APEM journal

Advances in Production Engineering & Management
Volume 17 | Number 1 | March 2022 | pp 75–88
https://doi.org/10.14743/apem2022.1.422

ISSN 1854-6250
Journal home: apem-journal.org
Original scientific paper

Modelling of multiple surface roughness parameters during hard turning: A comparative study between the kinematical-geometrical copying approach and the design of experiments method (DOE)

Tomov, M.[a,*], **Gecevska, V.**[a], **Vasileska, E.**[a]

[a]Ss. Cyril and Methodius University in Skopje, Faculty of Mechanical Engineering, Skopje, North Macedonia

ABSTRACT

This paper proposes and applies two different methodologies for modelling the roughness parameters in hard turning. The first method is based on the kinematical-geometrical copying of the cutting tool geometry onto the machined surface including a feedback loop through the parameter of statistic equality of sampling lengths in surface roughness measurements (*SE*). The other method employs the Design of Experiments (DOE) principles expressing the roughness parameters as first order nonlinear function of the input variables: cutting speed v, feed f, depth of cut a_p, and tool nose radius r_ε. The research includes the R_a and R_z roughness parameters which are commonly modelled throughout the research works, and additionally develops models for the R_p, R_v and $R_{mr(c)}$ roughness parameters which are more challenging to model compared to R_a and R_z as they depend more on the shape of the roughness profile and position of its mean line. Both methodologies for all roughness parameters were verified using a CNC lathe and special rings made of steel EN C55 with hardness of 53±1 HRC. Considering that the roughness profile is just a part of the total geometric deviations of the processed surfaces, and it is obtained from the total profile using software filtration, the research also considers the W_a parameter (waviness profile), as well as the deviations from the circularity (out-off-roundness) of the processed rings as indicators for the stability of the machining process.

ARTICLE INFO

Keywords:
Hard turning;
Surface roughness;
Roughness parameters;
Mathematical modelling;
Prediction modelling;
Design of experiments (DOE);
Kinematical-geometrical copying

**Corresponding author:*
mite.tomov@mf.edu.mk
(Tomov, M.)

Article history:
Received 16 November 2021
Revised 27 February 2022
Accepted 3 March 2022

References

[1] He, C.L., Zong, W.J., Zhang, J.J. (2018). Influencing factors and theoretical modeling methods of surface roughness in turning process: State-of-the-art, *International Journal of Machine Tools and Manufacture*, Vol. 129, 15-26, doi: 10.1016/j.ijmachtools.2018.02.001.

[2] Trung, D.D., Thinh, H.X. (2021). A multi-criteria decision-making in turning process using the MAIRCA, EAMR, MARCOS and TOPSIS methods: A comparative study, *Advances in Production Engineering & Management*, Vol. 16, No. 4, 443-456, doi: 10.14743/apem2021.4.412.

[3] Kramar, D., Cica, Dj. (2021). Modeling and optimization of finish diamond turning of spherical surfaces based on response surface methodology and cuckoo search algorithm, *Advances in Production Engineering & Management*, Vol. 16, No. 3, 326-334, doi: 10.14743/apem2021.3.403.

[4] Savkovic, B., Kovac, P., Rodic, D., Strbac, B., Klancnik, S. (2020). Comparison of artificial neural network, fuzzy logic and genetic algorithm for cutting temperature and surface roughness prediction during the face milling process, *Advances in Production Engineering & Management*, Vol. 15, No. 2, 137-150, doi: 10.14743/apem2020.2.354.

[5] Tamang, S.K., Chandrasekaran, M. (2015). Modeling and optimization of parameters for minimizing surface roughness and tool wear in turning Al/SiCp MMC, using conventional and soft computing techniques, *Advances in Production Engineering & Management*, Vol. 10, No. 2, 59-72, doi: 10.14743/apem2015.2.192.
[6] Heidari, M., Hosseini, S.V., Parvaz, H. (2021). Modelling and optimization of surface roughness and specific tool wear in milling process, *Tehnički Vjesnik – Technical Gazette,* Vol. 28, No. 5, 1626-1633, doi: 10.17559/TV-20200614105300.
[7] Aljinović, A., Bilić, B., Gjeldum, N., Mladineo, M. (2021). Prediction of surface roughness and power in turning process using response surface method and ANN, *Tehnički Vjesnik – Technical Gazette,* Vol. 28, No. 2, 456-464, doi: 10.17559/TV-20190522104029.
[8] Mgwatu, M.I. (2013). Integrated approach for optimising machining parameters, tool wear and surface quality in multi-pass turning operations, *Advances in Production Engineering & Management*, Vol. 8, No. 4, 209-218, doi: 10.14743/apem2013.4.168.
[9] Kang, W.T., Derani, M.N., Ratnam, M.M. (2020). Effect of vibration on surface roughness in finish turning: Simulation study, *International Journal of Simulation Modelling*, Vol. 19, No. 4, 595-606, doi: 10.2507/IJSIMM19-4-531.
[10] Bartarya, G., Choudhury, S.K. (2012). Effect of cutting parameters on cutting force and surface roughness during finish hard turning AISI52100 grade steel, *Procedia CIRP,* Vol. 1, 651-656, doi: 10.1016/j.procir.2012.05.016.
[11] Mohruni, A.S., Yanis, M., Kurniawan, E. (2018). Development of surface roughness prediction model for hard turning on AISI d2 steel using cubic boron nitride insert, *Jurnal Teknologi,* Vol. 80, No. 1, 173-178, doi: 10.11113/jt.v80.10492.
[12] Kumar, S., Singh, D., Kalsi, N.S. (2016). Surface quality evaluation of AISI 4340 steel having varying hardness during machining with TiN-coated CBN inserts, *Proceedings of the Institution of Mechanical Engineers, Part J: Journal of Engineering Tribology*, Vol. 231, No. 7, 925-933, doi: 10.1177/1350650116684243.
[13] Agrawal, A, Goel, S., Rashid, W.B., Price, M. (2015). Prediction of surface roughness during hard turning of AISI 4340 steel (69 HRC), *Applied Soft Computing,* Vol. 30, 279-286, doi: 10.1016/j.asoc.2015.01.059.
[14] Panda, A., Sahoo, A.K., Rout, A.K. (2016). Investigations on surface quality characteristics with multi-response parametric optimization and correlations, *Alexandria Engineering Journal*, Vol. 55, No. 2, 1625-1633, doi: 10.1016/j.aej.2016.02.008.
[15] Xiao, Z., Liao, X., Long, Z., Li, M. (2017). Effect of cutting parameters on surface roughness using orthogonal array in hard turning of AISI 1045 steel with YT5 tool, *International Journal of Advanced Manufacturing Technology*, Vol. 93, 273-282, doi: 10.1007/s00170-016-8933-5.
[16] Das, S.R., Panda, A., Dhupal, D. (2017). Experimental investigation of surface roughness, flank wear, chip morphology and cost estimation during machining of hardened AISI 4340 steel with coated carbide insert, *Mechanics of Advanced Materials and Modern Processes,* Vol. 3, Article No. 9, doi: 10.1186/s40759-017-0025-1.
[17] Jena, J., Panda, A., Behera, A.K., Jena, P.C., Das, S.R., Dhupal, D. (2017). Modeling and optimization of surface roughness in hard turning of AISI 4340 steel with coated ceramic tool, In: Chattopadhyay, J., Singh, R., Prakash, O. (eds.), *Innovation in Materials Science and Engineering,* Springer, Singapore, 151-160, doi: 10.1007/978-981-13-2944-9_15.
[18] Meddour, I., Yallese, M.A., Khattabi, R., Elbah, M., Boulanour, L. (2014). Investigating and modeling of cutting forces and surface roughness when hard turning of AISI 52100 steel with mixed ceramic tool: Cutting conditions optimization, *International Journal of Advanced Manufacturing Technology*, Vol. 77, 1387-1399, doi: 10.1007/s00170-014-6559-z.
[19] Zerti, O., Yallese, M.A., Khettabi, R., Chaoui, K., Mabrouki, T. (2017). Design optimization for minimum technological parameters when dry turning of AISI D3 steel using Taguchi method, *International Journal of Advanced Manufacturing Technology*, Vol. 89, 1915-1934, doi: 10.1007/s00170-016-9162-7.
[20] Khellaf, A., Aouici, H., Smaiah, S., Boutabba, S., Yallese, M.A., Elbah, M. (2017). Comparative assessment of two ceramic cutting tools on surface roughness in hard turning of AISI H11 steel: Including 2D and 3D surface topography, *International Journal of Advanced Manufacturing Technology*, Vol. 89, 333-354, doi: 10.1007/s00170-016-9077-3.
[21] Kacal, A., Yıldırım, F. (2012). Application of grey relational analysis in high-speed machining of hardened AISI D6 steel, *Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science,* Vol. 227, No. 7, 1566-1576, doi: 10.1177/0954406212466792.
[22] Günay, M., Yücel, E. (2013). Application of Taguchi method for determining optimum surface roughness in turning of high-alloy white cast iron, *Measurement,* Vol. 46, No. 2, 913-919, doi: 10.1016/j.measurement.2012.10.013.
[23] Tang, L., Gao, C., Huang, J., Shen, H., Lin, X. (2015). Experimental investigation of surface integrity in finish dry hard turning of hardened tool steel at different hardness levels, *International Journal of Advanced Manufacturing Technology*, Vol. 77, 1655-1669, doi: 10.1007/s00170-014-6484-1.
[24] Derakhshan, E.D., Akbari, A.A. (2009). Experimental investigation on the effect of workpiece hardness and cutting speed on surface roughness in hard turning with CBN tools, In: *Proceedings of the World Congress on Engineering 2009,* London, United Kingdom.
[25] Mia, M., Dhar, N.R. (2017). Optimization of surface roughness and cutting temperature in high-pressure coolant-assisted hard turning using Taguchi method, *International Journal of Advanced Manufacturing Technology*, Vol. 88, 739-753, doi: 10.1007/s00170-016-8810-2.
[26] Chinchanikar, S., Salve, A.V., Netake, P., More, A., Kendre, S., Kumar, R. (2014). Comparative evaluations of surface roughness during hard turning under dry and with water-based and vegetable oil-based cutting fluids, *Procedia Materials Science*, Vol. 5, 1966-1975, doi: 10.1016/j.mspro.2014.07.529.

[27] Naigade, D.M, Patil, D.K, Sadaiah, M. (2013). Some investigations in hard turning of AISI 4340 alloy steel in different cutting environments by CBN insert, *International Journal of Machining and Machinability of Materials*, Vol. 14, No. 2, 165-193, doi: 10.1504/IJMMM.2013.055736.

[28] Tomov, M., Karolczak, P., Skowronek, H., Cichosz, P., Kuzinovski, M. (2020). Mathematical modelling of core roughness depth during hard turning, In: Królczyk, G., Niesłony, P., Królczyk, J. (eds.), *Industrial Measurements in Machining. IMM 2019. Lecture Notes in Mechanical Engineering,* Springer, Cham, Switzerland, doi: 10.1007/978-3-030-49910-5_1.

[29] Tomov, M., Kuzinovski, M., Cichosz, M. (2016). Modeling and prediction of surface roughness profile in longitudinal turning, *Journal of Manufacturing Processes*, Vol. 24, Part 1, 231-255, doi: 10.1016/j.jmapro.2016.09.010.

[30] Tomov, M., Kuzinovski, M., Cichosz, P (2013). A new parameter of statistic equality of sampling lengths in surface roughness measurement*, Strojniški vestnik - Journal of Mechanical Engineering,* Vol. 59, No. 5, 339-348, doi: 10.5545/sv-jme.2012.606.

[31] Tomov, M., Prangoski, B., Karolczak, P. (2021). Mathematical modelling and correlation between the primary waviness and roughness profiles during hard turning. *Jordan Journal of Mechanical and Industrial Engineering,* Vol. 15, No. 3, 243-249.

[32] Tomov, M., Kuzinovski, M., Cichosz, P. (2016). Development of mathematical models for surface roughness parameter prediction in turning depending on the process condition, *International Journal of Mechanical Sciences*, Vol. 113, 120-132, doi: 10.1016/j.ijmecsci.2016.04.015.

APEM journal

Advances in Production Engineering & Management
Letnik 17 | Številka 1 | Marec 2022 | Strani 75–88
https://doi.org/10.14743/apem2022.1.422

ISSN 1854-6250
Spletna stran: apem-journal.org
Izvirni znanstveni članek

Modeliranje več parametrov površinske hrapavosti med struženjem trdih materialov: Primerjalna študija med pristopom kinematično-geometričnega kopiranja in metodo načrtovanja eksperimentov (DOE)

Tomov, M.[a,*], **Gecevska, V.**[a], **Vasileska, E.**[a]

[a]Ss. Cyril and Methodius University in Skopje, Faculty of Mechanical Engineering, Skopje, North Macedonia

POVZETEK

Ta članek predlaga in uporabi dve različni metodologiji za modeliranje parametrov hrapavosti pri struženju trdih materialov. Prva metoda temelji na kinematično-geometričnem kopiranju geometrije rezalnega orodja na obdelano površino vključno s povratno zanko preko parametra statistične enakosti vzorčnih dolžin pri meritvah površinske hrapavosti (*SE*). Druga metoda uporablja načelo načrtovanja eksperimentov (DOE), ki opiše parametre hrapavosti kot nelinearne funkcije prvega reda vhodnih spremenljivk: rezalna hitrost v, podajanje f, globina reza a_p in radij konice orodja r_ε. Raziskava vključuje parametra hrapavosti R_a in R_z, ki se običajno modelirata v primerljivih raziskavah, poleg tega pa razvije modele za parametre hrapavosti R_p, R_v in $R_{mr(c)}$, ki so v primerjavi z R_a in R_z zahtevnejši za modeliranje, saj so bolj odvisni od oblike profila hrapavosti in položaja srednje črte hrapavosti. Obe metodologiji sta bili za vse parametre hrapavosti preverjeni s pomočjo CNC struženja posebnih obročev iz jekla EN C55 s trdoto 53±1 HRC. Glede na to, da je profil hrapavosti le del skupnih geometrijskih odstopanj obdelanih površin in je pridobljen iz celotnega profila s programsko filtracijo, sta v raziskavi kot kazalnika stabilnosti obdelovalnega procesa upoštevana tudi parameter W_a (profil valovitosti) ter odstopanje od krožnosti (izven okroglosti).

PODATKI O ČLANKU

Ključne besede:
Struženje trdih materialov;
Hrapavost površine;
Parametri hrapavosti;
Matematično modeliranje;
Napovedovalno modeliranje;
Načrtovanje eksperimentov (DOE);
Kinematično-geometrijsko kopiranje

**Kontaktna oseba:*
mite.tomov@mf.edu.mk
(Tomov, M.)

Zgodovina članka:
Prejet 16. novembra 2021
Popravljen 27. februarja 2022
Sprejet 3. marca 2022