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DESIGN OF THE FOUR-WHEELED MOBILE ROBOTIC PLATFORM FOR DECONTAMINATION TASKS

This article presents the design of a four-wheeled mobile platform for a special service robot, intended to clean contaminated areas in the hot gas chamber of a nuclear power plant reactor. The reactor, KS-150, was part of Czechoslovakia's early nuclear energy development and encountered two significant accidents, leading to its decommissioning. Decommissioning efforts now require the removal of contaminated deposits from the reactor's hot gas chamber, a challenging task due to restricted access and radiation levels. The proposed solution involves using a mobile service robot to replace human workers in hazardous conditions, ensuring safety and efficiency. Five chassis designs were evaluated based on criteria such as energy consumption, structural complexity, contamination risk, and maneuverability. The selected design is a four-wheeled chassis with two steered wheels. The robot's mobility subsystem is a fundamental part of the overall design, supporting various attachments, including a robotic arm, a front brush, and a detachable container for waste removal. The design offers a robust and efficient solution for cleaning contaminated environments, contributing to safer decommissioning processes in nuclear facilities.

Keywords: *mobile robot platform; four-wheeled robot; mechatronic design.*
Fig.: 8. Table: 1. References: 10.

Relevance of the research. The KS-150 nuclear reactor (Fig. 1), developed in Jaslovské Bohunice, marked the beginning of Czechoslovakia's nuclear energy industry [1]. Its construction and commissioning were significant challenges for the industry at the time. This type of reactor, which used heavy water and natural metallic uranium as fuel, had an electrical output of 127 MW. The project was particularly notable for its use of natural uranium.

Construction of the reactor began in 1958, and in October 1972, the first controlled chain reaction was successfully achieved in the A1 nuclear power plant reactor. However, two accidents occurred during the operation of the A1 plant.

The first accident occurred on January 5, 1976, when a fuel assembly was unexpectedly ejected during a fuel replacement operation. The reactor was repaired and brought back into operation by the end of the year.

The second accident happened on February 22, 1977, caused by the rupture of a silica gel packet, which spilled its contents among the fuel elements, leading to the melting of one of the fuel cartridges. The subsequent contamination of both the primary and secondary circuits made further operation of the A1 plant impossible, and it was permanently decommissioned in 1979.

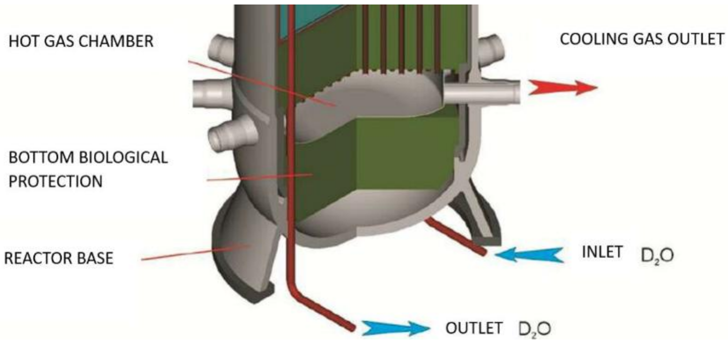

Fig. 1. The lower part of the Czechoslovak heavy water reactor KS150

Problem statement. According to the International Nuclear and Radiological Event Scale (INES), this accident was rated at level 4. Today, the reactor, including the hot gas chamber, is being gradually decommissioned [2; 3].

Before the hot gas chamber can be decommissioned, the contaminated deposits must first be removed. This process is challenging due to both the access to the chamber and the environmental conditions. The use of a mobile service robot is essential for this task [4].

Analysis of recent research and publications. The International Atomic Energy Agency (IAEA) recommends the use of mobile service robots in nuclear power plants due to the benefits they provide, such as replacing humans in hazardous environments, increasing efficiency and safety, and reducing costs [5].

Isolation of previously unexplored parts of the general problem. Currently, there are many universal mobile service robots available, but their versatility often does not meet the required level. In this case, it is necessary to develop a solution that fully meets the specific requirements. These requirements include exploration, dismantling operations, decontamination in areas with radiation [6].

Research objectives. Modern mobile service robots share common design elements and solution concepts. The overall system is divided into several subsystems, each of which is functionally and structurally interconnected. These subsystems typically include the mobility subsystem, the action superstructure subsystem (modules), the internal sensor subsystem, the external sensor subsystem, the control and navigation subsystem, the operator interface subsystem, and the energy support subsystem [7; 8]. The goal of this research is the design of the mobility subsystem.

Requirements for the four-wheel mobile platform for a special service robot. The requirements for the mobile platform are influenced by the environment in which the robot will be deployed and the tasks it will perform. The working environment of the mobile service robot is the hot gas chamber (Fig.2), where the bottom, the subject of cleaning, is angled at 34,2°. Access to the chamber will be provided through a circular opening with a diameter of 380 mm, which is based on a mobile platform and a key dimension for the design of the mobile platform and another subsystem.

The robot's design is also influenced by the pipes located at the bottom of the chamber. The radiation level in the hot gas chamber is 15 mSv/h, which is critical for the design of electronics. The ambient temperature is approximately 20 °C.

Fig. 2. Pollution in the hot gas chamber of the KS 150 reactor

Based on these conditions, we proposed five types of chassis (Fig.3) and selected the most suitable one. We considered five types: a tracked chassis and four variants of wheeled chassis, differing in the number of wheels and steering methods.

In the first variant, the wheeled chassis has two axles with four wheels. The second variant includes a wheeled chassis with six wheels and three axles. The third variant contains the same number of axles and wheels as variant two. From the point of view of steering, we will divide the first variant into a sub-variant with slip differential steering and a sub-variant with two controlled directional wheels.

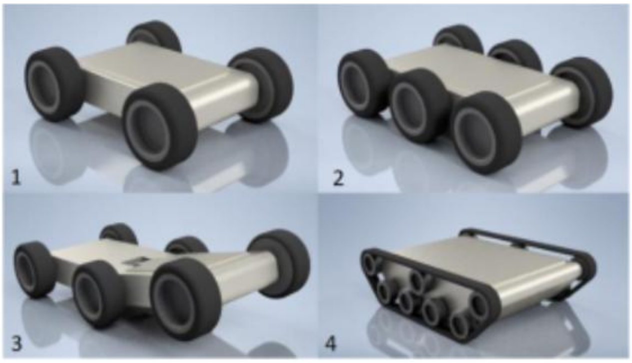

Fig. 3. Chassis variants [9]

We evaluated these 5 variants according to the following aspects:
- energy consumption,
- structural complexity,
- weight,
- complexity of production,
- contamination,
- maneuverability.

We assigned each aspect a priority from 0 to 5, where 5 represented the highest priority, and then assigned each variant a score from 0 to 10. The results are shown in Table.

Table – Chassis comparison

Aspects	Factor of importance	Variant č. 1	□∑	Variant č. 1.1	□∑	Variant č. 2	□∑	Variant č. 3	□∑	Variant č. 4	□∑
Energy consumption	2	9	18	9	18	7	14	6	12	5	10
Structural complexity	2	9	18	9	18	6	12	6	12	4	8
Complexity of maintenance	3	5	15	8	24	7	21	7	21	5	15
Weight	3	10	30	10	30	7	21	6	18	6	18
The complexity of production	2	9	18	8	16	8	16	7	14	5	10
Contamination	4	10	40	10	40	7	28	7	28	5	20
Maneuverability	5	9	45	9	45	8	40	7	35	9	45
Result value			184		191		152		140		126

After evaluating all the aspects, we concluded that variant 1.1, a four-wheeled chassis with two steered wheels, is the most suitable for our needs.

Design of the four-wheeled mobile platform. The mobile platform design begins with selecting the servo motors that will ensure movement and wheel steering. Then, we will design the shape and material of the wheels. Since the servo motors cannot be directly attached to the platform frame, we will create mounts for them. The front and rear parts of the divided frame will be symmetrical and connected by a pivot pin.

The output torque of the servo motors was calculated, based on the robot's movement on an inclined plane, rounding the angle of the plane to 35°.

Based on the calculations, we selected a servo motor, that integrates a motor and a harmonic gearbox. The supply voltage is 36VDC, and the maximum output torque is 30 Nm. In designing the mobile platform wheel, we used an aluminum disk (EN-AW 5083), which will be rubberized to increase the robot's traction. We determined the rubber hardness to be 75 ShA to ensure optimal adhesion and durability against wear. The frame (Fig.4) will consist of two parts connected by a pivot pin, allowing movement between the frame sections. This frame will connect all the necessary components and subsystems of the robot. The pivot pin will be housed in a hole in the front part of the frame and secured with a locknut. The other part of the frame will be connected to the pin via a bearing housing BK15.

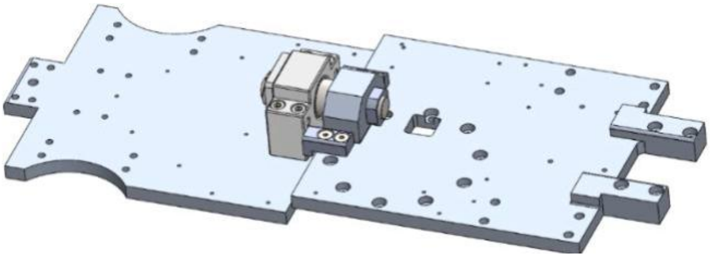

Fig. 4. Frame of the mobile platform which consist of two parts- bottom view

The main parts of the frame are the axles. The front divided axle is attached to the front part of the frame using a suspension and a drive unit that rotates the wheel. The rear divided axle is directional and ensures the robot's movement. Steering the directional wheels controls the robot's movement using Ackerman steering.

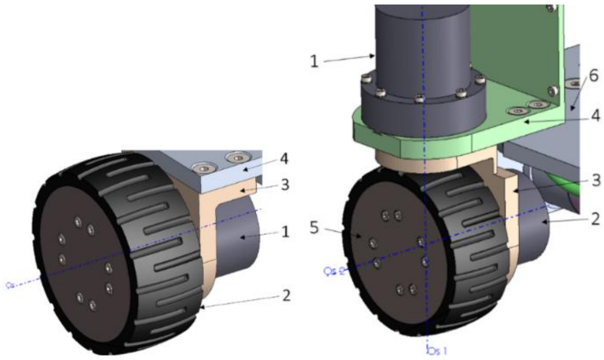

Fig. 5. Divided front and rear axles

By steering the rear wheel (Fig.5), we control the robot's movement direction. To avoid unwanted wheel slippage, we use an appropriate steering method. In this case, we employ Ackerman steering (Fig.6), which addresses the difference in steering angles between the wheels during movement. This approach ensures that the wheels follow the correct paths during turns, preventing slippage and improving maneuverability [7; 8].

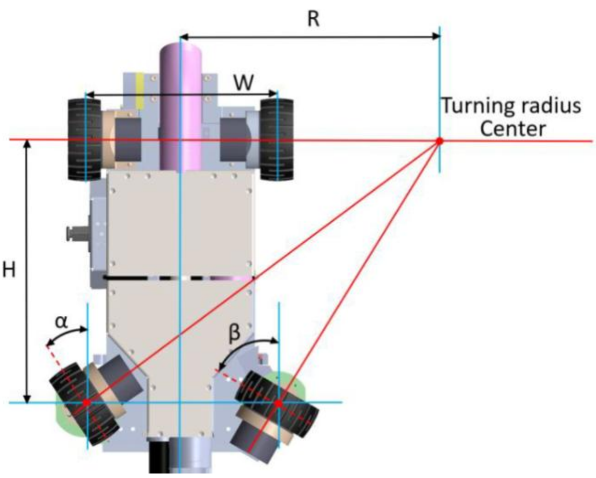

Fig. 6. Rear axle steering - bottom view on mobile platform

The overall design of the four-wheel mobile platform, which we can see in figure 7, includes a front axle and a rear directional axle.

The four-wheel mobile platform functions as the foundation of the entire mobile service robot, with other subsystems connected to it. Although the specifics of these subsystems are not detailed here, they are important for consideration. To accommodate these subsystems, we made modifications to the front and rear sections of the frame. Holes (Fig. 7, P5) are provided to secure the front rotating cylindrical brush, while other holes (Fig. 7, P6) are designated for attaching the robotic arm. A removable container is positioned at the rear of the mobile service robot (Fig. 7, P7), and a hose used for extracting deposits and transporting contaminated waste from the hot gas chamber runs inside the mobility subsystem (Fig. 7, P4). In the rear section, this hose connects to another that leads outside the chamber (Fig. 7, P9). In the lower part, there is also space for electronics (Fig. 7, P9).

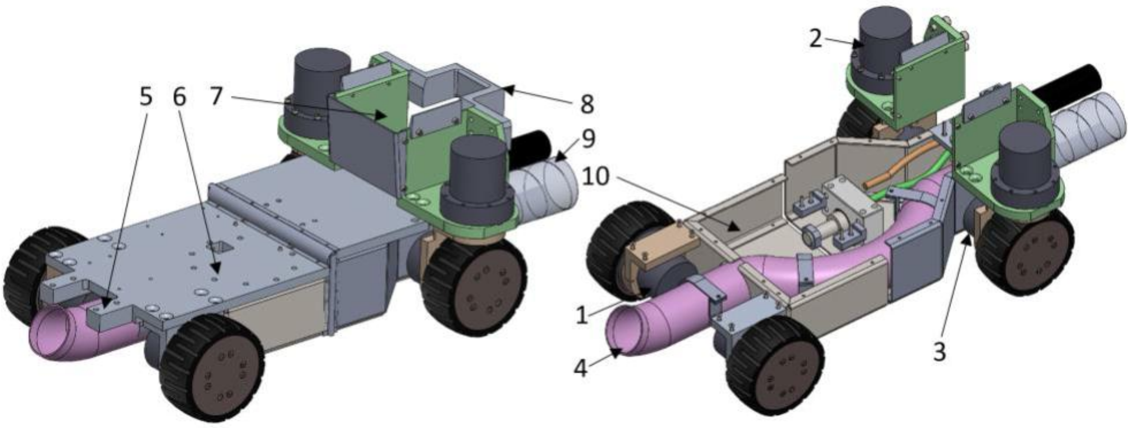

Fig. 7. Model of the mobility subsystem

Figure 8 shows a service robot with all subsystems and components installed.

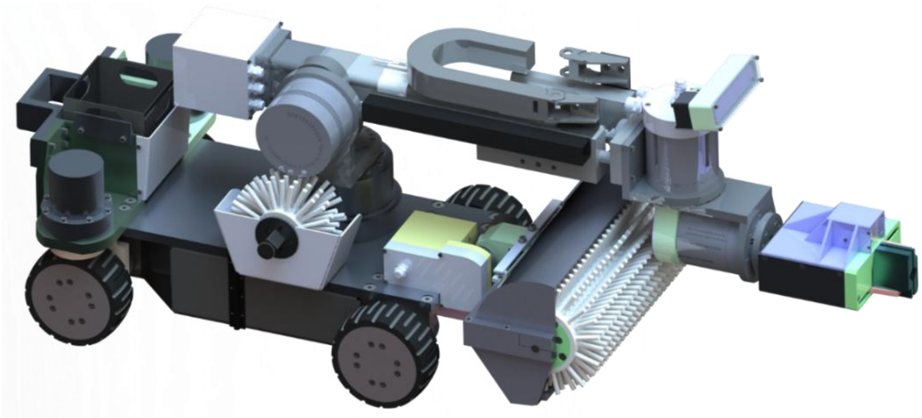

Fig. 8. Mobile platform equipped with action attachments: robotic arm, front brush, removable container

Conclusions. This paper describes the design of a mobile platform for cleaning the contaminated area of a hot gas chamber. This design results in a four-wheeled chassis with a split frame connected by a pivot pin. All wheels are driven, and direction control is ensured by rotating two directional wheels. The designed mobile platform will be equipped with such active extensions as a robotic arm, a front brush, and a detachable container.

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ПРОЄКТУВАННЯ ЧОТИРИКОЛІСНОЇ МОБІЛЬНОЇ РОБОТИЗОВАНОЇ ПЛАТФОРМИ ДЛЯ ЗАДАЧ З ДЕЗАКТИВАЦІЇ

Ця стаття представляє розробку чотириколісної мобільної платформи для спеціального сервісного робота, призначеного для очищення забруднених зон у гарячій газовій камері ядерного реактора КС-150, розташованого в Ясловське Богуніце. Реактор КС-150, введений в експлуатацію на початку 1970-х років, зазнав двох серйозних аварій, що зрештою призвело до його постійного відключення та виведення з експлуатації. Сьогодні процес виведення з експлуатації вимагає видалення радіоактивних відкладень із гарячої газової камери, що є складним завданням через обмежений доступ, небезпечний рівень радіації та труднощі доступу до самої камери.

Враховуючи ці умови, використання мобільного сервісного робота є необхідним для заміни людських працівників і мінімізації впливу шкідливої радіації. Дослідження зосереджене на розробці підсистеми мобільності, що дозволить роботу пересуватися у вузькому просторі камери. У процесі проектування було оцінено п'ять типів шасі: гусеничний варіант і чотири колісні варіанти з різними осями та методами кермування. Критерії оцінки включали енергоспоживання, структурну складність, простоту обслуговування, вагу, складність виробництва, ризик забруднення та маневреність.

Після оцінки конструкцій було обрано чотириколісне шасі з двома керованими колесами як оптимальне рішення. Ця конфігурація дозволяє точно контролювати рух і мінімізує ковзання під час роботи у вузьких просторах. Підсистема мобільності робота спроєктована таким чином, щоб бути сумісною з додатковими компонентами, включаючи роботизовану руку для маніпуляцій з об'єктами, передню циліндричну щітку для очищення та знімний контейнер для транспортування радіоактивних відходів. Підсистема мобільності також інтегрує систему шлангів для вилучення та транспортування забруднених відходів із камери.

На завершення, стаття детально описує технічну конструкцію надійної та ефективної мобільної платформи, здатної виконувати завдання з очищення та дезактивації у радіоактивних середовищах. Запропонована мобільна платформа відіграватиме критичну роль у забезпеченні безпечного та ефективного виведення з експлуатації ядерних об'єктів, знижуючи ризики для людських працівників і підвищуючи ефективність роботи в зонах забруднення.

Ключові слова: *платформа мобільного робота; чотириколісний робот; мехатронна конструкція.*
Рис.: 8. Табл.: 1. Бібл.: 9.

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