

Lecture Notes in Mechanical Engineering

Andrey A. Radionov

Oleg A. Kravchenko

Victor I. Guzeev

Yurij V. Rozhdestvenskiy *Editors*

# Proceedings of the 5th International Conference on Industrial Engineering (ICIE 2019)

Volume I

 Springer

# **Lecture Notes in Mechanical Engineering**

**Lecture Notes in Mechanical Engineering (LNME)** publishes the latest developments in Mechanical Engineering - quickly, informally and with high quality. Original research reported in proceedings and post-proceedings represents the core of LNME. Volumes published in LNME embrace all aspects, subfields and new challenges of mechanical engineering. Topics in the series include:

- Engineering Design
- Machinery and Machine Elements
- Mechanical Structures and Stress Analysis
- Automotive Engineering
- Engine Technology
- Aerospace Technology and Astronautics
- Nanotechnology and Microengineering
- Control, Robotics, Mechatronics
- MEMS
- Theoretical and Applied Mechanics
- Dynamical Systems, Control
- Fluid Mechanics
- Engineering Thermodynamics, Heat and Mass Transfer
- Manufacturing
- Precision Engineering, Instrumentation, Measurement
- Materials Engineering
- Tribology and Surface Technology

To submit a proposal or request further information, please contact the Springer Editor in your country:

**China:** Li Shen at [li.shen@springer.com](mailto:li.shen@springer.com)

**India:** Dr. Akash Chakraborty at [akash.chakraborty@springernature.com](mailto:akash.chakraborty@springernature.com)

**Rest of Asia, Australia, New Zealand:** Swati Meherishi at [swati.meherishi@springer.com](mailto:swati.meherishi@springer.com)

**All other countries:** Dr. Leontina Di Cecco at [Leontina.dicecco@springer.com](mailto:Leontina.dicecco@springer.com)

To submit a proposal for a monograph, please check our Springer Tracts in Mechanical Engineering at <http://www.springer.com/series/11693> or contact [Leontina.dicecco@springer.com](mailto:Leontina.dicecco@springer.com)

**Indexed by SCOPUS. The books of the series are submitted for indexing to Web of Science.**

More information about this series at <http://www.springer.com/series/11236>

Andrey A. Radionov · Oleg A. Kravchenko ·  
Victor I. Guzeev · Yuriy V. Rozhdestvenskiy  
Editors

# Proceedings of the 5th International Conference on Industrial Engineering (ICIE 2019)

Volume I

 Springer

*Editors*

Andrey A. Radionov  
South Ural State University  
Chelyabinsk, Russia

Victor I. Guzeev  
South Ural State University  
Chelyabinsk, Russia

Oleg A. Kravchenko  
Platov South-Russian State  
Polytechnic University  
Novocherkassk, Russia

Yurij V. Rozhdestvenskiy  
South Ural State University  
Chelyabinsk, Russia

ISSN 2195-4356 ISSN 2195-4364 (electronic)  
Lecture Notes in Mechanical Engineering  
ISBN 978-3-030-22040-2 ISBN 978-3-030-22041-9 (eBook)  
<https://doi.org/10.1007/978-3-030-22041-9>

© Springer Nature Switzerland AG 2020

This work is subject to copyright. All rights are reserved by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed.

The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.

The publisher, the authors and the editors are safe to assume that the advice and information in this book are believed to be true and accurate at the date of publication. Neither the publisher nor the authors or the editors give a warranty, expressed or implied, with respect to the material contained herein or for any errors or omissions that may have been made. The publisher remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

This Springer imprint is published by the registered company Springer Nature Switzerland AG  
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

# Preface

The International Conference on Industrial Engineering took place on March 25–29, 2019, in Sochi, Russian Federation. The conference was organized by four universities—South Ural State University (National Research University), Moscow Polytechnic University, Platov South Russian State Polytechnic University, and Volgograd State Technical University.

The conference was carried out under financial support of the South Ural State University (National Research University).

The conference was really large-scaled and international. The International Program Committee has selected more than 500 reports. The conferees represented 63 Russian cities from the western and central parts to the Far East regions. International participants represented such countries as China, Germany, Kazakhstan, Kyrgyzstan, Portugal, Saudi Arabia, Tajikistan, Ukraine, USA, and Uzbekistan.

The conference participants submitted papers reflecting recent advances in the field of industrial engineering, in Russian and English. The conference was organized in 13 sections, including Part I “Mechanical Engineering” (machinery and mechanism design; dynamics of machines and working processes; friction, wear, and lubrication in machines; design and manufacturing engineering of industrial facilities; transport and technological machines; mechanical treatment of materials; industrial hydraulic systems; green manufacturing) and Part II “Materials Engineering and Technologies for Production and Processing” (polymers, composites and ceramics; steels and alloys, metallurgical and metalworking technologies; chemical and hydrometallurgical technologies; surface engineering and coatings; processing and controlling technologies).

The International Program Committee selected 294 papers from Part I of the conference technical sections for publication in book series “Lecture Notes in Mechanical Engineering.”

The Organizing Committee would like to express our sincere appreciation to everybody who has contributed to the conference. Heartfelt thanks are due to authors, reviewers, participants, and to all the team of organizers for their support and enthusiasm which granted success to the conference.

Chelyabinsk, Russia

Andrey A. Radionov

# Contents

<b>Gear Transmission with Conic Axoid on Parallel Axes</b> . . . . .	1
S. Shevchenko, A. Mukhovaty and O. Krol	
<b>Mathematical Model of Mechanism for Sealing Hardly Deformable Materials</b> . . . . .	11
E. I. Kromsky, S. V. Kondakov and M. A. Asfandiarov	
<b>Promising Machine for Compacting Road-Building Materials</b> . . . . .	21
E. I. Kromsky, S. V. Kondakov and K. Z. Tilloev	
<b>Assessing Effectiveness of Technical Measures for Improving Working Conditions of Wheeled Vehicle Operators</b> . . . . .	29
V. Shkrabak, A. Kalugin and Y. Averyanov	
<b>Definition of Rational Modes of Use of Marginal Dug-Out Wells</b> . . . . .	41
V. Kushnir, O. Benyukh and S. Kim	
<b>Hose Regulating Device with Swirling</b> . . . . .	49
A. V. Fominykh, I. R. Chinyaev and A. A. Ezdina	
<b>Theoretical and Experimental Evaluation of Diesel Engine Derating Effect on Its Life Time</b> . . . . .	55
A. Malozemov, V. Dooun and D. Kozminykh	
<b>Failure Model for Gear Couplings Under the Criterion of Working Surface Endurance</b> . . . . .	65
M. G. Slobodianskii, Alexey V. Antsupov and S. V. Lukinskih	
<b>Analytical Model of Wear-Out Failures in Spur Gears of External Gearing.</b> . . . . .	75
Alexander V. Antsupov, M. G. Slobodianskii and V. P. Antsupov	
<b>Development of Analytical Methodology for Detail Durability Test While Arranging Metallurgical Machines.</b> . . . . .	83
Alexey V. Antsupov, Alexander V. Antsupov and V. P. Antsupov	



<b>Application of Kantorovich-Vlasov Method for Shaped Plate Bending Problem</b> .....	91
S. V. Konev, A. S. Fainshtein and I. E. Teftelev	
<b>Comparative Analysis of Stress–Strain Condition of Cylindrical Gears Arc Teeth and Spurs</b> .....	101
K. Syzrantseva, V. Syzrantsev and D. Babichev	
<b>Thermomechanical Fatigue Analysis of Diesel Engine Piston: Finite Element Simulation and Lifetime Prediction Technique</b> .....	109
S. M. Sivachev and L. L. Myagkov	
<b>Quantitative Assessment of Thermal Properties of the Metal-Cutting Machine Design</b> .....	119
B. M. Dmitriev	
<b>Estimation Method of Slip Ring Mechanical Strength in Current Collectors in Static Setting</b> .....	129
I. V. Kudryavtsev, O. I. Rabetskaya and A. E. Mityaev	
<b>Ensuring Operational Life and Reliability of Contact Rings in Plastic State</b> .....	137
I. V. Kudryavtsev, E. S. Novikov and V. G. Demin	
<b>Deformation and Stability of Cylindrical Shells Under Irregular Radial Loading</b> .....	145
S. V. Makhnovich, D. A. Permyakov and Yu. M. Khishchenko	
<b>Evaluation of Possible Limits of Forcing of High-Capacity Air-Cooled Engines</b> .....	159
A. V. Vasilyev, A. M. Lartsev and E. A. Fedyanov	
<b>Torsional Rigidity of Elastic Rods of Polygonal Cross Section</b> .....	167
A. V. Korobko, Yu. E. Lygina and S. Yu. Savin	
<b>Strength Calculation of the Frame of Tourist Solar-Powered Vehicle in the Conditions of Static Loading</b> .....	175
A. A. Polivanov and V. S. Galuschak	
<b>Durability of Centrifugal Pump Impeller Blades Exposed to Corrosive–Erosive Wear</b> .....	181
V. A. Pukhliy and S. T. Miroshnichenko	
<b>Theoretical Calculation of Compressed Media Leaks in Working Bodies of Single-Rotor Screw Compressor with Circumferential Tooth Shape</b> .....	191
A. F. Minikayev, V. A. Pronin and D. V. Zhignovskaya	

**Contact Strength Calculation of Straight Bevel Precessional Gears with Small Shaft Angle** ..... 197  
 V. Syzrantsev and A. Pazyak

**Research of Direction of Rope-Hydraulic Quarry Excavator Creation** ..... 205  
 S. A. Khoroshavin, V. S. Shestakov and V. I. Saitov

**Formation of Quality Indicators System at Design of Mechanical Engineering Products** ..... 213  
 E. A. Ivakhnenko, L. M. Chervyakov and O. Yu. Erenkov

**Mini-Converter for Processing of Poor-Quality Charge and Metal-Containing Waste** ..... 223  
 S. Eronko, S. Gorbatyuk and M. Tkachev

**Cabled Feeder for Underground Drilling Machines** ..... 231  
 A. M. Busygin

**Solving Problem of Curved Surface Approximation by Layers with Constant and Variable Sections During Forming by Additive Methods** ..... 239  
 A. N. Grechukhin, V. V. Kuts and M. S. Razumov

**Assessment of Natural Oscillation Frequencies of Rotor for Development of Hard-Bearing Balancing Machine** ..... 249  
 S. O. Gaponenko, A. E. Kondratiev and I. R. Tazeev

**Equipment with Disc Cutters for Destruction and Removal of Strength Snow and Ice Formations on Road Surface** ..... 259  
 A. V. Lysyannikov, Yu. N. Bezborodov and V. G. Shram

**Improvement of Equipment for Knocking Out Castings from Molds** ..... 269  
 V. G. Nekrutov, A. V. Irshin and B. A. Reshetnikov

**Theoretical Study of Sifting Heap on Finger Chaffer Sieve** ..... 277  
 A. V. Butovchenko, E. E. Petrov and A. A. Doroshenko

**Modeling Polymeric Centrifugal-Pump Impeller Blades** ..... 287  
 V. A. Pukhliy, S. T. Miroshnichenko and V. V. Sokolov

**Vibration Isolating and Impact Protecting Systems with Quasi-Zero Stiffness Providing Wide Operating Area** ..... 299  
 A. Zotov and A. Valeev

**Locating of Oscillating Defect in Rotary Equipment via Remote Strain Gauge Analysis** ..... 309  
 A. Valeev and A. Tokarev

<b>Results of Studying Cleaning of Exhaust Gases of Preheater-Equipped KamAZ-740 Diesel Engine . . . . .</b>	<b>319</b>
A. A. Melbert and A. V. Mashensky	
<b>Features of Rotor Friction Losses Balancing in Centrifugal Electric-Driven Pumps for Spacecrafts . . . . .</b>	<b>329</b>
A. Bobkov	
<b>Deformation of Prismatic Samples of U-Shaped Grooves and Their Stress–Strain State . . . . .</b>	<b>337</b>
E. V. Zenkov and D. A. Elovenko	
<b>Analysis of Gears’ Engagement Parameter in Period of Steady Wear . . . . .</b>	<b>349</b>
M. Akopyan, S. Reznikov and O. Kuznetsova	
<b>Kinostatics of Rotationally Reciprocating Stirred Tank Planetary Actuator . . . . .</b>	<b>359</b>
A. A. Prikhodko	
<b>Automation of Heat Exchanger Shell Holes Machining Operation . . . . .</b>	<b>367</b>
A. Yu. Gorelova, M. G. Kristal and V. A. Martynenko	
<b>Arching Design of Device for Cooling Cutting Zone of Milling Machine Based on Graph Model of Physical Working Principle . . . . .</b>	<b>377</b>
A. A. Yakovlev, V. S. Sorokin and S. G. Postupaeva	
<b>Processing of Renewable Wood Biomass into Thermally Modified Pellets with Increased Combustion Value . . . . .</b>	<b>387</b>
R. G. Safin, D. B. Prosvirnikov and T. O. Stepanova	
<b>Influence Estimate of Spectral Model of Combustion Product Radiation on Results of DKVR-10/13 Steam Boiler Furnace Simulating . . . . .</b>	<b>399</b>
D. A. Akhmedzaynov, A. E. Kishalov and V. D. Lipatov	
<b>Automated Control of Truck Drive Axle Performance Characteristics . . . . .</b>	<b>411</b>
A. Yu. Barykin, M. M. Mukhametdinov and R. Kh. Takhaviev	
<b>Simulation of Transforming Magnetic Systems Based on Permanent Magnets to Control Microparticles . . . . .</b>	<b>419</b>
N. N. Merzlova, A. V. Pashkovskiy and D. V. Boldyrev	
<b>Use in Cycle of Biogas Plant Boiler for Waste Disposal . . . . .</b>	<b>431</b>
S. A. Naumov, V. Y. Sokolov and A. V. Sadchikov	
<b>Simulation of Rectification Process Taking into Account Longitudinal Diffusion on Equations of Working Lines . . . . .</b>	<b>441</b>
A. B. Golovanchikov, V. N. Karev and N. A. Prokhorenko	

**Investigation of Process of Cutting Fruit and Vegetable Raw Materials into Slices Using Rotary Chopper** ..... 451  
 N. Lebed, N. Antonova and G. Rusakova

**Investigation of Kinematics of 3D Printer Print Head Moving Systems** ..... 461  
 A. R. Avdeev, A. A. Shvets and I. S. Torubarov

**Development of Algorithm for Creating Parametric 3D Models, Controlled by Mathcad Calculations, to Study Parameters of Enclosed Gears Housing** ..... 473  
 E. Petrakova and V. Sumatokhin

**Automated Method for Modular Selection of Components for Multi-bearing Unit of Internal Combustion Engine Assembling** ..... 485  
 V. A. Saninsky, V. V. Korzin and A. V. Petrukhin

**Improving Synthesis Accuracy of Topology Elements in Laser Pattern Generators with Circular Scanning Mode** ..... 497  
 A. V. Kiryanov and V. P. Kiryanov

**Estimation of Heat Losses in Fuel Combustion by Analysis of Gas Pressure in the Cylinder of Diesel** ..... 507  
 E. A. Lazarev, V. E. Lazarev and M. A. Matculevich

**Determination of Parameters and Characteristics of Injection in Fuel System of Accumulating Type at Cold Start of the Diesel Engine** .... 515  
 V. V. Shishkov and E. A. Lazarev

**Influence of Main Design Parameters of Motion Conversion Mechanism of Crankless Reciprocating Machine (Engine) on Torque Value on Output Shaft** ..... 523  
 B. A. Sharoglazov and V. V. Klementev

**Research of Dynamic Characteristics of Bearing Structures at Takeaway of Ventilation Equipment on the Workshop Roof** ..... 533  
 G. Voronkova, N. Borisova and A. Borisov

**Features of Pulsating Flows Thermomechanics in Exhaust System of Piston Engine with Turbocharging** ..... 541  
 L. V. Plotnikov, Yu M. Brodov and N. I. Grigor’ev

**Improvement of Environmental Characteristics of Diesel Locomotive Engine with Turbocharging by Changing Valve Timing (Based on Miller Cycle)** ..... 549  
 L. V. Plotnikov, S. Bernasconi and P. Jacoby

<b>Calculated Analysis of Efficiency of Fresh Charge Heating in Diesel Engine Under Cold-Start Conditions</b> .....	559
A. E. Popov, Z. V. Almetova and V. D. Shepelev	
<b>Theoretical Studies of Automobile Smooth Running on High-Safety Wheels</b> .....	567
V. V. Mazur	
<b>Computer Simulation of Numerical Description of Closed Curve Using Fourier Coefficients</b> .....	575
S. Ibrayev, Zh. Bidakhmet and Ay. Rakhmatulina	
<b>Simulation of Fuel Ignition Chemical Kinetics in Diesel Engine at Cold Start with Modelica Language</b> .....	585
A. Malozemov, A. Savinovskikh and G. Malozemov	
<b>Dynamic Pattern of Safe Operation Indicators for Heavy-Duty Machines</b> .....	595
Yu. A. Izvekov, V. V. Dubrovsky and A. L. Anisimov	
<b>Influence of Spherical Body Diameter on Impact Interaction Dynamics</b> .....	603
V. Lapshin, V. Yashenko and A. Eliseev	
<b>Indicative and Efficient Parameters of the Engine Operating Cycle When Using Fuels with Various Octane Numbers</b> .....	611
V. E. Lazarev, M. A. Matculevich and E. A. Lazarev	
<b>Interaction of Elastic Wheel with Bumps of Rectangular Shape</b> .....	621
A. Startcev, S. Romanov and O. Vagina	
<b>Opportunities for Using Spline Method to Calculate Orthotropic Plate Under Bending Conditions</b> .....	631
V. S. Zhernakov, V. P. Pavlov and V. M. Kudoyarova	
<b>Experiments to Find the Rolling Resistance of Non-pneumatic Tires Car Wheels</b> .....	641
V. V. Mazur	
<b>Peculiarities of Motion of Pendulum on Mechanical System Engine Rotating Shaft</b> .....	649
A. I. Artyunin, S. V. Barsukov and O. Yu. Sumenkov	
<b>Reducing Dynamic Loads in Hoisting Mechanism of Excavator Based on Feedbacks on Elastic Torque</b> .....	659
N. K. Kuznetsov, I. A. Iov and E. S. Dolgih	
<b>Determination of Magnetization Efficiency of Wheel-Rail Contact Zone</b> .....	669
D. Ya. Antipin, V. O. Korchagin and M. A. Maslov	

<b>Forecasting of Life Service of Hopper Car Body Load-Bearing Structure on Basis of Mathematical Modeling Methods</b> .....	677
D. Ya. Antipin, V. V. Kobishanov and A. S. Mitnikov	
<b>Evaluation of Heat Mechanical Loading of Piston of Gasoline Engine 4CH8,2/7,56 When It Is Forced at Average Effective Pressure</b> .....	687
G. V. Lomakin and V. M. Myslyayev	
<b>Losses Analysis in Gas Turbine Engines Flow Parts</b> .....	697
I. A. Krivosheev, N. B. Simonov and K. E. Rozhkov	
<b>Transfer Functions for Shearing Stress in Nonstationary Fluid Friction</b> .....	707
V. Sokolov	
<b>On Splitting of Bending Frequency Spectrum of Geometrically Imperfect Shells</b> .....	717
S. V. Seregin	
<b>Mathematical Model of Spindle Unit Bearing Assembly</b> .....	725
E. S. Gasparov and L. B. Gasparova	
<b>Evaluation of Contact Stresses in Railway Wheel When Rolling Through Rail Joint</b> .....	733
E. S. Evtukh and G. A. Neklyudova	
<b>Determination of Eigenforms and Frequencies of Transverse Vibrations of a Rod of Variable Cross Section in the Field of Centrifugal Forces</b> .....	743
A. P. Levashov and O. Yu. Medvedev	
<b>Problem of Calculation of Reliability of Hierarchical Complex Technical Systems</b> .....	753
P. A. Kulakov, D. D. Galyautdinov and V. G. Afanasenko	
<b>Developing Methods for Calculating Gas-Dynamic Parameters in Launch Canister During the Missile Launch</b> .....	765
R. A. Peshkov and A. V. Erpalov	
<b>The Detection of Electrode Breakage in Electric Discharge Process by Methods of Vibroacoustic Diagnostics</b> .....	775
M. Kozochkin, A. Porvatov and D. Allenov	
<b>Method of Estimation of Pressure Forces from Power Plant in Microtunneling</b> .....	783
E. Y. Kulikova and I. I. Shornikov	
<b>Diesel Work Cycle at Start</b> .....	791
V. V. Shishkov	

<b>Dynamic Analysis of Lifting Cranes</b> .....	801
N. N. Panasenko and A. V. Sinelschikov	
<b>Vibration Isolation Properties of Vehicle Suspension at Optimal Instantaneous Damping Control in Oscillation Cycle</b> .....	819
K. V. Chernyshov, A. V. Pozdeev and I. M. Ryabov	
<b>Monitoring Engine Toxicity Parameters and Selective Control of Its System Operation</b> .....	829
A. V. Gritsenko, Z. V. Almetova and V. V. Rudnev	
<b>Finding Stable Region of Torsional Vibrations of Agro-Industrial Rotary Cultivators</b> .....	839
S. A. Partko, L. M. Groshev and A. N. Sirotenko	
<b>Improvement of Fuel Injection and Atomization Processes in Transport Diesel Engine</b> .....	845
V. A. Markov, S. N. Devyanin and V. G. Kamaltdinov	
<b>Finding New Component in Displacement of Normal Supporting Surface Reaction to Car Wheels</b> .....	855
T. A. Golubeva and E. V. Balakina	
<b>Numerical Research of Combustible Mixture Inert Components Influence on Compression-Ignition Engines Combustion Process</b> .....	865
V. G. Kamaltdinov, V. A. Markov and K. S. Leonov	
<b>Results of Bench Tests of Pneumatic Suspension with Air-Hydraulic Damping</b> .....	875
V. V. Novikov, A. V. Pozdeev and D. A. Chumakov	
<b>Investigation of Stress-Strain State of Ball Mill Trunnion</b> .....	883
Ju. A. Bondarenko, S. I. Khanin and O. V. Bestuzheva	
<b>Influence of Stiffness of Rear Leaf Spring on Van Vibration Loading</b> .....	895
Yu. A. Polyakov	
<b>Hydroelastic Oscillations of Three-Layered Channel Wall Resting on Elastic Foundation</b> .....	903
D. V. Kondratov, V. S. Popov and A. A. Popova	
<b>Use of Vibration Isolation Systems with Negative Stiffness on the Basis of Special Shaped Guides to Reduce Pump Piping Vibration</b> .....	913
A. Tokarev, A. Valeev and A. Zotov	
<b>Effect of Two Cracks in a Rotor on Stiffness Using the Theory of Fracture Mechanics</b> .....	921
Salam Ahmed Abed, Mohammad Reza Bahrami and Jassim Farij Thijel	

<b>How Asymmetric Initial Imperfections in Shape Affect Free Oscillations of Thin Shells</b> .....	931
S. V. Seregin	
<b>Test Bench for Analyzing Adaptability of Foil Gas-Dynamic Bearings to External Changes</b> .....	941
A. V. Gorin, R. N. Poliakov and A. V. Sytin	
<b>Automatic System of Low-Pressure Gas Recycling at Liquid Removal from Wells and Gas Collectors</b> .....	951
M. Yu. Prakhova, A. N. Krasnov and E. A. Khoroshavina	
<b>Improvement of Procedure for Determining Antioxidant Additive (Ionol) in Insulating Oils</b> .....	963
M. Lyutikova and S. Korobeynikov	
<b>Resource-Saving Multifunctional Apparatus for Autonomous Energy and Water Supply Systems</b> .....	973
I. V. Dolotovskij and N. V. Dolotovskaya	
<b>Slag Cut-off During Steel Casting</b> .....	983
Yu. I. Eremenko and D. A. Poleshchenko	
<b>Arresting Longitudinal Cracks in Steel Pipelines: Computational Analysis Technique</b> .....	993
Baraa M. H. Albaghdadi and A. O. Cherniavsky	
<b>Improvement of Operational Characteristics of Aggregates by Nanostructuring Surfaces of Tribounits</b> .....	1003
M. Yu. Karelina, T. Yu. Cherepnina and N. Yu. Bugakova	
<b>Advantages of Using Wheel Rolling Radius for Calculating Friction Characteristics in Wheel-to-Road Contact Patch</b> .....	1015
E. V. Balakina, E. Y. Lipatov and D. S. Sarbayev	
<b>Lubrication Conditions and Development of Pre-failure State of Crankshaft Bearings</b> .....	1023
A. T. Kulakov, E. P. Baryl'nikova and I. P. Talipova	
<b>Investigations of Antifriction Films Formation in Dioctyl Sebacate Medium with Cholesteryl Esters</b> .....	1035
M. V. Boiko, A. P. Sychev and I. V. Kolesnikov	
<b>Dependence of Automatic Installation of Tool Carrier Process on Orientation Errors and Their Effect on Performance Characteristics of Spindle-Tool Subsystem</b> .....	1043
O. Yu. Kazakova and L. B. Gasparova	



<b>Automated Calculation and Control of Body Wear in Friction Pair</b> .....	1053
V. A. Saninsky, V. V. Korzin and M. A. Kononovich	
<b>Method for Modelling of Circulation of Lubricating Fluid in Models of Machine-Building Products</b> .....	1063
A. S. Gorobtsov, E. G. Gromov and N. V. Chigirinskaya	
<b>Influence of Physicochemical Processes on Reliability of Node of Sliding Current Collector of Electric Machines</b> .....	1073
S. A. Izotov, A. I. Izotov and A. A. Fominyh	
<b>Bench-Scale Tests Aimed at Finding Rate and Acceleration of Wear Determining Service Life of Thrust Bearing in Submersible Electric Motor</b> .....	1089
V. A. Butorin, I. B. Tsarev and R. T. Guseynov	
<b>Macromechanism Destruction of Structurally and Crystallographically Textured Titanium Billets</b> .....	1097
M. A. Skotnikova, G. V. Ivanova and A. A. Strelnikova	
<b>Study on Factors Having Influence Upon Efficiency of AC Motor Chain Drive Using Newly Developed Method and Procedure for Identification of Its Friction Losses</b> .....	1107
V. Belogusev, A. Egorov and I. Polyaniin	
<b>Discrete Contact in Toothed Gearing</b> .....	1117
Alexander Vladimirovich Titenok and Igor Alexandrovich Titenok	
<b>Contact Movement in Mating Conical Joints Within Resting Friction</b> .....	1127
V. Feropontov, N. Perfileva and A. Maksimenko	
<b>Forming Laminar Flow of Engine Oil Under Conditions of High-Speed Sliding Friction</b> .....	1137
V. I. Kubich, E. A. Zadorozhnaya and O. G. Cherneta	
<b>Study of Dependence of Kinematic Viscosity and Thermal-Oxidative Stability of Motor Oils</b> .....	1155
V. G. Shram, Yu. N. Bezborodov and A. V. Lysyannikov	
<b>Complex Method for Evaluating Lubricating Properties of Technological Tools and Stresses When Drawing Products from Sheet Steel</b> .....	1163
G. I. Shulga, A. O. Kolesnichenko and I. Y. Lebedinsky	
<b>Monitoring Technical Status of Engine Bearings by Pressure Parameters in Central Oil Line</b> .....	1175
A. V. Gritsenko, V. D. Shepelev and A. G. Karpenko	

<b>Evaluation of Thermal Condition of Turbocharger Rotor Bearing</b> . . . . .	1183
E. Zadorozhnaya, V. Hudyakov and I. Dolgushin	
<b>Ensuring Tightness of Sealing Joints at the Design Stage</b> . . . . .	1195
P. Ogar, A. Kozhevnikov and V. Kushnarev	
<b>Modeling Introduction of Rigid Sphere into Layered Elastic Body</b> . . . . .	1205
P. Ogar, A. Kozhevnikov and V. Kushnarev	
<b>Influence of Oxidation Products on Anti-wear Properties of Lubricants</b> . . . . .	1215
B. I. Kovalsky, N. N. Lysyannikova and E. G. Kravcova	
<b>Experimental Modeling of Wearing the Friction Surfaces of “Piston-Cylinder” Tribounit</b> . . . . .	1225
A. Doikin and K. Gavrilov	
<b>Investigation of Influence of Steel SH 15 on Oxidation and Anti-wear Properties of Mineral Oil</b> . . . . .	1233
E. G. Kravtsova, B. I. Kowalsky and N. N. Lysyannikova	
<b>Theoretical Research of Kinematic Pair “Shaft-Sleeve” of Friction Bearing of Gas-Compressor Unit at Variable Speeds of Shaft Rotation</b> . . . . .	1241
Y. P. Serdobintsev, M. P. Kukhtik and A. M. Makarov	
<b>Design Engineering and Manufacturing of Technology of Bearings for Heavy-Duty Friction Units</b> . . . . .	1251
R. V. Yudin, D. A. Parinov and I. N. Medvedev	
<b>Surface Films Formation on Steel During Friction of Polymer Composites Containing Microcapsules with Lubricant</b> . . . . .	1259
A. V. Sidashov and M. V. Boiko	
<b>Fabrication and Triboengineering Properties of Aluminum Composite Ceramic Coatings</b> . . . . .	1269
A. N. Bolotov, V. V. Novikov and O. O. Novikova	
<b>Formation and Properties of Multilayer Composite Solid Lubricant Coating</b> . . . . .	1279
I. N. Shcherbakov, A. A. Korotkiy and E. V. Egelskaya	
<b>Modeling Wear of Tool’s Front Surface During Turning</b> . . . . .	1287
S. A. Kurguzov and M. V. Nalimova	

**Evaluation of Lubricants Use with Ultrafine Copper-Containing Additives in Sliding Bearings with Reversible Friction** . . . . . 1295  
S. G. Dokshanin, V. S. Tynchenko and V. V. Bukhtoyarov

**Numerical Modelling of Fluid-Film Bearing Lubricated with Magnetorheological Fluid** . . . . . 1303  
A. Babin, A. Fetisov and V. Tyurin

# Gear Transmission with Conic Axoid on Parallel Axes



S. Shevchenko, A. Mukhovaty and O. Krol

**Abstract** The article presents the results of a study for gear transmission on parallel axes with gear axoids and wheels in the form of truncated cones (CGA). The tangential gear teeth and CGA wheels in the longitudinal direction coincide with the conical helical lines lying on the truncated cones, which are the axes of the CGA. In this case, the angle of these cones is invariant with respect to the transfer value of the CGA, which allows them to vary widely. The length of the CGA teeth is determined, the growth of which will lead to a decrease in bending and contact stresses in the teeth of the CGA. As a result, there will be an increase in the load capacity of the CGA in comparison with a cylindrical gear transmission with chevron teeth (CGCh) with the same dimensions according to the basic criteria for the performance of this type of transmission—bending and contact fatigue strength. For the practical calculation of the CGA, an enlarged scheme of the algorithm for calculating the CGA is proposed, with reference to the current calculation procedure for the CGCh. The design features of the CGA are noted.

**Keywords** Conical line · Cylindrical gear · Chevron teeth · Tangential teeth · Axoids

## 1 Introduction

The technical level of the technological and transport equipment largely predetermines the technical and economic indicators of the mechanical drives contained in them. This explains the relevance of research aimed at improving existing types of

---

S. Shevchenko · A. Mukhovaty  
Volodymyr Dahl Lugansk National University, 20-a Kvartal Molodezhny,  
Lugansk 91034, Ukraine

O. Krol (✉)  
Volodymyr Dahl East Ukrainian National University, 59-a Central Pr,  
Severodonetsk 93400, Ukraine  
e-mail: [krolos@snu.edu.ua](mailto:krolos@snu.edu.ua)

engagement gearing and creating their fundamentally new modifications which are introduced in the paper.

### 1.1 Formulation of the Problem

Improving the technical level of gearing engagement is associated with a set of problems optimizing the design parameters of mechanisms [1–4], upgrading devices already used [5–8], modifying working surface shapes [9–12] and researching tribological factors in the contact zone [13–16]. This article presents the research material connected with using the conical surfaces as axoids for pinions and wheels with parallel axes of rotation proposed by the authors [17].

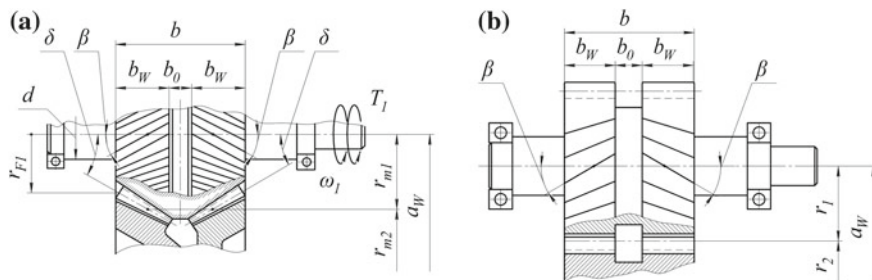
The task is to perform a comparison of some classical cylindrical gear geometric characteristics for involute gearing with chevron teeth (hereinafter referred to as CGCh) and its analog [17]—gear on parallel axes. The axoids of the considered gear are treated as cones with tangential teeth (hereinafter referred to as CGA). It is required to achieve the possibility of increasing the length of the gear teeth and wheel in gearbox transmission without changing the gear engagement width, which will give an advantage in terms of the load capacity of the gearbox in comparison with the CGCh transmission with other things being equal. There is a need to prove the possibility of increasing the load capacity of the CGA gearing by the main criterion—the contact endurance of the teeth, as compared with the existing type of gear on parallel axes—chevron gearing with the same overall dimensions and other conditions being equal.

## 2 Theoretical Part

1. Since the CGCh consists of two helical gears (hemi-chevron) with opposite teeth at the same angle of inclination, to calculate the length of the CGCh teeth we use the parametric equation of the helical teeth surface for the involute engagement [18].

$$\begin{cases} x = r_{O1} \cdot \cos v + u \cdot \cos \beta_O \cdot \sin v; \\ y = r_{O1} \cdot \sin v - u \cdot \cos \beta_O \cdot \cos v; \\ z = P \cdot v - u \cdot \sin \beta_O. \end{cases} \quad (1)$$

here,  $v$ —an independent variable that varies within  $[v_1; v_2]$ ;  $u, r_{O1}, \beta_O, P$ —constants; the coordinate  $z$  passes along the axis of gears rotation. The limits of variable  $v$  change are of the obvious condition:  $z = [0; b_{W\Sigma}]$ , where



**Fig. 1** **a** Gear of CGCh; **b** gear of CGA

$b_{W\Sigma} = 2 \cdot b_W$ —the width of the CGCh engagement gearing, equal to the width of the two hemi-chevrons  $b_W$ , Fig. 1a. As a result,

$$v = [v_1; v_2] = \left[ u \cdot \frac{\sin \beta_O}{P}; \frac{u \cdot \sin \beta_O + b_{W\Sigma}}{P} \right], \quad (2)$$

where  $\beta_O = \arctg(r_1/r_{O1} \cdot \tg \beta)$ —the angle of the teeth on the base cylinder pinion CGCh;  $r_1 = 0,5 \cdot m_n \cdot z_1 / \cos \beta$  and  $r_{O1} = r_1 \cdot \cos \alpha_t$ —the radii of the pitch and base pinion cylinders, respectively;  $\alpha_t = \arctg(\tg \alpha_n / \cos \beta)$ —face angle of the teeth profile on the pitch cylinder of the pinion, ( $\alpha_n = 20^\circ$ );  $\beta$ —slope angle of the teeth on the pitch cylinder pinion;  $P = r_1 \cdot \tg(\pi/2 - \beta)$ —helix teeth parameter.

The parameter  $u$  that determines the position of a point on the pitch circle of the tooth surface (1) is found from the condition:

$$\sqrt{x^2 + y^2} = r_1.$$

After substituting the coordinates  $[x, y]$  from the system of equations (1), we get

$$u = \frac{m_n \cdot z_1}{2} \cdot \frac{\sin \alpha_t}{\cos \beta \cdot \cos \beta_O}, \quad (3)$$

where  $\alpha_t = \arctg(\tg \alpha_n / \tg \beta)$ —the angle of the tooth profile on the pitch cylinder in the face section.

The joint consideration of dependencies (1) and (3) allows to determine the coordinates of the tooth longitudinal line on the hemi-chevron of the CGCh transmission (Fig. 1a), which is a helical cylindrical line. Its length  $L$  is

$$L = \int_{v_1}^{v_2} \sqrt{\dot{x}_v^2 + \dot{y}_v^2 + \dot{z}_v^2} \cdot dv, \quad (4)$$

where  $\dot{x}_v = dx/dv$ ;  $\dot{y}_v = dy/dv$ ;  $\dot{z}_v = dz/dv$ .

$$\begin{cases} \dot{x}_v = u \cdot \cos \beta_O \cdot \cos v - r_{O1} \cdot \sin v; \\ \dot{y}_v = u \cdot \cos \beta_O \cdot \sin v + r_{O1} \cdot \cos v; \\ \dot{z}_v = P. \end{cases} \quad (5)$$

After integrating the function (4) with the substitution of derivatives (5) and the limits of integration (2) into it, we obtain

$$L = \frac{b_W}{P} \cdot \sqrt{u^2 \cdot \cos^2 \beta_O + r_{O1}^2 + P^2}. \quad (6)$$

For practical calculations, a simpler version of the dependency is proposed for calculating the length of the CGCh tooth (Fig. 1a):

$$L' = b_{W\Sigma} / \cos \beta \quad (7)$$

Calculations show that numerical values  $L$  and  $L'$  differ by a fraction of a percent.

2. Considering the limited volume of the article and the more cumbersome structure of analytical dependencies for the CGA surface of the teeth, we will calculate their length  $L_K$  for the CGA pinion based on the following assumptions (Fig. 1b). The longitudinal direction of the tangential tooth on each hemi-chevron of the bevel gear is determined by the conical helix:

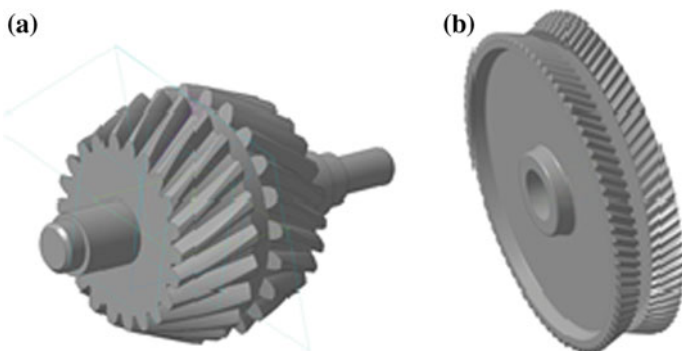
$$\begin{cases} x = a \cdot v \cdot \cos v; \\ y = a \cdot v \cdot \sin v; \\ z = b \cdot v. \end{cases} \quad (8)$$

Therefore, the length of the tangential tooth can be considered as the length of the conical helix (8) on a truncated cone with dimensions:

$r_{F1} = r_{m1} - 0,5 \cdot b_W \cdot \operatorname{tg} \delta$ —radius of the smaller base of the cone, ( $r_{m1} = r_1$ );  
 $b_W$ —the height of the truncated cone between its bases (coordinate  $z$ ), equal to the width of one CGA hemi-chevron;  
 $\beta$ —the angle between the tangent to the helix and generating line a cone;  
 $\delta$ —the angle between the generatrix of the cone and the axis  $z$ .

These parameters are given.

In the environment KOMPAS-3D, three-dimensional models of cylindrical gear transmission with chevron teeth (Fig. 2a) and gear transmission on parallel axes with gear axoids and wheels in the form of truncated cones on parallel axes (Fig. 2b) are developed. In this case, the “shafts and mechanical transmission” application included in the KOMPAS-3D [19–22].



**Fig. 2** **a** 3D model gear of CGCh; **b** 3D model gear of CGA

When determining a helical cylindrical line, the following parameters are determined:

$b_W$ —the height of the truncated cone between its bases (coordinate  $z$ ), equal to the width of one CGA hemi-chevron;  $\beta$ —the angle between the tangent to the helix and generating line a cone;  $\delta$ —the angle between the generatrix of the cone and the axis  $z$ .

These parameters are given.

In contrast to bevel gears with intersecting axes of links in CGA gearing (Fig. 1b), the angles of the pitch cones of the pinion ( $\delta_1$ ) and the wheel ( $\delta_2$ ) are the same that is  $\delta_1 = \delta_2 = \delta$ , and their numerical values are set independently of the gear ratio, but with one restriction:

$$\delta \leq \arctg \left( \frac{r_{m1} - 3,5 \cdot \sqrt[3]{T_1}}{0,5 \cdot b_W} \right), \quad (9)$$

where  $T_1$ —the torque on the pinion shaft, N m;  $r_{m1}$ —the average pitch radius of the toothed hemi-chevron of the CGCh pinion, mm; (the size  $r_{m2}$  in Fig. 1b denotes the average pitch radius of the toothed hemi-chevron of the CGA wheel);  $b_W$ —in mm.

### 3 Experimental Part

The specified limitation for the angle  $\beta$  is aimed at preventing possible flanking of the pinion teeth on a smaller base of the cone with a radius  $r_{F1}$  (Fig. 1b) into the shaft body with a diameter  $d_B$ , that is, for the realization of a constructive condition  $r_{F1} \geq d_B/2$ . We illustrate the constraint (9) as applied to the CGA, whose parameters are given in the numerical calculation of the function (13) given below in the article. Determine the values of the parameters included in the formula (9)



$$r_{m1} = m_{tm} \cdot z_1 / 2 = 39.9 \text{ mm},$$

where  $m_{tm} = m_n / \cos \beta = 4 / \cos 17.82^\circ = 4.2$ —the average face module CGA;

$$T_1 = \frac{T_2}{u \cdot \eta} = \frac{3097.8}{5.26 \cdot 0.97} = 607.1 \text{ N m},$$

where  $u = \frac{z_2}{z_1} = \frac{100}{19} = 5.26$  and  $\eta = 0.97$ , respectively, the gear ratio and the coefficient of performance for the CGA.

After substituting these parameters in condition (9), we obtain the restrictive value of the angle  $\delta$ :

$$\delta_{\max} = \arctg \left( \frac{39.9 - 3.5 \cdot \sqrt[3]{607.1}}{0.5 \cdot 42} \right) \approx 26^\circ.$$

Thus, for the CGA with the specified parameters, the pitch angle of the axoid cones of the pinion and wheels should be assigned with the restriction:

$$\delta \leq \delta_{\max} = 26^\circ.$$

The length of the conical helix (8) is determined from the following dependence [20]:

Conical helix length:

$$L_K = \int_{v_1}^{v_2} \sqrt{\dot{x}_v^2 + \dot{y}_v^2 + \dot{z}_v^2} \cdot dv = \int_{v_1}^{v_2} \sqrt{a^2 \cdot (v^2 + 1) + b^2} \cdot dv, \quad (10)$$

where

$$\dot{x}_v = dx/dv = a \cdot (\cos v - v \cdot \sin v);$$

$$\dot{y}_v = dy/dv = a \cdot (\sin v + v \cdot \cos v);$$

$$\dot{z}_v = dz/dv = b.$$

The limits of integration of the function (10) are determined by the parameters of the pinion axoid, that is, the truncated cone on which the conical helix (8) is located:

$$\begin{aligned} v_1 &= \frac{\operatorname{tg} \beta}{\sin \delta}; \\ v_2 &= v_1 \cdot \left( 1 + \frac{b_W}{r_{F1}} \cdot \operatorname{tg} \delta \right) = \frac{\operatorname{tg} \beta}{\sin \delta} \cdot \left( 1 + \frac{b_W}{r_{F1}} \cdot \operatorname{tg} \delta \right). \end{aligned} \quad (11)$$

Constant values:

$$a = r_{F1} \cdot \sin \delta / \operatorname{tg} \beta; \quad b = a / \operatorname{tg} \delta = r_{F1} \cdot \cos \delta / \operatorname{tg} \beta. \quad (12)$$

As a result,

$$L_K = 2 \cdot (L_{K2} - L_{K1})|_{v_1}^{v_2}, \quad (13)$$

where

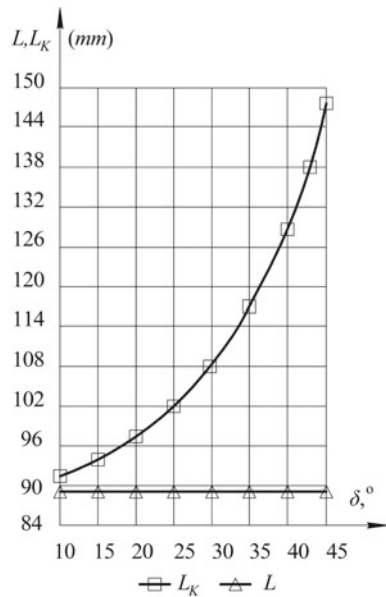
$$L_{K1,2} = \frac{v_{1,2}}{2} \cdot \sqrt{a^2 \cdot (v_{1,2}^2 + 1) + b^2} + \frac{a^2 + b^2}{2 \cdot a} \cdot \ln \left[ \sqrt{a^2 \cdot (v_{1,2}^2 + 1) + b^2} + v_{1,2} \cdot a \right]. \quad (14)$$

The factor “2” in the formula (13) takes into account the fact that the pinion in the CGA transmission consists of two hemi-chevrons, that is, of two truncated cones, each of which has parameters  $[r_{F1}, b_W, \beta, \delta]$ .

The calculations of function (13) show a nonlinear dependence  $L_K = L_K(\delta)$ . In Fig. 3 shows the graph of this function, built on the dependencies (8)–(13) for transmission with the parameters:

$$a_W = 250 \text{ mm}; \quad m_n = 4 \text{ mm}; \quad z_1/z_2 = 19/100; \quad \beta = 17.82^\circ; \\ b_W = 42.5 \text{ mm}.$$

**Fig. 3** Lengths of teeth in CGCh ( $L$ ) and CGA ( $L_K$ )



For comparison, Fig. 3 shows a graph of the CGCh teeth length with the same engagement parameters as in the transmission of the CGA. An increase in the length of CGA teeth in comparison with CGCh with their identical overall dimensions will lead to an increase in the load capacity of CGA for bending and contact endurance of the teeth.

The increase in the teeth length of the CGA compared with the CGCh is from 5.3% at  $\delta = 15^\circ$  up to 65% at  $\delta = 45^\circ$ . For a preliminary assessment of the reduction of contact stresses in the teeth during the transition from the CGCh transmission to the CGA transmission, we use the Hertz dependence for the linear contact of two surfaces [19]. With other things being equal, contact stresses in CGA and CGCh are connected by the relation:

$$\sigma_{H(K)}/\sigma_H = \sqrt{L/L_{(K)}}.$$

For the specified gains  $L_K$ , we get

$$\sigma_{H(K)}/\sigma_H = \begin{cases} 0.97 & \text{for } \delta = 15^\circ; \\ 0.8 & \text{for } \delta = 45^\circ. \end{cases}$$

That is the reduction of contact stresses in the CGA as compared with the CGCh is from 3 to 20%. It is obvious that for a more significant reduction, it is advisable to take large values of the axoids angle, but taking into account the restrictive condition (9).

3. Pinion 1 CGA transmission performed together with the shaft. Wheel CGA is an assembly unit consisting of two wheels—2 and 3, each of which has tangential teeth. Conical semi-chevrons mounted on the centers and bolted to them. In order to exclude vibrations when the transmission is in operation, the semi-chevrons should be centered in three directions:

- radial—due to the interference fit of rims on the centers;
- axial—with the help of a shim gasket;
- circumferential—by means of annular grooves in which fastening bolts are placed (in Fig. 2, only the teeth rims of the hemi-chevrons are depicted, and the centers on which they are mounted with the help of bolts, annular grooves and shim gasket are not shown).

Wheels 2 and 3, bolted 4 and centered in three directions:

- radial—by fit on the bead diameter  $D_6H_7/m_6$ ;
- axial—using the shim 5;
- circumferential—through the annular grooves in which the bolts 4 are placed.

4. The following calculation algorithm is recommended for the design of the CGA transmission.

- 4.1. The allowable stresses, as well as the design calculation, in which the axial distance  $a_w$  and the main engagement parameters  $m_n, b_w, \beta, z_1, z_2$  of the condition of the teeth contact endurance are performed according to the existing design of cylindrical helical transmission [23] (here,  $m_n$ —the average normal engagement modulus used in the calculations of modern bevel gears).
- 4.2. The angle of the pitch cones of the pinion and the wheel  $\delta \approx 30^\circ \dots 60^\circ$  is assigned, taking into account the obtained limitation—formula (9). To accept the numerical value of the angle, the average face module  $m_{tm} = m_{nm} \cos \beta$  is preliminarily calculated, along which the average pitch diameters of the pinion and wheel are  $r_{m1} = m_{tm} \cdot z_1/2; r_{m2} = m_{tm} \cdot z_2/2$  (wherein  $r_{m1} + r_{m2} = r_1 + r_2 = a_w$ ).
- 4.3. Tests for contact points ( $\sigma_H$ ) and bending ( $\sigma_{F1}, \sigma_{F2}$ ) stresses are carried out using the existing method of calculating cylindrical helical gears [23, 24] with one difference—calculations  $\sigma_{F1}$  and  $\sigma_{F2}$  are carried out using tooth shape factors  $Y_{F1}$  and  $Y_{F2}$  according to the graph [23] or table depending on biequivalent numbers of CGA pinion teeth and wheel teeth:  $z_{vni} = z_i / (\cos^3 \beta \cdot \cos \delta)$ , ( $i = 1, 2$ ) as in bevel gears. This is due to the fact that the pitch surfaces of the CGA transmission links are cones, which is different from the CGCh transmission where axoids are cylinders.

## 4 Conclusion

1. An analytical base for designing CGA bevel transmission on parallel axes with tangential pinion teeth and wheel teeth has been developed.
2. A comparative assessment of the CGA transmission with its analog—a cylindrical transmission with chevron teeth CGCh with the same dimensions is made. The result of an increase in the teeth length of the CGA is an increase in the transmission capacity according to the main criterion for the performance of closed gears—the contact endurance of the teeth.
3. An enlarged scheme of the algorithm for the practical calculation of the CGA transmission with reference to the current method of calculating the CGCh is proposed.

## References

1. Kosarev OI (2011) Reducing the vibration in helical transmissions. J Probl Mashinostr Nadezhn Mash 1:19–27
2. Shevchenko SV, Stoyanov AA (1993) Some properties of gears with slope-arched teeth. J Des Prod Transp Veh 22:64–69
3. Niemann G, Winter G (1985) Maschinenelemente, Band 2. Springer, Berlin

4. Shevchenko S, Mukhovaty A, Krol O (2017) Gear clutch with modified tooth profiles. *J Procedia Eng* 206:979–984. <https://doi.org/10.1016/j.proeng.2017.10.581>
5. Mayor VP (1983) Study of the loading and contact endurance of cylindrical gears with arched teeth. Dissertation, University of Kurgan
6. Malakhov AG (1983) Investigation of the bending endurance of cylindrical gears with arched teeth. Dissertation, University of Kurgan
7. Dusev II (1977) Synthesis of gearing with controlled contact. *J Issues Designing Studying Mech Mach Automat*, 3–14
8. Kosarev OI, Bednyi IA, Mamonova MG (2011) Reducing the vibration of a chevron gear. *J Vestn Mech Eng* 11:19–23
9. Wagaj P, Kahraman A (2002) Influence of tooth profile modification on helical gear durability. *J Trans ASME Mech Des* 124:501–510
10. Kahraman A, Bajpai P, Anderson N (2005) Influence of the deviation of the profile of the helical gear. *J Trans ASME Mech Des* 127:656–663
11. Kravchuk AA (1975) Theoretical and experimental study of a cylindrical transmission with arc teeth. Dissertation, University of Khabarovsk
12. Shevchenko S, Mukhovaty A, Krol O (2016) Geometric aspects of modifications of tapered roller bearings. *J Procedia Eng* 150:1107–1112. <https://doi.org/10.1016/j.proeng.2016.07.221>
13. Holmes MJA, Evans HP, Snide RW (2005) Analysis of mixed lubrication effects in simulated gear tooth contacts. *J Trans ASME Tribol* 127:61–69
14. Ren N, Zhu W, Chen W et al (2009) Three-dimensional, deterministic model for rough surface, line contact. ehl problems. *J Trans ASME Tribol* 131:1–9
15. Drozdov YuN, Nazhestkin BP, Smirnov NI (1990) Development of methods for calculating the wear of gears. *J Bull Mech Eng* 11:15–17
16. Pirro DM, Wesso AA (2001) *Lubrication fundamentals*. Marcel Dekker, Marsel
17. Shevchenko SV, Krol OS, Khmel'nitsky AV (2017) Bevel gear. Ukraine Patent 120217, 20, 25 Oct 2017
18. Litvin FL (1968) *Theory of gearing*. Science, Moscow
19. Krol O, Sokolov V (2018) Modelling of spindle nodes for machining centers. *J Phys Conf Ser* 1084:1–7. <https://doi.org/10.1088/1742-6596/1084/1/012007>
20. Krol O, Sokolov V (2018) Development of models and research into tooling for machining centers. *J Eastern-Eur J Enterprise Technol* 3(1(93)):12–22. <https://doi.org/10.15587/1729-4061.2018.131778>
21. Sokolov V, Rasskazova Y (2016) Automation of control processes of technological equipment with rotary hydraulic drive. *J Eastern-Eur J Enterprise Technol* 2(2(80)):44–50. <https://doi.org/10.15587/1729-4061.2016.637111>
22. Sokolov V, Krol O (2019) Determination of transfer functions for electrohydraulic servo drive of technological equipment. *Advances in design, simulation and manufacturing*. DSMIE 2018. *Lecture Notes in Mechanical Engineering*. Springer, Cham, pp 364–373. [https://doi.org/10.1007/978-3-319-93587-4\\_38](https://doi.org/10.1007/978-3-319-93587-4_38)
23. Reshetov DN, Gusenkov AP, Drozdov YN (1995) *Mechanical Engineering, Encyclopedia*. V. IV-1. In: Reshetov DN (ed) *Machine parts, structural strength, friction, wear, lubrication*. Mechanical Engineering, Moscow
24. Korn G, Korn T (1970) *Handbook of mathematics*. Science, Moscow

# Mathematical Model of Mechanism for Sealing Hardly Deformable Materials



E. I. Kromsky, S. V. Kondakov and M. A. Asfandiarov

**Abstract** A schematic diagram of the shock-vibration for compacting materials (including hard-to-deform) and the principle of its action based on the lever of Archimedes, which is part of a four-link mechanism, is considered. The article shows the expression for calculating the gain mechanism of the compression mechanism. In the course of work, a mathematical model of the mechanism is described; formulas for the kinematic and force calculation of all links of the mechanism are derived. With the help of the derived mathematical model, it is possible to select the most optimal options for the sizes of links according to the force or dimensional characteristics. The necessary conditions for a successful operation of the new mechanism are described. Its 3D model and general view of the pilot plant, which was designed and installed at SUSU at the Wheeled and Tracked Vehicles department, are shown. According to the tests carried out on it, the technological capabilities and advantages of this mechanism were confirmed in comparison with the vibration compaction technology adopted on modern wheeled or crawler concrete pavers, namely concrete control samples obtained on a molding machine with a shock-vibration mechanism showed an increase in strength of 1.3–1.5 times in comparison with the strength of the samples obtained by a traditional sealing technology.

**Keywords** Road-building machines · Sealing of especially rigid mixtures · Archimedes' shoulder · Molding unit · Four-link mechanism

## 1 Introduction

In the Russian Federation, as in the rest of the world, hard-surface construction machines use vibratory mechanisms to compact road-building materials. This mechanization of compaction allows to obtain the required quality of the road

---

E. I. Kromsky · S. V. Kondakov · M. A. Asfandiarov (✉)  
South Ural State University, 76, Lenin Avenue, Chelyabinsk 454080, Russia  
e-mail: [loko315@mail.ru](mailto:loko315@mail.ru)

© Springer Nature Switzerland AG 2020  
A. A. Radionov et al. (eds.), *Proceedings of the 5th International Conference on Industrial Engineering (ICIE 2019)*, Lecture Notes in Mechanical Engineering,  
[https://doi.org/10.1007/978-3-030-22041-9\\_2](https://doi.org/10.1007/978-3-030-22041-9_2)