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DEFINING THE CHARACTERISTICS NEEDED FOR THE COBOTS DESIGN USED FOR THE SUPPLY OF CNC MACHINES

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Abstract: *Flexibility and reconfigurable systems are features mandatory in any manufacturing system. This paper presents and determines the main characteristics needed for the cobots design used for the supply of CNC machines. Also, an approach to cobot automation in machine tending was proposed. This approach is feasible for series production in machine shops where the same parts are produced more frequently while replacing the human operator with a collaborative robot for the repetitive tasks of loading, unloading of parts but also cleaning the machine and parts after each part is finished.*
Another problem to be solved with the proposed system is the production of the finished parts at a maximum efficiency, which can be achieved by not interrupting the process loading and unloading of parts in the machine tool while the materials are loaded in the system.
Key words: *CNC machine, cobots, interchangeable palette system, characteristics*

1. INTRODUCTION

Industry 4.0 focused in maximizing manufacturing by integrating machines and robots into the manufacturing sector. One of the objectives of the Industry 4.0 concept is to maximize productivity and to shorter product life cycles. Also, increasing flexibility and adaptability of the current processes are targets of the concept [1]. Cooperation between machines and operators lead to an improved manufacturing and performance. The human intervention needs to be reduced, and all processes automated. [2]

Robots have been around in the manufacturing industry since the 1960s and at first, they were nothing but blind metal arms that couldn't be operated outside of a steel cage or any other protective environment because of the potential danger they could pose to nearby workers because they lacked the technology needed for collaborative operations.

Modern robots have evolved from separate work area and started working side by side with humans in a collaborative environment. These types of robots can perform sequential or parallel task and can have the following characteristics: the ability to interact safety with humans, risk reduction in task implementation, flexibility and easy programming. The usage of cobots in this environment is called HRC (Human-Robot Collaboration and it's the most prospective technology in modern intelligent manufacturing. This is because cobots are easy to integrate and program in the work environment. With the development of modern cobot technology, HRC has a huge potential for companies of all sizes and different economic sectors. Cobots can attract more investment in comparison to traditional robots. The main task in modern factories is related to ensuring safety and efficient human-robot collaboration in dynamic uncertain environments.

Cobots are defined as "a robot specifically designed for direct interaction with a human within a defined collaborative workspace" [3].

Johan Kildal [4] identifies the features that are the most valuable for the end user, both from the industry view or the student view. A questionnaire was applied during two workshops. 91 persons answered the questionnaire: 51 persons that worked into the

industry and 40 that are students. The results showed that both groups were concerned by the safety, usability and flexibility of a cobot. Students were also concerned about the efficiency of the cobots, feature that was not a problem for the industry.

Devices, such as computers or robots are in connection with smart technologies like sensors, artificial intelligence, Internet of Things, automation and cloud computing. Manufacturing becomes predictable, allowing managers to take quick decisions, based on real-time data received from production [5-7].

Machine tending is one of the most common manufacturing processes where automation and cobots can bring added value by performing repetitive tasks needed for series production of parts [8]. While Industry 4.0 focuses on improving mass production by connecting smart devices with machines the new trend is to bring in touch human with smart machines (Industry 5.0) [9].

A process of supplying numerically controlled machines by the robot can be repeated indefinitely, provided that the robot has semi-finished parts and the machine tool will produce the finished parts. Some industries use robots for a single stage of production, such as emptying injection moulding machines or numerically controlled machines. When production takes place non-stop, the robots allow to minimize the cycle time and run the process continuously, eliminating the parts from the working area of the machine with numerical control.

Having the above in mind, we propose a cobot - parts feeder system and finished parts easily set-up with a mobile cobot system such as the OVI and a CNC machine that will take into account the crictical to quality characteristics. In this case, the human worker will be responsible to supply the semi-finished parts and load them into the feeder and afterwards remove the finished parts from the feeder. The cobot will per-form the repetive task of loading the semi-finished parts, closing the CNC door and starting a new machining cycle. When the machinig program is over, the cobot would offload the finished parts and feed a new part.

2. METHODOLOGY

The problem identified and specified at the beginning of the paper took into account the developed supply system that offers the possibility of conducting various research in the field of numerically controlled machines in order to improve the supply process. A first application that took place on the described stand refers to the loading-unloading of parts of the same size and the same type, thus optimizing the supply process of the machine tool.

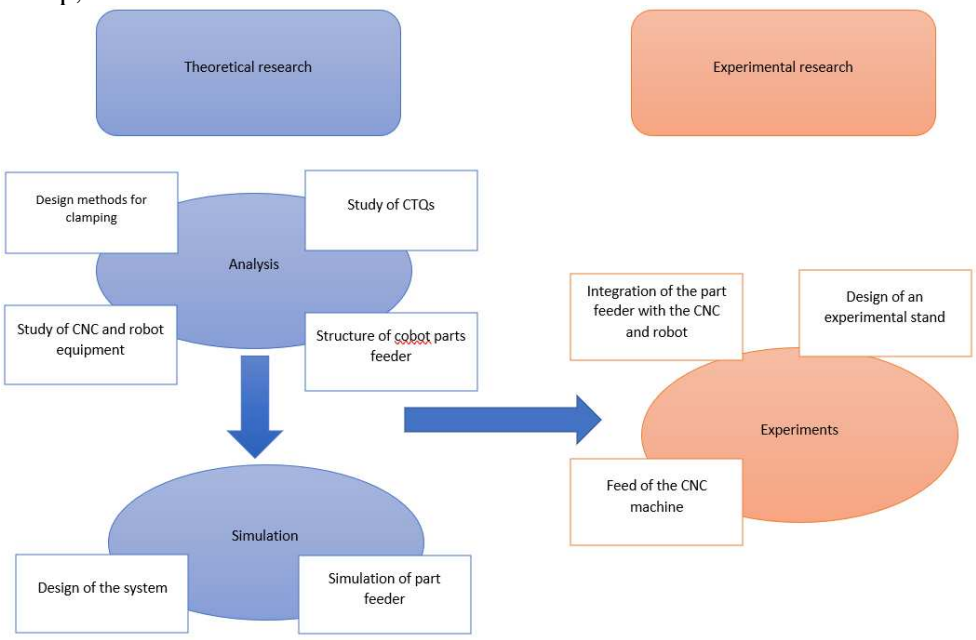

Fig. 1. Research methodology

In order to conduct the study, we used the observation and the brainstorming method needed to identify the characteristics that will help us to integrate the CNC and robot (Figure 1). To validate the results, we used the finite element method. The tests were performed using the Catia program and were used to calculate the ideal weight of the pallet for semi-finished products [10]. The next step will be the practical integration of the robot with the CNC.

This study is part of a larger PhD research which is conducted with the support of industry. In this paper we will focus on determining the characteristics needed for configuration of the cobot part feeder. For this, we identified the critical characteristics for three of the systems components:

- cobot;
- CNC machine;
- cobot - parts feeder system.

Having this in mind, the cobot - parts feeder system can be designed, and simulation of the system can be done.

3. IDENTIFICATION OF THE SYSTEM CRITICAL CHARACTERISTICS

The proposed methodology begins by identifying the customer requirements – in our case from CNC machine, OVI station control box, Mobile OVI cobot and part feeder. For this we used the observation and the brainstorming method, where members from production and product development participated. With the help of this analysis, we eliminated the redundant criteria and the process was much better understood by the participants [11, 12]. Also, the relations between the main elements of the robot, CNC machine and part feeder have been determined [13].

For a better understanding of the process, several data need to be mentioned:

- The proposed system is mobile and can be moved from one CNC machine to another depending on where it's needed the most in terms of number of parts that needed to be processed.
- The setup time after the cobot system and parts holder is moved to another CNC machine is minimal thanks to the patented OVI Point zero system and the pre-programmed waypoints.
- The assumption in this case is that all the components are capable to run in automatic mode without the intervention of workers.
- In order to ensure a buffer for the feeder, the semi-finished parts are placed onto ex-changeable palettes. It's possible to mount 2 palettes on each rack into the feeder in order to make a buffer for the cobot loading the CNC machine.
- For pick & place applications such as machine tending for CNC machines, it's important to maintain the repeatability for the pick and place points.
- For the design of the fixtures, we have taken into account the most common geometries for raw and processed parts - cylinders and parallelepipeds.
- In order to ensure the flexibility of the fixtures for the cylindrical parts, the fixture must be designed in a way that could accommodate changes in diameter and length of cylindrical parts.

  In order to achieve this, we have identified that the developed system must have these minimum characteristics (Table 1) so that the automation can be possible:

Table 1.

The identified characteristics

Number	Characteristics	Performance standards
1	Cobot gripper should be able to pick and place raw and finished parts without any tool changes	Zero tool changes
2	Cobot position relative to the parts holder and CNC machine must be fixed as any changes in the physical setup will affect the waypoints of the cobot	Same distance between the parts holder and CNC machine for each machined part
3	Cobot must be able to manipulate the parts holder	Number of pieces manipulated by the cobot

4	Part holder relative position to cobot and CNC must be kept	Same distance between the parts holder relative to CNC machine and cobot
5	Fixtures is needed on the exchangeable palettes	Number of fixtures on each exchangeable palettes
6	Part holder need to have fixtures for finished parts	Number of fixtures on each finished parts
7	Part holder need to have fixtures for raw parts	Number of fixtures on each raw parts
8	Position of CNC machine must be fixed	Number of rearrangements for each CNC
9	The exchange of signals between the cobot and the CNC machine is needed	Existence of an electrical interface
10	The vice needs to be controlled from an input point of the cobot	Number of cobot commands regarding the vice
11	The CNC machine needs to be able to set the origin of the semi-finished part automatically	Zero origin setting
12	The semi-finished parts needs to self-align under their own weight	Angle of the part holder
13	Geometrical family flexibility of the gripped parts	Shape of fixture
14	Repeatability of the process	Number of pieces of the same kind that are taken over

4. DESIGNING OF THE PICK AND PLACE SYSTEM

Having the main characteristics defined, we now can design and simulate the process. For each characteristic, at least one feature is found in the design of the pallet part (Table 2). Having in mind the main features described in Table 2, all these requirements were implemented from the design phase to each assembly as necessary.

Table 2.

System characteristics

Number	Characteristics	System characteristic
1	Cobot gripper should be able to pick and place raw and finished parts without any tool changes	This characteristic can be ensured by using the appropriate gripper type for each type of part geometry – centric grippers for cylindrical parts and parallel grippers for parallelepiped parts.
	Cobot position relative to the parts holder and CNC machine must be fixed as any changes in the physical setup will affect the waypoints of the cobot	By using the "Point Zero" calibration feature which can be found in the Ovi cobot and having point zero tools assembled on the CNC machine and on the parts holder , it is possible to automatically readjust the waypoints if the physical setup is changed.
3	Cobot must be able to manipulate the parts holder	The parts fixture is assembled on a drawer that can be opened and closed by the cobot arm.
4	Part holder relative position to cobot and CNC must be kept	By using the Point zero calibration feature and having the point zero tool assembled on the parts holder, it is possible to maintain the same relative position between the cobot and the parts holder.
5	Fixtures is needed on the exchangeable palettes	In order to accommodate both types of parts which are the most frequently used, we have devised a interchangeable carrier palette system that can hold different types of fixtures depending on which type of semi-finished parts are to be machined. The usage of palettes allows the worker to easily load and offload the semi-finished parts onto carriers and take them to the next part of the process. It is also possible for the worker to remove the finished parts and

Number	Characteristics	System characteristic
		load the semi-finished without stopping the automatic cycle of the cobot feeding the CNC machine.
6	Part holder need to have fixtures for finished parts	When it comes to choosing the right cobot gripper, it's necessary to take into consideration the geometry of the part that will be manipulated and the type of contact between the gripper jaws and the part. For instance, for loading prismatic parts into the vice of a mill, it's more practical to use a parallel gripper. But, if it's necessary to load cylindrical parts into a CNC lathe, then a different tool is required.
7	Part holder need to have fixtures for raw parts	By using the inclined fixtures or the "V-shaped" fixtures, it is possible to hold both and raw and finished parts.
8	Position of CNC machine must be fixed	The position of the CNC machine is fixed to the ground by using adjustable levelling feet.
9	The exchange of signals between the cobot and the CNC machine is needed	The exchange of signals between the cobot and the CNC machine is achieved using 24V discrete signals.
10	The vice needs to be controlled from an input point of the cobot	The vice is pneumatically operated and can be controlled by the CNC machine
11	The CNC machine needs to be able to set the origin of the semi-finished part automatically	The setup of the cobot system is fairly easy due to the Point Zero calibration feature present on the feeder structure. It's possible to automatically recalibrate the waypoints after the feeder is moved manually connecting the feeder
12	The semi-finished parts needs to self-align under their own weight	For the design of the fixtures, we have taken into account the most common geometries for raw and processed parts - cylinders and parallelepipeds. In order to ensure the flexibility of the fixtures for the cylindrical parts, the fixture must be designed in a way that could accommodate changes in diameter and length of cylindrical parts. This can be achieved by using "V" shaped self-centering jaws. Having the part inclined is necessary in order to maintain the same relative position of the semi-finished parts in the fixtures. The jaws can be moved on the palette in order to accommodate bigger lengths of cylinders as needed in a fast way (Figure 3). In the design of the fixtures for the prismatic parts, the same principle can be used. The fixtures can be easily adjusted in order to accommodate different sizes. By having placed these parts in a inclined plane which can be assured by the fixture design, it is possible to maintain the same relative position between the cobot and the semi-finished parts (Figure 4).
13	Flexibility of the gripped parts	For the improvement of the flexibility of the gripped type parts, we propose to use a mechanical tool changer system. This mechanical tool changer has an electrical interface which enables the cobot system to identify the tool type and reconfigure the settings accordingly according to the tool that has been mounted thus drastically reducing the setup and change-over time.
14	Repeatability of the process	For pick & place applications such as machine tending for CNC machines, it's important to maintain the repeatability for the pick and place points. This means that the raw parts cabinet and fixtures must be designed in a way that would ensure that the position of parts do not move during the process. This can be achieved through the design of the fix-

Number	Characteristics	System characteristic
		tures by having the semi-finished parts sitting in a inclined plane that would allow the parts to self-align under their own weight.

For the design of the system Catia CAD software was used [14].

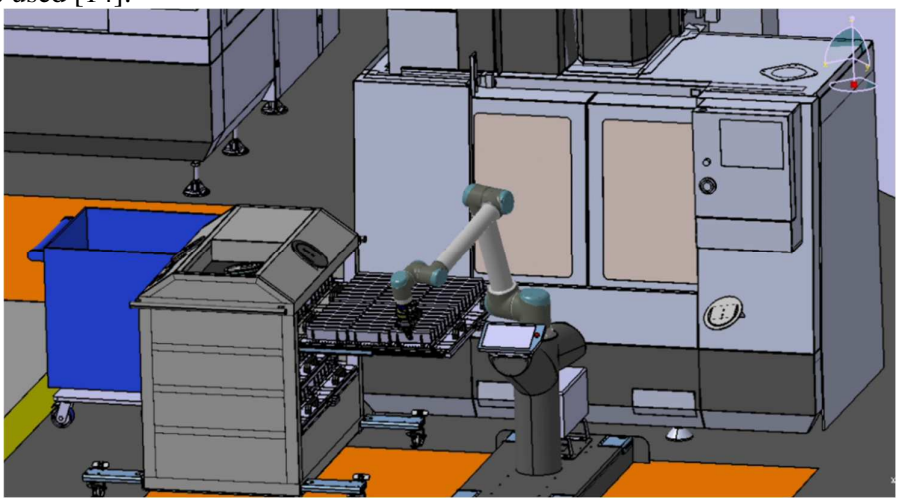

Fig. 2. Design of the pick and place system

Figure 3 shows how the parallelepiped parts are positioned on the fixture, while Figure 4 shows how the cylindrical parts are positioned on the fixture.

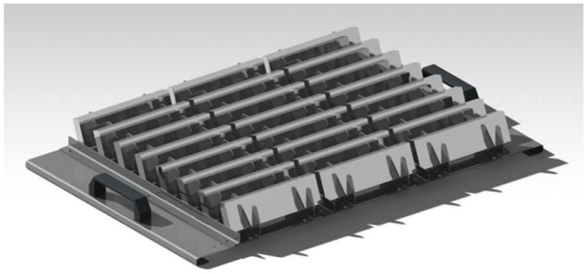

Fig. 3. The parallelepiped parts

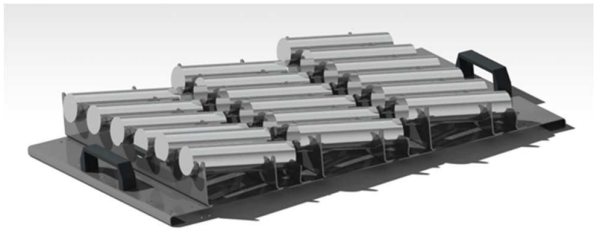

Fig. 4. The cylindrical parts

5. CONCLUSIONS

Industry 4.0 started to change the way goods are produced. Flexibility and increasing production are two of the main features Industry 4.0 wants to improve. This paper describes how the design and development of the pick and place system was developed for a CNC machine and a cobot. Using observation and brainstorming, the system critical characteristics have been determined so that the automation can be possible. Three of the system components were analysed: cobot, CNC machine and cobot - parts feeder system. Using them, the pick and place system was designed using the Catia software.

In order to assure the positioning precision of the parts that will be machined on the CNC machine a trajectory analysis was done. The role is to maintain the repeatability for the pick and place points between processed parts while maintaining unattended operations. By using the Ovi cobot, it's possible to obtain a safe solution on a smaller footprint while maintaining flexibility which clearly is an advantage on the shop floor.

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Definirea caracteristicilor necesare pentru proiectarea coboților folosiți pentru alimentarea mașinilor CNC

Rezumat: *Flexibilitatea și sistemele reconfigurabile sunt caracteristici obligatorii în orice sistem de producție. Această lucrare prezintă și determină principalele caracteristici necesare pentru proiectarea coboților utilizați pentru alimentarea mașinilor CNC. De asemenea, a fost propusă o automatizare a sistemului folosit pentru deservirea mașinilor. Această abordare este fezabilă pentru producția de serie unde aceleași piese sunt produse mai frecvent si au rolul de a înlocui operatorul uman cu un robot colaborativ pentru sarcinile repetitive de încărcare, descărcare a pieselor.*
O altă problemă rezolvată cu sistemul propus este producerea pieselor finite la o eficiență maximă, care se poate realiza prin neîntreruperea procesului de încărcare și descărcare a pieselor în mașina unealtă în timp ce materialele sunt încărcate în sistem.

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