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The development and application of the new methodology for conveyor idlers fits testing

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Abstract

The proper interference fit between the joined parts is a prerequisite for an effective pressure joint. The main purpose of the pressure joint is to transfer tangential, radial and axial loads between the joined parts. In order to provide proper functioning of the machine assembly (whose component parts are connected by the pressure joints), i.e. the transfer of loads without skidding, it is essential to determine the pressure joints interference fit parameters. The new methodology for the conveyor idlers pressure joints quality control is presented in this paper. The procedure for the analytical determination of the expected disassembling force (limiting value) in the pressure joints between the shaft – rolling bearing and the bearing – idler shell is described in detail. The analytically calculated boundary values are compared with the experimental ones. According to the presented criteria, the evaluation of the conveyor idler fits quality was performed and reliable conclusions were successfully adopted.

Keywords: conveyor idlers; experimental testing; testing methodology; interference fits;

1. Introduction

Pressure joints (interference fit joints) are achieved through cylindrical contact surfaces of the joined parts. They provide reliable transfer of circumferential, axial and radial loads. The diameter tolerances of contact cylinders are manufactured in the way that generates interference (firm) fit after the assembling (Nieman 1975). They are manufactured in one of the following ways: longitudinal pressing (with a hydraulic or a mechanical press) or transversal pressing (by cooling of the inner and/or heating of the outer part) (Marghitu 2001, Carvill 1993) .

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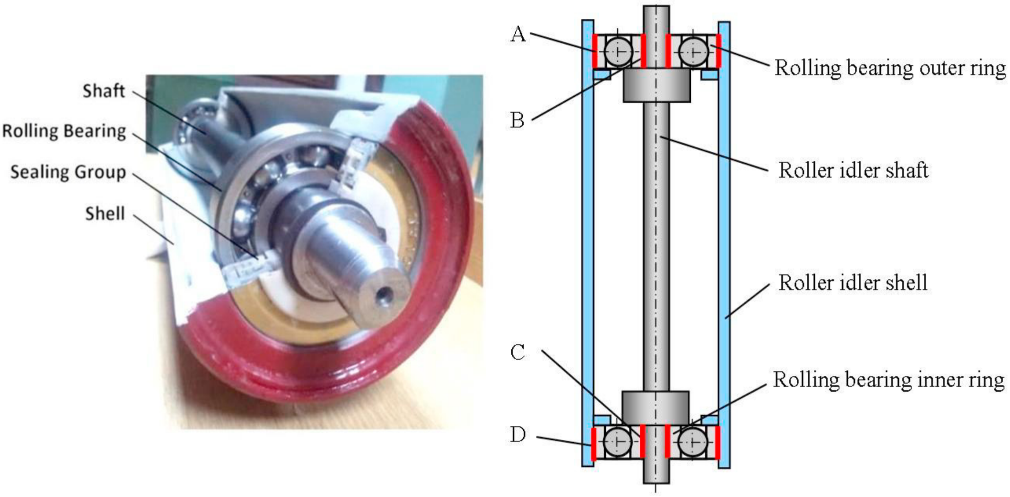
Conveyor idlers are the key component parts of overland conveyor systems. Their main purpose is to transfer the radial load (due to the mass of the conveyor belt and transported material) to the supporting frame. A typical conveyor idler usually consists of a shell (tube), a shaft, a pair of rolling bearings and a pair of sealing groups, Fig. 1a (Mišković 2017). In a typical conveyor idler assembly, there are four pressure joints – presented in Fig. 1b [4].



a) b)

Fig. 1. A typical conveyor idler assembly (Mišković 2017)

The main advantage of pressure joints is the fact that they are assembled with the direct contact between the joined parts (without intermediaries), while their key disadvantages are the following:

1. High accuracy of dimensions and profiles (tolerances), as well as fine quality of the joined parts contact surfaces (roughness), must be achieved before the pressure joints assembling;
2. Special equipment should be used for the assembling of the pressure joints;
3. So far, there have been no reliable methodologies for the pressure joint quality control.

2. Theoretical background

The load in a pressure joint is transferred due to elastic deformations of the connected parts, which, consequently, causes their surface strain. When the pressure joint is assembled at room temperature, the elastic deformation depends on the nominal overlap (P) and the contact surfaces roughness (R). However, the effective overlap is much smaller than the nominal one – it is significantly reduced by the contact surface flattening during the assembling process.

For the contact surface pressure calculation, the well-known analytical expressions for pressed cylinders are used (Ristivojević et al. 2011). The assumption is that the pressure of the contact surfaces is evenly distributed. Due to this assumption, the effective overlap has its maximal and minimal values: $P_{ef\min}$ and $P_{ef\max}$, and, therefore, the contact stress also has extreme values, which can be calculated as:

$$p_{\min} = \varepsilon_{\min} \cdot E_{red} = \frac{P_{ef\min}}{d} \cdot E_{red} \qquad \text{and} \qquad p_{\max} = \varepsilon_{\max} \cdot E_{red} = \frac{P_{ef\max}}{d} \cdot E_{red}$$

where:

E_{red} [daN/cm^2] – Reduced elastic modulus;

E_e, E_i [daN/cm^2] – Young's modulus for the external (e) and internal (i) joint section.

2.1. Pressing force F_p – pressure joint forming

Pressing force F_p is axial load acting on the inner part of two joined parts – as presented in Fig. 2a. For the proper axial pressing, the following conditions must be met:

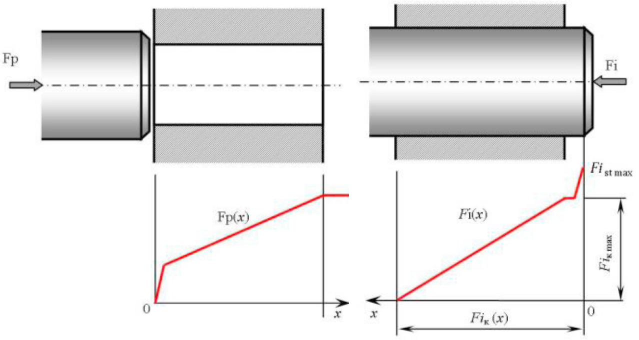
1. The edges of both parts should be chamfered;
2. Contact surfaces should be well lubricated (for specific cases: steel/steel, steel/cast steel, steel/cast iron);
3. Pressing speed should be lower than 0.5 m/s (at higher speeds load capacity is reduced).

The pressing force during the pressure joint forming is not constant, but it changes depending on the relative position of the parts, i.e. the overlapped surface size (Fig. 2a).

2.2. Disassembling (ejection) force F_i – pressure joint disassembling

The disassembling (ejection) force F_i is axial load acting on the inner part of two joined parts – as presented in Fig. 2b. Similar to the pressing force F_p, the disassembling force F_i is not constant during the pressure joint disassembling, but depends on the relative position of the joined parts (Fig. 2b). Generally, there are two phases during the pressure joint disassembling:

1. Static – disassembling force Fi_{st} [kN], the relative motion of the joined parts begins (x=0) – this is the maximal force generated during the pressure joint disassembling;
2. Kinematic – disassembling force Fi_{K} [kN], the relative motion of the joined parts is continued until their separation has been completed (x>0). ;



a) b)

Fig. 2. Change of: (a) pressing force and (b) disassembling force, as a function of the joined parts' relative position

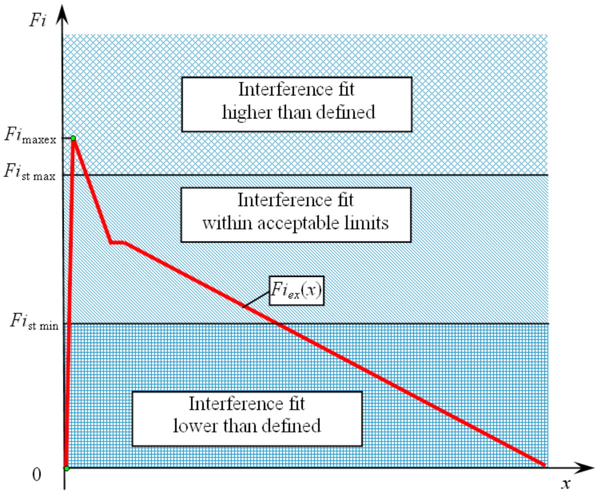


Fig 3. Disassembling force boundary values used for pressure joint quality control

The effective (real) disassembling force Fi_{ex} is determined experimentally, and the obtained results are used for the fits quality control. The maximal experimentally determined disassembling force Fi_{maxex} must have a value smaller than the maximal analytically determined one, which is derived from the condition that the disassembling force has a largest nominal value if the interference fit before the joint has been formed is maximal (P_{max}):

$$Fi_{st\max} = 0{,}30 \cdot A \cdot \frac{|P_{\max}| - 2 \cdot \varphi \cdot (R_e + R_i)}{d} \cdot E_{red},$$

and the lowest experimentally determined disassembling force Fi_{maxex} should be larger than:

$$Fi_{st\min} = 0{,}30 \cdot A \cdot \frac{|P_{\min}| - 2 \cdot \varphi \cdot (R_e + R_i)}{d} \cdot E_{red}$$

Static friction coefficient μ_{st} for steel conveyor idlers equals μ_{st} = 0.30; and φ (offset prominence factor) equals 0.6 (Stamenković et al. 2011, Stamenković et al. 2012). The maximal experimentally determined disassembling force Fi_{maxex} has to be compared with the calculated values of Fi_{stmin} and Fi_{stmax}. Based on the results of this comparison, the appropriate conclusions can be made, according to the following boundary conditions (applicable only to interference fits):

1. $Fi_{maxex}<Fi_{stmin}$ – the interference fit between the joined parts was too small before the assembling;
2. $Fi_{stmin}<Fi_{maxex}<Fi_{stmax}$ – the interference fit between the joined parts was within the allowed boundaries;
3. $Fi_{maxex}>Fi_{stmax}$ – the interference fit between the joined parts was too large before the assembling.

The boundary conditions listed above are graphically illustrated in Fig. 3.

3. Analytical determination of the disassembling force boundary values

For the conveyor idlers fits control and quality evaluation, it is necessary to analytically determine the proper maximal and minimal values of the disassembling forces. The appropriate analytical equations have been derived in order to calculate the nominal values which could be further compared with the experimental results. Also, the derived equations are harmonized with the experiment phases shown in Fig. 4.

3.1. *Analytical determination of the disassembling force boundary values for the conveyor idlers shaft separation from its rolling bearings – $F_{i1stmin}$ and $F_{i1st\,max}$*

The disassembling force needed to separate the conveyor idler shaft from its rolling bearing F_{i1} [kN] is the axial force acting on the conveyor idler shaft during the disassembling, Fig. 4, phase B. This pressure joint was previously formed by longitudinal (axial) pressing.

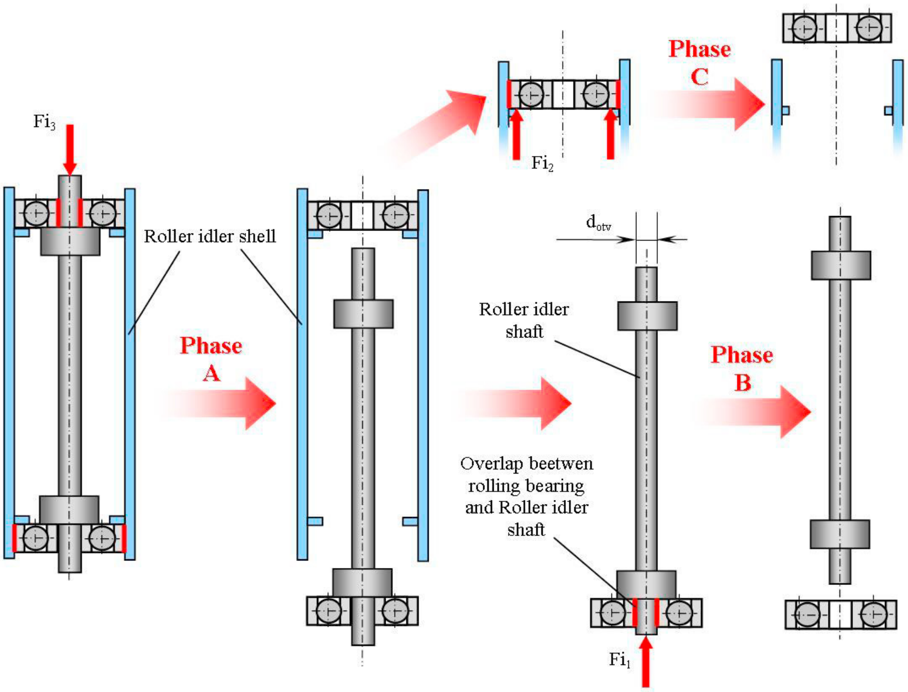


Fig. 4. Graphical presentation of the conveyor disassembling phases

For the analytical determination of the disassembling forces boundary values during the separation of the conveyor idlers shaft from its rolling bearings, it is necessary to determine the values of the nominal maximal interference fit. The bases for this calculation are the tolerance fields' positions and the IT tolerance quality. The tolerances of the rolling bearings are defined by the international standard (DIN 620-2:1999) – for the relevant inner rolling bearing diameter ($D_{up\,kl}$).

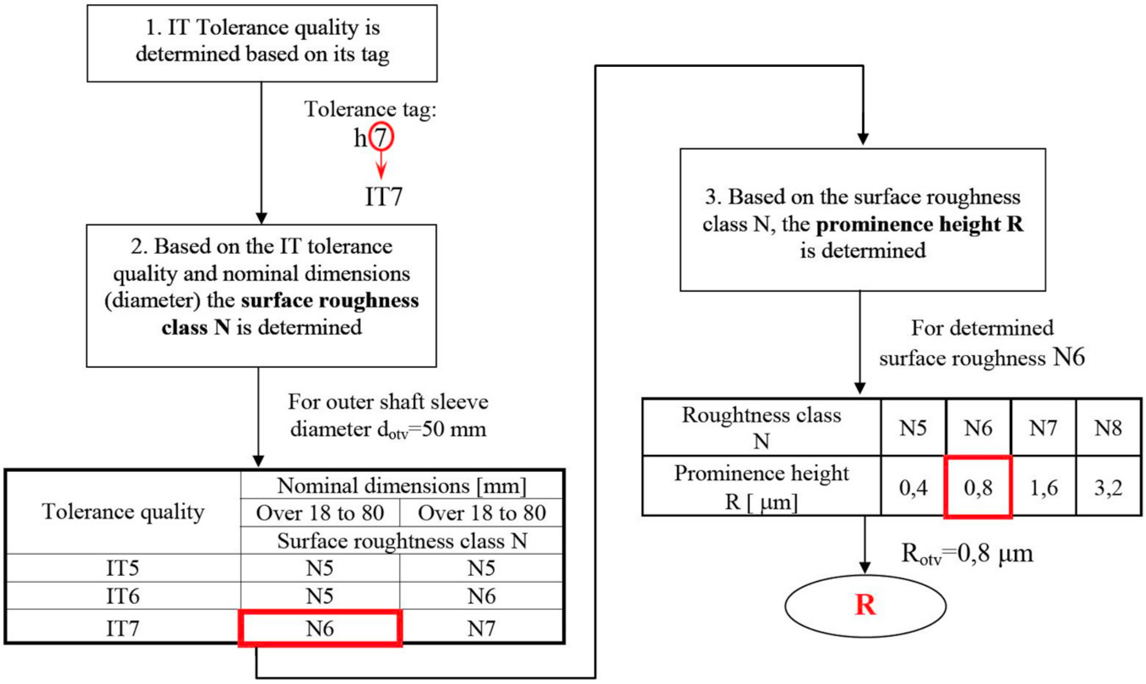
In conveyor idlers, the rolling bearings types 6306 2Z C3, 6308 2Z C3, 6310 2Z C3 and 6312 2Z C3 are used most commonly – with the general accuracy class P$_0$, so the appropriate values for the bearings inner diameters of ∅30, 40, 50 and 60 mm were adopted – for ∅30 mm and ∅40 mm: $ES_{upkl} = 0$, $EI_{upkl} = -12$ µm; for ∅50 mm and ∅60 mm: $ES_{upkl} = 0$, $EI_{upkl} = -15$µm.

The tolerances of the conveyor idlers shaft sleeve outer diameters (d_{otv}) are usually g6, h6 and h7. The corresponding upper and lower deviations ei_{spotv} and es_{spotv} depend on the nominal dimensions of the outer diameter of the shaft sleeve and its IT tolerance quality. Those deviations, for the diameters ∅30÷60 mm, have been determined according to (2017).

The algorithm for the surface roughness determination (prominence height) on the shaft sleeve with the outer diameter of ∅50 mm and tolerance class h7, as well as the obtained values, are presented in Fig. 5. The minimal (Fi_{1stmin} *[kN]*) and maximal (Fi_{1stmax} *[kN]*) boundary values for the experimentally obtained disassembling forces used for the separation of the conveyor idlers shaft from its rolling bearings, are calculated as:

$$Fi_{1st\min} = 0{,}03\cdot 10^{-6}\cdot (D_{upkl}\cdot \pi \cdot B)\cdot \frac{\left|(ES_{upkl}-ei_{spotv})\right|-1{,}2\cdot (R_{otv}+R_{upkl})}{D_{upkl}}\cdot \left(\frac{2100000}{\frac{1+(D_{upkl}/d_{upkl})^2}{1-(D_{upkl}/d_{upkl})^2}+1}\right) \qquad (1)$$

$$Fi_{1st\max} = 0{,}03\cdot 10^{-6}\cdot (D_{upkl}\cdot \pi \cdot B)\cdot \frac{\left|(EI_{upkl}-es_{spotv})\right|-1{,}2\cdot (R_{otv}+R_{upkl})}{D_{upkl}}\cdot \left(\frac{2100000}{\frac{1+(D_{upkl}/d_{upkl})^2}{1-(D_{upkl}/d_{upkl})^2}+1}\right) \qquad (2)$$



Tolerance quality	Nominal dimensions [mm]	
	Over 18 to 80	Over 18 to 80
	Surface roughtness class N	
IT5	N5	N5
IT6	N5	N6
IT7	N6	N7

Roughtness class N	N5	N6	N7	N8
Prominence height R [µm]	0,4	0,8	1,6	3,2

Fig. 5. The algorithm for the surface roughness (prominence height) determination on a ∅50 mm shaft sleeve surface, tolerance class h7

3.2. Analytical determination of the disassembling force boundary values for the conveyor idlers rolling bearings separation from its shell – $Fi_{2st\min}$ and $Fi_{2st\max}$

The disassembling force needed to separate the conveyor idlers rolling bearings from its shell Fi_2 [kN] is an axial force acting on the conveyor idlers rolling bearing during the disassembling, Fig. 4, phase C. This pressure joint was previously formed by longitudinal (axial) pressing.

For the analytical determination of the disassembling forces boundary values during the separation of the conveyor idlers rolling bearings from its shell, the corresponding equations for the pressurized thick wall vessels were used, i.e. the bedding was considered as an internally pressurized thick wall vessel, and outer bearing rings were considered as externally pressurized thick wall vessels. Therefore, the allowed minimal ($Fi_{2st\min}$ *[kN]*) and maximal ($Fi_{2st\max}$ *[kN]*) values of disassembling forces can be calculated as:

$$Fi_{2st\min} = 0{,}03\cdot 10^{-6}\cdot (d_{spkl}\cdot \pi \cdot B)\cdot \frac{\left|(ES_{uputv}-ei_{spkl})\right|-1{,}2\cdot (R_{utv}+R_{spkl})}{d_{spkl}}\cdot \left(\frac{\frac{1+(D_{spkl}/d_{spkl})^2}{1-(D_{spkl}/d_{spkl})^2}-0{,}3+\frac{D_{utv}}{d_{utv}-D_{utv}}}{2100000}\right) \qquad (3)$$

$$Fi_{2st\max} = 0{,}03\cdot 10^{-6}\cdot (d_{spkl}\cdot \pi \cdot B)\cdot \frac{\left|(EI_{uputv}-es_{spkl})\right|-1{,}2\cdot (R_{utv}+R_{spkl})}{d_{spkl}}\cdot \left(\frac{\frac{1+(D_{spkl}/d_{spkl})^2}{1-(D_{spkl}/d_{spkl})^2}-0{,}3+\frac{D_{utv}}{d_{utv}-D_{utv}}}{2100000}\right) \qquad (4)$$

The experimentally measured disassembling forces during the separation of the conveyor idlers rolling bearings from its shell Fi_{2maxex} should be compared with the calculated values Fi_{2stmin} and Fi_{2stmax}.

3.3. Analytical determination of the disassembling force boundary values for the conveyor idlers shaft separation from its shell – Fi_{3stmin} and $Fi_{3st\,max}$

The disassembling force during the separation of the conveyor idlers shaft from its shell Fi_3 [kN] is an axial force acting on the idler shaft, as shown in Fig. 4 (phase A). The allowed minimal and maximal values of the experimentally obtained disassembling force (Fi_{3maxex} [kN]) can be determined using the previously calculated values of Fi_{1st}[kN] and Fi_{2st}[kN], that is:

$$Fi_{3st\min} = Fi_{1st\min} + Fi_{2st\min} \tag{5}$$

$$Fi_{3st\max} = Fi_{1st\max} + Fi_{2st\max} \tag{6}$$

where:

Fi_{1stmin}[kN] – The minimal allowed disassembling force for the separation of the conveyor idlers shaft from its rolling bearings;

Fi_{1stmax}[kN] – The maximal allowed disassembling force for the separation of the conveyor idlers shaft from its rolling bearings;

Fi_{2stmin}[kN] – The minimal allowed disassembling force for the separation of the conveyor idlers rolling bearings from their beddings in the conveyor idlers shell;

Fi_{2stmax}[kN] – The maximal allowed disassembling force for the separation of the conveyor idlers rolling bearings from their beddings in the conveyor idlers shell.

The maximal experimentally obtained values of the disassembling force for the separation of the conveyor idlers shaft from its shell Fi_{3maxex} should be compared with the calculated ones, Fi_{3stmin} and Fi_{3stmax}, and, on the basis of that comparison, it is possible to draw a conclusion about the quality of the relevant manufacture interference fits.

4. Experimental testing of the conveyor idlers interference fits – the application of the testing methodology

The experimental testing of the conveyor idlers interference fits was carried out in accordance with the scheme presented in Fig. 4. The steel conveyor idler was examined.

The main geometrical characteristics of the tested conveyor idler were [4]: diameter – *159 mm*, shell length – *600 mm*, shell thickness – *5 mm*, rolling bearings type – *6310 2Z C3*, shaft sleeve tolerances – *h*7 and tolerances of the inner bearing bedding – *M*7 (Krsmanovic and Mitrovic 2015).

According to the developed experimental testing methodology, the following activities were performed:

1. Analytical determination of the conveyor idlers disassembling forces boundary values;
2. Experimental measurement of the disassembling forces – for the conveyor idlers pressure joints separation;
3. Comparison of the experimentally measured disassembling forces with the calculated boundary values.

4.1. Results of the analytical determination of the disassembling forces boundary values

The tested conveyor idlers bearings geometrical characteristics are: D_{upkl}= *50 mm*, d_{upkl}= *68.8 mm*, *B = 27 mm*, D_{spkl}= *95.2mm*, d_{spkl}= *110 mm*. The allowed deviations of the shaft sleeve diameter (d_{otv}) ∅50 *h*7 are: es_{otv}= *0* µm and ei_{otv}= *-12 µm*. The inner surface roughness of the conveyor idlers rolling bearing 6310 2Z C3 equals R_{upkl}= *0.8 µm*. According to the equations (2), (4) and (6), the maximal measured values of disassembling forces should be smaller than:

Fi_{1stmax} = 12.7 kN
Fi_{2stmax}= 9.42 kN
Fi_{3stmax}= Fi_{1stmax} + Fi_{2stmax}= 22.12 kN

4.2. Experimental measurement of the disassembling forces during the conveyor idlers pressure joints separation

The experimental measurement of the actual disassembling force Fi_{ex} was performed on the servo-hydraulic machine for the dynamic and static materials characteristics testing – Zwick Roell HB250 (Fig.6), using specific, custom-made tools (Fig. 7). The experiment flow has been defined according to the phases shown in Fig. 4, while some of the testing phases are presented in Fig. 8. The maximal measured disassembling forces Fi_{ex}, for different phases of experimental testing, have been presented by graphs obtained during the tests – for each phase separately, Figs. 9-11.

Fig. 6. Servo-hydraulic machine for the dynamic and static material testing ZwickRoell HB250

Fig. 7. Custom-made tools for the actual ejecting force testing

Fig. 8. Some of the experiment phases for the determination of an actual ejecting force Fi_{ex}

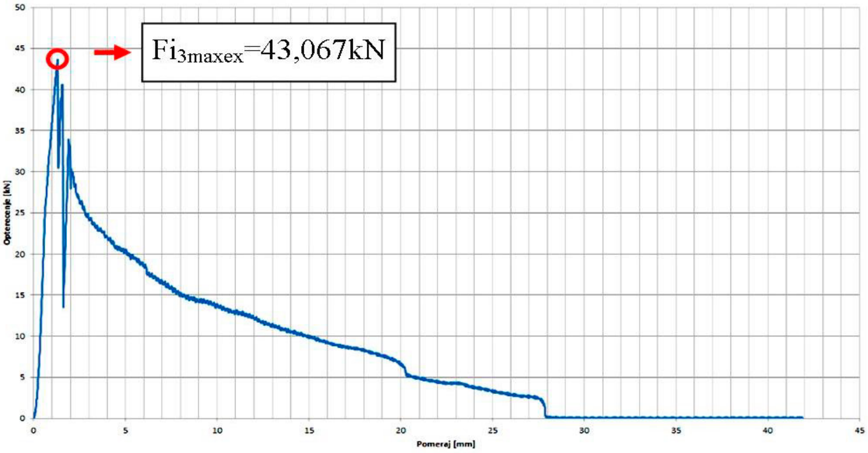


Fig. 9. Phase A – The diagram of the measured disassembling force Fi_{3maxex}

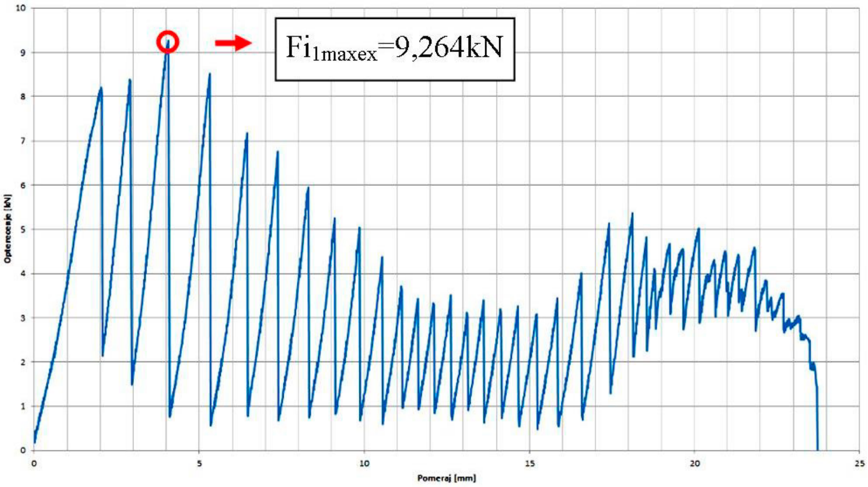


Fig. 10. Phase B – The diagram of the measured disassembling force Fi_{1maxex}

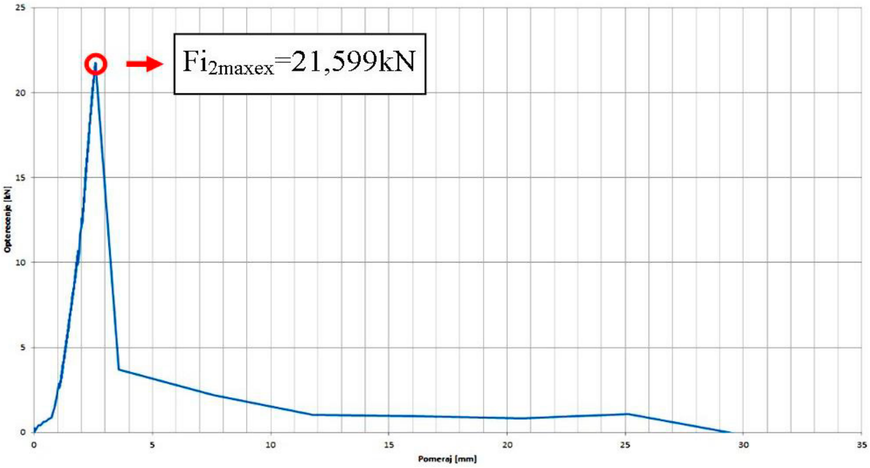


Fig 11. Phase C – The diagram of the measured disassembling force Fi_{2maxex}

5. Conclusion

The comparison of the measured disassembling forces with the analytically obtained boundary values has shown that the tested conveyor idlers interference fits were assembled with the satisfactory quality, i.e. the maximal measured disassembling forces were smaller than the maximal analytically obtained boundary values. The results of the performed evaluation are given in the final column in Table 1.

Table 1. Interference fits evaluation in a conveyor idler Ø159x600 mm

Criteria	Max. allowable value [kN]	Max. measured value [kN]	Is the measured value higher than allowed?	**Comment**
PHASE A $Fi_{3maxex}>Fi_{3stmax}$	$Fi_{3stmax}=22.12$	$Fi_{3maxex}=43.067$	YES	At least one of two interference fits between the shaft sleeve and the first bearing inner ring, and between the second bearing outer ring and idler bedding is out of the defined limits, i.e. higher than allowed
PHASE B $Fi_{1maxex}>Fi_{1stmax}$	$Fi_{1stmax}=12.7$	$Fi_{1maxex}=9.264$	NO	Interference fit between the bearing inner ring and the idler shaft sleeve is within the allowed limits
PHASE C $Fi_{2maxex}>Fi_{2stmax}$	$Fi_{2stmax}=9.42$	$Fi_{2maxex}=21.599$	YES	Interference fit between the bearing outer ring and the bedding (idler cylinder) is not within the allowed limits – several times higher than the defined one

The presented methodology can be applied to the interference fit joints in many different mechanical systems and assemblies. As such, it can also be used for an accurate evaluation of pressure joints, especially if we bear in mind that, so far, there have been no similar testing methodologies described in the relevant literature. Still, as with every methodology that is under development, it is possible to further improve it, both in the analytical and experimental way.

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