ANALELE UNIVERSITĂȚII
"EFTIMIE MURGU" REȘIȚA
ANUL XIII, NR. 1, 2006, ISSN 1453 - 7397

Siniša Kuzmanović, Ružica Trbojević, Milan Rackov

Causes Analyse of Breakages of Foundation Screws

The paper deals with problematic of gear units and machine foundating and consequences that occur by foundation screws releasing. Namely, reliable operating of gear units, as well as other stationary machines, requires properly foundating. However, after certain period of time, relaxation of screw material, self-untightening of nuts and looseness of foundation screws influence on reducing the force of preload screw tightening and unequal load distribution. This unequal load distribution causes unequal deformations, which generate occuring vibrations. In extreme cases, breakages of screws and heavier accidents of systems driven by that gear units or machines can happen. With this paper authors want to indicate influence of deterioration degree on its load capacity.

1. Introduction

Properly foundating of gear units, as well as other stationary machines, is very important for their reliable operating requires. However, after certain period of time, relaxation of screw material, self-untightening of nuts and looseness of foundation screws influence on reducing the force of preload screw tightening and unequal load distribution. This unequal load distribution causes unequal deformations, which generate occuring vibrations. In extreme cases, breakages of screws and heavier accidents of systems driven by that gear units or machines can happen. With this paper authors want to indicate influence of deterioration degree on its load capacity.

2. Problem Description

It is well known that foundation of almost all stationary machines is required for their reliable operating. However, during certain period of time, relaxation of screw material and self-untightening of nuts are occuring which influences that force of preload screw tightening is significantly reduced. Beside this, due to operating forces, foundation screws become more and more loose, which also influences on reducing of preload screw tightening force (Fig. 1).

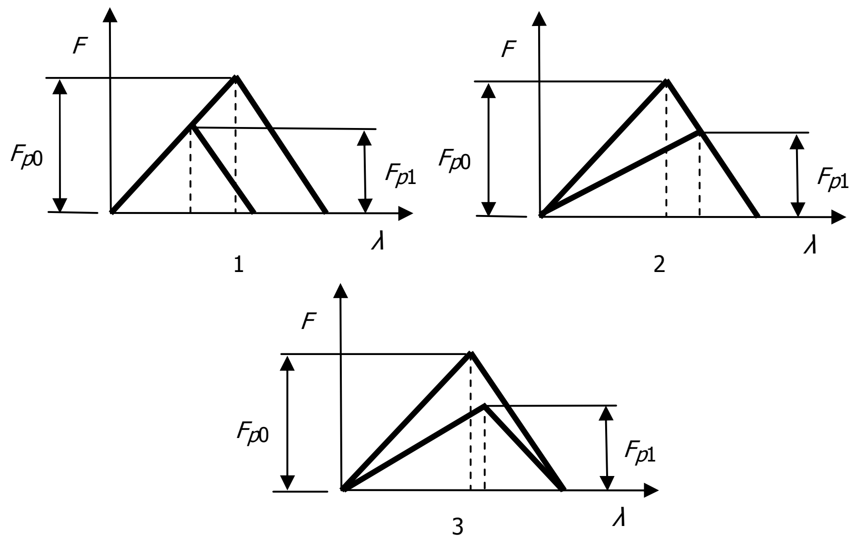

Figure 1. Shematic review of reducing of preload screw tightening force (F_{p1}) due to: (1) material relaxation and self-untightening of nuts, (2) elasticity modifying of screw, (3) elasticity modifying of screw and plates

The example with dimension of foundation screws M30 is discussed. Here, the preload tightening force is calculated:

$$F_{p0} = A_s \cdot \sigma_p = A_s \cdot 0{,}6 \cdot R_{eH} = 561 \cdot 0{,}6 \cdot 240 = 80784 \text{ N} \qquad (1)$$

R_{eH} = 240 N/ mm^2 – yield strength for the material of strength class 4.6 (Č 0370)
A_s = 561 mm^2 – area of cross section of screw dimension M30

When screw becomes loose, its force of preload tightening (F_{p1}) is reduced and can be determined from the condition of equal deformations of screw and plates:

$$\lambda_{z0} + \lambda_{b0} = \lambda_{z1} + \lambda_{b1} \qquad (2)$$

$$\frac{F_{p0}}{c_{z0}} + \frac{F_{p0}}{c_{b0}} = \frac{F_{p1}}{c_{z1}} + \frac{F_{p1}}{c_{b1}} \qquad (3)$$

$$\left(\frac{1}{c_{z0}}+\frac{1}{c_{b0}}\right)F_{p0}=\left(\frac{1}{c_{z1}}+\frac{1}{c_{b1}}\right)F_{p1} \tag{4}$$

$$F_{p1}=\frac{\frac{1}{c_{z0}}+\frac{1}{c_{b0}}}{\frac{1}{c_{z1}}+\frac{1}{c_{b1}}}F_{p0}=\frac{\frac{1}{1{,}828\cdot 10^6}+\frac{1}{4{,}44\cdot 10^6}}{\frac{1}{1{,}167\cdot 10^6}+\frac{1}{0{,}755\cdot 10^6}}\cdot 80784=28600\,\mathrm{N} \tag{5}$$

Overall stiffness of tensile screw (its lenght is l = 60 mm) is calculated from the expression:

$$\frac{1}{c_{z0}}=\frac{1}{c_g}+\frac{1}{c_s}+\frac{1}{c_n}=\frac{1}{2{,}474\cdot 10^6}+\frac{1}{7\cdot 10^6}=\frac{1}{1{,}828\cdot 10^6} \tag{6}$$

$$c_{z0}=1{,}828\cdot 10^6 \tag{7}$$

In this case, stiffness of screw head can be neglected, so that overall screw stiffness is calculated from different parts, as folows:

1. screw shank stiffness:

$$\frac{1}{c_s}=\frac{1}{E_s}\sum_{i=1}^{n}\frac{l_i}{A_i}=\frac{1}{2{,}1\cdot 10^5}\frac{60}{\frac{30^2\pi}{4}}=\frac{1}{2{,}474\cdot 10^6} \tag{8}$$

2. nut stiffness:

$\frac{1}{c_n}=(0{,}95-0{,}8)\frac{1}{Ed}$ for d / P = 6 – 10 (which is the case in this example). (9)

$$\frac{1}{c_n}=0{,}9\frac{1}{2{,}1\cdot 10^5 30}=\frac{1}{7\cdot 10^6} \tag{10}$$

Stiffness of tightened plates can be approximately calculated using expression:

$$c_{bo}=\frac{E_b A_b}{l_b}=\frac{2{,}1\cdot 10^5\cdot 1268{,}12}{60}=4{,}44\cdot 10^6 \tag{11}$$

where, for the approximate calculation (if $l_b < D_0$), although this isn't such case here:

$$A_b=\frac{\left(D^2-D_0^2\right)\pi}{4}=\frac{\left(52^2-33^2\right)\pi}{4}=1268{,}42\ \mathrm{mm}^2 \tag{12}$$

$D = s + l_b / a = s + 0{,}1\ l_b = 46 + 0{,}1 \cdot 60 = 52$ mm
D_0 = 33 mm – hole diameter
s = 46 mm – width across flats of nut
a = 10 – for steel

Stiffness of the relaxed screw (l = 106 mm in the analysed example):

$$\frac{1}{c_{z1}} = \frac{1}{c_g} + \frac{1}{c_s} + \frac{1}{c_n} = \frac{1}{1{,}4 \cdot 10^6} + \frac{1}{7 \cdot 10^6} = \frac{1}{1{,}167 \cdot 10^6} \tag{13}$$

$$c_{z1} = 1{,}167 \cdot 10^6 \tag{14}$$

Stiffness of the screw head can be also neglected, so that overall screw stiffness is calculated from the expressions:

1. screw shank stiffness:

$$\frac{1}{c_s} = \frac{1}{E_s} \sum_{i=1}^{n} \frac{l_i}{A_i} = \frac{1}{2{,}1 \cdot 10^5} \frac{106}{\frac{30^2 \pi}{4}} = \frac{1}{1{,}4 \cdot 10^6} \tag{15}$$

2. nut stiffness:

$$\frac{1}{c_n} = (0{,}95 - 0{,}8)\frac{1}{Ed} \quad \text{for d / P = 6 – 10 (which is such a case here).} \tag{16}$$

$$\frac{1}{c_n} = 0{,}9 \cdot \frac{1}{2{,}1 \cdot 10^5 \cdot 30} = \frac{1}{7 \cdot 10^6} \tag{17}$$

Stiffness of the most relaxated „plate" (in analysed example l_b = 106 mm) can be approximately calculated from two parts (one is screw shank – 60 mm, and the other is in concrete – 46 mm), as folows:

$$\frac{1}{c_{b1}} = \frac{1}{c_{b11}} + \frac{1}{c_{b12}} = \frac{1}{4{,}44 \cdot 10^6} + \frac{1}{0{,}91 \cdot 10^6} = \frac{1}{0{,}755 \cdot 10^6} \tag{18}$$

$$c_{b11} = c_{b0} = 4{,}44 \cdot 10^6 \tag{19}$$

$$c_{b12} = \frac{E_{b2} A_{b2}}{l_{b2}} = \frac{0{,}3 \cdot 10^5 \cdot 1396{,}49}{46} = 0{,}91 \cdot 10^6 \tag{20}$$

$$A_{b2} = \frac{\left(D^2 - D_0^2\right)\pi}{4} = \frac{\left(51{,}75^2 - 30^2\right)\pi}{4} = 1396{,}49 \ \text{mm}^2 \tag{21}$$

$E_{b2} = 0{,}3 \cdot 10^5$ N/mm^2 – elasticity module for concrete
l_{b2} = 106 mm – 60 mm = 46 mm

$D = s + l_{b2} / a = s + 0{,}125\ l_{b2} = 46 + 0{,}125 \cdot 46 = 51{,}75$ mm
D_0 = 30 mm – diameter of hole in concrete
s = 46 mm – width across flats of nut
a = 8 – for concrete

This looseness of foundation screws significantly influences on increasing of their elasticity and on modifying of their loading (Fig. 2) and thus also on their reliability.

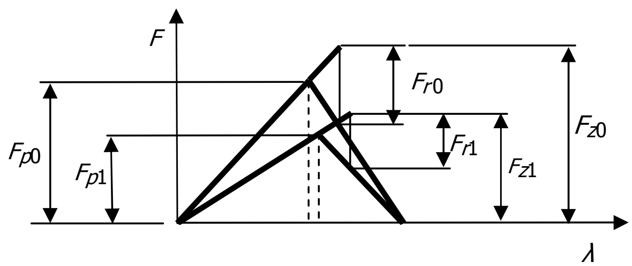

Figure 2. Shematic review of deformations of screws with different elasticity

Theoretically, the bigest alowable operating force of untightened screw is:

$$F_{r0} = \frac{F_{p0}}{\gamma} = \frac{80784}{3} = 26928 \text{ N} \tag{22}$$

where: $\gamma = 2 \div 4$ – coefficient of tightening for variable loading,
it is adopted $\gamma = 3$.
and the bigest alowable operating force of loose screw is:

$$F_{r1} = \frac{F_{p1}}{\gamma} = \frac{28600}{3} = 9533 \text{ N} \tag{23}$$

Since machine or gear units housings are compact, approximately equal additional deformations occur to all screws (Fig. 3). Thus, it follows that screws with biger elasticity are less loaded and receive smaller operating force (F_{r1}).

Because screws have to transmit operating load, and stiffer screws receive biger loading, than it is calculated, which means they are exposed to greater possibility of occuring cracks than untightened elastic screws are.

Since both screws, tightened andf loose, have equal deformations:

$$\Delta\lambda = \Delta\lambda_{z0} = \Delta\lambda_{z1} \tag{24}$$

it follows:

$$\frac{\Delta F_{zo}}{c_{zo}} = \frac{\Delta F_{z1}}{c_{z1}} \tag{25}$$

which can be written and calculated as:

$$\Delta F_{z1} = \frac{c_{z1}}{c_{z0}} \Delta F_{z0} = \frac{1{,}167 \cdot 10^6}{1{,}828 \cdot 10^6} \cdot 7853 = 5013\ \text{N} \tag{26}$$

where:

$$\Delta F_{z0} = \frac{c_{z0}}{c_{z0} + c_{b0}} F_{r0} = \frac{1{,}828 \cdot 10^6}{1{,}828 \cdot 10^6 + 4{,}44 \cdot 10^6} \cdot 26928 = 7853\ \text{N} \tag{27}$$

and the real operating load of loose screw is:

$$F_{r1} = \frac{c_{z1} + c_{b1}}{c_{z1}} \Delta F_{z1} = \frac{1{,}167 \cdot 10^6 + 0{,}755 \cdot 10^6}{1{,}167 \cdot 10^6} \cdot 5013 = 8256\ \text{N} \tag{28}$$

which is a little smaller than it is foreseen for loose and relaxed screw (9533 N), but it is much smaller than real operating load of tightened tensile screw.

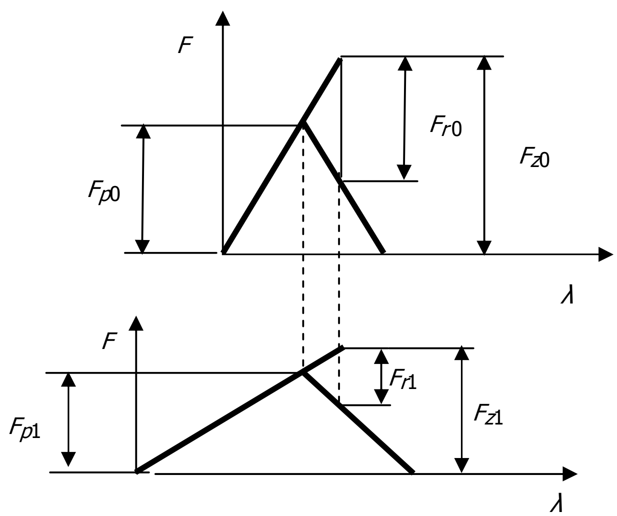

Figure 3. Shematic review of deformations of screws with different elasticity values for the same screws deformations

This means that for transmission of overall loading ($F_r = z_1\ F_{r1} + z_2\ F_{r2} + ...$), tightened screws have to receive biger loading.

Analysing the example with two screws (one is tightened and the other is loose), screw force in tightened tensile screw can be calculated from the expression:

$$F_{z0} = F_{p0} + \frac{c_{z0}}{c_{z0} + c_{b0}} F'_{r0} = 80784 + \frac{1{,}828 \cdot 10^6}{1{,}828 \cdot 10^6 + 4{,}44 \cdot 10^6} \cdot 41205 = 92801 \text{ N} \tag{29}$$

and screw force in loose elastic screw is:

$$F_{z1} = F_{p1} + \frac{c_{z1}}{c_{z1} + c_{b1}} F_{r1} = 28600 + \frac{1{,}167 \cdot 10^6}{1{,}167 \cdot 10^6 + 0{,}755 \cdot 10^6} \cdot 8256 = 33613 \text{ N} \tag{30}$$

So, it follows that loose and relaxed screw is less loaded for 64% than tightened screw, and thus possibility of its breakage is much smaller.

Maintaining the same force of preload screw tightening (by periodical tightening nuts of foundation screws), this problem can be corrected, ie. operating load in each screw can be nearly equated (Fig. 4), but the problem always remains actuel and present.

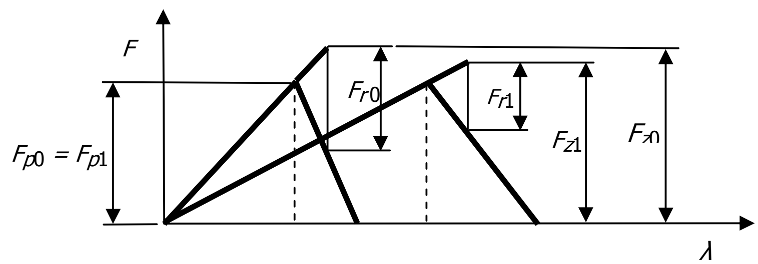

Figure 4. Shematic review of deformations of screws with different elasticity for the same preload tightening force ($F_{p0} = F_{p1}$)

For providing the same loading of foundation screws, it should be necessary to determine preload tightening force, ie. tightening torque of each screw particularly.

3. Conclusion

On the basis of implemented analyse, it follows that looseness and relaxation of foundation screws have significant influence on reducing their operating load. Because of that, tightened tensile screws receive biger loading than it is foreseen, and thus cracks and breakages of those screws can more easier occur. So, it can be concluded that periodical maintaining and checking the tighteness of foundation screws is necessary, so that calculated screw tightening torque and system reliability can be preserved.

This analyse is done for a small foundation damaging (l = 106 mm), but when there is a biger damaging, the situation is much worse because breakages easily happens. Also, when there is a problem with much more screws with different damaging, ie. relaxation, the calculation is more complicated.

References

[1] Kuzmanović Siniša, *Machine Elements 1*, Faculty of Technical Sciences, Novi Sad, 2005

[2] Kuzmanović Siniša, *Constructing, Shaping and Design 1*, Faculty of Technical Sciences, Novi Sad, 2006

[3] Kuzmanović Siniša, *Constructing, Shaping and Design 2*, Faculty of Technical Sciences, Novi Sad, 2005

[4] Kuzmanović Siniša, Milan Rackov, Ružica Trbojević, Analysis Of Influence of Relaxation of Foundation Screws on Their Load Capacity, Annals of the Faculty of Engineering Hunedoara, 2006, Tome IV, Fascicole 2, (ISSN 1584 – 2665), Faculty of Engineering Hunedoara, 5, Revolutiei, 331128, Hunedoara, Romania, p. 167-172

[5] Miltenović Vojislav, *Machine Elements*, Faculty of Mechanical Engineering, Niš, 2006

[6] Robert L. Norton, *Machine Design – An Integrated Approach*, Worcester Polytechnic Institute, Worcester, Massachusetts, Prentice-Hall, 2000

[7] Milosav Ognjanović, *Machine Elements*, Faculty of Mechanical Engineering, Belgrade, 2006

Addresses:

- Prof. Dr. Eng. Siniša Kuzmanović, University of Novi Sad, Faculty of Technical Sciences, Trg Dositeja Obradovića 6, 21000 Novi Sad, Serbia, kuzman@uns.ns.ac.yu
- Ass. Mr. Eng. Ružica Trbojević, University of Novi Sad, Faculty of Technical Sciences, Trg Dositeja Obradovića 6, 21000 Novi Sad, Serbia, ruzica@uns.ns.ac.yu
- Ass. Eng. Milan Rackov, University of Novi Sad, Faculty of Technical Sciences, Trg Dositeja Obradovića 6, 21000 Novi Sad, Serbia, racmil@uns.ns.ac.yu