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KRITIČNI POLOŽAJ ZUBA HCR ZUPČANIKA S OBZIROM NA ODSTUPANJA KORAKA NA ZAHVATNOJ CRTI
CRITICAL POSITION OF HCR GEAR'S TEETH WITH REGARD TO PITCH ERROR

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Sažetak: *Iako su vrlo osjetljivi na nepravilnosti nastale u proizvodnji, zupčanici s velikim stupnjem prekrivanja profila (HCR, engl. high transverse contact ratio) u sve su češćoj upotrebi zbog povećane nosivosti u odnosu na zupčanike s niskim stupnjem prekrivanja profila. Procedura izračuna raspodjele sile na parove zuba u istodobnom zahvatu izvedena za HCR zupčanike s odstupanjem koraka na zahvatnoj crti bitno ovisi o položaju parova zuba u zahvatu s obzirom na vrijednosti odstupanja. Kritični položaj parova zuba u zahvatu koji izaziva najveći porast naprezanja u odnosu na naprezanja geometrijski točnih zupčanika, definiran je u ovom radu.*

Ključne riječi:
– zupčanici
– velik stupanj prekrivanja profila
– odstupanje koraka na zahvatnoj crti

Abstract: *High transverse contact ratio (HCR) gears are more frequently in use because of their increased load-carrying capacity compared to low contact ratio gears, although they are very sensitive to manufacturing errors. The calculation procedure of load distribution, established for HCR gears with pitch errors, depends on the position of tooth pairs, with regard to pitch error. The critical position of tooth pairs, which causes the maximum stress increase, compared to geometrically ideal gears, is defined in this paper.*

Keywords:
– gears
– high transverse contact ratio
– pitch error

1. UVOD

Kod HCR zupčanika stupanj prekrivanja profila veći je od dva. To znači da su tijekom zahvata u istodobnom kontaktu dva, odnosno tri para zubi pa se pri opterećenju HCR zupčanika sila raspodjeljuje na dva, odnosno tri para zubi. Područje dvostrukog zahvata je od točke B do D i od točke E do F na zahvatnoj crti, a trostrukog od točke A do B, D do E i F do G (Slike 3 i 4). Standardna procedura izračuna raspodjele sile na parove zubi u istodobnom zahvatu [1], a posljedično i raspodjele naprezanja, ne uzima u obzir elastičnu deformaciju zuba. U [2, 3] za izračun raspodjele sile elastična deformacija zuba uzeta je u obzir, ali samo za geometrijski točne zube zupčanika. Kod zupčanika s odstupanjem koraka na zahvatnoj crti (u daljnjem tekstu: odstupanje koraka) netočnosti geometrije bitno utječu na deformaciju zuba u zahvatu, a time i na raspodjelu sile [4]. Stoga je preporučljivo za proračun raspodjele sile uzeti u obzir odstupanja koraka [5].

1. INTRODUCTION

High contact ratio gears have a transverse contact ratio higher than two. That means that HCR gears have two or three tooth pairs in simultaneous contact during mesh and therefore, load is distributed among two or three tooth pairs in HCR gears. The double contact region is from point B to D and from E to F on the line of action and the triple contact region is from point A to B, D to E and F to G (Figures 3 and 4). The standard calculation procedure of load distribution on tooth pairs in simultaneous contact [1], and consequently of stress distribution does not take into account the influence of elastic deformation. Load distribution calculation in [2, 3] takes into account teeth elastic deformation, but only for geometrically ideal gears. Pitch errors have significant influence on teeth elastic deformation in HCR gears and therefore on load distribution [4]. Hence, a load distribution calculation procedure should include pitch errors [5].

2. OSTUPANJE KORAKA

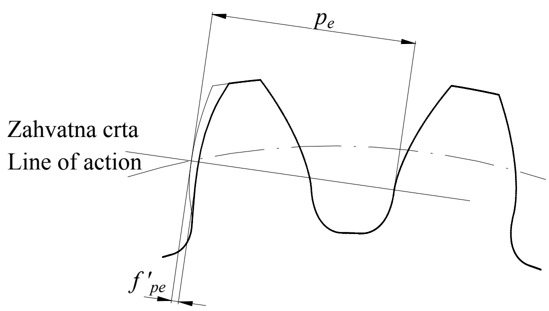
Zupčanici se, kao ni drugi strojni dijelovi, ne mogu izraditi s apsolutnom geometrijskom točnošću. Stoga postoje definirane granice dopuštenih odstupanja – tolerancija [6], kako ne bi došlo do zaglavljivanja zubi u radu, kako bi se omogućilo stvaranje uljnog filma između bokova zuba sparenih zupčanika, zbog mogućnosti elastičnog deformiranja i toplinskog dilatiranja zuba te da bi se osigurala zamjenjivost zupčanika zupčanih parova, miran rad i konstantan prijenosni omjer. Jedna od posljedica izrade zupčanika u okviru dozvoljenih tolerancija je odstupanje koraka.

Jedinično odstupanje koraka f'_{pe} je razlika razmaka dvaju lijevih ili dvaju desnih profila zuba zupčanika u smjeru zahvatne crte (Slika 1) i nazivne vrijednosti koraka na zahvatnoj crti p_e [7, 8]. To osnovno odstupanje razlikuje se za svaka dva susjedna zuba zupčanika.

2. PITCH ERROR

As with any other machine part, geometrically ideal gears cannot be manufactured. Therefore allowable tolerances are defined [6] to avoid teeth blocking, to allow oil layer formation between tooth flanks, elastic deformation and thermal dilatation of teeth and to assure gears' replacement possibilities, quiet functioning and a constant transmission ratio. Pitch error is one outcome of gear production with an allowable tolerance.

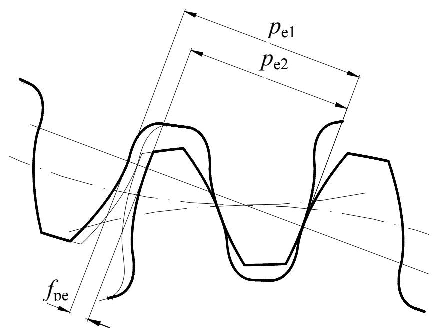
Pitch error f_{pe} is the deviation between the distance of two left- or right-sided tooth profiles in the pressure line direction (Figure 1) and theoretical base pitch p_e [7, 8]. This is an elemental error that changes between each two neighbouring teeth around the circumference of the gear.



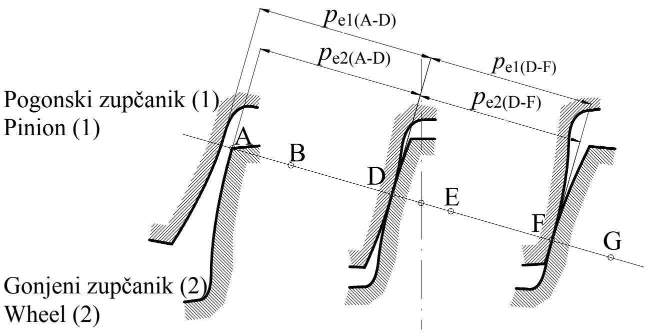
Slika 1. Jedinično odstupanje koraka
Figure 1. Single pitch error

Tijekom zahvata zupčanika odstupanja koraka pogonskog i gonjenog zuba zbrajaju se (Slika 2) ili oduzimaju, ovisno o kombinaciji njihovih odstupanja. Budući da HCR zupčanici imaju dva ili tri para zubi u istodobnom zahvatu, ukupno odstupanje koraka može se pojaviti pri osam mogućih položaja zuba zupčanika, prikazanih na Slikama 3 za trostruki i Slikama 4 za dvostruki kontakt.

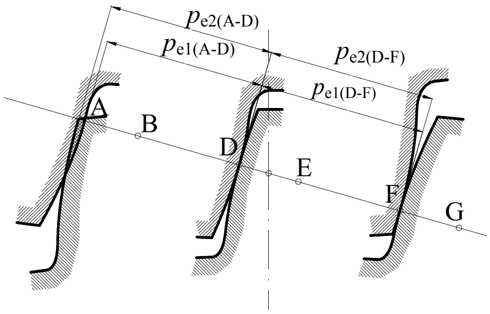
When the gears are in mesh, pitch errors of the pinion's and wheel teeth are added (Figure 2) or subtracted, depending on the combination of their deviations. Since HCR gears have two or three tooth pairs in simultaneous contact, the total pitch error can occur in eight different positions, which are shown in Figures 3 for triple and Figures 4 for double contact.



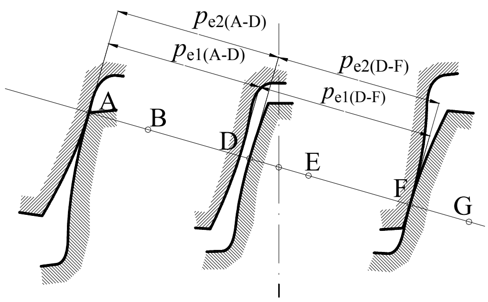
Slika 2. Ukupno odstupanje koraka
Figure 2. Total pitch error



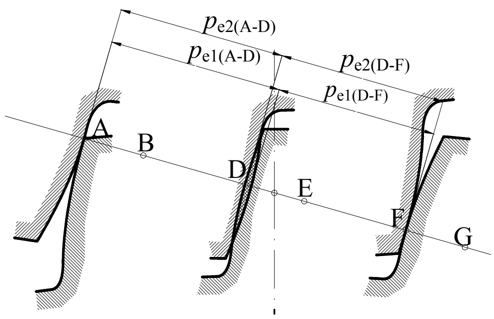
Slika 3a. Odstupanje koraka u trostrukom zahvatu, $p_{e1(A-D)} > p_{e2(A-D)}$, $p_{e1(D-F)} = p_{e2(D-F)}$
Figure 3a. Pitch error in triple contact, $p_{e1(A-D)} > p_{e2(A-D)}$, $p_{e1(D-F)} = p_{e2(D-F)}$



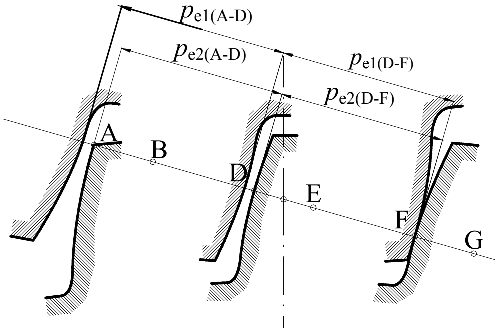
Slika 3b. Odstupanje koraka u trostrukom zahvatu, $p_{e1(A-D)} < p_{e2(A-D)}$, $p_{e1(D-F)} = p_{e2(D-F)}$
Figure 3b. Pitch error in triple contact, $p_{e1(A-D)} > p_{e2(A-D)}$, $p_{e1(D-F)} = p_{e2(D-F)}$



Slika 3c. Odstupanje koraka u trostrukom zahvatu, $p_{e1(A-D)}<p_{e2(A-D)}$, $p_{e1(D-F)}>p_{e2(D-F)}$, $p_{e1(A-D)} + p_{e1(D-F)} = p_{e2(A-D)} + p_{e2(D-F)}$
Figure 3c. Pitch error in triple contact, $p_{e1(A-D)} < p_{e2(A-D)}$, $p_{e1(D-F)} > p_{e2(D-F)}$, $p_{e1(A-D)} + p_{e1(D-F)} = p_{e2(A-D)} + p_{e2(D-F)}$

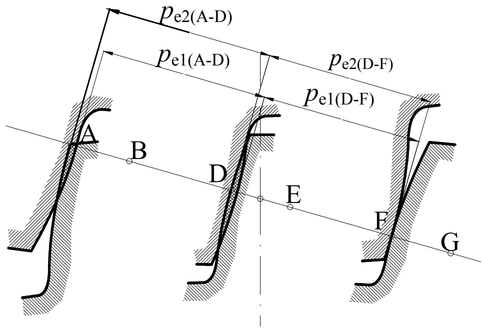


Slika 3d. Odstupanje koraka u trostrukom zahvatu, $p_{e1(A-D)} > p_{e2(A-D)}$, $p_{e1(D-F)} < p_{e2(D-F)}$, $p_{e1(A-D)} + p_{e1(D-F)} = p_{e2(A-D)} + p_{e2(D-F)}$
Figure 3d. Pitch error in triple contact, $p_{e1(A-D)} > p_{e2(A-D)}$, $p_{e1(D-F)} < p_{e2(D-F)}$, $p_{e1(A-D)} + p_{e1(D-F)} = p_{e2(A-D)} + p_{e2(D-F)}$



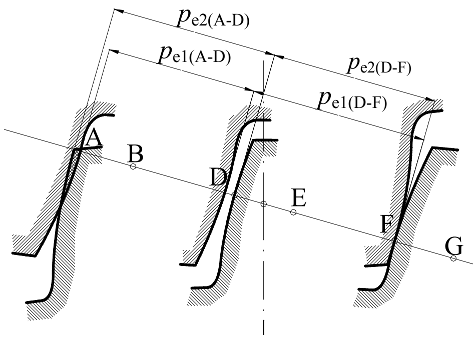
Slika 3e. Odstupanje koraka u trostrukom zahvatu, $p_{e1(D\text{-}F)} > p_{e2(D\text{-}F)}$ *,* $p_{e1(A\text{-}D)} + p_{e1(D\text{-}F)} > p_{e2(A\text{-}D)} + p_{e2(D\text{-}F)}$

Figure 3e. Pitch error in triple contact, $p_{e1(D\text{-}F)} > p_{e2(D\text{-}F)}$ *,* $p_{e1(A\text{-}D)} + p_{e1(D\text{-}F)} > p_{e2(A\text{-}D)} + p_{e2(D\text{-}F)}$



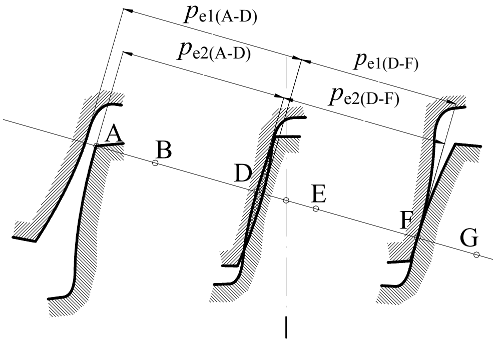
Slika 3f. Odstupanje koraka u trostrukom zahvatu, $p_{e1(D\text{-}F)} < p_{e2(D\text{-}F)}$ *,* $p_{e1(A\text{-}D)} + p_{e1(D\text{-}F)} < p_{e2(A\text{-}D)} + p_{e2(D\text{-}F)}$

Figure 3f. Pitch error in triple contact, $p_{e1(D\text{-}F)} < p_{e2(D\text{-}F)}$ *,* $p_{e1(A\text{-}D)} + p_{e1(D\text{-}F)} < p_{e2(A\text{-}D)} + p_{e2(D\text{-}F)}$



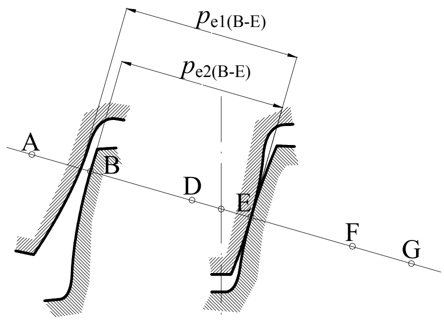
Slika 3g. Odstupanje koraka u trostrukom zahvatu, $p_{e1(D\text{-}F)} < p_{e2(D\text{-}F)}$ *,* $p_{e1(A\text{-}D)} + p_{e1(D\text{-}F)} > p_{e2(A\text{-}D)} + p_{e2(D\text{-}F)}$

Figure 3g. Pitch error in triple contact, $p_{e1(D\text{-}F)} < p_{e2(D\text{-}F)}$ *,* $p_{e1(A\text{-}D)} + p_{e1(D\text{-}F)} > p_{e2(A\text{-}D)} + p_{e2(D\text{-}F)}$

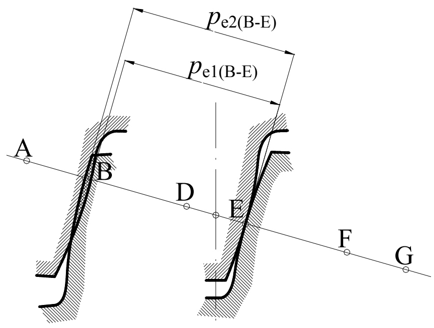


Slika 3h. Odstupanje koraka u trostrukom zahvatu, $p_{e1(D\text{-}F)} > p_{e2(D\text{-}F)}$ *,* $p_{e1(A\text{-}D)} + p_{e1(D\text{-}F)} < p_{e2(A\text{-}D)} + p_{e2(D\text{-}F)}$

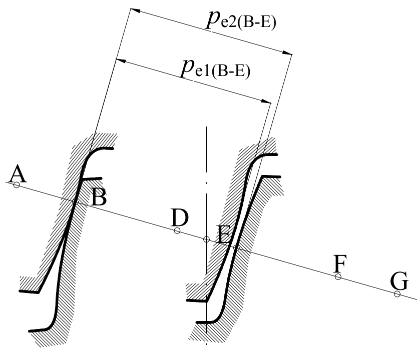
Figure 3h. Pitch error in triple contact, $p_{e1(D\text{-}F)} > p_{e2(D\text{-}F)}$ *,* $p_{e1(A\text{-}D)} + p_{e1(D\text{-}F)} < p_{e2(A\text{-}D)} + p_{e2(D\text{-}F)}$



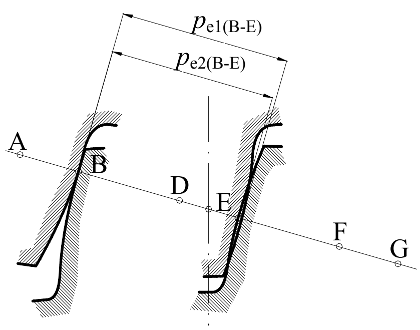
Slika 4a. Odstupanje koraka u dvostrukom zahvatu, $p_{e1(A-D)} > p_{e2(A-D)}$, $p_{e1(D-F)} = p_{e2(D-F)}$
Figure 4a. Pitch error in double contact, $p_{e1(A-D)} > p_{e2(A-D)}$, $p_{e1(D-F)} = p_{e2(D-F)}$



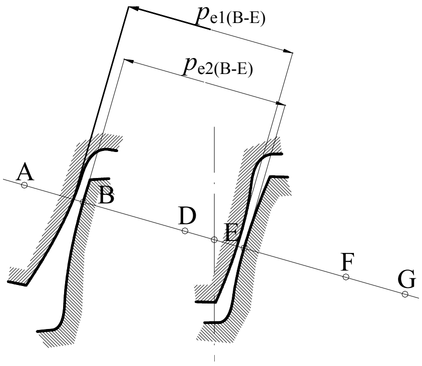
Slika 4b. Odstupanje koraka u dvostrukom zahvatu, $p_{e1(A-D)} < p_{e2(A-D)}$, $p_{e1(D-F)} = p_{e2(D-F)}$
Figure 4b. Pitch error in double contact, $p_{e1(A-D)} > p_{e2(A-D)}$, $p_{e1(D-F)} = p_{e2(D-F)}$



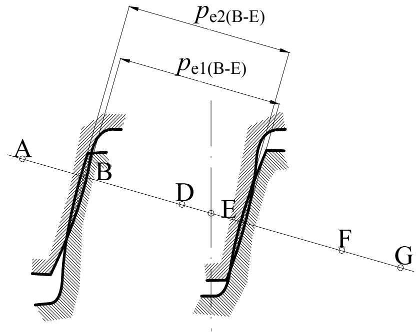
Slika 4c. Odstupanje koraka u dvostrukom zahvatu, $p_{e1(A-D)}<p_{e2(A-D)}$, $p_{e1(D-F)}>p_{e2(D-F)}$, $p_{e1(A-D)} + p_{e1(D-F)} = p_{e2(A-D)} + p_{e2(D-F)}$
Figure 4c. Pitch error in double contact, $p_{e1(A-D)} < p_{e2(A-D)}$, $p_{e1(D-F)} > p_{e2(D-F)}$, $p_{e1(A-D)} + p_{e1(D-F)} = p_{e2(A-D)} + p_{e2(D-F)}$



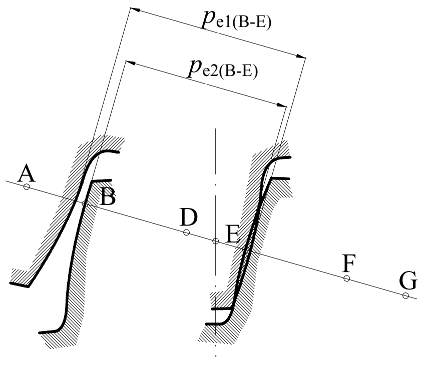
Slika 4d. Odstupanje koraka u dvostrukom zahvatu, $p_{e1(A-D)} > p_{e2(A-D)}$, $p_{e1(D-F)} < p_{e2(D-F)}$, $p_{e1(A-D)} + p_{e1(D-F)} = p_{e2(A-D)} + p_{e2(D-F)}$
Figure 4d. Pitch error in double contact, $p_{e1(A-D)} > p_{e2(A-D)}$, $p_{e1(D-F)} < p_{e2(D-F)}$, $p_{e1(A-D)} + p_{e1(D-F)} = p_{e2(A-D)} + p_{e2(D-F)}$



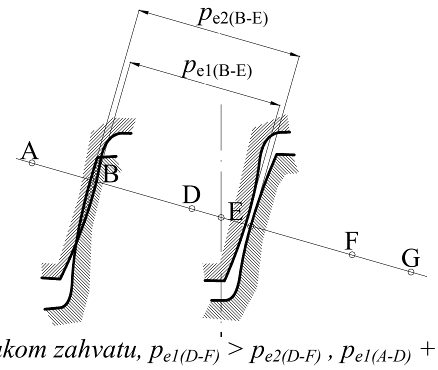
Slika 4e. Odstupanje koraka u dvostrukom zahvatu, $p_{e1(D-F)} > p_{e2(D-F)}$,$p_{e1(A-D)} + p_{e1(D-F)} > p_{e2(A-D)} + p_{e2(D-F)}$
Figure 4e. Pitch error in double contact, $p_{e1(D-F)} > p_{e2(D-F)}$,$p_{e1(A-D)} + p_{e1(D-F)} > p_{e2(A-D)} + p_{e2(D-F)}$



Slika 4f. Odstupanje koraka u dvostrukom zahvatu, $p_{e1(D-F)} < p_{e2(D-F)}$, $p_{e1(A-D)} + p_{e1(D-F)} < p_{e2(A-D)} + p_{e2(D-F)}$
Figure 4f. Pitch error in double contact, $p_{e1(D-F)} < p_{e2(D-F)}$, $p_{e1(A-D)} + p_{e1(D-F)} < p_{e2(A-D)} + p_{e2(D-F)}$



Slika 4g. Odstupanje koraka u dvostrukom zahvatu, $p_{e1(D-F)} < p_{e2(D-F)}$,$p_{e1(A-D)} + p_{e1(D-F)} > p_{e2(A-D)} + p_{e2(D-F)}$
Figure 4g. Pitch error in double contact, $p_{e1(D-F)} < p_{e2(D-F)}$,$p_{e1(A-D)} + p_{e1(D-F)} > p_{e2(A-D)} + p_{e2(D-F)}$



Slika 4h. Odstupanje koraka u dvostrukom zahvatu, $p_{e1(D-F)} > p_{e2(D-F)}$, $p_{e1(A-D)} + p_{e1(D-F)} < p_{e2(A-D)} + p_{e2(D-F)}$
Figure 4h. Pitch error in double contact, $p_{e1(D-F)} > p_{e2(D-F)}$, $p_{e1(A-D)} + p_{e1(D-F)} < p_{e2(A-D)} + p_{e2(D-F)}$

2. UVJETI JEDNAKOSTI ELASTIČNIH DEFORMACIJA

Izračun raspodjele sile temelji se na uvjetu jednakosti elastičnih deformacija parova zuba u istodobnom zahvatu [2]. Za geometrijski točne zupčanike ti su uvjeti za trostruki i za dvostruki zahvat:

2. CONDITIONS OF EQUAL ELASTIC DEFORMATION

The basis for calculation of load distribution is the condition of equal elastic deformation on every tooth pair in simultaneous contact [2]. For geometrically ideal gears the conditions for triple and for double contact are:

$$\frac{F_{\mathrm{bti(A\text{-}B)}}}{c'_{\mathrm{i(A\text{-}B)}}\cdot b}=\frac{F_{\mathrm{bti(D\text{-}E)}}}{c'_{\mathrm{i(D\text{-}E)}}\cdot b}=\frac{F_{\mathrm{bti(F\text{-}G)}}}{c'_{\mathrm{i(F\text{-}G)}}\cdot b} \tag{1}$$

$$\frac{F_{\mathrm{bti(B\text{-}D)}}}{c'_{\mathrm{i(B\text{-}D)}}\cdot b}=\frac{F_{\mathrm{bti(E\text{-}F)}}}{c'_{\mathrm{i(E\text{-}F)}}\cdot b} \tag{2}$$

Uvođenjem odstupanja koraka u analizu, ono mora biti dodano vrijednosti elastične deformacije, ovisno o svojem položaju. Opći izrazi za uvjet jednakosti elastičnih deformacija su:

If the pitch error is included in the analysis, it must be added to the elastic deformation, depending on its position. The general expressions for the condition of equal elastic deformations are:

$$\frac{F_{\mathrm{bti(A\text{-}B)}}}{c'_{\mathrm{i(A\text{-}B)}}\cdot b}+f_{\mathrm{pe(A-B)}}=\frac{F_{\mathrm{bti(D\text{-}E)}}}{c'_{\mathrm{i(D\text{-}E)}}\cdot b}+f_{\mathrm{pe(D-E)}}=\frac{F_{\mathrm{bti(F\text{-}G)}}}{c'_{\mathrm{i(F\text{-}G)}}\cdot b}+f_{\mathrm{pe(F-G)}} \tag{3}$$

$$\frac{F_{\mathrm{bti(B\text{-}D)}}}{c'_{\mathrm{i(B\text{-}D)}}\cdot b}+f_{\mathrm{pe(B\text{-}D)}}=\frac{F_{\mathrm{bti(E\text{-}F)}}}{c'_{\mathrm{i(E\text{-}F)}}\cdot b}+f_{\mathrm{pe(E\text{-}F)}} \tag{4}$$

3. KRITIČNI POLOŽAJ ZUBA HCR ZUPČANIKA S OBZIROM NA ODSTUPANJA KORAKA

Raspodjela sile na parove zuba u zahvatu izračunata je za svih osam mogućih položaja zuba, prikazanih na Slikama 3 i 4, za zupčanike čije su karakteristike dane u Tablici 1 i stupnjeve kvalitete Q = 5 do 10, korištenjem izraza izvedenih na osnovi općih izraza za uvjet jednakosti elastičnih deformacija [5].

Raspodjela naprezanja ovisi o udjelima sila na svaki par zuba u istodobnom zahvatu [1]. Najveći porast naprezanja u korijenu zuba pogonskog zupčanika izračunat je za položaj zuba zupčanika prikazan na Slikama 3e i 4e ($p_{\mathrm{e1(D\text{-}F)}} > p_{\mathrm{e2(D\text{-}F)}}$, $p_{\mathrm{e1(A\text{-}D)}} + p_{\mathrm{e1(D\text{-}F)}} > p_{\mathrm{e2(A\text{-}D)}} + p_{\mathrm{e2(D\text{-}F)}}$), a u korijenu gonjenog zupčanika za položaj zuba zupčanika prikazan na Slikama 3f i 4f ($p_{\mathrm{e1(D\text{-}F)}} < p_{\mathrm{e2(D\text{-}F)}}$, $p_{\mathrm{e1(A\text{-}D)}} + p_{\mathrm{e1(D\text{-}F)}} < p_{\mathrm{e2(A\text{-}D)}} + p_{\mathrm{e2(D\text{-}F)}}$). Najveći porast naprezanja na boku zuba također se pojavljuje za položaj zuba zupčanika prikazan na Slikama 3f i 4f.

Odstupanja koraka za kritične položaje zuba u zahvatu su:

3. CRITICAL POSITION OF HCR GEAR'S TOOTH PAIRS WITH REGARD TO PITCH ERROR

The load distribution on tooth pairs in contact along the line of action is calculated for all possible positions of the teeth, shown on Figures 3 and 4, for the gear characteristics given in Table 1 and quality grades Q = 5 to 10, by using expressions, which are obtained on the basis of the general conditions of equal elastic deformation [5].

The stress distribution depends on load shares on each tooth pair in simultaneous contact [1]. The maximum increase of the tooth root stresses in the pinion is calculated for the position of gear teeth shown in Figures 3e and 4e ($p_{\mathrm{e1(D\text{-}F)}} > p_{\mathrm{e2(D\text{-}F)}}$, $p_{\mathrm{e1(A\text{-}D)}} + p_{\mathrm{e1(D\text{-}F)}} > p_{\mathrm{e2(A\text{-}D)}} + p_{\mathrm{e2(D\text{-}F)}}$) and in the wheel for the position of gear teeth shown in Figures 3f and 4f ($p_{\mathrm{e1(D\text{-}F)}} < p_{\mathrm{e2(D\text{-}F)}}$, $p_{\mathrm{e1(A\text{-}D)}} + p_{\mathrm{e1(D\text{-}F)}} < p_{\mathrm{e2(A\text{-}D)}} + p_{\mathrm{e2(D\text{-}F)}}$). The maximum increase of the contact stresses occurs for the position of gear teeth shown in Figures 3f and 4f.

The pitch errors for critical positions of mating teeth are:

$$f_{\mathrm{pe(A\text{-}B)}}=f_{\mathrm{pe(B\text{-}D)}}=p_{\mathrm{e2(A\text{-}D)}}+p_{\mathrm{e2(D\text{-}F)}}-p_{\mathrm{e1(A\text{-}D)}}-p_{\mathrm{e1(D\text{-}F)}} \tag{5}$$

$$f_{\mathrm{pe(D\text{-}E)}}=f_{\mathrm{pe(E\text{-}F)}}=p_{\mathrm{e2(D\text{-}F)}}-p_{\mathrm{e1(D\text{-}F)}} \tag{6}$$

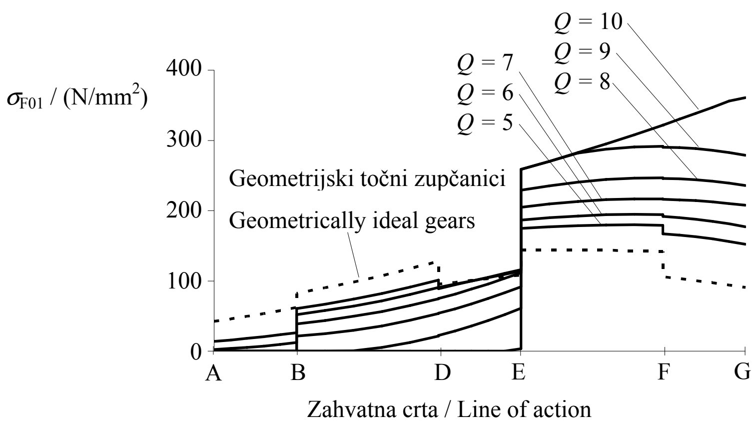
$$f_{\mathrm{pe(F\text{-}G)}}=0 \tag{7}$$

Tablica 1. Geometrijske karakteristike zupčanika
Table 1. Geometrical characteristics of gears

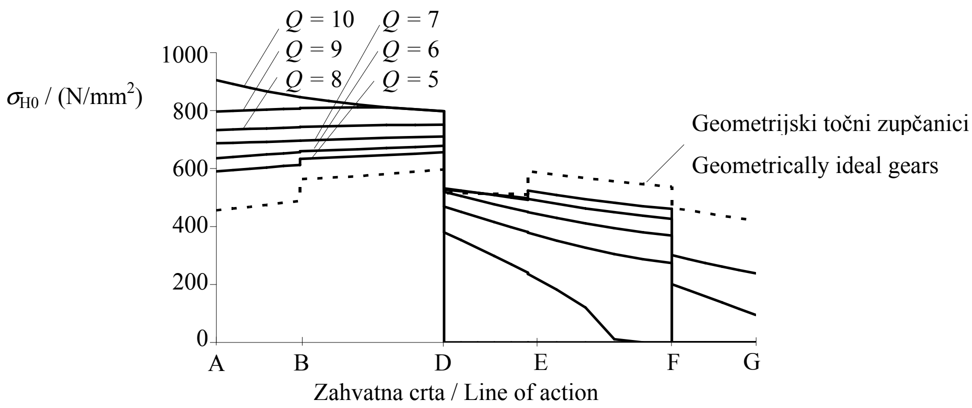
Karakteristike Characteristics	Model I	Model II	Model III	Model IV	Model V
$z_{1/2}$	27 / 54	33 / 132	40 / 160	41 / 328	58 / 67
m_n (mm)	12	12	12	5	12
α_n	16°	15°	18°	15°	16°
$h^*_{a01/2}$	1,5	1,5	1,5	1,5	1,5
$\rho^*_{a01/2}$	0,2	0,1	0,2	0,1	0,25/0,1
$c^*_{1/2}$	0,2	0,2	0,1	0,1	0,345/0,317
$x_{1/2}$	0,5 / -0,5	0,4 / 0,482	0 / 0	0,448 / 0,062	0 / 0
$b_{1/2}$ (mm)	200	150	100	200	10
$d_{a1/2}$ (mm)	367,2 / 667,2	437,8 / 1627	214 / 814	223,4 / 1654,5	724,4 / 831,7
n_1 (min^{-1})	500	500	1000	1000	424
P (kW)	1000	1250	400	750	133,67
ε_α	2,286	2,489	2,623	2,781	2,368

Primjer raspodjele naprezanja u korijenu zuba za zupčanike (Model V) s odabranim stupnjevima kvalitete Q = 5 - 10, kao i za geometrijski točne zupčanike, za kritični položaj parova zuba (Slike 3e i 4e) s obzirom na odstupanja koraka prikazan je na Slici 5. Raspodjele naprezanja na boku zuba za kritični položaj (Slike 3f i 4f) prikazane su na Slici 6.

The example of tooth root stress distributions for gears (Model V) with chosen quality grades Q = 5 - 10 as well as for geometrically ideal gears, for critical position of tooth pairs (Figures 3e and 4e), regarding the pitch error are presented in Figure 5. Contact stress distributions for critical position (Figures 3f and 4f) are presented in Figure 6.



Slika 5. Raspodjele naprezanja u korijenu pogonskog zupčanika
Figure 5. Tooth root stress distributions in pinion



Slika 6. Raspodjele naprezanja na boku zuba zupčanika
Figure 6. Contact stress distributions in gears

4. ZAKLJUČAK

Odstupanja koraka na zahvatnoj crti imaju bitan utjecaj na raspodjelu sile na parove zubi u zahvatu, a time i na naprezanja u korijenu i na boku zuba. Naprezanja se mogu značajno povećati ako stvarni kontakt nije jednak teoretskom. Analizom povećanja naprezanja provedenom na osam mogućih položaja zuba zupčanika u zahvatu s obzirom na odstupanja koraka određen je kritični položaj zuba za naprezanja u korijenu i na boku zuba zupčanika. Procedura izračuna raspodjele sile na parove zuba zupčanika trebala bi se provoditi za zube u kritičnom položaju kako bi se omogućilo što točnije određivanje nosivosti zupčanika.

4. CONCLUSION

Pitch errors have a major influence on load distribution on mating teeth and consequently on tooth root and contact stresses. The stresses can be significantly increased if theoretical contact is not equal to the real contact. The analysis of stress increase on tooth pairs with pitch errors in eight possible positions led to the determination of the critical position of teeth. The calculation procedure of load distribution should be performed on the critical positions of the gears to enable more precise calculation of their load-carrying capacity.

5. POPIS OZNAKA

5. LIST OF SIMBOLS

moment inercije	I,	m^4	moment of inertia
širina zupčanika	b	mm	face width
jedinična krutost zuba	c'	N/(mm·μm)	tooth stiffness
faktor tjemene zračnosti	c^*	-	bottom clearance factor
promjer preko glave zuba	d_a	mm	tip diameter
udio sile	F_{bti}	N	load share
jedinično odstupanje koraka	f'_{pe}	mm	single pitch error
ukupno odstupanje koraka	f_{pe}	mm	total pitch error
faktor visine glave zuba alata	h^*_{a0}	-	tool addendum factor
modul u normalnom presjeku	m_n	mm	normal module
brzina vrtnje	n	min^{-1}	rotational speed
snaga	P	kW	transmitted power
korak na zahvatnoj crti	p_e	mm	pinion's base pitch
stupanj kvalitete ozubljenja	Q	-	quality grade
faktor pomaka profila	x	-	addendum modification coefficient
broj zubi zupčanika	z	-	number of teeth
kut zahvata	α_n	°	normal pressure angle
stupanj prekrivanja profila	ε_α	-	transverse contact ratio
faktor polumjera zakrivljenosti zuba alata	ρ^*_{a0}	-	tip radius of the tool factor
točke na zahvatnoj crti	A, B, D, E, F, G		points on path of contact

indeksi:

pogonski zupčanik	1	pinion
gonjeni zupčanik	2	wheel
točka na zahvatnoj crti	*i*	point on the path of contact
na zahv. crti između A i B	(A-B)	on the path of contact between points A and B
na zahv. crti između B i D	(B-D)	on the path of contact between points B and D
na zahv. crti između D i E	(D-E)	on the path of contact between points D and E
na zahv. crti između E i F	(E-F)	on the path of contact between points E and F
na zahv. crti između F i G	(F-G)	on the path of contact between points F and G
na zahv. crti između A i D	(A-D)	on the path of contact between points A and D
na zahv. crti između B i E	(B-E)	on the path of contact between points B and E
na zahv. crti između D i F	(D-F)	on the path of contact between points D and F

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