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IMPROVEMENT OF PRODUCTION TECHNOLOGY FOR COLD-ROLLED SHEET STEEL WITH REQUIRED SURFACE MICROTOPOGRAPHY INTENDED FOR AUTOMOTIVE INDUSTRY

Speciality 05.16.05 – Metal Forming

ABSTRACT
Doctor’s Thesis in Engineering Science

Magnitogorsk – 2011

The research was carried out in Magnitogorsk State Technical University named after G.I.Nosov.

Thesis Supervisor:	Cand. Sc. [Physics and Mathematics], Professor Valery Konstantinovich Belov
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Proponent Organization:	OJSC AVTOVAZ, city of Tolyatti

The thesis will be defended on the 26th of April, 2011, at 3 p.m., during the meeting of Dissertation Committee D 212.111.01 in Magnitogorsk State Technical University named after G.I.Nosov at the following address: Small Assembly Hall, MSTU, 33 Lenin str., 455000, Magnitogorsk.

The thesis is available in the library of Magnitogorsk State Technical University named after G.I.Nosov.

Abstract is distributed «___»_________ 2011

Scientific Secretary of Dissertation Committee V.N. Selivanov

GENERAL

Relevance. Manufacture of state-of-the-art cars remains the most important performance indicator for a country and one of the most essential driving forces for the global ferrous metallurgy. Car makers are particularly focused on the body of modern cars. Surface quality is of prime importance for exposed body parts (bonnet, doors, fenders, boot, roof) which define the image of a car. Currently, domestic and foreign car makers place more stringent requirements to surface microtopography. Careful study of these requirements shows that they consist in the following:

1. Changing the roughness profile filter. Filter 2RC with a long-wavelength cutoff λc = 0.8 mm only was changed by Gaussian bandpass filter with a long-wavelength cutoff λc = 2.5 mm and short-wavelength cutoff λs = 0.008 mm.

2. For rough surface topology, where profile is a stochastic process, the following ratio of *Ra* and *Pc* parameters is observed:

$$Ra = A \cdot (1 / Pc)^n ,$$

where *A* and *n* – indices defined by type of surface treatment,
Ra – arithmetic mean deviation of the assessed profile, *Pc* – peak count per 1 cm of profile. As a rule, *n* is close to 1. Thus, simultaneous increase of *Ra* and *Pc* values is hardly obtainable.

To meet these requirements, it is necessary to review earlier applied technologies and develop advanced engineering solutions.

Tasks and Objectives. This study is aimed at developing interrelated operating practices for electrical discharge texturing (EDT) of work rolls and for skin-pass rolling of cold-rolled steel sheets (CRS) which would fulfill car-makers' requirements to roughness height parameters and spacing parameters of CRS surface profile.

Novelty. The researches with CRS intended for automotive industry showed the following first results:

1. The most effective means to assess surface microtopography were found: (ADF(z) – amplitude distribution function; ACF(τ) – autocorrelation function; FP(z,Δ) – phase patterns; fractal characteristics; point estimations of these functions: *Rq* (or *Ra*), *Rsk*, τ, Pc_{max} (or HSC_{max}), *D*, SRC). Measurement precision was estimated.

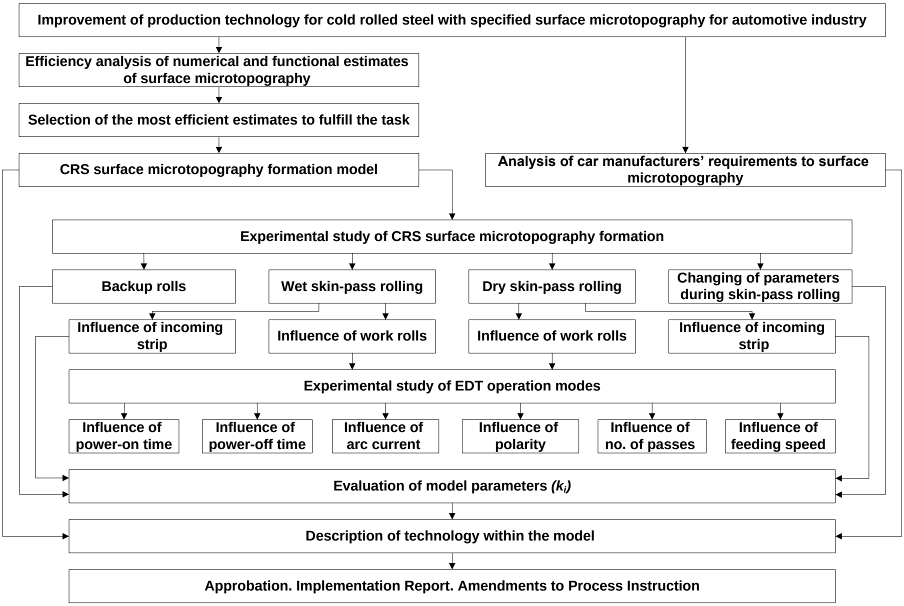


Fig 1. Research Structure

2. The influence of EDT parameters (pulse time - τ; discharging cycle time - τ_2; ratio of τ and τ_2; peak arc current - *I*; polarity of electrodes; number of passes - *N*; speed of roll feeding into processing area - *V*) on WR surface microtopography was found experimentally. EDT modes which ensure required WR surface microtopography were defined.
3. Transformation behavior of surface microtopography for: 1) work rolls during preparation (grinding, electrical discharge texturing, chromium coating, running-in); 2) backup rolls during running-in and skin-pass rolling; 3) work rolls and CRS surface during skin-pass rolling, was studied experimentally. Moreover, the influence of incoming strip microtopography on CRS microtopography was determined.
4. On the basis of experimentally found mechanisms of EDT and calculated transmissibility factors by height and spacing parameters of surface microtopography ($K_{Ra,\ Rq}$ and $K_{Pc,\ HSC}$) during skin-pass rolling with/without rolling fluid, the interrelated operating practices of roll texturing and CRS skin-pass rolling were developed to ensure production of cold-rolled steel sheets with required surface microtopography for automotive industry.
5. The model for assurance of required CRS surface microtopography was suggested.

Practical Importance. Results of this study allow higher effectiveness of CRS production technology to comply with today's requirements of automotive industry with respect to surface microtopography. Correlated EDT and skin-pass practices were developed, tested, implemented and are currently applied in Cold Rolling Shop No.5 at Magnitogorsk Iron and Steel Works to produce CRS samples to be approved by Renault, Volkswagen, GM, Hyundai-KIA Motor Company, as well as for full-scale production of CRS for OJSC AVTOVAZ.

Approbation. The main research findings were presented and discussed at the following events:

- VI Rolling Congress (18-21 October 2005, Lipetsk)
- VII Rolling Congress (15-18 October 2007, Moscow)
- VIII Rolling Congress (11-15 October 2010, Magnitogorsk)
- International Science and Technology Conference «Steel Sheet Production - Theory and Practice» (29-30 May 2008, Lipetsk)
- III International Research and Practice Conference «Materials in Automotive Industry» (19-20 June 2008, Tolyatti)
- 66th Science and Technology Conference hosted by Magnitogorsk State Technical University (2008, Magnitogorsk)
- VI International Science and Technology Conference «Steelmaking of New Millennium» (16-19 November 2009, Lipetsk)
- International Research and Practice Conference «Innovative Technologies and Equipment for Production of Rolled Products, Tubes and Wire Products» under III International Industrial Forum «Renewal of Industrial Plants – Breakthrough Steelmaking and Machine-Building Technologies» (23-26 March 2010, Chelyabinsk)
- 68th Interregional Science and Technology Conference hosted by Magnitogorsk State Technical University (2010, Magnitogorsk)
- VIII Research and Practice Conference «Advanced Materials and Respective Production Equipment and Technologies» under Metal Week in Moscow (10-13 November 2009, Moscow).

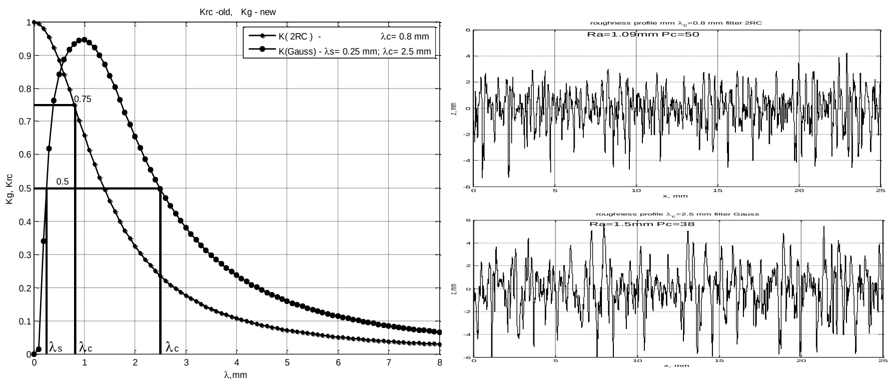
Publications. On the subject of thesis, 26 papers including 8 publications in journals of High Attestation Commission and 8 patents were released.

Structure and Volume of Thesis. The thesis contains 157 typescript pages. It comprises introduction, 4 chapters, conclusion, and includes 85 figures, 18 tables, bibliography of 134 references and 9 annexes.

MAIN CONTENTS

<u>Introduction</u> defines the relevance of problem with fulfillment of today's requirements to CRS surface microtopography set by automotive industry.

<u>Chapter 1</u> gives the analysis of requirements to CRS surface microtopography set by the leading Russian and foreign carmakers. Body parts are made of cold-rolled sheets with matte surface which is governed by roughness height parameter *Ra* and spacing parameter *Pc* (Table 1). Note that these parameters are determined for the roughness profile which was obtained using a new type of filtration process with Gaussian filters. Earlier applied filtration by means of 2RC filters and new filtration are compared in Fig.2.



a б

Fig 2. a – transmission characteristic of 2RC filter and Gaussian filter,
b – roughness profiles obtained after filtration of initial profile with these filters (top – 2RC filter, bottom – Gaussian filter)

Analysis of literature data on specific features of CRS production technology (influence of incoming strip, roll preparation, annealing and skin-pass rolling conditions) which can influence the formation of final CRS surface microtopography was performed.

Table 1

Car manufacturers' requirements to specification of CRS surface microtopography

Company	Parts	Norm	Gauge length, mm	*Ra* (±2σ*), μm	*Pc* (±2σ*), cm^{-1}	Measurement standard
Mercedes Benz, BMW, Audi, Volkswagen, Adam Opel	Internal (O3)	PW-Forum 1998	2.5	1.1–1.7	> 50	SEP 1940, EN 10049
	External (O5)			1.1–1.6	> 60	
Ford Motor, Volvo, Land-Rover, Jaguar	Unexposed	ES-6H52-00001-AA	2.5	1.0–1.7	—	SEP 1940
			0.8	0.8–1.5		
	Exposed		2.5	1.0–1.6	≥ 50	
			0.8	0.8–1.4		
Hyundai-KIA Motor Company	Unexposed	Global Material Guide 2008.05 (GGS-2008-1)	—	0.6–1.5	—	—
	Exposed			0.6–1.2	—	—
PSA Peugeot Citroen	Exposed and unexposed	B 53 3059	2.5	0.9–1.5	—	ISO 4287
Renault	Unexposed (X)	11-04-013/ ---	2.5	1.2–1.8	—	D35 1754
	Exposed (Z)			0.9–1.4	≥ 90	
АВТОВАЗ, ГАЗ, КАМАЗ	Exposed and unexposed	GOST 9045-93	0.8	0.6–1.6	—	GOST 2789-73

*σ - mean square deviation.

The literature data were used as the basis for benchmark analysis of existing methods of work roll surface treatment (shot-blasting, electrical discharge texturing, laser texturing, electron beam texturing, TOPOCROM texturing) for production of CRS with specified surface microtopography. Advantages and disadvantages of these methods were studied. Microtopography formation behavior for both unaffected surface and the surface in deformation region was described. The most significant researches in this field belong to the following authors: M.Oyane, V.L.Mazur, E.A. Garber, V.M. Salganik, A.I. Traino, N.N. Ogarkov, V.K. Belov, M.I. Rumyantsev, M.A. Benyakovsky, L.D. Devyatchenko, A.P.Chekmaryov and others.

On the basis of performed analysis, the main objective and tasks of research were defined.

The task of producing the automotive sheet with higher *Ra* and *Pc* values can be fulfilled by means of electrical discharge texturing of work rolls. Having replaced shot-blast texturing, this method, though not quite efficient, is yet more beneficial, since it makes the roll surface more adhesive. During skin-pass rolling, dirt on the strip surface is carried over to work rolls with resulting defect “dirt mark” (see Fig.3). Hence, the initial objective of the study was extended to cover the development of CRS production technology with the use of EDT work rolls and skin-pass rolling without resulting “dirt marks”.

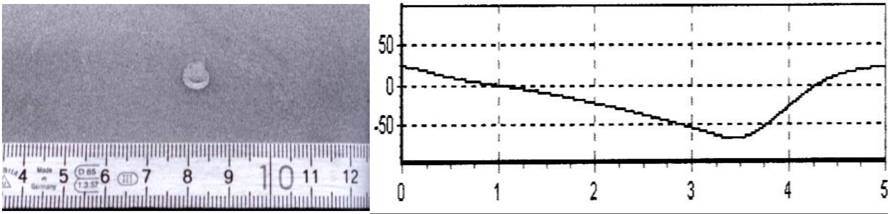
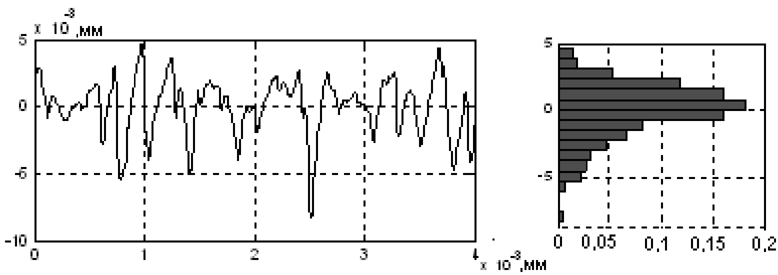


Fig.3. Picture of “dirt mark” and its profile diagram

Chapter 2 analyses the efficiency and accuracy of calculated numerical and functional estimates of surface microtopography. By the example of comparative analysis of surface microtopography obtained for automotive sheets which were produced at various domestic and foreign plants with different technologies, the chapter demonstrates the applicability of respective functional characteristics and point estimations thereof for topography analysis. It was found that the most efficient functional and point estimates are: ADF(z) - amplitude distribution function; ACF(τ) - autocorrelation function; FP(z,Δ) – phase patterns; fractal characteristics; point estimates of these functions:

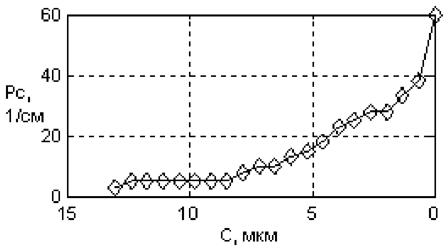


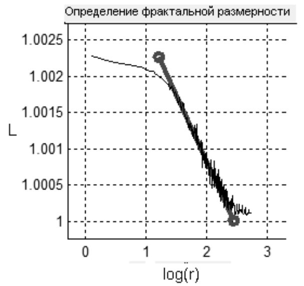
PROFILE HEIGHT PARAMETERS:

01. Average roughness Ra: 1.590 μm
02. Root-mean-square deviation Rq: 2.104 μm
03. Skewness Rsk: -0.874
04. Kurtosis Rku: 4.141
05. Max peak height Rp: 4.694 μm
06. Max valley depth Rv: -8.365 μm
07. Distance from the highest peak to the deepest valley Rt: 13.059 μm
08. Distance between five highest peaks and five lowest valleys Rz5: 6.511 μm

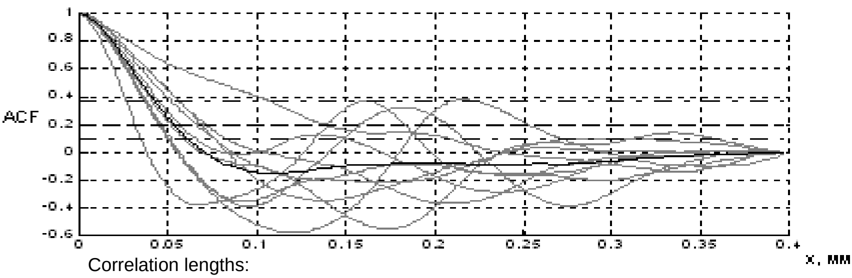
MISCELLANEOUS PARAMETERS:

01. Root-mean-square angle Dq: 0.067 deg.
02. Profile length ratio L: 1.00249
03. Average profile slope Da: 0.048 deg.
04. Developed profile length Lo: 4.002 mm
05. Mean curvature R: 0.046 mm





D =1.0018; Lsfc =1.8237; SRC =285мкм



Correlation lengths:
1. t(R – 0.1)… 62.00 μm
2. t(R – 0.2)… 54.00 μm
3. t(R – 1/c)… 43.00 μm

Fig.4. Example of CRS Roughness Profile Evaluation Protocol

Rq – root-mean-square deviation of profile (or *Ra*), *Rsk* – profile skewness, τ – correlation length, *Pc* (or *HSC*), *D* – fractal dimension, *SRC* – smooth-rough crossover scale. Example of this evaluation is shown in Fig.4.

The chapter also suggests a comparative analysis of CRS topography obtained with different methods of WR texturing. The analysis proved that shot-blast texturing (SBT) is not applicable to production of CRS with specified surface topography used for manufacture of exposed autobody parts. TOPOCROM and EDT methods ensure a required combination of height and spacing parameters of surface microtopography with low dispersion thereof over the roll surface. Cold-rolled steel sheets can be produced using EDT rolls only if skin-pass rolling with fluid for roll cleaning is performed to prevent formation of “dirt marks”.

Chapter 3 focuses on research and development of operation modes for EDT machine which would ensure the specified surface microtopography and decrease the tendency to formation of “dirt marks” during skin-pass rolling of CRS. The researches were done using Sarclad-Herkules machine installed in Cold Rolling Shop No.5, OJSC «ММК». Influence of EDT machine settings on microtopography formation was analyzed. The settings are: pulse time (τ); discharging cycle time (τ_2); ratio of τ and τ_2; peak arc current (*I*); polarity of electrodes; number of passes (*N*); speed of roll feeding into processing area (*V*). Experimental findings allow adjustment of the process to achieve the required microtopography. The results revealed the following:

- Surface microtopography characteristics largely depend on τ, *I* and *V*. Higher values increase height parameters and decrease spacing parameters.
- Empirical dependences were derived to obtain the required *Ra* and *Pc* values:

$$Ra \sim 0{,}026 \cdot \tau; \qquad Ra \sim 0{,}845 \cdot \ln(I); \qquad Ra \sim 0{,}057 \cdot V;$$
$$Pc \sim -0{,}72 \cdot \tau; \qquad Pc \sim -20{,}4 \cdot \ln(I); \qquad Pc \sim -0{,}97 \cdot V.$$

- Positive polarity of electrodes, unlike negative polarity, results in higher roughness height parameter and spacing parameter.
- With a bigger number of passes, microgeometry characteristics remain the same, but surface topology alters considerably (profile peaks become sharper). The optimum is a two-pass mode.
- With lower feeding speed, height parameters decrease and spacing parameters increase.
- Experimental observations showed that during skin-pass rolling of CRS using shot-blasted rolls, the tendency to “dirt marks” is minimized. These observations make us suppose that, to prevent “dirt mark” defects, surface microtopography of EDT rolls should be similar to surface microtopography of SBT rolls (see Fig.5).

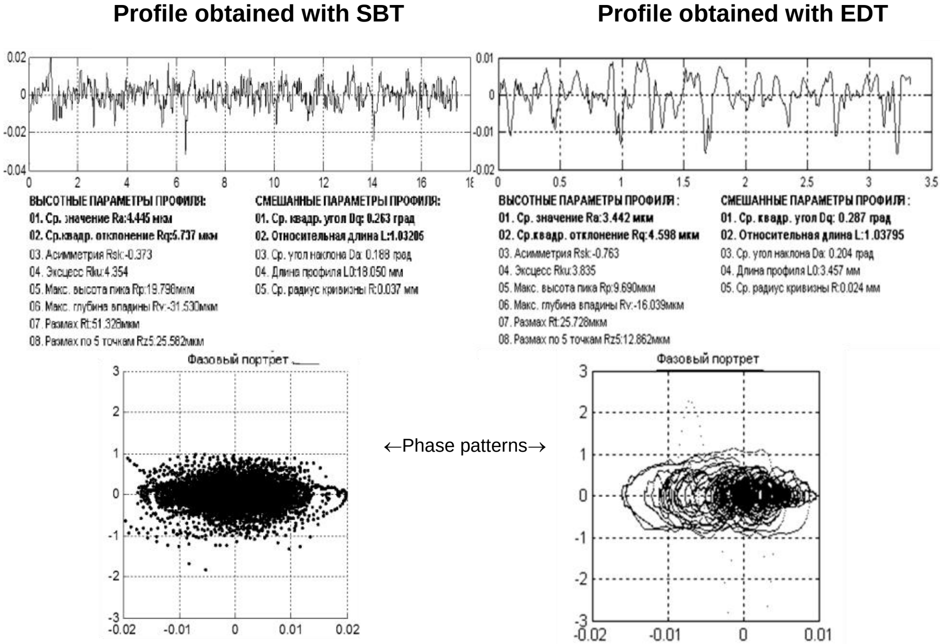


Fig.5. Comparison of WR surface profiles obtained with SBT and EDT, point estimations and phase patterns thereof

On the basis of performed researches, the so-called “base” mode for Sarclad-Herkules EDT machine in Skin-Pass Mill 2500 (Cold Rolling Shop No.5, MMK) was developed to produce CRS with $Ra_{2,5}$ 0.8–1.2 µm, $Pc > 50$ cm^{-1}. The profile has $Rsk = –0.7$, without harmonic component, and is wear-resistant.

Chapter 4 covers the development of skin pass technology aimed at producing CRS with surface microtopography in compliance with the requirements of automotive industry.

Transformation behavior of surface microtopography for: 1) work rolls during preparation (grinding, electrical discharge texturing, chromium coating, running-in); 2) backup rolls during running-in and skin-pass rolling; 3) EDT work rolls and CRS surface during skin-pass rolling, was studied experimentally. Moreover, the influence of incoming strip microtopography on CRS microtopography was determined. Experiments revealed the following:

- EDT forms symmetrical surface profile. Roll running-in modifies this profile to nonsymmetrical one in terms of its amplitude characteristics (valleys prevailing over peaks) and to symmetrical one in terms of profile slope, with these features remaining unchanged during the whole life-cycle of work rolls during skin-pass rolling of CRS.

- Chromium coating of EDT work rolls does not practically change their surface microtopography in terms of both height and spacing parameters.
- Changes in roughness parameters after running-in can be demonstrated with the following relations:

$$Ra_{\text{roll after running-in}} \approx 0.75 \cdot Ra_{\text{roll before running-in}}; \qquad K_{Ra\ \text{running-in}} \approx 0.75;$$
$$Pc,HSC_{\text{roll after running-in}} \approx Pc,HSC_{\text{roll before running-in}}; \quad K_{Pc,HSC\ \text{running-in}} \approx 1.$$

- Changes in both height and spacing parameters can be regarded as similar for top and bottom work rolls.
- Analysis of changing surface microtopography of backup rolls during running-in and CRS skin-pass rolling showed that after installation of ground backup rolls, during running-in and skin-pass rolling of first coils, the roughness of EDT work rolls is extensively transferred to the surface of backup rolls.
- In view of the fact that skin-pass rolling can be performed both with and without fluid supplied to work rolls, analysis of changing surface microtopography of EDT work rolls and CRS during skin-pass rolling was carried out with due consideration of these process features (Fig.6).
- After running-in of EDT work rolls, during skin-pass rolling of three-five coils, the surface of work rolls is breaking-in with resulting rapid decline of height parameters of WR and CRS surfaces. Subsequently, roughness height parameters of CRS surface tend to decrease slowly, while spacing parameters remain almost the same (Fig.6).
- Transmissibility factors which are equal to the ratio between surface microtopography parameter of skin-passed CRS and that of the roll were determined:

- skin-pass rolling with fluid:
  - by height parameters: $K_{Ra,\ Rq} \approx 0.40$;
  - by spacing parameters: $K_{Pc,\ HSC} \approx 1.00$;
- skin-pass rolling without fluid:
  - by height parameters: $K_{Ra,\ Rq} \approx 0.33$;
  - by spacing parameters: $K_{Pc,\ HSC} \approx 0.90$.

Changing microtopography of work rolls during "dry" skin-pass rolling | **Changing microtopography of CRS during "dry" skin-pass rolling** | **Changing microtopography of CRS during "wet" skin-pass rolling**

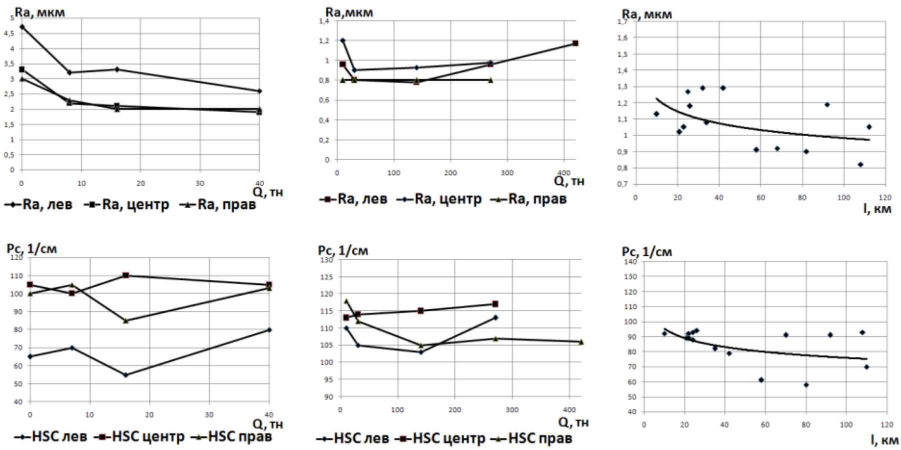


Fig.6. Changing surface microtopography of work rolls and strip during skin-pass rolling

- Presence of skin-pass fluid in deformation region enhances WR roughness imprinting (transmissibility) into CRS surface.
- Studies of skin-pass process with and without fluid showed that incoming strip microtopography by its roughness height and spacing parameters has very little impact on the surface microtopography of skin-passed CRS.

The studies suggested the model for assurance of required CRS surface microtopography (see Fig.7).

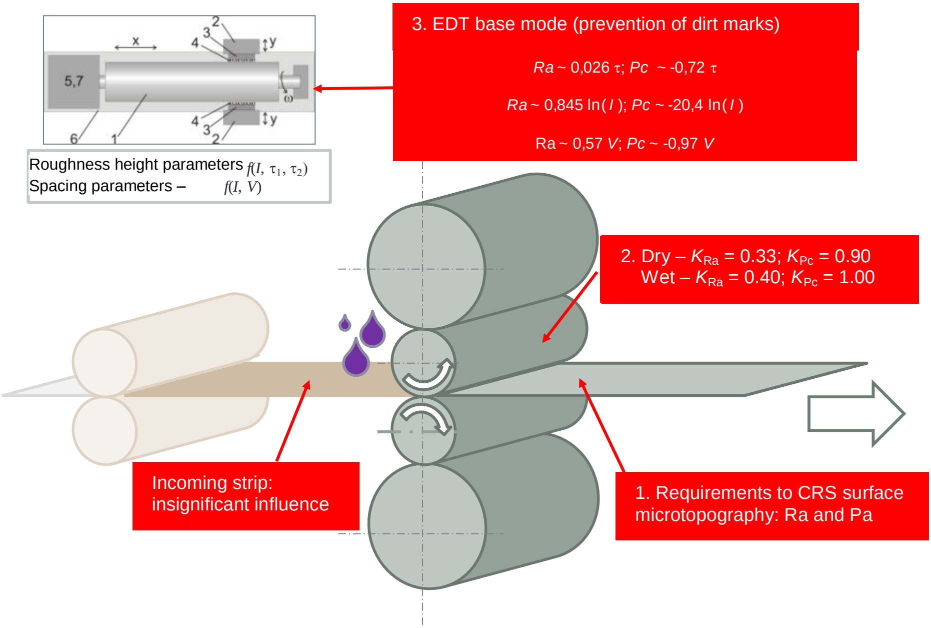


Fig.7. CRS surface microtopology assurance model

Knowing the customers' requirements to CRS surface microtopography (Table 1), this model permits to define the parameters of "base" operation mode for EDT machine (i.e. peak arc current (*I*), pulse time (τ), feeding speed (*V*).

Summarized in Table 2 below, the procedure of determination and control of surface microtopography of work rolls in Skin-Pass Mill 2500 (Cold Rolling Shop No.5, MMK) and that of cold-rolled steel sheets demonstrates the way to achieve CRS surface with the specified *Ra* and *Pc* values using the recommended "base" mode of EDT machine.

Table 2

Determination and control of surface microtopography of work rolls in Skin-Pass Mill 2500 (Cold Rolling Shop No.5, MMK) and that of cold-rolled steel sheet

Controlled parameters of interrelated processes	*Ra*, μm	*Pc*, 1/cm
WR surface microtopography after EDT	2.7-3.6	65-70
$\langle K_{Ra\ transmissibility} \rangle \approx 0.33$; $\langle K_{Pc\ transmissibility} \rangle \approx 0.90$		
CRS surface microtopography after skin-pass rolling, at the beginning of WR life-cycle	0.9-1.2	55-60
CRS surface microtopography after skin-pass rolling of approx. 200 tons	0.8-1.1	50-55

Controlled parameters of interrelated processes	*Ra*, μm	*Pc*, 1/cm
WR surface microtopography after EDT	2.2-3.0	55-60
$\langle K_{Ra\ transmissibility} \rangle \approx 0.40$; $\langle K_{Pc\ transmissibility} \rangle \approx 1.00$		
CRS surface microtopography after skin-pass rolling, at the beginning of WR life-cycle	0.9-1.2	55-60
CRS surface microtopography after skin-pass rolling of approx. 200 tons	0.8-1.1	50-55

Conclusion summarizes the main findings of the research.

Focused on improvement of production technology for cold-rolled steel sheet with required surface microtopography for automotive industry, the studies showed the following results for the first time ever:

1. The most effective means to assess surface microtopography were found: (ADF(z) – amplitude distribution function; ACF(τ) – autocorrelation function; FP(z,Δ) – phase patterns; fractal characteristics; point estimations of these functions: *Rq* (or *Ra*), *Rsk*, τ, Pc_{max} (or HSC_{max}), *D*, SRC). Measurement precision was estimated.
2. The influence of EDT parameters on WR surface microtopography was found experimentally. These are: pulse time - τ; discharging cycle time - τ_2; ratio of τ and τ_2; peak arc current - *I*; polarity of electrodes; number of passes - *N*; speed of roll feeding into processing area - *V*). EDT modes which ensure required WR surface microtopography were defined.
3. Transformation behavior of surface microtopography for: 1) work rolls during preparation (grinding, electrical discharge texturing, chromium coating, running-in); 2) backup rolls during running-in and skin-pass rolling; 3) work rolls and CRS surface during skin-pass rolling, was studied experimentally. Moreover, the influence of incoming strip microtopography was determined.
4. On the basis of experimentally found mechanisms of EDT and calculated transmissibility factors of surface microtopography during skin-pass rolling

with/without rolling fluid, the interrelated operating practices of roll texturing and skin-pass rolling were developed to ensure production of cold-rolled steel sheets with required surface microtopography for automotive industry.
5. The model for assurance of required CRS surface microtopography was suggested.

The basic provisions of the thesis were published in the following papers:

1. G.A.Kunitsyn, A.V.Gorbunov, E.V.Zharkov, etc. Analysis of Hot-Dip Galvanized Steel Surface Microgeometry, 66th Science and Technology Conference Proceedings, Vol.1. Magnitogorsk State Technical University, 2008, pp.13-15.
2. A.V.Gorbunov, E.V.Zharkov, A.V.Ishchenko, etc. State-of-the-Art Technologies of Work Roll Surface Preparation for Production of Automotive Sheet with Stricter Requirements to Surface Microtopography, International Research and Practice Conference, Innovative Technologies and Equipment for Production of Rolled Products, Tubes and Wire Products, 23-26 March, 2010, city of Chelyabinsk, Proceedings, pp.115-117.
3. V.F.Djachenko, A.V.Gorbunov, E.V.Zharkov, etc. Comparative Analysis of Surface Microtopography of HDG Steel for Exposed Body Parts, Rolling Journal, No.10, 2008. pp. 12-17.
4. A.V.Gorbunov, V.K.Belov, D.O.Begletsov. Comparative Analysis of Roll Surface Treatments for Production of Automotive Sheet, Steel Journal, 2009, No.8, pp. 50-53.
5. A.V.Gorbunov, V.K.Belov, D.O.Begletsov, A.S.Sotnikov. Influence of Different Roll Surface Treatments on Topography of Cold-Rolled Steel Sheets, Steel Journal, 2010, No.1, pp. 68-72.
6. A.V.Gorbunov, V.K.Belov, O.V.Krivko, D.O.Begletsov. Formation of Unaffected Surface Microtopography during Skin-Pass Rolling, Steel Journal, 2008. No.1, pp. 40-44.
7. Yu.A.Bodyaev, A.V.Gorbunov, A.F.Radionov, etc. Electrical Discharge Machining of Work Rolls for Skin-Pass Rolling of Automotive Sheet, Steel Journal, 2007, No.3, pp. 52-56.
8. A.V.Gorbunov, E.V.Zharkov, A.I.Brusjanina, etc. Analysis of Micro- and Macrotopography of HDG Steel Used for Exposed Autobody Parts, Theory and Practice of Sheet Steel Production, Collection of Scientific Papers, Part 1, 2008, pp. 45-47.
9. Yu.A.Bodyaev, A.V.Gorbunov, A.F.Radionov, etc. Production of Automotive Sheet with Specified Surface Microtopography, VI Rolling Congress, 18-21 October, 2005, Lipetsk, Proceedings, Vol. 2, pp. 167-171.

10. Yu.A.Bodyaev, A.V.Gorbunov, A.F.Radionov, etc. Influence of Electrical Discharge Textured Work Rolls in Skin-Pass Mill on Product Surface Microtopography, Steel Journal, 2006, No.5, pp. 90-94.
11. A.V.Gorbunov, V.E.Zlov, E.V.Aphanasiev, etc. Research into the Causes of “Shagreen” Defect during Stamping of Cold-Rolled Steel Sheets, Rolling Journal, 2006, No.4. pp. 35 - 36.
12. A.V.Gorbunov, A.F.Radionov, V.K.Belov, etc. Production of Automotive Sheet with Specified Surface Microtopography, Rolling Journal, 2007, No.4. pp. 15 - 17.
13. A.V.Gorbunov, V.K.Belov, O.V.Krivko, D.O.Begletsov. Control of Unaffected Surface Microtopography Formation during Skin-Pass Rolling of Cold-Rolled Steel, VII Rolling Congress in Moscow, 15-18 October, 2007, Proceedings, Vol.2, pp. 609 - 615.
14. V.F.Djachenko, A.V.Gorbunov, D.G.Ruzaev, etc. Comparative Analysis of Topography of HDG Steel for Exposed Body Parts from Domestic and Foreign Suppliers to OJSC AVTOVAZ, III International Research and Practice Conference, Materials in Automotive Industry. Part 1 – Metallic Materials, city of Tolyatti, 19-20 June, 2008, Proceedings, pp. 83 - 94.
15. A.V.Gorbunov, E.V.Zharkov, A.V.Ishchenko, V.K.Belov. Achievement of Specified Surface Microtopography of Hot-Dip-Galvanized Steel for Automotive Industry, IV International Science and Technology Conference, Steelmaking of New Millennium, 16-19 November, 2009, Lipetsk, Proceedings, Vol. 2, pp. 54-60.
16. V.K.Belov, D.O.Begletsov, S.A.Laskov, A.V.Gorbunov, etc. Determination of Microtopography Variables during Production of Automotive Cold-Rolled Steel, 68th Interregional Science and Technology Conference, Magnitogorsk State Technical University, Proceedings, Vol.2, pp. 206-209.
17. A.V.Gorbunov, A.V.Papshev, E.V.Zharkov, V.K.Belov, etc. Provision of Specified Surface Microtopography of Hot-Dip Galvanized Steel for Manufacture of Automobile Parts, Metal Week in Moscow, 10-13 November, 2009, Proceedings, pp.589-595.
18. S.A.Laskov, A.V.Gorbunov, V.K.Belov, etc. Development of Manufacturing Technology for Automotive Sheet with Specified Surface Microtopography to Meet Requirements of Domestic and Foreign Carmakers. VIII Rolling Congress in Magnitogorsk, 11-15 October, 2010, Proceedings, Vol.1, pp.155-163.
19. Surface Preparation Method for Rolls in Cold Rolling Mills. Patent RU 2356665 C1 dated 09.01.2008.
20. Assessment Method for Work Roll Surface. Patent RU 2360752 C2 dated 20.08.2007.

21. Surface Preparation Method for Rolls of Cold Rolling Mills. Patent RU 2356666 C1 dated 27.05.2009.
22. Production Practice for Cold-Rolled Galvanized Automotive Sheet. Patent RU 2354466 C1 dated 12.12.2007.
23. Steel Sheet Cold Rolling Method. Patent RU 2334569 C2 dated 25.07.2006.
24. Production Practice for Cold-Rolled Steel Coils. Patent RU 2315118 C1 dated 17.05.2006.
25. Surface Preparation Method for Rolls of Skin-Pass Mills. Patent RU 2393944 C2 dated 10.07.2010.
26. Surface Quality Assessment Method for Cold-Rolled Steel Sheets. Patent RU 2377528 C2 dated 27.12.2009.