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Robotic quality control system for the components with complex shape

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Abstract. This paper represents the concept of an intelligent system for manufacturing components with the complex shape that combines automated technological operation and non-destructive testing modules. The engineering solution for development of the automated ultrasound tomography module is discussed, which is the key element for quality assessment of the components at both early and final stages of the manufacturing process. The proposed solution includes a robotic manipulator to perform scanning of products of any size and shape, as well as the use of a specialized positioning table to achieve accurate testing results. The proposed automation solution for the ultrasound tomography module is performed as a three-level system, including development of an automated workplace for the operator, which provides interconnection between every module included in the manufacturing process.

1. Introduction

Taking into account growing manufacturing demands and industrial design complication the technological processes require constant improvement. One of such advances is considered to be automation of different technological stages. It is vital for different industries such as textile, automotive, chemical and others [1–3]. Automation is considered to be most pressing for the mechanical and metalworking manufacturing industries. In addition to the increase of the technological process efficiency by reducing number of the manufacturing stages, automation also allows to improve the quality of the final components via implementation of advanced testing techniques [4].

Metalworking manufacturing industry is a segment of mechanical engineering complex which plays the crucial role in Russian manufacturing market, embracing fabrication of components for application in various industrial fields, including critical areas such as military industry, mining, nuclear energy, and others. This conditions toughening the quality requirements for the produced components.

At the same time, components with specific structure, such as large dimensions and complex shape, are often used in these critical areas. This not only affects the manufacturing process, but also complicates the following quality assessment performance.

Thus, a new concept of smart manufacturing was introduced as a response to these challenges [5]. It provides for industrial automation by implementation of advanced technological and information technology solutions that allow to optimize the manufacturing procedure.

One of the most important steps to ensure the effectiveness of the proposed automation of the manufacturing is the initial determination of the factors that may lead to the loss of quality of the final components. For the mechanical manufacturing these factors include: low initial quality of the workpiece; inaccurate settings of the final component characteristics; and failures in the technological process.

In this paper we discuss manufacturing of the critical components with complex shape. In particular, shutoff and regulating pipeline components are considered. Manufacturing of these products is primarily associated with the use of metalworking equipment, such as milling machines. The object of study is made of steel by casting, and further complex geometry is achieved by milling.

Milling process has improved significantly over the past decades. At present, application of computer numerical control (CNC) equipment is quite common. It is implemented so that the setting of the final component's characteristics is generated via software and represented as a digital file. Further, this file is used to determine the parameters for the mechanical treatment. At that stage the accuracy of the final component characteristics is vital, as it may influence the reliability of further mechanical treatment.

For this purpose, this paper suggests development of an automated workplace for the operator (AWO), which will enable the use of special software. To achieve the highest accuracy, it is suggested to determine the characteristics of the final products by creating appropriate CAD models and further CNC based on these models. It should be noted that the important function of the developed software is to provide the option of manufactured items registration and storage of all the information regarding them, including specified CAD models. Thus, further necessary adjustments may be possible.

The main advantage of the proposed solution is enabling the quality control of the components throughout the entire manufacturing process, as well as providing the option to adjust the parameters before the start of manufacturing process. In order to achieve high quality and reliability of the manufactured pipeline components, it is proposed to create modules for non-destructive testing (NDT) at various stages of the production process. Each of them is responsible for ensuring the reliability of a particular stage and will be based on the implementation of physical principles. Further to that, within the framework of smart manufacturing concept implementation, integration of these modules by the means of the developed AWO is considered. Therefore, it will be possible to conduct integrated automation of the entire manufacturing process.

2. The concept of implementation of advanced measuring and information technology systems into the manufacturing process of complex shaped components

As part of the study, modernization and improvement of the existing manufacturing process of complex shaped components is proposed. When creating an automated system, it is necessary to take into account the existing features of technological processes to enable gradual automation, while developing a new smart manufacturing system starting not from zero but rather performing smooth step-by-step transformation. This approach is considered to be more realistic, rather than development of a new design, in which technological processes are developed entirely anew, and not on the basis of existing industrial facilities.

At that, as mentioned earlier, one of the main aspects is effective quality assessment of the components. Inspections are to be conducted at the final stage of the technological process as well as at the initial and early stages of the process to assess the quality of the workpieces thus enabling the quality monitoring during treatment to eliminate appearance of any possible defects caused by machining processing. Such approach requires structuring the entire process into several modules, while providing the option for interaction among them for further optimization and acceleration, at the same time minimizing human intervention and applying the principles of digitalization.

There are the following modules proposed:

— X-ray testing module.

— Ultrasonic testing module (UT testing module).

— Optical testing module.

— Automated machining module.

— Automated workplace for the operator (AWO).

The existing manufacturing cycle stages with the modules integrated are represented in Figure 1.

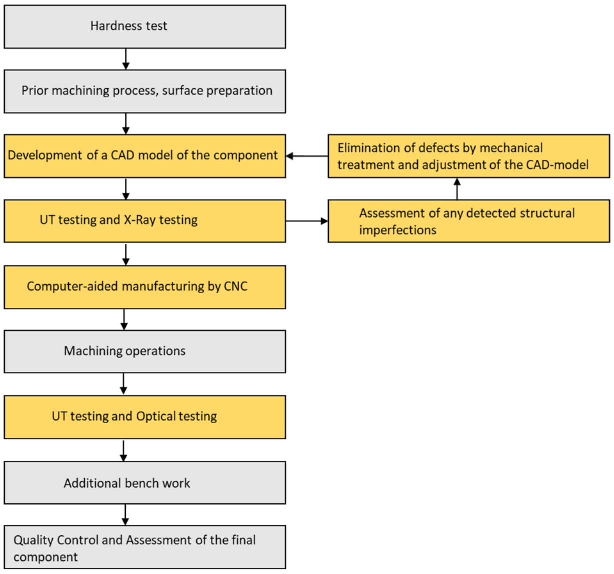

Figure 1. Modified manufacturing cycle diagram.

Each block of the diagram requires direct human intervention which significantly increases labour costs and consequently the total production costs as well as the probability of defects occurrence. The first step to transition to smart manufacturing is development of an automated workplace for managing all manufacturing stages concurrently.

The X-ray and UT testing modules are designed to assess the component in terms of the presence of any defects in its internal structure. Moreover, the UT testing module allows to control the quality of the final component. The implementation of these two modules will enable to determine the size and location of a defect with very high accuracy. Further, this information will enable CNC parameters adjustment to provide better settings of the machining path for the efficient use of the workpiece while avoiding the detected structural defects. More detailed description of the proposed solutions for the discussed modules is given in [6].

This paper discusses in more detail the engineering solutions of the regulating system and the automated workplace of the UT testing module, as the most important part of quality assurance of the component during the entire manufacturing process. The design of the UT testing module, its technical characteristics, and the structure of the its regulation system are described further; prospective implementation of information technology solutions is discussed.

3. Automated ultrasonic testing module

The structure of the automated regulation system (ARS) of the UT testing module, based on ultrasound tomography, includes:

— Ultrasound tomography system, including the robotic manipulator.
— Electrical actuator for the positioning.
— Controller for collecting, transmitting and managing data.
— The control system for the coupling water control.
— Automated work place for the operator.

Figure 2 represents the block diagram of the ARS.

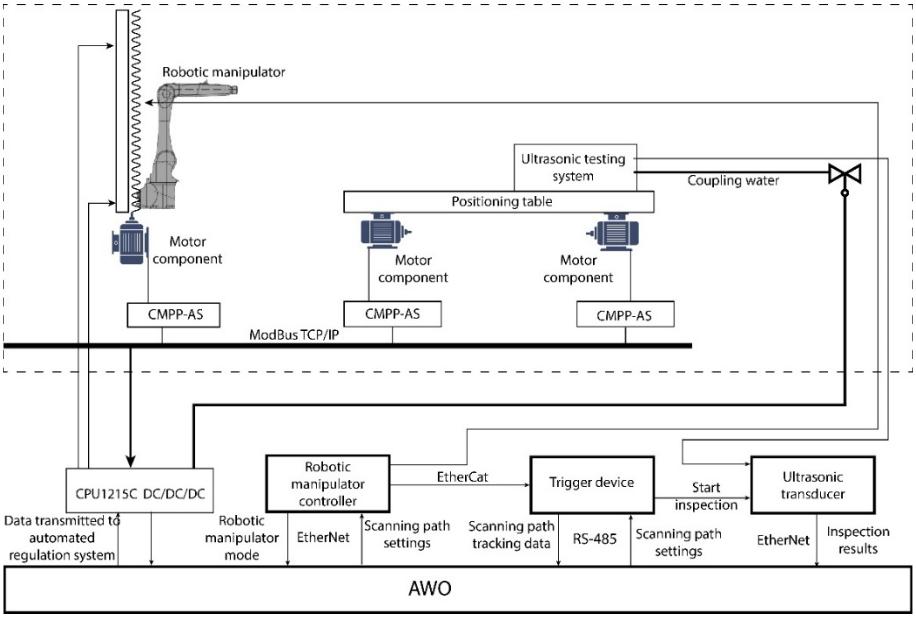

Figure 2. ARS block scheme.

The interacting parts of the UT testing module are the following: a turning table with the device for center adjustment and positioning of the controlled object; robotic manipulator with fixed ultrasonic transducer and acoustic coupling system; robotic manipulator positioning module; coupling water handling system.

The structural diagram of the interaction of these parts is represented in Figure 3.

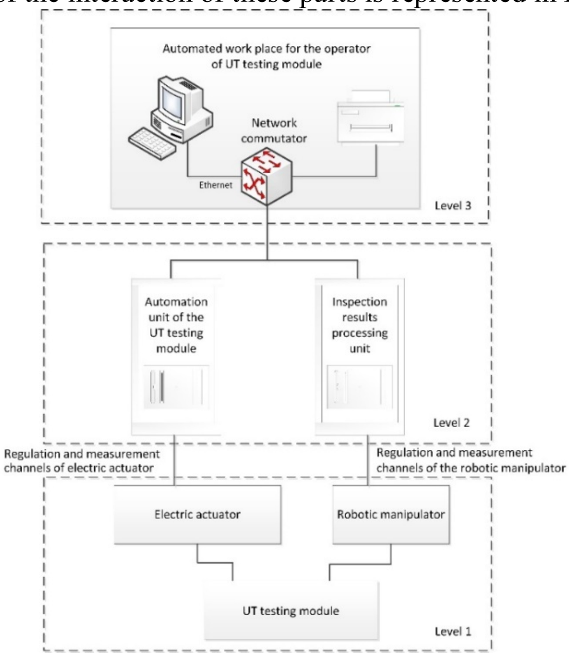

Figure 3. Three-level interaction system of the ARS of the UT testing module.

Operation process regulation, control of the technological equipment and quality assessment performance regulation are carried out at three levels:

1) Local automation (positioning table and robotic manipulator controllers) provides specified table rotations with a strictly fixed component positioned in the center as well as vertical movement of an

industrial manipulator with an ultrasonic transducer and an acoustic coupling system placed on it. Automated control of rotations of the table and the robotic manipulator ensure the movements according to the control program sequence.
2) Controllers for data collecting, transmitting and managing connect servodrives of the electrical actuator with the PLC, as well as the controller of the robotic manipulator. They are used for transmitting the data via:
- industrial Ethernet (TCP / IP exchange protocol), which forms the data transmission channel between controllers and AWO;
- control channels of the manipulator;
- drive control channels.
3) The regulation of AWO and ultrasound tomography system is performed via Ethernet network.
Interaction of these regulation levels provides:
- high reliability of the automated regulation systems during operation;
- simplification of the procedures for assessment and self-assessment, maintenance of most important specific channels in hot operational mode;
- development of automated regulation systems individually due to the modular replacement at each level of software and hardware;
- compatibility and integration of individual measurement channels at the level of the programmable logic controller in the ARS.

The operational mode of the ARS is determined by the setting of the quality inspection program. The operational diagram of the automated regulation system of the UT testing module is presented in Figure 4.

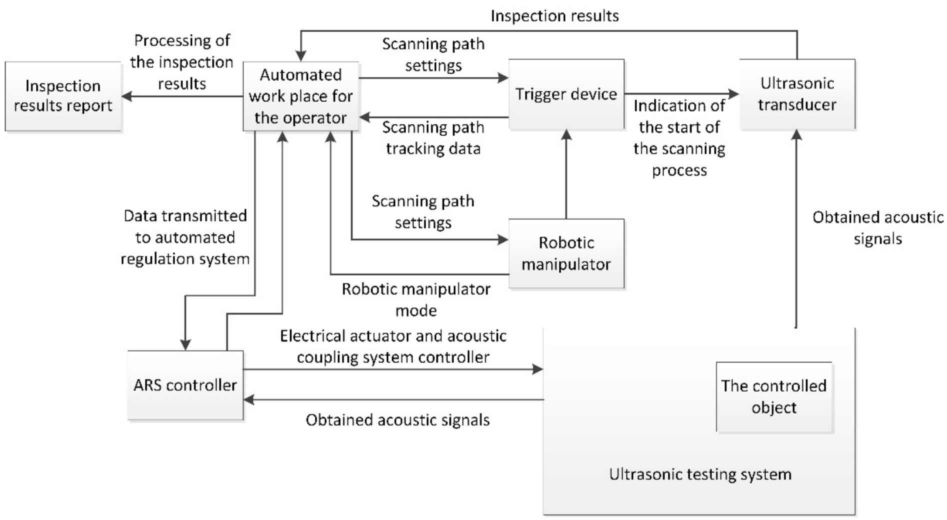

Figure 4. Operational diagram of the automated regulation system of the UT testing module.

The controller of the external automated regulation system of the automated ultrasound testing module for the components operates the electric drives of UT testing module using the data of the external automation. The selected electric drives for regulation of the mobile components of the UT testing module perform positioning of the robotic manipulator with specified accuracy. The scanning path settings are provided by the robotic manipulator movements, the latter is regulated by the robotic manipulator controller. The electric drives of the positioning table enable rotations of the component.

The control of the movements is regulated through the encoder signals. The operator's automated workplace receives the data about the positioning and its correspondence to the control program sequence settings. The control and measurement units are synchronized with the special Ethernet communication channel. The AWO allows processing of the scanning results in accordance with the defect qualifications and generating the inspection protocol. The scanning results are also provided in real time as three-dimensional reconstruction of the internal structure of the component, which allows the operator to conduct overall assessment of the quality. The reconstruction and visualization is performed as ultrasonic tomography based on digital focused array technique (DFA) developed by TPU in collaboration with Fraunhofer Institute [7]. Figure 5 represents the UT testing module, as well as an example of the obtained inspection results.

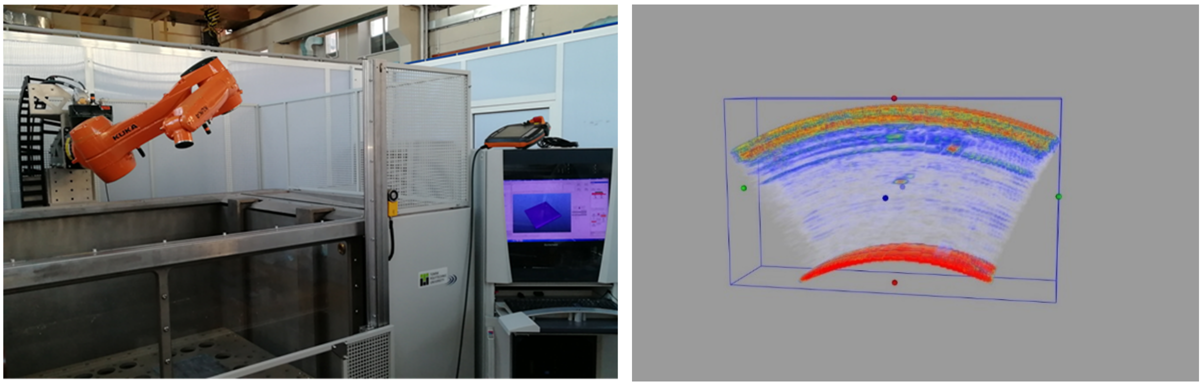

Figure 5. An example of ultrasound tomography results using a robotic manipulator.

4. Summary

The discussed concept allows to create smart manufacturing system which increases the quality of the fabricated components with complex shape by implementation of advanced hardware and software solutions for non-destructive testing and regulation of the technological process stages. The automation solution for the ultrasonic testing module, which is a part of the system, is described in more detail. This module enables to conduct ultrasound tomography inspections of the workpiece, as well as of the final component. The use of a robotic manipulator, while providing interaction through the automated regulation channels and enabling processing of the obtained results and further adjustment of machining of the component has been discussed in this paper. This will significantly improve the technological processes efficiency, minimize the risk of failures, and reduce the probability of manufacturing defects.

Acknowledgments

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