

Prevention of corrosion fracture of agricultural equipment during storage

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Abstract. The aim of the study is to reduce metal losses of structural elements of agricultural machines caused by atmospheric corrosion. The presents the theoretical justification and practical implementation of method of storing agricultural machinery in an open area under an active thermal cover. The object of research is the experimental design of an active heat-reflecting screen equipped with heating elements that provide an infrared radiation flux in the mid-wave range of the spectrum with a wavelength of $\lambda = 5\text{-}20 \mu\text{m}$. A design feature of the heat-reflecting screen is the location of heating elements relative to the agricultural machine in it. The protective effect is achieved due to the fact that when the probability of dew drops increases, the elements heating the internal surface of the heat-reflecting screen and the surface of the machine are automatically switched on, while the air, which is an optically transparent medium, does not heat up, which creates conditions excluding dew. During the tests, it was found that the use of an active heat-reflecting screen allows to ensure reliable safety of the protected machine. The possibility of local heating of the inner surface of the heat-reflecting screen and the surface of the machine without heating the entire volume of air space inside the storehouse can reduce the cost of electric energy. There is no need to preheat the airspace inside the store due to the fact that the thermal effect from the heating elements is observed immediately after being switched on.

1 Introduction

The process of maintaining the transport-technological machines in a technically sound condition during operation, as well as during storage, is a complex

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engineering task, the successful solution of which allows for a long period of efficient use of equipment. As practice shows, during the entire period of operation, destructive processes of various nature occur in the design of the machine. The causes of these processes may be due to changes in the geometry of the car body and other structural elements, the destruction of threaded and welded joints of parts and the effect of atmospheric corrosion on metal surfaces of machines. A characteristic feature of the operation of agricultural technological machines is the cyclical nature of their use, when they are used with a high degree of load for a short period and are stored in closed rooms or on specially equipped sites for the rest of the time. The closed method of storing agricultural machinery is more efficient than the open one, but it involves high material costs [1] for the construction of garages and hangars, as well as operating costs for maintaining them in good condition. For this reason, agricultural producers are forced to use open paved areas for off-season storage of equipment, but in this case, it is necessary to carry out a set of additional organizational and technical measures aimed at preventing the negative impact of the environment on structural elements of machines.

The authors of [1] propose to use the entire volume of the enclosed space for storing the equipment. For this purpose, the equipment is to be placed on three levels. At the first lower level, it is advisable to arrange power equipment. The second level includes small-sized agricultural machinery - cultivators, seeders and machines for plant protection. It is formed using L-shaped platforms controlled by four-link mechanisms attached to the front wall and lifting agricultural machines mounted on platforms. At the third level, containers with spare parts for machines are suspended with the help of brackets. This solution suits for storing technological machines and equipment of small size and weight, while placing in the garage, for example, a combine harvester, will not allow to set additional levels above it. As it has already been mentioned above, agricultural machinery as well as others are stored in most cases in open areas where they are exposed to destructive effects of atmospheric factors [2]. During such storage, a thin film of moisture, caused by temperature changes during the day or precipitation, is often formed on the surface of machines. The presence of moisture on metal structural elements of machines leads to the appearance of sites of corrosion damage, especially in those places where the paintwork has defects. The processes of atmospheric corrosion are also common for various types of joints of metal parts of machines (threaded, welded, etc.), because water droplets easily penetrate between mating elements of machines, and their removal or drying takes a longer time than on open surfaces. The atmospheric corrosion of metal structures represents one of the most severe forms of corrosion, resulting in huge economic and structural performance losses [3].

To prevent corrosion of metal in a case of an open storage method, the authors of [4] propose the use of oil-based preservation materials, which have shown high efficiency in protecting metal surfaces even at high concentrations of SO₂ in the atmosphere. The corrosion inhibitors considered in [5] also provide reliable protection against atmospheric corrosion. The volatile corrosion inhibitor IFKhAN-114 effectively suppresses the local corrosion of carbon steel under atmospheric conditions at a concentration of stimulating micro impurities in air (ammonia, hydrogen sulphide, carbon dioxide) many times exceeding background values [6]. The possibility of using corrosion inhibitors to protect ferrous and non-ferrous metals is also considered in [7-10].

Both the manual method and the application of anticorrosive material by a mechanized method using some special equipment are used for laying preservative coatings on the treated surface of agricultural machinery [11]. Currently, the industry produces a wide range of such equipment, which differs mainly in function. The authors in [12] consider the design of the installation for the preparation and deposition of protective material on the treated surface, which includes an indirect heating system of the lubricant by an induction heater. The use of this installation will reduce the specific energy consumption when preparing protective composite materials.

The analysis of literary sources showed that conservation materials are widely used to reduce the corrosion losses of metal structural elements of machines for various purposes during storage. However, this method of protection requires re-conservation of machines, as otherwise, the chemical components of the protective compounds when flushed with rainwater fall into the soil and pollute the environment. Consequently, the material costs of anticorrosion measures also increase.

In this work, it is proposed to consider the possibility of using a new method of protecting the technological equipment from corrosion damage during storage in open areas.

2 Objects and Methods

A characteristic feature of the operation of machinery engaged in agricultural production is its short repeated and intensive use with the upcoming long-term storage [13]. During long-term storage, the machine is actually under the influence of meteorological conditions prevailing for a given area (solar radiation, temperature and humidity, wind and precipitation) [14]. Such conditions significantly affect changes in the physico-chemical properties of structural materials (wood, metal, textiles, rubber, leather, plastic, etc.), worsening their performance.

The surrounding atmosphere is a permanent carrier of corrosive agents. In general, it includes atmospheric air, consisting of atoms of oxygen, hydrogen, carbon dioxide and inert gases, water vapor, as well as aerosols of sea salts, industrial gases and solid particles (dust). Almost all atmospheric components affect corrosion. The gas composition of air at the surface of the earth is relatively constant. The content of moisture and various impurities in it can vary within wide limits. Not all impurities in the atmosphere are equally corrosive, but they can enhance each other's actions. Water and oxygen have the greatest impact on corrosion processes.

Chemical corrosion in dry air occurs due to oxidation of metals by oxygen and this process proceeds slowly. An increase in relative humidity leads to atmospheric (electrochemical) corrosion. Its development begins with a relative humidity of more than 60%, since only in this case sharp fluctuations in air temperature lead to dew drops on the surface of the part (electrolyte formation).

Oxygen has a significant effect on atmospheric corrosion. Its concentration in the electrolyte and diffusion conditions become the most important factors determining the rate of atmospheric corrosion. In addition, it must be borne in mind that destruction is observed first in areas of metal to which oxygen access is difficult. That is why corrosion occurs under dirt, in areas of poorly made welds, etc. Various

salts from seas and oceans enter the atmosphere and increase the electrical conductivity of the electrolyte films, thereby increasing the rate of atmospheric corrosion.

A significant impact on the intensification of corrosion processes is exerted by industrial gases, where SO₂ is the most dangerous gas. The presence in the atmosphere of even a small amount of sulfur dioxide increases the corrosion rate by 10 times. The intensity of corrosion increases if the surface of the part is covered with dust. Solid dust particles settling on metal surfaces contribute to formation of a moisture film, as a result of which the corrosion rate increases.

The rate of atmospheric corrosion also depends on temperature. At a low temperature, corrosion practically stops, and with an increase in temperature it increases by 1-3% per degree.

Atmosphere also has an adverse effect on non-metallic materials (textiles, rubber, plastic, coatings) in the process of storing machines.

Rubber products change their properties to the greatest extent [15]. Rubber aging occurs as a result of oxidation. The aging rate of rubber products greatly depends on temperature and solar radiation [16].

Plastic materials age under the influence of the same factors. As a result of aging, there is a change in the mass and size of parts, deterioration of the dielectric property and strength. This is the main reason for the loss of functionality of electronic devices.

The main reasons for the destruction of paints and varnishes are the ultraviolet part of the spectrum of solar radiation and atmospheric moisture. The destruction of painted surfaces occurs due to a decrease in the quality of the film itself and as a result of the destructive effect of metal corrosion products under painting.

The main type of destruction of metal parts is electrochemical corrosion. It takes place when an electrolyte is formed on the surface of parts, anode and cathode sections in the form of tiny droplets of atmospheric moisture. Anode and cathode sections on the surface of the part arise not only due to the contact of different materials, but also the unequal degree of surface treatment of the same part, different tolerance of oxygen to the surfaces. In other words, micro-galvanic vapors occur almost everywhere where there are water droplets on the metal.

The results of analytical studies show a steady increase in the number of agricultural machines having various kinds of failures and malfunctions. An analysis of the causes of failures and malfunctions of parts and components of equipment that fail during storage showed that they are caused by both the low quality of the work performed to prepare the machine for storage and the climate and its components. Climate is understood as a multi-year regime of weather observed in a particular area. It depends on the geographical latitude of the terrain, the general circulation of the atmosphere (cyclones, anticyclones, etc.), altitude, the protection of the terrain by mountains, and the distance from the sea or ocean. The climate is characterized by solar radiation, temperature and humidity, wind and precipitation. Each of these climate factors is estimated by the annual and daily course of indicators in a separate or integrated form, as well as by the probability of recurrence of certain weather events over a certain period. The most dangerous climate factors affecting the reliability of parts and assemblies of machine objects are solar radiation, precipitation and dew. Storage in a closed room, under a canopy or a protective cover can fully or partially protect the machine from exposure to solar

radiation or precipitation, but will not be able to protect against dew on the surface of the machine.

Due to air cooling, water vapor condenses on objects near the earth and turns into water droplets. When the sun heat in the form of sunlight ceases to enter the near-Earth space, the surface of the earth cools quickly. In this case, sufficiently strong cooling of the lower layers of air occurs. At this moment, thermal energy is radiated by any heated body, depending on the density. In this case, the radiating bodies are cooled. An agricultural machine, being a denser body, cools more intensively than the surrounding air. However, when the temperature difference on its surface and the surrounding air drops below the dew point, water vapor saturation occurs and dew drops appear on the surface of the machine. Dew is observed in the evening, night and morning hours. In this case, it is necessary to create conditions when the cooling rate of the surface of the machine would be equal to or less than the cooling rate of air. It is possible to achieve such results by installing a barrier for heat transfer from one body to another in the form of thermal energy of the beam.

In the laboratory of Ryazan State Agrotechnological University, a device was developed for storing agricultural machinery in an open area under a protective thermal shield [17,18].

The proposed device (Figure 1) is a storage, the walls and the roof of which are made in the form of heat-reflecting screen 4, mounted on frame 1. The heat-reflecting screen has the shape of a dome, which consists of parts 5 and 6. Two parts of the dome are interconnected using a special quick coupler. Metal hinges 7 are fixed along the edge of the first part of dome 5, and rectangular holes 8 are made along the edge of the second part of dome 6.

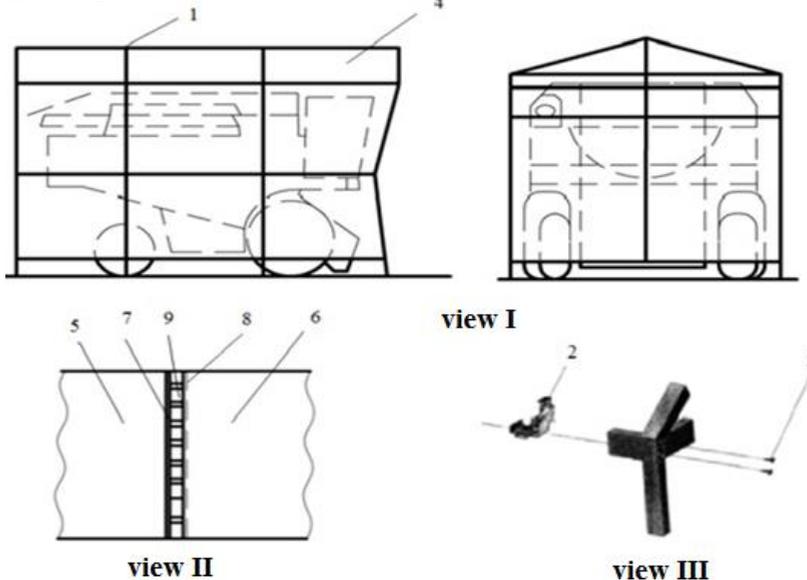


Fig. 1. A device for storing agricultural machinery in an open area under a protective thermal shield. I – general view of the device for storing equipment; II – fragment of quick disconnect coupling; III - profile connection node with single-level connectors; 1 – cage; 2 – single-level connector; 3 – fasteners; 4 – heat-reflective screen; 5 and 6 – the first and second parts of the dome, respectively; 7 – metal hinges; 8 – rectangular holes; 9 – wire cable

When applying the edge of the second part of the dome to the edge of the first part of the dome, the hinges pass through the holes of a rectangular shape. Then, wire cable 9 is threaded through hinges projected above edges of the second part of the dome. As a result of this connection of the two parts of the dome, a heat-reflective screen of a given shape and size is formed. The cage consists of metal profiles. The profiles are connected to each other using single-level connector 2 and fasteners 3.

The heat-reflective screen is made by combining a heat insulator based on foamed polyethylene with a double-sided coating of aluminum foil. This material prevents the transfer of heat from one body to another in the form of thermal energy of the beam, and also prevents the penetration of moisture, while protecting the insulated machine from rainfall. Between the surface of the storage site and the lower edges of the heat-reflective screen of the store there is a gap for natural ventilation, which avoids dew on the surface of the insulated object when changing weather conditions. An air space is created inside the store between the heat-reflective screen and the machine.

With this storage method, the transfer of thermal energy from the environment to the machine can be carried out in three ways: through the thermal conductivity of the medium, through convection and through radiation. In this case, the transfer of internal energy is possible with unevenly heated parts of the insulated object, depending on the ambient temperature. A convection method of heat transfer is possible with a sufficiently large amount of air space, since the air moves between the heat-reflective screen and the machine in the air. The transfer of environmental heat in the form of thermal energy of the beam through the heat-reflective screen in this case is eliminated or insignificant. Due to this, heating and cooling of the agricultural machine takes place for a long time, which helps to avoid dew on its surface

The fact that the cooling rate of the protected machine must be equal to or less than the cooling rate of the air inside the storage is an important condition for this method of storage. Compliance with this condition will prevent dew both on the inner surface of the heat-reflective screen and the surface of the machine. However, with sharp fluctuations in the ambient air temperature, there is a high probability of dew both on the inner surface of the heat-reflective screen and the surface of the object. In this case, this storage will not be able to provide adequate protection for the machine during long-term storage. Elimination of this disadvantage can be achieved by installing heating elements inside the storage, the use of which will allow to respond to changes in meteorological conditions quickly and timely.

3 Experimental part

Given the prospects of operating the device an experimental design of an active heat-reflective screen is proposed for long-term storage of agricultural machinery in an open area under a protective thermal shield.

The purpose of the design solution is to reduce the cost of maintaining the function of agricultural machinery, and therefore, ensuring its reliable safety from environmental influences for the entire storage period. To do this, the device for storage in an open area under a protective thermal shield is equipped with heating

elements that provide a stream of infrared radiation in the mid-wave range of the spectrum with a wavelength of $\lambda = 5\text{-}20\ \mu\text{m}$.

The experimental design of the active heat-reflective screen (Figure 2) is a storage, the walls and roof of which are made in the form of heat-reflective screen 2, mounted on cage 1. Heating elements 3 are installed in a certain sequence inside the storage, in the airspace between the heat-reflective screen and the protected machine. *V*

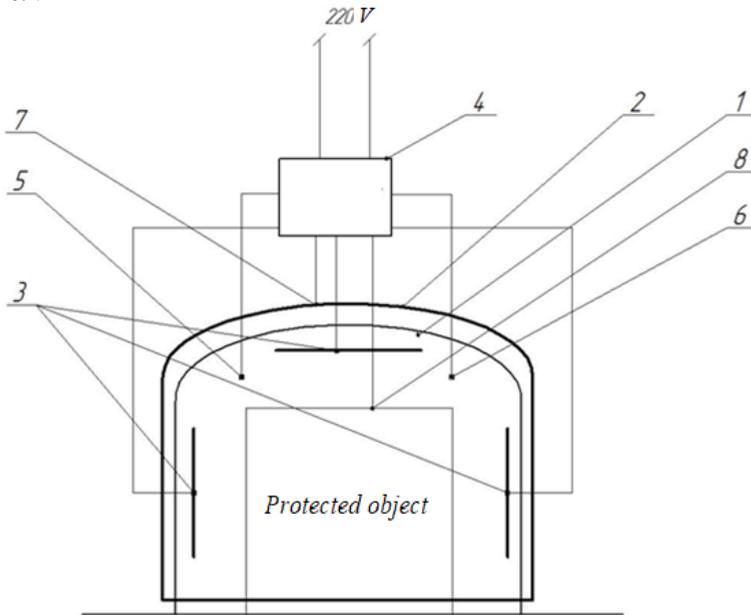


Fig. 2. Experimental design of an active heat-reflective screen. 1 – cage; 2 – heat-reflective screen; 3 – heating components; 4 – microclimate control device; 5 – electronic sensor to monitor air temperature inside the storage; 6 – electronic humidity control sensor inside the storage; 7 – electronic sensor to monitor the temperature of the inner surface of the heat-reflective screen; 8 – electronic sensor to monitor the surface temperature of an agricultural machine.

The heating elements are connected to special measuring device 4, which controls the microclimate parameters. The device is equipped with the following measuring instruments: an electronic sensor to control air temperature inside the store 5, an electronic sensor to control air humidity inside the store 6, an electronic sensor to control the temperature of the heat-reflective screen 7 and an electronic sensor to control the temperature of the surface of the stored object 8.

The heating elements are controlled, namely, turned on or off, by measuring device 4. Having analyzed the readings of electronic sensors for monitoring temperature and air humidity inside the store, the temperature of the internal surface of the heat-reflective screen and the surface of the protected object, the device determines the moment of the dew point, i.e. such a temperature when vapor in the air becomes saturated.

A positive effect when using the considered design of the active heat-reflective screen is achieved as follows. With increasing probability of dew, heating elements are switched on, which provide a infrared radiation flux in the mid-wave range of

the spectrum with a wavelength of $\lambda = 5\text{-}20\ \mu\text{m}$. Radiant energy, falling on the inner surface of the heat-reflective screen and the surface of the protected object, is absorbed by them within the limits of visibility and, turning into thermal energy, heats them. After that, the principle of convection comes into effect, namely, the heated surfaces of the heat-reflective screen and the machine transfer their heat to the air inside the storehouse, which eliminates dew drops, both on the inner surface of the heat-reflective screen and on the surface of the protected object itself. In addition, this heating principle is more uniform than that of conventional convection systems.

Since air is an optically transparent medium, it becomes possible to heat the internal surface of the heat-reflective screen and the surface of the machine without heating the entire volume of air space inside the store. In addition, the thermal effect of the heating elements is observed immediately after switching on, which avoids the preliminary heating the air inside the store.

Thus, this experimental design of an active heat-reflective screen makes possible to respond to changes in microclimatic conditions quickly and timely, which will ensure the safety of the agricultural machine from the negative effects of the environment during the entire period of long-term storage.

4 Results

To confirm the theoretical research, preliminary tests of the experimental design of the active heat-reflective screen were carried out. A combine harvester of S 300 "Nova" brand was stored under an active thermal cover. As a result of the tests, it was found that the application of the proposed design of the active heat-reflective screen allows to ensure reliable safety of the combine, eliminates the dew on its surface during sharp fluctuations in ambient temperature, including those in the morning and evening. The effectiveness of the experimental design of the active heat-reflective screen device will be maximum at positive air temperature. At low temperature, the probability of dew is extremely small, so the operation of heating elements is not required. The installed power of the heating elements is 130 W. The average monthly energy consumption for the entire storage period was 12.86 kWh with an active thermal shield of 10 m³. As a result, the costs of maintaining the function of the combine decreased by 10-15%.

5 Conclusion

The use of the designed active heat-reflective screen allows to obtain the following technical and economic indicators:

1. the heat-reflective screen has low thermal conductivity, prevents moisture, solar radiation and thermal radiation;
2. the screen eliminates dew on the surface of the machine during sudden fluctuations in ambient temperature;
3. the possibility of local heating of the inner surface of the heat-reflective screen and the surface of the machine without heating the entire volume of air space inside the storehouse can significantly reduce the cost of electric energy;
4. there is no need for pre-heating the air inside the store due to the fact that the thermal effect from the heating elements is observed immediately after switching on.

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