

39th ASPE Annual Meeting 2024

Houston, Texas, USA
5-8 November 2024

ISBN: 979-8-3313-1440-8

Printed from e-media with permission by:

Curran Associates, Inc.
57 Morehouse Lane
Red Hook, NY 12571



Some format issues inherent in the e-media version may also appear in this print version.

Copyright© (2024) by American Society for Precision Engineering (ASPE)
All rights reserved.

Printed with permission by Curran Associates, Inc. (2025)

For permission requests, please contact American Society for Precision Engineering (ASPE)
at the address below.

American Society for Precision Engineering (ASPE)
3434 Edwards Mill Road, Suite 112-325
Raleigh, NC
27612

Phone: (984) 268-9756

www.aspe.net

Additional copies of this publication are available from:

Curran Associates, Inc.
57 Morehouse Lane
Red Hook, NY 12571 USA
Phone: 845-758-0400
Fax: 845-758-2633
Email: curran@proceedings.com
Web: www.proceedings.com

Oral Technical Sessions

Technical Session 1 – Precision Design

Session Chairs: Aaron E. Ramirez (MIT Lincoln Laboratory) and Todd Noste (Lawrence Livermore National Laboratory)

Wednesday, November 6, 2024

8:00 AM – 9:45 AM

- 1. A Bending-type Actuator Based on Single-Crystal Piezoelectric Plates for Use in an Actuated Wafer Table**
S.J. Hermanussen, J.P.M.B. Vermeulen, M.F. Heertjes (Eindhoven University of Technology); M.B.I. Habets (ASML B.V.) 1
- 2. Enhancement of Squeeze-film Damper Performance with Poroelastic Materials**
Justin M. Verdirame, Samir A. Nayfeh (Physical Precision LLC)..... 6
- 3. Kinematic Coupling Sensitivity Analysis**
Folkers E. Rojas (Millie Rojas Engineering Corporation)..... 11
- 4. Program for Design of Accurate 3D Kinematic Couplings with Error Propagation**
Tyler Seawright, Michel Pharand (San José State University) 16
- 5. Modeling and Simulation of Mounting Materials with Anisotropic Thermal Expansion**
Mostafa Peysokhan, James Prince, Jason Orach
(Keysight Technologies Inc.)..... No abstract available

Technical Session 2 – Controls and Mechatronics I

Session Chairs: Stephen J. Ludwick (Aerotech, Inc.) and Burak Sencer (Oregon State University)

Wednesday, November 6, 2024

10:15 AM – 12:00 Noon

- 1. Experimental Validation of a Piezoelectric Wafer Stage Concept Combined with Highly Variable Viscoelastic Stiffness**
R.G.C. de Bruijn, J.P.M.B. Vermeulen (Eindhoven University of Technology);
J.J.M. van de Wijdeven (ASML) 21
- 2. Surrogate-assisted Control Co-design for Over-actuated Lightweight Motion Systems**
Jingjie Wu, Lei Zhou (University of Wisconsin-Madison)..... 26
- 3. Feasibility Study of Maglev Planar Motor with Large Range Rotation**
K. Azami, H. B. Koolmees, C.A.M. Verbaan (NTS Group); J.P.M.B. Vermeulen
(Eindhoven University of Technology) 30

4. Mechanical Assistance for High-acceleration in Precision Motion Systems Adam Kim, Charles B. Seaberg, David L. Trumper (Massachusetts Institute of Technology)	35
---	----

Technical Session 3 – Metrology Systems & Characterization

Steven R. Gillmer (MIT Lincoln Laboratory) and Felipe Guzman (University of Arizona)

Wednesday, November 6, 2024

1:30 PM – 3:15 PM

1. Mobile Mass Metrology: The First-ever Deployment of a Tabletop Kibble Balance from Maryland to Alabama Leon Chao, Kumar Arumugam, John Draganov, Stephan Schlamming, Thapelo Mametja, Zane Comden, Lorenz Keck, Frank Seifert, David Newell (National Institute of Standards and Technology)	No abstract available
2. Beam Steering Interferometry with Mirror Tracking Through Contrast Based Extremum Seeking Control: Proof-of-Concept K. Looman, L.C. Cacace, J.P.M.B. Vermeulen (Eindhoven University of Technology); R. Hendrix (Prodrive Technologies).....	39
3. Towards Diffraction-Limited X-ray Optics Mallory M. Whalen, Alan Garner, Sarah N.T. Heine, Herman L. Marshall, Ralf K. Heilmann, Mark L. Schattenburg (MIT Kavli Institute for Astrophysics and Space Research); Brandon D. Chalifoux (University of Arizona).....	44
4. To a Newton Meter and Beyond: Tabletop Torque Realization Advancements Under the New SI Zane Comden, Leon Chao, Kumar Arumugam, Chandra Shahi, Stephan Schlamming, Frank Seifert, David Newell (National Institute of Standards and Technology)	48

Technical Session 4 – Precision Manufacturing

Session Chairs: Ping Guo (Northwestern University) and Christopher J. Morgan (Moore Nanotechnology Systems, LLC)

Thursday, November 7, 2024

8:00 AM – 9:45 AM

1. Fabrication of Flexure Geometries in Ceramic Additive Manufacturing Anand Rathnam, Stuart T. Smith (University of North Carolina – Charlotte)	52
2. A Sample Partitioning Approach for Milling Stability Modeling with Chatter Frequency Test Point Selection Tony L. Schmitz (University of Tennessee, Knoxville)	57
3. High-pressure Plasma Etching Technique Up to 900 kPa for Damage-free Ultra-precision Machining Shotaro Matsumura, Masafumi Miyake, Yasuhisa Sano, (Osaka University); Kenichi Morita (S-Surface Technologies); Kazuto Yamauchi (Osaka University-RIKEN Center for Science and Technology).....	63

4. **Uniform Metal Powders Produced by Cylindrical Turning with Ultrasonic Modulation**
Yaoke Wang, Malachi Landis, Clement Ekaputra, Valeria Vita, Ping Guo (Northwestern University) No abstract available
5. **Performance and Uncertainty Evaluation of Optical Coordinate Metrology for Hybrid Manufacturing**
Jake Dvorak, Ross Zamoski, Tony L. Schmitz (University of Tennessee, Knoxville) 67

Technical Session 5 – Controls and Mechatronics 2

Session Chairs: David L. Trumper (Massachusetts Institute of Technology) and Lei Zhou (University of Wisconsin – Madison)

Thursday, November 7, 2024

10:15 AM – 12:00 Noon

1. **Frame Deformations Control Based on Reduced Order Thermo-elastic Models**
Walter Aarden, Theo Ruijl (MI-partners BV) 73
2. **High Accuracy Fast Tool Servo Utilizing Moving-magnet Voicecoil**
Christopher Morgan, Zachary Timothy (Moore Nanotechnology Systems) 79
3. **Data-Driven Feedforward Control of Active Inertial Dampers for High Performance Vibration Mitigation**
Kaan Bahtiyar, Burak Sencer (Oregon State University); Xavier Beudaert (IDEKO) 84
4. **Operational Modelling of Rotor-Magnetic Bearing Systems in Rotation**
Brett Wallace, Jihyun Lee (University of Calgary); Armand Farhat (SKF S2M Magnetic Mechatronics) 90

Technical Session 6 – Micro-Nano Technologies

Session Chairs: Michael A. Cullinan (The University of Texas at Austin) and Robert M. Panas (Bright Silicon Technologies)

Thursday, November 7, 2024

1:30 PM – 3:15 PM

1. **Precision Engineering Challenges in Electronics Packaging**
Texas Institute for Electronics No abstract available
2. **Towards Manufacturing and Metrology of Roll-to-Roll Holographic Nanostructures**
Luis Arturo Aguirre, Barbara Groh, Kwon Sang Lee, Shashank Venkatesan, Michael Baldea, Chih-Hao Chang, Michael Cullinan (University of Texas at Austin); Liam G. Connolly (National Institute of Standards and Technology) 95

3. **Multi-stimuli, Multi-scale Transduction via Mechanical Logic**
Melika Ahmadi, Amin Farzaneh, Jonathan B. Hopkins (University of California-
Los Angeles); Widiyanto P. Moestopo, Abhinav Parakh, Logan Bekker, Elaine Lee,
Caitlyn C. Cook, Hilary A. Johnson, , John Cortes, Andrew J. Pascall (Lawrence
Livermore National Laboratory); Robert M. Panas
(Bright Silicon Technologies) No abstract available
4. **Balancing Intrinsic Stress Nonlinearities to Realize an Isochronous Clock
Gravimeter**
Charles A. Condos, Aman Agrawal, Jack Manley, Dalziel Wilson (University of
Arizona); Jon R. Pratt, Stephan Schlamming (National Institute of Standards
and Technology) 100
5. **Characterizing Calcination-Induced Mechanical Evolution of TPP-printed
Polymer-derived Ceramics**
Cameron M. Crook, John Cortes Gutierrez (Lawrence Livermore
National Laboratory) No abstract available

Technical Session 7 – Precision Design (Flexure Use and Design)

**Session Chairs: Tyler A. Seawright (KLA) and Folkers Rojas (Millie Rojas
Engineering Corporation)**

Friday, November 8, 2024

8:00 AM – 9:45 AM

1. **T-Flex ELC: A Flexure-based Hexapod with Economical Actuation, Sensing
and Kinematics**
Jeffrey Uitbeijerse, Marijn Nijenhuis, Dannis M. Brouwer
(University of Twente) 104
2. **Design and Characterization of a High-Accuracy, Stackable, Tip/Tilt Mirror
Actuator Driven by a Piezoelectronic Ultrasonic Motor**
Aaron E. Ramirez, Christopher Roll, Jeffrey M. Roth
(MIT Lincoln Laboratory)..... No abstract available
3. **Design and Analysis of Flexure-based Screw Motion Mechanism**
Subrat, Vivek Chaudhary, Jitendra P. Khatait, Sudipto Mukherjee (Indian Institute
of Technology Delhi) No abstract available
4. **Dynamic Balancing a 1-DOF Positioning Stage to Maximize External
Vibration Rejection**
Vinayak J. Kalas, Francesco Patti, Herm Nelissen, Rick Baade, Johannes M.
Vogels (VDL ETG Technology & Development); Jan J. de Jong (University of
Twente) 108
5. **A Novel Sandwich Design for Improved Out-of-Plane Stiffness in Double
Parallelogram Flexure Mechanism**
Moeen Radgolchin, Siddharth Rath, Shorya Awtar (University of Michigan)..... 112

Technical Session 8 – Combined Session: Metrology Systems & Characterization and Precision Manufacturing (Process Improvement and Validation)

Session Chairs: Tony L. Schmitz (University of Tennessee, Knoxville) and Axel Grabowski (Physik Instrumente (PI) GmbH & Co. KG)

Friday, November 8, 2024

10:15 AM – 12:00 Noon

- 1. Constrained-motion Drilling Dynamometer Design and Evaluation**
Ross W. Zamoski, Tony Schmitz (University of Tennessee, Knoxville);
Christoph M. Ramsauer, Christoph Habersohn, Friedrich Bleicher (Technical
University of Vienna)..... 118
- 2. On-Machine Metrology for Diamond Turning Applications**
Daodang Wang, Wenjun Kang, Yihan Wang, Hongzhang Ma, Rongguang Liang
(The University of Arizona) No abstract available
- 3. Modal Testing of KDP Flycutting Machine Vacuum Chucks**
Todd Noste, Edwin Northcutt, Ahmed Abdel-Gwad (Lawrence Livermore
National Laboratory) 124
- 4. Spindle Speed Selection in Additive Friction Stir Deposition for Desired
Temperature**
Tony L. Schmitz (University of Tennessee, Knoxville) 131
- 5. Velocity Dependent Process Damping Calibration in Milling**
Gregory M. Corson, Christopher Tyler, Tony L. Schmitz (University of
Tennessee, Knoxville)..... 137

Poster Sessions

Wednesday, November 6, 2024

Thursday, November 7, 2024

3:15 PM – 4:45 PM (Both Days)

Controls and Mechatronics

- 1. Iterative Learning Control with Data-driven Inversion for Non-linear Dynamic Systems**
Seung Guk Baek, Chang Kyu Song, Seung Kook Ro (Korea Institute of Machinery and Materials); Ja Choon Koo (Sungkyunkwan University)..... 143
- 2. Data-driven Sliding Mode Control with Applications to Precision Motion Systems**
Lei Cao, Sen Lu, Kaiming Yang, Tao Liu, Shaowei Zhan (Tsinghua University); Min Li (China University of Geosciences)..... 147
- 3. Over-actuated Lightweight Precision Motion Stage Design Framework Based on Topology Optimization**
Junnan Gao, Jingjie Wu, Lei Zhou (University of Wisconsin-Madison) 153
- 4. Hybrid Model for Predictive Maintenance of Z-axis Belts Tension Wear in Wafer Transfer Robots**
MD Saiful Islam, Eunjong Choi, Juhyeop Park, Jaehong Sim, Kihyun Kim, Hyo-Young Kim (Tech University of Korea) 158
- 5. Development of Magnetic Levitation Coarse-Fine Stage with 6-Axis Laser Interferometers**
Motohiro Takahashi, Takanori Kato (Hitachi, Ltd.) 164
- 6. Momentum-enhanced Extremum Seeking Control for Advanced Controller Parameter Tuning**
Shaowei Zhan, Sen Lu, Kaiming Yang, Lei Cao, Tao Liu, Yu Zhu (Tsinghua University)..... 170

Metrology Systems

- 1. Enhancing Milling Process Efficiency Through Real-time Tool Condition Monitoring Using Advanced Sensor Systems**
Katarzyna Antosz, Jarosław Sęp, Sławomir Prucnal (Rzeszow University of Technology); Edward Kozłowski (Lublin University of Technology) No abstract available
- 2. Development of the Second Harmonic Noise Decomposition Method for Enhanced the Quality of Fringe Pattern Denoising using Deep Learning**
Juncheol Bae, Hwan Kim, Jurim Jeon and Yangjin Kim (Pusan National University)..... 176
- 3. Development of Mobile Robot Based 3D Position Measurement System**
Pilgong Choi, JengO Kim, Kyunghan Kim (Korea Institute of Machinery & Materials)..... 181

4. Range Revolved Interferometry for Use in High Precision Positioning Systems	
Axel Grabowski, Sven Mittag, Carolin Walenda (Physik Instrumente GmbH & Co. KG); Thomas Kissinger (Technical University of Ilmenau).....	187
5. Deep Learning-Based Wavefront Reconstruction: Optical Interferometric Technique for Surface Topography of Silicon Wafer	
Hwan Kim, Juncheol Bae, Jurim Jeon, Yangjin Kim (Pusan National University)	192
6. Dynamic Behavior of a Kinematic Style, Gravity-closed, XYθ-Compliant Baseplate Mount	
Jimmie Miller, Sania Khan, Deniz Arda Gulmez, Lutfi Taner Tunc (University of North Carolina – Charlotte).....	196
7. Performance Evaluation for Hall Effect Sensors Based on Configuration	
Tobechukwu D. Nwabueze, Ross Zamoski, Tony L. Schmitz (University of Tennessee, Knoxville).....	202
8. Fiducial Patterning for Large-part Manufacturing via Three-ball Artifact Master (T-BAM)	
Hadarel Rappaport, Jimmie A. Miller, Edward P. Morse (University of North Carolina – Charlotte).....	207
9. Measurement of Recoating Plane Error in Laser Powder Bed Fusion Additive Manufacturing Machines with an Inertial Measurement Unit	
Jesse Redford, Jordan Weaver, Greg Vogl (National Institute of Standards and Technology)	213
10. Development of the External Force Estimation Model for Parallel Link Mechanism Robot	
Akari Tawa, Takumi Nozaki, Taiki Anan, Yuta Shinomiya, Yoshitaka Morimoto, Akio Hayashi, Hidetaka Yamaoka, Nobuaki Fujiki (Kanazawa Institute of Technology)	219

Micro-Nano Technologies

1. High-resolution Full-color Quantum Dots Patterning for Display Applications Based on Femtosecond Laser Induced Forward Transfer	
Shu-Yu Liang, Shi-Qi Chen (University of Hong Kong); Yue-Feng Liu (Jilin University).....	No abstract available
2. Spatiotemporal Modulation of Light in Microscale Selective Laser Sintering for Enhanced Process Resolution	
Aaron Liao, Joshua Grose, Michael Cullinan (The University of Texas Austin); Heejin Kim, Chinedum Okwudire (University of Michigan)	No abstract available
3. Design and Fabrication of a Mezo-sized, Thermal Linear Transducer for Active Metamaterials	
Andrew Gray, Chenyang Luo, Michael A. Cullinan (The University of Texas at Austin); Pietro Sainaghi, Jonathan B. Hopkins (University of California-Los Angeles).....	223

Other

- 1. Repeatability of Robotic WAAM Geometric Properties for Aluminum Printing**
Kamren M. Sargent, Hutchison R. Peter, Joshua J. Penney, Tony L. Schmitz (University of Tennessee, Knoxville)..... 227
- 2. Direct Motor Cooling Using Liquid Immersion Cooling Technique**
Genki Uchiyama, Yusei Hashimoto, Yohichi Nakao (Kanagawa University) 233
- 3. Additive Friction Stir Deposition Dynamometer Design and Evaluation**
Tyler R. Woodard, Bradley Edwards, Matthew R. Patterson, Elijah Charles, Tony L. Schmitz (University of Tennessee, Knoxville) 237
- 4. Design and Fabrication of Desktop CNC Milling Machine**
Tyler R. Woodard, Andrew Honeycutt, John Greene, Tony L. Schmitz (University of Tennessee, Knoxville)..... 242

Precision Design

- 1. Coupled Elasto-hydraulic Model for Large Hydrostatic Rotary Tables**
Markel Alana, Julen Bastardo, Natalia Colinas, Harkaitz Urreta, Gorka Aguirre (IDEKO); Jaione Iriondo (Mondragon Unibertsitatea) 248
- 2. Design of Z/Tilt Parallel Mechanism Based on a Flexible Joint and Piezo Stepping Actuator**
Kyung-Rok Kim, Dongwoo Kang, Hyunchang Kim, Jaeyoung Kim (Korea Institute of Machinery and Materials) 252
- 3. Modeling and Verification of Shear Film Heat Generation for an Ultra-Precision Air Bearing Spindle**
Byron Knapp, Dan Oss, Dave Arneson (Professional Instruments Company) 256
- 4. Evaluation of Link Length Errors for a 6-axis Serial Robot Based on Kinematics**
Sung Hwan Kweon, Young Hun Jeong, Seung Han Yang (Kyungpook National University)..... 260
- 5. Estimation of Loop Stiffness for Multi-axis Machine Tool**
Sungcheul Lee, Changkyu Song, Gyungho Khim, Seung-Kook Ro (Korea Institute of Machinery and Materials)..... No abstract available
- 6. Mechanical Design of Parallel Flexure-based RADSII Instrument for Curved X-ray Mirror Metrology**
Lukas M. Lienhard, Corey Austin, Weihe Xu, Mourad Idir, Steven Hulbert, Evgeny Nazaretski, David Scott Coburn, Tianyi Wang, Lei Huang (Brookhaven National Laboratory) 264
- 7. Advancements and Analyses of Novel In-plane Flexure-based Clamp Designs**
Vineet Padia, Bryce D. Forsgren Ian W. Hunter (Massachusetts Institute of Technology)..... 269

8. A Torsion Balance for Testing the Nature of Gravity	
Jon R. Pratt, Stephan Schlamming (National Institute of Standards and Technology); Lorenz Keck, Jacob Taylor (University of Maryland)	275
9. Design and Evaluation of Fixture for Random Vibration Testing of Fire Extinguisher for its Airworthiness	
Deepak Singh D, Tapas Debnath, Shashanth Nag (C-ASMP, Central Manufacturing Technology Institute)	No abstract available
10. Development of a Machine Tool Energy Consumption Evaluation System Based on ISO 14955	
Gyungho Khim, Jeong Seok Oh, Sungcheul Lee (Korea Institute of Machinery and Materials (KIMM)); Jaehak Lee (Korea Institute of Industrial Technology (KITECH))	No abstract available
11. Development of Large Deflection Single DOF Compliant Rotary Joint	
Subrat, Jitendra P. Khatait (Indian Institute of Technology)	No abstract available
12. Open Source Air-Bearing Simulation	
Janis H. Wortmann, Manuel Scholz (Eitzenberger GmbH)	279
Precision Manufacturing	
1. Upcycling Machining Chips for a Circular Economy in Additive Friction Stir Deposition	
Sweta Baruah, Tony Spezia, Rob Patterson, Jose Nazario, Tony Schmitz (University of Tennessee, Knoxville)	284
2. Precision Glass Molding of Aspherical Lenses Using Multi-cavity Tooling	
Dhanooj Bobba, Christopher Morgan (Moore Nanotechnology Systems)	289
3. The Impact of Temperature Fluctuations on Air Bearing Performance: Addressing the Challenges	
Ayberk Erturk, Jeff Sward (OAV Air Bearings)	293
4. Observation of Metal Powder Behavior in Additive Manufacturing Method by Selective Solidification Using Electrical Discharge	
Katsushi Furutani, Kokei Hirako, and Hiroki Yamagishi (Toyota Technological Institute)	297
5. Integrating Project and Group Based Learning to Develop Hands-On Precision Manufacturing Skills in Post-Graduate Students	
Zareena Gani (University College London)	301
6. Surface Finish Prediction of Modulated Tool Path of Tapered Workpieces	
Ryan A. Garcia, Tony L. Schmitz (University of Tennessee, Knoxville)	306
7. Deep Learning for the Measurement and Compensation of Laser Micro Hole Drilling	
Meongjun Kim (Chungnam National University); Pilgong Choi, Kyunghan Kim (Korea Institute of Machinery & Materials)	311

8. Analytical Approach for Precise Localization and Quantitative Assessment of Surface Defects in Additive Manufacturing	
Xiangjun Kong, Tibebe Yalew , Qingkang Bao, Mingda Harvey Yang, Gerardo Adesso, Samanta Piano (University of Nottingham).....	315
9. Increasing Resolution of Additive Friction Stir Deposition using a Flexure-based Implementation	
Malachi Landis, Marko Beric, Ping Guo (Northwestern University)	No abstract available
10. Look-ahead Based Feedrate Planning For CNC Interpolator	
Chan-Young Lee, Chang Kyu Song, Seung Kook Ro, Chan-Ju Kim (Korea Institute of Machinery and Materials).....	320
11. Challenges With Metal Big Area Additive Manufacturing for Machine Tool Cross Beam Manufacturing	
Tyler Poon, Justin L. West, Emma D. Betters, Tony Schmitz (University of Tennessee, Knoxville); Scott Smith, Christopher T. Tyler (Oak Ridge National Laboratory)	324
12. Extended Study on the Composition of Magnetorheological Fluids for the Post-processing of Micro-milling Tools	
Fabian Sordon, Christian Lahoda, Mitchel Polte, Eckart Uhlmann, , Jürgen Maas (Technische Universität Berlin)	330
13. Evaluation of Surface Properties of Ultraprecision Diamond-cut Copper-plated Surfaces	
Hideo Takino (Chiba Institute of Technology); Hidenori Aizawa (Sendai Nikon Corporation); Masahiko Kanaoka (JTEC Corporation).....	336
14. High Precision Positioning Using Electrical Contact Verification	
David Taub (ASML).....	No abstract available
15. Fundamental Investigation of Manufacturing and Application of Ball Nose End Mills Made of Binderless Carbide for Machining AlMgSi1	
Eckart Uhlmann, Mitchel Polte, Christian Lahoda, Niklas Maschke (Technische Universität Berlin)	No abstract available
16. Investigation on Reduction of Tool Wear in Electrical Discharge Finishing Processes with Graphite Tool Electrodes	
Eckart Uhlmann, Mitchel Polte, Sergio Lezama, Kai Thißen (Technische Universität Berlin)	340
17. Precision Manufacture of Microstructured Polymer Surfaces: a Roll-to-plate Embossing Method	
Zhanchen ZHU, Chi Fai Cheung (The Hong Kong Polytechnic University).....	No abstract available

Surface Characterization and Applications of Measurement Science

1. Stochastic Modelling of Surface Topography Data Using Autocorrelation Information

Mohammed A. Isa, Helia Hooshmand, Samanta Piano, Richard Leach (University of Nottingham) 344

2. Accurate Measurement of Ball Volumetric Wear

Pawel Pawlus (Rzeszow University of Technology); Rafal Reizer (University of Rzeszow) 350

3. Measurement and Evaluation of Machine Tool Errors Under Simulated Tool Loads

Tyler C. Young, Gracious Ngaile (North Carolina State University) 356

4. EUV Light Source Integration Into the Berkeley Microfield Exposure Tool

Dmytro Zaytsev, Arnaud Allézy, Ryan Miyakawa, Senajith Rekawa (Lawrence Berkeley National Laboratory) 361