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ANALYSIS OF INFLUENCE OF RELAXATION OF FOUNDATION SCREWS ON THEIR LOAD CAPACITY

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ABSTRACT:
Foundation screws are used to fix gear units and different machines to the ground. After particular time, due to vibration, screws elasticity and damages of ground, screw connection becomes more and more untightened. This relaxation influences negatively on load capacity distribution and can induce greater vibration and crack of screws. This paper analyses influence of foundation screws relaxation on their load capacity.
KEYWORDS:
Foundation screws, screws calculation

1. INTRODUCTION

Gear units are fixed to the ground with foundation screws, thus their relaxation can, in certain cases, have a great influence on reliable system's operating. Because of that, it is very important to control the condition of foundation screws. This paper indicates the influence of foundation screws relaxation on their load capacity.

2. PROBLEM DESCRIPTION

During operating time of gear units and machines which are attached to the ground with foundation screws, the screw connection is becoming weaker and untighten (Fig. 1). Thus, efective screw lenght rises, and thus screw's elasticity. However, screw elasticity increasing influences (Fig. 2) reducing the maximum load capacity of screw (F_{z1}), for the same value of force of preload screw tightening (F_p). If it is provided that operating force is equal ($F_r = const.$) on each screw, it means that elongation of screws will be different, which can cause vibration occuring.

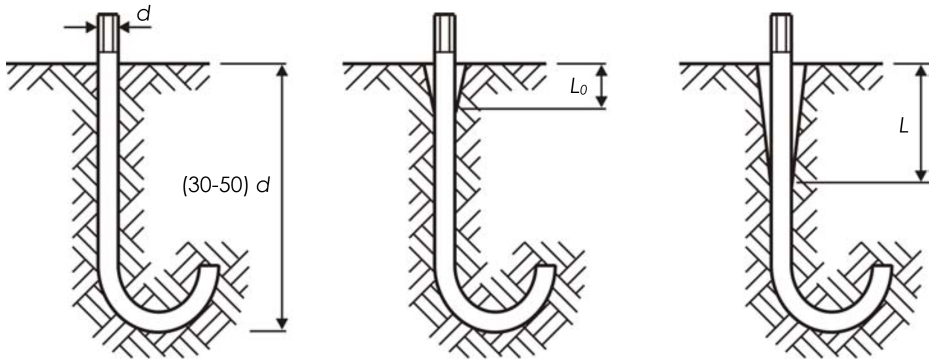

Figure 1. Screw connection getting weaker and occuring of untightening

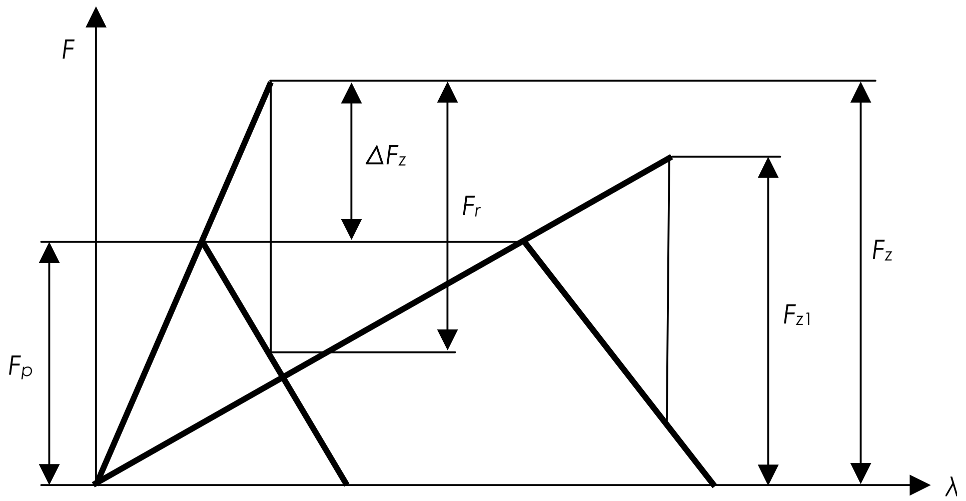

Figure 2. Influence of screw elasticity on its maximum load capacity

If it is realized constructively that deformations of all screws are approximately equal ($\Delta\lambda$ = *const*.), it means that screws are not loaded by the same forces (Fig. 3). In this case, more elastic screws are less loaded (for the value of ΔF) and they withstand smaller operating force (F_{r1}), but shorter and stiffer screws withstand bigger operating force, than it is calculated, which means they are exposed to greater possibility of occuring cracks.

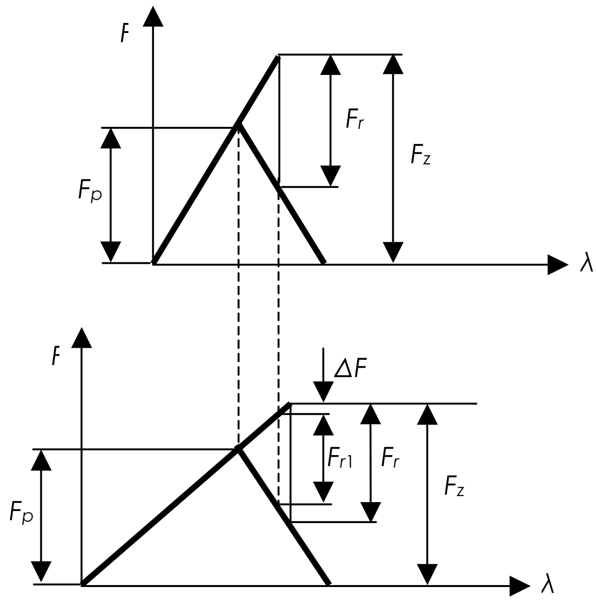

Figure 3. Load capacities of screws with different elasticities for the same value of deformation

3. FINDING SOLUTION

Suggested solution of this problem is that the screws with greater elasticity values should be tightened more firmly, in order to provide equal load receiving, so that, when the full loading is applied, they could be equally loaded as the stiff screws are (Fig. 4).

If maximum load capacities in untightened and stiff screws had to be equal, requisite tightening force value of elastic screws should amount:

$$F_{p2} = F_z - \Delta F_{z2}. \quad (1)$$

Since all screws have equal deformations:

$$\Delta\lambda = \Delta\lambda_{z1} = \Delta\lambda_{z2}, \quad (2)$$

it follows that:
$$\frac{\Delta F_{z1}}{c_{z1}} = \frac{\Delta F_{z2}}{c_{z2}}, \tag{3}$$

and:
$$\Delta F_{z2} = \frac{c_{z2}}{c_{z1}} \Delta F_{z1}, \tag{4}$$

where:
$$\Delta F_{z1} = \frac{c_{z1}}{c_{z1} + c_{b1}} F_r . \tag{5}$$

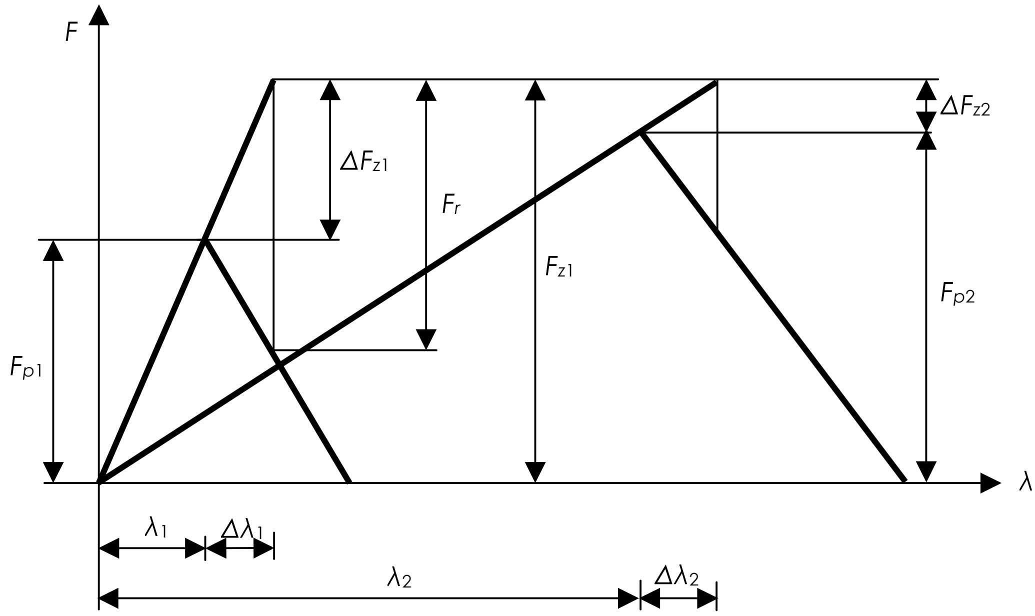

Figure 4. Tightening of different elasticity screws due to equal load receiving

4. EXAMPLE ANALYSING

In order to reconsider the suggested solution, practical example will be analysed considering foundation screws with dimension M30, made of material of strength class 4.6. Preload tightening force value, for the given screw dimensions, amounts:

$$F_p = A_s \cdot \sigma_p = A_s \cdot 0{,}6 \cdot R_{eH} = 561 \cdot 0{,}6 \cdot 240 = 80784 \text{ N} \tag{6}$$

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

Tightening torque of screw is:

$$T_p = \frac{F_p d_2}{2} \left(tg(\varphi + \rho_n) + \mu \frac{d_\mu}{d_2}\right) \tag{7}$$

where: d_2 = 27,727 mm

$\varphi = 2{,}30°$

$\rho_n = \text{arc tg}\ \mu_n = \text{arc tg}\ 0{,}15 = 8{,}531°$

$\mu = 0{,}2$

$d_\mu \approx d_{sr} = \frac{d_s + d_u}{2} = \frac{46+33}{2} = 39{,}5$ mm

$d_s = s = 46$ mm

$d_u = D_0$ – diameter of the hole for screw mounting (according to the standard, it should be 33 mm)

Tightening torque of undamaged (stiff) screw:

$$T_p = \frac{80784 \times 27{,}727}{2}\left(tg(2{,}30 + 8{,}531) + 0{,}2\frac{39{,}5}{27{,}727}\right) = 533366 \text{ Nmm} \tag{8}$$

The maximum operating force that can subject the screw:

$$F_r = \frac{F_p}{\gamma} = \frac{533366}{3} = 177789 \text{ N} \tag{9}$$

Overall screw stiffness can be calculated from the expression:

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

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: $$\frac{1}{c_s} = \frac{1}{E_s}\sum_{i=1}^{n}\frac{l_i}{A_i} = \frac{1}{2{,}1 \times 10^5}\frac{60}{\frac{30^2\pi}{4}} = \frac{1}{2{,}474 \times 10^6} \tag{11}$$

2. nut stiffness:

$$\frac{1}{c_n} = (0{,}95 - 0{,}8)\frac{1}{Ed} \quad \text{za d / P = 6 – 10 (which is the case in this example).} \tag{12}$$

$$\frac{1}{c_n} = 0{,}9 \times \frac{1}{2{,}1 \times 10^5 \times 30} = \frac{1}{7 \times 10^6} \tag{13}$$

3. sheet stiffness: $$c_b = \frac{E_b A_b}{l_b} = \frac{2{,}1 \times 10^5 \times 3330}{60} = 11{,}655 \times 10^6 \tag{14}$$

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

$$A_b = \frac{(D^2 - D_0^2)\pi}{4} = \frac{(73^2 - 33^2)\pi}{4} = 3330 \text{ mm}^2 \tag{15}$$

$D = s + 0{,}45\, l_b = 46 + 0{,}45 \cdot 60 = 73$ mm
D_0 – hole diameter
s – width across flats of nut.
Force increasing in screw due to operating load:

$$\Delta F_{z1} = \frac{c_{z1}}{c_{z1} + c_{b1}}F_r = \frac{1{,}828 \times 10^6}{1{,}828 \times 10^6 + 11{,}655 \times 10^6} \times 177789 = 24104 \text{ N} \tag{16}$$

Force increasing in damaged screw, for the same screw deformation, can be calculated:

$$\Delta F_{z2} = \frac{c_{z2}}{c_{z1}}\Delta F_{z1} = \frac{1{,}167 \times 10^6}{1{,}828 \times 10^6} \times 24104 = 15388 \text{ N} \tag{17}$$

Stiffness of the most damaged screw:

$$\frac{1}{c_z} = \frac{1}{c_g} + \frac{1}{c_s} + \frac{1}{c_n} = \frac{1}{1{,}4 \times 10^6} + \frac{1}{7 \times 10^6} = \frac{1}{1{,}167 \times 10^6} \Rightarrow c_z = 1{,}167 \cdot 10^6 \tag{18}$$

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

1. screw shank stiffness: $$\frac{1}{c_s}=\frac{1}{E_s}\sum_{i=1}^{n}\frac{l_i}{A_i}=\frac{1}{2{,}1\times10^5}\frac{106}{\frac{30^2\pi}{4}}=\frac{1}{1{,}4\times10^6} \quad (19)$$

2. nut stiffness:

$$\frac{1}{c_n}=(0{,}95-0{,}8)\frac{1}{Ed}$$ for d / P = 6 – 10 (which is such a case here). (20)

$$\frac{1}{c_n}=0{,}9\times\frac{1}{2{,}1\times10^5\times30}=\frac{1}{7\times10^6} \quad (21)$$

Knowing screw force:

$$F_z=F_{p1}+\frac{c_{z1}}{c_{z1}+c_{b1}}F_{r1}=80784+\frac{1{,}828\times10^6}{1{,}828\times10^6+11{,}655\times10^6}\times177789=104888\ \text{N} \quad (22)$$

it follows that tightening force of damaged screw:

$$F_{p2} = F_z - \Delta F_{z2} = 104888 - 15388 = 89500\ \text{N} \quad (23)$$

Coefficient *k* presents ratio of torques and is inducted as follows:

$$k=\frac{T_{p2}}{T_{p1}}=\frac{F_{p2}}{F_{p1}}=\frac{89500}{80784}=1{,}1079 \quad (24)$$

so that, tightening torque of damaged screws is:

$$T_{p2} = k\cdot T_{p1} = 1{,}1079\cdot 533366 = 590914\ \text{Nmm} = 590{,}914\ \text{Nm} \quad (25)$$

One practical example of a machine fixed with ten foundation screws is given in Tab. 1. After certain operating time these screws are relaxed, they are controled and damage depth of each of them is measured. Based on these data, different elasticities and stiffness values of them are calculated, and value of tightening torque is proposed for each of them.

TABLE 1. DATA REVIEW OF RELAXED FOUNDATION SCREWS

Screw mark	Damage depth, mm	Active screw lenght, mm	Screw shank stiffness, $C_s\cdot 10^6$	Screw stiffness, $C_z\cdot 10^6$	Torque ratio, *k*	Tightening torque, T_p, Nm
A01	0	60	2,474	1,828	1,0000	533,366
A02	27	87	1,706	1,372	1,0744	573,048
A03	41	101	1,470	1,215	1,1000	586,703
A04	4	64	2,319	1,742	1,0140	540,833
A05	22	82	1,810	1,438	1,0642	567,608
A06	24	84	1,767	1,411	1,0681	569,688
A07	46	106	1,400	1,167	1,1079	590,916
A08	24	84	1,767	1,411	1,0681	569,688
A09	33	93	1,596	1,300	1,0862	579,342
A10	30	90	1,649	1,335	1,0780	574,968

Important note:
It is assumed ideal case by the calculation, i.e. all screws are equally loaded, which is nota a case in real practice, so that results of this calculation don't entirely show the real situation.

5. CONCLUSION

On the basis of implemented analyse, it follows that maximum load capacities of screws (F_z), in operating condition, can be equated by stronger tightening of damaged screws, and by doing this sheet forces (F_b) are also equated. This influences very favourable on reducing vibration activities of screws and systems which are fixed to the ground by them.

Disadvantages of stronger tightening of relaxated screws is additional loading of relaxated screws, in operating conditions, which can additionally deteriorate their situation. However, these screws are designed to carry the maximum load, so that this additional loading shouldn't present any problem.

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