DOI 10.32820/2079-1747-2021-27-5-21
UDC 621.002.5-52:621.771.07:658.587

PREREQUISITES FOR CREATING AN AUTOMATED CONTROL SYSTEM FOR THE PROCESS OF THERMAL ASSEMBLY OF OVERSIZED COMPOSITE GEAR WHEELS

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The intensity of the dynamic loads of large composite gear wheels during their operation makes high demands on the quality of the processing and assembly of such parts. These requirements are maintained during the subsequent restoration of the product. Large-sized products include gear wheels with a diameter of more than 3250 mm, and heavy ones – starting from 25 tons and above. The technological processes during the machining of such parts have a number of peculiarities, which are associated with the dimensions and weight of the parts, as well as with the conditions of their manufacture. Therefore, improving the quality of the assembly process due to automated control of measurements of the parameters of a large gear ring when it is heated is an urgent task. The article analyzes the technological features of the assembly of gears, which is carried out by heating the embracing part. With the overall dimensions of the wheel, which do not allow heating operations to be performed on standard technological equipment, this process is to be carried out from individual heating elements stationary or on a rotary platform. It has been found that to control the body temperature of the part and change its bore diameter during heating, it is necessary to interrupt the process. In this case, the parameters are to be measured by two operators manually. To ensure automation of the measurement process and the subsequent control of these parameters, the application of modern methods and means of remote measurement of temperature and linear parameters of the covering part has been considered. This will allow measurements to be taken without interrupting the process. Investigations were made of the heating process of the covering part in order to obtain information about the behavior of the measured parameters. Analysis of product heating was performed by modeling the gear ring heating process in SolidWorks Simulation. A measuring system has been developed for collecting, converting data received from temperature and linear displacement sensors, as well as for subsequent data transfer to a computer at the operator's workplace for processing in a user program. The developed software involves the dynamic control of the heating of the gear ring using the scheduling process. To ensure high-quality performance of the process of heating the gear ring, an algorithm has been created for the program in case of unplanned failures of sensors, equipment or a violation of the technological process. Experimental studies were carried out, which consisted of physical modeling of the process of thermal expansion while heating the ring gear for assembly in the temperature range starting from 20 ° C to 300° C. Modeling of the process was carried out on an installation with a model of the workpiece in a scale of 1:10. The results of experimental studies allow us to lay foundations of the basic prerequisites for automating the assembly process of composite wheels by developing and creating an intelligent complex to control the parameters of the gear ring during the heating process.

Keywords: oversized composite gear wheels, parameters of measurements, automation, system, modeling, experiment.

Лебідь В.Т., Суботін О.В., Целик Ю.Б. **«Передумови створення автоматизованої системи управління процесом термічного складання негабаритних складених зубчастих коліс»**

Інтенсивність динамічних навантажень великогабаритних складених зубчастих коліс при їх експлуатації пред'являє високі вимоги до якості процесу обробки та складання таких деталей. Ці вимоги зберігаються і при наступному відновленні виробів. До великогабаритних виробів відносяться зубчасті колеса діаметром більше 3250 мм, а до великовагових – від 25 т і вище. Технологічні процеси при обробці таких деталей мають ряд особливостей, що пов'язано з габаритами і масою деталей, а також з умовами їх виготовлення. Тому підвищення якості процесу складання за рахунок автоматизованого контролю вимірювань параметрів великогабаритного зубчастого вінця при його нагріванні є актуальним завданням. В роботі проведено аналіз технологічних особливостей складання зубчастих коліс, яке здійснюється шляхом нагрівання вінця колеса. При габаритних розмірах колеса, що не дозволяють проводити операції нагріву на типовому технологічному обладнанні, цей процес виконується від окремих нагрівальних елементів стаціонарно або на поворотній платформі. Встановлено, що для контролю температури тіла деталі і зміни його посадкового діаметра при нагріванні необхідно переривання технологічного процесу. При цьому вимірювання параметрів проводиться двома операторами вручну. Для забезпечення автоматизації процесу вимірювань і подальшого контролю цих параметрів розглянуто застосування сучасних методів і засобів дистанційного вимірювання температури і лінійних параметрів вінця колеса. Це дозволить проводити вимірювання без переривання технологічного процесу. Проведено дослідження процесу нагрівання вінця колеса з метою отримання інформації про поведінку вимірюваних параметрів. Аналіз нагріву виробу виконано шляхом моделювання процесу нагрівання вінця в SolidWorks Simulation. Розроблено вимірювальну систему для збору, перетворення даних, прийнятих від датчиків температури і лінійного переміщення, а також для подальшої передачі даних в комп'ютер на робочому місці оператора для обробки в призначеній для користувача програмі. Розроблене програмне забезпечення передбачає динамічний контроль ведення нагріву вінця за допомогою диспетчеризації процесу. Для забезпечення якісного проведення процесу нагріву зубчастого вінця створено алгоритм роботи програми при непланових збоях датчиків, обладнання або порушення технологічного процесу. Проведено експериментальні дослідження, які полягали у фізичному моделюванні процесу термічного розширення при нагріванні зубчастого вінця під збірку в діапазоні температур від 20 °С до 300 °С. Моделювання процесу проводилося на установці з моделлю заготовки в масштабі 1:10. Результати експериментальних досліджень дозволяють закласти основні передумови для автоматизації процесу складання складених коліс шляхом розробки і створення інтелектуального комплексу з контролю параметрів вінця в процесі нагрівання.

Ключові слова*:* великогабаритні складені зубчасті колеса, параметри, вимірювання, автоматизація, система, моделювання, експеримент.

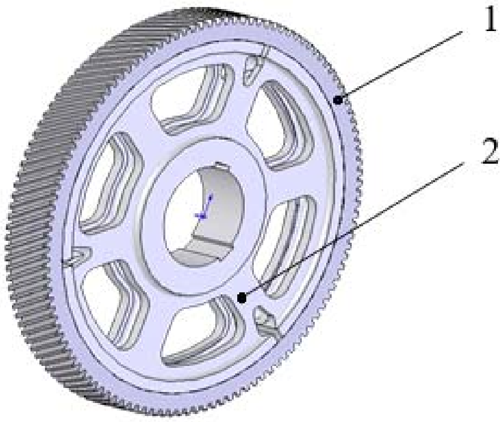
ISSN 2079 – 1747 Машинобудування, 2021, №27
DOI 10.32820/2079-1747-2021-27

Introduction

In modern machines and assemblies, heavily loaded gear wheels are widely used, which are designed to transfer torque with a change in the shaft rotation per min [1].

In Fig. 1, as an example, a general view of the large-sized composite gear wheel (LSCGW) of the gearbox is shown.

a
Composite gear wheel
of a reducer (example)



b
1 – a gear ring; 2 – a center wheel

Figure 1 – General view of large composite gears (*a*, *b*)

The design of large gear wheels is usually implemented in a composite version, as shown in Fig. 1. *a*.

In Fig. 1. a: a ring gear (embracing part) (1) and a hub or center (embraced part) (2) are marked.

It is considered that large-sized products include gear wheels with a diameter of more than 3250 mm [2]. Technological processes during the machining of such parts have a number of peculiarities. On the one hand, this is related to the dimensions and weight of the parts, and on the other hand, to the conditions for their manufacture (individual or small-scale production).

The relevance of the problem. Current trends are aimed at increasing of the intensity of dynamic loads of large-sized composite products (LSCP) during their operation. This makes high demands for the quality of the processing of such parts. The specified requirements are followed also during the subsequent restoration of the product.

The aim of the present development is to improve the quality of the assembly process and the culture of technological operations at the expense of the automated control of measurements of the parameters of a large gear ring (LGR) during thermal treatment of it. This will ensure the optimal performing of the heating process of the embracing part when using an intellectual complex of measuring facilities.

The object of study is a system of automated control of the gear ring of LSCGW parameters in the process of its thermal preparation for assembly with a center (hub) under the guaranteed interference.

The subject of the study is automatic control of the temperature parameters and linear expansion of the short-circuit protection during thermal exposure.

Scientific novelty is determined by establishing the prerequisites for creating an integrated intellectual system for measuring the parameters of a large composite gear wheel in the process of thermal preparation of the gear ring for the assembly with the center.

The practical value of the study is the development of the prerequisites for the creation of an automated complex for monitoring and measuring a number of parameters of large-sized parts to ensure an optimal thermal assembly process.

According to the normative documentation [2–4], large-sized products of the rolling body class include parts with a diameter of 3250 mm or more, and heavy ones from 25 t (previously 20 t [2]) and more.

In the study [3], this indicator is 72 tons. In the framework of this article, the products with a lower level of the mass ranging from 5 tons and overall dimensions from 1000 mm are being considered. The values of these meanings are established on the basis of the cost analysis of the blanks produced at the heavy engineering plant.

Composite (bandaged) gear wheels with gear rings with spur, helical and chevron teeth with one, two or three discs in a cast-iron center are being considered (Fig. 1.b). These products are widely used in industry, for example, in gearboxes of stands of rolling mills.

The structural dimensions of the bandage and the oversized composite gear wheels (OSCG) cast-iron center are taken based on the conditions of their equal strength, and the fitting diameter of the crown boring is determined based on the condition of the transfer with an interference fit of the maximum torque allowable by the bending strength of the teeth The generalized parameters of a number of LSCGW are given in Table 1.

The assembly of the ring gear with the center of the wheel is carried out by thermal action (heating) on the embracing part according to the technological parameters (Fig. 2). The gear ring is heated in the heating furnaces (with the appropriate dimensions of the product and the characteristics of the processing equipment). The heating time is adjusted depending on the overall dimensions of the embracing part. After the assembly of OSCG, processing is to be carried out in accordance with typical technologies.

The main provisions (stages) of the thermal action assembly and processing of the OSCG are shown in Fig. 3 [5, 6].

When the overall dimensions of OSCG that do not allow heating operations to be performed on typical technological equipment, this process is to be carried out from individual heating elements permanently or on a rotary platform.

When heating the gear ring, the control of the body temperature of the part and changes in its boring diameter is required for LSCGW. To ensure safe access for the personnel with a measuring tool to the embracing part, according to the safety conditions, of the process should be interrupted. In this case, the measurement of the inner diameter of the heated gear ring is to be made by two operators (controllers).

General conditions of the processing of large sized composite gear wheels when being assembled by heating (Fig. 3).

Based on the basic provisions of the technology, in order to ensure an automated measurement process and subsequent control of their parameters, the following tasks are solved:

– application, based on the analysis of traditional ways, modern methods of measuring temperature and linear parameters of the embracing part;

– assessment and selection of methods and means of measuring temperature and linear parameters of the embracing part.

The main part of the preparation of the gear ring LSCGW for assembly by thermal influence is the measurement and control of these two parameters to assess the state of the heated crown.

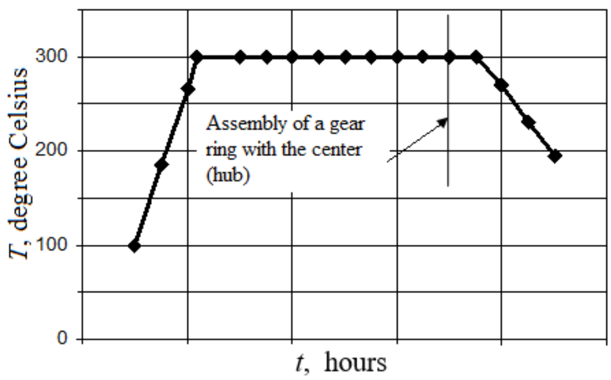


Figure 2 – Technological parameters of the temperature heating of the ring gear for the assembly of LSCGW

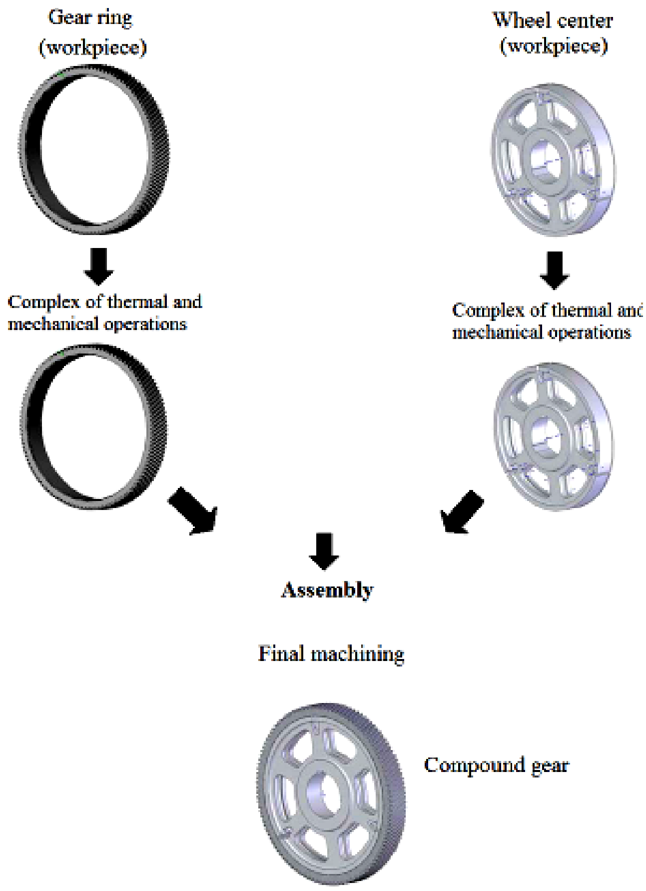


Figure 3 – General provisions for the processing of oversized gears in a composite version during assembly by thermal action

One of the directions of modern trends in improving engineering and processing technology in heavy engineering is to increase the accuracy and prompt response when conducting the measuring parameters during the manufacturing process.

Automation of production and the widespread use of flexible production systems allow us to solve this problem [7–12].

It is advisable to measure the linear dimensions of the fitting diameter of the crown and its temperature during heating in automatic mode, without interrupting the process [13]. The organization of the measurement process is shown in Fig. 4.

The main means of heating the oversized gear ring of OSCG are induction heaters and gas burners. The heating of the part occurs due to the thermal conductivity of the material and is weakened by the convective influence of the environment. To eliminate this phenomenon, a special device [14] has been developed.

When a temperature of 300 °C is reached at the heating sites, the intermediate sections of the embracing part are at a lower temperature level. For a part in a static position, it is 130 ... 160 °C.

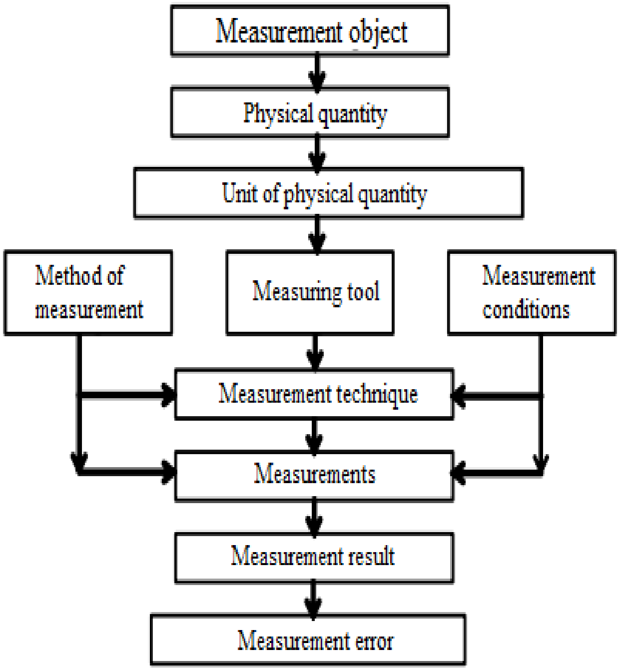


Figure 4 – Process measurement structure

The control of the heating process of the embracing part for assembly is usually performed in the manual mode. With this approach, in some cases, uneven heating of the embracing part and an overspending of the energy can be noticed.

The task is to automate the measurement process, which requires the selection of appropriate primary measuring transducers (sensors) to ensure the necessary accuracy and quick response of the speed of control of the required parameters [15, 16].

Table 2 shows the characteristics of the main types of analog non-contact sensors for measuring distances.

Table 3 shows the ways for measuring the main parameters (temperature and linear displacements) and their features.

Based on the analysis of the sensors, pyrometric and ultrasonic non-contact sensors were used to measure the temperature and determine the change in diameter of the gear ring model of LSCGW. Investigations were made of the heating process of the embracing part in order to obtain information about the behavior of the measured parameters.

The analysis of product heating was performed by modeling the thermal process on the ring in SolidWorks Simulation. The simulation results of the basic process of heating the embracing part are shown in Fig. 5 and Fig. 6.

In Fig. 6 shows the results of a study of the temperature distribution during heating of the embracing part.

A visual representation of a uniformly heated gear ring to a temperature of 310 °C is shown in Fig. 6. Uneven expansion when the part is heated reaches 6 mm.

During the simulation, the basic parameters of the LSCGW and the conditions of the performing the process taking into account the material of the part, the environment (air) and temperature effects (local heating at variable power) have been considered.

At the present stage of research, the model is simplified, but sufficiently fully provides information about transient processes during thermal influence on the embracing part.

The main parameters adopted during the simulation are summarized in Table 4, and the simulation results are shown in Table 5.

A measuring system has been developed for collecting, converting data received from temperature and linear displacement sensors, as well as for subsequent data transfer to a computer at the operator's workplace for processing in the user program [13, 19].

Monitoring the normal operation of the system is provided by indicators in the form of signal LEDs. Peripheral device management is guaranteed by the STM32L4A6ZG logic controller with ultra-low power consumption (Table 6).

The block diagram of the measuring device of this system is presented in Fig. 7. *a*, and the operator's workplace – in Fig. 7. *b*.

Table 2 – Characteristics of linear distance measuring sensors

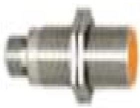
Parameter \ A type	Sensors			
				
	inductive	ultrasound	optical	
			triangulation	radar
Distance, mm	0 ... 200	10 ... 10 000	10 ... 2 000	10 ... 500 000
Resolution, microns	0,1	100,0	1,0	500,0
Accuracy, microns	1	200	2	2000
Linearity, %	0,4 ... 5,0	0,5	0,05 ... 1,00	0,001
Time, ms	0,3	20,0	1,0	1,0

Table 3 – Comparison of methods for measuring temperature and linear parameters

Tool type	Measurement error	Tool reliability	Instrument value (relative units)	Safety and comfort when using
Contact, manually	subjective factor	positive	1,0	non-compliance with safety standards
Contact, automated	low	negative (due to tool wear)	5,0	need for service
Contactless automated	low	positive	6,0	safety compliance

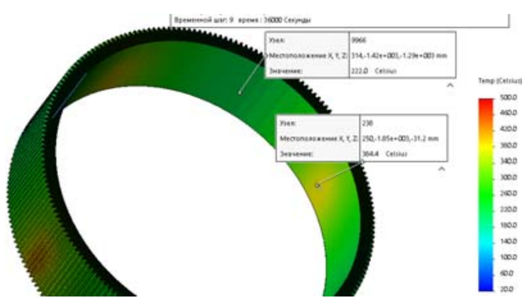


Figure 5 – SW Simulation: temperature gradient when heated

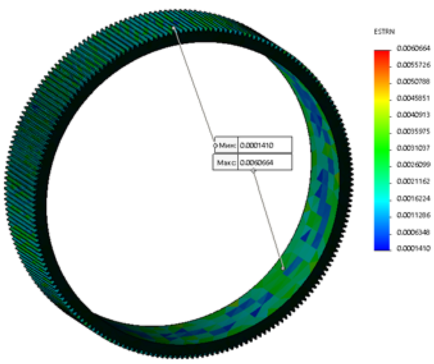


Figure 6 – SW Simulation: diameter expansion at T = 310 °C

Table 4 – the Source parameters of the simulation SW Simulation

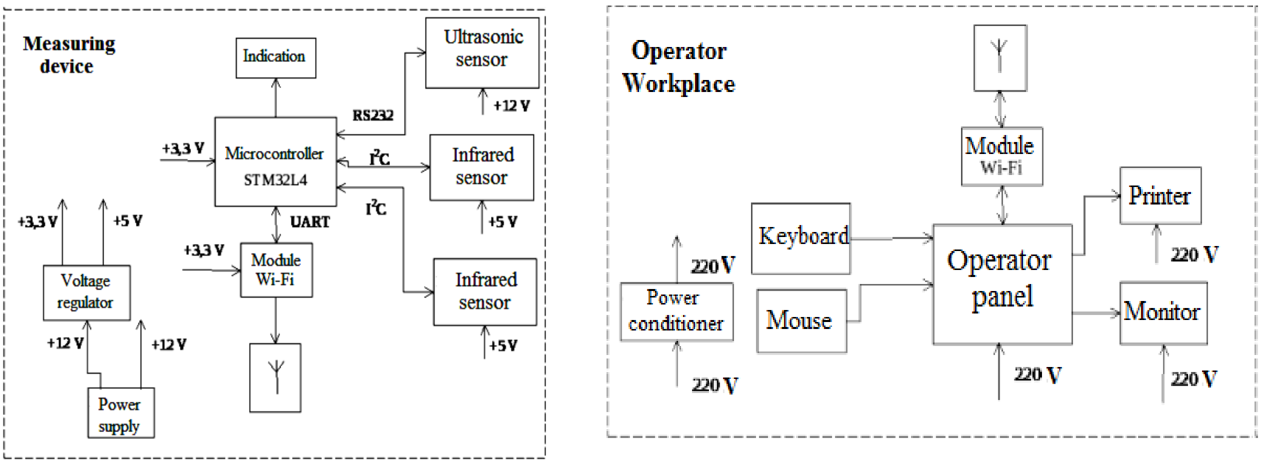
Parameter	Units	Value
Ambient temperature	°C	20
Convection	W / (m^2 °C)	7
Thermal expansion transitions	1 / °C	1,7 x 10^{-5}
Thermal conductivity	W / (m^2 °C)	384
Specific heat capacity	J / (kg °C)	390
Diameter	mm	3700
Weight	kg	15 730

Table 5 – SW Simulation simulation results

Parameter	Units	Value
Spent time	seconds	36 000
Power consumption	kW	1000
Delta temperature	°C	162
Maximum temperature	°C	385

Table 6 – Controller Specifications

Parameter	Value
Core	ARM® 32-bit Cortex®-M4 CPU with FPU
Working frequency	up to 80 MHz
Memory	1 MB Flash, 320 KB of SRAM
Supply voltage	1.71 V to 3.6 V power supply
Current	91 μA / MHz run mode (LDO Mode)
Interfaces	USB OTG 2.0, SAIs, I2C FM +, U (S) ARTs, CAN



a *b*

Figure 7 – Block diagram of the measuring device (*a*) and block diagram of the operator's workplace (*b*)

During the cycle of heating the gear ring, it is necessary to control the uniformity of heating of the embracing part. To solve this problem, it is necessary to take measurements in two zones – the closest to the heat source and the intermediate zone, which requires two sensors. Also, when choosing a sensor, the main parameter is the optical resolution of the measuring device. The temperature, depending on the state of the metal, can be measured with sufficient accuracy by infrared pyrometers. Moreover, the choice of the most effective method is associated with the consideration of several factors.

The decisive factors are: the stability of the radiating characteristics of the surface during the assembly process, the degree of condition of the metal surface and climatic conditions in the measurement zone [15].

Theoretical analysis is based on the assumption that pyrometers are used in a narrow wavelength range and therefore the change in readings depending on the temperature measurement can be determined according to the Planck's law. As practice shows, most radiation receivers have a wide range of waves, and the use of filters does not sufficiently limit this range to consider it to be strictly monochromatic.

According to additional studies, pyrometric monochrome sensors operating in the wavelength range of 8 ... 14 microns have been chosen for consideration.

The most promising option for application is the Melexis MLX9061DCI model. Its difference from expensive sensors is that it has version without housing with subsequent installation in a complete measuring device. The main advantage is the availability of inbuilt temperature sensor that measures the temperature of the sensor. Connection to the controller is performed by using the I2C interface.

This infrared thermometer provides non-contact temperature measurement. Due to the low noise level of the 17-bit analog-to-digital converter and a powerful digital signal processor, high accuracy and resolution are achieved.

To ensure the elimination of interference in the form of radiation close to infrared, an optical filter is provided with a transmission range of 5.5 to 14.0 μm.

The device is available in the TO39 industry standard enclosure.

The thermometer is calibrated over a wide range of temperatures: -40 ... +125 °C for ambient temperature and -70 ... +380 °C for object temperature. MLX9061 is made of two chips:

- infrared sensor based on thermoelectric battery MLX81101;
- ASSP MLX9030 output signal processor.

The sensor supports a two-wire data transfer protocol, in Slave mode (secondary device), built on the basis of PWM / SDA and SCL:

- SCL - a digital input that is used as a timer for SMBus joint communication. This contact has an auxiliary function to provide stabilization of the external voltage;
- PWM / SDA - digital input / output, which is used to output PWM measured object temperature (s) or digital input / output for the SMBus protocol.

To control the change in the diameter of the gear ring during thermal treatment, a sensor has been adopted that provides accuracy within ± 0.5mm with a measurement range of not less than least 3000 mm [20].

A comparison of the characteristics of a number of sensors for some indicators is given in Table. 7. According to the aggregate of the compared parameters, the wms-340 / RT model of Microsonic GmbH is a promising option.

In the conditions of machine assembly factory shops, for the considered gear rings, the ultrasonic distance sensor can be the best choice (Table 7).

The task of the monitoring microcontroller STM32L4A6ZG is to form a trigger pulse and measure the value of the echo signal. The sensor is connected to the port A, 8-pin is responsible for initializing measurements and port 15 is responsible for obtaining the result. The code that provides this task starts with initializing the pins in the port.

To get the distance value anywhere in the program, the get Distance Intact () method is used. The result is written to the echoSMResult variable. To cyclically obtain the distance, it is necessary to ensure the interval between measurements.

The required accuracy is ensured by changing the coefficient value in a global variable when debugging a device which has been installed on equipment.

The communication of the measuring device with the computer is provided by Wi-Fi wireless technology. The SPWF04SA module, which is a multi-element turnkey solution, provides 802.11 b / g / n data transfer standard. The exchange of information, as well as the transmission of commands and the reception of messages from the module, is carried out by using the USART interface. There is also a microcontroller on board, with the help of which the low-level operation with the module is carried out.

The control of this measuring system (module) is carried out by using AT-commands. To connect the module to a common network, it is necessary to enter a series of commands in a terminal program in sequence. After a reboot, the module is connected to the network and access point, and it is assigned an IP address.

The process of assembling LSCGW by thermal treatment on the embracing part is time-consuming due to the significant overall dimensions and masses of the products which require consideration of environmental conditions. When creating software, the problem remains of the dynamic control of the heating of the gear ring with the help of process scheduling.

The program is being developed for the Microsoft Windows operating system in the free VisualStudio Community application development tool. A system is used to build Windows Presentation Foundation (WPF) client applications, which provides visually attractive user experience.

Table 7 – Comparison of indicators of ultrasonic sensors

Model	Range of measurements, mm	Measu-rement accuracy, mm	Reliability EN 60529	Cost, conventional units
Microsonicwms-340 / RT	350 ... 5 000	± 0.35	IP 65	170
Microsonic mic-340 / IU / M	350 ... 5 000	± 0.16	IP 67	620
PIL Sensoren Series P48	10 ... 3 000	± 1.00	IP 67	150
Maxbotix MaxSonar-WRLST	500 ... 10 000	± 1.00	IP 67	220

The basis of WPF is a vector visualization system that is created taking into accounts the capabilities of modern graphic devices.

It is planned to develop a program interface for presenting in a convenient form the values characterizing the temperature and the bore diameter of the embracing part. Creating a calculation module provides the calculation of the necessary resulting values from the source data (initial mass and diameter). At the same time a manual mode is provided, which ensures flexibility in using the program.

The work is carried out using the extensible markup language XAML (eXtensible Application Markup Language) for declarative programming of applications. Everything developed in XAML can be converted by using more traditional NET languages, such as: C # or Visual Basic.NET.

A peculiarity of the application of this technology is the reduction in the complexity of the tools used for processing.

In the upper part of the workspace there is the “Menu” panel, in the lower part there is a status panel that reflects the current date, time and current status of the program.

A program interface has been developed for dialogue with the user when entering data or switching functions.

To ensure a high-quality conduct of the gear ring heating process, a program algorithm has been created for unplanned failures of sensors, equipment, or a technological process violation.

The software application in automatic mode monitors the value of temperature sensors and a sensor of linear dimensions. The application informs about exceeding threshold values by a message. This function allows timely response in an unpredictable situation, for example, in case of the failure of the measuring device.

The algorithm of the program in emergency mode is shown in Fig. 8.

The demonstration of the trial program (Fig. 9. *a*) shows its interface in the operating mode.

In the information input fields, the set values for the initial, current and threshold values of temperature and the diameter of the ring gear are displayed. The graph shows a dynamic change in the current value and the mark of the required diameter is highlighted. When determining the temperature, the average measurement value of two sensors is given. The maximum permissible heating temperature is controlled in a logic code, when a critical point is reached; a warning is displayed on the screen.

The measuring system with the developed software is installed on the stand and meets the minimum requirements for Microsoft to use Windows. Fig. 9.b shows the screen for consuming the computer resources by software.

Experimental studies have been carried out, which resulted in modeling the process of thermal expansion when heating the ring gear for assembly in the temperature range from 20 ºС to 300 ºС. The parameters of OSCG are accepted for consideration, with its fitting diameter of 2735 mm and a width of 120 mm. Modeling of the process was carried out on an installation with the gear ring model OSCG in a scale of 1:10.

A general view of the experimental setup for trial testing of the process of heating of the gear ring and the subsequent assembly of the OSCG model is shown in Fig. 10.
The LSCGW model is represented by a gear ring (1) with a diameter of 273.5mm, a width of 12 mm, mounted on a platform (2). The installation consists of a base platform (3) with an electric drive (4), providing rotation of the product for uniform heating. Warming up is carried out by a gas ring burner (5) located under the gear ring. Measuring equipment (6) is placed in a zone that excludes temperature effects.

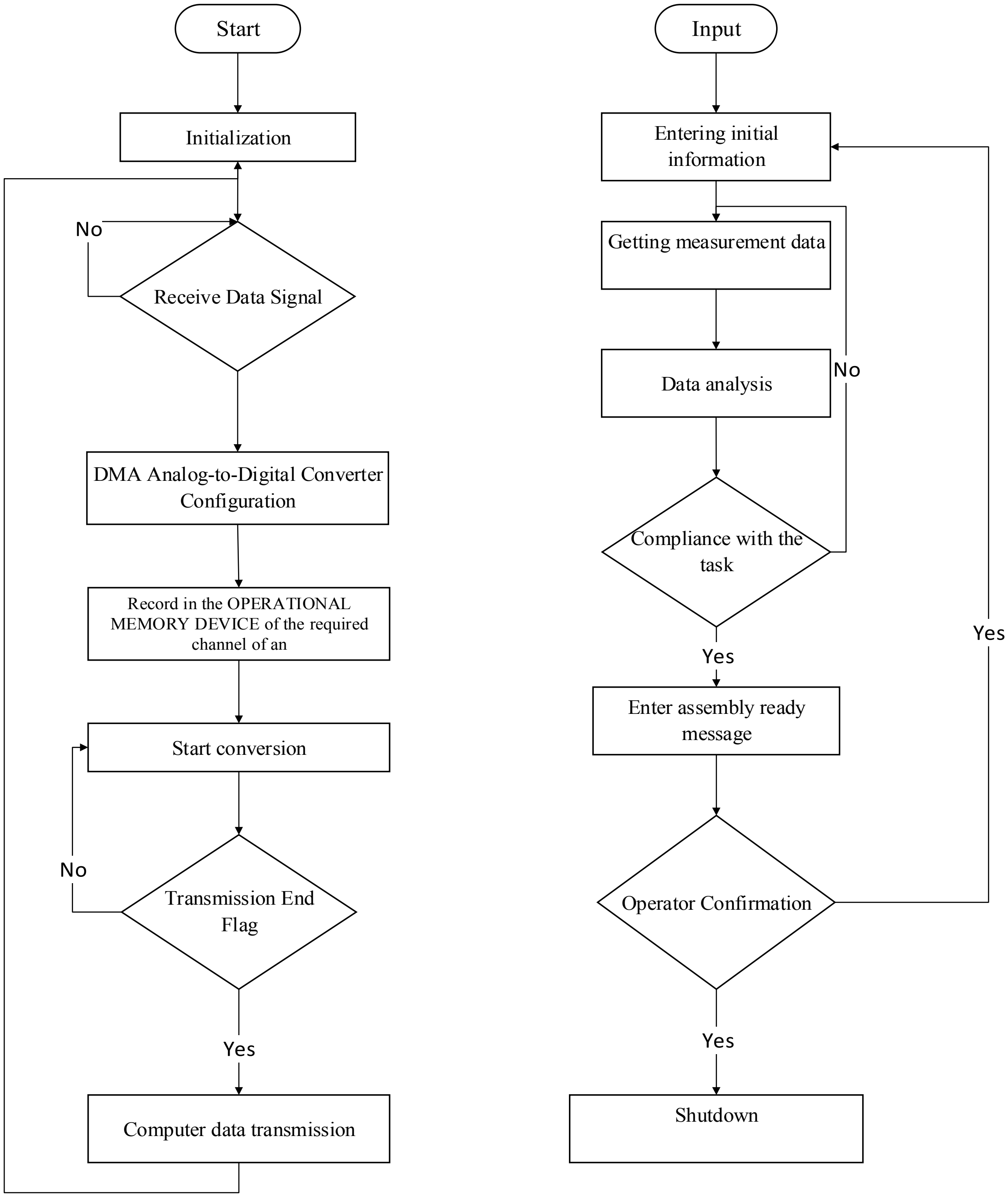
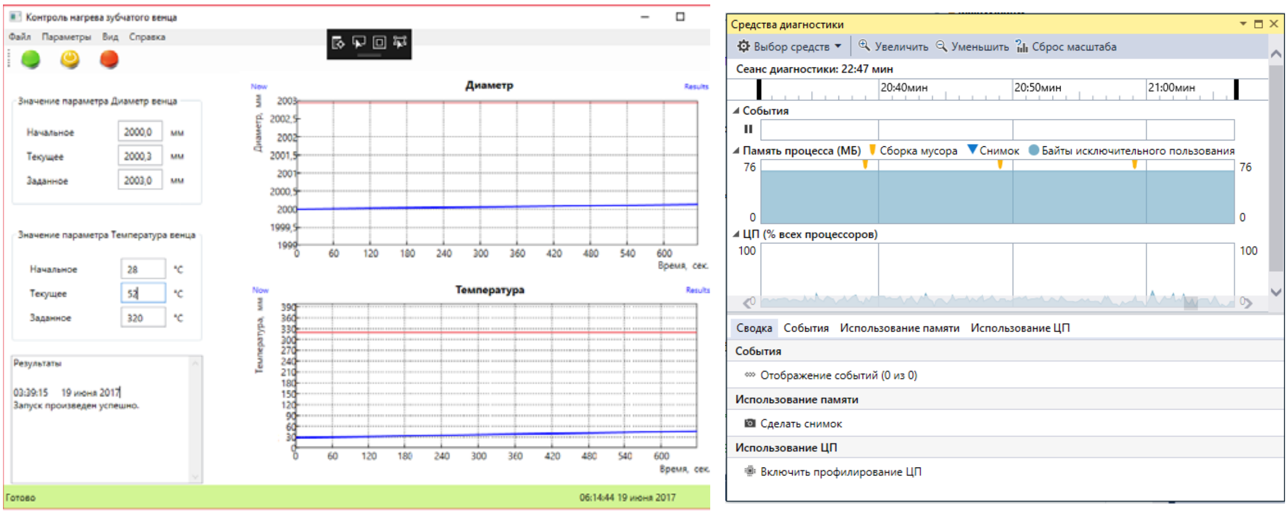


Figure 8 – The algorithm of the program in emergency mode



a *b*

Figure 9 – Demo mode of the trial program (*a*) and computer resource consumption by software (*b*)

Trial testing of the experimental setup for the process of heating the ring gear and subsequent assembly of the LSCGW model is shown in Fig. 11

A comparison of a number of measurement results made by automatic and manual methods is carried out.

The control of temperature parameters and the size of the bore diameter during heating were carried out automatically by sensors of infrared temperature measurement (7) and ultrasonic distance measurement (8) with an interval of 30 seconds.

At the same time, an additional control of temperature measurement was carried out using a Testo 830-T4 pyrometer with an interval of 300 seconds. Measurement error of ±2 °C is over the entire range. A control measurement of the diameter of the gear ring was carried out by using a caliper. Instrument - ЧИЗ models (Cl.2).

The measurement interval is the above mentioned. Measurement of the fitting diameter of the crown (273.5 mm) was carried out in two planes with an accuracy of ± 0.1mm at 20 °C.

The control measurement of the diameter, after the end of the heating process to T = 240 ºC, is qual to 274.3 mm.

The models of the gear ring and the hub, as well as their assembly into the model of the composite gear wheel are shown in Fig. 11.

ISSN 2079 – 1747 Машинобудування, 2021, №27
DOI 10.32820/2079-1747-2021-27

Figure 10 – General view of the heating installation:
1 – model of the gear ring; 2 – rotary platform; 3 – installation casing; 4 – electric drive; 5 – gas burner; 6 – measuring equipment; 7 – temperature sensor; 8 – distance sensor

a *b*

Gear ring models (*a*) and hub (*b*)

c

Gear ring heating (*c*) for assembly

d

Assembly of the crown
and hub (*d*)

e

Compound gear model (*e*)

Figure 11 – Trial testing of the process of heating the ring gear and the subsequent assembly of the OSCG model

Conclusions

Ensuring a high-quality assembly process by the thermal treatment of LSCGW with optimal process control in laboratory conditions is achieved by creating a measuring system to control the parameters of the embracing part. The system consists of a device for the direct measurement of temperature and linear dimensions and a software product; it provides scheduling of the technological process of assembly of gear rings under thermal treatment on the embracing part.

Measurements of the parameters of the embracing – temperature and linear dimensions – were made by non-contact sensors. To take into account the temperature gradient along the inner surface at significant dimensions (width) of the crown, two temperature sensors are used that measure the values of heating in the zones of active heating and in the intermediate position of the product in order to control the temperature gradient.

An automated control system for the process of heating the gear ring for assembly of the LSGW model under thermal treatment at the experimental bench has been tested.

The applied non-contact measurement method has advantages in terms of results by comparing indicators of reliability, accuracy, cost and compliance with the prod T uction culture up to 4 %.

The results of experimental studies make it possible to lay foundations for the basic prerequisites for automating the assembly process of the LSGW by developing and creating an intelligent complex for controlling the parameters of the gear ring during the heating process.

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Стаття надійшла до редакції 12 квітня 2021 року