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Universal tester of length sensors

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Keywords: sensor, signal, uncertainty, gauge, length.
Abstract: The article deals with the design of a universal tester of length and position sensors. It is composed of a rotary table and a sliding mechanism for generating displacement. Length parallel gauges are used as standards. The result of the testing is the static and calibration characteristics of the sensor and the verification of the maximum permissible errors of the sensor and measuring chain.

1 Introduction

Position sensors are a relatively widespread category of sensors applied in almost all areas of science and technology. Before the actual application of position sensors, it is necessary to verify the properties of the selected sensor and possibly identify the unknown properties of the tested sensors.

The properties of the sensors listed in the catalogue sheets are specified under certain measurement conditions. However, sensors are often used in other than laboratory conditions, so it is necessary to verify their properties in other conditions as well.

Existing test equipment is developed for each sensor type and application separately and does not allow testing other sensors and testing multiple sensor properties. Test devices are developed as single-purpose test devices for output control by sensor manufacturers.

In the case of sensors, it is necessary to test the static characteristic as the dependence of the sensor's output reference value on the input measured value. The dynamic properties of the sensors include the transient characteristic, which shows the response of the sensor to a step change in the measured input quantity. Among the dynamic properties of the sensor is also the impulse characteristic, which describes the response of the sensor to the impulse of the input measured value. Another dynamic property is the speed characteristic, which investigates the response of the sensor to the input quantity with increasing speed of change of the input quantity. A frequently monitored dynamic property is also the frequency characteristic, which describes the response of the sensor to the harmonically varying input quantity. With some types of sensors, it is also necessary to investigate the influence of the inaccuracy of the positioning of the sensor with respect to the detected object. This means that during testing it is necessary to deviate the axis of the sensor with respect to the perpendicular to the detected object. With sensors sensitive to magnetic fields, it is necessary to place a permanent magnet as the detected object, and the solution of the test equipment must be adapted to this. Another feature that is interesting for the application of sensors is their lifetime defined by the number of cycles that can be realized during the entire lifetime of the sensor [1-5].

Current solutions of test equipment do not allow comprehensive testing of sensors from the point of view of the mentioned properties.

Parallel gauge blocks (Figure 1) are precisely manufactured prisms with defined dimensions that can be used as length standards. These are materialized length measures, which are used for the verification of length sensors and length gauges. They are made of metal or ceramics with a low coefficient of thermal expansion. Parallel gauge blocks are available as a multi-piece set that allows for any size assembly. The accuracy of these etalons is defined by the ISO 3650 standard [2].


Figure 1 Set of parallel gauge blocks

2 Length sensor tester concept

In the test device (Figure 2), the tested position sensor is placed on a plastic arm connected to a slide moving along a horizontal line. The detected object is placed on a rotary and height-adjustable table attached to the base plate. The slide is attached to the toothed belt with a slide carrier. The movement of the slide with the sensor is ensured by a toothed belt and toothed pulleys. This toothed pulley is attached to a DC motor with a gearbox, which ensures the movement of the toothed belt and thus the slide. The movement of the slide is also sensed by a separate sensor of the position of the slide to obtain information about its current position. The runner of this sensor is connected by means of a runner carrier with a slide. The horizontal guide of the slide, the sensor of the position of the slide and the gear with a DC motor are attached to the frame, which is placed on a rotating base, which allows the rotation of the whole system with respect to the detected object by a specified angle. A DC motor with a gearbox and a toothed gear enables automated testing of the static and dynamic properties of the tested position sensor, and it is also possible to carry out tests of the life of the tested sensor. In addition, the rotary table makes it possible to test the influence of the deviation of the sensor from the perpendicular with respect to the detected object, whose position the sensor detects (Figure 2).

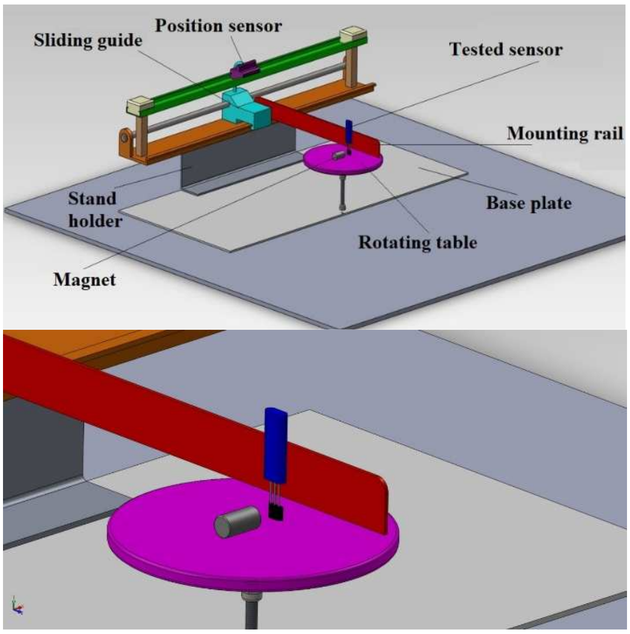
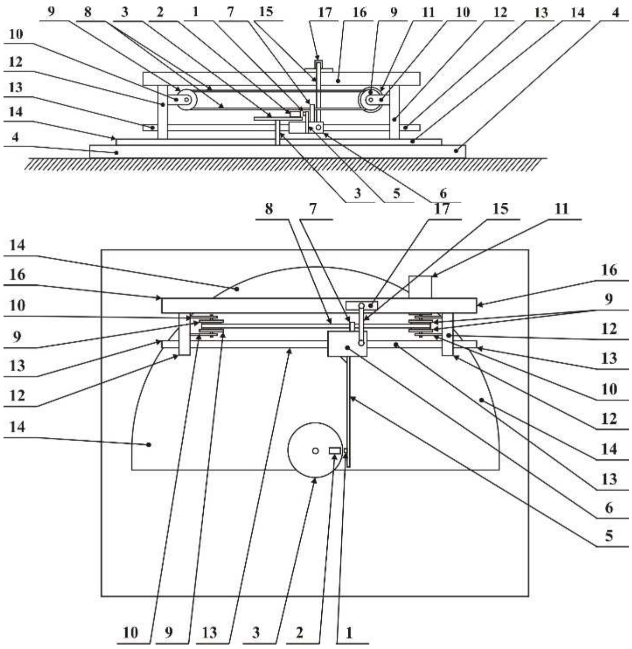


Figure 2 Length sensor tester concept

3 Technical solution of the tester

In the tester (Figure 3), the detected object 2 is mounted on a rotary and height-adjustable table 3, which is attached to the base plate 4. The tested sensor 1 is mounted on a plastic arm 5 firmly connected to a slide 6 moving along a horizontal guide 13.



1 – Tested sensor; 2 – Detected object; 3 – Rotating and height adjustable table; 4 – Base plate; 5 – Plastic arm; 6 – Slide; 7 – Slide driver; 8 – Timing belt; 9 – Toothed pulleys; 10 – Bearing the pulley; 11 – DC motor with gearbox; 12 – Frame; 13 – Horizontal line; 14 – Swivel base; 15 – Runner drifter; 16 – Slider position sensor; 17 – Slide position sensor runner.

Figure 3 Tester arrangement

The slide 6 is attached by means of the carrier 7 of the slide 6 to the toothed belt 8, which moves with the help of a DC motor 11 with a gearbox connected to one of the toothed pulleys 9 on which the toothed belt 8 is mounted. The toothed pulleys 9 are stored in the bearing 10 of the pulleys. The movement of the DC motor 11 with the gearbox creates the movement of the toothed belt 8 and thus also the slide 6 with the tested sensor 1. The slide 6 is connected to the runner 17 of the sensor 16 of the position of the slide 6, which is part of the sensor 16 of the position of the slide 6. Horizontal line 13, storing 10 pulleys, DC motor 11 s by the gearbox and the position sensor 16 of the slide 6 are attached to the frame 12, which is firmly connected to the rotating base 14. The entire horizontal positioning system is formed by the pay arm 5, the slide 6, the driver 7 of the slide 6, the toothed belt 8, the toothed pulleys 9, the bearings 10 of the pulley , DC motor 11 with gearbox, frame 12, the horizontal guide 13, the rotating base 14, the driver 15 of the runner, the sensor 16 of the position of the slide 6 and the runner 17 of the sensor 16 of the position of the slide 6, together with the tested sensor 1, it is thus possible to film with respect to the axis of the rotary and height adjustable table 2 with the detected object 2 and to investigate the influence of the deviation of the perpendicularity of the tested sensor 1 with respect to k to the detected object 2. The detected object 2 is selected according to the type of the tested sensor 1. For example, for the tested sensor 1 sensitive to the magnetic field, a permanent magnet is used as the detected object 2. If the

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tested sensor 1 is based on the inductive principle, a metal object and the like is selected as the detected object 2.

4 Experimental testing of the Hall-effect distance sensor

During the experimental testing of the distance sensor based on the Hall-effect principle (Figure 4), a permanent magnet was placed on the rotary table, which is made of non-ferromagnetic material so as not to affect the magnetic field of the placed permanent magnet. Hall-effect distance sensor vol mounted on a plastic beam that can be positioned relative to the permanent magnet. The relative position of the sensor relative to the permanent magnet can be adjusted using parallel gauge blocks.

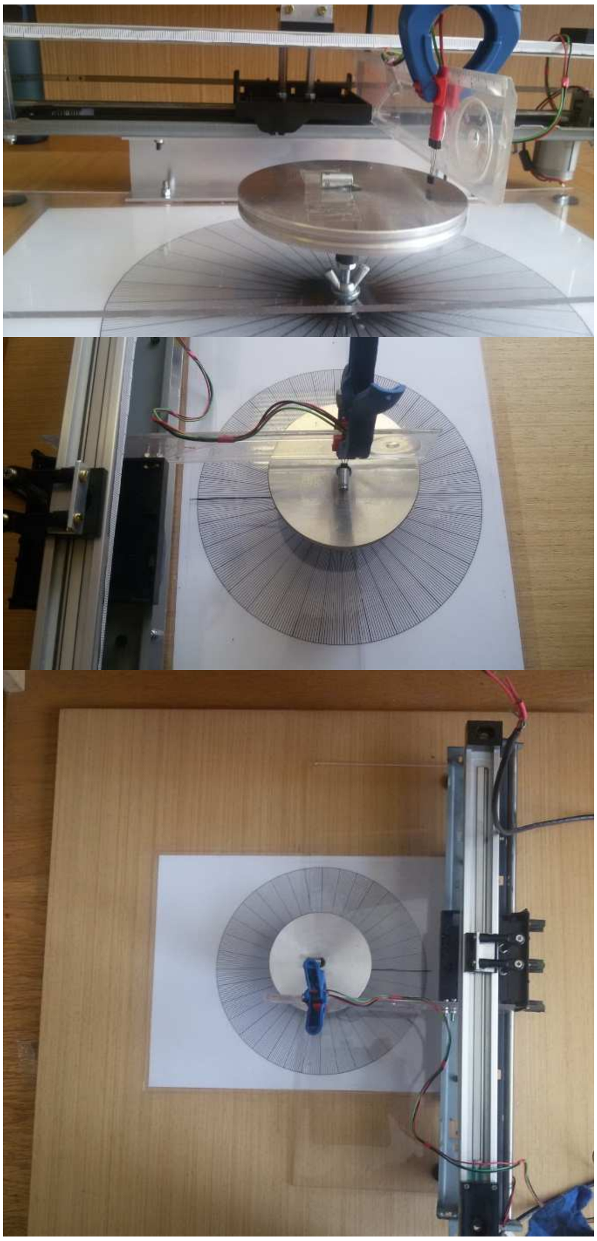

Figure 4 Experimental testing of the Hall-effect distance sensor

When testing the Hall-effect distance sensor, it is possible to realize four possible configurations of the arrangement of the sensor and the permanent magnet (Figure 5). From the obtained experimental data, the best solution is the U4 configuration, which has the largest useful distance measurement range and the minimum hysteresis.

The result of the experimental testing of the sensor (Figure 6) shows the course of the output electric voltage of the sensor when changing its position relative to the permanent magnet in the U4 configuration. The graph shows a slight hysteresis, which, however, can be neglected and the working area of the distance measurement range is suitable for dimensions from 4mm to 20mm (Figure 6).

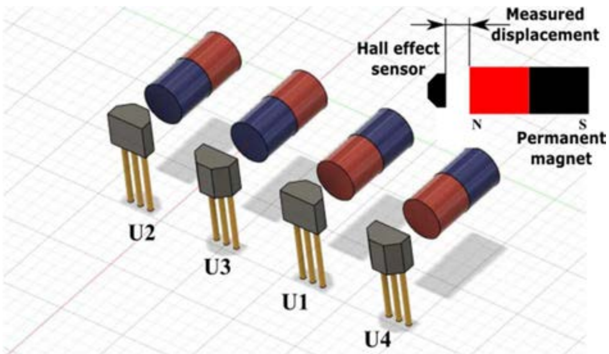

Figure 5 Sensor and permanent magnet arrangement options configurations

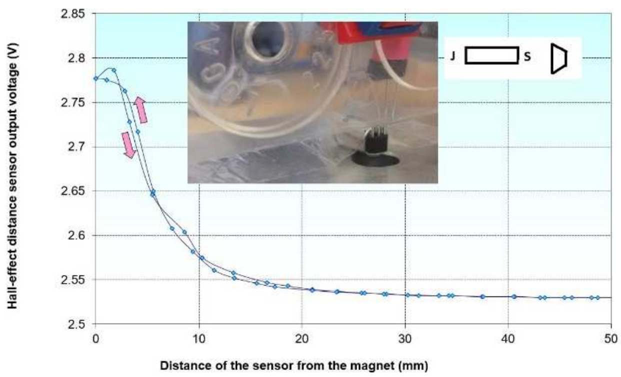

Figure 6 Experimental testing of the Hall-effect distance sensor during uniaxial distance change

The proposed test device also provides the possibility of changing the direction of the permanent magnet relative to the axis of the sensor (Figure 7). With this multi-axis approach and distance of the sensor with respect to the magnet, it is possible to observe the directional characteristics of the sensor based on the principle of the Hall effect. The 90° rotation angle is when the axis of the sensor is identical to the axis of the permanent magnet. It can be seen from the graph (Figure 7) that when the sensor is rotated with respect to the magnet, the sensitivity of the sensor improves and the usable range of distance measurement also increases slightly. At the same time, it is possible to find out from the graph (Figure 7) how sensitive the sensor is to the accuracy of the adjustment of the axis of the sensor to the axis of the permanent magnet.

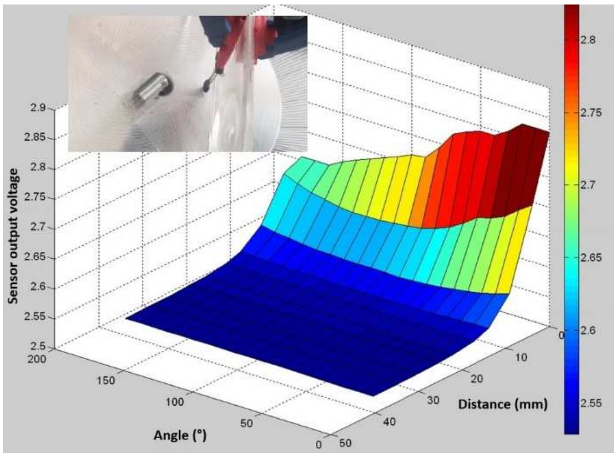

Figure 7 Experimental testing of the Hall-effect distance sensor during multi-axis distance change

5 Conclusion

The result of this study is the design of an experimental test device that allows testing the characteristics of the distance sensors and at the same time it is possible to identify the directional characteristics of the sensors using a rotary table.

The proposed tester for testing sensors can be used to simulate the application of the tested position sensor and verify its properties in this application. In addition to the static and dynamic characteristics of the sensor, it is also possible to test the lifetime of the sensor and non-standard motion cycles according to the application in which the sensor is planned to be used.

Similar to other applications, it is important to test and diagnose systems for identifying their properties and for their periodic diagnostic verification of their functionality [6-21].

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Possibilities of creating spur gear geometry

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Keywords: gearbox, gearing, design, model.
Abstract: The swift advancement of science in computer technology enables the resolution of increasingly intricate engineering challenges through contemporary calculation techniques. Numerical methods employed in mathematics are among these. The finite element method, also known as FEM, is widely recognized as a prevalent numerical technique. The Finite Element Method (FEM) is a versatile technique employed to tackle diverse engineering challenges. These may include problems related to flexibility, strength, heat transfer, and a variety of gear solutions. The Finite Element Method is primarily employed in this domain to address deformation and stress analyses pertaining to the gears under examination. Numerous programs are available for addressing issues through the Finite Element Method. However, a crucial prerequisite for effectively analyzing deformation and stress in gearing is the precise definition of the computer model representing the gear system under investigation. The focus of the article is on discussing the process of designing gear geometry within CAD software systems.

1 Introduction

Complex mechanical systems called gear drives are found in almost every kind of technology, including cars, airplanes, and robots. Gear drive design is a laborious and time-consuming procedure that heavily relies on the designer's intuition and expertise. Many complex issues and a wide range of influencing elements must be taken into account at the early design phase. One of the crucial factors to take into account is the gear transmission chain configuration. The way the gears, shafts, bearings, couplings, clutches, and other components are connected to one another so that the gear transmission system can transfer motion and power is known as the gear transmission chain configuration. It is a crucial choice made early in a gear transmission's design. Any errors in these early design stages can significantly increase the challenges in later design and manufacturing. Decisions made in these stages frequently have a significant impact on the full-life-cycle product properties, including costs, performances, reliabilities, safety, maintenance, and so on. Numerous significant system attributes, including reduction ratios, system level proficiencies, system dynamic features, and even the forces transferred by each component, are impacted by the transmission chain arrangement. In the early stages of a gear drive's design, modeling and configuration assessment are crucial issues. The configuration model can serve as a basis for additional research and assessment [1-3].

Modern calculating techniques may now be used to address even more challenging engineering issues because to the quick advancement of research in the realm of computer technology. Among them are mathematical techniques that use numbers. One of the most used numerical techniques is the finite element method (FEM). Numerous engineering problems, including those involving strength and flexibility, heat transport, and a variety of gear systems, may be resolved using the FEM approach. In this field, deformation and stress jobs in the gears under study are mostly solved using the FEM. Although there are several programs for utilizing FEM to solve issues, the most accurate determination is one of the requirements for successfully solving the deformation and stress analysis of gears using this approach [4-5].

2 The involute tooth shape modelling conditions for spur gear

Developing a computer model of the thing under investigation begins with the creation of geometry. Involute gear geometry may be created using a variety of CAD programs, including AutoCAD, Bentley, Pro/Engineer, I-DEAS, Solid Works, NX, and others.

It should be mentioned that the side of the involute tooth is made up of the involute and dedendum transition curves for modeling spur gears manufactured with a rack tool without protuberance. When the gear wheel is operating, only the involute portion of the tooth flank may function as the active portion. The transition curve's job is to make the transition from the dedendum circle to the involute portion of the gearing smooth and rounded. As a result, the most accurate involute structures, such the transition portion of the involute tooth's side, must be the main emphasis of any geometric model of spur gearing. The straight portion of the rack tool, which runs from the addendum to the dedendum, forms the involute portion of the tooth. The profile normal is known to be a tangent to the base circle, traveling through the instantaneous center of rolling. The line of action always goes through the instantaneous center of rolling because, for the involute profile, it is the same as the profile normal line, which is the common normal of the two contacting sides of the teeth at their locations of contact. The angle of the tool profile is the same as the gearing's production meshing angle. A planar curve that crosses every tangent perpendicular to the circle is called an involute from a geometric perspective. This circle is its evolute, or by the collection of the involute's centers of curvature (geometric points). It is referred to as the foundation circle for gearing [6-10]. The radius of the fundamental circle is the only parameter that clearly determines the involute. The trochoid building technique states that the involute is formed by the trajectory of a point that is securely attached to the forming line and rolls along its evolute, or base circle (Figure 1).

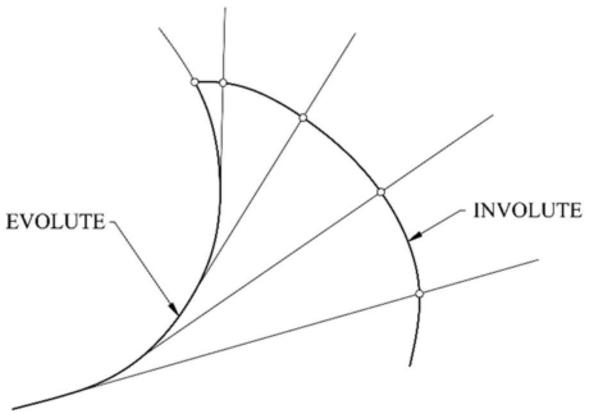

Figure 1 Definition of Involute, Evolute

The dedendum transition refers to the area situated between the involute surface of a gear and the dedendum circle. The purpose of the transition curve is to facilitate a smooth changeover between the gear's involute section and the bottom land. The dedendum transmission curve of a tooth shaped by the rack tool is generated by progressively rolling the rack tool around the gear wheel's pitch circle. The radius of curvature along the transition curve changes at different points [11-15]. Thus, the transition curve is created as an envelope of the rounded positions of the rack tool that moves along the pitch circle of the gear wheel. The tooth shape is formed by connecting the involute section with the transition part. In order to create a complete tooth shape, additional information is necessary, such as the measurements of the addendum and dedendum circles, which will determine the height of the tooth. To design one tooth, it is essential to have the required values of the tooth width at a specific radius (such as the pitch radius) or the corresponding chord length.

In practical applications, corrected spur gears are also utilized. There are two primary types of corrections used in involute gearing. A required correction eliminates the undercut of the gear tooth, while a desirable correction is applied to achieve specific characteristics of the gear profile. When developing a geometric model of a corrected spur gear, it is crucial to begin with the relationships for the fundamental dimensions of these corrected gears.

3 Implementation of combined CAD modelling for spur gears

A technique used for gear production involves simulating either the entire machining process or only specific parts of it. The creation of a CAD model involves the solid modeling of a semi-finished product that will transform into a gear wheel, as well as the tool used in the machining process. These two models need to be positioned correctly. In the subsequent phase of the process, the simulation advances by incorporating specific movement instructions for the tool, and in certain instances, for both the tool and workpiece. The gearing is designed by subtracting the volume of one object from another; specifically, the volume of the tool is removed from the workpiece volume at their intersection points. The drawback of this approach (Figure 2) lies in the pairing of steps and precision. The more accurate the model, the finer the steps it must take, yet smaller steps lead to a longer generation time.

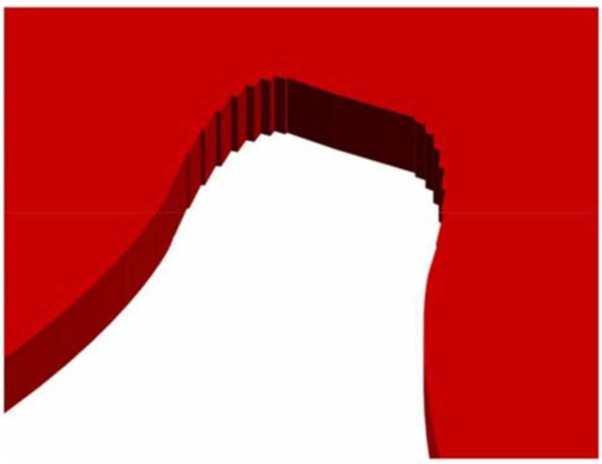

Figure 2 Example of made tooth gap by subtraction

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Mixed CAD modeling involves simulating the machining process using a tool profile, rather than a solid tool, as illustrated in Figure 3. This profile performs a similar step movement as described in the subtraction method above, with the key distinction being that it exclusively produces points.

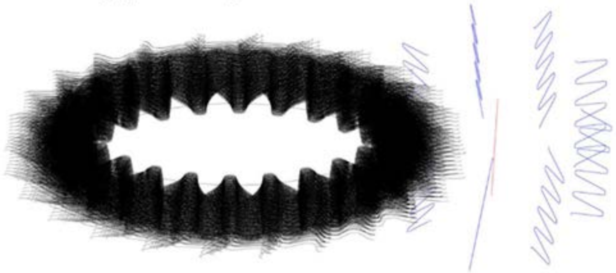

Figure 3 Definition of mixed CAD modelling method

The points produced form a point cloud that needs to be refined, ideally using an algorithm, to eliminate any unnecessary points (see Figure 4-a). In the last phase, the refined point cloud is utilized to generate surfaces through NURBS modeling (refer to Figure 4-b).

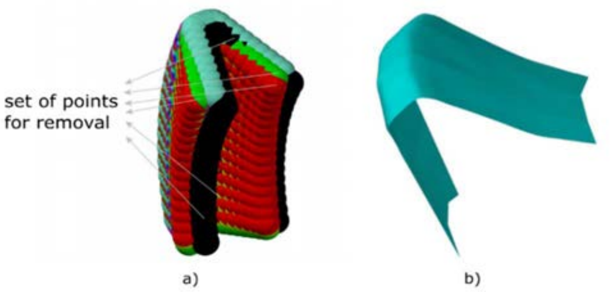

Figure 4 Generation of tooth gearing by a) points, b) surfaces made through points

The CAD model is produced by incorporating volume within the surfaces generated. Obtaining a point cloud enables quicker and m
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4 Implementation

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leads to complete gearing.

By utilizing the ProE
appropriate parameter settings, a diverse selection of gears can be efficiently manufactured with satisfactory precision within a reduced time frame. The Pro/Engineer program allows for the creation of a comprehensive gear model in a straightforward manner, simplifying a traditionally time-consuming process. Afterwards, it becomes feasible to integrate specific gear characteristics into this model and link them through mathematical formulas. It's feasible to craft any gear wheel by adjusting various aspects like the dimensions of the gearing, such as the modulus, number of teeth, displacement, and more. Additionally, further modifications can also be made if necessary. The initial action involves establishing the geometric specifications for the spur gearing. An illustration can be found in Figu

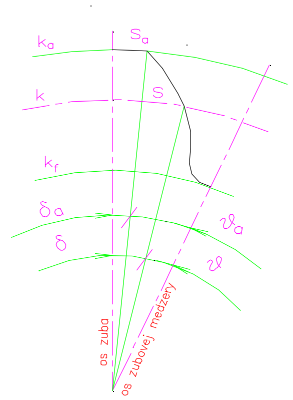

Figure 5 Influence of wheel web on the tooth stiffness

Figure 6 illustrates a detailed portrayal of the sketch or model. It is recommended to perform parameterization on the model for the corrected gearing. Variable values such as the number of teeth z, the modulus mn, and the unit height displacement x need to be specified using different elements. These elements could be defined by specific features, like offsetting by a value to display as ±x, or by

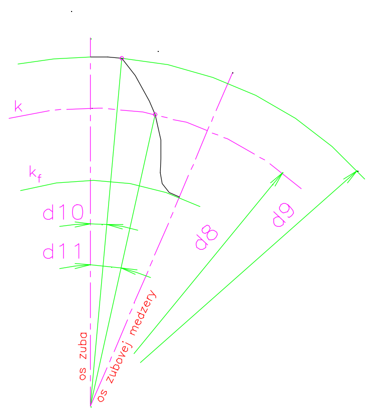

Figure 6 An illustration showcasing the parametric description of the model

The parametric description incorporated a modification in the designation of individual parameters:

- the quantity of teeth, denoted as d0, was referred to as z,
- the normalized value assigned to the modulus m_n was denoted as d1,
- the symbol used to represent the unit height displacement x is denoted as d2,
- the symbol d3 denotes the helical angle β.

Subsequently, the equations necessary for determining the gear dimensions were defined parametrically. Equation (1) parametrically defined the diameter of the pitch circle as determined by equation (2).

$$d8 = d0 \cdot d1 / \cos d3 \tag{2}$$

$$d = \frac{z \cdot m_n}{\cos \beta} \tag{1}$$

Equation (3) parametrically defined the angular coordinates of the involute point on the pitch circle described by equation (4).

$$d11 = \frac{(0{,}5 \cdot \pi + 2 \cdot d2 \cdot \sin 20 / \cos 20) d1 \cdot 180°}{(d8 \cdot \pi \cdot \cos d3)} \tag{3}$$

$$\delta = \frac{s}{d} \cdot \frac{180°}{\pi} \tag{4}$$

In this manner, all the gear parameters were sequentially determined.

5 Implementation of Face gears modelling

The face gear depicted in Figure 7 is a novel transmission mechanism that has been extensively studied. This mechanism has been implemented in a specialized transmission group, especially within the aviation sector.

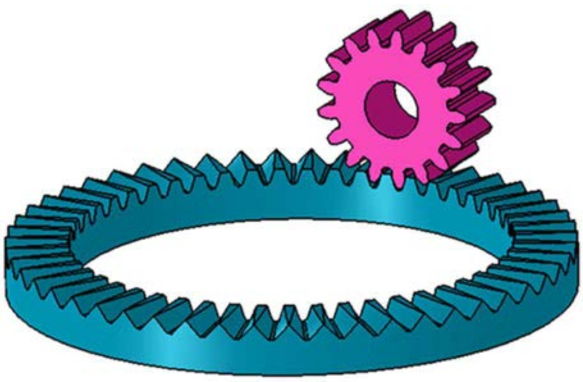

Figure 7 Face gearing model

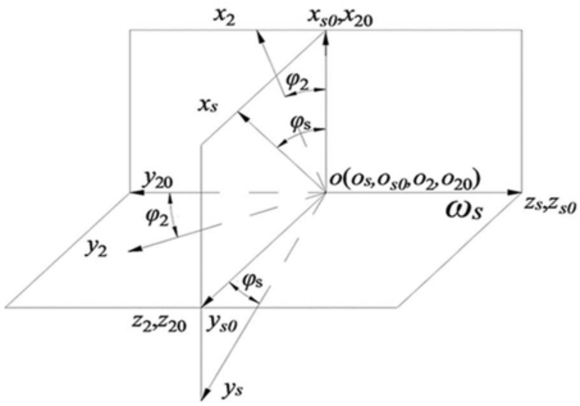

Figure 8 Face gear generation coordinate system

The coordinate system employed for the involute tool tooth surface aligns with the one shown in Figure 8, featuring a cross-section that embodies an involute tooth design.

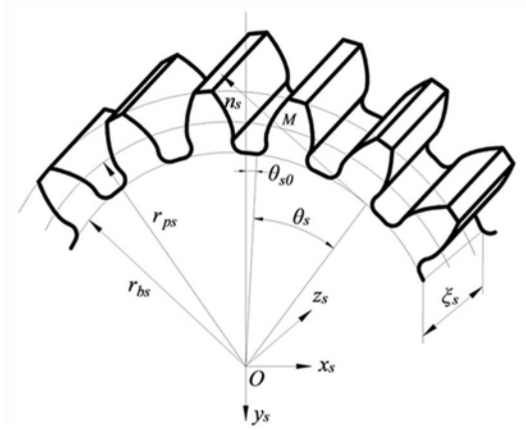

Figure 9 The involute tool's parametric model

The distinctive shape and measurements can be found in Figure 9.

An instance illustrating the parametric definition of the tool's involute tooth surface vector equation rs is expressed in equation (5):

$$\vec{r}_s(\xi_s, \theta_s) = \begin{bmatrix} x_s \\ y_s \\ z_s \end{bmatrix} = \begin{bmatrix} \pm r_{bs}\left[\sin(\theta_s + \theta_{s0}) - \theta_s \cdot \cos(\theta_s + \theta_{s0})\right] \\ -r_{bs}\left[\cos(\theta_s + \theta_{s0}) + \theta_s \cdot \sin(\theta_s + \theta_{s0})\right] \\ \xi_s \end{bmatrix} \tag{5}$$

In the smooth tone of writing, we consider ξ_s as the axial parameter that specifies the tooth width on the tooth surface of the tool, while θ_s indicates the angle parameter along the involute curve, determining the height of the tooth surface. The r_{bs} stands for the base circle radius of the tool involute, and θ_{s0} represents the angle parameter of the tool slot symmetry line from the starting point of the involute.

The calculated point coordinates have been adjusted to create a point cloud in files compatible with CAD software. The tooth's surface is created using a CAD program. The entire gear wheel is crafted through an intricate arrangement of individual teeth and discs.

6 Conclusions

The geometric design plays a significant role in determining the quality of gears. Should the geometric design be flawed, the transmission's reliability cannot be guaranteed, even if top-quality materials are used. On the flip side, skillful geometric gear design has the potential to reduce costly material expenses. Hence, it is essential to craft a precise geometric model of the gear.

CAD programs have become an essential instrument for designers. Because of their benefits, developers have swiftly expanded and advanced them to a point where they are now applicable in all areas of engineering practice. One aspect includes crafting and designing gear models. In the process of creating gears, having the ability to efficiently generate a 3D model is essential. This visual representation aids in better visualization and eventual control using methods like the finite element method, ensuring swift and precise execution. It is commonly understood that the more precise a model is, the more time it requires to be developed or produced. With the ongoing advancements in CAD programs and the ever-increasing computing power, the distinction is becoming less significant.

By utilizing a CAD application, we are able to generate a precise geometric model of gearing. The computer-generated body models can be utilized for drawing documentation or for various purposes, like addressing issues related to elasticity and strength. This includes tackling challenges like static deformation and stress analysis of gears through the finite element method.

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Educational procedures for training students in the field of pneumatic systems

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Keywords: pneumatic systems, educational procedures, methodology, laboratory equipment.

Abstract: The aim of this article is to present an educational model of the process of teaching students in subjects focused on the use of compressed air in automated industrial operations. The starting point is the existing commercially available training platform kit, the use of which provided the basis for developing the student training model described in the article. The article further discusses the training needs in all methods of controlling pneumatic circuits and focuses on the possibility of building an independent training workplace based on the electropneumatic base of the components used. The article describes several stages of the constantly improved educational platform, also with the contribution of student involvement in this activity. The conclusions of the article offer further guidance in the gradual completion of the educational model focused mainly on the practical training of graduates resulting in the ability to respond to market challenges after completing their university studies at our faculty.

1 Introduction

The operations of current companies operate at various levels of automation, therefore they increasingly require well-founded and professionally trained personnel for operation, maintenance, and possibly also for the design or construction of automated equipment. Production automation is still massively based on the use of components using compressed air as an energy or signal source. Therefore, forms of personnel training are increasingly oriented towards methods of training in the field of compressed air. This trend is also followed by the currently strongly preferred form of dual education in secondary schools. Theoretical mastery of the issue is beginning to appear insufficient for the direct deployment of graduates of technical schools into practice. The only viable path is education in the form of laboratory exercises and practical training of routine activities of future technicians in automated operations.

However, there is no need to tell yourself that technical higher education does not have to follow this trend.

1.1 Basis for the educational training model

The need for practical training of our students led us to gradually build laboratory spaces supporting the training of practical skills needed in practice.

These skills consist of the graduates' ability to respond to problems that may arise in operation (whether as malfunctions or signs of progressive wear and tear) and the ability to solve or eliminate these problems by directly intervening in the system.

An important aspect of our intentions was to prepare our graduates on technical equipment built on real components identical to those used in technical practice.

The starting point was the purchase of training tables with the designation PNEUTRAINER Pneu 200 from SMC Corp. (Japan), Figure 1.

Figure 1 PNEUTRAINER 200. Sources: left: [3]; right: author's archive

The disadvantage of this system for practicing practical skills in connecting pneumatic circuits is the fact that it allows work only in the mechanical, manual and pneumatic control modes. This method of using the system is based on the method of controlling the valves used in the kit, Figure 2.

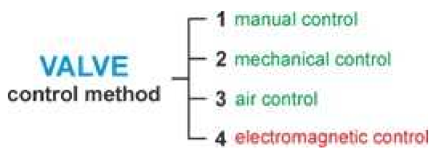

Figure 2 Valve control methods

The method of implementing the education of our students was initially designed as a reduced one and represented only the connection of circuits, which can be solved by the three mentioned methods of controlling the valves used (methods 1 - 3; Figure 2).

2 Methodology

For this method of applying education, some methodological procedures have been developed that should help the student more quickly orientate himself in the issue of using the potential of the building kit used.

Despite the incompleteness of the possibilities to cover the entire spectrum of control elements used in pneumatic systems, the described methodology (after mastering pneumatic symbols and practicing "reading" pneumatic diagrams by students) provides the following possibilities:

1. ***Connecting a pneumatic circuit according to the wiring diagram.*** Students have a total of 40 wiring diagrams of varying difficulty available and have the opportunity to try each one. In the overall evaluation of some courses, this procedure is also used for partial evaluation of the student (the student draws a connection scheme number and is evaluated based on the submitted performance during its connection). Of course, before connecting the relevant wiring diagram, the student must demonstrate his knowledge by “reading” the diagram in front of the teacher (describing what will happen after connecting and activating the circuit).
2. ***Drawing a circuit diagram of a circuit connected by the teacher.*** The students are tasked with drawing a circuit diagram of a circuit prepared (connected) by the teacher. The drawn circuit diagram is compared with the existing diagram by the teacher.
3. ***Finding and eliminating faults in the circuit.*** Students are given a connected circuit and a corresponding wiring diagram. The instructor intentionally “introduces” several anomalies into the circuit, which lead to the circuit not functioning. After reading the wiring diagram, the student has the task of finding out what the circuit is supposed to do and, based on the incorrect manifestations of the “faulty” circuit, eliminating individual shortcomings in the wiring.

This training model has proven its worth in practice, and its suitability has been confirmed by the satisfaction of the participants from practice who attended our training courses.

A simple "navigation" system for searching for the necessary components in the kit was used with a positive response from students, Figure 3.

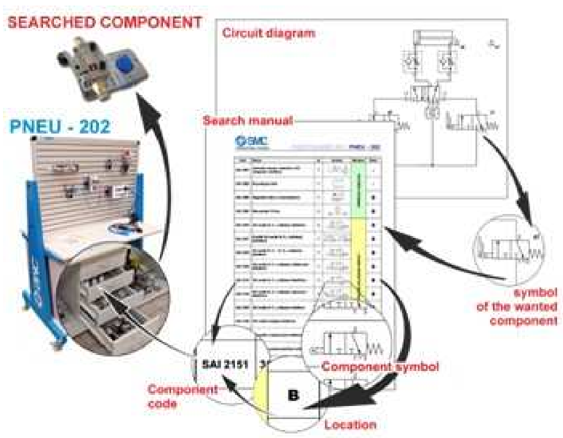

Figure 3 Methodological model for component search

In parallel, a series of lectures is being held in the described model, containing the theoretical basis necessary for understanding the connections valid for the pneumatic circuit. These lectures are supplemented with demonstrations of representatives of individual categories of pneumatic components.

During the implementation of this model, it was discovered that the practice also requires training in the use of electro-pneumatic components for its needs. For this purpose, the existing set and its methodological training model were unusable.

Two options were considered in the search for a solution:

1. Purchase electro-pneumatic components and the control superstructure of the existing kit from the supplier of the basic kit (ultimately, this solution was rejected due to the amount of necessary initial investments).
2. Develop a separate model training workplace that would offer even greater freedom in implementing student training.

Option 2 was accepted as feasible and was developed as part of the diploma project of a student at our institute [1], Figure 4.

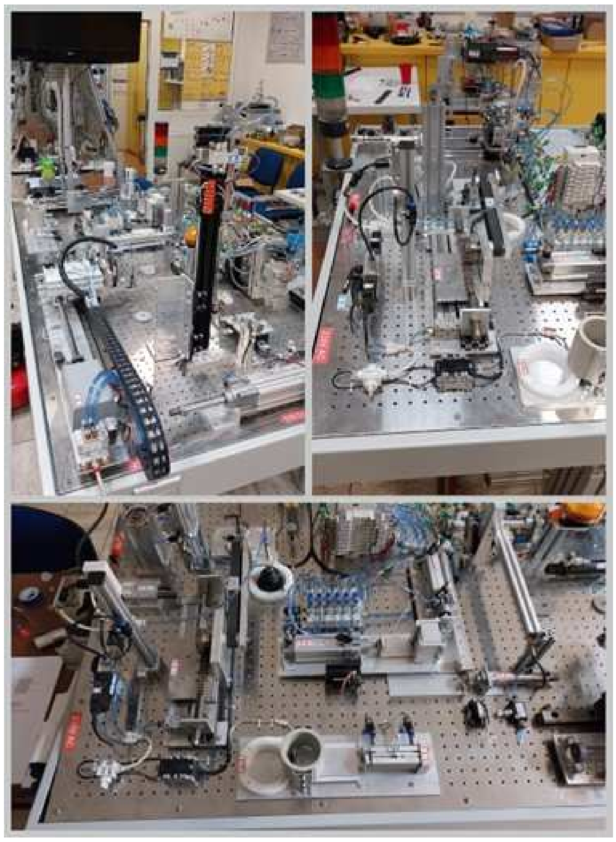

Figure 4 Training table for electro-pneumatics teaching

The workstation (trainer) provides opportunities to understand the methods of controlling pneumatic circuits

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solved by electropneumatic control of control elements (monostable and bistable electropneumatic valves organized in the form of valve islands: a total of 7 valve islands with different numbers of valves used - max. 8 valves in combination of 5/2 bistable and 5/3 valves with a closed center position) with actuators whose extreme positions are provided with appropriate sensor equipment (electronic/reed magnetic sensors, mechanical microswitches, diffusion sensors).

A simple binary operating control unit (SIEMENS LOGO!), Figure 5, is available, enabling the solution of assigned tasks in controlling the activities of a total of 12 separate workplaces with varying degrees of difficulty (from simple movement between the extreme positions of one drive, through the solution of sequential movements of a pair of drives to the solution of movements of an electro-pneumatic mechanism).

Figure 5 SIEMENS LOGO! PLC modified for use on a trainer

The control unit is designed to be ready for changing the controlled mechanism so that individual inputs and outputs are solved via connector fields (3-pin for input signals from sensors, 2-pin for outputs). In addition to simpler configuration of inputs/outputs for new tasks, they prevent the control unit (PLC) from being damaged by repeatedly screwing the wires providing the input and output signals needed for a specific task on the unit's terminal block.

Students in practical seminars also have the opportunity to solve the assigned task in the form of a design proposal with its physical implementation, Figure 6.

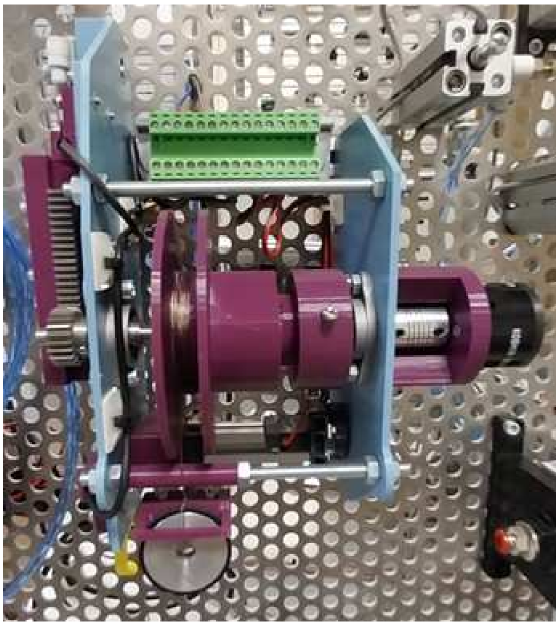
Figure 6 Pneumatic winch mechanism

Figure 6 shows a winch mechanism equipped with a single-acting pneumatic drive, operating on the principle of a free-wheel bearing and a rack-pinion transformation pair as the output of solving a task by students of our department within the subject Teamwork.

The entire educational model was tested as part of the teaching for its suitability for off-line use and therefore its suitability for application in the form of e-learning [2], Figure 7.

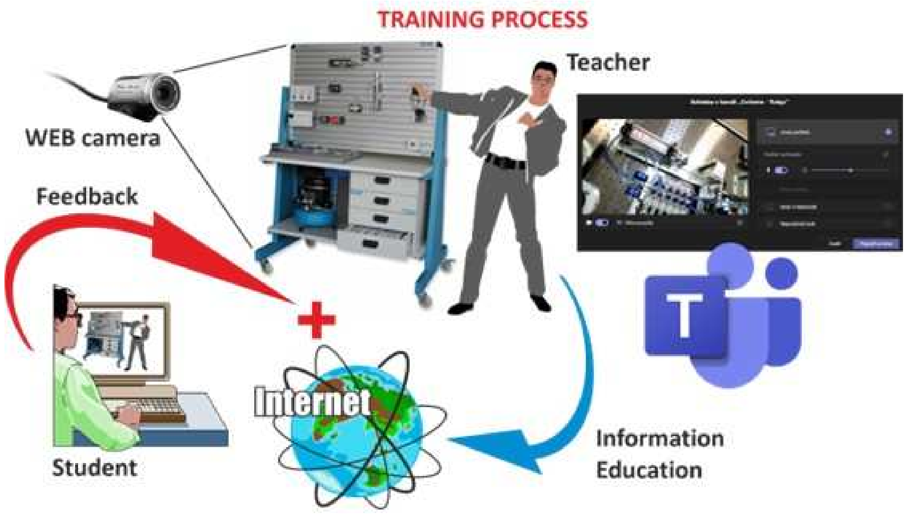

Figure 7 Model of incorporating a methodological model into an e-learning form of training

3 Results and discussion

The described educational model is in constant development, but the current state fully meets the needs of teaching at our workplace. The solution in the described setting was positively received by students and many praised the opportunity to solve some tasks in a practical form. We also received a positive response after completing the training of operators and maintenance of several companies operating in the Košice area.

Currently, the system for training in the field of electropneumatics is being upgraded to a higher version of PLC control (the original LOGO! PLC in version 0BA6 is being replaced with the latest version LOGO! 8.4), Figure 8.

Figure 8 PLC control unit with expansion module in SIEMENS LOGO! v. 8.4 version

This will increase the possibility of integrated control from one central PC at multiple workstations within the laboratory. This will significantly expand the possibilities of using the current potential of the laboratory's equipment.

4 Conclusions

Practical experience with the use of the described educational model has not only revitalized the teaching process, but also increased interest in information regarding the use of pneumatic systems in technical practice.

There is also feedback regarding successfully defended bachelor's and master's theses, as well as other projects (the AVENTICS/EMERSON Pneumobile project) in which our students have been and are involved.

We believe that with the above-mentioned reconstruction we will reach an even higher level and, above all, the compaction of the hitherto considerably non-compact system into a connected whole with significantly higher possibilities of use.

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In-pipe robot with automatic wheel span adjustment

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Keywords: robot, wheeled, pipe, motion.
Abstract: The wheeled in-pipe robot with automatic adjustment of the wheel span according to the diameter of the pipeline is intended for movement in pipelines. This robot includes a mechanism for adapting the width of the wheels according to the inner diameter of the pipe. The developed motion module can be used multiple times and thus realize a robot with a larger number of modules to achieve greater traction force.

1 Introduction

The wheeled inpipe robot is intended for movement inside the pipeline for the purpose of inspection or repair of damaged pipelines or for the purpose of transporting cables or other equipment inside the pipeline. Existing solutions mostly use the wheel principle of movement in the pipeline, but the problem with these devices is that their use is problematic if there are dirt, deposits, changes in diameter or other obstacles in the pipeline, for example associated with the technology of the production of pipeline networks such as couplings, elbows, T - piece, reductions, etc. [1-7].

The robot enables movement in the pipeline with the help of wheels, the span of which can be adjusted according to the current value of the diameter of the pipeline, and it is also possible to adjust the normal pressing force of the wheels on the pipeline wall so that the wheels of the device inside the pipeline do not slip or collide.

2 Principle of the robot drive module

The robot (Figure 1) is designed to move inside the pipeline with the possibility of automatic adjustment of the width of the robot's wheels according to the internal diameter of the pipeline.

For its movement in the pipeline, the robot uses three groups of wheels evenly distributed around the perimeter of the device on a retractable mechanism, which can be used to change the width of the wheels, that is, the distance of the wheels from the axis of the device. Between the main body and the fixing body, three guide rods are attached, along which the slide moves with the movement nut and the guide screw located in the middle of the guide rods. In the main body, the servo drive of the guide screw is located, which turns the movement screw and thus allows the slide to change its position. The drive wheel carrier moves on the guide rods, which is connected to the slide by means of a spring. The idler wheel carrier is placed on the auxiliary guide rods, which is connected to the slide by springs. The main arms of the driving wheels are attached to the drive wheel carrier by a rotary joint, the movement of which is tied to the main body of the robot by the auxiliary arms. At the end of the main arms of the drive wheels, the drive wheels are mounted on a drive shaft with a bevel gear, with the help of which the torque from the servo drive of the drive wheels is transmitted. The idler carrier is mounted on the auxiliary guide rods attached to the slide with the movement nut. The idler arms with the attached idler wheels are attached to the idler carrier by rotary joints. The drive and idler wheels are connected by connecting rods. Three such groups of mechanisms for such wheel adjustment are attached to the device, which are evenly distributed around the perimeter of the device at an angle of 120°. Between the slide and the drive wheel carrier is a position sensor composed of a permanent magnet and a sensor sensitive to the magnetic field. This position sensor detects the deformation of the spring located between the slide and the drive wheel carrier. This deformation of the spring is caused by a change in the internal diameter of the pipe and thus an increased or decreased normal pressure force of the wheels.

The principle of operation of the drive module of the robot consists in the fact that the information about the normal pressure force of the wheels on the pipe wall obtained from the position sensor is used in the control unit to automatically adjust the slide using the servo drive of the lead screw, and thus the span of the wheels will be adjusted, that is, the distance between the driving and driven wheels in a direction perpendicular to the pipe wall.

The advantage of this principle is that there is an automatic setting of the normal pressure force of the wheels on the pipe wall, and thus the wheels of the invention do not slip or get in the way of the pipe. From the principle of equality of forces, it follows that with this arrangement of groups of wheels at an angle of 120° around the perimeter of the device, there is an automatic centering

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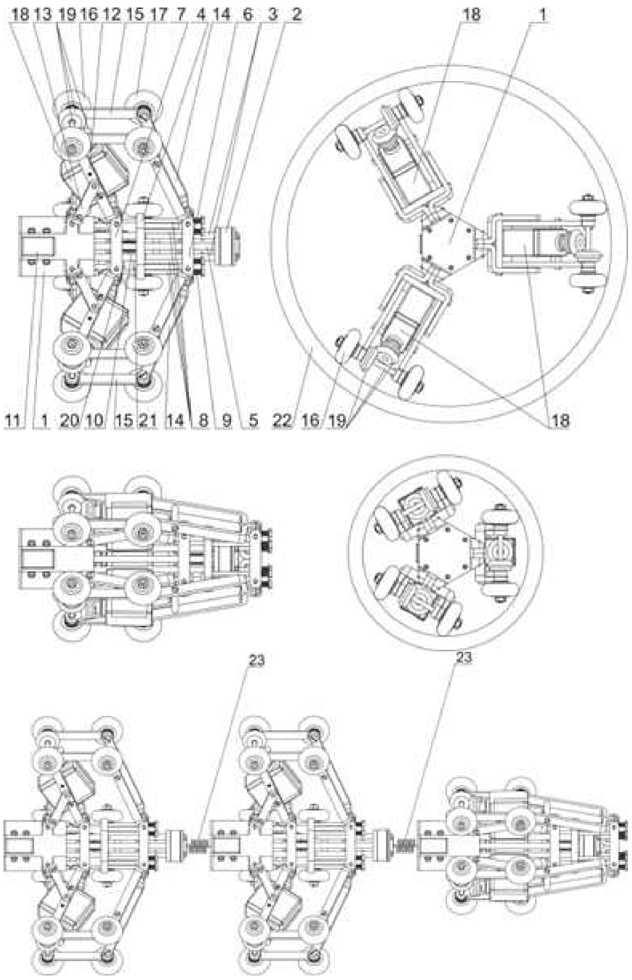
of the wheels with respect to the wall of the pipe and an even distribution of normal pressure forces on all drive wheels. Several such drive modules can then be connected behind each other using joints or connecting springs to create a modular robot with the ability to traverse even complicated pipe networks containing elbows, T-pieces and branches. Another advantage of the robot is that with this arrangement it is possible to change the width of the wheels to a large extent in relation to the overall dimensions of the device. Another advantage is that there is a spring between the slide and the drive wheel carrier and the idler wheel carrier, which also enables passive compensation of pipe unevenness.



1 – The main body of the robot; 2 – Fixing body; 3 – Guide rod; 4 – Slide with movement nut; 5 – Guide screw; 6 – Freewheel carrier; 7 – Drive wheel carrier; 8 – Auxiliary guide rod; 9 – Auxiliary guide rod spring; 10 – Guide screw spring; 11 – Servo drive of the guide screw; 12 – Main drive wheel arm; 13 – Auxiliary drive wheel arm; 14 – Arm of idle wheels; 15 – Connecting rod; 16 – Drive wheel; 17 – Freewheel; 18 – Drive wheel servo drive; 19 – Drive shaft with bevel gear; 20 – Position sensor; 21 – Permanent magnet; 22 – Pipeline; 23 – Connecting springs.

Figure 1 Overall layout of the wheeled inpipe robot with automatic wheel span adjustment according to the pipe diameter

However, if the degree of unevenness of the pipe or the change of the diameter of the pipe exceeds a certain set limit, then the control unit will adjust the wheel span to a new value using the servo drive of the adjusting screw, so that the movement of the equipment in the pipe is efficient.

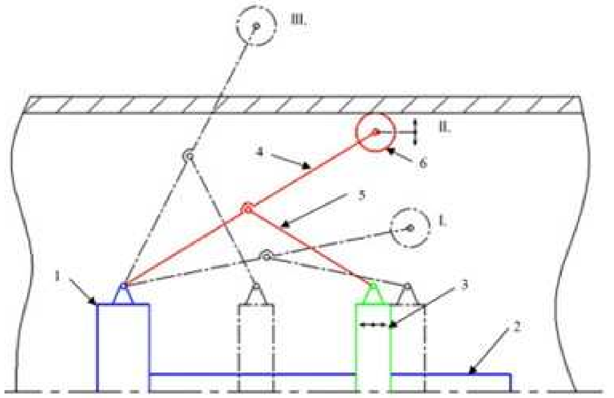
The robot (Figure 1) includes a main body (1) and a mounting body (2), between which guide rods (3) are attached. The slide with the movement nut (4) moves along the guide rods (3) with the help of the movement of the guide screw (5) driven by the servo drive (11). The drive wheel carrier (7) also moves along the guide rods, and the idler wheel carrier (6) moves along the auxiliary guide rods. There is a spring (10) between the slide (4) and the drive wheel carrier (7), and the springs (9) are located between the slide (4) and the idler wheel carrier (6). The main arms of the driving wheels (12) are attached to the carrier of the driving wheels (7) by means of a rotary joint, and they are connected to the main body of the robot (1) by means of the auxiliary arms of the driving wheels (13). On the main arms of the driving wheels (12) there is a driving shaft and bevel gear (19) which is connected to the servo drive (18). The freewheel arms (14) are attached to the freewheel carrier (6) by means of a rotary joint. Drive and wheels (16) and idler wheels (17) are connected by rotary joints using a connecting rod (15). On the main body (1) there are three such mechanisms consisting of arms (12, 13, 14), connecting rods (15), drive wheels (16), idler wheels (17), drive wheel servo drive (18) and a drive shaft with a conical gears (19). A position sensor (20) sensitive to the magnetic field is located on the drive wheel carrier (7) and a permanent magnet (21) is located on the slide (4). Drive wheels (16) and idler wheels (17) are in contact with the pipe wall (22). The device according to the proposed solution can be connected modularly with other such devices by means of connecting springs (23) and thus create a device with a higher traction force and wider application possibilities.

3 Kinematics of the robot drive module

The kinematics of the robot should ensure the change of wheel span so that it is possible to change the position of the wheels as needed (Figure 2).

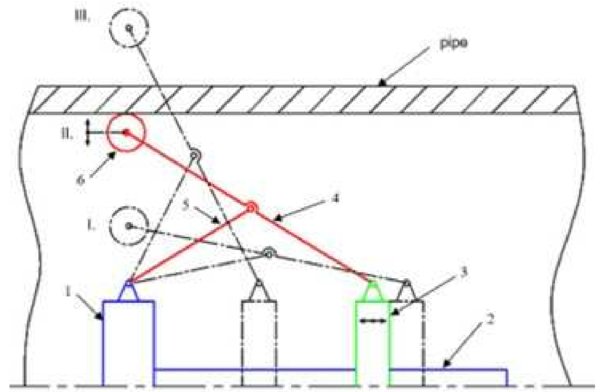
Members 1 and 2 are firmly connected. Member 3 slides over member 2, which changes the lift height of the arm formed by 4, 5 and the pressure wheel. In this way, the arms are able to adapt to a relatively large range of pipe diameters.

The main disadvantage of this solution is that in position I. for the smallest diameter of the pipe, the entire mechanism of the arms moves backwards and thus also the wheel, which moves the entire center of gravity of the inpipe robot significantly forward. Also, the distance between the point of contact of the wheel with the pipe and the origin of the inpipe robot will increase to a large value in proportion to the diameter of the pipe. As a result, it would be impossible for the robot to pass through the curved pipe. For these reasons, it is more appropriate to choose the design in Figure 3.



1 – basic member, which is immovable; 2 – member on which member no. 3; 3 – sliding member; 4, 5 – arm elements; 6 – pressure wheel; I., II., III. – positions of the inpipe robot in its working range

Figure 2 Design of the basic kinematics of the inpipe robot - variant 1



1 – basic member, which is immovable; 2 – member on which member no. 3; 3 – sliding member; 4, 5 – arm elements; 6 – pressure wheel; I., II., III. – positions of the inpipe robot in its working range

Figure 3 Design of the basic kinematics of the inpipe robot - variant 2

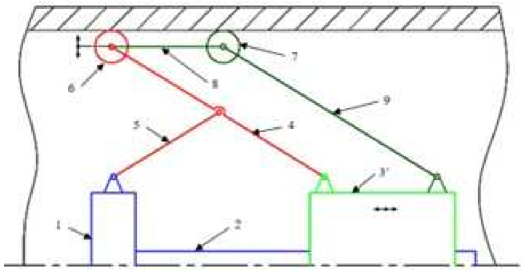
The position of the wheels relative to the origin of the inpipe robot does not change to the same extent as in the previous design. With a suitably chosen length of arms, this distance does not change at all.

By moving member 3, the center of gravity moves in the direction of its displacement. Assuming that the member is several times smaller (has a lower weight) than member 1 and the proposed drive for moving member 3 will be located in the front part, the change in the position of the center of gravity in this case is smaller than in the first case.

With this design, in the case of horizontal movement of the inpipe robot relative to the earth's surface, due to the influence of gravity and the uneven distribution of weights to the right and left of the pressure wheels, the proposed robot would tip over, i.e. fall. By designing another trio of wheels connected by arms to the original wheels, this problem is eliminated (Figure 4).

The problem with this solution arises when the pipe diameter changes (Figure 5). If the diameter of the pipe decreases, the front pressure wheels copy the change in diameter and the entire structure shrinks. In this way, the rear wheels cannot copy the wall of the pipe, which is behind the front wheels of a larger diameter.

When expanding, the opposite situation occurs and the front wheels cannot copy the pipe wall.



1 – basic member, which is immovable; 2 – member on which member no. 3; 3' – member 3 extended and supplemented with a pin for arm 9; 4, 5 – arm elements; 6 – pressure wheel; 7 – rear pressure wheel; 8 – connecting arm; 9 – rear pressure arm

Figure 4 Design of the basic kinematics of the inpipe robot - variant 3

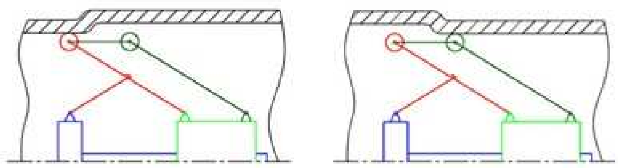


Figure 5 Changing the pipe diameter

From the above, it follows that with any change in the diameter of the pipe, not all pressure wheels will be in contact with the pipe.

By dividing the part 3' (Figure 4) into two separate parts 3 and 10, which will be connected by a flexible member 11 (e.g. a spring), this problem is eliminated (Figure 6). The part 10 is pressed and pushed away by the spring 11 from the member 3, thereby adapting to the shape of the pipe.

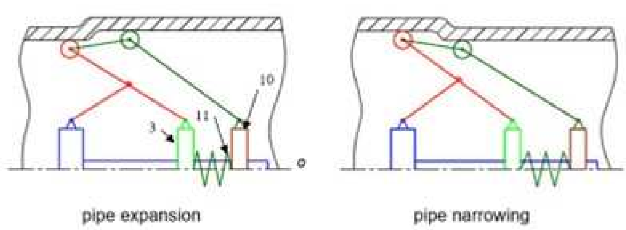


Figure 6 Adaptation to change in pipe diameter

In this design, two pressure wheels are used with an average distance *l* from each other (Figure 7, Figure 8).

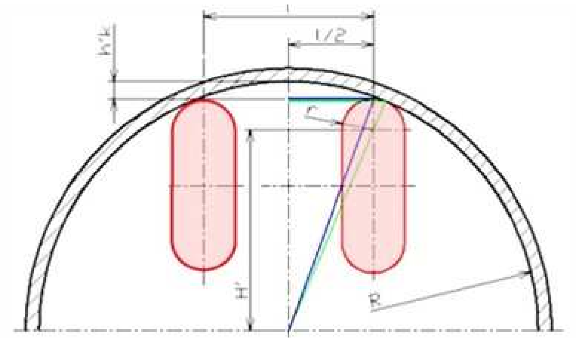


Figure 7 Contact of the pressure wheel with the pipe wall

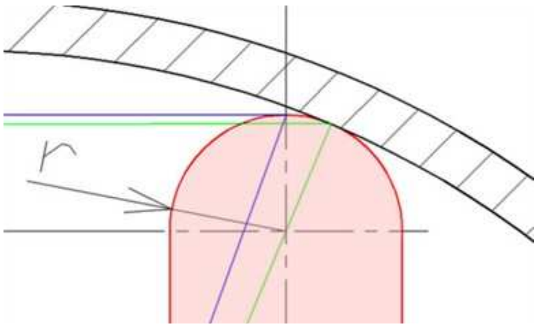
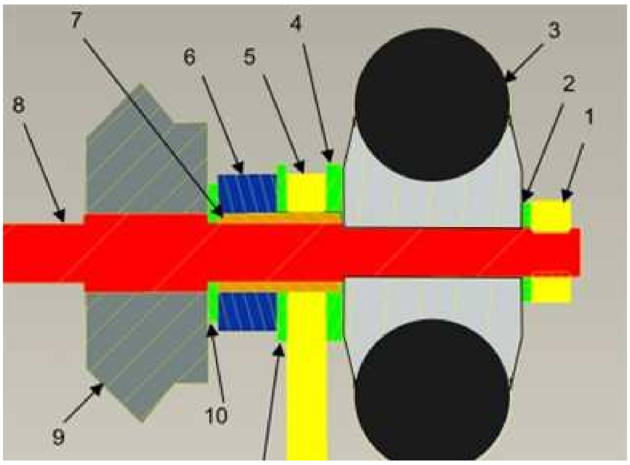


Figure 8 Detail of the contact of the pressure wheel with the pipe wall

4 Design of the robot mechanism

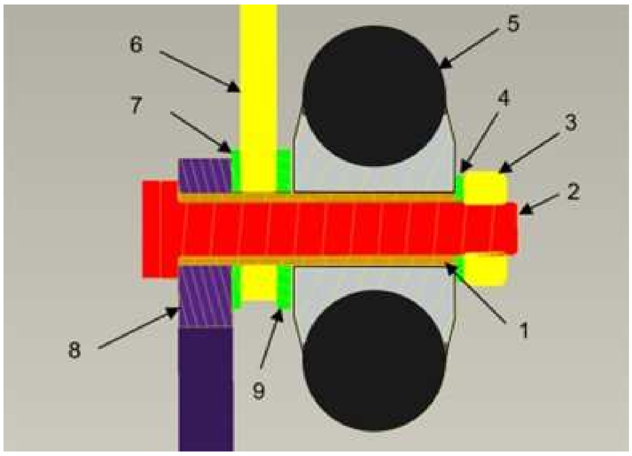
The design of the structure of the robot arm mechanism is created according to kinematic variant 3 (Figure 4). The wheels are housed in sliding bearings with direct transmission using a bevel gear (Figure 9). The bevel wheel 9 (Figure 7) is pressed onto the shaft 8. The sliding bearing also serves as a pin which is pressed into the arm 6. The arm 5 rotates freely around this pin (7). The driven wheel is slid onto the shaft and secured with a lock washer and nut. Sliding bearing 7 is designed from a brass rod blank of intermediate cross-section, due to the favorable coefficient of friction between steel and brass.



1 – nut; 2 – flexible mat; 4, 10, 11 – mat; 3 – driven wheel; 5 – connecting arm; 6 – shoulder; 7 – sliding bearing; 8 – shaft; 9 – bevel wheel

Figure 9 Construction of the driven wheel

The idler wheel (Figure 10) is designed to stabilize the robot when moving in the pipeline. It is mounted on a sliding bearing and carries part of the load caused by the normal force on the pipe wall. The normal force on the pipe wall is necessary to ensure sufficient contact for the robot to be able to move even in a vertical pipe.



1 – sliding bearing; 2 – screw; 3 – nut; 4, 7, 9 – mat; 5 – idle wheel; 6 – connecting arm; 8 – arm

Figure 10 Construction of the idle wheel

5 Adaptable wheel adjustment mechanism

The opening of the arms of the inpipe robot is ensured by the movement of member 3 (Figure 11). The movement of this member can be ensured by using a threaded rod 7 located in the axis of the pipe stand. This rod is placed in bearings at both ends and passes through the face 3, in which there is a thread. The rotary movement of the threaded rod causes the movement of member 3 and thus also the opening and closing of the arms of the inpipe robot. Due to the ability to adapt to the change in the pipe diameter of the front and at the same time the rear wheels, the threaded rod passes through part 4 freely, so it does not affect its position.

The guidance of member 3 and 4 is secured by guidance formed by 3 rods of circular diameter 6. By using 3 guide rods, rotation of member 3 relative to member 1 in a plane perpendicular to the direction of movement of the inpipe robot is prevented. This also prevents twisting of the shoulders.

The guide rods 6 are firmly attached by means of screws in members 1 and 2 (Figure 11). Member 2 can freely pass through member 5, which shortened the total length of the inpipe robot compared to the solution if member 5 abutted member 2. In this case, member 2 abuts up to member 3. The extreme positions are equipped with rubber stops 11.

Adaptation of the robot in the pipeline is ensured by force control using a spring and servo drive system.
The adaptation of the in-pipe robot to the inner surface of the pipe is a key function in terms of ensuring the movement of the robot in the pipe, especially when moving

in a vertical pipe, where it is also necessary to overcome the weight of the robot. The pressure of the wheels on the pipe wall creates the necessary friction force between the wheels and the pipe wall. Since the internal dimensions of the pipe are not the same and, in addition, there are also technological residues after joining the pipe inside, it is also important to ensure the adaptability of the robot's wheels.

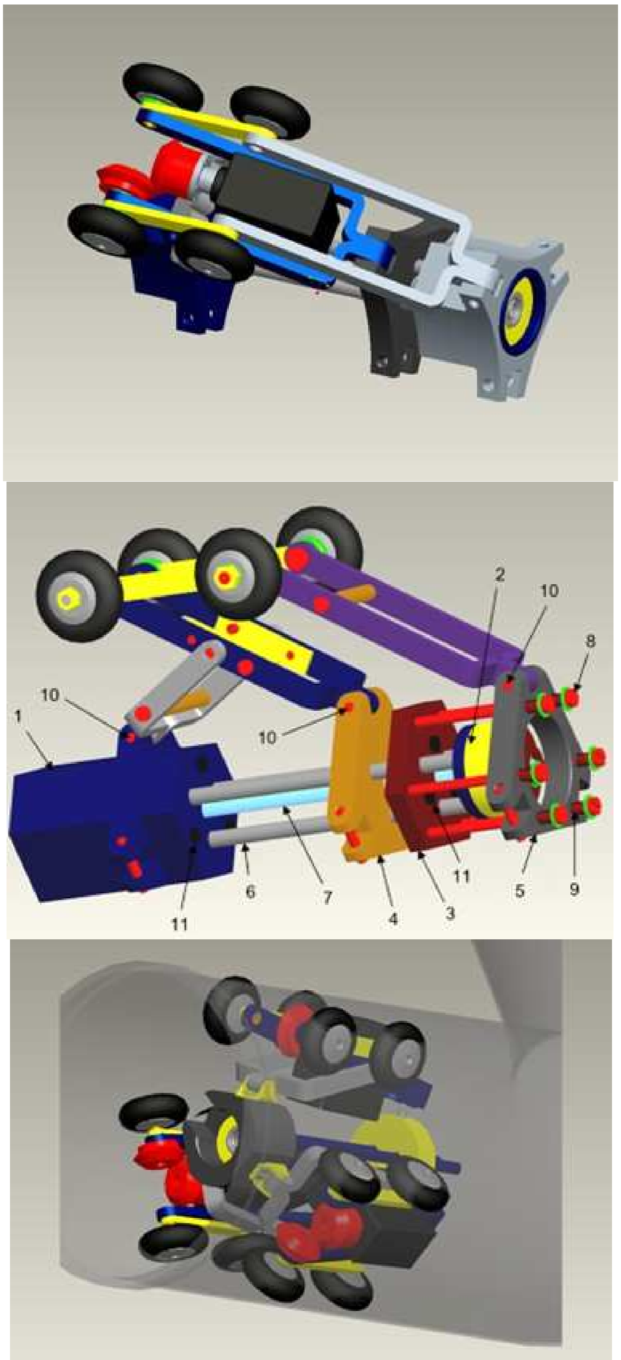


Figure 11 Adaptable wheel adjustment mechanism

6 Conclusion

In this article, an inpipe robot was designed, which is able to move in pipes with an internal diameter from 100mm to 200mm. It has the ability to adapt to the current internal diameter in order to ensure sufficient traction force and speed of movement of the robot. The robot is intended for service activities such as pipe inspection and repair.

The design of such devices that are used in confined spaces requires a comprehensive approach in the design of the concept of this device, and the design of mechanics, electronics and controls for the proposed device must be created at the same time [8-19].

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