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Development of Modern Production Prototypes of Wide-Coverage Sprinkler Irrigation Equipment

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***Abstract*: Creating effective irrigation systems requires solving the dialectic problem: selecting high-performance equipment and irrigation technology that takes into account the rational water and energy use requirements and maximum adaptation to the region of their application ensuring environmental safety, preserving and increasing the fertility of irrigated soils. The fundamental is the principle of maximum adaptation of sprinkling equipment to specific soil, climatic and relief conditions, taking into account the environmental indicators acceptable for a particular landscape.**

In the period from 2015, development work on the reconstruction of domestic wide-coverage sprinklers in the Russian Federation was resumed. Over this short period, a number of companies went from developing working design documentation for prototype models of preproduction series of sprinkler machines to conducting state acceptance tests confirming the status of a Russian manufacturer to their active introduction in irrigated areas of domestic agricultural producers.

When developing a number of models of sprinkler machines, the FSBI All-Russian Research Institute "Raduga" took an active part in their designing and in experimental work, development of technical documentation and support for conducting state tests; they are that were considered in this article.

All samples were developed on the basis of the conditions of compliance with modern agrotechnical requirements, namely, when watering, artificial precipitation should form in its structure close to natural rains with a droplet diameter of 0.8-1.2 mm and an intensity of up to 0.25 mm / min. with a uniform distribution over area not less than 0.8.

Testing of the samples was carried out by the Federal State Institution "Vladimir State Zone Machine Testing Station" in accordance with " STO AIST 11.1-2010. Sprinkling machines and installations. Methods for assessing functional indicators", and also related standard and regulatory documents. The tests passed allowed us to obtain positive protocols of state acceptance tests with recommendations on putting in serial production or putting in production after implementing the corrections.

Key words: wide-coverage-sprinkler irrigation machines, design documentation, tests, protocol, sprinkling, modernization

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I. INTRODUCTION

The irrigation technique and technology have a decisive influence on the quality of water distribution and regulation of the water regime in a soil, and consequently, crop productivity, efficient use of water, soil and climatic, material and technical and energy resources, and ecological state of the environment.

The main criterion for irrigation equipment and technologies, the main purpose of which is to obtain guaranteed yields in areas of insufficient and unstable watering regardless of weather conditions, is the absence of reduced productivity of the irrigated area and the prevention of environmental pollution and degradation of soil fertility.

The insufficiently high agroecological quality of rain leads to a decrease in irrigation efficiency due to water loss to surface runoff, the development of irrigation erosion, and a decrease in soil fertility. Therefore, one of the factors for the implementation of water-saving irrigation technologies is to ensure high agro-ecological quality of rain by improving the technical means of irrigation.

The purpose of the research and production activity of the Federal State Budgetary Scientific Institution Al-Russian Research Institute "Raduga" is to conduct priority applied research and development for the engineering system of the land reclamation industry in the agricultural sector of the Russian Federation, aimed at creating and introducing new, environmentally friendly technologies, irrigation equipment, agricultural water supply, and new types of irrigation equipment for the reconstruction and operation of hydro land reclaiming systems.

The purpose of the development work is to develop, in accordance with the customer's technical specifications, irrigation equipment models of new generation and design documentation for them that will ensure the efficient use of the natural resource potential of reclaimed land, increase the operational reliability and energy efficiency of hydro land reclaiming systems, reduce capital and operating costs, and also rational use of material and technical resources.

The scientific novelty of the work is the justification and development of engineering solutions, design and technological documentation for resource-saving and environmentally friendly sprinkling equipment of a new generation ensuring the efficient use of the natural resource potential of reclaimed land, increasing the operational reliability and energy efficiency of hydro land reclaiming systems, reducing capital and operational costs, rational use of material and technical resources.

II. RESULTS AND DISCUSSION

For the period from 2015 to 2018, the specialists of the Federal State Scientific Institution All-Russian Research Institute "Raduga" took a direct part in the development of design, operational, technical and technological documentation, as well as in the preparation and support of state testing of prototype models of sprinkler machines:

- In 2015 - Modernized sprinkler machine MDM - B409 Fregat-3;
- In 2017 - Electrified sprinkling circular machine MDEC "Aquarius A";

In this paper we will focus on the modernized MDM - B409 Fregat-3 sprinkler machine which passed tests in 2015 (Figure 1).

The modernization of the machine consisted in equipping it with an additional pipeline supplying the hydraulic drives of the bogies (Figure 2). This allows the machine to ensure the movement without watering and reduce the total pressure at the inlet.

The machine was equipped with simple and reliable due to its design sectorial action sprinkler nozzles as rain-forming devices (Figure 3a).

Tests of the MDM - B409 "Fregat-3" were held from 23.09 to 06.10 of 2015 on the lands of Novikov peasant farm enterprise of the village Verkhnie Belozerki, Stavropolsky District, Samara Region, in irrigation of perennial grasses of a cultural pasture, protocol No. 03-28-15 (9030046) dated October 6, 2015.

The manufacturer of the machine is LLC “BSG”, Tolyatti, Stavropol district, Samara region

The organization that submitted the machine for testing is the Federal State Scientific Institution All-Russian Research Institute “Raduga", Kolomna, Moscow region

Tests were conducted on the compliance of the machine with the requirements of the technical conditions TU RAMP 2712410447 approved by the director of BSG LLC N.V. Lysov 09/03/2015 according to the working program methodology approved by the director of the FSBI "Vladimir MIS" Yu.A. Matvienko on 09/23/2015.

Sprinkling machine “Fregat-3” MDM-B409 (hereinafter referred to as MDM “Fregat-3”) with pipelines with a diameter of 177.8 mm and 152 mm and with an additional polyethylene pipe with a diameter of 63 mm (Figure 1-2) is designed for irrigation with sprinkling of grain, vegetable and industrial crops, perennial grasses and pastures, as well as other crops, including tall-stalked plants.

The MDM Fregat-3 automated self-moving sprinkler irrigates around a fixed support; water is taken from the hydrant of a closed irrigation network with water being supplied from an open reservoir by a pump station or a well.

MDM "Fregat-3" (Figure 1) consists of a fixed support, water and supply pipelines, supporting bogies, as well as aggregates, mechanisms and systems, control devices that ensure the functional purpose of the machine.

The main structural differences of the presented model from the same modification DMU "Fregat" are as follows:

– The availability of two pipelines: a water supply pipeline - serves to supply water to rain-forming devices, and an additional pipeline which serves to power the hydraulic drive of the machine and ensures its movement around the site without watering.

The technological process of the MDM "Fregat-3" is as follows. Force-fed water from a closed irrigation network or well enters through a filter and a central support pipeline into a water supply pipeline and then to rain - forming devices. At the same time, water from the central support pipeline enters an additional polyethylene hydraulic drive pipe to move the machine in a circle. The process of irrigation with the MDM Fregat-3 sprinkler machine is automated and can be carried out around the clock without the presence of an operator mechanic. The machine provides a wide range of irrigation rates in almost any soil and climate areas.

The amount of actions by the operator-mechanic is reduced to setting the irrigation rate, periodically monitoring the operation of the machine, troubleshooting, and performing maintenance.

When using the machine, special field planning is not required: the maximum allowable slope of the field surface along the length of the machine is from +0.038 to -0.05.

The arrangement of rain - forming devices eliminates their manual adjustment. The irrigation rate varies depending on the speed of movement of the last bogie by adjusting the flow area of the setpoint crane.

The organization of work on preparing the Fregat-3 MDM for operation consists in starting up a pumping station and supplying water to a sprinkler and an additional polyethylene hydraulic pipeline.

Figure 1 - General view of the "Fregat-3" DM-B409

Figure 2 - General view of the

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water supply and additional pipelines "Fregat-3" DM-B409 Tests of the Fregat-3 MDM-B409 sprinkler were carried out in Novikov peasant farm in the village of Verkhnye Belozerki, Stavropol district, Samara region, on irrigation of the field after harvesting; the conditions met the technical requirements.

By an agrotechnical assessment, it was established that MDM Fregat-3 performs the technological process at the irrigation mode of 367 m ^{3} at a water flow rate of 64.63 l / s with quality indicators corresponding to the technical specifications.

According to the results of the operational and technological assessment, the machine, under economic conditions, reliably and with sufficient quality performs the technological process at the irrigation mode of 367 m ^{3} at a water flow rate of 64.63 l / s (according to TU 65l / s). The water pressure at the inlet of the machine and on the last bogie was 0.4 and 0.3 MPa, respectively. Productivity obtained for 1 h of the main time was 0.63 ha. The effective supply ratio was 0.74 (not less than 0.7 according to TU), the land use coefficient of the irrigated area was 0.999 (according to TU not less than 0.98).

For the entire period of testing, there was not noted any technical failures in the sprinkler machine MDM-B409.

Daily maintenance mainly consists of visual monitoring of the irrigation quality and the operation of components and parts of the machine.

When calculating the economic assessment, the following data were obtained:

– Labour costs for irrigating 1 ha amounted to 1.64 man-hours, provided that an operator serviced one sprinkler;

– Prime cost of performing mechanized work was in the amount of 1466.24 roubles / ha, including 22.2% - the labour cost; 57.6% - depreciation expenses; 20.2% - the cost of repair and maintenance of the machine.

However, provided that one operator serves three to four sprinklers, as recommended in TU, labour costs can be reduced by 67% –75%, and the cost of irrigation by 15% –17%.

Sprinkler machine "Fregat-3" MDM-B409 has the following advantages:

– Availability of two separate pipelines - supply and additional, which allows the machine to move across the field without watering by supplying water to the hydraulic drives of the bogies;

– Low rain intensity obtained from 0.14 to 0.16 mm / min.; this characterizes rain as sparing the soil;

– Simplicity and reliability of the rain-forming devices design in contrast to sprinkler devices.

However, it should be noted that in this arrangement of rain-forming devices, as well as in the Fregat machines previously manufactured in series, the most dangerous area in relation to the formation of surface drains and irrigation erosion is the area located at the rear of the water supply pipeline. The reason is that in this place the sprinklers (especially the sprinklers of the 3rd and 4th series) have, along with increased water flow, an increased nozzle diameter. These nozzles form coarse rain ($d_{average}$ << 2.0 mm) and, together with overfilling, cause a decrease in soil strength characteristics compared to its value in the initial part of the machine for light soils up to 50%.

According to studies, to reduce the degree of impact of rain on the bearing properties of soils during their irrigation, optimization of such its characteristics as the sufficient irrigation rate before runoff and runoff value was carried out.

Given the above, as well as using theoretical and experimental research by B.M. Lebedev, A.P. Isaev, N.S. Erkhov et al., 5 sprinkler arrangement schemes were developed at the All-Russian Research Institute "Raduga" for various soil-relief and natural-climatic conditions. They were based on the installation in the rear part of sprinkler machines of their low-consumption modifications with an increase in the number of sprinklers.

For example, the calculations made it possible to establish that for heavy soils (by the criterion of water permeability) and large slopes of irrigated areas in order to reduce the impact of rain (reduce the diameter of the droplets), and also, based on the possibility of reducing the pressure at the entrance to the machine, especially for a flat terrain, it is recommended to install low-consumption less energy-intensive sprinklers of series No. 2 with a spacing of 2.6 m in the rear part of the machine, in a section of 1/6 - 1/8 of its total length. (Figure 3b)

In general, to ensure energy-saving water and soil-saving and erosion-safe irrigation technologies for circular sprinkling machine, the following soil-friendly sprinkler placement schemes are justified and recommended for their equipping.

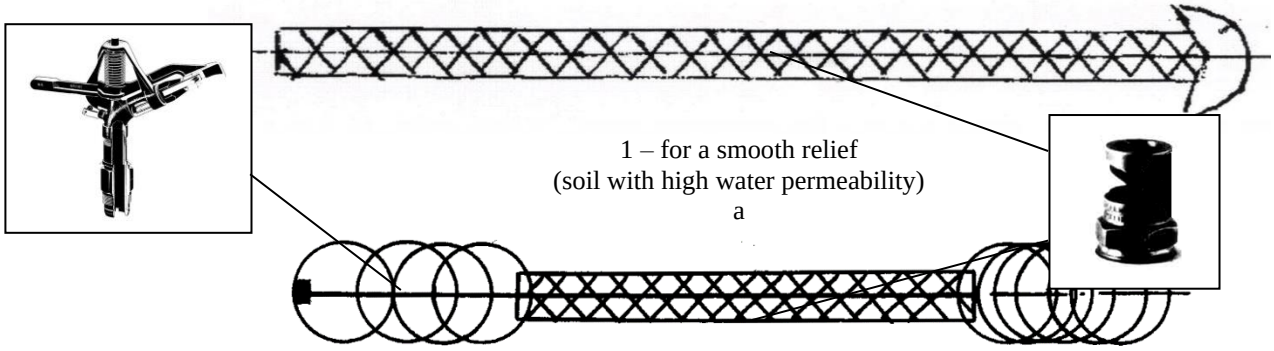
Scheme 1 (Figure 3a) based on economic considerations (reducing the cost of the machine and less demanding on the quality of the rain) low-intensity short-jet nozzles are installed along the entire length of the machine for a quiet terrain and high water permeability soils,.

Scheme 2 (Figure 3b) for a smooth relief and all types of soils, sprinklers are installed in the front part of the machine (series No. I) and more often (series No. 2) in its rear part, and short-bladed nozzles are installed between them.

Scheme 3 (Figure 3c) for slopes of up to 0.05 and soils with high water permeability, sprinkling apparatuses of series No. 1, 2 and 3 are sparsely installed along the length of the machine (serial scheme for previously produced Fregats)

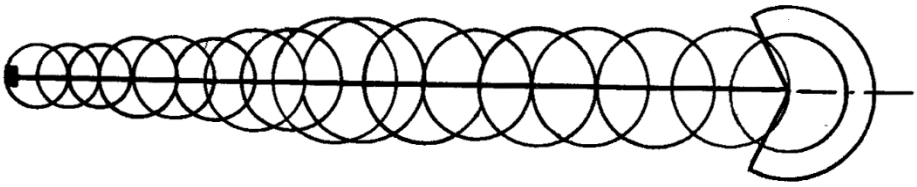
Scheme 4 (Figure 3d) for slopes of up to 0.05 and soils with low permeability, devices of the series No. 1 and 2 are sparsely installed in the front part along the length of the machine, and at the rear, more often, only devices of the series No. 2 are installed.

Scheme 5 (Figure 3D) for slopes of up to 0.07 and all types of soils, the same sprinkler arrangement is recommended as in the previous version, but for machine lengths of not more than 300 m and their low-consumption modifications, without a rear sprinkler.

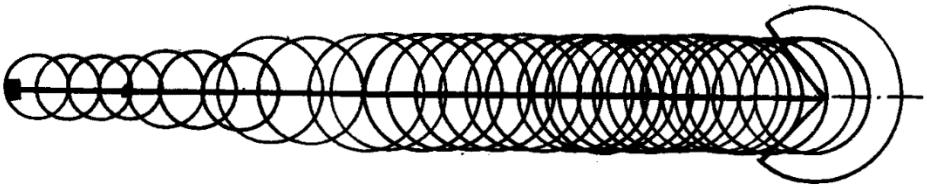


1 – for a smooth relief
(soil with high water permeability)
a

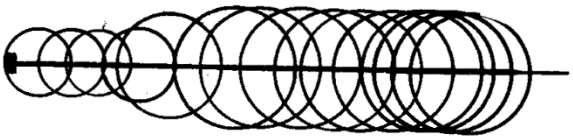
2 – for a smooth relief (all types of soil)
b



3 – for slopes up to 0.05 (soil with high permeability)
c



4 – for slopes up to 0.05 (soil with low permeability)
d



5 – for slopes up to 0.07 (all soil types)
e

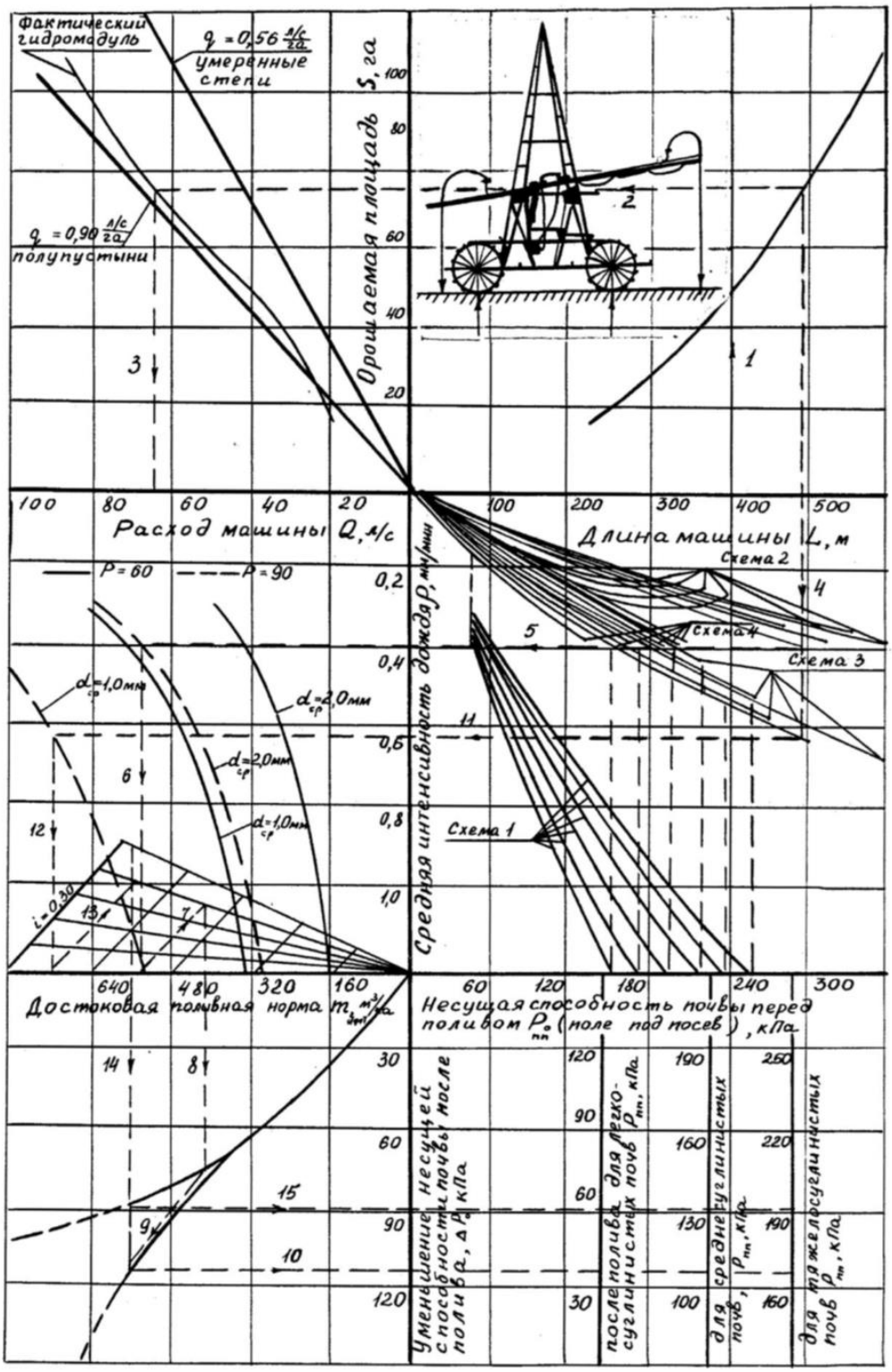


Figure 4. Nomogram for assessing the effective influence of rain-forming device arrangement on the reliability of wide-coverage sprinkler movement

To exclude fluctuations in water flow rate in a sprinkler machine on a challenging terrain, the arrangement of rain-forming devices was calculated taking into account the increase in water pressure in the pipeline on a flat terrain up to the pressure at the inlet of the sprinkler machine with a positive slope. Comprehensive results of theoretical and experimental studies of the regime and quality of irrigation by the sprinkler machine, as well as strength indicators of soils, formed the basis for building the nomogram (Figure 4). On the basis of the established irrigation regime, the selected parameters of the machine's water supply pipeline and sprinkler arrangements, for a corresponding type of soil and agricultural background, it allows to roughly determine the load bearing capacity of the irrigated surface along the length of the machine depending on irrigation rates and machine flow rate, and ultimately, the permissible pressure of the running systems on it.

And on the contrary, after determining the necessary values of the bearing capacity of the soil along the path of the bogies, it is possible to optimize the water supply pipeline parameters, choose a rational arrangement of sprinklers, as well as the necessary technology and irrigation mode. The procedure for using the nomogram n is shown by dashed lines: 1-2-3-4-5-6-7-8-8-10-10: determining the bearing capacity of the soil under the machine with a serial sprinkler arrangement (2); 1-2-3-4-5-9-10-11-12-13-13-14: the same without the presence of runoff (scheme 3). The slope of the field is 0.06.

As an analysis of the data shows, equipping the machines with improved arrangements and types of sprinklers depending on soil and relief conditions generally made it possible, in comparison with the previously recommended design (3), to reduce the impact irrigation rate for all conditions by reducing rain impact on the soil and, accordingly, to reduce the amount of runoff, especially in the rear part of the machine, on average for the entire range of soil conditions from 25 to 5%.

The bearing capacity value under the last spans for basic modifications of the sprinkler machine (t_e = 600 m3 / ha) on light loamy soils increases from 40 to 60 kPa or 50%, and on medium loamy soils from 107 to 130 kPa or 21.7%. On clay soils, this increase is from 170 to 190 kPa, or 11.7%.

III. CONCLUSION

State tests of the MDM - B409 Fregat-3 conducted with a positive evaluation, taking into account the latest developments for its further improvement, are one of the main steps to achieve the strategic goal of creating an automated, high-performance, environmentally friendly irrigation technique while minimizing the cost of information support, material and technical, energy, water, labour resources, depending on human and climatic factors, and maximizing ergonomic criteria, reliability, controllability, safety, aesthetics, and planning.

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