equipment that includes hardware as well as software. The first phase requires setting up the main server that is connected to every production segment. Since two machines differ in work principles and control, postprocessors must be set in order to generate appropriate CNC code for each machine. In addition to the communication between machines, automatization process requires physical transport workpieces and tools between two machines therefore selection and programming of robot is also required.

The case presented was executed according to flipped classroom principles that means that all theoretical knowledge students acquired on their before we discussed case specifics. Before case discussion students learned about high speed cutting, EDM process, measurement protocol, CAD design, industry 4.0 principles, lean production principles, productivity and efficiency, IT and data transfer, MES system and M2M communication as well as RFID sensoring and identification. By enabling themselves to be vocational literate, the students were able to communicate about the presented case as well as analyse and validate the case problems.

4. Summary

Setting up the die mold system of two machines and robotized magazine represents machining organised according to smart industry concepts since it runs without operator interfering. The case presented teaches us about connectivity of machines, connectivity between machines and MES system, as well as influences of automatization on productivity and effectivity. From our case we learned that high accuracy demands hard work of skilled operators. As a rule, automatization does not mean losing jobs in usually means losing jobs of lower quality for jobs that require skills and knowledge. Our case demonstrated that automatization is a process that requires all production levels involved from management to the operator’s level. We also learned that introducing an automated isle in the production process requires systematic approach and activity planning. In our case we learned that IT hardware was not prepared for information flow that occurred when machines were connected and communicated. Additional work was represented with robot programming and tool and workpiece labelling with RFID tags. Due to adapter pallet and RFID recognition tool selection and workpiece selection is automatized.

It is important to realize that upgrade of the system is always available. Smart industry concepts include digital twin and shadow production concepts as well as cyber-physical systems and IIOT with wireless connections of the machines and devices that allow distributed control systems to take place.

From didactic point of view our case demonstrated that one casa covers multiple areas of required knowledge. Solutions generated by one case are learning tools that excide any theory book and examples that have been generated. If, however it is possible for students to gain vocational literacy and theoretical knowledge before case (Kaizen, lean manufacturing, KPI, TPE, 6S) study than the teaching can focus on problems and problem-solving techniques.

At the beginning as well as at the end it is people involvement that is important. Automatization requires worker to monitor processes, to prepare tools and workpieces, to design the workpieces as well as tools. Engineering stays teamwork as much as ever, proved also by our case.

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