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DESIGN OF CONTROL FOR THE DEVICE USING FOR THE DETERMINATION OF RESIDUAL STRESSES BY RING-CORE METHOD

Urgency of the research. Residual stresses in machine parts and constructions greatly affect their service life and reliability. They are introduced into the manufactured object at each production process and their level can change significantly due to the operation of the product. Their main risk lies in the fact that they add up to the external load and can be the cause of the failure of the construction. Residual stresses can not be determined by simulation methods. They can only be determined using experimental methods. One of these method is the Ring-Core method, the principle of which is to form an annular groove around the strain gauge. Creating of annular groove releases the internal stresses, which can be recorded by a strain gauge. The quality of the formed groove has a significant impact on the overall results of residual stress determination, so it is important to make it as accurate as possible. For this reason, it is necessary to have the most reliable device to form an annular groove.

Target setting. Our goal was to design the drive and control for the measuring device for milling the annular groove. This will make it possible to mill the annular groove more precisely, and the resulting residual stresses will be minimally affected by the inaccuracy of the groove.

Actual scientific researches and issues analysis. When designing the control of the device and preparing this paper, we took into account not only current sources – publications and papers dealing with the current state of existing measuring devices used for determining residual stresses by Ring-Core method, but – we also took into account our practical experience gained in numerous residual stress determinations by experimental methods.

Uninvestigated parts of general matters defining. A modified device requires thorough testing, which has not been implemented during the research for this paper.

The research objective. The goal of the research was to create a control for the existing mechanical measuring device used for creating annular groove for determining residual stresses by Ring-Core method.

The statement of basic materials. The original mechanical device was supplemented by actuators, which were designed to automate the movement in horizontal axes as well as in the vertical axis. Thanks to this, we have achieved greater precision when positioning the work tool above the center of the strain gauge. At the same time, the original equipment was completed with a servo motor that serves to drive the cutter. For all these elements, control by Programmable Logic Controller was proposed.

Conclusions. Our task was to design control for the original device used for residual stress measurement by the Ring-Core method. We needed to design drives to automate the device. For our needs, we decided to apply linear actuators selected according to the requested criteria. After designing of the electric drives and modifying of the original device, we proceeded to implement control by Programmable Logic Controller. After that, we created a control program in the Automation studio software. This modified measuring device is able to achieve a much higher precision of the annular groove milling, which makes it possible to determine the residual stresses in the structures more precisely.

Keywords: residual stresses, Ring-Core method, control, actuator, servomotor, Programmable Logic Controller.

Fig.: 7. References: 10.

The current state of the problem

Our aim was to modify the original device used to determine residual stresses by the Ring-Core method (Fig. 1) [1; 2]. Residual stresses have a significant impact on the overall life of each construction. Therefore, they need to be given sufficient attention. Residual stresses can not be determined by simulation methods, they can only be determined by experiment. To make the experiment, a reliable measurement device is needed to get the most accurate measured values.

The original device had a relatively simple design, and since no electronic components were used, all processes were manually controlled [3]. This resulted in several disadvantages of this system.

Disadvantages of the original system:

- Manual positioning,
- Manual feed control in the vertical direction,
- Manual controlling of the rotation speed of the milling process,
- Significant impact of human factor.

Design of components

The main purpose of our design was to modify the original system so that it is possible to manage individual processes such as positioning and milling of the annual groove. For this purpose, actuators have been designed to provide positioning and drive for the milling cutter itself. For our needs, we have to consider the optimal type of drives according to the requirements. Addition of the actuators requires the modification of the original device. It was necessary to create a control unit capable of communicating with a personal computer. Finally, completing of the measuring chain was needed.

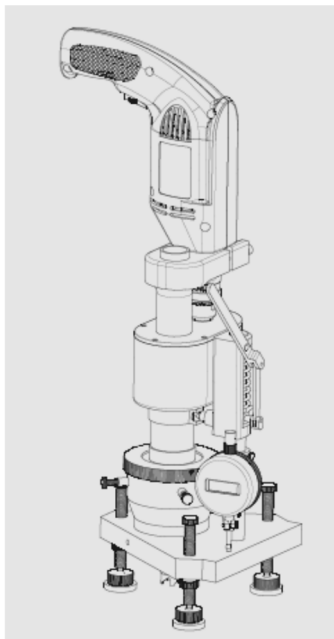


Fig. 1. Original design solution

Actuator requirements:

- Positioning accuracy,
- Repeatability of positioning,
- Sufficient load capacity,
- Sufficient movement range,
- Effectiveness of management,
- Low financial costs.

Design of the drive in horizontal direction

For the design, an electric drive was chosen whose accuracy ranges in μm . The most suitable type of electric drive has proved to be a linear actuator, namely, we chose the CXS6050-S2NN-ND [4]. Such an actor was used for positioning in x and y axes.

Actuator CXS6050-S2NN-ND is a linear drive type with single axis positioning. The maximum possible ejection is 50mm, which is sufficient, because only the fine positioning of the cutter will be realized in this way. The actuator's carrying capacity is 7kg, the weight carried will be 5.2kg. A positioning accuracy of $25\mu\text{m}$ is also sufficient. It is a two-step stepper motor and the supply voltage is 24V. The EE-SX498 optical sensor is also part of the actuator [4].

Design of the drive in vertical direction

In the next step it was necessary to solve the positioning of the device in the vertical direction. As in the previous case, we used a linear actuator, but it was necessary to create an additional structure that would allow the drive to be placed in the vertical direction. For vertical movement, we needed an actuator with a greater range of motion, so we chose the linear actuator CXN5075-S1VN-ND-P1 [5].

Again, this is a two-step stepper motor with 24V supply and a load of 10 kg. The accuracy for this type of device is reported at $0.25\mu\text{m}$, which is sufficient for our needs [5]. Locations suitable for attaching the actuator to the auxiliary construction have to be designed so that the actuator and the construction do not prevent positioning in the axes x and y. Therefore, we placed the construction on a platform that is attached to an x-axis actuator.

The next step was to fix the linear actuator to the original system. On the actuator, we connected the auxiliary piece with screws and we connected it to the top of the gearbox. In this way, we have ensured that it is also possible to position the device in the z-axis. The modified construction is visible in Fig. 2.

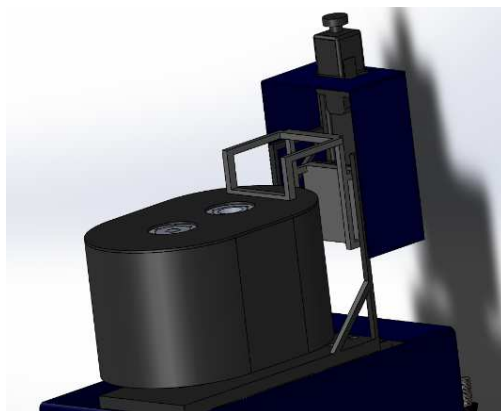


Fig. 2. Positioning mechanism in axis z

Selection of the cutter drive

The original device used a drill mounted in the rack as a drive, and the torque was transmitted through the gearing to the milling cutter. In principle, we designed a similar system, but not using a drill whose speed is controlled manually, but we used an electric motor controlled by a PLC. An important question was the type of electric drive. We have selected the B&R 8LVA33.ee021ffgg-0 servo motor. It is a synchronous electric servo drive with self-cooling with a nominal speed of 2200rpm and the power of 539W [6]. For the selected electric drive it was not necessary to change the structure of the device.

Assembling of the device

The original device was supplemented by two linear actuators designed to provide a horizontal displacement in the direction of the x and y axes. Due to the location of the individual electrical components, we had to adapt the original construction. We have placed three linear stepping motors for positioning in the vertical axis (z) and two horizontal axes (x, y). We used a servo motor to drive the milling cutter itself, with which we transmit the torque through the gear. We put the engine in the casing together with the gear. The complete device is shown in Fig. 3. The working range of the device allows us to move 50mm in the x axis direction and also 50mm in the y-direction. A working range of 75mm is available for z-axis positioning. The positioning accuracy in x and y axes is 15 μ m and 25 μ m in the z-axis.

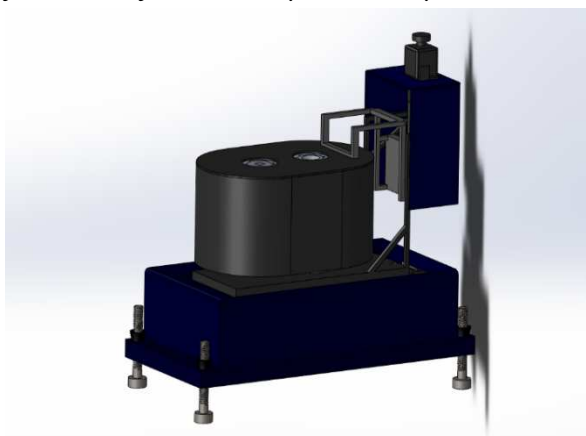


Fig. 3. Final modified device

Design of control unit

We have selected a Programmable Logic Controller (PLC) to control each element of the system. It is a small industrial computer that is used to automate industrial processes in real time. It is used in various branches of industry and automation. The difference between a microcomputer and PLC is that for a microcomputer, the length of the program depends on the number of commands, in the PLC it depends on the loop length setting and not on the number of commands in the loop [7; 8].

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We used the PLC 4PPC70.0702-20W, B&R Modular Programmable Logic Controller. It is a device with a power panel and belongs to the C-series. It has a touch-screen display, and works at a maximum work cycle speed of up to 1ms. The PLC has 256MB of RAM. 2GB of FLASH memory and the processor Intel E620T, which operates at 333MHz. [9]

For the system, we also used PowerLink, Ethernet, USB, and two X2X bus. Each connector has its specific role. Ethernet provides communication with PC. Via the X2X bus, other bus cards are connected to the bus controller.

Using the PowerLink connector, a bus controller is attached to the PLC to connect additional cards.

The bus controller has two PowerLink ports, one is connected to the PLC and the other to the servo driver. A servo driver is a device that contains a controller for drive control and is powered by 230V.

The last steps were to connect the PLC to the PC with an Ethernet connector and to set the correct IP address of the PC and the PLC. The complete control system is shown in Fig. 4.

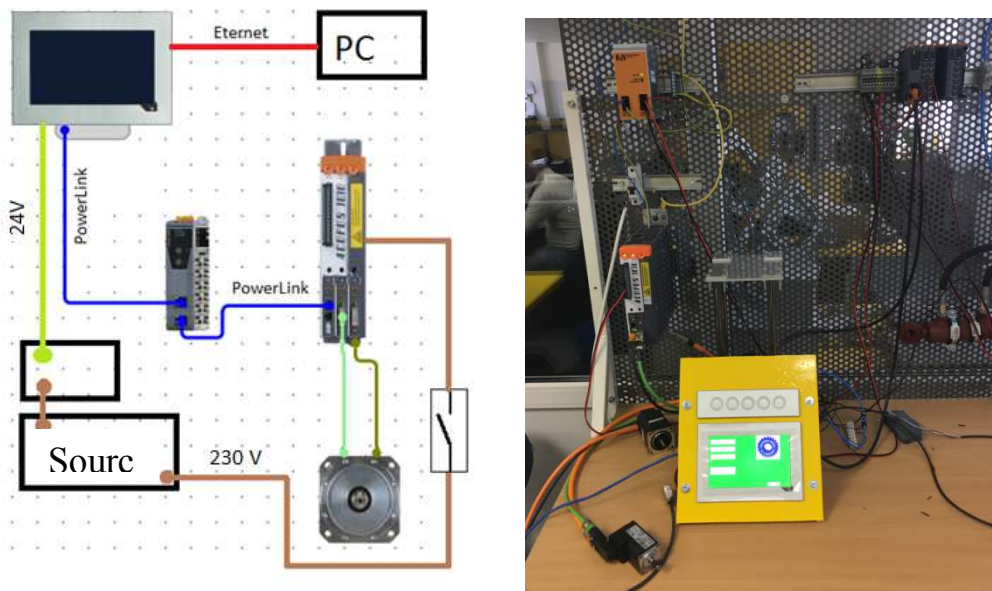


Fig. 4. Hardware Configuration

Software control was developed in Automation Studio 4. It is software designed for B&R logic automation programming (Fig. 5) [10].

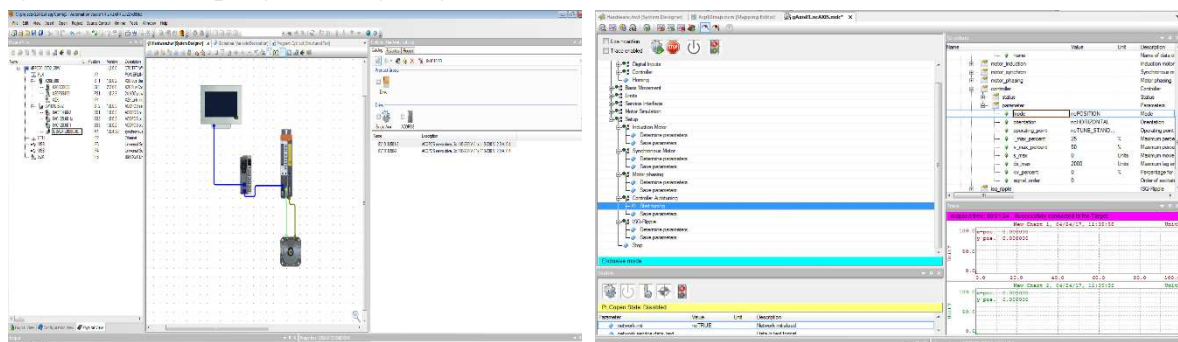


Fig. 5. Realization of control in the Automation Studio 4 software

In Fig. 6 we can see a preview of the created control program.

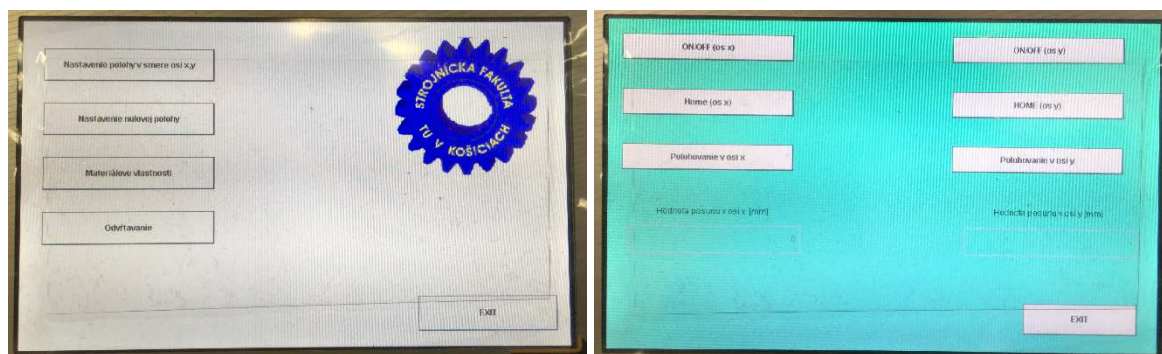


Fig. 6. Demonstration of the control program

Finalization of the measurement chain

The final step was to complete the measurement chain. We have added additional components to the modified measuring device with newly created control.

The final version of the measuring chain consists of the following components (Fig. 7):

- Measuring device,
- Control unit (PLC),
- QuantumX MX 840,
- QuantumX SCM-SG-120,
- Strain gauge RY 51,
- PC.

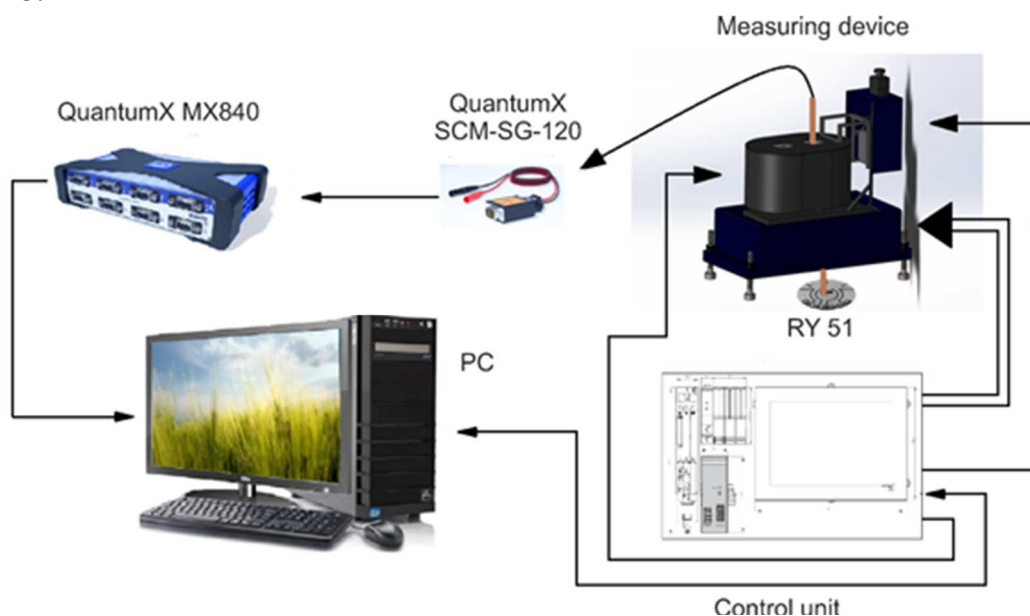


Fig. 7. Final measuring chain

Conclusions

Our task was to design control for the original device used for residual stress measurement by the Ring-Core method.

We needed to design drives to automate the device. For our needs, we decided to apply linear actuators selected according to the requested criteria. The advantage of these drives is their relatively simple control. For the drive of the cutter we used a 537W servo motor.

After designing of the electric drives and modifying of the original device, we proceeded to implement PLC control, completed the components to control the selected drives and created a control unit. After that, we created a control program in the Automation studio software and we also designed visualization on PLC panels where we can control the operation of the device using the programmed buttons.

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The last part of the work was the completion of the measuring chain, which includes, in addition to the measuring device and the control unit, the QuantumX MX 840 measuring device with the necessary reduction to the SCM-SG-120 bridge, the RY 51 strain gauge and the PC.

Our improved automated measuring device is able to achieve much greater accuracy of ring groove milling, which makes determination of the residual stresses in the constructions more precise.

Acknowledgement

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РОЗРОБКА СИСТЕМИ КЕРУВАННЯ ПРИСТРОЄМ ДЛЯ ВИЗНАЧЕННЯ ЗАЛИШКОВИХ НАПРУЖЕНЬ МЕТОДОМ КІЛЬЦЕВОЇ КАНАВКИ

Актуальність теми дослідження. Залишкові напруження в деталях і конструкціях машин сильно впливають на термін їх служби і надійність. Вони з'являються в об'єктах виробництва при кожному виробничому процесі, і їх рівень може значно змінюватися в результаті роботи об'єкта. Їх основний ризик полягає в тому, що вони додаються до зовнішнього навантаження і можуть бути причиною відмови конструкції. Залишкові напруження не можуть бути визначені методами моделювання. Вони можуть бути визначені тільки з використанням експериментальних методів. Одним з таких методів є метод кільцевої канавки, принцип якого полягає у формуванні кільцевої канавки навколо тензодатчика. Створення кільцевої канавки знімає внутрішні напруження, які можуть бути записані тензодатчиком. Якість сформованої канавки робить істотний вплив на загальні результати визначення залишкових напружень, тому важливо зробити її якомога більш точною. З цієї причини необхідно мати найнадійніший пристрій для формування кільцевої канавки.

Постановка проблеми. Метою цієї роботи було розроблення привода й системи керування вимірювальним пристроєм для фрезерування кільцевої канавки. Це дасть змогу більш точно фрезерувати кільцеву канавку, і результуючі залишкові напруження будуть мінімально залежні від похибки обробки канавки.

Аналіз останніх досліджень і публікацій. При розробці системи керування пристроєм і підготовці цієї статті були враховані не тільки наявні джерела – публікації та статті, присвячені існуючим вимірювальним приладам, які використовуються для визначення залишкових напружень методом кільцевої канавки, але також взято до уваги наш практичний досвід, отриманий у численних визначеннях залишкових напружень експериментальними методами.

Виділення недосліджених частин загальної проблеми. Модифікований пристрій вимагає ретельного тестування, яке не було реалізовано під час дослідження для цієї статті.

Постановка завдання. Метою дослідження було створення системи керування для існуючого механічного вимірювального пристрою, що використовується для створення кільцевої канавки для визначення залишкових напружень методом кільцевої канавки.

Виклад основного матеріалу. Існуючий механічний пристрій було доповнено виконавчими механізмами, які були розроблені для автоматизації руху по горизонтальній осі, а також по вертикальній осі. Завдяки цьому ми досягли більшої точності при розміщенні робочого інструмента над центром тензодатчика. Водночас існуюче обладнання було укомплектовано серводвигуном, який служить для приводу різця. Для всіх цих елементів було запропоновано управління за допомогою програмованого логічного контролера.

Висновки відповідно до статті. Нашим завданням було розробити систему керування вимірювальним пристроєм, що використовується для вимірювання залишкових напружень за методом кільцевої канавки. Нам потрібно було спроектувати привода для автоматизації пристрою. Для наших потреб ми вирішили використовувати лінійні приводи, обрані відповідно до необхідних критеріїв. Після проектування електроприводів і модифікації існуючого пристрою ми приступили до реалізації управління за допомогою програмованого логічного контролера. Після цього ми створили керуючу програму в програмному забезпеченні *Automation studio*. Цей удосконалений вимірювальний пристрій дозволяє досягти набагато більш високої точності фрезерування кільцевих канавок, що дозволяє більш точно визначати залишкові напруження в конструкціях.

Ключові слова: залишкові напруження; метод кільцевої канавки; управління; привод; серводвигун; Програмований логічний контролер.

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