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Research Article

HYDRODYNAMIC MODEL OF WATERING OF THE FREGAT SPRINKLING SYSTEM EQUIPPED WITH DEFLECTOR NOZZLES

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Abstract:

The FREGAT Sprinkling System is the main sprinkling system in Russia, and in the Volga region region. Design data of this system constantly changed in the course of its long-term operation, as well as in result of new watering technologies and constructive decisions introduction into production that led to divergences in comparison with technical parameters of watering. There was a need for developing hydrodynamic model of the FREGAT DMU-463-90 system performance allowing to make numerical experiments and to receive technical characteristics of watering for the sprinkling systems which underwent modernization. Theoretical researches on determining parameters of creating hydrodynamic model of the sprinkling system were conducted; the model of the linear system of water use on length of the sprinkling system is created and the modes of optimum work the deflection nozzles are considered. The admissible norm of watering by overhead irrigation of sandy loam soils and the scheme of a complete set of the FREGAT Sprinkling System deflection nozzles for VOLZHNIGIM design is defined.

Keywords: sprinkling system, irrigation norm, hydrodynamic model, water consumption, pressure loss, deflection nozzle.

1. Introduction

The basic operation purpose of the sprinkling system is to supply the irrigating water to an agrophytotsenozis and its transfer to a condition of soil humidity in volume of the meeting optimum irrigation standard which size has to be less than erosive admissible irrigation norm. The FREGAT Sprinkling System came in use in the beginning of the 70th years of the last century and is till present the main sprinkling system in a meliorative complex of Russia and in the Volga region region, in particular. During this time the basic design of the sprinkling system (SS) was improved and changed manufacturer. Also design data of the sprinkling systems and in the course of their long-term operation, after performing out repair work and introduction in production of new watering technologies and constructive decisions changed. As a result, technical characteristics of the system which is in process of its long-term operation significantly change in comparison with the technical parameters of watering declared in the certificate at its acquisition [1,2,3,4]. Developing hydrodynamic model of work of the sprinkling system "FREGAT" DMU-463-90 allowing to make numerical experiments and to receive technical characteristics of watering for the sprinkling systems which underwent modernization is urgent now.

2. Research Methods

2.1 Research of conditions of creating hydrodynamic model

The main technological objective facing the sprinkling system – distribution of irrigating water across the field, and distribution has to be characterized by creating the irrigation mode of the agricultural field with the set irrigation norm and with the set watering duration. Each sprinkling system has the, design data defining its control for irrigation norm and for duration of performing out watering [5,6,7]. Therefore the hydrodynamic model of the sprinkling system determines first of all the parameters proceeding from the size of irrigation norm, at the same time the volume of water supply by the sprinkling system (SS) will be equal (m^3):

$$W_i = mA_i = \frac{m\pi R_j^2}{10000}, \qquad (1)$$

where: W_i – the volume of water supply SS for watering at i quantity of self-moving support; m – size of irrigation norm, m^3/he A_i - the area of watering SS, at quantity of support ($i = s$) and quantity deflection nozzles ($j = k$), he R_j - radius of watering SS, m.

The important criterion defining operation of the machine is traveling speed of the system. The system moves cyclically, and traveling speed is expressed as (m/hour):

$$V = 60 \cdot n, \qquad (2)$$

where: n – number of steps of the course of a hydraulic cylinder in a minute.

The watering duration (hour) at the whole revolution SS on one position counted through quantity of steps of a hydraulic cylinder is equal:

$$T = \frac{Z_i}{60n}, \qquad (3)$$

where: T – watering duration at the whole revolution SS with the given traveling speed of the system (V); Zi – total of steps of a hydraulic cylinder (i) – oh a self-propelled support, at the whole revolution SS of "FREGAT" is determined by dependence

$$Z_i = \frac{L_i}{l}, \qquad (4)$$

l - step of driving of the system at one step of a hydraulic cylinder, l = 0,16 m; n – traveling speed SS of "FREGAT", steps/mines; L_i – length of a way of the movement (m) i self-propelled support on a circle with a radius Ro, at the whole revolution of the system, is defined:

$$L_i = 2 \cdot \pi \cdot Ro_i, \qquad (5)$$

The water volume relation by the time of its giving is water discharge size. The water discharge of the sprinkling system (p/a) for watering of a crop irrigation norm (m) is determined by dependence:

$$Q_i = \frac{W_i}{3,6T}, \qquad (6)$$

where: Q_i – expense of the sprinkling system for an area irrigation A_i, p/a.

Having substituted giving volume size in expression (6) (W_i), from dependence (1) and having expressed duration of watering (T), through dependence (3, 4, 5) we will receive more complete and developed expression:

$$Q_i = \frac{\pi m R_j^2}{3,6 \cdot 10000} \cdot \frac{60nl}{2\pi \cdot Ro_i} = 1,333 \cdot 10^{-4} \cdot (nm) \frac{R_j^2}{Ro_i} \qquad (7)$$

For the FREGAT system, on its design and running characteristics, the work of number of steps (courses) of a hydraulic cylinder of the last system in a minute on the irrigation norm given at this speed, is a stationary value for this design, on condition of constant head of water on a hydrant [8].

Value of a constant can be defined by field researches by measurement of traveling speed of the last system, size of "FREGAT" of irrigation norm and head of water given to SS on a hydrant of connection SS.

2.2 Work research deflection nozzles

Value of a water discharge in the water conductive pipeline of the sprinkling system changes longwise its pipeline. The main part of a water discharge leaves on watering through deflection nozzles, and a small part of water works well together through hydraulic cylinders of self-propelled support.

Required water discharge for nozzle j the having area of watering in the form of the ring formed by concentric circles of the maximal radiuses of an irrigation zone the deflection nozzles R_j and R_{j-1}, it is possible to define, using expression (7) in a look:

$$Q_j = 1,333 \cdot 10^{-4} \cdot nm \; \frac{(R_j^2 - R_{j-1}^2)}{Ro_i} \qquad (8)$$

Passing to the following sprinkler towards the fixed support it is possible to write down:

$$Q_{j-1} = 1{,}333 \cdot 10^{-4} \cdot nm \ \frac{(R_{j-1}^2 - R_{j-2}^2)}{Ro_i} \qquad (9)$$

The water discharge necessary for work of hydraulic cylinders changes longwise the sprinkling system. The expense depends on traveling speed of the system (n, steps/mines) and therefore on total of steps of hydraulic cylinders (Z_i, step) at the whole revolution of the system, volume of the building bag of a hydraulic cylinder (V, l) and locations of an action longwise for FREGAT SS concerning a hydrant [9,10]. Calculated dependence have an appearance:

- for the last self-driving support (p/a):

$$q_i = \phi_i \cdot \frac{n \cdot V}{60}, \qquad (10)$$

where ϕ_i - the reduction coefficient characterizing intensity of change (decrease) of volume of water delivery for work of hydraulic cylinders of self-driving support longwise by DM:

$$\phi_i = \frac{Z_i}{Z_i}, \quad \phi_{i-1} = \frac{Z_{i-1}}{Z_i}, \quad \phi_{i-2} = \frac{Z_{i-2}}{Z_i} \ \ldots \ \phi_1 = \frac{Z_1}{Z_i}, \qquad (11)$$

- a water discharge for a hydraulic cylinder of a penultimate self-driving support (p/a):

$$q_{i-1} = \phi_{i-1} \cdot \frac{n \cdot V}{60}, \qquad (12)$$

Longwise of the sprinkling system we form model of the linear system of water discharges, starting with the last j of a deflection nozzle and moving radially to the fixed support. A water discharge in a water conductive belt in a calculated point consist of a transit water discharge on sprinkler, a water discharge on a deflection nozzle or a water discharge on a hydraulic cylinder:

$$\sum Q_{\text{дм}} = Q_{tr} + \sum_{j=1}^{j=k} Q_j + \sum_{i=1}^{i=s} Q_i =$$

$$= Q_{tr} + 1{,}333 \cdot 10^{-4} \cdot nm \frac{\sum_{j=k}^{j=1} (R_j^2 - R_{j-1}^2)}{Ro_{i=s}} + \frac{n \cdot V \cdot (Z_i + Z_{i-1} + \ldots + Z_1)}{60 \cdot Z_{i=s}} \qquad (13)$$

Pressure loss of water in the pipeline of the sprinkling system consist of losses longwise and local pressure loss. The SS water conductive belt is split on (*k* + *s*) sites. Each site has the hydraulic parameters ($v_{j,i}$, $\square_{j,i}$, $l_{j,i}$, $d_{1,2}$) and the size of pressure loss on each site is determined by dependence:

$$h_{\partial л,ji} = \frac{\lambda_{ji} \cdot l_{ji} \cdot v_{ji}^2}{d_{1,2} \cdot 2g}, \qquad (14)$$

where $h_{\partial л,ji}$ – water pressure loss longwise pipeline, m; l_{ji} – length of the pipeline, m; $d_{1,2}$ – diameter of the pipeline, m; g – free fall acceleration, m/s^2; v_{ji} - driving of water in the pipeline which is determined by a formula:

$$v_{ji} = \frac{Q_{дм}}{0{,}785 \cdot d_{1,2}{}^2}, \qquad (15)$$

Re_{ji} - coefficient of a hydraulic sliding friction. The coefficient of a hydraulic sliding friction for pipes with the uniform roughness is determined by A. D. Altshul's formula:

$$\lambda_{ji} = 0{,}11\left(\frac{\Delta_э}{d_{1,2}} + \frac{68}{Re_{ji}}\right)^{0,25} \qquad (16)$$

where $\Delta_э$ – the equivalent roughness of pipes or height of ledges of an equigranular roughness, mm. For steel galvanized pipes $\Delta_э$=0,15 mm, for polyethylene $\Delta_э$ = 0,065 mm; Re_{ji} – the Reynolds number, is equal:

$$Re_{ji} = \frac{v_{ji} \cdot d_{1,2}}{v'} \qquad (17)$$

where v' – kinematic coefficient of viscosity of the liquid, for water having temperature 18 ^oC: V'=0,01 cm^2/s.

Local pressure loss arise on the 11th self-moving support at change of diameter of the SS water conductive belt. The dependence considering pressure loss when narrowing a pipe has an appearance:

$$h_{м,i} = \left(\frac{1}{d_2^2 / d^2} - 1\right)^2 * \frac{v_{ji}^2}{2g}, \qquad (18)$$

Total losses of pressure (mHg) in the SS water conductive belt will be determined by dependence:

$$h_{общ,ji} = h_{м.,i} + h_{дл,ji}, \qquad (19)$$

Knowing design characteristics of the SS water conductive elements and an algorithm of calculation of the hydraulic parameters shown in expressions (14-19) it is possible to receive the characteristic of change of head of water in the SS water conductive belt on the site, from the fixed support to the last sprinkler of the SS located in console part (m):

$$H_{ji} = H_{св} - h_{общ,ji}, \qquad (20)$$

where H_{ji} – head of water in the SS water conductive belt, MPa.

The expense of sprinkling nozzle (p/a) depends on jet size of a nozzle, water pressure at the exit, before a nozzle and design features of a sprinkler and is determined by a formula [9,13]:

$$q_j = \mu \cdot \omega \cdot \left(2 \cdot g \cdot H_{и,j}\right)^{0,5}, \qquad (21)$$

where q_j – expense of a deflection nozzle; g – free fall acceleration; ω_∂ – clear area of a nozzle; μ – coefficient of discharge, with an average $\mu = 0,87$, expression (21) takes a form [9]:

$$q_j = \frac{D_{\partial,j}^2 \cdot H_{u,j}^2}{330}, \qquad (22)$$

where $D_{\partial,j}$ – diameter of nozzle opening j of a deflection nozzle SS, mm; $H_{u,j}$ – head of water at the exit before j a deflection nozzle, is defined using an empirical-formula dependence [9,11], ratios of head of water in the SS water conductive belt and head of water before a sprinkler, (mCE):

$$H_{u,j} = H_{ji} / (0,2258 \left(\frac{10 \cdot \omega_н}{\omega_\partial} \right)^{0,68} \cdot \left(\frac{D_{cm,j}}{D_{\partial,j}} \right)^{0,456} \left(0,1 \cdot H_{ji} \right)^{0,15}), \qquad (23)$$

where $\omega_н$ – area of a nozzle; $D_{cm,j}$ – caliber of an adjusting nozzle, $D_{cm,j}$ =18 mm.

The established principal specifications defining the SS duty need to be checked for quality of a simulated rain, to estimate its structure and to compare to admissible parameters.

Average intensity of a rain (mm/min.) is determined by a formula:

$$\rho_{cp,j} = \frac{60 \cdot q_j \cdot K_П}{\pi \cdot Rd_j^2} = \frac{19,1 \cdot q_j \cdot K_П}{Rd_j^2}, \qquad (24)$$

where $K_П$ – the nozzle stream overlapping coefficient, is determined by dependence:

$$K_П = \frac{Rd_j}{0,5 \cdot l_{н,j}} \qquad (25)$$

where $l_{н,j}$ – distance between nozzles, m; Rd_j – capture radius rain of a deflection nozzle, m. At installation of a nozzle at the height of 2,0 m from the surface of the soil, the radius of capture (m) is equal [6,7]:

$$Rd_j = H_{u,j} \left(0,728 + 0,742 \cdot H_{u,j} / D_{\partial,j} \right), \qquad (26)$$

3. Results

Optimum norms of watering are established by their minimization without decrease in productivity of crops. The main methods of decrease of water giving were: differentiation of a calculated layer, differentiation of irrigation norm during vegetation of cultures [12].

The admissible norm of watering at a way of watering by overhead irrigation depends not only on water physical properties of the soil, on its blotting capacity taking into account a relief and biases of a surface of the raflux field, an agrohum noise, but also on technology of watering, i.e. on intensity and structure of a rain. Erosion admissible or pre-nozzle irrigation norm can be established on dependence [12]:

$$m_{\partial,j} = \frac{K_v}{\sqrt{\rho_{cp,j}} \cdot \ell^{0,5-dk_{cp,j}}}, \qquad (27)$$

where $m_{\partial,j}$ – pre-drain irrigation norm, mm; K_v – index of the free free-flow absorption of water to the soil, mm. For sandy loam and sandy soils an index K_v makes 61... 90 mm, for the mid-loamy 31... 60, and for the high-loamy 21... 30 mm; $\rho_{cp,j}$ - average intensity of a rain under this j a deflection nozzle SS, mm/min.; $dk_{cp,j}$ - effective diameter of drops of a cumulonimbus cloud of educated j deflection nozzle SS, mm; e - basis of natural logarithm equal 2,71828.

The size of drops of a rain the deflection nozzles is established by jet size (nozzle) and a pressure at the stream exit. Effective diameter of drops of a rain the deflection nozzles increases with increase in the relative radius of flight of drops *(X_i/Rd_j)*, jet size and with decrease of pressure [9]:

$$dk_{cp,j} = dk_{\min,j} \cdot X_i / Rd_j \cdot \left(dk_{\max,j} - dk_{\min,j}\right) \cdot e^{-0,757(1-X_i/Rd_j)}, \qquad (28)$$

where X_i - radius of flight of a drop from a deflection nozzle, m; $dk_{max,j}$ - maximal diameter of drops of a cumulonimbus cloud of educated j deflection nozzle SS, mm; $dk_{min,j}$ - minimum diameter of drops of a cumulonimbus cloud of educated j deflection nozzle SS, mm;

Minimum and maximal diameter of drops at the beginning and the end of radius of coverage a rain of a nozzle depends on diameter of a nozzle *($D_{\partial,j}$)* and pressure *($H_{u,j}$) also are defined by the equations [9]:*

$$dk_{\max,j} = 1,558 \cdot H_{u,j}^{-0,358} \cdot D_{\partial,j}^{-0,490}, \qquad (29)$$

$$dk_{\min,j} = 0,274 \cdot H_{u,j}^{0,5397} \cdot D_{\partial,j}^{-1,07}, \qquad (30)$$

By calculations it is defined that the complete set of the FREGAT Sprinkling System deflection nozzles for VOLZHNIGIM design (figure 1) according to the following scheme is necessary for watering of sandy loam soils: No. 4 – 1 piece, No. 6 – 7 pieces, No. 8 – 10 pieces, No. 10 – 9 pieces, No. 12 – 9 pieces, No. 14 – 10 pieces, No. 16 – 2 pieces.

4. Discussion

Watering on the site of an irrigation is carried out by the FREGAT Sprinkling System, the cultivated crop – corn on grain, a soil cover – dark-chestnut soils sandy loam, the index of the free free-flow absorption of water to the soil makes 80 mm, irrigation norm 500 m^3/he

Modernization needs to be carried out by the complete replacement of the sprinkling devices on deflection nozzles for VOLZHNIGIM design. Brand of the modernized FREGAT system - DMU-B-463-90. A system expense – 90 p/a, head of water on a connection hydrant – 0,60 MPas. The water conductive belt consists of two sites, one from the fixed support to the 11th self-moving support has diameter of 177,8 mm, the second site from the 11th support to a console part – 152,4 mm. The coefficient of roughness for a galvanized pipe after several years of operation is equal to 0,50. Sprinkling devices No. 1 … No. 4 – 50 pieces, the size of their physical wear – 100%.

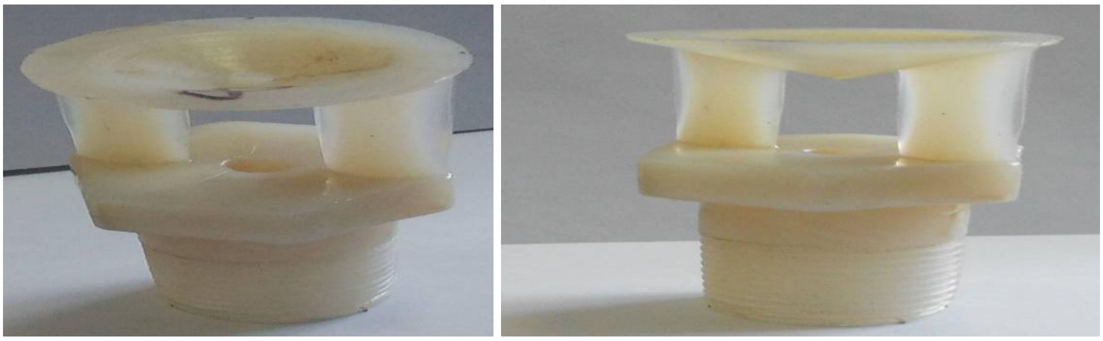

Fig. (1). Deflection nozzles for VOLZHNIGIM design

5. Conclusion

The developed hydrodynamic model for the basic FREGAT Sprinkling System allows to determine hydraulically dependent design data and to estimate admissible irrigation norm.

For watering of sandy loam soils it is necessary FREGAT systems deflection nozzles for VOLZHNIGIM design according to the following scheme: No. 4 – 1 piece, No. 6 – 7 pieces, No. 8 – 10 pieces, No. 10 – 9 pieces, No. 12 – 9 pieces, No. 14 – 10 pieces, No. 16 – 2 pieces.

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