Investigation of elastic properties of helical springs of the control unit of the gearbox 25.01-15-20 SB

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Abstract. Paper discusses the elastic properties of helical springs of the control unit of the gearbox 25.01-15-20 SB. During the analysis of the results of the study it was determined that the reason for the failure of the springs was the insufficient difference between the maximum shearing stress and the shearing stress under the working deformation. It was also found that the endurance of the cylindrical springs depends not only on the magnitude of the maximum operating voltage, but also on the amplitude of the oscillations themselves.

1. Introduction
The research of the elastic properties of helical springs of the control unit of the gearbox 25.01-15-20 SB was carried out in two stages. At the first stage, studies were made of the elastic properties of springs in a static mode and resource tests at a fixed vibration frequency. The main studied parameters of the first stage were: compression force under working deformation, tangential stress in spring coils under working deformation, resource by limiting number of deformation cycles before fracture and checking for absence of contact of turns. At the second stage of the study of the elastic properties of springs, the dynamo and phase-frequency characteristics of strain oscillations were removed.

The main studied parameters of the second stage were: compression force and shear stress at working deformation and critical frequency for each type of springs. In the course of the research, regular patterns of regularity that are stable and quantitatively different for each type of springs are found: compression force and shear stress of springs in the static mode are not equal to the compression force and tangential stress in the dynamic mode; each type of spring in the dynamic and phase-frequency characteristics has a critical frequency, which is equal to its own - resonant; the excess of the frequency of vibration of the deformation of the critical frequency causes a sharp increase in the compression force and tangential stress; the critical frequency is a point that divides the characteristics of the graph into two characteristic sections - the range: allowed and forbidden to work.

During the analysis of the results of the study it was determined that the reason for the failure of the springs was the insufficient difference between the maximum shearing stress and the shearing stress under the working deformation. It was also found that the endurance of the cylindrical springs depends not only on the magnitude of the maximum operating voltage, but also on the amplitude of the oscillations themselves. The larger the amplitude of the oscillations at a given value of the maximum voltage, the fewer cycles the spring can withstand.
2. Research Method
A significant number of gearbox failures 25.01-15-20 SB tractor T-330 is associated with premature failure of the helical coil springs of the control unit, i.e. with their breakdown.

To determine the causes of breakage of springs, it was decided to investigate the elastic properties of helical springs in order to determine their reliability and durability (endurance).

The objects of research were screw springs 25.01-15-162 - 6 pcs., 385159 - 6 pcs., 385048 - 6 pcs., 38327 - 6 pcs., 385278 - 6 pcs.

The studies were carried out according to a standard procedure under ambient atmospheric conditions using the PEZ 1449 Schenck hydro-pulsator unit and the PU-61SP device. Examples of calculations of the reliability of various springs are also known [1-5].

Measuring tools, measured parameters and limits of their measurements are presented in Table 1.

| No | Measured parameter | Range measurements | The error required in accordance with GOST 16118-70 | Measuring means used | Measuring range | Error measuring instruments |
|----|-------------------|--------------------|-----------------------------------------------|---------------------|----------------|-----------------------------|
| 1  | Deformation S, mm | 0...60             | ±10%                                          | The "Move" channel of the PEZ 1449 installation | 0...250          | ±1.500                      |
| 2  | Frequency f, Hz   | 0...100            | ±10%                                          | Frequency Counter CH3-33 | 0...10^6        | ±0.010                      |
| 3  | Working hours N, cycle | 0..1.5-1.06   | ±0.01%                                         | The counter of cycles VZ 12 of installation PEZ 1449 Schenck | 0...9.9·10^6    | ±0.001                      |

Determination of the reliability and durability of the helical cylindrical helical springs of the gearbox control unit 25.01-15-20 SB consisted in the investigation of the elastic properties of helical springs in the static (first stage) and dynamics (second stage). Studies on the probabilities of reliability of structural elements with a gradual loss of strength are presented in [6, 7].

3. Results and discussions
At the first stage, studies were made of the elastic properties of springs in a static mode and resource tests at a fixed vibration frequency. Investigated the mechanical properties of helical ceramic springs manufactured from MgO partially stabilized zirconia [8].

The main studied parameters of the first stage were:
a) compression force under working deformation F2 stat;
b) shearing stress in the coils of the spring with working deformation F2 stat;
c) resource according to the limiting number of cycles of deformation before the fracture Npred;
d) check for the absence of contact turns.

At the second stage, studies were made of the elastic properties of helical springs by the method of removing the dynamo-frequency and phase-frequency characteristics of vibration deformation.

The main studied parameters of the second stage were:
a) the force F2 under the working deformation of two components:
- dynamic component of F2 dyne;
- static component of F2 stat;
b) shearing stress τ2 under the working deformation of two components:
- dynamic component;
- static component;
c) the frequency critical for each type of spring fcrit.
The first stage testing program consisted in removing the elastic characteristics for compliance with the requirements of the design documentation and testing the resource in a dynamic mode in the volume of 1500000 cycles.

The test method was supposed to carry out measurements of the compression forces of springs with preliminary and working deformations before the tests for the resource and after.

Criteria for the failure of springs on the elastic characteristics are considered to be: the presence of fractures, cracks, delaminations and deviation of the effort value by more than 10% from the requirements of the drawings of design documentation.

Resource tests were carried out on a hydro pulsatory unit "PEZ 1449 Schenck" with a PU-61SP device with deformation parameters and frequency according to table 2.

| № | Designation of springs | Length of spring L0, mm | Length preliminary deformation L1, mm | Working deformation length L2, mm | Frequency f, Hz | Force at length L3 and L2, H (kgf) |
|---|------------------------|------------------------|--------------------------------------|----------------------------------|----------------|----------------------------------|
| 1 | 25.01-15-162           | 50.5±1.5               | 50.5                                 | 27                               | 15             | 121.0 (12.4)                     |
| 2 | 385159                 | 50.0±1.5               | 5.5                                  | 27                               | 10             | 95.4...120.2 (9.9...12.1)        |
| 3 | 385048                 | 40.0±1.0               | 27.0                                 | 27                               | 20             | 27.4...10.0 (9.7)...9.13         |
| 4 | 38327                  | 54.0±2                 | 36.0                                 | 28                               | 20             | 143.0...188.0 (14.6...19.2)      |
| 5 | 385278                 | 70.0±2                 | 53.0                                 | 45                               | 20             | 269.0...125.4 (27.5)...12.76     |

Tests on the resource were subjected only to those springs that, according to their elastic characteristics, corresponded to the drawings of the design documentation. The most dangerous flaw is the flaw for which the most unfavorable combination of size, location and orientation in the stress field is obtained [9].

The predetermined loading regime ensured that the loops did not collide during the resource tests. The law of oscillation of deformation is sinusoidal for all types of springs. The number of cycles is 1500000 for all types of springs.

During the test, the oscillation amplitude of the deformation of the springs was periodically monitored on an oscilloscope.

Criteria for the failure of springs on tests for the resource is considered to be: the presence of fractures, cracks, delaminations when operating less than 1500000 cycles and the deviation of the values of effort, determined by the elastic characteristics of the requirements given in table 2 by more than ± 10%.

As a detailed derivation of the probability of using, the reader is referred to the literature [10].

The results of spring tests for the resource are given in table 3.

After the springs are tested for life, a second check of their force is made with the working deformation. The springs 25.01-15-162 and 385159 did not survive the endurance test in a given volume of loading cycles (not less than 1500000), their destruction occurred, respectively, at 317970 and 526100 cycles. Metallographic analysis of the material of the destroyed springs showed no signs of decarburization on them. This indicates that the technological process of their heat treatment during manufacture was not violated.

Springs 38327, 385048, 385278 have passed the endurance test in a given volume of not less than 1500000 loading cycles without failure.
Table 3. Results of resource tests of springs of the block of management of a transmission.

| No | Designation of springs | Frequency of cycles, Hz | Amplitude deformation, mm | Working hours, thousand cycles | Availability refusals |
|----|------------------------|-------------------------|---------------------------|--------------------------------|-----------------------|
| 1  | 38327 (3 pcs.)         | 20                      | ±4.0                      | 1500                           | not available         |
| 2  | 385048 (3 pcs.)        | 20                      | ±2.5                      | 1500                           | not available         |
| 3  | 385278 (3 pcs.)        | 20                      | ±4.0                      | 1500                           | not available         |
| 4  | 25.01-15-162 (3 pcs.)  | 15                      | ±11.75                    | 317,970                        | the destruction of one spring (by 1/3 of the length) |
| 5  | 385159 (3 pcs.)        | 10                      | ±11.75                    | 526,100                        | the destruction of one spring (by 1/3 of the length) |

The force value for working deformation in all tested springs corresponds to the requirements of the design documentation, except for springs 385278 - in one spring the force was reduced by 33%.

The main results of the first stage of research:

- the spring resource at a fixed vibration vibration frequency is inversely proportional to the vibration amplitude of the deformation, i.e. The larger the amplitude, the less the resource;
- the spring resource at a fixed frequency is directly proportional to the difference between the maximum shearing stress $\tau_{3\text{ stat}}$ and the working tangential stress $\sigma_{2\text{ stat}}$, the larger the difference, the greater the resource;
- a check for the absence of contact of the turns showed that none of the five types of springs submitted for the study in the frequency range 0 ... 50 Hz does not have contact between the turns (figure 1).

At the second stage of the investigation of the elastic properties of the helical springs of the gearbox control unit 25.01-15-20 SB using the "PEZ 1449 Schenck" hydro-pulsator unit, the dynamo and phase-frequency characteristics of the strain oscillations were removed. As an example, figure 1 shows the dynamo and phase-frequency characteristics of the spring 385159.

In the course of research, regularities that are frequently repeated, stable and quantitatively different for each type of springs are found:

- compression force $F_2\text{ stat}$ and tangential stress $\sigma_2\text{ stat}$ of springs in the static mode are not equal to the compression force $F_2\text{ dyn}$ and tangential stress $\sigma_2\text{ dyn}$ in dynamic mode;
- dynamo-frequency characteristics of springs have a complex form, but they are almost identical for different samples of the same type of springs, and are very different when comparing the characteristics of different types of springs;
- each type of spring in the dynamo- and phase-frequency characteristics has a critical frequency $f_{\text{crit}}$, which is equal to its own - the resonant frequency of the spring and is the point of inflection, the extremum in the characteristics (figure 1a);
- if the oscillation frequency of the deformation of springs $f_{\text{def}}$ is greater than the critical crack frequency, the compression force $F_2$ and the tangential stress $\sigma_2$ sharply increase (figure 1b);
- In addition to increasing the force and stress at precisely this point, a phase shift of 90 degrees occurs between the deformation pulses and the force pulses, namely, the force pulses begin to outrun the deformation pulses by 90 degrees in phase (figure 1).
- The critical frequency is a point dividing the characteristics graphs into two characteristic ranges-the range allowed for operation and the band that is forbidden for operation;
The permitted frequency range for operation is the range of frequencies at which the force and strain pulses coincide in phase and the shear stress $\tau_2$ does not exceed the limiting time.

The frequency range forbidden for operation is the frequency range at which the force pulses advance the deformation pulses.

The permissible voltage is $1170 \ldots 1300$ N / mm$^2$.

**Figure 1.** Dynamo and phase-frequency characteristics of the spring 385159, where

- $a$ is the dependence the dynamic component of the spring from the frequency of the oscillations of the working deformation;
- $b$ is the dependence of the static component of the shear stress of the spring on frequency vibrations of working deformation;
- $c$ is the dependence of the angle of the phase outside shift "deformation-force" from the frequency of vibration of deformation; $R^2$ is the coefficient of reliability of approximation.

Conclusions on the second stage of the study of the elastic properties of helical springs of the gearbox control unit 25.01-15-20 SB:

- The reason for the sharp increase is the advance in the phase of the force with respect to deformation.
- The increase in compression force and tangential stress in the spring turns caused by the operation of springs in the forbidden frequency range became the main causes of the destruction of springs such as 385159, 25.01-15-162 and a significant "shrinkage" in other types of springs due to the compression force for a given strain exiting beyond the tolerance.
limits (table 4). From table 4 it can be seen that all the represented helical springs in the resource tests worked under the conditions of the forbidden frequency range.

- Reduction of the compression force of the springs for a given deformation after the resource tests "shrinkage" was: spring 385278 on average in three samples of 15%, spring 385048 on average 6% (not more than 5%). The reason is that the static component of the shear stress τ stat on the average is 10 times higher than the limiting value 1170 ... 1300 N / mm² (figure 1b).

Thus, the results of the second stage of the investigation of the elastic properties of helical springs of the box control box 25.01-15-20 SB characterize the low information content of the results of the first stage of the study, besides they were obtained in the forbidden frequency range of the oscillations of the working deformation. This explains the failure of springs 25.01-15-162 and 385159 during resource tests, even in the absence of contact of turns.

Table 4. Results of the analysis of the frequency ranges of the operation of springs in resource tests.

| No | Notation springs | Frequency of resource tests, Hz | Frequency of critical frequencies | Frequency bands | Running time in life cycles tests |
|----|------------------|-------------------------------|----------------------------------|----------------|---------------------------------|
| 1  | 385159           | 15                            | 6                                | 0 – 2.5 и 5.5 - 8 | 2.5 – 5.5 и 8 - 50 | 317970 |
| 2  | 25.01-15-162     | 10                            | 6                                | 0 – 2.2 и 3.5 – | 2.2 – 3.5 и 6.5 - | 526100 |
| 3  | 38327            | 20                            | 8                                | 6.5            | 50                             | 1500000 |
| 4  | 385048           | 20                            | 9.2                              | 0 – 9.2        | 9.2 - 50                      | 1500000 |
| 5  | 385278           | 20                            | 7.5                              | 0 – 7.5        | 7.5 - 50                      | 1500000 |

Note: The difference in operating time is explained by the fact that the springs 385159 and 25.01-15-162 were heavily loaded with the destructive dynamic component, since their amplitude of strain oscillations was on the average 5 times greater than in the other springs (table 4).

4. Conclusion
In comparison with the first stage, the second stage of the investigation of the elastic properties of helical springs by the method of removing dynamo-frequency and phase-frequency characteristics at working amplitudes of deformation vibrations is more informative, and allows for each specific operating mode to select the type of coil springs according to dynamic characteristics, does not contain contradictions and disadvantages of the first method and less laborious.

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