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DESIGN AND CONSTRUCTION OF A MULTIFUNCTIONAL DISINFECTION ROBOT

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This paper proposes a robot designed for automated routine or emergency disinfection in closed premises. The robot is related to the combined type robots.

The robot consists of two functional parts: a universal mobile platform (lower part) and a disinfector (upper part), which, if necessary, can be freely moved by personnel on 4 wheels. In the initial position, the upper part of the disinfection robot is at the charging station. The mobile robot drives up to the disinfector, «hooks» it (puts it on itself) and moves along the planned route. The upper part of the disinfector will have its own independent intelligent system, separate from the mobile robot, which, when a person is recognized, stops liquid disinfection: in this case, the UV lamps turn through 180°, the cylindrical body closes and ventilation of the disinfected air from the enclosed space is turned on. In addition, liquid disinfection is only enabled when detecting beds, tables and chairs.

With the spray nozzles located at a height of 400 mm, the disinfector can carry out a simultaneous combined treatment of rooms with equipment and furniture, including high-quality processing of the lower surfaces of tables, chairs and beds.

To improve the functional characteristics of robotic disinfectors and to simplify their design, a multifunctional robotic disinfector has been proposed.

It was found that the result is achieved by the fact that in a multifunctional disinfection robot containing a mobile cart with an autonomous positioning and navigation system, a disinfection platform with a disinfection liquid spraying system and UV lamps with reflectors installed on it, the disinfection platform will have its own autonomous control and power systems

Keywords: multifunctional disinfection robot, COVID-19 pandemic, UV lamps, combined type of disinfection, medical robot

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1. Introduction

COVID-19 can spread not only through close contact with sick people, but also through unclean surfaces; it can persist for several days on inanimate surfaces such as metal, glass or plastic [1]. Consequently, surfaces and objects must be sterilized: sterilization kills all forms of microbial life on an object or surface [2]. Studies show that with existing cleaning methods, up to 30 % of surfaces still contain biofilm even after cleaning [3]. These statistics indicate that the current course of action is insufficient to protect susceptible patients from serious, life-threatening infections such as COVID-19 [4]. To automate scheduled or emergency disinfection in closed rooms, various types of disinfectants and robotic disinfectants have been developed.

In existing robotic disinfectants, ultraviolet light with a wavelength of 200 nm to 280 nm, a combined disinfection method (with UV-C and chemical disinfection, by spraying a disinfection liquid), and chemical disinfection are used.

Therefore, research on the design and construction of a multifunctional disinfection robot is of scientific relevance.

2. Literature review and problem statement

The paper [5] presents the results of studies of Blue Ocean Robotics UV-Disinfection robot. The microbiological effectiveness of the equipment was confirmed by medical institutions of the following countries: Italy, Japan, Taiwan, Australia, Denmark, Germany, China, Russia, USA, etc. This is the world's most popular model of a robot with UV lamps for 2020.

The UVD robot of the Blue Ocean Robotics is equipped with a UV-C light source and destroys 99.99 % of microorganisms, including the COVID-19 virus, is able to disinfect about 4,600 m^2/h in large rooms. It works in a potentially infected area without personnel, unlike conventional disinfection products (chemicals, wipes, hand-held UV-C devices), moves independently within the premises and turns off (interrupts work) when there is a risk of exposure, the lamps of the UVD robot require replacement after 12,000 hours of use. But the robot does not have the ability to work in rooms where people are. Since the open radiation of bactericidal lamps has a harmful effect on humans, causing superficial erythema and inflammation of the mucous membranes of the eye, and at high doses, retinal detachment.

In [6], it is shown that to combat the COVID-19 virus, Chanprakon and others have developed a UVC robot that can move around the room and thoroughly sterilize the entire operating room with or without human intervention. The robot is equipped with three UV lamps installed in a circle at a distance of 120° from each other, and six ultrasonic sensors. Each lamp has an output power of 19.3 watts. It uses 4 freewheels for movement (0–1.4 m/s) and is controlled from a central command center. In case of an obstacle, the microcontroller controls the robot wheels with the help of a motor driver to avoid a collision.

However, the work of the robot in rooms with the presence of a person is not considered. The recirculator mode is not provided.

The following papers present the research results of companies that have released disinfection robots: Geek+Robotics has released Lavender and Jasmin robots, Omron [7], Akara Robotics at Trinity College Dublin [8], Milagrow Robotics has developed Indoor Disinfection RoboCop [9], Youibot [10] has developed an ARIS-K2 anti-virus robot that disinfects 1000 m^2 in 150 minutes. The Milvus Robotics company [11] has developed a SEIT-UV disinfection robot, Anscer Robotics developed an Anscer Robotics UV disinfection AMR robot [12], WellWit Robotics [13] developed a disinfector robot, and also released a Sunburst UV Bots UV-disinfecting robot [14]. PAL Robotics has released a new design for the UV light disinfection AMR robot [15]. However, all these robots use only ultraviolet sterilization, which is not safe disinfection in the presence of a person.

The paper [16] shows that robots with combined disinfection provide ultrasonic disinfection with dry mist. The tank capacity of 15 liters allows you to forget about frequent replenishment of the disinfectant solution. Puductor 2 is equipped with an ozone-free UV lamp, providing the industry's best UV illumination of 180 MW/cm^2 within 1 meter. The UV-C lamp is very effective against most types of bacteria and viruses and provides a degree of disinfection of 99.99 %. The robot is equipped with two batteries. The total battery capacity is 51.2 Ah, the maximum disinfection time is up to 6 hours, which allows disinfection of 12–15 rooms (20 liters/room). But Puductor 2 does not have a recirculator mode. Also, the processing of premises with dry fog takes 1–2 hours, depending on their area. You can use the room almost immediately after processing, but everything needs to be ventilated.

The work [17] presents a portable air sanitizer consisting of a housing in which an input protective device against ultraviolet radiation, a working chamber with at least two ultraviolet LEDs mounted on a holder acting as a heat sink, a suction fan, a block of extinguishing resistors for LEDs, an output protective device against ultraviolet radiation are sequentially located. The inner surface of the working chamber is covered with a reflective layer. The final sections of the input and output protective devices from ultraviolet radiation are covered with a light-protective layer inside. The input and output protective devices are made in the form of vacuum valves. The working chamber is equipped with two reflective diffraction gratings. But the portable air sanitizer uses only UV sterilization.

In [18], a disinfection robot is also proposed (UVD robot). It has a movable trolley with an autonomous positioning and navigation system and bactericidal ultraviolet lamps placed on it. The disadvantage of the device is that it uses only one method of disinfection. Although the bactericidal ultraviolet lamp does not cause damage to the respiratory system and subsequently it is not necessary to ventilate the room, it still causes inflammation of the mucous membranes of the eye. Therefore, during disinfection, the presence of a person is not recommended.

The work [19] shows a mobile disinfectant containing a water tank, an electrolyzer, a pump, a battery, a discharge sleeve, a tube, a nozzle, a control unit. The disinfectant allows to carry out a flow mode of operation without preliminary water treatment and to obtain a disinfectant (sodium hypochlorite) in autonomous conditions directly at the place of consumption by electrolysis of tap water or a chloride-containing solution. The disadvantage of the device is that it uses only liquid disinfection, which reduces functionality. Also, chemical treatment requires ventilation of the room and the absence of a person during disinfection.

It is shown in [20] that the Keenon Robotics company has developed and released a new autonomous mobile robot with ultraviolet radiation and spraying of disinfection liquid. The robot is designed to move autonomously around a hospital or other institution and perform various disinfection processes.

But there were unresolved issues related to disinfection in the presence of a person and high-quality treatment of lower surfaces.

All this suggests that it is advisable to conduct a study dedicated to improving the functional characteristics of disinfection robots and simplifying the design of multifunctional disinfection robots.

3. The aim and objectives of the study

The aim of the study is to design and construct a multifunctional disinfection robot. The robot belongs to the combined type robots, which will improve the functional characteristics of disinfection robots.

To achieve the aim, the following objectives are accomplished:

– to design and construct a multifunctional disinfection robot;

– to create a hierarchical structure of the robot, its nodes and parts;

– to study the kinematics and carry out calculations on the strength of the gear mechanism.

4. Materials and methods of research

The proposed robot is designed to automate scheduled or emergency disinfection in closed rooms.

The multifunctional disinfection robot consists of two autonomous parts – the mobile platform of the robot 1 and the disinfecting platform 2 in Fig. 1. The mobile platform has a lifting mechanism 3 for the disinfecting platform 2 and an autonomous positioning and navigation system and power supply. The disinfection platform 2 has a «P»-shaped portal 4, in the lower part of which wheels 5 are installed, and a system for spraying disinfection liquid and ultraviolet lamps 6 with reflectors 7 are installed on top. In the first operating position, the ultraviolet lamps 7 are located outside of the housing 8 in Fig. 2, *a*, and in the second operating position, the ultraviolet lamps 6 with reflectors 7 are rotated by 180 degrees relative to the first position, while the reflectors 7 with the housing 8 form a closed cylindrical protective cavity 9, which contains ultraviolet lamps 6 in Fig. 2, *b*. On the housing 9 there are sensors for the presence of a person 10.

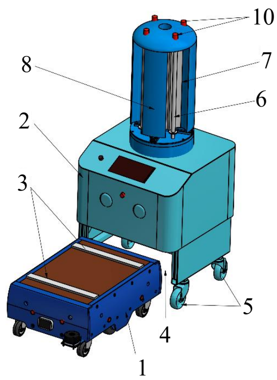
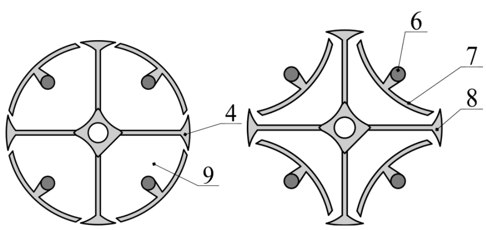


Fig. 1. 3D model of the disinfection robot



a *b*

Fig. 2. Operating positions of ultraviolet lamps

The multifunctional disinfection robot works as follows. In the initial position, the disinfection platform is at the charging station. At the beginning of the operation, the mobile platform 1 enters under the «P»-shaped portal 4 and lifts it using the lifting mechanism 3 in Fig. 1 and moves it along the required route or to the destination and can leave it there, while performing other functions, for example, moving another platform. In addition, operating personnel can move the disinfection platform to its destination without the aid of a mobile platform. In addition, liquid disinfection is only enabled when detecting beds, tables and chairs.

With the spray nozzles located at a height of 400 mm, the disinfector can carry out a simultaneous combined treatment of rooms with equipment and furniture, including high-quality processing of the lower surfaces of tables, chairs and beds.

The robot kills 99.99 % of bacteria by emitting ultraviolet light from a Philips TUV germicidal lamp (15 W, wavelength 253.7 nm (UV-C)) on high, medium and low touch surfaces. Taking into account the organizational and logistic aspects, the disinfection time for a room with an area of 30 m^2 is 10–15 minutes.

The technical parameters of the disinfection robot will be justified by the fact that we will use a TUV Philips (15 W, wavelength 253.7 nm (UV-C)) low-pressure mercury discharge lamp, which gives short-wave UV radiation with a maximum of 253.7 nm, which has a bactericidal action. The shell of the lamp is made of special ultraviolet glass with an internal protective coating that limits the reduction of useful ultraviolet radiation.

Also, the atomizer nozzle will be equipped with a high-pressure pump article 2MN.025.16.00.00.0 with a built-in check valve. Such nozzles provide a misty spray of antiseptic at high pressure of 60–100 bar and can give a droplet size of 10 to 50 microns.

As a disinfectant, we will use products based on chlorine dioxide (ClO_2). Chlorine dioxide is 2.5 times more active than sodium hypochlorite as an oxidizing agent. Chlorine dioxide is most active at pH=8.5.

For the development and manufacture of an experimental sample of a disinfection robot with a dispenser and a spray, a hierarchical structure of the robot and its units and parts was drawn up:

1) functional disinfection robot:
1. 1) platform for installing disinfector elements:
1. 1. 1) rack for installing quartz lamps;
1. 1. 2) holders for quartz lamps;
1. 1. 3) quartz (ultraviolet) lamps;
1. 1. 4) reflectors;
1. 1. 5) recirculator;
1. 1. 6) protective cover for quartz lamps;
1. 1. 7) device for connecting to a mobile robot:
1. 1. 7. 1) mechanical connection device;
1. 1. 7. 2) electrical connection device;
2) the control system is integrated with the control system of the mobile robot with:
3) information and sensory system:
3. 1) internal sensors:
3. 1. 1) lamp health monitoring sensors;
3. 1. 2) voltage sensor;
3. 1. 3) buck-boost LED drivers;
3. 2) external sensors:
3. 2. 1) sensors for the presence of a person in the room (infrared sensors);
3. 2. 2) IR sensors.

Fig. 3 shows the gear mechanism used to rotate the reflectors of the UV disinfector.

Table 1 shows the number of teeth, average diameter and outer diameter of the gears used to turn the UV reflector lamps.

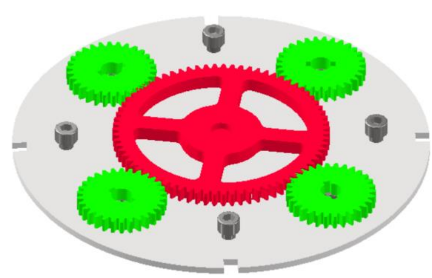


Fig. 3. Gear mechanism

Table 1

Gear wheels

Denomination		Gear wheel 1	Gear wheel 2
Number of teeth	z	26	117
Average diameter	d	39.000 mm	175.500 mm
Outer diameter	d_a	41.930 mm	180.000 mm

The gear ratio is determined by the formula:

$$i=\frac{T_2}{T_1}, \quad (1)$$

where T_1 is the number of teeth on the first gear, T_2 is the number of teeth on the second gear.

Then the transmission ratio of the gear mechanism will be:

$$i=\frac{117}{26}=4.5. \quad (2)$$

Table 2 shows the loads on the gears.

Table 2

Loads

Loads		Gear wheel 1	Gear wheel 2
Power	P	1.000 kW	0.980 kW
Speed	n	1000.00 rpm	222.22 rpm
Torque	T	9.549 Nm	42.112 Nm
Efficiency	η	0.980 br	
Radial force	F_r	143.307 N	
Circumferential force	F_t	486.307 N	
Axial force	F_a	0.000 N	
Loading cycle	F_n	506.983 N	
Peripheral speed	v	2.042 m/s	
Resonant speed	n_{E1}	25327.215 rpm	

Calculation of the strength of gears.

In gear drives, two conditions are used when assessing performance:

a) the condition of the contact strength of the surface:

$$\sigma \leq [\sigma]. \quad (3)$$

Determination of actual contact stresses.

When assessing the performance according to the condition of contact endurance (3), it is necessary to calculate the actual contact stresses arising on the flank surfaces of the teeth.

To determine the contact stresses, we will use the Hertz formula to calculate the maximum normal stress in the contact zone of two cylinders along a linear contact:

$$\sigma=\sqrt{\left(\frac{qE}{[2\pi(1-\upsilon^2)\mu]}\right)}, \quad (4)$$

where q is the load per unit length of the contact line (specific load); $q=FtK/bw$, here K is the load factor; bw is the working width of the gear wheel; E – reduced modulus of elasticity obtained from the relation $2/E=1/E_1+1/E_2$, where $1/E$ – some characteristic of material compliance, whence: $E=2E_1E_2/(E_1+E_2)$; for wheels, μ – Poisson's ratio; ρ – reduced radius of curvature of the cylinders, determined from the relation $1/\rho=1/R_1+1/R_2$, (where $1/\rho$ – surface curvature), whence: $\rho=R_1R_2/(R_1+R_2)$.

Ultimately, in the calculations, the nominal (design) forces F_{nom} or torques T_{nom} are multiplied by the load factor K, thereby determining the design load as close as possible to the actual one:

$$F=KF_{nom}, \quad (5)$$

where F is the calculated force; F_{nom} – nominal force and torque corresponding to the required (design) power of the calculated machine.

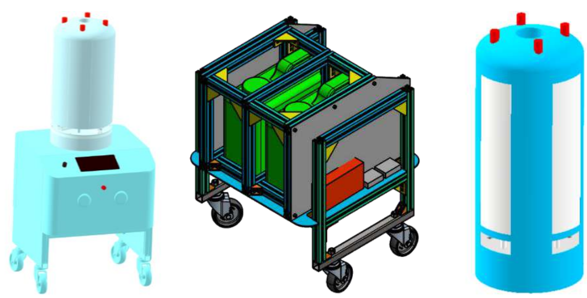
The load factor is determined separately for each of the main performance criteria of the gear wheels. The main performance criteria for most gears are fatigue contact strength as well as bending strength of the teeth.

5. Results of mathematical modeling and design of a disinfection robot

5. 1. Design and construction of a multifunctional disinfection robot

Fig. 4 shows a 3D model of a disinfection robot in the Inventor software package.

Fig. 5 shows a general view of the top of the multifunctional robotic disinfector.



a *b* *c*

Fig. 4. 3D model of the disinfection robot: *a* – general view; *b* – the lower part of the robot for liquid disinfection; *c* – the upper part of the robot, designed for UV disinfection and for operation in recirculator mode

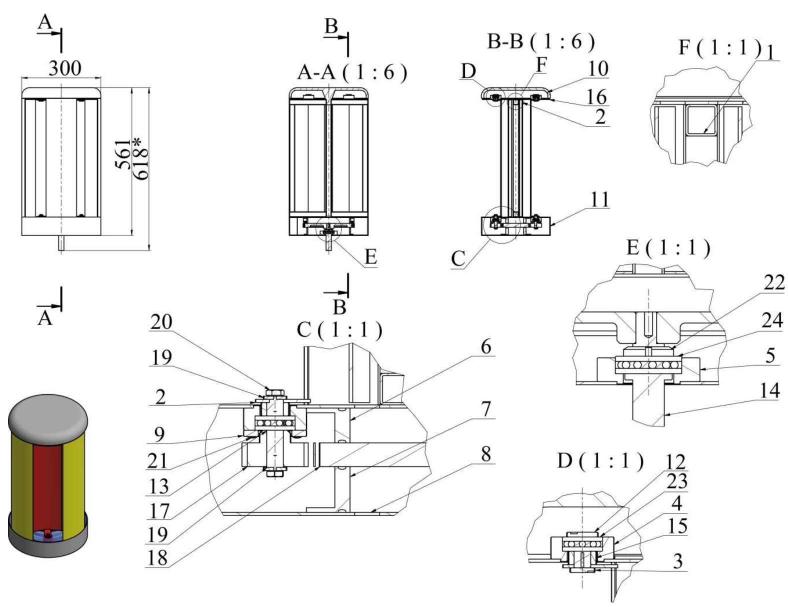


Fig. 5. General view of the upper part of the multifunctional robotic disinfector

The assembly drawing of the upper part of the disinfection robot consists of the following assembly units (Table 3).

Table 3

Assembly units

No.	Name	Number
1	Frame	1
2	Slide gate	4
3	Screw	4
4	Slot	8
5	Slot 2	1
6	Filler	1
7	Lower filler	1
8	Bottom 2	1
9	Cover	4
10	Cover 2	4
11	Shell	1
12	Axis	4
13	Axis 2	4
14	Axis 3	1
15	Spacer sleeve	8
16	Flange top	2
17	Spur gear	4
18	Spur gear	1

The upper part of the disinfection robot consists of ultraviolet lamps with reflectors, which are rotatable by 180 degrees and have two working positions. In the first operating position, the ultraviolet lamps are located outside of the housing, and in the second operating position, the ultraviolet lamps form a closed cylindrical protective cavity inside which the ultraviolet lamps are located. In the second position, the disinfection robot will operate in recirculator mode, which allows the presence of a person.

5. 2. Hierarchical structure of the robot and its nodes and parts

The hierarchical structure of the robot and its nodes and parts has been compiled:

1) functional disinfection robot:

1. 1) platform for installing disinfector elements:

1. 1. 1) rack for installing quartz lamps;

1. 1. 2) holders for quartz lamps;

1. 1. 3) quartz (ultraviolet) lamps;

1. 1. 4) reflectors;

1. 1. 5) recirculator;

1. 1. 6) protective cover for quartz lamps;

1. 1. 7) device for connecting to a mobile robot:

1. 1. 7. 1) mechanical connection device;

1. 1. 7. 2) electrical connection device;

2) the control system is integrated with the control system of the mobile robot with:

3) information and sensory system:

3. 1) internal sensors:

3. 1. 1) lamp health monitoring sensors;

3. 1. 2) voltage sensor;

3. 1. 3) buck-boost LED drivers;

3. 2) external sensors:

3. 2. 1) sensors for the presence of a person in the room (infrared sensors);

3. 2. 2) IR sensors.

5. 3. Study of kinematics and strength calculations of the gear mechanism

Table 4 shows the dynamic load factors: external dynamic load factor, dynamic factor, surface load factor, lateral load factor, one-time overload factor.

Table 4

Dynamic load factor

External dynamic load factor	K_A	1.200 br	
Dynamic factor	K_{Hv}	1.087 br	1.087 br
Surface load factor	$K_{H\beta}$	1.940 br	1.582 br
Lateral load factor	$K_{H\alpha}$	1.473 br	1.581 br
One-time overload factor	K_{AS}	1.000 br	

Table 5 shows the contact stress factors: elasticity factor, area factor, overlap factor, contact factor of two teeth, durability factor, lubrication factor, roughness factor, speed factor.

Table 5

Contact stress factors

Elasticity factor	Z_E	189.812 br	
Area factor	Z_H	2.697 br	
Overlap factor	Z_ε	0.824 br	
Contact factor of two teeth	Z_B	1.073 br	1.058 br
Durability factor	Z_N	1.000 br	1.000 br
Lubrication factor	Z_L	0.962 br	
Roughness factor	Z_R	1.000 br	
Speed factor	Z_v	0.958 br	
Tooth angle factor	Z_β	1.000 br	
Size factor	Z_X	1.000 br	1.000 br
Mechanical seal factor	Z_W	1.000 br	

Table 6 shows the bending stress factors: shape factor, stress correction factor, tooth sharpening factor, tooth angle factor, overlap factor, load change factor, manufacturability factor, durability factor, penetration sensitivity factor, size factor, cavity surface factor.

Table 6

Bending stress factors

Shape factor	Y_{Fa}	3.107 br	2.423 br
Stress correction factor	Y_{Sa}	1.549 br	1.894 br
Tooth sharpening factor	Y_{Sag}	1.000 br	1.000 br
Tooth angle factor	Y_β	1.000 br	
Overlap factor	Y_ε	0.632 br	
Load change factor	Y_A	1.000 br	1.000 br
Manufacturability factor	Y_T	1.000 br	1.000 br
Durability factor	Y_N	1.000 br	1.000 br
Penetration sensitivity factor	Y_δ	1.247 br	1.310 br
Size factor	Y_X	1.000 br	1.000 br
Cavity surface factor	Y_R	1.000 br	

Table 7 shows the results of a study on corrosion margins, tooth breaking strength, contact strength, bending strength.

Table 7

Results

Corrosion margin	S_H	1.192 br	1.209 br
Safety margin for teeth breaking	S_F	2.046 br	2.255 br
Safety margin on contact	S_{Hst}	1.081 br	1.096 br
Bending strength	S_{Fst}	4.101 br	4.303 br
Check calculation		Negative	

Tables 4–7 show all the strength calculations of the gear mechanism that is used on the top of the disinfector to rotate the reflectors of the ultraviolet lamps.

Table 8 shows an analysis of the stress-strain state of the gear mechanism, for which the material of the mechanism and working conditions are selected.

Table 8

Material properties

ABS plastic	
Density	1.06 g/sm^3
Yield strength	20 MPa
Strength at break	29.6 MPa
Young modulus	2.24 GPa
Shear modulus	0.811594 GPa

Table 8 shows the characteristics of the ABS plastic used in gear manufacturing. An external load acts on the gear mechanism – a torque equal to 10 Nmm.

Fig. 6 shows the application of external loads on the elements of the gear mechanism.

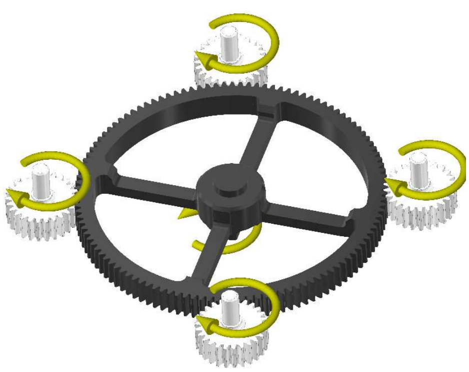


Fig. 6. Selected faces

Table 8 shows the results of the stress-strain state of the elements of the gear mechanism. The results show that the structure is solid.

The Mises maximum stress criterion is based on the Mises-Hencky theory, also known as the shape change energy theory.

Table 9

Results

Name	Min	Max
Volume	712,914 mm^3	
Weight	0.755689 kg	
Von Mises stress	12.794 MPa	9.35677 MPa
Safety factor	2	3

In Fig. 7, the von Mises stress results are displayed using colored outlines to visually show the stresses generated by the model calculations. The deformed model is displayed. The colors of the contours correspond to the stress values. The maximum stress value is 12.794 MPa and the minimum value is 9.35677 MPa. The tensile strength of ABS plastic is 30 MPa (2,400 MPa (23 °C)). Using the tensile strength based on the maximum principal stress, we determine the safety factor.

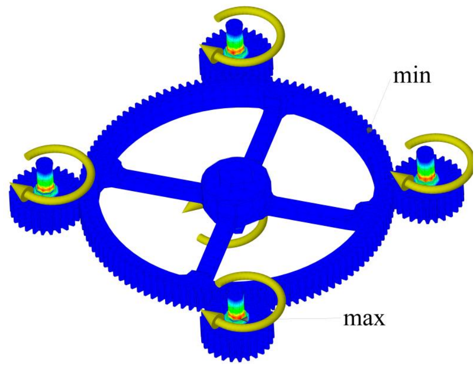


Fig. 7. Von Mises stress

Fig. 8 shows a safety factor map where the maximum value is 3. This shows that the design safety factor is sufficient.

Fig. 9 shows an experimental sample of the upper part of the disinfection robot in two working positions.

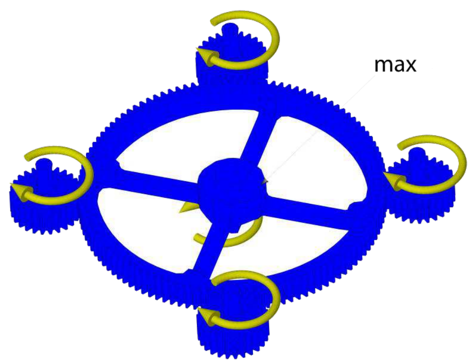


Fig. 8. Safety factor

Fig. 9. Working positions of the upper part of the multifunctional robot

UV lamps with reflectors are rotatable by 180 degrees and have two working positions. In the first working position in Fig. 9, the ultraviolet lamps are outside of the housing and operate in the mode of ultraviolet irradiation of the environment. Fig. 2 shows the second working position, where the lamps with reflectors are rotated by 180 degrees and the reflectors with the body form a closed cylindrical protective cavity, inside which there are ultraviolet lamps, while the robot operates in the air recirculation mode.

6. Discussion of the developed design of a multifunctional disinfection robot

The disadvantage of the devices in the considered works [12–15] is that they use only one method of disinfection, which reduces their functionality. Also in the works [17–20], a mobile cart and disinfectants are a single design with a single power supply and control unit, as well as the placement of the air recirculator separately inside the case, which accordingly reduces its functionality and complicates the design. The work [16] uses robots with a combined disinfector, which provides ultraviolet disinfection with a dry fog.

The developed multifunctional robot has three disinfection methods: ultraviolet radiation method, disinfection method with spraying a disinfection liquid and air filtration (recirculation) method. The robot, depending on the needs for disinfection of the room, can use several disinfection modes individually or in any combination.

The technical result is achieved by the fact that in a multifunctional disinfection robot containing a mobile cart with an autonomous positioning and navigation system, a disinfectant platform with a disinfection liquid spraying system and ultraviolet lamps with reflectors installed on it, the disinfection platform will have its own autonomous control and power systems.

The hierarchical structure of the robot and its components and parts is presented in Section 5. 2, which allows breaking the development into its component parts, which establishes the distribution of work on the implementation of the development of the disinfection robot.

A complete study of kinematics, strength calculations and analysis of the stress-strain state of the gear mechanism were carried out. Fig. 7 shows the von Mises stress results, where the maximum stress value is 12.794 MPa and the minimum value is 9.35677 MPa. The safety margin of the gear mechanism is also determined.

The disadvantage of this development may be the complexity of manufacturing individual parts of a multifunctional disinfection robot.

An application for an international patent (Eurasia) has been filed for this development of a multifunctional disinfection robot – application No. 121006, registration No. 2021/055, dated 10/13/2021.

The development consists in carrying out work on the development of a control system of disinfection robot, which will take into account the dynamic characteristics of the robot when the robot moves. The introduction of dynamic system models will also be accompanied by the introduction of regulators.

7. Conclusions

1. The design of a multifunctional disinfection robot has been developed, which will operate in three modes: ultraviolet radiation, disinfection with spraying a disinfecting liquid and air filtration (recirculation). By emitting ultraviolet light with a Philips TUV germicidal lamp (15 W, wavelength 253.7 nm (UV-C)), the robot can kill 99.99 % of bacteria on surfaces with high, medium and low touch levels. Thanks to the spray nozzles located at a height of 400 mm, the disinfector can carry out a simultaneous combined treatment of rooms with equipment and furniture, including high-quality processing of the lower surfaces of tables, chairs and beds. In the air filtration mode, safe air disinfection is ensured in the presence of a person. The design of the developed multifunctional disinfection robot is shown in Fig. 4, 5.

2. For the development and manufacture of an experimental model of a disinfection robot with a dispenser and a nebulizer and a function of air filtration, a hierarchical structure of the robot and its assemblies and parts was drawn up. The hierarchical breakdowns show all the components needed to design a multifunctional disinfection robot.

3. The study of kinematics and strength calculations of the gear mechanism were carried out. The load factor is determined separately for each of the main performance criteria of the gears. The fatigue contact strength and the bending strength of the teeth are taken as the main performance criteria for the gears. When evaluating the performance according to the condition of contact endurance, the actual contact stresses arising on the lateral surfaces of the teeth were calculated. To determine the contact stresses, we used the Hertz formula to calculate the maximum normal stress in the contact zone of two cylinders along a linear contact.

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