Research project:

Improvements in the Design, Manufacture and Lubrication in Spiral Bevel and Hypoid Gears

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The developed method

More strength, less transmission error, higher efficiency and lower temperature in the gear mesh are major demands in the design of gear transmissions. These goals can be achieved by introduction of optimal tooth surface modifications. In practice, these modifications are introduced by applying the appropriate machine tool setting for the manufacture of the pinion and the gear, and/or by using a tool with an optimized profile. Therefore, the main goal of this project is to systematically define optimal tool geometry and machine tool settings to simultaneously minimize tooth contact pressure, angular displacement error of the driven gear and average temperature in the gear mesh, and to maximize the efficiency of the gear pair.

A multi-objective optimization method of face-milled and face-hobbed spiral bevel and hypoid gears correlating to the operating characteristics is developed. Optimal design of gears demands that multiple objectives be simultaneously achieved. The basic elements of this optimization method are:

1. The mathematical description of the manufacture of face-milled and face-hobbed spiral bevel and hypoid gears on cradle type and CNC hypoid generators. It includes the determination of the influence of machine tool setting parameters and tool geometry on the tooth surface geometry of the pinion and the gear. By the change of machine tool settings the appropriate modifications can be introduced into the teeth surfaces.

2. Loaded tooth contact analysis. In the newly developed method it is assumed that the point contact under load is spreading over a surface along the “potential” contact line, which line is made up of the points of the mating tooth surfaces in which the separations of these surfaces are minimal, instead of assuming the usually applied elliptical contact area. The real separations of contacting tooth surfaces are calculated by applying the full theory of tooth surface generation in face-milled and face-hobbed spiral bevel and hypoid gears.

3. The mixed-thermal-elastohydrodynamic lubrication analysis. A full numerical solution for the mixed elastohydrodynamic lubrication in spiral bevel and hypoid gears is derived. The equation system and the numerical procedure are unified for a full coverage of all the lubrication regions including the full film, mixed, and boundary lubrication. In the hydrodynamically lubricated areas the calculation method employed is based on the simultaneous solution of the Reynolds, elasticity, energy, and Laplace's equations. In the asperity contact areas the Reynolds equation is reduced to an expression equivalent to the mathematical description of dry contact problem. The transient nature of gear tooth mesh is included. The oil viscosity variation with respect to pressure and temperature and the density variation with respect to pressure are included. The non-Newtonian behaviour of the lubricant is considered.

4. The multi-objective optimization method. A multi-objective optimization method of sipral bevel and hypoid gears correlating to the operating characteristics is developed. The optimal design of hypoid gears demands that multiple objectives be simultaneously achieved. Four objectives considered in this project are the minimization of the maximum tooth contact pressure, transmission error and the average temperature in the gear mesh, and the maximization of the mechanical efficiency of the gear pair. The goals of the optimization are achieved

by the optimal modification of meshing teeth surfaces. In practice, these modifications are introduced by applying the appropriate machine tool settings for the manufacture of the pinion and the gear, and/or by using a tool with an optimized profile. The proposed optimization procedure relies heavily on the loaded tooth contact analysis for the prediction of tooth contact pressure distribution and transmission errors, and on the mixed elastohydrodynamic analysis of lubrication to determine temperature and efficiency. A fast elitist nondominated sorting genetic algorithm (NSGA-II) is applied to solve the model.

Achieved improvements

The effectiveness of the method is demonstrated by using hypoid gear examples. The following improvements in the operating characteristics are achieved: the maximum tooth contact pressure is reduced for 68%, the transmission error for 77%, the average temperature for 11%, and the efficiency of the gear pair is increased from 0.9442 to 0.9663.

Related publications

a) Publications in journals with impact factor:

1. Simon, V., "Design of Face-Hobbed Spiral Bevel Gears with Reduced Maximum Tooth Contact Pressure and Transmission Errors", Chinese Journal of Aeronautics, Vol. 26, 2013, pp.777-790.
2. Simon, V., "Optimal Tooth Surface Modifications in Face-Hobbed Hypoid Gears", Key Engineering Materials, Vol. 572, 2013, pp. 351-354.
3. Simon, V., "Optimization of Face-Hobbed Hypoid Gears", Mechanism and Machine Theory, Vol. 77, 2014, pp. 164-181.
4. Simon, V., "Manufacture of Optimized Face-Hobbed Spiral Bevel Gears on Computer Numerical Control Hypoid Generator", ASME Journal of Manufacturing Science and Engineering, Vol. 136, 2014(3), Art. No. 131009, pp. 1-9.
5. Simon, V., "Optimal Tooth Modifications in Face-Hobbed Spiral Bevel Gears to Reduce the Influence of Misalignments on Elastohydrodynamic Lubrication", ASME Journal of Mechanical Design, Vol. 136, 2014(7), Art. No. 071007, pp. 1-9.
6. Simon, V., "Optimal Machine Tool Settings for the Manufacture of Face-Hobbed Spiral Bevel Gears", ASME Journal of Mechanical Design, Vol. 136, 2014(8), Art. No. 081004, pp. 1-8.
7. Simon, V., "Micro Tooth Surface Topography of Face-Milled Hypoid Gears", Mechanism and Machine Theory, Vol. 104, 2016, pp. 370-381.
8. Simon, V., "Optimal Machine Tool Settings for Face-Hobbed Hypoid Gears Manufactured on CNC Hypoid Generator", The International Journal of Advanced Manufacturing Technology, Vol. 88(5-8), 2017, pp. 1579-1594.
9. Simon, V., "Improvements in the Micro Tooth Surface Topography of Hobbed Spur and Helical Gears", Journal of the Brazilian Society of Mechanical Sciences and Engineering, Vol. 40(4), April 2018, Art. 210.

b) Publications in the proceedings of congresses and conferences:

1. Simon, V., "Optimal Machine Tool Settings for the Manufacture of Face-Hobbed Spiral Bevel Gears", ASME International Power Transmission and Gearing Conference, Portland, USA, 2013, Paper No. DETC2013/PTG-12058, pp. 1-16.

2. Simon, V., “Minimization of the Influence of Misalignments on EHD Lubrication in Face-Hobbed Spiral Bevel Gears”, ASME International Power Transmission and Gearing Conference, Portland, USA, 2013, Paper No. DETC2013/PTG-12080, pp. 1-11.
3. Simon, V., “Optimal Tooth Surface Modifications in Face-Hobbed Hypoid Gears”, 5th International Conference on Advanced Design and Manufacture (ADM2013), Valencia, Spain, 2013, Paper No. A1315, pp. 1-4, Key Engineering Materials, Vol. 572, pp. 351-354.
4. Simon, V., “Gear Optimization”, Proceedings of the 8th International Symposium Machine and Industrial Design in Mechanical Engineering, Balatonfüred, Hungary, 2014, pp. 155-162.
5. Simon, V., “Optimal Tooth Surface Modifications of Face-Hobbed Hypoid Gears Manufactured on CNC Hypoid Generator”, Proceedings of the TrC-IFToMM Symposium on Theory of Machines and Mechanisms, Izmir, Turkey, 2015, pp. 280-293.
4. Simon, V., “Micro Aspects of Gear Manufacture”, Proceedings of the 14th IFToMM World Congress, Taipei, Taiwan, 2015, Invited Paper, pp. 1-7.
5. Simon, V., “Optimization of Face-Hobbed Spiral Bevel Gears to Improve EHD Lubrication”, Proceedings of the 14th IFToMM World Congress, Taipei, Taiwan, 2015, Paper No. OS18-009, pp. 1-11. (Best Paper Award)
6. Simon, V., “Micro Surface Topography of Face-Milled Hypoid Gears”, Proceedings of the 14th IFToMM World Congress, Taipei, Taiwan, 2015, Paper No. OS6-008, pp. 1-11.
7. Simon, V., “Improvements in Gear Lubrication”, Proceedings of the Lubrication, Maintenance and Tribology Conference, Bilbao, Spain, 2016, pp. 646-650.
8. Simon, V., “Advanced Manufacture of Spiral Bevel and Hypoid Gears”, Proceedings of the International Conference on Advanced Technology Innovation 2016, Bali, Indonesia, 2016, Vol. 2., No. 3, pp. 61-67.
9. Simon, V., “Optimization of Gear Design and Manufacture”, Proceedings of the 2017 International Conference on Mechanical and Mechatronics Engineering, Bangkok, Thailand, 2017, pp. 259-263.
10. Simon, V., “Advanced Design and Manufacture of Spiral Bevel, Hypoid and Worm Gears”, Proceedings of the Fifth International Conference on Advances in Mechanical and Robotics Engineering – AMRE 2017, 2017, Rome, Italy, pp. 12-16.
11. Simon, V., “Mixed Elastohydrodynamic Lubrication of Hypoid Gears”, Proceedings of the Lubmat 2018 – Sixth Congress in Lubrication, Tribology and Condition Monitoring, San Sebastian, Spain, 2018, pp. 1-6.
12. Simon, V., “Optimized Manufacture to Improve Operating Characteristics of Gears”, Proceedings of the Tenth International Conference Engineering Computational Technology 2018, Sitges, Barcelona, Spain, 2018, Paper No. 03.44, pp. 1-4.
13. Simon, V. “Multi-Objective Optimization of Hypoid Gears to Improve Operating Characteristics”, Proceedings of the 15th IFToMM World Congress, Krakow, 2019.