New Formula for Strength Calculation of Pressure Fire Hoses under Intrinsic Hydraulic Pressure

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Abstract: *Considered purpose, the device of pressure fire hoses, conditions of their operation are considered, a brief analysis of the publications on their project name the calculation of the hydraulic impact of the identified achievements in the field of their calculation and design, in particular on the basis of the nonlinear theory of calculation of single-layer fabrics of plain weave obtained a new formula relating the breaking strength of the internal hydraulic pressure in the fire sleeve tensile load in the weft yarn and a number of other parameters. The resulting formula is the basis of the developed technique of calculation and rational designing of pressure fire hoses, allowing to carry out an important step in the manufacture of new pressure fire hoses, namely, perform strength calculation and to choose the rational parameters of woven reinforcing carcass sleeve.*

Keywords: *structural shell fire hose, internal hydraulic pressure, the breaking strength of the weft threads.*

I. INTRODUCTION

One of the primary means of fire extinguishing are pressure fire hoses, which are flexible pipelines used to supply water and aqueous foam with hydrogen index pH = 7÷10 at the distance under pressure. The main element pressure fire hose, perceiving the internal pressure of the liquid, is a reinforcing frame, which is a woven carrier shell. An important parameter characterizing the strength of the pressure of fire hoses, burst pressure is the fluid pressure inside the fire hose (MPa), wherein the reinforcing frame is destroyed. The calculation of the strength of fire hoses mainly to the calculation of the strength of their woven carrier shell. Analysis of bearing shells pressure fire hoses most manufacturers (Russian Federation, People's Republic of China, Republic of India, etc.) showed that most of them consist of single layer of fabrics of plain weave. In this case the length of fire hose are the main strands, which are mutually interwoven with the weft yarns lay on its circumference.

II. MATERIAL AND METHODS

Most global manufacturers make pressure fire hoses of three types: 1) rubber covered, only the inside layer of rubber, when vulcanized to a fabric sleeve; 2) double-side coating when the layer of rubber fire hose covered both outside and inside; 3) latex-treated, covered inside and outside with a layer of latex. Such design of pressure fire hoses gives the grounds to carry these products to composite materials.

Pressure fire hose with its technical parameters must meet the requirements for the inner diameter, the sleeve length in the roll, working, test and bursting pressure, temperature embrittlement coating for moderate and cold climate, the strength of the inner layer of the coating to the fabric frame with the gap (for sleeves with single and double sided coating), the relative elongation of the sleeve at the working pressure relative to the increased diameter of the sleeve, the abrasive wear resistance, resistance to contact burn sleeves, ground sleeves of 1 m the thickness of the inner layer of the coating. Sleeves of all types must be sealed for operating and testing hydraulic pressure, i.e., not to pass water.

At operation pressure fire hoses are exposed to a mechanical wear, influence of low and high temperatures, action of sunshine, an irreversible process of an aging of material, casual hit on them reactive substances. For this reason increased requirements which have to have the high durability, resilience to an abrasive attrition, rather high temperature of melting, firmness at effect of reactive substances are imposed to material of synthetic threads of pressure fire hoses. Most global manufacturers make pressure fire hoses of the polyester threads on the basis of poly (ethylene terephthalate) (PETF) having slight removability, excellent sacred and the atmospheres firmness, rather high durability and melting point, good resistance to organic solvents.

For creation of hi-tech pressure fire hoses besides perfecting of technology of their receiving, the choice of material of synthetic threads development and deepening of the theory of calculation and projection of fire hoses at hydraulic influence which, certainly, will be demanded during the calculating and design of new types of pressure fire hoses, and also for identification of the reasons of their gap at fire extinguishing is important.

Let's carry out the short analysis of the most significant publications according to the theory of calculation and projection of pressure fire hoses at hydraulic influence.

In article [1] on the basis of the non-linear theory of calculation of single-texture fabrics of a calico weave [2] the theoretical bases of strength calculation of pressure fire hoses at hydraulic influence including system of assumptions at the solution of a task, the calculated and mathematical models of a structure of fabric of the bearing envelope of a sleeve which are base for development of a technique of strength calculation and projection of pressure fire hoses are developed. However the mathematical model received in article [1] is quite bulky, has no analytical decision, and its numerical decision is complicated by methods of a direct integration. In this regard in the publication [3] the task of simplification of the mathematical model of a structure of fabric of the bearing envelope of a pressure fire hose received in article [1] and obtaining dependences for strength calculation of the bearing envelope of a pressure fire hose at hydraulic influence is set and solved.

In work [4] the task of check of reliability of theoretical provisions and a formula (37) [3] for strength calculation of pressure fire hoses at hydraulic influence by comparison of calculation data on the explosive pressure received on the basis of this formula, and the existing experimental data is set and solved. In these publication dependences of size of explosive pressure on explosive effort of a filling, diameters of threads, geometrical density on a basis and a filling of the bearing woven envelope of pressure fire hoses and other factors are received.

Authors of works [1], [3], [4] made an essential contribution to development of the theory, a calculation procedure and projection of pressure fire hoses. However some provisions of these works, in our opinion, are not deprived also shortcomings. So, authors at a research of interaction of threads in the woven bearing envelope of a sleeve enter an assumption that contact arch length between the main and weft threads for a filling is equal in calculated model to diameter of a core thread. Authors accept a similar assumption also for a filling, namely: contact arch length between a weft and warp yarn for a piece of a basis is equal in calculated model to diameter of a filling [3]. On the basis of these assumptions, and also some other, authors also developed theoretical bases for calculation of pressure fire hoses, and, in particular, the ratio (37) [3] is received. These assumptions for strands are in our opinion insufficiently proved and led to a noticeable divergence on the explosive pressure calculated by a formula (37) [3] with the experimental values of explosive pressure the latex-treated of pressure fire hoses of production of a science and production association "BEREG" (Russian Federation) (this divergence made for sleeves of diameters of 77 mm, 66 mm, 51 mm about 10%) (See [5], tab. 10.2, p. 425-426). It is possible to confirm or disprove reliability of these assumptions only as a result of the pilot study of zones of contact of threads in a pressure fire hose that [1], [3], [4] was not done by authors.

In addition, in [3] it is insufficiently proved, in our opinion, length of the deformed axis of a core thread (a curvilinear piece of thread in a woven framework of a pressure fire hose the close to a sine curve) with a straight line - a triangle hypotenuse is replaced that can also lead to decrease in accuracy of calculations for a formula (37) [3]. At the same time the error of such approach by authors does not miscalculate.

It is also necessary to note that unlike the majority of other fabrics of technical purpose of fabric of the bearing envelopes of the pressure fire hoses which are under the influence of intrinsic hydraulic pressure work in more intense conditions. Because of action of intrinsic hydraulic pressure weft and core threads of the woven bearing envelope of a pressure fire hose perceive tensile strains, larger in size, which can reach several tens or even hundreds of newton's. At the same time between threads there are larger forces of the relative pressure which lead to the strong bearing strain of threads in the radial direction.

In work [4] when checking reliability of theoretical provisions and formulas (37) [3] for strength calculation of pressure fire hoses at hydraulic influence and obtaining dependence of size of explosive pressure on a number of parameters coefficients of a radial bearing strain of the main and a filling of fabrics of the bearing envelopes the latex-treated pressure fire hoses of all diameters taken equal to 0.5.

It is necessary to agree with conclusions of authors of works [4], [5] about complexity of determination of sizes of a vertical bearing strain of threads of a basis and filling of the woven bearing envelopes of fire hoses at the time of a gap. In our opinion, it is a problem of extreme complexity and at this level of development of measuring technique it is hardly solvable. However we consider that with the larger forces of the relative pressure between threads and the strong bearing strain of threads in the radial direction for a long time permanent deformations become dominating, and the role of a resilient component which disappears after unloading in a share of the common deformation is not considerable. Therefore more precise determination of coefficients of a vertical bearing strain of threads of a basis and filling with their subsequent use in formulas by strength calculation of pressure fire hoses expediently can also lead to increase in accuracy of calculations.

III. RESULT OF DISCUSSION

On the basis of the non-linear theory of calculation of single-texture fabrics of a calico weave [2] we received the new formula for calculation of explosive intrinsic hydraulic pressure in a fire hose considering actual lengths of arches of contact between the main and weft threads, the actual sizes of coefficients of a vertical bearing strain of threads of a basis and filling in pressure fire hoses of various diameters, length of the deformed axis of a core thread (a curvilinear piece of thread, the close to a sine curve), the Formula has the following appearance:

$$p_{разр} = \frac{2N_{разр}L_o}{R\left\{L_y(2L_o - \beta_o d_o) + L_o\left[2\left(L_y^2 + (d_o\eta_{OB} + d_y\eta_{YB})^2\right)^{\frac{1}{2}} + \frac{0{,}212\cdot L_Y^2(d_o\eta_{OB} + d_y\eta_{YB})^2}{\left(L_y^2 + (d_o\eta_{OB} + d_y\eta_{YB})^2\right)^{\frac{3}{2}}} - \beta_y d_y\right]\right\}}, \quad (1)$$

where N_{burst} –in weft yarn tension at break;
P_{burst} –burst internal hydraulic pressure in a fire hose;
R - radius of the fire hose;
L_{warp},L_{weft} - geometric density, respectively warp and weft woven carrier shell of a fire hose;
d_{warp}, d_{weft}, η_{warp} η_{weft}- respectively diameters of warp and weft yarns in woven carrier shell of a fire hose and the coefficients of the vertical collapse;
β_{warp} , β_{weft} - coefficients characterizing the length of the contact zone between the yarns.

Calculations for a formula (1) taking into account the values of lengths of arches of contact found experimentally between the main and weft threads, sizes of coefficients of a vertical bearing strain of threads of a basis and filling yield significantly more precise results on explosive pressure in fire pressure hoses in comparison with a formula (37) [3].

The explosive pressure determined by a formula (1) is one of the most important strength parameters of the pressure fire hoses at hydraulic influence regulated by standards on fire hoses. Explosive pressure characterizes durability of fire hoses, that is their ability to resist a gap from the hydraulic pressure operating in fire hoses.

The resulting formula is the basis of methods of strength calculation and design of pressure fire hose with the specified characteristics strength by a pressure impact, which define the parameters of the fire hose and assessed the influence of various factors on its durability.

IV. CONCLUSION

1. The new formula for calculation of explosive internal hydraulic pressure in a fire hose considering besides other parameters actual lengths of arches of contact between the main and weft threads, the actual sizes of coefficients vertical a shear of threads of a basis and a duck in pressure head fire hoses of various diameters, and also close to actual length of the deformed axis of the main thread is received.
2. Calculations for the received formula with found experimentally values of parameters yield significantly more exact results on explosive pressure in pressure head fire hoses in comparison with formulas of other authors.
3. The received formula is the basis for a technique of strength calculation and design of a pressure head fire hose with the set characteristics of durability at action of internal hydraulic pressure.

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