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EFFECT OF ASYMMETRICAL ROLLING ON BROADENING OF THE PRODUCT LINE OF ROLLED SHEETS

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An analysis of asymmetrical band rolling in the last two stands of a finishing sheet hot rolling mill has been performed in the study. Investigations were carried out to determine the range of values of roll peripheral speed asymmetry ratios which would assure the permissible bending of band upon its exit from the roll gap and to reduce the value of the overall metal pressure on the rolls without causing overloading of the drives of the finishing group of the continuous sheet rolling mill. The application of asymmetrical rolling on the last two stands has made it possible to reduce deviations in band thickness, decrease the minimum thickness of finished sheet from 2.00 mm to 1.80 mm and increase the width of sheets produced in the thickness range from 1.80 - 2.00 mm to above 925 mm.

Key words: *hot rolling of thin plates, asymmetric rolling, band curvature, force parameters*

Efekt asimetričnog valjanja za proširivanje proizvodne linije valjanih limova. U ovom radu je provedena analiza asimetričnog valjanja trake na prolazu kroz dva zadnja stana završne pruge za toplo valjanje limova. Izvršena su istraživanja radi određivanja odnosa opsega vrijednosti periferne asimetrije brzine valjanja koja bi treba osigurati dozvoljeno savijanje trake nakon njenog izlaska iz stana i smanjiti ukupnu vrijednost tlaka metala na valjke da ne dođe do preopterećivanja pogona u završnom dijelu pruge za kontinuirano valjanje limova. Primjena asimetričnog valjanja u 2 zadnja stana omogućila je smanjenje odstupanja u debljini trake, smanjenje minimalne debljine lima s 2.00 mm na 1.80 mm i povećanje širine limova proizvedenih s debljinom od 1.80 - 2.00 mm na širinu od 925 mm.

Ključne riječi: *toplo valjanje tankih ploča, asimetrično valjanje, zakrivljenost trake, parametri sile*

INTRODUCTION

A small tolerance of thickness on the length and width of the band is required. From many works, realized in Institute of Modelling and Automation of Plastic Working Processes, it follows that better geometric quality of rolled bands can be obtained also by the application of asymmetric rolling process.

The use of asymmetrical rolling can be compared with the use of tension and back tension with resulting reduction of the force of the overall metal pressure on the rolls. A lower value of the pressure force means a smaller elastic deflection of working stand elements and a possibility of using smaller values of working roll bending forces [1-4].

There are no concrete guidelines in the literature concerning the choice of the values of roll peripheral speed asymmetry ratio for real sheet rolling mills, at which a reduction of the forces of the overall metal pressure on the rolls and either a straight band or the one with a small curvature enabling the accomplishment of the rolling process in successive rolling stands and band coiling will be obtained.

The theoretical analysis of the asymmetrical rolling process was performed by using the Elroll and FORGE2 programs for bands rolled to a final thickness of $h_1 = 1.80$ mm to $h_1 = 6.00$ mm. The range of rolling reductions used was $\varepsilon = 0.10 - 0.40$ for stand F9 and $\varepsilon = 0.07 - 0.20$ for stand F10. The peripheral roll speed asymmetry factor was changed in the range $a_v = 0.95 - 1.05$. The verification and implementation of the theoretical investigation of asymmetrical sheet rolling in a continuous system were carried out in the sheet hot rolling mill of an industrial works.

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EFFECT OF THE ASYMMETRY FACTOR R_n/R_d ON BAND CURVATURE

Examples of the results of testing the effect of roll speed asymmetry, R_n/R_d, deformation, ε, and the band shape ratio, H_0/R, on the value of unit pressure in the last-but-one stand for bands rolled to a final thickness of 1.94 mm,

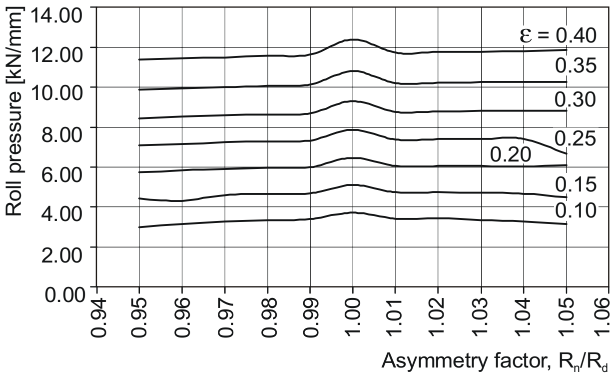

Figure 1. **Effect of the asymmetry factor R_n/R_d on the value of unit roll pressure H_1 = 1.94 mm (stand F9)**

Slika 1. **Efekt faktora asimetrije R_n/R_d na vrijednost jedinice tlaka valjka H_1 = 1.94 mm (valjački stan F9)**

3.53 mm and 6.67 mm, respectively, are shown in Figures 1. through 3.

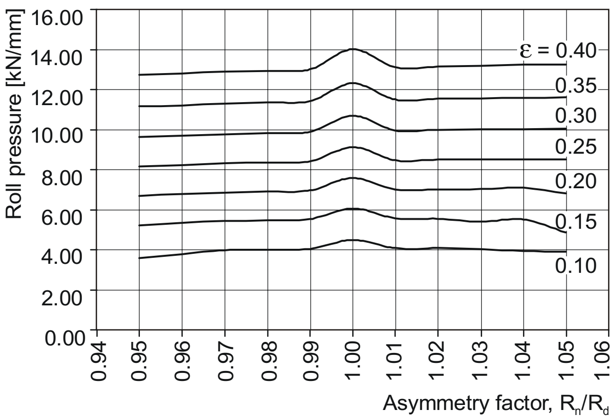

Figure 2. **Effect of the asymmetry factor R_n/R_d on the value of unit roll pressure H_1 = 3.57 mm (stand F9)**

Slika 2. **Efekt faktora asimetrije R_n/R_d na vrijednost jedinice tlaka valjka H_1 = 3.57mm (valjački stan F9)**

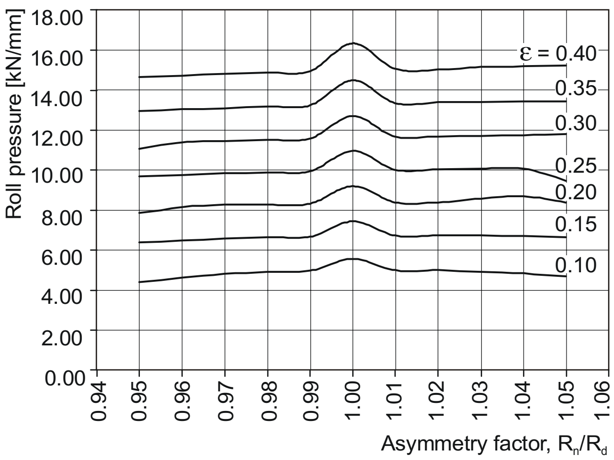

Figure 3. **Effect of the asymmetry factor R_n/R_d on the value of unit roll pressure H_1 = 6.67 mm (stand F9)**

Slika 3. **Efekt faktora asimetrije R_n/R_d na vrijednost jedinice tlaka valjaka H_1 = 6.67 mm (valjački stan F9)**

The data given in Figures 1. - 3. indicates that the application of asymmetrical rolling has resulted in a reduction of the value of pressure per unit width of the rolled sheet by (7 - 10 %) compared to symmetrical rolling (a_v = 1.00).

The largest drop in pressure (by as much as 16 %) occurred for the values of speed asymmetry ration a_v = 1.01 and a_v = 0.99.

Increasing speed asymmetry in the last-but-one stand from a_v = 0.99 to a_v = 0.98 and from a_v = 1.01 to a_v = 1.02 cause a further, but this time only a slight decrease in the value of metal pressure on the rolls. The maximum decrease in the value of unit pressure for asymmetrical rolling on this stand amounted to about 20% for the maximum investigated values of the ratio of a_v = 1.05.

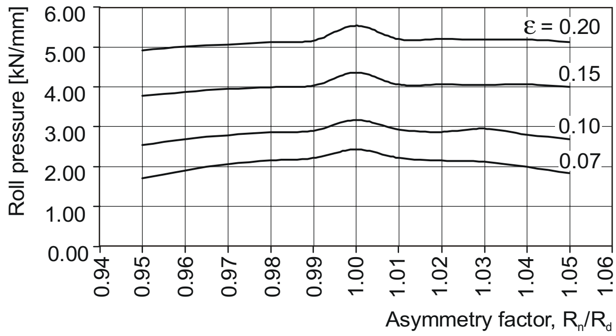

Figure 4. **Effect of the asymmetry factor R_n/R$_d$ on the value of unit roll pressure H_1= 1.80 mm (stand F10)**

Slika 4. **Efekt faktora asimetrije R_n/R_d na vrijednost jedinice tlaka valjaka H_1 = 1.80 mm (valjački stan F10)**

EFFECT OF THE ASYMMETRY FACTOR R_n/R_d ON THE TOTAL ROLL SEPARATING FORCE

Figures 4. - 6. show examples of the results of examination of the effect of roll speed asymmetry, R_n/R_d, deformation, ε, and the band shape ratio, H_0/R, on the value of unit pressure on the last stand for bands rolled to a final thickness of 1.80 mm, 3.00 mm and 6.00 mm, respectively.

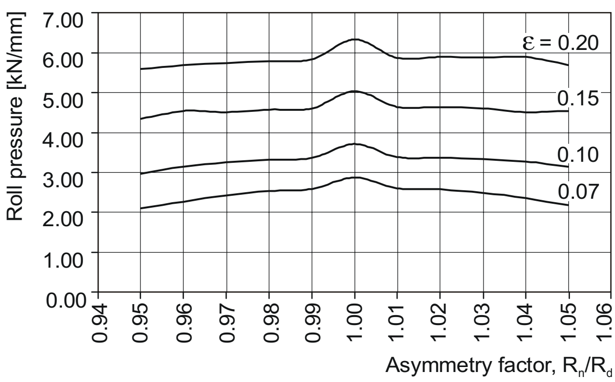

Figure 5. **Effect of the asymmetry factor R_n/R_d on the value of unit roll pressure H_1 = 3.00 mm (stand F10)**

Slika 5. **Efekt faktora asimetrije R_n/R_d na vrijednost jedinice tlaka valjaka H_1 = 3.00 mm (valjački stan F10)**

In the last rolling stand, the effect of the roll peripheral speed asymmetry ratio on the value of unit pressure of metal on the rolls is similar. The largest drop in the pressure force (by 10 - 14 %) is observed for small values of speed asymmetry ratio, that is $a_v = 0.99$ and $a_v = 1.01$.

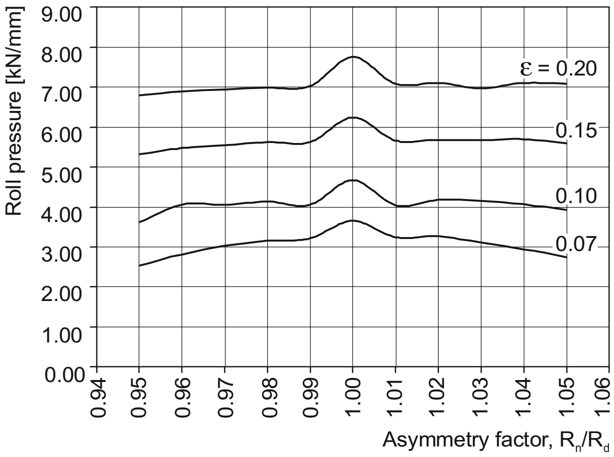

Figure 6. **Effect of the asymmetry factor R_n/R_d on the value of unit roll pressure H_1 = 6.00 mm (stand F10)**
Slika 6. **Efekt faktora asimetrije R_n/R_d na vrijednost jedince tlaka valjaka H_1 = 6.00 mm (valjački stan F10)**

Increasing speed asymmetry on the last-but-one stand from $a_v = 0.99$ to $a_v = 0.98$ and from $a_v = 1.01$ to $a_v = 1.02$ produces a further, though negligible decrease in the value of metal-to-roll pressure force.

From the tests carried out no significant relationships between further changes in the pressure force were found depending on the thickness of band rolled and deformation applied.

The reduction of the value of unit metal-to-roll pressure force as a result of applying asymmetric rolling, for the smallest range of speed asymmetry ($a_v = 0.99$ and $a_v = 1.01$) by about 7 - 10 % on the last-but-one stand and by 10 - 14 % in the last stand, will cause a reduction of the force of the overall metal pressure on the rolls by the same value.

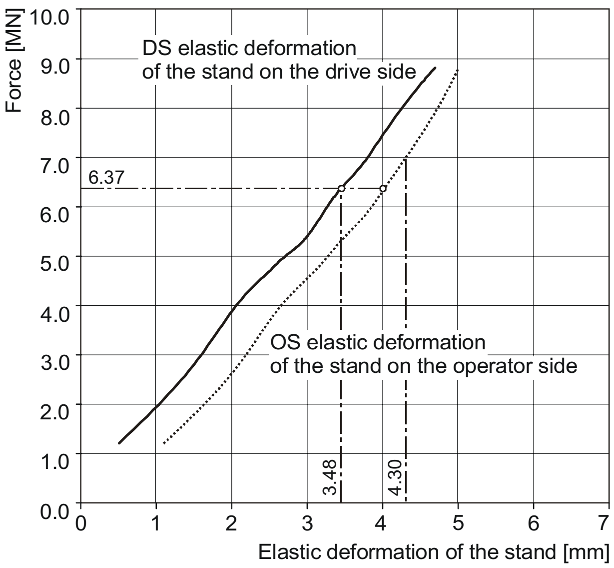

Figure 7. **Deformation curves of the stand F9**
Slika 7. **Deformacija krivulja valjačkog stana F9**

The data given in Figure 7. indicate that in symmetrical rolling with a pressure force of 7000 kN, the elastic deformation of the stand is 3.80 mm on the drive side and 4.30 mm on the operator side. Reducing the pressure force to the value of 6370 kN will result in a elastic deflection of the stand lower by 0.32 mm on the drive side and by 0.30 on the operator side.

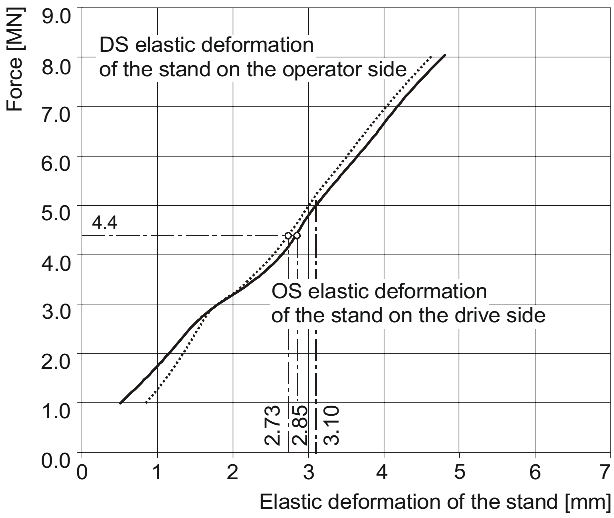

Figure 8. **Deformation curves of the stand F10**
Slika 8. **Deformacija krivulja valjačkog stana F10**

It can be found from Figure 8. that during symmetrical rolling, for an overall pressure force of 5000 kN, the elastic deformation of the stand is 3.00 mm on the operator side and 3.10 mm on the drive side. Decreasing this force to the value of 4400 kN as a result of applying asymmetrical rolling will cause a reduction of the elastic deflection of the stand by 0.27 mm on the operator side and by 0,25 mm on the drive side.

Thanks to applying even the lowest values of the speed asymmetry ratio ($a_v = 0.99$ and $a_v = 1.01$) it was possible to reduce the minimum thickness of sheets able to be rolled from about 2.00 mm to 1.80 mm, while increasing at the same time the minimum rollable width of those sheets was from 865 mm to 950 mm.

The results of computer simulations were confirmed by experimental tests carried out in the sheet hot rolling mill of an industrial works.

EXPERIMENTAL VERIFICATION OF THEORETICAL EXAMINATION RESULTS

The verification of the results of the theoretical examinations of asymmetric sheet rolling in a continuous system was carried out at the Hot Sheet Rolling Mill of an industrial plant. Examples of experimental tests for sheets rolled to a final thickness of H_1 = 1.80 mm are given in Tables 1. and 2.

Table 1. **Theoretical calculations, experimental research**
Tablica 1. **Teoretski izračuni, eksperimentalna istraživanja**

Theoretical calculations							
F9	Symetrical R_n/R_d = 1.00 R = 329.6 mm				Asymetrical R_n/R_d = 1.0 R_{av} = 327.9 mm		
ε	H_0 [mm]	l_d [mm]	F [kN/mm]	P_{av} [MPa]	l_d [mm]	F [kN/mm]	P_{av} [MPa]
0.245	2.77	14.96	7.81	522.20	14.92	7.21	483.30
0.265	2.83	15.72	8.37	532.37	15.68	7.73	492.91
0.255	2.74	15.18	8.05	530.47	15.14	7.44	491.51
0.230	2.64	14.15	7.34	518.84	14.11	6.77	479.76
0.220	2.62	13.78	7.07	512.94	13.75	6.52	474.23
0.218	2.65	13.80	6.95	503.66	13.76	6.41	465.70

Experimental research				
Symetrical R_n/R_d = 1.00 R = 329.6 mm				
H_{exp} [mm]	B_{exp} [mm]	F_{exp} [kN]	F [kN/mm]	P_{av} [MPa]
2.09	843	6153.90	7.30	488.10
2.08	846	6666.48	7.88	501.21
2.04	851	6493.13	7.63	502.79
2.03	863	6058.26	7.02	496.22
2.04	856	5675.28	6.63	481.01
2.07	855	5583.15	6.53	473.23

Experimental research					$\frac{P_{avsym} - P_{avasym}}{P_{avsym}}$ [%]
Asymetrical R_n/R_d = 0.99 R = 337.2 mm					
H_{exp} [mm]	B_{exp} [mm]	F_{exp} [kN]	F [kN/mm]	P_{av} [MPa]	
2.09	856	5692.40	6.65	445.76	8.67
2.08	856	6026.24	7.04	448.91	10.43
2.04	852	5708.40	6.70	442.62	11.97
2.03	853	5143.59	6.03	427.32	13.89
2.04	860	5160.00	6.00	436.41	9.27
2.07	859	5007.97	5.83	423.57	10.49

Comparison of the results of experimental studies on the symmetrical and asymmetrical rolling of sheets to a final thickness of H_1 = 1.80 mm on rolling stands F9. and F10. are presented in Table 1. and Table 2.

Based on the analysis of the values of real mean unit roll separating force obtained from the industrial tests of symmetric and asymmetric rolling of bands to a final thickness of h_1 = 1.80mm it can be stated that rolling with different diameters of working rolls (R_n/R_d = 0.99) has resulted in a reduction of the value of the mean unit roll separating force, on the average, by about 11 % for the last-but-one stand and by 19 % for the last stand.

Table 2. **Theoretical calculations, experimental research**
Tablica 2. **Teoretski izračuni, eksperimentalna istraživanja**

Theoretical calculations							
F10	Symetrical R_n/R_d = 1.00 R = 336.7 mm				Asymetrical R_n/R_d= 0.99 R_{av} = 338.4 mm		
ε	H_0 [mm]	l_d [mm]	F [kN/mm]	P_{av} [MPa]	l_d [mm]	F [kN/mm]	P_{av} [MPa]
0.139	2.09	9.89	4.46	450.95	9.91	3.74	377.21
0.135	2.08	9.72	4.64	477.20	9.75	3.64	373.42
0.116	2.04	8.93	4.18	468.29	8.95	3.31	369.89
0.115	2.03	8.87	4.05	456.81	8.89	3.16	355.53
0.116	2.04	8.93	4.18	468.29	8.95	3.27	365.42
0.131	2.07	9.56	4.51	471.99	9.58	3.54	369.55

Experimental research				
Symetrical R_n/R_d = 1.00 R = 341.2 mm				
H_{exp} [mm]	B_{exp} [mm]	F_{exp} [kN]	F [kN/mm]	P_{av} [MPa]
1.80	843	3506.88	4.16	420.62
1.80	846	3705.48	4.38	450.46
1.80	851	3386.98	3.98	445.88
1.80	863	3244.88	3.76	424.10
1.80	856	3372.64	3.94	441.40
1.80	855	3599.55	4.21	440.60

Experimental research					$\frac{P_{avsym} - P_{avasym}}{P_{avsym}}$ [%]
Asymetrical R_n/R_d = 0.99 R = 337.2 mm					
H_{exp} [mm]	B_{exp} [mm]	F_{exp} [kN]	F [kN/mm]	P_{av} [MPa]	
1.80	856	2910.40	3.40	342.92	18.47
1.80	856	3038.80	3.55	364.18	19.15
1.80	852	2786.04	3.27	365.42	18.04
1.80	853	2644.30	3.10	348.78	17.76
1.80	860	2631.60	3.06	341.95	22.53
1.80	859	2937.78	3.42	357.02	18.97

CONCLUSIONS

The investigation of the effects of rolling speed asymmetry on the force of metal pressure on the rolls indicate that due to a decrease in the value of this force and the elastic deflection of rolling stand elements, in the process of continuous sheet rolling on the last-but-one stand the speed asymmetry ratio should be used from the range (a_v = 0.99 - 1.01), while for the last stand this range can be broader, i.e. (a_v = 0.97 - 1.03).

As a result of the lower elastic deflection of the rolls in the last-but-one and last stands, it is possible to broaden the product line of rolled sheets by reducing the minimum rollable sheet thickness from 2.00 mm down to 1.80 mm and increasing the maximum width of sheets from 865 mm to 950 mm for their minimal thickness.

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