Lishchenko Natalia

Лищенко Наталия Владимировна

Ліщенко Наталя Володимирівна.

Larshin Vasil

Ларшин Василь Петрович

Ларшин Василий Петрович

Uminsky Sergey

Уминский Сергей Михайлович

Уминський Сергій Михайлович

Lishchenko N., Larshin V., Uminsky S. (2020) **Finite Element Analysis of Profile Grinding Temperature**. In: Ivanov V., Trojanowska J., Pavlenko I., Zajac J., Peraković D. (eds) Advances in Design, Simulation and Manufacturing III. DSMIE 2020. Lecture Notes in Mechanical Engineering. Springer, Cham: 422-431.
https://doi.org/10.1007/978-3-030-50794-7_41
https://link.springer.com/chapter/10.1007%2F978-3-030-50794-7_41

Abstract

The analysis of equations for determining the grinding temperature taking into account the curvature of the grinding profile, is performed. Mathematical models of the temperature field were proposed, which makes it possible to identify the influence of the curvature radius of the surface to be ground on the grinding temperature in the range from a semicircular profile to a linear one as the radius of the semicircular profile tends to infinity. The variation range of the curvature radius is established, in which the curvature of the profile being ground can be neglected when calculating the grinding temperature. The influence of the profile curvature radius on the maximum grinding temperature was established using both direct calculating and computer simulating of the temperature field by the analytical model and the finite element method (FEM), respectively. Grinding temperature FEM simulation results differ by no more than 0.5% compared to the analytical model under otherwise similar conditions. It is established that the FEM simulation is more suitable due to its greater sophistication, which makes it possible considering the individual geometric features of the surface to be ground as well as any instantaneous distribution of the heat flux in the grinding zone. At the same time, an analytical model for direct calculating of the grinding temperature takes much less time to get a result and can be used in computer monitoring and grinding diagnosing of subsystems on CNC machines.

Keywords

Curvature radius Temperature field Heat flux Analytical model Finite element method

In [25-27] sequentially considered one-dimensional thermal schemes in a cylindrical coordinate system. It was found the following equation [26]

where r is the current radius vector of the surface point; $F_0 = a\tau / R^2$ is the Fourier number; τ is the heat source time, s; q is the heat flux density, W/m^2; R is the radius of the limiting cylindrical surface (the radius of the cylindrical heat source); λ is thermal conductivity of the material, W/(m·°C); J_0, J_1 are the Bessel functions of first kind of zero and first order; Y_0, Y_1 are the Bessel functions of second kind of zero and first order; ζ is integration variable.

Eqution (1) is the solution of the following one-dimensional differential equation of heat conduction [26]

For example, eqution (1) one can be used for the grinding temperature determination in the semicircular thread profile grinding under the second kind boundary condition and zero initial condition, i.e.

In turn, equation (1) is the closest analogue of the following solution of one-dimensional differential equation of heat conduction when $R \to \infty$, to wit [24]:

where x is the current coordinate which is perpendicular to the heat source surface; a is the thermal diffusivity of the material, m^2/c.

To determine the depth x of the temperature penetration into the thread surface layer it is necessary to take into account the formula

Equation (1) we can write in the form

It is performed a temperature calculation using the formula (3) for the different depth of the surface layer, i.e. for different radius of the profile being ground, to wit for $1 \le R \le 6$ mm (Fig. 1) and for different values $0 \le x \le 0.6$ (Fig. 2). To solve this problem in the MathCAD 2000 Professional environment, it is necessary to specify three groups of input parameters: the thermal (a, λ), geometric (R, x) and energetic (q, τ) ones. The calculation were performed for λ=30 W/(m·°C), q=40·10^6 W/m^2, and the duration of the heat source acting τ = 0.1 s.

It can be seen that a change in radius R from 1 to 3 mm significantly affects the surface temperature (x = 0) and its distribution over the surface layer depth (Fig. 1). At the same time, a change in radius R from 4 to 6 mm slightly affects the temperature (Fig. 1). For example, a change in radius R from 4 to 6 mm on the surface (x = 0) leads to an increase in the grinding temperature from 1120 °C to 1136 °C (by 3.1%), and with an increase R from 1 to 3 mm the temperature increases from 1003 °C to 1219 °C (by 21.5%).

Fig. 1 shows the temperature distribution over the depth of the surface layer, obtained by the equation (2) for a flat heat source with $R \to \infty$. This dependence $R = \infty$ is the limiting case of the calculation by equation (3) with $R \to \infty$. Thus, the curves in Fig. 2 show the close agreement of equations (2) and (3). You can see at what values of the radius R the thermophysical calculations for the semicircular thread profile can be carried out using equation (2), obtained for a flat heat source. So, for example, at $R = 6$ mm, the difference in calculations according to equations (2) and (3) at a depth of a double temperature drop (x = 0.6 mm) is 724.06 ° C and 653.9 °C, respectively, i.e.

no more than 11% (Fig. 1), which is acceptable for engineering calculations at the grinding operation design stage.

Equation (3) describes the temperature on an ideal cylinder at a constant heat flux and can be used to describe the temperature field in the area of the contact zone which is remote from this zone. To describe the temperature field at all points of the contact zone you can use the simulation method, for example, implemented in the COMSOL Multiphysics program.

To solve the problem the following sequence of actions may be used.

1. Selecting the dimension of the model. It is selected in the Model Wizard window the following: 3D, 2D Axisymmetric; 2D, 1D Axisymmetric; and 1D, 0D.
2. Selecting the physical section: Heat Transfer in Solids, Heat Transfer in Fluids, Diffusion, Fluid Dynamics, Structural Mechanics, Acoustics, etc.
3. Selecting a stationary (Stationary) or non-stationary (Time Dependent) process to be studied.
4. Creating the geometric object for which simulation will be performed. This object can be created using constructors embedded in COMSOL Multiphysics or special programs (for example, AutoCAD) and imported into COMSOL Multiphysics.
5. Setting the thermophysical properties of the material (thermal conductivity, density, heat capacity at constant pressure).
6. Setting the initial conditions (Initial Values).
7. Setting the boundary conditions (Boundary conditions).
8. Dividing the region into finite elements. By default COMSOL builds a triangular grid in two-dimensional mode, and a tetrahedral (triangular pyramid) grid in three-dimensional mode.
9. Choosing a solver.
10. Visualizing the results.

References

1.

Larshin, V., Lishchenko, N.: Gear grinding system adapting to higher CNC grinder throughput. MATEC Web Conf. 226, 04033 (2018)

CrossRefGoogle Scholar

2.

Larshin, V., Lishchenko, N.: Adaptive profile gear grinding boosts productivity of this operation on the CNC machine tools. In: Ivanov, V., et al. (eds.) CONFERENCE 2019, LNME, pp. 79–88. Springer, Cham (2019)

Google Scholar

3.

Deivanathan, R., Vijayaraghavan, L.: Theoretical analysis of thermal profile and heat transfer in grinding. Int. J. Mech. Mater. Eng. (IJMME) 8(1), 21–31 (2013)

Google Scholar

4.

Tan, J., Jun, Y., Siwei, P.: Determination of burn thresholds of precision gears in form grinding based on complex thermal modelling and Barkhausen noise measurements. Int. J. Adv. Manuf. Technol. 88(1–4), 789–800 (2017)

Google Scholar

5.

Jun, Y., Ping, L.: Temperature distributions in form grinding of involute gears. Int. J. Adv. Manuf. Technol. 88(9–12), 2609–2620 (2017)

CrossRefGoogle Scholar

6.

González-Santander, J.L.: Maximum temperature in dry surface grinding for high Peclet number and arbitrary heat flux profile. Hindawi Publishing Corporation Mathematical Problems in Engineering, pp. 1–9 (2016)

Google Scholar

7.

Foeckerer, T., Zaeh, M., Zhang, O.: A three-dimensional analytical model to predict the thermo-metallurgical effects within the surface layer during grinding and grind-hardening. Int. J. Heat Mass Transf. 56, 223–237 (2013)

CrossRefGoogle Scholar

8.

Lishchenko, N., Larshin, V.: Comparison of measured surface layer quality parameters with simulated results. Appl. Aspects Inf. Technol. 2(4), 304–316 (2019)

Google Scholar

9.

Zhang, L.: Numerical analysis and experimental investigation of energy partition and heat transfer in grinding. In: Salim Newaz Kazi, M. (eds.) Heat Transfer Phenomena and Applications, Sense Publishers, Rotterdam, The Netherlands (2012)

Google Scholar

10.

Tahvilian, A.M., Champliaud, H., Liu, Z., Hazel, B.: Study of workpiece temperature distribution in the contact zone during robotic grinding process using finite element analysis. In: 8th CIRP Conference on Intelligent Computation in Manufacturing Engineering, Ischia, Italy, pp. 205–210 (2013)

Google Scholar

11.

Li Hao, N., Axinte, D.: On a stochastically grain-discretised model for 2D/3D temperature mapping prediction in grinding. Int. J. Mach. Tools Manuf 116, 1–27 (2017)

CrossRefGoogle Scholar

12.

Jermolajev, S., Epp, J., Heinzel, C., Brinksmeier, E.: Material modifications caused by thermal and mechanical load during grinding. In: 3rd CIRP Conference on Surface Integrity (CIRP CSI) (2016). Procedia CIRP 45, 43–46

Google Scholar

13.

Jermolajev, S., Brinksmeier, E., Heinzel, C.: Surface layer modification charts for gear grinding. CIRP Ann. Manuf. Technol. 67(1), 333–336 (2018)

CrossRefGoogle Scholar

14.

Heinzel, C., Sölter, J., Jermolajev, S., Kolkwitz, B., Brinksmeier, E.: A versatile method to determine thermal limits in grinding. In: 2nd CIRP Conference on Surface Integrity (CSI) (2014). Procedia CIRP, vol. 13, pp. 131–136

Google Scholar

15.

Vrkoslavová, L., Louda, P., Malec, J.: Analysis of surface integrity of grinded gears using Barkhausen noise analysis and X-ray diffraction. In: 40th Annual Review of Progress in Quantitative Nondestructive Evaluation APP Conference Proceedings, vol. 1581, pp. 1280–1281 (2014)

Google Scholar

16.

Crow, J.R., Michael, A.: Pershing standard samples for grinder burn etch testing. Gear Technology, pp. 54–56 (2018)

Google Scholar

17.

Zaborowski, T., Ochenduszko, R.: Grinding burns in the technological surface of the gear teeth of the cylindrical gears. MECHANIK NR 90, 880–884 (2017)

Google Scholar

18.

de Lima, A., Gâmbaro, L.S., Junior, M.V., Baptista, E.B.: The use of cylindrical grinding to produce a martensitic structure on the surface of 4340 steel. J. Braz. Soc. Mech. Sci. Eng. 33, 34–40 (2011)

CrossRefGoogle Scholar

19.

Rena, X., Hu, H.: Analysis on the temperature field of gear form grinding. Appl. Mech. Mater. 633–634, 809–812 (2014)

Google Scholar

20.

Beizhi, L., Dahu, Z., Zhenxin, Z., Qiang, Z., Yichu, Y.: Research on workpiece surface temperature and surface quality in high-speed cylindrical grinding and its inspiration. Adv. Mater. Res. 325, 19–27 (2011)

CrossRefGoogle Scholar

21.

Lishchenko, N., Larshin, V.: Gear-grinding temperature modeling and simulation. In: Radionov, A., et al. (eds.) Proceedings of the 5th International Conference on Industrial Engineering (ICIE 2019), vol. 2, pp. 289–297. Springer (2019)

Google Scholar

22.

Yadav, R.K.: Analysis of grinding process by the use of finite element methods. ELK Asia Pacific J. Manuf. Sci. Eng. 1(1), 35–42 (2014)

Google Scholar

23.

Linke, B., Duscha, M., Vu, A.T., Klocke, F.: FEM-based simulation of temperature in speed stroke grinding with 3D transient moving heat sources. Adv. Mater. Res. 223, 733–742 (2011)

CrossRefGoogle Scholar

24.

Sharma, C., Ghosh, S., Talukdar, P.: Finite element analysis of workpiece temperature during surface grinding of inconel 718 alloy. In: 5th International & 26th All India Manufacturing Technology, Design and Research Conference, IIT Guwahati, Assam, India, pp. 420-1–420-6 (2014)

Google Scholar

25.

Patil, P., Patil, C.: FEM simulation and analysis of temperature field of environmental friendly MQL grinding. In: Proceedings of the International Conference on Communication and Signal Processing 2016 (ICCASP 2016), pp. 182–186 (2017)

Google Scholar

26.

Lishchenko, N., Larshin, V.: Temperature models for grinding system state monitoring. Appl. Aspects Inf. Technol. 2(3), 216–229 (2019)

Google Scholar

27.

Chen, X., Öpöz, T.: Effect of different parameters on grinding efficiency and its monitoring by acoustic emission. Prod. Manuf. Res. Open Access J. 4(1), 190–208 (2016)

Google Scholar

28.

Carslaw, H.S., Jaeger, J.C.: Conduction of Heat in Solids, 2nd edn. Oxford University Press, Oxford (1959)

zbMATHGoogle Scholar