Transport and Engineering. Production Technologies

2013 / 35

Ball Burnishing as Finish Method of Compressor Shaft Wear Sleeve

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Abstract **– Nowadays more and more advanced technologies in surface finish are developed. The ball burnishing technology of wear sleeve gives smoothened surface characteristics, which improves initial abrasive wear resistance, bearing rate, and residual compressive stresses in the surface layer of the wear sleeve. These parameters may significantly increase the life cycle of PTFE sealing knot. This paper recognizes the technology advances in wear sleeve manufacturing and gives directions for further research and discussion.**

Keywords **– ball burnishing, wear sleeve, PTFE seal.**

I. INTRODUCTION

Traditional technology of PTFE wear sleeve manufacturing is plunge grinding. This is the way how to process hardened shaft wear sleeve and obtain reasonable surface texture for sealing surface [1.]. The wear sleeves of PTFE lip seals, which are highly reliable in standard working conditions, are made from 100Cr6 (AISI52100) tempered steel. Most of the sealing knot manufacturers use needle roller bearing inner race for shaft protection (Fig.1), because its surface texture and roughness satisfy good sealing requirements (Table.1). These sleeves guarantee leakage free operating of a screw compressor at least for 10,000 hours. Sometimes during these periods of time, we find out deep wear grooves on the wear sleeve sealing surface, which may become a cause of oil leaks (Fig.2). Small abrasive particles in size up to 5-10µm, which often are present in the working environment, are the cause of excessive wear of the shaft protective sleeve.

The one of ways how to improve wear endurance of the sleeve against small abrasive particles is the usage of sleeve material with higher surface wear resistance. Residual compressive stress, which remains in the surface layer after plastic deformation, is the factor which increases fatigue strength of the processed material. Hence it increases wear resistance against sliding wear. Thus, the problem solution is to make a wear sleeve with higher initial surface hardness, lower friction coefficient, and enough deep and large residual compressive stresses in the surface layer. This may be successfully obtained with the change the manufacturing technology of the wear sleeve. The ball burnishing process can provide same surface quality as grinding. Usage of tungsten carbide balls allows performing plastic deformation even on hardened and tempered steels with surface hardness up to 65HRC. The abrasive processing technology nowadays is replaceable with surface plastic deformation, thus giving opportunity to obtain 5-10% harder upper layer of the surface with the same surface roughness parameters. The other advantage of this processing technology is that this technology works without material cutting or removing. Hence at the same time burnishing process is much friendlier to the working environment, there are no small grinding grains in the processing area, and there is no need for a large amount of cooling liquid, because temperature increase in the processing area is much lower than in abrasive cutting with undefined cutting angles. Extensive research on temperature fields in burnishing process has been made by Russian scientist D.Papshev [3.]. The plastically deformed materials have higher density of crystal grid and are more resistant to any external influences. One of the attractive aspects of burnishing technology is relieving of residual tensile stresses, which are in the surface layer after hard turning. After burnishing the surface often has compressive stresses in the upper layer.

Burnishing technology is quite simple and available for any machine shop, but still now potential users of this technology do not have sufficient knowledge on the advantages of plastic deformation technology. Thus, the burnishing technology still is like a non-traditional or alternative processing technology. The best samples of using of burnishing can be found in aviation, marine and military industries.

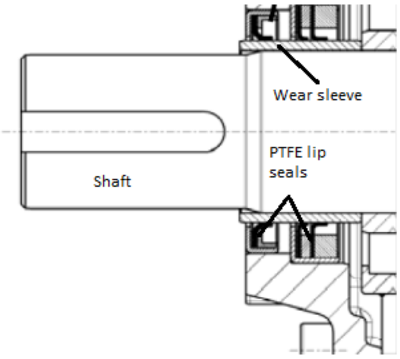


Fig. 1.Sealing knot assembly of GHH OS 70 screw compressor air end.

Fig. 2.New and hardly worn out shaft protective sleeve.

TABLE 1

SOME STANDARDS AND SEALING MANUFACTURER RECOMMENDATIONS FOR SHAFT SURFACE QUALITY

	DIN 3760	**DIN 3761**	**Elring**	**SKF**	**Garlock**	**IDG**
R_a[µm]	0.2 – 0.8	0.2 – 0.8	0.2 – 0.8	0.2 – 0.8	0.2 – 0.3 – 0.5 – 0.6	0.05 – 0.5
R_z[µm]	1 – 5	1 – 4	1 – 4	1 – 4		
R_{max}[µm]	6.3	6.3		6.3	0.8 – 1 – 2 – 3	
Spiralfree	Yes	Yes	Yes	Yes		
Hardness	45HRC	600HV	>45HRC	55HRC/600HV	40–45HRC	>58HRC
Other			DIN 3761		R_a and R_{max} depend on speed v>16m/s, v=11–16m/s, v<16m/s	T_p>50% R_t=0.05 - 2

II. TECHNOLOGY

The processing technology how to obtain a wear sleeve with an attractive surface quality and spend less money in manufacturing includes initial hard turning of the hardened steel pipe with the cubic boron nitride cutting tool (CBN) and sequential low plasticity burnishing with the tungsten carbide ball. This technology excludes abrasive processing. Thus, it eliminates abrasive grain penetrating in sleeve material during processing, which may heighten initial abrasive wear of protective sleeve and sealing lips at the beginning of exploitation.

The technology of hard turning and sequential burnishing of some hard materials was already developed many years ago by Russian, German and other scientists. The most prominent of them are D.Pashev, F.Klocke [4]. A couple of recent researches in this area are done by L.Luca [8] and Yung – Chang Yen [6]. The hard turning processing for surface preparation for ball burnishing is done by CBN cutting tool with 60° major and minor cutting edge angles and relative small tool nose radius R=0.1mm (Fig.3). The theoretical peak to valley height can be easily calculated by equation:

$$R_{tth} = r_\varepsilon\left(1-\sqrt{1-\left(\frac{S}{2\cdot r_\varepsilon}\right)^2}\right) \approx \frac{S^2}{8r_\varepsilon} \qquad (1)$$

where r_ε – tool nose radius, mm ;
S- feed mm/rpm.

The selected geometry ensures that the hard turned surface profile will be capable for surface plastic deformation with enough high deformation and burnishing speed and feed.

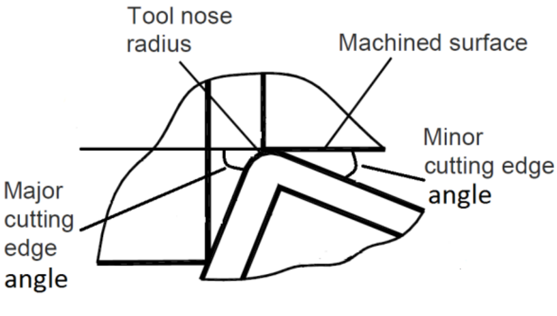


Fig.3. CBN cutting tool base plane geometry

The surface contact between the burnishing tool and the workpiece often is an ellipse, with the major axis oriented in parallel to the longitudinal axis of the workpiece. Therefore, according to
sphere-to-sphere elastic contact [5] contact length of minor axis may be calculated.

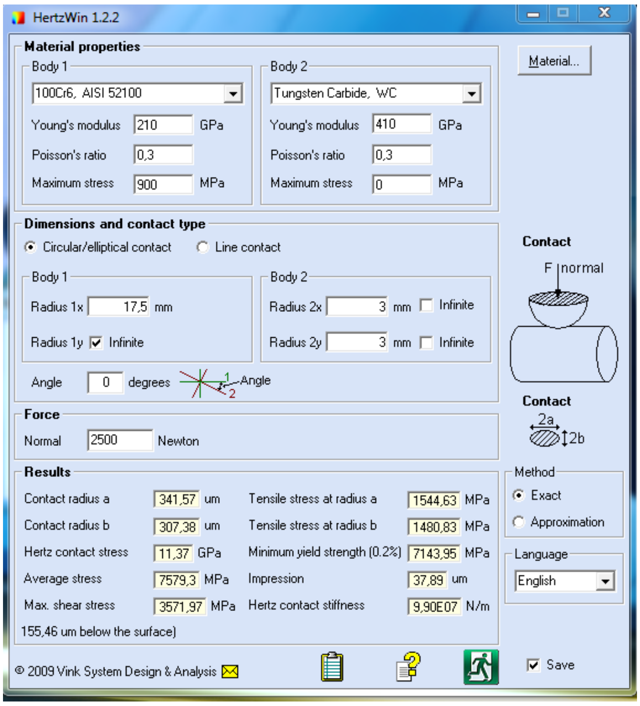
$$r_c = \sqrt[3]{\frac{3\cdot(1-v^2)\cdot r\cdot F_b}{2\cdot E}} \qquad (2)$$

where $$r = \frac{r_w\cdot r_t}{r_w+r_t} \qquad (3)$$

$$E = \frac{2\cdot E_w\cdot E_t}{E_w+E_t} \qquad (4)$$

r_w,r_t – workpiece and tool radius;
E_w,E_t – Young's modulus of the workpiece and tool;
γ - workpiece's Poisson's ratio, (0.3)

More easily contact surface can be calculated by Hertz stress calculator like HertzWin 1.2.2.or mesys.chonline stress calculator.



Material properties
Body 1: 100Cr6, AISI 52100
Young's modulus 210 GPa
Poisson's ratio 0,3
Maximum stress 900 MPa
Body 2: Tungsten Carbide, WC
Young's modulus 410 GPa
Poisson's ratio 0,3
Maximum stress 0 MPa

Dimensions and contact type
● Circular/elliptical contact ○ Line contact
Body 1: Radius 1x 17,5 mm; Radius 1y ☑ Infinite
Body 2: Radius 2x 3 mm ☐ Infinite; Radius 2y 3 mm ☐ Infinite
Angle 0 degrees

Force
Normal 2500 Newton

Results
Contact radius a 341,57 um
Contact radius b 307,38 um
Hertz contact stress 11,37 GPa
Average stress 7579,3 MPa
Max. shear stress 3571,97 MPa
155,46 um below the surface)
Tensile stress at radius a 1544,63 MPa
Tensile stress at radius b 1480,83 MPa
Minimum yield strength (0.2%) 7143,95 MPa
Impression 37,89 um
Hertz contact stiffness 9,90E07 N/m

Method: ● Exact ○ Approximation
Language: English
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Fig.4. HertzWin1.2.2 calculation sample for 2500N normal force

Hertz Win stress application calculates and displays contact stress values and surface radiuses. Contact radius in the longitudinal direction of the workpiece is slightly larger (341.57μm) than in cross direction (307.38μm); The depth of impression draws up 37.89μm in case of 2500N normal force.
The surface contact area of ellipse:

$$F = \pi \cdot a \cdot b \tag{5}$$

F=0.33mm^2

Further contact time of any surface point may be calculated:

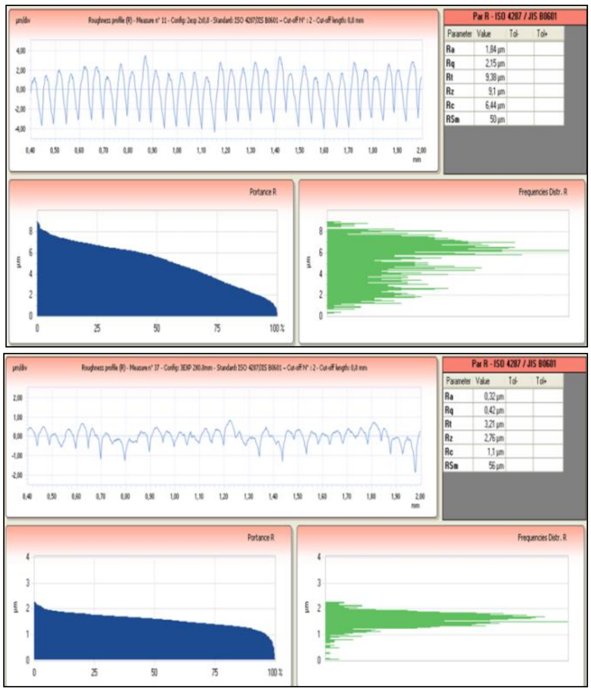
$$t_c = \frac{60 \cdot d_c}{v_b \cdot 1000} = \frac{60 \cdot 2 \cdot b}{v_b \cdot 1000} \tag{6}$$

t_c=0.0004sec

III. MATHEMATICAL MODEL OF SLEEVE BURNISHING PROCESS

Low plasticity ball burnishing was performed on conventional lathe 16K20. The full three factor experiment was done for characterization of the burnishing process. Burnishing force, speed and feed rates are chosen as factors, which have the most significant influence on the processed surface quality. The initial surface roughness of sample pieces before burnishing tests: Ra≈2μm, processed material: hardened steel 100Cr6, with initial surface hardness 53HRC. The burnishing tool: 6mm tungsten carbide ball (grade25), preloaded by a spring mechanism. Spring tension force of burnishing tool was calibrated by indicator gauge and 3000N force dynamometer.

The surface roughness profile of wear sleeve before and after burnishing is displayed in Fig.4a.



Par R - ISO 4287 / JIS B0601

Parameter	Value	Tol-	Tol+
Ra	1,84 µm		
Rq	2,15 µm		
Rt	9,38 µm		
Rz	9,1 µm		
Rc	6,44 µm		
RSm	50 µm		

Par R - ISO 4287 / JIS B0601

Parameter	Value	Tol-	Tol+
Ra	0,32 µm		
Rq	0,42 µm		
Rt	3,21 µm		
Rz	2,76 µm		
Rc	1,1 µm		
RSm	56 µm		

Fig.4a. General view of hard turned and ball burnished wear sleeve surface.

TABLE 2

VARYING FACTORS OF BURNISHING EXPERIMENT

Force, F_b(N)	1500 – 2500
Speed, v_b(m/min)	88 – 135
Feed, S_b(mm/rpm)	0.05 – 0.15

TABLE 3

EXPERIMENTALLY OBTAINED RESULTS

N	S_b, mm/rpm	V_b, m/min	F_b, N	Y1	Y2	Y3	R_a
1.	0.05	88	1500	0.65	0.71	0.65	0.67
2.	0.15	88	1500	0.55	0.58	0.55	0.56
3.	0.05	137	1500	0.76	0.77	0.87	0.80
4.	0.15	137	1500	0.8	0.76	0.72	0.76
5.	0.05	88	2500	0.54	0.48	0.57	0.54
6.	0.15	88	2500	0.45	0.47	0.55	0.49
7.	0.05	137	2500	0.49	0.55	0.64	0.56
8.	0.15	137	2500	0.59	0.54	0.61	0.59

The obtained mathematical model for prediction of surface roughness after ball burnishing is presented as follows:

$$Ra = 0.515 - 3.16S + 0.052v + 0.000018F + 0.013Sv \\ + 0.00064SF - 0.0000021vF$$

The obtained surface roughness is acceptable for sealing application paired with PTFE lip seal. Wear resistance and friction losses have higher characteristics for wear sleeve application. In addition, surface layer has compressive stresses, which significantly increases sliding wear resistance and strongly reduces spread and formation of corrosion seeds.

Analysis of the mathematical model displays that increasing of burnishing speed generally has a tendency for producing a rougher burnished surface, it could be explained by too short contact force time for plastic deformation of sample material. The experiment also displays that too small burnishing feed rate did not yield the expected result, and better results were obtained with 0.15mm/rpm feed rate.

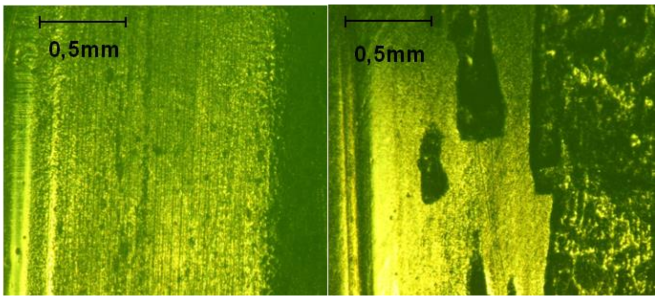


Fig.5. Corrosion seeds on ball burnished – left, and grinded shaft wear sleeve – right.

IV. CONCLUSION

1. The replacement of grinding technology allows excluding abrasive grain penetration in the surface of protective sleeve, thus eliminating the initial wear of shaft protective sleeve and PTFE lip seal.

2. The low plasticity ball burnishing of 100Cr6 wear sleeve raises the hardness of the sleeve surface layer for about 3HRC units. An experimental test gives results of hardness increasing from 53 to 56HRC units.

3. Hard cutting parameters for further low plastic burnishing are as follows: cutting speed 100m/min., depth<0.15mm, feed rate 0.05mm/rpm.

4. The parameters for ball burnishing technology of hardened 100Cr6 steel pipe, which give the acceptable surface sealing applications: burnishing force2000N on 6mm tungsten carbide ball, speed v=100m/min, feed S≤0.1mm/rpm.

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His fields of scientific interest include: cutting theory; machining tools; fluid mechanics; machine diagnostics and monitoring; and Computer Numerical Control machines.

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Guntis Pikurs, Guntis Bunga, Viktors Gutakovskis, Artis Kromanis. Virskārtas plastiskā deformēšana ar lodīti kā nobeiguma apstrāde kompresora vārpstas aizsargčaulai

Zinātniskā raksta tēma ir skrūves kompresora blīvslēga mezgla ekspluatācijas īpašību uzlabošana, paaugstinot blīvslēga mezgla vārpstas aizsargčaulas nodilumizturību pret sīkajām abrazīvajām daļiņām. Vārpstas aizsargčaulas nodilumizturības paaugstināšanās tiek panākta, izmantojot šīs detaļas izgatavošanas tehnoloģijas nomaiņu no bezcentra slīpēšanas tehnoloģijas uz virskārtas plastiskās deformēšanas tehnoloģiju. Lai noteiktu izgatavošanas tehnoloģijas parametrus, tika veikti triju faktoru eksperimenti aizsargčaulas izgatavošanas tehnoloģiskajām operācijām.

Pēc triju faktoru eksperimenta veikšanas un datu apstrādes, tika iegūts matemātiskais modelis plastiskajā deformēšanā iegūstamā virsmas raupjuma vidējās aritmētiskās novirzes atkarībai no plastiskās deformēšanas apstrādes parametriem.

Vārpstas aizsargčaulas izgatavošana ar plastiskās deformēšanas metodi izslēdz abrazīvo daļiņu nonākšanu aizsargčaulas materiāla virskārtā, kas ir raksturīga slīpēšanas operācijām, tādējādi izslēdzot abrazīva sākotnējo nonākšanu starp PTFE blīvslēga un 100Cr6 vārpstas aizsargčaulas virsmām un intensīvāku sākotnējo dilšanu.

Гунтис Пикурс, Гунтис Бунга, Виктор Гутаковский, Артис Кроманис. Обкатка шариком как метод завершающей обработки для защитной гильзы вала винтового компрессора.

Тема научной статьи - повышение качества эксплуатационных свойств винтового компрессора за счет улучшения качества работы уплотнительного узла, защиты истирания гильзы вала от крошечных абразивных частиц. Увеличение износостойкости гильзы вала достигается за счет использования технологий поверхностно-пластической деформации и замены технологии шлифовки. Исследование проводилось при производстве защитной пленки с помощью пластического деформирования поверхности. Для определения параметров технологии обработки было проведено три опыта для изучения защитных факторов технологических операций.

После трехфакторного эксперимента и обработки данных были получены математические модели пластической деформации для определения зависимости шероховатости поверхности от среднего отклонения по пластическим параметрам обработки деформации.

Производство защитной гильзы вала методом пластического деформирования исключает попадание абразивных частиц в защитный поверхностный материал, в отличие от шлифовальных операций, тем самым исключает попадание абразива в исходное PTFE-уплотнение и защитной гильзы 100Cr6 поверхностей, а также повышенный износ оригинала.