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MODIFICATION OF DRIVE ROLLER CHAIN LINK PLATES

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***Summary**. The article deals with the problem of effect assessment on strain-stress state of drive roller chain link plates, their shapes and dimensions. It is noticed that decrease of strain concentration in plates cross-section depends on their dimensions and shape. Optimal plate shape providing sufficient decrease of stress coefficient and thereby increase of chain durability on fatigue resistance is determined.*
***Key words:** drive roller chain, chain link, link plate, plate strain-stress state.*

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Problem statement. Drive roller chains are used in various machines and mechanisms (internal combustion engines, drilling rigs, helicopters, agricultural machines, etc.) with the speed of operating strand up to 20 m/sec. and transmitting power up to 750 kW. As the result exclusive standards to reliability of drive roller chains are required. Optimization of plates shape providing decrease of stress concentration in their cross-sections is one of the ways of problem solution. Long-term practice of chain gears maintenance has defined various options of drive chain structural designs (chain links and their parts), the most widely used ones are shown in Fig. 1 and Fig. 2. Plates with cam contour („figure-eight“ type) shown in Fig. 2 are considered to be the classical shape of link plates.

Stress concentration in cross sections of drive roller chain link plates is one of the factors determining durability of plates and chain as well and chain gear operational reliability. Thus link plates modification due to their shape optimization providing stress concentration decrease and operational reliability increase in heavy loaded high-speed drives is of vital importance.

Figure 1. Link plates with straight side edges – primary in fine-pitch drive chains

Figure 2. Link plates with curved side edges („figure-eight“ type) – in most drive chains (classical shape)

Analyses of recent researches and papers. Researchers of shapes and strain-stress state (SSS) of drive roller chain link plates are considered in papers [1, 3, 6, 7]. It is well known that the plate shape affects the stress concentration in their cross sections and as the author notes [1], plate classical shape of „figure-eight“ type (Fig. 2) with the largest width b (Fig. 4) providing lower plate weight at other states being equal, reduces its durability in 1.25 – 1.5 times in comparison with straight side edged plate (Fig. 1). in such a case even partial replacement of curved surfaces of side edges by flat ones (Fig. 3) provides significant increase of plates durability (according to the data [2] up to 30%). Strain-stress state (SSS) of drive roller chain link plates is has been almost completely investigated on the basis of mathematical modelling by means of finite-element method (FEM) using universal CAE-system „ANSYS“ in paper [3]. Estimation of design-engineering perfection of drive chains is widely presented in papers [6, 7]. But at the same time the problem of plates modification by means of their shape optimization is not sufficiently covered in literature sources.

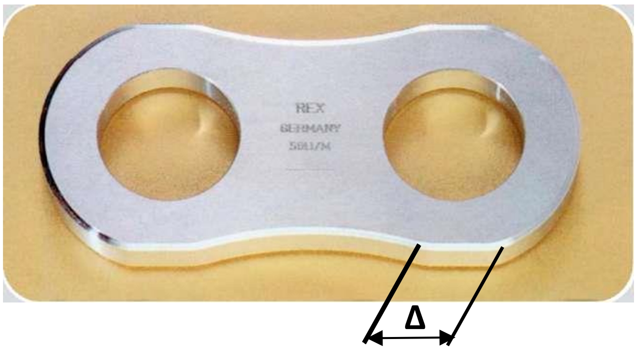

Figure 3. Plates with „flattenings“ – plate side edges containing sections with curved and flat surfaces (Δ) (firm Rexnord Kette GmbH – [2])

Research objective is to derive modified shape with decreased stresses in cross-sections using FEM and universal CAE-system „ANSYS“ and carrying out experimental researches.

The main purpose of the research. To investigate stresses concentration in the link plates under its Δ flattening produced by different construction solutions: changing of eye end height R; changing radius value R_1 by contour rounding plate end portions and cove radii R_c (ratio of radius r with holes in the plate).

Results of the researches. Parameter-oriented model developed for this purpose was represented as combination of finite-element models of outer chain link and its two inner links. Inner (IP) and outer (OP) plates of simplex chains with 25.4 mm pitch (plate thickness δ is 3.2 mm) were taken as initial for this experiment.

Determination of the plate SSS parameters was conducted in intervals of Δ „flattening“ values, provided that interval limits were determined taking into consideration the limits for eye end height R dimensions and radius values R_1 of contour rounding by condition of chain links assembly and possibility of their mutual rotation on transmission gear while in operation. Values of the plate width b and b_1, hole diameters 2r and thickness δ were constant. Fracture loading on the plate was 32.5 Kn.

Plate contour modification was realized in „flattening“ versions I, II and III (three total) on standard (without „flattening“) plates of manufacturer „A“ (Fig. 4 – 7). In all versions the plate width b_1 met the requirements $b_1 \geq (b-2r)$.

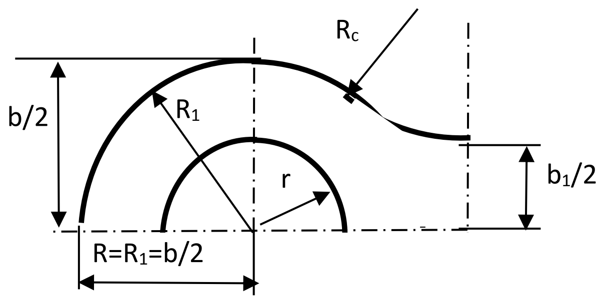

Figure 4. Standard plate of „figure-eight“ type (without flattening)

SSS dimensions and parameters of OP and IP plates of manufacturer „A“ are given in Table 1 and Table 2.

Table 1

SSS dimensions and parameters of IP plates of manufacturer „A“

Δ, mm	b, mm	b_1, mm	δ, mm	2r, mm	R_1, mm	R_c, mm	G, g	σ_{nom}, MPa	σ_{Max}, MPa	$\alpha_{\sigma K}$
0,00	23,0	18	3,20	11,67	11,500	22,008	17,971	896,403	2543,554	2,838

Let us denote henceforward: G-plate weight (while relative density of the material is 7.85 g/cm^3), σ_{nom} and σ_{Max} are nominal and maximum stresses in plate cross section respectively; α_σ is concentration value.

Table 2

SSS dimensions and parameters of OP plates of manufacturer „A“

Δ, mm	b, mm	b_1, mm	δ, mm	2r, mm	R_1, mm	R_c, mm	G, g	σ_{nom}, MPa	σ_{Max}, MPa	$\alpha_{\sigma K}$
0,00	20,0	15	3,20	7,75	10,000	23,508	16,467	829,082	3330,631	4,017

Flattenings were made on the side edge to the left of hole axis (Fig. 5, type I, increased eye end height), symmetrically relatively to hole axis (Fig. 6, type II, increased eye end height and rounding radius of the plate) and to the right of hole axis (Fig. 7, type III).

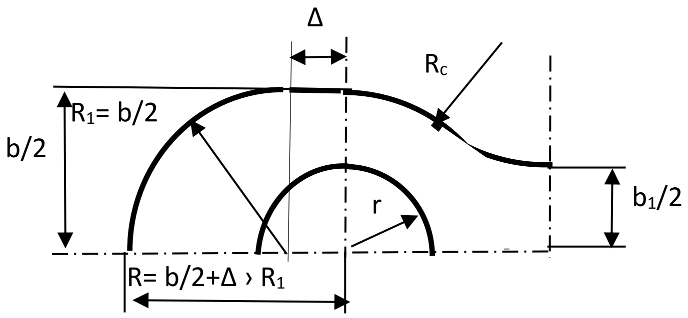

Figure 5. The plate with increased eye end height R– type I (with flattening Δ)

SSS dimensions and parameters of IP and OP plates by type I are given in Tables 3 and 4.

Table 3

SSS dimensions and parameters of IP plates by type I

Δ*, mm	B, mm	b_1, mm	δ, mm	2r, mm	R_1, mm	R_c, mm	G, g	σ_{nom}, MPa	σ_{max}, MPa	$\alpha_{\sigma\kappa}$
0,000	23,0	18	3,20	11,67	11,500	22,008	17,971	896,403	2543,554	2,838
0,120	23,0	18	3,20	11,67	11,500	22,008	18,110	896,403	2530,513	2,823
0,240	23,0	18	3,20	11,67	11,500	22,008	18,248	896,403	2517,819	2,809
0,360	23,0	18	3,20	11,67	11,500	22,008	18,387	896,403	2505,460	2,795
0,480	23,0	18	3,20	11,67	11,500	22,008	18,526	896,403	2493,426	2,782
0,600	23,0	18	3,20	11,67	11,500	22,008	18,664	896,403	2481,708	2,769
0,720	23,0	18	3,20	11,67	11,500	22,008	18,803	896,403	2470,295	2,756
0,840	23,0	18	3,20	11,67	11,500	22,008	18,942	896,403	2459,184	2,743
0,960	23,0	18	3,20	11,67	11,500	22,008	19,080	896,403	2448,361	2,731
1,080	23,0	18	3,20	11,67	11,500	22,008	19,219	896,403	2437,820	2,720
1,200	23,0	18	3,20	11,67	11,500	22,008	19,352	896,403	2427,979	2,709

Table 4

SSS dimensions and parameters of OP plates by type I

Δ*, mm	b, mm	b_1, mm	δ, mm	2r, mm	R_1, mm	R_c, mm	G, g	σ_{nom}, MPa	σ_{max}, MPa	$\alpha_{\sigma\kappa}$
0,000	20,0	15	3,20	7,75	10,000	23,508	16,467	829,082	3330,631	4,017
0,270	20,0	15	3,20	7,75	10,000	23,508	16,738	829,082	3293,431	3,972
0,540	20,0	15	3,20	7,75	10,000	23,508	17,009	829,082	3263,070	3,936
0,810	20,0	15	3,20	7,75	10,000	23,508	17,280	829,082	3227,655	3,893
1,080	20,0	15	3,20	7,75	10,000	23,508	17,552	829,082	3198,571	3,858
1,350	20,0	15	3,20	7,75	10,000	23,508	17,823	829,082	3175,917	3,831
1,620	20,0	15	3,20	7,75	10,000	23,508	18,094	829,082	3151,237	3,801
1,890	20,0	15	3,20	7,75	10,000	23,508	18,366	829,082	3128,461	3,773
2,160	20,0	15	3,20	7,75	10,000	23,508	18,637	829,082	3107,173	3,748
2,430	20,0	15	3,20	7,75	10,000	23,508	18,908	829,082	3087,508	3,724
2,700	20,0	15	3,20	7,75	10,000	23,508	19,174	829,082	3069,441	3,702

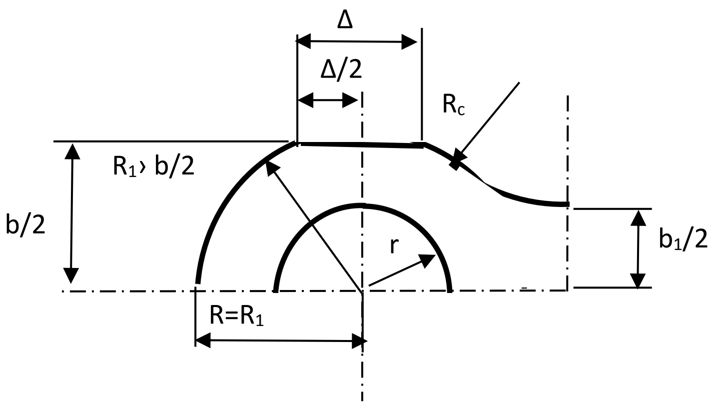

Figure 6. The plate with side edges cut, increased eye end height R and rounding radius R_1 – type II (with flattering Δ, symmetrical relatively to hole axis in the plate)

When constructing the plates according to Fig. 6 the following relations (1) are used:

$$R_c = \left(t^2 + b_1^2 - 4R_1^2\right)/(8R_1 - 4b_1)\text{, where } R_1 = \left[(b/2)^2 + (\Delta/2)^2\right]^{0,5} \quad (1)$$

Substituting the constant values of plate IP (t=25,4 mm; $b_{1\text{-}IP}$=18 mm; b_{IP}=23 mm; Δ_{IP}/2=0…5,3889 mm) into (1) gives dependences (2) and (3) for $R_{1\text{-}IP}$ and $R_{c\text{-}IP}$ values calculation as function Δ_{IP}:

$$R_{1-IP} = \left[132,25 + \left(\Delta_{IP}/2\right)^2\right]^{0,5}\text{, mm;} \quad (2)$$

$$R_{c-IP} = \left(440.16 - \Delta_{IP}^2\right)/\left(4\left[529 + \Delta_{IP}^2\right]^{0,5} - 72\right)\text{, mm.} \quad (3)$$

By analogy for plates OP (t=25,4 mm; $b_{1\text{-}EP}$=15 mm; b_{EP}=20 mm; Δ_{EP}/2=0…7,8288 mm) dependences (4) and (5) are derived:

$$R_{1-EP} = \left[100 + \left(\Delta_{EP}/2\right)^2\right]^{0,5}\text{, mm;} \quad (4)$$

$$R_{c-EP} = \left(470,16 - \Delta_{EP}^2\right)/\left[4\left(400 + \Delta_{EP}^2\right)^{0,5} - 60\right]\text{, mm.} \quad (5)$$

SSS dimensions and parameters of IP and OP plates by type II are given in Tables 5 and 6.

Table 5

SSS dimensions and parameters of IP plates by type II

Δ*, mm	b, mm	b_1, mm	δ, мм	2r, mm	R_1, mm	R_c, mm	G, g	σ_{nom}, MPa	σ_{Max}, MPa	$\alpha_{\sigma к}$
0,000	23,0	18	3,20	11,67	11,500	22,008	17,971	896,403	2543,424	2,837
1,078	23,0	18	3,20	11,67	11,513	21,840	18,002	896,403	2561,176	2,857
2,156	23,0	18	3,20	11,67	11,550	21,345	18,093	896,403	2549,409	2,844
3,234	23,0	18	3,20	11,67	11,613	20,555	18,237	896,403	2521,385	2,813
4,312	23,0	18	3,20	11,67	11,700	19,515	18,431	896,403	2500,478	2,789
5,390	23,0	18	3,20	11,67	11,811	18,279	18,668	896,403	2487,178	2,775
6,468	23,0	18	3,20	11,67	11,946	16,902	18,946	896,403	2467,839	2,753
7,546	23,0	18	3,20	11,67	12,103	15,439	19,261	896,403	2434,309	2,716
8,624	23,0	18	3,20	11,67	12,282	13,935	19,608	896,403	2407,015	2,685
9,702	23,0	18	3,20	11,67	12,481	12,427	19,984	896,403	2361,627	2,635
10,778	23,0	18	3,20	11,67	12,700	10,978	20,379	896,403	2333,364	2,603

Table 6

SSS dimensions and parameters of OP plates by type II

Δ*, mm	b, mm	b_1, mm	δ, mm	2r, mm	R_1, mm	R_c, mm	G, g	σ_{nom}, MPa	σ_{max}, MPa	$\alpha_{\sigma к}$
0,000	20,0	15	3,20	7,75	10,000	23,508	16,467	829,082	3330,567	4,017
1,566	20,0	15	3,20	7,75	10,031	23,103	16,533	829,082	3319,002	4,003
3,132	20,0	15	3,20	7,75	10,122	21,948	16,721	829,082	3310,910	3,993
4,698	20,0	15	3,20	7,75	10,272	20,205	17,011	829,082	3280,239	3,956
6,264	20,0	15	3,20	7,75	10,479	18,083	17,389	829,082	3245,002	3,914
7,830	20,0	15	3,20	7,75	10,739	15,780	17,840	829,082	3199,186	3,859
9,396	20,0	15	3,20	7,75	11,048	13,453	18,353	829,082	3155,975	3,807
10,962	20,0	15	3,20	7,75	11,403	11,209	18,917	829,082	3110,818	3,752
12,528	20,0	15	3,20	7,75	11,799	9,107	19,525	829,082	3055,492	3,685
14,094	20,0	15	3,20	7,75	12,233	7,172	20,172	829,082	3013,441	3,635
15,658	20,0	15	3,20	7,75	12,700	5,426	20,845	829,082	2964,718	3,576

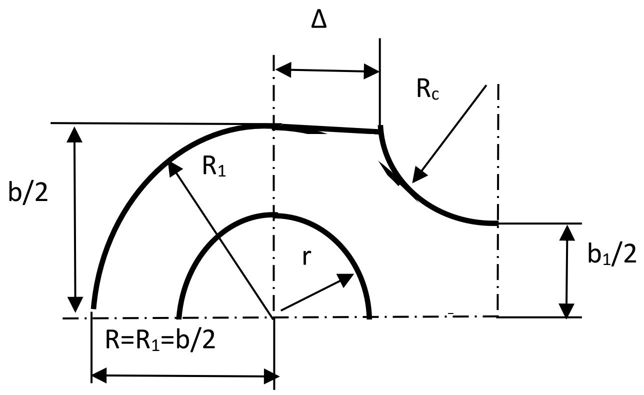

Figure7. The plate with Δ flattening shifted from hole axis towards the plate symmetry axis – version III

When constructing the plates according to Fig. 7 the following relations (6) are used:

$$R_c = \left[(t-2\Delta)^2 + (b-b_1)^2\right] / \left[4(b-b_1)\right]; \; R_{c\min} = (b - b_1/2). \tag{6}$$

Substituting the constant values of plate OP (t=25,4 mm; $b_{1\text{-ВП}}$=18 mm; $b_{ВП}$=23 mm) and IP (t=25,4 mm; $b_{1\text{-EP}}$=15 mm; b_{EP}=20 mm) into (6) gives $\Delta_{\text{maxIP}}=\Delta_{\text{maxEP}}$ =10,2 mm and dependence (12) and for $R_{c\text{-IP}}$ and $R_{c\text{-EP}}$ values calculation as function $\Delta_{IP(EP)}$:

$$R_{c-IP(EP)} = \left[(25{,}4 - 2\Delta)^2 + 25\right]/20 \text{, mm.} \tag{7}$$

SSS dimensions and parameters of IP and OP plates by type III are given in Tables 7 and 8.

Table 7

SSS dimensions and parameters of IP plates by type III

Δ*, mm	b, mm	b_1, mm	δ, mm	2r, mm	R_1, mm	R_c, mm	G, g	σ_{nom}, MPa	σ_{Max}, MPa	$\alpha_{\sigma\kappa}$
2,512	23,0	18	3,20	11,67	11,5	22,009	18,011	896,403	2664,945	2,973
3,281	23,0	18	3,20	11,67	11,5	18,994	18,139	896,403	2656,783	2,964
4,050	23,0	18	3,20	11,67	11,5	16,216	18,265	896,403	2646,600	2,952
4,818	23,0	18	3,20	11,67	11,5	13,674	18,392	896,403	2608,821	2,910
5,587	23,0	18	3,20	11,67	11,5	11,368	18,518	896,403	2600,338	2,901
6,356	23,0	18	3,20	11,67	11,5	9,299	18,643	896,403	2590,116	2,889
7,123	23,0	18	3,20	11,67	11,5	7,467	18,767	896,403	2568,233	2,865
7,894	23,0	18	3,20	11,67	11,5	5,870	18,891	896,403	2560,188	2,856
8,662	23,0	18	3,20	11,67	11,5	4,510	19,013	896,403	2551,485	2,846
9,431	23,0	18	3,20	11,67	11,5	3,387	19,131	896,403	2531,548	2,824
10,200	23,0	18	3,20	11,67	11,5	2,505	19,242	896,403	2514,871	2,806

Table 8

SSS dimensions and parameters of OP plates by type III

Δ*, mm	b, mm	b_1, mm	δ, mm	2r, mm	R_1, mm	R_c, mm	G, g	σ_{nom}, MPa	σ_{Max}, MPa	$\alpha_{\sigma\kappa}$
2,151	20,0	15	3,20	7,75	10,0	23,506	16,496	829,082	3284,646	3,962
2,956	20,0	15	3,20	7,75	10,0	20,239	16,630	829,082	3275,514	3,951
3,761	20,0	15	3,20	7,75	10,0	17,232	16,762	829,082	3266,569	3,940
4,566	20,0	15	3,20	7,75	10,0	14,483	16,895	829,082	3259,434	3,931
5,371	20,0	15	3,20	7,75	10,0	11,994	17,027	829,082	3254,860	3,926
6,176	20,0	15	3,20	7,75	10,0	9,764	17,158	829,082	3247,000	3,916
6,980	20,0	15	3,20	7,75	10,0	7,793	17,289	829,082	3241,271	3,909
7,785	20,0	15	3,20	7,75	10,0	6,081	17,418	829,082	3236,545	3,904
8,590	20,0	15	3,20	7,75	10,0	4,628	17,546	829,082	3231,689	3,898
9,395	20,0	15	3,20	7,75	10,0	3,434	17,670	829,082	3228,609	3,894
10,200	20,0	15	3,20	7,75	10,0	2,505	17,789	829,082	3225,724	3,891

* – in tables 3 – 8 measurement pitch Δ was assumed to be equal to 0.1 of measurement interval Δ

Analyzing data given in tables 1 – 8 it can be noted that the lightest are manufacturer's chain plates of type I and II (identical to factory ones) at zero flattening. When flattenings reach their maximum values the plates of type III have the lowest weight. Stress concentration values decrease (in comparison with the same ones in manufacturer's plates) when flattenings increase for all three modification types, moreover the lowest values are obtained for the plates of type III.

Considering direct metal savings we had rather dwell on the version with manufacturer's lighter plates. But reduce of chain durability at high values of stress concentration requires from chain manufacturers to increase overall production of the latter ones resulting in inexpediency of primary metal savings. In view of this while choosing the version of plate modification we suggested to use complex criterion of conditional relative metal consumption of specific metal content (SMC) (8):

$$SMC = (G_M / G_S)\cdot(\alpha_{\sigma M} / \alpha_{\alpha S})^m , \qquad (8)$$

G_M and G_S – being the weights of modified and standard plates correspondingly; $\alpha_{\sigma M}$ and $\alpha_{\sigma S}$ – values of stress concentration in modified and standard „B“ (manufacturer’s) plates correspondingly; m – fatigue curve index for drive roller chains, m=6,95 [4].

The results of SMC index calculations on the basis of experimental data from tables 1 – 8 are given in Table 9.

Table 9

Indicator values of conditional metal consumption of SMC

D	Conditional relative metal consumption of SMC							
	IP plate				OP plate			
	Version				Version			
	B	I	II	III	Б	I	II	III
0,0	1	1	0,997556	1,384315	1	1	1	0,910232
0,1	1	0,971297	1,049274	1,365076	1	0,939911	0,979941	0,900065
0,2	1	0,945460	1,021674	1,336348	1	0,896562	0,974001	0,889800
0,3	1	0,920142	0,954278	1,218084	1	0,843893	0,928817	0,882718
0,4	1	0,897544	0,908672	1,200310	1	0,805028	0,881571	0,881780
0,5	1	0,875267	0,888723	1,174091	1	0,778518	0,819713	0,872953
0,6	1	***0,853411***	***0,853417***	1,115331	1	0,748332	0,767407	0,868748
0,7	1	0,831931	0,789736	1,098411	1	***0,721532***	***0,714900***	0,867479
0,8	1	0,812840	0,742315	1,078885	1	0,699121	0,651027	0,864563
0,9	1	0,796113	0,663897	1,028582	1	0,678314	0,611677	***0,864482***
1,0	***1***	***0,779361***	***0,621898***	***0,989577***	***1***	***0,660104***	***0,564137***	0,865655

* D – flattening in interval fraction from minimum Δ_{min} to maximum Δ_{max} flattening values on the plate

SMC values responding the most perfect combinations of plates dimensions of various versions are boldface italicized in Table 9. It should be noticed that flattening version by type III has a definite effect but it is substantially smaller than in versions I and II (for these versions the effects are much the same at flattening values within the limits 0.6 – 0.7 of maximum values D). Dependences of SMC changes on flattening changes for OP plates versions by type I and II of chain links with 25.4 mm pitch are shown as examples in Fig. 8. Experimental data approximation was done by polynomial (9) and (10) with approximation reliability R^2 equal to 0,9995 and 0,9988 for plate versions by type I and II correspondingly:

$$\text{OP- I:} \quad SMC = -0{,}1312D^3 + 0{,}4133D^2 - 0{,}6224D + 1{,}0000\,; \qquad (9)$$

$$\text{OP- II:} \quad SMC = 0{,}5356D^3 - 0{,}9799D^2 + 0{,}0134D + 0{,}9974 \qquad (10)$$

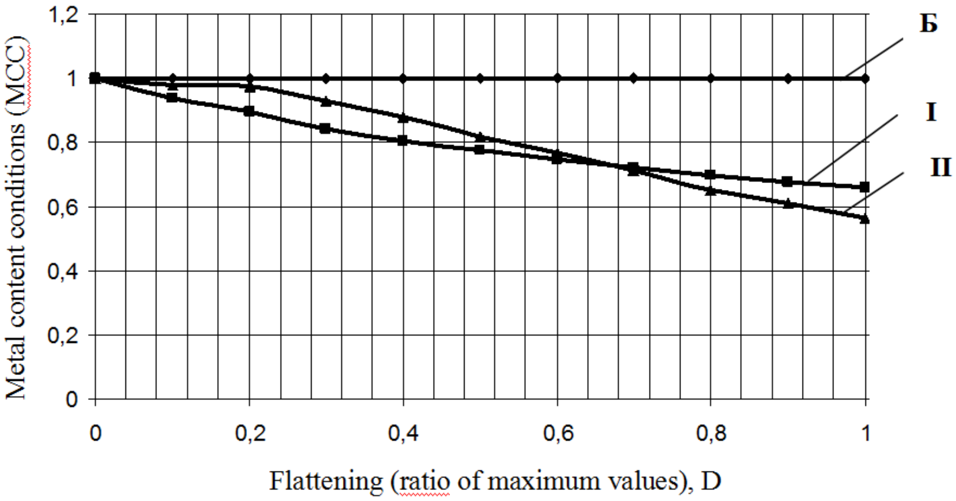

Figure 8. SMC dependence on OP plate flattening.

It is reasonable to assume flattening values within the limits (0,9 – 1,0) maximum possible for each version. Taking into account SMC values we can suggest that real metal saving in chain production (provided that plates weight in the chain equals to 50 – 60% of total chain weight) comprises about 15% and 20% for I and II type versions (if IP and OP plates version is produced in the same form). Greater effect is reached on the plates of outer links. In such a case the weights of chain plates and chains in total can exceed similar chain characteristics of the manufacturer specific failure loading (SFL) [2, 6, and 7] can be slightly lower. Hence, for more objective choice of chain design, it is necessary to use not only SFL criterion but SMC value of conditional relative metal consumption of chain plates as well.

Conclusions.

Stress concentration values in cross sections of drive roller chain plates depend on relations of plate dimensions and shape.

Reduction of concentration values is possible due to various plate versions using flat sectors (flattenings) on the plate side edges (at possible flattening values on the plates of inner links of 25.4 pitch chains reduction of concentration value amounts to 4,55 – 8,25%, on outer link plates – 1,79 – 10,98%).

Plate version by type II (the plate with side edges cut, increased eye end height and rounding radius and flattering, symmetrical relatively to hole axis in the plate), allowing decrease of concentration value by 8,25% and 10,98% for plates of inner and outer links correspondingly (equivalent to chain durability increase in regards to plate fatigue strength by 73,5% with increase of the chain weight by about 10%) can be considered as the most advantageous. Differences between concentration values effect reduce on inner and outer chain link plates can be explained by relation of plate width dimensions and hole diameters in them for use as joint parts (hub and shaft relatively) which for investigated plates equal to 1,97 and 2,58 correspondingly.

Version by type III (with Δ flattening shifted from hole axis towards the plate symmetry axis) has not a meaningful effect and its use is not advantageous.

For integrated assessment of the chain design excellence it is necessary to use criteria of specific failure loading and conditional relative metal consumption of the plates.

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МОДИФІКАЦІЯ ПЛАСТИН ЛАНОК ПРИВОДНИХ РОЛИКОВИХ ЛАНЦЮГІВ

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Резюме. *Стаття присвячена оцінюванню впливу форми і розмірів пластин ланок приводних роликових ланцюгів на їх напружено-деформований стан. Відзначено, що зниження концентрації напружень у перерізах пластин залежить від їх розмірів і форми. Встановлено оптимальну форму пластин, яка дозволяє суттєво знизити коефіцієнт напружень і тим самим підвищити довговічність ланцюга за опором втоми.*

Ключові слова: *приводний роликовий ланцюг, ланка ланцюга, з'єднувальна пластина, пластина деформованого стану стресу.*

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