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# INVESTIGATION OF PNEUMATIC CLEANING SYSTEM EFFECTIVENESS FOR RADAR NAVIGATION SENSORS ON SELF-PROPELLED SPRAYERS IN FIELD CONDITIONS

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*The article is devoted to experimental research of the efficiency of the pneumatic cleaning system of radar sensors of navigation systems on self-propelled sprayers in field conditions. The relevance of the research is due to the problem of contamination of visual row guidance sensors with plant residues, dust, dew and other elements, which reduces the accuracy of the navigation systems and requires frequent stops for manual cleaning.*

*The paper presents the design of the developed pneumatic cleaning system, which consists of an air compressor with a receiver, a distribution system, air nozzles and an electronic control unit. The technical characteristics of the system components and the principle of its operation in pulse mode are described.*

*Field tests were carried out during a full 24-hour work shift on a self-propelled sprayer Case Patriot with a Raven navigation system in the conditions of processing corn crops in the milk ripeness phase. The effect of different operating modes of the system (pressure 2, 4, 6, 8 bar and pulse time 1, 5, 10, 20 seconds) on the efficiency of cleaning sensors under different types of pollution and microclimatic conditions in four time periods of the day was studied.*

*The results showed that in the daytime, with dry dust pollution, the 4 bar mode with 5 seconds of blowing is sufficient (efficiency 95%). In the evening, with combined pollution, a pressure of 6-8 bar for 15-20 seconds is required (efficiency 75-85%). The most difficult conditions are observed at night with high humidity of 85-95%, when the maximum mode provides 80% of the cleaning efficiency. The morning period is characterized by rapid drying of wet dirt, which requires a 6-8 bar mode for 15-20 seconds (efficiency 70-78%).*

*The study confirms the feasibility of using pneumatic cleaning systems on self-propelled sprayers, which contributes to increasing productivity, reducing crop losses and improving the quality of technological operations.*

***Key words:*** *pneumatic cleaning, radar sensors, navigation systems, self-propelled sprayer, visual row guidance, field tests, cleaning efficiency.*

***Fig. 11. Table. 2. Ref. 13.***

## 1. Problem formulation

Modern agriculture requires high precision in performing technological operations, particularly during the spraying of row crops. Traditional spraying methods are often accompanied by uneven application of agrochemicals, leading to resource waste, environmental pollution, and reduced crop yields. Plant trampling by the wheels of self-propelled sprayers or tractors with mounted sprayers also contributes to yield reduction, which can vary from 1.5% to 5% of crop losses.

The implementation of navigation systems in the spraying process allows for increased efficiency of technological operations through precise positioning of equipment in the field. The use of Global Navigation Satellite Systems (GNSS) in autopilot systems and differentiated application of preparations contributes to reducing overlaps and gaps, which improves the uniformity of plant treatment, increases yields, and optimizes costs for plant protection products. Visual row guidance systems, which operate based on cameras and sensors, reduce the percentage of plant trampling, decrease operator fatigue, and improve the quality of equipment operation during nighttime hours.

However, there is a problem of contamination of radar row guidance sensors with plant residues, dust, dew, dirt, and other elements. This problem significantly reduces guidance quality and affects the efficiency of the entire guidance system. The operator is forced to frequently clean the sensor lenses to continue using the guidance system.

Various methods are used to solve the problem of sensor cleaning on agricultural machines, one of which is pneumatic cleaning.


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Thus, there is a need for scientific research on the effectiveness of pneumatic sensor cleaning in field conditions and determining the optimal pressure and airflow duration for sensor lens cleaning at different times of day.

## 2. Analysis of recent research and publications

The world is currently experiencing an unprecedented technological transformation in which vehicles and autonomous driving systems are developing at a breathtaking pace [1, 2]. Optimistic predictions claim that by 2030, autonomous vehicles will be sufficiently reliable, affordable, and widespread to displace most human driving, providing enormous savings and benefits [3]. However, most vehicles today are manually controlled, and to achieve full driving autonomy, they must evolve through different levels of driving automation as defined by the Society of Automotive Engineers (SAE) [4]: levels 0–No Driving Automation, 1–Driver Assistance, and 2–Partial Driving Automation require a human driver to monitor the driving environment, while at levels 3–Conditional Automation, 4–High Automation, and 5–Full Automation, the automated system is capable of autonomously monitoring and navigating the driving environment.

Modern navigation systems for agricultural machinery also demonstrate rapid development towards full automation. Parallel steering systems have acquired auto-turn functionality, which significantly improves the repeatability of equipment route through the field and optimizes the use of headland areas. Self-propelled machines are appearing on the market that operate according to pre-programmed routes, taking into account field trajectories and existing obstacles [5, 6]. LiDAR systems are used to detect unpredictable obstacles, scanning the perimeter and automatically stopping the machine in case of danger.

The experience of the automotive industry in developing autonomous driving systems is of significant importance for agricultural machinery. With the start of mass production of vehicles with level 3 autonomous driving technology, leading manufacturers and government agencies are actively working on implementing level 4 autonomy technologies. Numerous global companies, including Tesla, Waymo, GM, Audi, Valeo, Hyundai Motor Company, and NVIDIA, have released vehicles equipped with autonomous control systems.

Autonomous vehicles collect real-time environmental data using a complex of sensors: LiDAR (Light Detection and Ranging), radars, cameras, and ultrasonic sensors. This process is critically important for proper obstacle detection, timely response, and instant decision-making in unexpected situations. However, the accuracy and performance of sensors can be significantly reduced by contaminants such as dust, rain, and snow that accumulate on their working surfaces. Sensor performance degradation can lead to potentially dangerous situations due to inaccurate object recognition [7].

In recent years, a significant number of researchers have been conducting experiments to determine the speed and quality of cleaning from various types of contaminants that have clear standardization.

In the study by Son et al. [8], the influence of various factors on the cleaning efficiency of LiDAR sensors for autonomous driving systems was investigated, including: washer fluid pressure, spray duration, spray angle, and target point. The results showed that washer pressure and spray duration have the greatest impact on cleaning efficiency. At the same time, it was established that washer pressure cannot be increased indefinitely due to physical limitations and economic feasibility of using appropriate pumps. The optimal water pressure was determined to be 7-8 bar.

The study [9] describes methods for cleaning LiDAR and camera sensors more resource-efficiently compared to existing systems on the market. The research authors developed and tested several cleaning methods. The developed cleaning systems showed that ensuring low washer fluid consumption negatively affects scalability, durability, compactness, and system complexity compared to existing cleaning systems. The study showed that when using high-pressure fluid, a flat spray nozzle is more resource-efficient than a static cone spray nozzle typically used in conventional sensor cleaning systems.

The operating conditions of sensors on agricultural machinery differ significantly from automotive applications. The main contaminating factors are: dry dust, wet dirt, plant residues, sticky chemical preparations, insects, and water droplets. Moisture plays a special role, acting as a catalyst for the transformation of dry dust into wet dirt, which significantly complicates the cleaning process. In addition, water droplets on sensor surfaces create a screening effect: signals reflect off the droplets, distorting the direction of propagation or changing the signal movement angle [10].

An additional obstacle to sensor operation is dust storms, which can occur both due to weather conditions and during equipment operation in the field during soil cultivation or sowing. The phenomenon of dust blinding makes visual systems ineffective for accurate obstacle detection, which can lead to accident situations [11].

In turn, non-contact radar row guidance sensors are critically important for the functioning of navigation systems in late crop development stages. Contamination of the sensor working surface is the main factor limiting system efficiency in field conditions. Previous studies have shown that when more than 30% of the sensor surface area is contaminated, system accuracy decreases by a factor of 4, making further use of automatic guidance impossible.

Microclimatic conditions in the sensor operation zone [12, 13] create specific requirements for maintaining their working surfaces in a clean state. Particularly critical are nighttime and early morning hours when dew forms and wet dust creates persistent contamination. Under existing practices, operators are forced to periodically stop work and manually clean sensor surfaces, which reduces productivity and technological process efficiency.

Analysis of scientific publications shows that the problem of sensor contamination is relevant for both the automotive industry and agricultural machinery manufacturing. However, the specifics of agricultural machinery operating conditions require the development of specialized solutions taking into account contamination characteristics and microclimate in the sensor operation zone.

The experience of using liquid cleaning systems in the automotive industry demonstrates their effectiveness; however, for agricultural machines operating in long shifts in locations remote from infrastructure, the search for alternative methods is relevant. Pneumatic cleaning systems can become an effective solution, as they do not require liquid supplies and can provide long-term autonomous operation.

Currently, there are no comprehensive studies on the effectiveness of pneumatic cleaning of radar sensors in navigation systems under real field conditions throughout a full work shift, taking into account variable microclimatic factors, which justifies the relevance of this study.

## 3. The purpose of the article

The purpose of this article is to experimentally investigate the effectiveness of pneumatic cleaning of the working surface of a radar sensor in a navigation system installed on a self-propelled sprayer, and to determine the optimal airflow parameters taking into account compressed air pressure and pulse duration under various microclimatic conditions throughout the work shift.

## 4. Results and discussion

The operational efficiency of non-contact radar sensors in navigation systems on self-propelled sprayers directly depends on the cleanliness of their working surfaces. Under field conditions, sensors are subject to intensive contamination of various types: dry dust, wet dirt, plant residues, dew, and working solution droplets. According to previous studies, contamination of more than 30% of the sensor surface area leads to a fourfold decrease in system accuracy, making further use of automatic row guidance impossible.

To address this problem, a pneumatic sensor cleaning system was developed and implemented to ensure their continuous operation throughout the entire work shift. However, the effectiveness of such a system depends on many factors: compressed air pressure, airflow pulse duration, type of contamination, and microclimatic conditions in the sensor operation zone.

A distinctive feature of sprayer operation is the need to perform technological operations at different times of day, including nighttime and early morning hours when dew forms. It is during this period that the most intensive sensor contamination occurs due to the combined effect of moisture and dust, creating persistent contamination on sensor surfaces that is difficult to remove.

The purpose of this section is to present the results of an experimental study on the effectiveness of the developed pneumatic cleaning system under real field conditions during a full 24-hour work shift. During the study, the impact of different system operating modes (pressure of 2, 4, 6, 8 bar and pulse duration of 1, 5, 10, 20 seconds) on the degree of sensor cleaning under different types of contamination and microclimatic conditions was evaluated.

The study was conducted on a Case Patriot self-propelled sprayer equipped with a Raven navigation system, under conditions of treating corn crops at the milk ripeness stage. The choice of this crop and development stage was determined by the maximum intensity of sensor contamination due to high planting density and significant moisture in the lower plant tier.

The research results will allow determining the optimal operating parameters of the pneumatic cleaning system for various operating conditions and developing recommendations for system adjustment depending on the time of day and weather conditions.

Design and operating principle of the air blowing system

Based on the results of research into the impact of pollution on the operation of non-contact sensors, an air blowing system was developed to maintain their performance in field conditions.

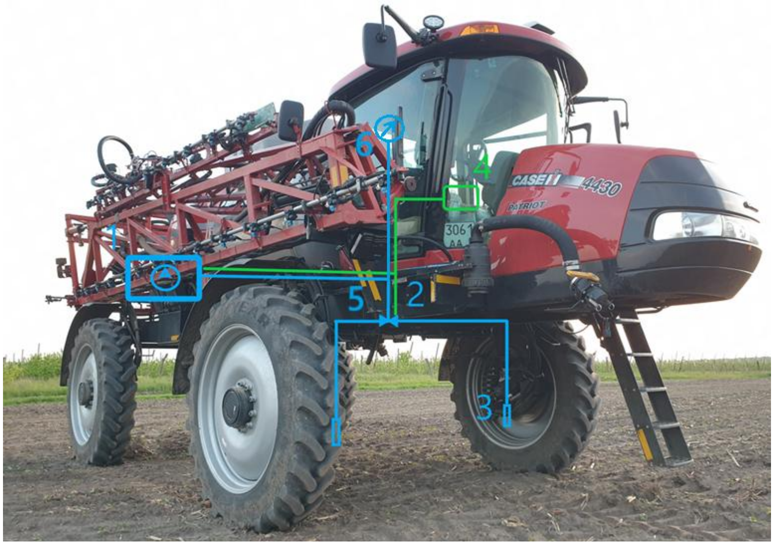


***Fig. 1. Structural scheme of the system:***

***1 – Air compressor with receiver - source of compressed air; 2 – Distribution system - pipelines and connecting elements; 3 – Air nozzles - direct cleaning elements; 4 – Control system - electronic control unit for blowing modes; 5 – Air valve - turns off and on the air flow; 6 – Pressure gauge - monitoring the air pressure in the receiver***

***Table. 1***

***Technical characteristics of the system***

| **Component** | **Parameter** | **Value** |
|---|---|---|
| Compressor | Type | Piston, single-stage |
| | Productivity | 200 l/min |
| | Max. pressure | 20 bar |
| | Power | 2,2 kW |
| | Drive | By engine |
| Receiver | Volume | 30 l |
| | Working pressure | 8-12 bar |
| | Material | Steel, anti-corrosion coating |
| Nozzles | Number | 2 pcs |
| | Nozzle diameter | 1 mm |
| | Spray angle | 120° |
| | Air consumption | 10 l/min per nozzle |
| Pneumatic valve | Operating voltage | 12 v |
| | Operating current | 0,4 A |
| | Speed of work | 0,2-0,4 сек |
| | Degree of protection | IP68 |
| Tubes | Material | Nylon |
| | Working pressure | 17,2 bar |
| | Burst pressure | 68 bar |
| | Outer diameter | 8 mm |

The principle of operation of the system:

After starting the engine, the compressor pumps air into the receiver to the threshold discharge pressure of 12 bar. The operator in the cabin can observe the pressure on the pressure gauge, after which the operator activates the air valve control system. The control system sets the time parameters when the valve is in the closed position and in the open position. Thus, the system operates on the principle of pulse blowing with the ability to set time modes:

1. Continuous mode - constant blowing with low intensity

2. Pulse mode - short powerful pulses at set intervals

Location of system elements:

Compressor and air tank layout:

The compressor is mounted on the sprayer engine and is driven by a flywheel. The compressor has a capacity of 200 litres per minute. The air receiver is mounted on the ladder near the engine and has a capacity of 30 litres.

Nozzle layout diagram:

The air nozzle is located in the middle of the protective metal cover of the radar sensor and, in turn, covers the radar sensor, which prevents dirt from getting between the metal cover and the radar sensor. Due to its design, the nozzle tightly surrounds the sensor lens.radar sensor. Due to its design, the nozzle tightly surrounds the sensor lens.

Nozzle attack angle: 180° to the lens surface

Distance from sensor: 2 mm

Coverage area: 120° around the sensor


***Fig. 2. Structural diagram of the air nozzle***

The air nozzle consists of:

1. Nozzle body – made of flexible plastic to fit around the surface of the radar sensor
2. Fitting for an 8 mm diameter air hose – has the option of quick connection of the air duct
3. Air nozzle – has the shape of a semicircle for high-quality lens cleaning

Control system location:

The control system is located in the sprayer hog, in the operator's accessible area for convenient control. The electronic control unit provides on/off control system, programming the duration of the blowing pulses for effective and at the same time economical consumption of air from the receiver.

Pneumatic valve:

It is located under the sprayer cab on the main pipeline from the receiver to the nozzles. After the valve, a tee is installed through which the pipelines to the nozzles exit.

Field efficacy testing methodology:

Field tests were conducted on a Case Patriot sprayer equipped with a Raven navigation system. The sprayer operator must warm up the vehicle before starting work so that the hydraulic oil is at operating temperature for proper auto-guidance. The sprayer should be operated at a speed of 18-20 km per hour in a straight line across the field. The vision system should be set to a threshold of 50% quality.

The experiment is conducted in the “Radar Only” mode as the source of determining the distance to the row.

The test was conducted over a 24-hour work shift to take into account all climatic aspects such as dew and wet soil at night and in the morning.

During the test, the effectiveness of the radar sensors is measured under different pressures and blowing times. The corresponding data is entered in a table.

Preparation for the field test consists of the following activities and preliminary work:

• Selection of fields for testing;
• Calibration of installed navigation components;
• Checking the pneumatic blowing system;
• Preparation and checking of measuring instruments, tools and equipment;

Test conditions:

• Crop: corn, milky maturity phase

• Weather conditions: clear, daytime temperature +28°C, night +16, daytime humidity 65%; humidity in the lower parts of the plants at night 85%, morning 95%; wind 3-5 m/s

• Soil conditions: dry black soil after 3 days without precipitation

• Working speed: 18-80 km/h

• Blowing mode: pulse with pressures 2, 4, 6, 8 and pulse time 1, 5, 10, 20 seconds.

Field test results:

**Test 1 - from 8:00 to 20:00**

During test 1, the radar sensors were mainly exposed to dust contamination, which did not lead to a significant decrease in tracking quality - photo 1. Also, this condition was caused by the fact that the sensor was wiped off by plant leaves when driving near them.

Blowing was used for comparison - figure 3.


***Fig. 3. Test 1 – radar condition without using air blowing***

***Fig. 4. Test 1 – radar condition using air blowing***

**Test 2 – 20:00 to 23:00**

During test 2, the radar sensors were exposed to both dust and dirt that rose from the wheels and moisture from dew that began to appear on the lower leaves of the plants, which led to greater contamination of the sensor lens than in test 1.

***Fig. 5. Test 2 – radar condition without air blowing***

***Fig. 6. Test 2 – radar condition using air blowing***

During the test, air blowing was used according to the methodological instructions.

**Test 3 – from 23:00 to 6:30**

During test 3, the radar sensors were exposed to the greatest contamination. There was high humidity in the sensor operating area in the form of dew. The sprayer and sensors were completely covered with water, which dripped down in drops. The dust that rose from the wheels stuck to the protective cover and sensor lenses and completely contaminated the lens – figure 7.

***Fig. 7. Test 3 – radar condition without using air blowing***

During testing using air blowing at 8 bar for 20 seconds, the lens condition remained satisfactory throughout the time the liquid barrel was being emptied, which was approximately 25-30 minutes. In between refills of the sprayer barrel, the operator must manually clean the radar lenses.

***Fig. 8. Test 3 – radar condition using air blowing***

**Test 4 – 6:30 to 8:00**

During test 4, the radar sensors were exposed to a medium level of pollution. During the test from 6:30 to 8:00, dew began to evaporate on the leaves of the plant, which led to less moisture on the sensors. At this time, the moisture that remained on the plants, getting on the sensor with dust, also quickly evaporated, which led to the rapid drying of the swamp on the lenses - figure 9.

The rapid drying process made it difficult for the blowing system to clean the sensor lenses. However, the blowing ensured a high degree of sensor performance during spraying.

***Fig. 9. Test 4 – radar condition without using air blowing***

***Fig. 10. Test 4 – radar condition using air blowing***

Based on the results of field tests, the obtained data is entered into a table and a graph is formed.

*Table. 2*

***Results of all field tests***

| | | | Blowing time, sec. | | | |
|---|---|---|---|---|---|---|
| | | | 1 | 5 | 10 | 20 |
| Type of pollution | Pressure, bar | Elementary level | Cleaning efficiency (%) | Cleaning efficiency (%) | Cleaning efficiency (%) | Cleaning efficiency (%) |
| Test 1 - from 8:00 to 20:00 | 2 | 100 % | 90 | 92 | 95 | 95 |
| Test 2 - from 20:00 to 23:00 | | | 40 | 43 | 45 | 50 |
| Test 3 - from 23:00 to 6:30 | | | 30 | 32 | 35 | 40 |
| Test 4 - from 6:30 to 8:00 | | | 40 | 42 | 45 | 50 |
| Test 1 - from 8:00 to 20:00 | 4 | | 92 | 95 | 95 | 95 |
| Test 2 - from 20:00 to 23:00 | | | 60 | 60 | 65 | 70 |
| Test 3 - from 23:00 to 6:30 | | | 54 | 60 | 70 | 75 |
| Test 4 - from 6:30 to 8:00 | | | 58 | 62 | 65 | 70 |
| Test 1 - from 8:00 to 20:00 | 6 | | 95 | 95 | 95 | 95 |
| Test 2 - from 20:00 to 23:00 | | | 62 | 67 | 70 | 75 |
| Test 3 - from 23:00 to 6:30 | | | 56 | 70 | 72 | 80 |
| Test 4 - from 6:30 to 8:00 | | | 60 | 65 | 70 | 78 |
| Test 1 - from 8:00 to 20:00 | 8 | | 95 | 95 | 95 | 95 |
| Test 2 - from 20:00 to 23:00 | | | 65 | 65 | 72 | 85 |
| Test 3 - from 23:00 to 6:30 | | | 60 | 70 | 75 | 80 |
| Test 4 - from 6:30 to 8:00 | | | 62 | 68 | 70 | 78 |

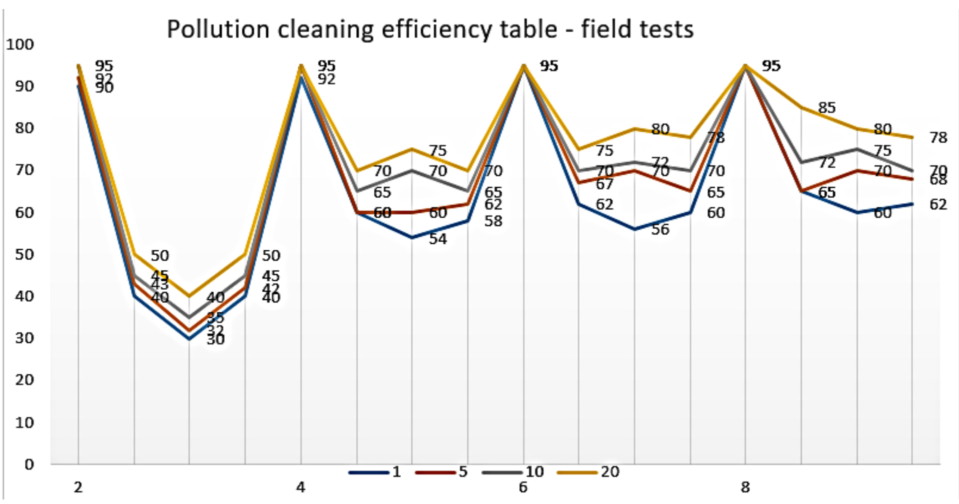


*Fig. 11. Pollution cleaning efficiency table - field tests*

## 5. Conclusion

Analysis of field trial results showed that under predominantly dry dust contamination during daytime hours (8:00-20:00), a mode of 4 bar with an airflow duration of 5 seconds is sufficient, providing 95% cleaning efficiency. During evening hours (20:00-23:00) with combined contamination (dry dust + moisture), an increase in pressure to 6-8 bar with airflow duration of 15-20 seconds is necessary to achieve 75-85% efficiency. The most challenging conditions are observed during nighttime hours (23:00-6:30) with high humidity of 85-95%, when even the maximum mode (8 bar, 20 seconds) provides only 80% efficiency, requiring periodic manual sensor cleaning during sprayer refilling every 25-30 minutes. The morning period (6:30-8:00) is characterized by rapid drying of wet dirt, creating persistent contamination and requiring a mode of 6-8 bar with airflow duration of 15-20 seconds to achieve 70-78% efficiency.

The structural design of the pneumatic cleaning system demonstrated high reliability and functionality under field conditions. The placement of air nozzles inside a protective metal housing with a 120° coverage angle and 2 mm distance from the sensor surface ensures uniform airflow distribution and effective limitation of contamination ingress. The programmable control system with adjustable pulse duration allows optimization of compressed air consumption depending on specific operating conditions. No design deficiencies were identified during trials; all elements functioned reliably. The use of the pneumatic cleaning system significantly reduces the number of stops for manual sensor cleaning, ensures stable operation of navigation systems throughout the entire shift, including critical periods with high humidity, and reduces operator fatigue. During daytime periods with low contamination levels, system use can be limited or disabled, which reduces compressor wear and extends its operational life.

The research results confirm the advisability of mandatory use of pneumatic cleaning systems on self-propelled sprayers equipped with row guidance navigation systems, especially when operating under conditions of increased humidity and intensive dust formation. Implementation of such systems contributes to increased sprayer productivity, reduction of crop losses from trampling, and improvement of technological operation quality.

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## ДОСЛІДЖЕННЯ РОБОТИ СИСТЕМИ ПНЕВМАТИЧНОГО ОЧИЩЕННЯ РАДАРНИХ ДАТЧИКІВ НАВІГАЦІЇ НА САМОХІДНИХ ОБПРИСКУВАЧАХ В ПОЛЬОВИХ УМОВАХ

*Стаття присвячена експериментальному дослідженню ефективності системи пневматичного очищення радарних датчиків навігаційних систем на самохідних обприскувачах у польових умовах. Актуальність дослідження обумовлена проблемою забруднення датчиків візуального ведення по міжряддю рослинними рештками, пилом, росою та іншими елементами, що знижує точність роботи навігаційних систем та вимагає частих зупинок для ручного очищення.*

*У роботі представлено конструкцію розробленої системи пневматичного очищення, яка складається з повітряного компресора з ресивером, системи розподілу, повітряних форсунок та електронного блоку керування. Описано технічні характеристики компонентів системи та принцип її роботи в імпульсному режимі.*

*Польові випробування проводилися протягом повної 24-годинної робочої зміни на самохідному обприскувачі Case Patriot з навігаційною системою Raven в умовах обробки посівів кукурудзи у фазі молочної стиглості. Досліджувався вплив різних режимів роботи системи (тиск 2, 4, 6, 8 бар та час імпульсу 1, 5, 10, 20 секунд) на ефективність очищення датчиків при різних типах забруднення та мікрокліматичних умовах у чотири часові періоди доби.*

*Результати показали, що в денний період при сухому пиловому забрудненні достатнім є режим 4 бар при 5 секундах обдуву (ефективність 95%). У вечірній період при комбінованому забрудненні необхідний тиск 6-8 бар протягом 15-20 секунд (ефективність 75-85%). Найскладніші умови спостерігаються в нічний період з високою вологістю 85-95%, коли максимальний режим забезпечує 80% ефективності очищення. Ранковий період характеризується швидким висиханням вологого бруду, що потребує режиму 6-8 бар протягом 15-20 секунд (ефективність 70-78%).*

*Дослідження підтверджує доцільність застосування систем пневматичного очищення на самохідних обприскувачах, що сприяє підвищенню продуктивності, зменшенню втрат врожаю та покращенню якості виконання технологічних операцій.*

***Ключові слова:*** *пневматичне очищення, радарні датчики, навігаційні системи, самохідний обприскувач, візуальне ведення по міжряддю, польові випробування, ефективність очищення.*

***Рис. 11. Табл. 2. Літ. 13.***

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