Determination of mechanical characteristics of stuffing box packings

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Abstract. The resource of stuffing box seal is determined not only by the unit design and by the conditions of its operation, but also essentially depends on the correct choice of stuffing box packing. Not one of stuffing box packing manufacturers does not provide data on mechanical properties. Therefore, in this paper the results of experimental investigations on determining the mechanical properties of packings are presented. The obtaining mechanical characteristics allow to clarify existing methods of calculation and to increase sealing and durability of stuffing box packing seals.

1. Introduction
The braided stuffing box packings impregnated with lubricants are most widely used for sealing of centrifugal pumps for general industrial usage. An important factor affecting the work of stuffing box seal are tribomechanical characteristics of the packing, the account of which affects the seal life. However, none of producers of the packing does not provide data on physical and mechanical properties (elastic modulus and Poisson’s ratio), which are one of the main characteristics and are mandatory in calculating the packing seals.

2. Definition of physical and mechanical properties of the packings
The experimental studies of physical and mechanical properties of the packing were carried out on the rig that described in [1, 4].

In the experiment, a specimen of the stuffing box packing is pressurized three times to determine the effect of pressure testing on physical and mechanical properties of the packing. Before testing the specimen of packing is pressurized with a maximum load, in order to compress the packing by deleting its initial waviness and voids between fibers. After that we apply vertical load $F_y$ to the test specimen of packing gradually increases to a maximum value, varies with a predetermined step. Axial deformation $\Delta_y$ is incremented at each step. The increment of axial deformation $\Delta_x$ can be observed while unloading spring pack by screw. Obtained data define elasticity modulus $E$ and Poisson ratio $\nu$ as the relation of the respective magnitudes of increments [1-6].

The elastic modulus is determined from the ratio
\[
E = \frac{\Delta \sigma_y}{\Delta \varepsilon_y} \tag{1}
\]

where \( \Delta \varepsilon_y = \Delta \varepsilon_x / b_0 \), \( \Delta \sigma_y = \Delta F_y / A_0 \), \( A_0 \) – the cross sectional area of the packing.

Poisson’s ratio is determined by the formula

\[

\nu = \frac{\Delta x}{\Delta y} \tag{2}
\]

Experiments were carried out for various stuffing box packings, such as GAMBIT 608 in size of 10×10 (made of a yarn of fibrous PTFE, filled with graphite and saturated with silicone oil), GAMBIT 6088 in size of 8×8 (made of a yarn of fibrous PTFE, filled with graphite) MS-360 POLMAN in size of 8×8 (interlacing of fibers made of PTFE with graphite and aramid fibers).

The experiments are presented in Figure 1-5. Figures 1-3 are shown dependencies of relative deformation on the axial load of several cyclic loading. On the first loading cycle, the packing compression occurs by filling the voids between the existing warp and partial extrusion of lubricant. It appears residual deformation. On subsequent loading cycles occur only compression of the material and extrusion of impregnation. With increase in load, the packing is strengthened, and its rigidity is increased. As can be seen from these figures the dependence of the relative deformation on applied load under uniaxial stress state is non-linear. Figures 4 and 5 show the dependence of the Poisson ratio on the axial load.

![Figure 1](image)

**Figure 1.** The dependence of the relative deformation on the axial load at several cyclic loadings (GAMBIT 6088 in size of 8×8).
Figure 2. The dependence of the relative deformation on the axial load at several cyclic loadings (GAMBIT 608 in size of 10×10).

Figure 3. The dependence of the relative deformation on the axial load at several cyclic loadings (MS-360 POLMAN in size of 8×8).

Figure 4. The dependence of the Poisson ratio on the axial load (GAMBIT 608 in size of 10×10).
Because the dependence of the elastic modulus and Poisson's ratio on the axial load is not linear, it is necessary to choose an analytic function with sufficient precision approximating the experimental data. Least-squares method (LSM) is used for this purpose.

Tables 1 and 2 show the regression equations derived LSM as well as indexes of correlation.

**Table 1.** The regression equations of relative deformation on the axial load.

| Type of stuffing box packing | Equation of regression | Correlation Index |
|-----------------------------|------------------------|-------------------|
| GAMBIT 6088 in size of 8×8  | \( \varepsilon_y = 0.0007 \cdot \sigma_y^2 + 0.0011 \cdot \sigma_y + 0.0018 \) | 0.9857 |
| GAMBIT 608 in size of 10×10 | \( \varepsilon_y = -0.0057 \cdot \sigma_y^2 + 0.0412 \cdot \sigma_y - 0.001 \) | 0.9963 |
| MS-360 POLMAN in size of 8×8| \( \varepsilon_y = -0.00 \cdot \sigma_y^2 + 0.0147 \cdot \sigma_y \) | 0.9838 |

**Table 2.** The regression equations of Poisson's ratio on the axial load.

| Type of stuffing box packing | Equation of regression | Correlation Index |
|-----------------------------|------------------------|-------------------|
| GAMBIT 608 in size of 10×10 | \( \nu = 0.341 \cdot \sigma_y^{-0.1364} \) | 0.8186 |
| MS-360 POLMAN in size of 8×8| \( \nu = 0.3121 \cdot \sigma_y^{-0.1317} \) | 0.8219 |

3. **Determination of the stuffing box packing roughness**

Stuffing box packing has a braided structure, so by the friction it will have a relief-textured work surface. At that leaks through the seals are defined by microchannels resulting from contact of the surface with support disk. Determination of roughness profile of stuffing box packing using traditional contact method is impossible, since packing has quite a small hardness. Therefore, it is necessary to use modern non-contact optical methods for determining of roughness.
Roughness profile of stuffing box packing (GAMBIT 608 in size of $10 \times 10$) was defined by optical method. Before determining the roughness of a sample of the stuffing box packing was first pressed in order to reduce the impact of packing braided structure, then conducted packing running.

The roughness of the packing was measured using a three-dimensional non-contact profilograph-profilometer.

Figures 6-8 show the results of measuring the roughness profile of the stuffing box packing surface in the design of face packing seal with hydrodynamic unloading of friction pair [5]. Roughness profile of stuffing box packing has a uniform distribution of peaks and valleys. This shows the uniform distribution of the contact pressure over the width of the friction pair and wear of the friction surfaces of the stuffing box packing and the support metal disc.

**Figure 6.** Two-dimensional roughness profile of the stuffing box packing.

**Figure 7.** Three-dimensional roughness profile of the stuffing box packing.

| **ISO 25178** | **Parametry wysokości** |
|---------------|-------------------------|
| $Sq$          | 21.6 $\mu m$            |
| $Ssk$         | 0.0648 $\mu m$          |
| $Sku$         | 2.89 $\mu m$            |
| $Sp$          | 0.13 $\mu m$            |
| $Sv$          | 72.6 $\mu m$            |
| $Sz$          | 154 $\mu m$             |
| $Sa$          | 17.9 $\mu m$            |

**Figure 8.** Parameters of surface roughness of the stuffing box packing.
In Figures 9-11, the results of measurements of the roughness profile of the stuffing box packing in the traditional design of face packing seal are presented [6]. These figures show that the roughness profile is divided into two sections: section with greater roughness corresponding overloaded section of face packing seal and with a function of a sealer, and a section of a lower surface roughness, on which there is no contact between the stuffing box packing and support metal disk.

![Figure 9](image1.png)

**Figure 9.** Two-dimensional roughness profile of the stuffing box packing.

![Figure 10](image2.png)

**Figure 10.** Three-dimensional roughness profile of the stuffing box packing.

| ISO 25178 |  |
|---|---|
| Parametry wysokości |  |
| $S_q$ | 7.21 $\mu$m |
| $S_{sk}$ | 0.203 |
| $S_{ku}$ | 4.50 |
| $S_p$ | 34.3 $\mu$m |
| $S_v$ | 23.0 $\mu$m |
| $S_z$ | 58.2 $\mu$m |
| $S_a$ | 5.41 $\mu$m |

**Figure 11.** Parameters of surface roughness of the stuffing box packing.

The results of measurement of the roughness profile of the stuffing box packing enable us to determine at the stage of calculating the initial gap in the seal (3) [7] needed to solve the problem of elastohydrodynamical lubrication of face packing seal [8]. Roughness value of the stuffing box packing depends on the method of braiding, packing material, impregnation and its physical and mechanical properties.

$$h = 0.5 \left( \frac{R_{max1}}{R_{ail}} + \frac{R_{max2}}{R_{a2}} \right)$$

(3)
4. Conclusions
The results of experimental studies of physical and mechanical properties of the stuffing box packing indicate their non-linearity. The amount of the applied load and the number of loading cycles is significantly affected on the physical and mechanical properties of the stuffing box packing. With increasing load stuffing box packing is strengthened and becomes more rigid. According to the experimental studies physical and mechanical properties of the stuffing box packing stabilized only after the third loading cycle. Nonlinearity of physical-mechanical properties of the stuffing box packing may affect on the results of seal calculation, and consequently, its performance and service life. Obtained empirical relationships make it possible to determine the elastic modulus and Poisson's ratio of the stuffing box packing, depending on the applied load. Therefore, it is necessary that the stuffing box packing manufacturers cited data on modulus elasticity and Poisson's ratio for each type of stuffing box packing, depending on the method of braiding, material, impregnation, and also its size.

Measurement results of the roughness profile of the stuffing box packing provide an opportunity to identify the seal initial gap needed to solve the problem of elastohydrodynamical lubrication of face packing seal. Roughness value of the stuffing box packing depends on the method of braiding, packing material, impregnation and its physical and mechanical properties.

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