IOP Conf. Series: Materials Science and Engineering **327** (2018) 022091 doi:10.1088/1757-899X/327/2/022091

Smart manufacturing of complex shaped pipe components

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Abstract. Manufacturing industry is constantly improving. Nowadays the most relevant trend is widespread automation and optimization of the production process. This paper represents a novel approach for smart manufacturing of steel pipe valves. The system includes two main parts: mechanical treatment and quality assurance units. Mechanical treatment is performed by application of the milling machine with implementation of computerized numerical control, whilst the quality assurance unit contains three testing modules for different tasks, such as X-ray testing, optical scanning and ultrasound testing modules. The advances of each of them provide reliable results that contain information about any failures of the technological process, any deviations of geometrical parameters of the valves. The system also allows detecting defects on the surface or in the inner structure of the component.

1. Introduction

Modern manufacturing is rapidly changing. The production process has signicantly improved in all areas such as electrical, chemical, metallurgical industries and others. Due to the significant technological development and high demands for quality of the components, the most important requirements are reliability and efficiency of the production. If in the earliest form, the manufacturing process was up to the employees only, after Industrial and Technical Revolution it became possible to integrate mechanical tools and machines. Acceleration of technologies and their implementation to the manufacturing process at each step formed the trend for automation [1-3]. Broad automation as well as implementation of information technologies can be beneficial as they allow to increase efficiency and preciseness of all operations.

Application of novel instruments for technological operations improvement is the most relevant for industrial manufacturing facilities that include mechanical treatment of components. Metallurgical industry requires a wide range of components with complex shape, which can be further used in various application fields such as aerospace, oil and nuclear industries. The main challenge is adaptation of the manufacturing process to the complexity of the desired components.

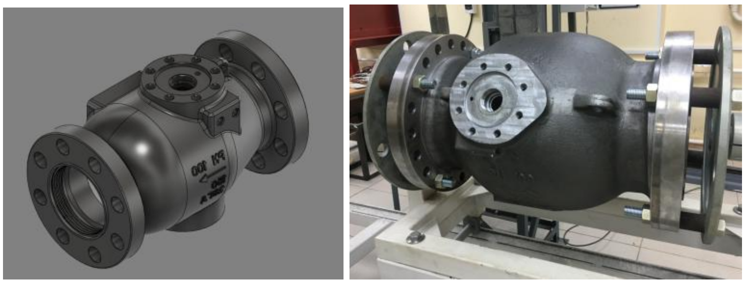
2. Integrated system for smart manufacturing

Nowadays mechanical engineering facilities extensively implement computerized numerically controlled (CNC) machines. It is mainly used in technological process such as mechanical treatment. For instance, cutter milling centers can be integrated with CNC whilst the manufacturing process also includes several steps such as fabrication or construction of a workpiece, mechanical treatment and quality assurance process. The aim of this study is to develop a concept of an integrated system and perform its approbation. It will allow automation of each of the given manufacturing stages.

The main aspects that can influence quality of the finished part are: characteristics programmed via CNC, prior quality of a workpiece or a blank component; and failures in technological process during mechanical treatment.

In this study, mechanical treatment is performed by application of the milling system that includes the mechanical part containing several milling tools with different shape, work tables or work pallets that can be placed at different angles and mechanical operation equipment such as tools and spindles that enable the cutting process; some other auxiliary equipment like the coolant system and pallet changer or pallet magazine, lubrication systems; and a range of integrated modules with software solutions that allow automation, such as integrated CNC.

The information about a component is contained in corresponding CAD models (Figure 1). Advanced technologies enable accurate representation of the components with complex shape, for example, computer graphics for generating surfaces in three-dimensional space such as NURBS or T-splines can be used for this purpose. Moreover, reverse engineering approach can be beneficial in this terms. For example, structured light or laser scanning can collect necessary data of the geometrical parameters of the object and then can be converted to CAD model via computer software [4].



a b

Figure 1. CAD model of the pipe valve (a) and the finished item (b).

To increase efficiency of the production cycle, it will be useful to receive information about the inner structure of the component prior mechanical treatment. This can be achieved by application of nondestructive quality assurance module. Most of Russian mechanical engineering facilities perform separate inspections at the first and the last stages of manufacturing, and the results are received separately. Thus, complex analysis of quality of a component is complicated and not accurate enough.

In this study, the concept of the integrated smart manufacturing system is presented. It is aimed to increase efficiency and reliability of manufacturing complex shaped pipe valves made of steel.

The system contains a computerized numerically controlled module for mechanical treatment and an advanced quality assurance module based on implementation of different nondestructive testing methods. Within the project, specialized software is to be developed to allow control of each step of the manufacturing process and integral quality analysis.

The block of numerical control of mechanical treatment process is performed by CNC machine as described above. It should be noted that the results will be influenced mainly by the developed CAD model of an object.

Quality assurance will consist of several modules aimed to provide solution for estimation of the quality of a workpiece prior and after mechanical treatment. The X-ray tomography module is applied for reliable control of the workpiece quality; the optical module which allows to establish any failure in technological process is used for geometrical parameters measurement and surface control; and ultrasound tomography system is applied for quality control at the final manufacturing stage.

2.1. X-ray testing module

Most of current Russian industrial facilities still exploit classical film radiography methods. However, there is a trend towards replacing it by application of detectors based on digital radiography. Digital X-ray methods provide higher accuracy and reliability of the results [5]. This allows to optimize and reduce costs for selective control and perform reverse engineering tasks. The results are received as a digital file which can be used for integration of this module into the combined system of smart manufacturing; and it enables qualitative and quantitative analysis which is highly important for following technological stages.

The received results are compared with the given CAD model of the component for further calibration. It allows to eliminate technological defects at the next stages. Moreover, if there are any structural defects detected before mechanical treatment, then the created milling path can be reconsidered in order to avoid defective areas and use the given blank item more efficiently.

In this project the betatron-type accelerator is used as the radiation source. This type of emitting sources is quite common due to their simple construction. The lowest values of operating range are the most suitable for testing of the suggested control object – steel pope valves.

Detector chosen for X-ray system is another important part. As it was mentioned above, radiography films are still widely used. However, computer tomography with digital detectors can be more efficient. In this case a special flat-panel detector that contains detection elements, storage elements and image processing module is applied. It is relevantly new technology and allows to store X-ray interaction signals electronically.

A sequence of projections of the object in accordance with each angle by full 360° rotation is be received. Furthermore, these projections are reconstructed via software and 3D model is created. Along with the information about surface parameters the reconstruction also contains the information about the inner structure of the object in accordance with density distribution. The main challenge is to develop the efficient reconstruction algorithm. The algorithm of back projections is a well-known image-reconstruction technique in computed tomography [6]. However, the reconstruction accuracy will be influenced by the scanning technique applied. Parallel scanning is considered to be the most common, thus there are known reconstruction algorithms for it [7-9]. At the same time, for a given object of control the betatron-type accelerator is used as a radiation source, which has a fan-shaped beam. Currently for reconstruction of the signals received from fan-beam scanning an algorithm that transfers it to parallel can be applied [10]. This can lead to increase of reconstruction errors due to additional data processing. For that reason, under the scope of this project the development of a novel reconstruction technique based on the original data from fan-beam scanning of the valve is suggested. General principles used for this purpose are more precisely described in [11].

2.2. Optics testing module

Roughness of the surface can initiate occurrence of different defects under the given operational conditions, such as high temperatures, pressure and humidity level. This can lead to the surface damage such as occurrence of cracks or corrosion. Therefore, appropriate surface roughness is one of the major reliability factors.

Nowadays, contact or non-contact methods can be used for surface quality assurance [12-15]. Contact methods require special tools such as stylus profilometer, surface analyzer or a microscope in order to make measurements. The displacement errors as well as geometrical parameters of these instruments can lead to inaccurate measurement results; also the measurements can be very time consuming. Non-contact calibration methods are fast and reliable. They can be based on different methods such as optical scanning and ultrasound [16], the latter is more expensive and difficult to perform. For that reason, under the scope of this project it is suggested to use optical scanning.

Taking into account the complexity of the shape of the manufactured components it is also important to enable preceise control of geometrical parameters. Thus, three dimensional reconstruction of the object can be very useful.

As a scanning technique, three-dimensional laser triangulation is used. The basic principles are to project the laser band on the surface of the controlled item and capture its distribution by the sensor. In general, the digital camera with sensitive matrix that captures the light can be used as a sensor [17]. The measurement of the distance between the laser source and the matrix detector allows to calculate the signal at each surface point position within the laser band. As result two dimentional surface profile is formed in accordance with the position of the laser. However, two dimentional scans are not sufficient to enable valid estimation of the quality of the entire surface of the object. For that reason, under the scope of this project the authors suggest implementation of the six-axis industrial robot that can perform scanning of complex objects.

The laser light source is to be assembled on the flange of the robotic manipulator. As a result, sufficient volume of the scanning data of the component will be acquired for reconstruction of the component surface and geometry. However, when the controlled object has complex geometry the scanning process can be performed along multiple scanning paths. This requires accurate calibration of the manipulator in accordance with the coordinate system of the object and the coordinate system of the sensor. The main principles of the calibration techniques that can be applied in this case are discussed in [18].

As the result of the optical scanning, the object is reconstructed as a three dimensional model. Further, to detect any failures in the technological process, reconstruction results for each of the finished parts can be compared with the original CAD models used for the mechanical treatment. If any deviations occur, the technological process parameters are to be reconsidered.

2.3. Ultrasonic testing module

Besides the assessment of the geometry and surface roughness, it is also necessary to inspect the quality of the inner structure of an object. For that reason, ultrasonic testing module is to be developed. At present, Russian industrial ultrasonic quality assurance systems are based on the traditional echo-impulse scanning with normal transducers, which do not allow to build a three dimensional reconstruction of inner structure of the objects. However, considering technological improvements and development of image reconstruction techniques it is possible to perform industrial tomography by means of ultrasonic testing [19-21].

To perform reliable inspection of complex shaped valves, it is important to provide automated access from different angles. For that reason, new automated scanning system with the six-axis robotic manipulator is to be developed. It will include specialized software that enables single processing and further image reconstruction by application of synthetic aperture focusing technique (SAFT). The reconstruction algorithm is described in [22].

3. Conclusion

This study introduces the concept of the semi-automated system that integrally includes modules of numerical control of the mechanical treatment and quality assurance modules for manufacturing of pipe valves with complex geometry.

The overview of the suggested smart manufacturing system emphasizes the advances of each particular module, including nondestructive testing modules based on X-ray, optical and ultrasonic principles. Further development of specialized software will allow to integrate this system into existing production process at Tomsk Vakhrushev Electromechanical Plant. The implementation of the proposed solution will enable to significantly optimize the manufacturing process, increase quality of the products, and reduce inspection and operational costs. Moreover, validation of the system will provide novel opportunities for future broad automation of the manufacturing sector.

4. Acknowledgments

Research has been conducted with the financial support of the Federal Target Programme, the project unique identifier is RFMEFI57817X0251.

References

[1] Dixit U S, Hazarika M, Davim J P 2017 *A Brief History of Mechanical Engineering.* (Springer)

[2] Ershov D Y, Zlotnikov E G, Koboyankwe L E 2017 Dynamic processes in technological systems of machining and the nature of their origin *IOP Conference Series: Earth and Environmental Science* **87 (8)** 82016

[3] Koptev V Yu, Kopteva A V 2017 Structure of energy consumption and improving open-pit dump truck efficiency *IOP Conf. Ser.: Earth Environ. Sci.* **87** 022010

[4] Werner A 2011 *Advances in Manufacturing Science and Technology* **35** 37-57

[5] Korner M, Weber C H, Wirth S, Pfeifer K J, Reiser M F, Treitl M 2007 *Radiographics* **27** 675-686

[6] Simonov E N, Avramov D V 2015 *Vestn. South Ural State Univ. Ser. Komp. Tekhn. Upr. Radioelektron* **15(4)** 50–57

[7] Cloetens P, Barrett R, Baruchel J, Guigay J P, Schlenker M 1996 *Journal of Physics D: Applied Physics* **29(1)** 133

[8] Landron C, Maire E, Adrien J, Suhonen H, Cloetens P, Bouaziz O 2012 *Scripta Materialia* **66(12)** 1077-1080

[9] Bolobov V, Chupin S, Bochkov V 2017 About increasing wear resistance of rock-breaking tool to abrasion by using mechanical and thermo-mechanical treatment International. *Review of Mechanical Engineering* **11 (5)** 301-304

[10] Komissarov A A 2014 *Vestn. Moscow State Univ. Finance Law* **3** 128–136

[11] Ozdiev A K, Kryuchkov Y Y 2017 *Russian Journal of Nondestructive Testing* **53(5)** 387-392

[12] Aulbach, L, Salazar B F, Lu M, Koch A W *2017 Sensors* **17(3)** 596

[13] Li Z, Brand U, Ahbe T 2016 *Precision Engineering* **45** 110-117

[14] Olt J, Liyvapuu A, Madissoo M, Maksarov V 2016 Dynamic simulation of chip formation in the process of cutting. *International Journal of Materials and Product Technology*. **53(1)** 1–14

[15] Krasnyi V, Maksarov V 2017 Improving wear resistance of friction assemblies of oil-well pumps having seals from directionally reinforced polymer composites. *Chemical and Petroleum Engineering*. **53(1)** 1–5

[16] Sukmana D D, Ikuo I 2017 *Japanese Journal of Applied Physics* **46** 4508

[17] Lu J. R, Huang Y Q 2004 *Journal-Xiamen University Natural Science* **43(1)** 50-53

[18] Filippov G, Zhvyrblya V, Sharavina S, Salchak Y 2016 *MATEC Web of Conferences* **48** 03002

[19] Bulavinov A et al. 2010 *European Conference for Non-destructive Testing, Moscow* 1-9

[20] Ploskov N A et al. 2012 *Russian Physics Journal* **54** 1389-1393

[21] Salchak Y A et al. 2015 *Physics Procedia* **70** 484-487

[22] Dolmatov D O, Salchak Y A, Pinchuk R 2017 *MATEC Web of Conferences* **102** 1015