

32nd ASPE Annual Meeting 2017

**Charlotte, North Carolina, USA
29 October – 3 November 2017**

ISBN: 978-1-5108-5356-0

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© (2017) by American Society for Precision Engineering (ASPE)
All rights reserved.

Printed by Curran Associates, Inc. (2017)

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

American Society for Precision Engineering (ASPE)
P.O. Box 10826
Raleigh NC 27605-0826

Phone: (919) 839-8444
Fax: (919) 839-8039

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

Contents

Preface	ii
Organizing Committee	iii-iv
Table of Contents	v
ASPE Lifetime Achievement Award	vi
ASPE Distinguished Service Award	vii
2017 Scholarship Recipients and Sponsors	viii
Sustaining Corporate Sponsors	ix-x
Corporate Sponsors	xi
Technical Paper Index	1-12
Technical Papers	15-666
Author Index	667

Technical and Poster Sessions

Welcome Remarks & Session 1

Precision Engineering Potpourri

Tuesday, October 31, 2017, 8:00 AM -10:00 AM

Session Chairs: Robert D. Grejda (Corning Tropel Corporation) and Brian P. O'Connor (Aerotech, Inc.)

1. Diamond Tool Wear/Built-up Edge Machining Ferrous Materials	
Dow, T. A.; Garrard, K. P. (North Carolina State University); Suit, B. M. (Lockheed Martin)	15
2. Optical Form and Relational Metrology of Aspheric Micro Optics	
Colonna de Lega, X.; Dresel, T.; Liesener, J.; Fay, M. F.; Gilfoy, N.; Delldonna, K.; de Groot, P. J. (Zygo Corporation)	20
3. Optimal Three-Point Mounts for Square and Rectangular Plates	
Verdirame, J. M.; Nayfeh, S. A. (Physical Precision, LLC)	24
4. The Problem of ‘Weak’ Equivalence in Measurement Comparisons: X-ray CT Metrology Case	
Villarraga-Gómez, H. (Nikon Metrology, Inc.); Smith, S. T. (University of North Carolina-Charlotte)	30
5. Additive Manufacturing of Reflective Optical Components	
Jared, B. H.; Chavez, T.; Choi, J.; Cook, A. W.; Dianotnio, C. B.; Reinholtz, W.; Saavedra, M. P.; Saiz, D. J.; Winrow, E. G. (Sandia National Laboratories)	36
6. Contactless Shape Manipulation of Thin Substrates Using Air Bearing Table	
Spaan-Burke, T. M.; van Dam, T.; Overschie, P. M.; Spaan, H. A. M. (IBS Precision Engineering)	40

Session 2

Controls & Mechatronics

Tuesday, October 31, 2017, 10:30 AM -12:00 PM

Session Chairs: Dennis M. Brouwer (University of Twente) and Stephen J. Ludwick (Aerotech, Inc.)

1. Trends in Control Techniques for Precision Mechatronic Systems	
Brouwer, D. M. (University of Twente); Ludwick, S. J. (Aerotech, Inc.); Okwudire, C. E. (University of Michigan); Peijnenburg, A. T. (VDL Enabling Technologies Group)	46
2. Detailed Experimental Evaluation of the Compliant Joint Method for Feedforward Compensation of Pre-Motion Friction	
Dong, X.; Okwudire, C. E. (University of Michigan)	52
3. Multi-Axis Trajectory Generation with Optimal Frequency Spectrum for Vibration Avoidance	
Dumanli, A. A.; Sencer, B. (Oregon State University)	57

4. Strong and Quiet Linear Iron-core Synchronous Motor	Yoon, J. Y.; Trumper, D. L. (Massachusetts Institute of Technology)	63
5. Hybrid Design Approach for Constrained Layer Dampers to Balance Dynamic Performance in Combination with Geometrical Constraints	Verbaan, K.; Duiven, M.; Henselmans R.; Nuij, P. W. J. M.; Rijlaarsdam, D. J. (NTS-Group)	68

Session 3

Characterization

Wednesday, November 1, 2017, 8:30 AM -10:00 AM

Session Chairs: Brandon M. Lane (National Institute of Standards & Technology) and Christopher J. Evans (University of North Carolina-Charlotte)

1. *Characterization: Extracting Key Signatures from Complex Data	Lane, B. M. (National Institute of Standards & Technology)	
2. Observations on Stitching Interferometry on Parts with Radically Different Surface Topographies	Hovis, C. D.; Reese, Z.; Shahinian, H.; Evans, C. J. (University of North Carolina-Charlotte)	72
3. Quantification of Part Profile Scanning Error	Javidpour, F.; Morse, E. P. (University of North Carolina-Charlotte)	78
4. Experimental Verification of One Side Constrained Minimum Total Least Square Algorithm for Planar Datum Establishment and Associated Uncertainty Analysis	Kang, W.; Morse, E. P. (University of North Carolina-Charlotte)	84
5. An Evaluation of Non-contact Laser Scanner Performance Using Calibrated Artifacts	Gomez, M.; Vaccaro, C.; Maness, C.; Lawrence, C.; Murray, C.; Vargas, L.; Caskey, G. W.; Evans, C. J.; Schmitz, T. L. (University of North Carolina-Charlotte)	90

Session 4

Precision Micro-Nano Developments

Wednesday, November 1, 2017, 10:30 AM -12:00 PM

Session Chairs: Robert M. Panas (Lawrence Livermore National Laboratory) and Michael A. Cullinan (The University of Texas at Austin)

1. *Overview of Research in Precision Micro- and Nano-technology	Panas R. M. (Lawrence Livermore National Laboratory)	
2. Integration of Wafer-Level Solar Cells and Micro-Optic Concentrators for Micro-Scale Concentrating Photovoltaics	Jared, B. H.; Hains, C.; Keeler, G. A.; Miller, B. K.; Paap, S. M.; Saavedra, M. P.; Sweatt, W. C.; Tauke-Pedretti, A.; Wood, M. (Sandia National Laboratories); Li, L.; Li, D.; Gu, T.; Hu, J. (Massachusetts Institute of Technology)	95
3. DMD-Based Random-Access Scanner for Fast 3D Imaging and Fabrication	Geng, Q.; Wang, D.; Chen, S-C (The Chinese University of Hong Kong)	99

*No Abstract Available

4. Design of High Resolution and High Force MEMS Tensile Testers for Direct Metrology of Submicron Polymer Features	Ladner, I. S.; Cullinan, M. A. (The University of Texas at Austin); Saha, S. K.; Cao, A. (Lawrence Livermore National Laboratory)	103
5. Automated Assembly with Optical Tweezers	Shaw, L.; Chizari, S.; Porter, M.; Austin, S.; Hopkins J. B. (University of California - Los Angeles)	109
6. Multi-Beam Interference Lithography Based on Evanescent Wave for Functional Nano-Complex Surface	Masui, S.; Suzuki, Y.; Matsumoto, Y.; Michihata, M.; Takamasu, K.; Takahashi, S. (The University of Tokyo)	113

Session 5

Metrology Systems

Wednesday, November 1, 2017, 1:30 PM - 3:00 PM

Session Chairs: Jimmie A. Miller (University of North Carolina-Charlotte) and Kate M. Medicus (Optimax Systems, Inc.)

1. *The Role of Precision Engineering for the Revision of the International System of Units	Schlamminger, S. (National Institute of Standards & Technology)	
2. Computer Generated Holograms as 3-Dimensional Calibration Artifacts	Parks, R. E. (Optical Perspectives Group, LLC); Ziegert, J. C.; Groover, J. (University of North Carolina-Charlotte)	117
3. Colored Light Interferometry	Abolbashari, M. (Optoniks, Inc.); Azari, M.; Habibi, N.; Farahi, F. (University of North Carolina-Charlotte)	121
4. Dense Error Evaluation for Laser Trackers	Morse, E. P.; Heysiattalab, S. (University of North Carolina-Charlotte); Wang, J. (Southwest Jiaotong University)	127

Session 6

Applications of Precision Design and Manufacturing to Telescopes and Synchrotron Optics

Thursday, November 2, 2017, 8:30 AM - 10:00 AM

Session Chairs: Jonathan D. Ellis (University of Rochester) and Senajith B. Rekawa (Lawrence Berkeley National Laboratory)

1. Optomechanical Design and Fabrication of a Snap Together Freeform TMA Telescope	Horvath, N.; Barron, I.; Owen, J. D.; Dutterer, B. S.; Davies, M. A. (University of North Carolina-Charlotte); Schiesser, E.; Bauer, A. M.; Rolland, J. P. (University of Rochester)	133
2. Fabrication of Lightweight Monocrystalline Silicon Mirror Segments to Enable High Resolution X-ray Telescopes	Biskach, M.; Riveros, R. E.; Zhang, W. W. (NASA Goddard Space Flight Center); Allgood, K.; Kearney, J.; Mazzarella, J.; Solly, P. (Stinger Ghaffarian Technologies, Inc.)	139

*No Abstract Available

3. Fabrication of X-ray Imaging Mirrors for an Achromatic and High-Resolution Full-Field X-ray Microscope Yamada, J.; Matsuyama, S.; Yasuda, S.; Sano, Y.; Yamauchi, K. (Osaka University)	143
4. Design of Positioning System for X-ray Split and Delay Shi, H.; Zhu, D.; Schafer, D.; Barada, A. H.; James, J. H.; Lee, L.; Johnson, T.; Sun, Y.; Gumerlock, K. L.; Zhang, L.; Osier, T. O.; Whitney, R. A.; Smith, B. E. (SLAC National Accelerator Laboratory)	147

Session 7

Precision Design

Thursday, November 2, 2017, 10:30 AM - 12:00 PM

Session Chairs: Mark A. Stocker (Cranfield Precision, Division of Fives Landis Ltd.) and Mark T. Kosmowski (Electro Scientific Industries, Inc.)

1. *Precision Machine Design Review Stocker, M. A. (Cranfield Precision, Division of Fives Landis Ltd.)	
2. Paradigm Change in Gear Inspection Based on a Holistic Description, Measurement and Evaluation of Gear Flanks Goch, F. G.; Ni, K.; Peng, Y. (University of North Carolina-Charlotte); Guenther, A. (Reishauer AG)	151
3. Error Budgeting Analysis for Determining Axis Configuration of Ultra Precision Jig Grinding Machines Badrawy, S. J. (Moore Nanotechnology Systems, LLC)	158
4. Additively Manufactured Lattice Structures for Precision Engineering Applications Elmadih, W.; Syam, W. P.; Maskery, I.; Leach, R. K. (University of Nottingham)	164
5. Design of a Long-Travel, Flexure-Based Nanopositioner with Reduced Higher Order Resonant Modes Roy, N. K.; Cullinan, M. A. (The University of Texas at Austin)	170

Session 8

Precision Manufacturing Technology

Thursday, November 2, 2017, 1:30 PM - 3:00 PM

Session Chairs: Deepak Ravindra (Micro-LAM Technologies, LLC) and Lucas M. Valdez (Los Alamos National Laboratory)

1. *Precision Machining Review Ravindra, D. (Micro-LAM Technologies, LLC)	
2. Recent Advances in Ultra-precision Milling with Multiple-cutting Edges Schönemann L.; Riemer, O.; Brinksmeier, E. (University of Bremen)	175
3. Grinding of Silicon Carbide for Freeform Optics Shanmugam, P.; Sizemore, N. E.; Owen, J. D.; Davies, M. A. (University of North Carolina-Charlotte); Fess, E.; Hamel, J.; Ross, J. (Optipro Systems, LLC); Lambropoulos, J. C. (University of Rochester)	180

*No Abstract Available

4. An Investigation of Multi-Jet Polishing of Precision Surfaces	Cheung C-F.; Wang, C. J.; Ho, L.-T.; Lee, W. B. (The Hong Kong Polytechnic University)	186
5. High-pressure Aerostatic Bearing Technology - Combining Robustness with Speed, Thermal Stability and Low Errors in Motion	Dupont, R. (Levicron GmbH)	192

Poster Session 1

Tuesday, October 31, 2017, 4:30 PM - 6:00 PM

Session Chairs: Brian P. O'Connor (Aerotech, Inc.) and Michael L. Barkman (Zygo Corporation)

Additive Manufacturing

1. Current Use and Potential of Additive Manufacturing for Optical Applications	Brunelle, M.; Ferralli, I.; Whitsitt, R.; Medicus, Kate M. (Optimax Systems, Inc.)	198
--	--	-----

Characterization, Data Reduction and Applications of Measurement Science

2. Statistical Analysis of Surface Measurements and Images	Azimi, F.; Young, B.; Mullany, B. A. (University of North Carolina-Charlotte)	204
3. Metrology Techniques for Evaluating and Aligning DESI Focal Plate Structure	Duan, Y.; Ahlen, S. P. (Boston University); Buice, E. S.; Claybaugh, T. M. (Lawrence Berkeley National Laboratory)	208
4. Experimental Fused Illumination Mechanism Design with Discriminant Function for Steel Plate	Kim, G-B; -Bum; Doek, C-E (Korea National University of Transportation)	214
5. Any-Degree-of-Freedom Registration of Three-Dimensional Surfaces with Unbalanced Deviations	Liu, S.; Cheung C-F; Wang, C. J. (The Hong Kong Polytechnic University)	219
6. Methods to Determine the Center of Contrast Targets from Terrestrial Laser Scanner Data	Rachakonda, P. K.; Muralikrishnan, B.; Sawyer, D. S. (National Institute of Standards & Technology); Wang, L. (China Jiliang University)	223
7. Compensation of Measured Frequency Response Functions Using Accelerometer Models and Inverse RCSA	Satyanarayana, H.; Schmitz, T. L. (University of North Carolina-Charlotte)	230
8. Task-Specific Measurement Uncertainty of a Hemispherical Artifact	Valdez, L. M.; Valdez, M. O.; Montaño, J. D. (Los Alamos National Laboratory)	236
9. Characterizing Spatial Resolution of a Fringe Projection System for Measuring Additively Manufactured Surfaces	Zhang, B.; Davies, A. D.; Ziegert, J. C.; Evans, C. J. (University of North Carolina-Charlotte)	241

Historical and/or Education Perspective on Precision Engineering

- 10. Managing Risks when Single-Point Diamond Machining a 24-Day-Cut Germanium Blazed Diffraction Grating**
Montesanti, R. C.; Kuzmenko, P. J.; Little, S.; Bixler, J. V.; Jackson, J. L.; Mirkarimi, P.; Priest, R. E.; Thelin, P. A.; Watkins, J. A.; Yoxall, B. E.
(Lawrence Livermore National Laboratory) 246
- Metrology Systems and Techniques**
- 11. Stress Induced Frequency Modulation of a Microchip Green Laser**
Arumugam, K.; Smith, S. T.; Her, T.-H. (University of North Carolina-Charlotte) 253
- 12. Simultaneous Measurement of Backlash and Geometric Errors of Linear Axes with a Laser Tracer**
Cong, H.; Chen, Y.; Zhang, C.; Han, L.; (Xi'an Jiaotong University) 257
- 13. Multi-Scale Contextual Characterization via High Throughput Multi-beam Electron Microscopy**
Crosby, K. (Carl Zeiss Microscopy, LLC); Bauza, M. B. (Carl Zeiss Industrial Metrology); Garbowksi, T.; Eberle, A. L. (Carl Zeiss Microscopy GMBH) 261
- 14. Error Budgeting Analysis for X-ray Systems Using a 0D Uncertainty Model**
Cuadra, J. A.; Divin, C. J.; Panas R. M. (Lawrence Livermore National Laboratory) 267
- 15. An Optical Method for In-situ Measurement of Form and Surface Profile of Axisymmetric Objects**
Farahi, N.; Babaie, J.; Ziegert, J. C.; Farahi, F. (University of North Carolina-Charlotte); Abolbashari, M. (Optoniks, Inc.) 272
- 16. Attrition/Abrasive Wear Monitoring of Cutting Tools Based on Knife-Edge Interferometry**
Lee, C-B.; Zhao, R.; Jeon, S.; Zolfaghari, A. (Tennessee Technological University).... 276
- 17. Challenges in Measuring Spherical Geometry Using Terrestrial Laser Scanners**
Muralikrishnan, B.; Rachakonda, P. K.; Shilling, K. M.; Lee, V.; Sawyer, D. S.; Cheok, G. (National Institute of Standards & Technology); Cournoyer, L. (National Research Council of Canada) 281
- 18. Optical Sensor for Use in the R-test**
Parks, R. E. (Optical Perspectives Group, LLC); Ziegert, J. C.; Groover, J. (University of North Carolina-Charlotte) 286
- 19. Surface Area Measurement Using Curved Screen Deflectometry for Increased Dynamic Range and Sensitivity**
Pouyafard, A.; Davies, A. D. (University of North Carolina - Charlotte) 290
- 20. Replication Assessment of Surface Texture at Sub-micrometre Scale**
Quagliotti, D.; Tosello, G.; Hansen, H. N. (Technical University of Denmark) 293

21. Alignment and Period Measurement of Critical-Angle Transmission Gratings Using a Scanning Laser Reflection Tool	Song, J.; Heilmann, R. K.; Schattenburg, M. L. (Massachusetts Institute of Technology); Brucolari, A. R. (Izentis, LLC); Hertz, E. (Harvard-Smithsonian Center for Astrophysics)	299
22. Fabrication of Probe Tips for Nanoscale 3D Metrology	Uchiyama, K.; Murakami, H. (The University of Kitakyushu); Katsuki, A.; Sajima, T. (Kyushu University); Yamamoto, T.; Nagata, R. (Inatsuki Science Co., Ltd); Fujiyoshi, K. (Fukuoka Industrial Technology Center)	305
23. Statistical Reduction Technique for Zero Position Error Between Sensors in Improved Sequential Three-Point Method	Uda, Y.; Natsume, Y.; Tamagawa, T.; Shimada, S. (Osaka Electro-Communication University); Imura, R. (Nagase Integrex Co., Ltd.)	311
24. Minimizing Task-Specific Uncertainty in CMM-Based Freeform Optics Metrology	Uwakwe, M.; Evans, C. J. (University of North Carolina-Charlotte).	315
25. Uncertainty Analysis for Part Density Determination via Hydrostatic Weighing	Valdez, M. O.; Montaño, J. D.; Valdez, L. M. (Los Alamos National Laboratory)	321
26. The Next Generation Heterodyne Interferometric Grating Encoder System for Multi-Displacement Measurement of a Wafer Stage	Wang, L. J.; Zhang, M.; Zhu, Y.; Ye, W. N.; (Tsinghua University); Ding, S. Q.; Jia, Z.; (Beijing Uprecision Tech Co., Ltd); Xia, Y. (University of Electronic Science and Technology)	326
27. Geometric Error Measurement and Compensation of a Rotary Table Using a Circular Ball Plate Artifact	Wang, Q.; Goch, F. G. (University of North Carolina-Charlotte)	332
28. Reference Metrology System for Compensation of Level Control in Precision State System	Woo, S.; Park, S-H. (Samsung Electronics Co., Ltd.)	337
29. Large Area Inspection Using a Multi-point, Tip-Based Nanometrology System	Yao, T-F.; Cullinan, M. A. (The University of Texas at Austin)	341
30. Development of an Innovative Sensor for Measuring Two-degree-of-freedom Motions of Single-Axis Linear Nanopositioning Stage	Zolfaghari, A.; Jeon, S.; Lee, C-B. (Tennessee Technological University); Kim, G. (TRI-N Co. Ltd.)	346
Precision Design of Instruments and Machines		
31. Axial and Radial Static Stiffness Testing for Ultra-Precision Air Bearing Spindle	Arneson, S.; Arneson, D. A.; Knapp, B. R.; Oss, D. D. (Professional Instruments Company)	352

32. In-Line, Tip Based Nanometrology for Roll-to-Roll Manufactured Materials and Electronic Devices	Connolly, L. G.; Cullinan, M. A. (The University of Texas at Austin)	355
33. Design of a Precision, Active, High-Strain Composite (HSC) Hinge	Echter, M. A.; Silver, M. J. (MIT Lincoln Laboratory); Peterson, M. E. (Air Force Research Laboratory)	360
34. An Instrument to Measure Temporal Stability of Spring Compression Force	Jaycox, A. W. (Lawrence Livermore National Laboratory); Lawton, K. M.; Patterson, S. R. (University of North Carolina-Charlotte)	366
35. Error Analysis for a High-Precision Five Degree of Freedom Hybrid Mechanism for High-Power High-Repetition Rate Laser Operations	Karim, S.; Piano, A.; Leach, R. K. (University of Nottingham); Tolley, M. (Science and Technology Facilites Council (STFC))	372
36. Design and Testing of an Air Bearing Spindle at Low Speed for Nanometer-Level Asynchronous Error	Knapp, B. R.; Arneson, D. A.; Oss, D. D. (Professional Instruments Company)	378
37. Long-term Creep Measurements of 302 Stainless Steel and Elgiloy	Lawton, K. M.; Patterson, S. R. (University of North Carolina-Charlotte)	382
38. Development of Novel Two-DOF Nano-Positioning Stage with High Thermal Stiffness	Lee, J-C.; Lee, H-H; Yang, S-H (Kyungpook National University)	387
39. A Flexure-Based Multi-Layer Roll-to-Roll Printing Systems	Li, C.; Chen, S-C. (The Chinese University of Hong Kong)	393
40. Large Stroke High Support Stiffness Flexure Based Universal Joint	Naves, M.; Aarts, R. G. K. M.; Brouwer, D. M. (University of Twente)	398
41. Precision Mechanical Design and Test of Miniature Dynamic Mirror Benders with Laminar Flexure Bending Mechanism for X-ray Microfocusing	Shu, D.; Kearney, S.; Anton, J.; (Argonne National Laboratory); Li, A.; Mao, C.; Yan, S.; Liang, D.; Pan, Y. (Shanghai Institute of Applied Physics)	403
42. Design, Development and Testing of Large-caliber Precision CNC Double-sided Polishing Machine	Sun, X.; Zhang, Z.; Zha, J.; Chen, Y. (Xi'an Jiaotong University); Chen, J. (Jiangsu Yichuang Institute of Intelligent Equipment Co.Ltd.)	407
43. Design of a High-Speed Oscillating Blade Microtome	Wang, J.; Li, C.; Chen, S-C. (The Chinese University of Hong Kong)	412
44. Design Strategy for Cryogenic Optical Housing Using Stewart Truss with Dissimilar Materials	Yoxall, B. E.; Montesanti, R. C.; Bixler, J. V.; Hunt, W. E.; Kuzmenko, P. J.; Priest, R. E. (Lawrence Livermore National Laboratory)	417

- 45. Gantry-Type Machine Tool Accuracy Enhancement Through Geometric Error Real-Time Compensation Based on Open-Architecture PA CNC**
 Zhang, C.; Cong, H.; Chen, Y. (Xi'an Jiaotong University) 422
- 46. Analysis of Error Motions of Hydrostatic Rotary Table**
 Zhang, P.; Chen, Y.; Cong, H. (Xi'an Jiaotong University) 427

Poster Session 2

Wednesday, November 1, 2017, 3:30 PM - 5:00 PM

Session Chairs: Brian P. O'Connor (Aerotech, Inc.) and Michael L. Barkman (Zygo Corporation)

Controls and Mechatronics

- 47. Vacuum Compatible Contactless Active Magnetic Linear Bearings for High Cleanliness Robotic Applications**
 Baade, R.; Steinbuch, M. (Eindhoven University of Technology);
 Peijnenburg, A. T. (VDL Enabling Technologies Group) 433
- 48. A High Performance Feedforward Tuning Approach for Ultra-precision Motion Control**
 Dai, L-Y.; Li, X.; Zhu, Y.; Zhang, M. (Tsinghua University) 439
- 49. Multi-Axis Trajectory Generation with Optimal Frequency Spectrum for Vibration Avoidance**
 Dumanli, A. A.; Sencer, B. (Oregon State University) 445
- 50. A Linear Positioning Stage Using a Thermal Actuator**
 Fan, C.; Smith, S. T.; Tarbutton, J. (University of North Carolina - Charlotte) 451
- 51. Basic Characteristics of Novel Hybrid Actuator Integrating a Thermal Bias Element and an Electromagnetic Driving Element**
 Hama, T.; Sato, K. (Toyohashi University of Technology) 456
- 52. Identification of Friction Energy Dissipation Using Free Vibration Velocity: Measurement and Modeling**
 Kossack, C.; Schmitz, T. L.; Ziegert, J. C.
 (University of North Carolina-Charlotte). 462
- 53. The Velociprobe: Pushing the Limits with Fast and Robust Control**
 Mashrafi, S. T.; Salapaka, S. (University of Illinois at Urbana-Champaign);
 Preissner, C. (Argonne National Laboratory). 468
- 54. Development of Dynamic Model to Estimate the Frequency Response of Four-Axis Machine Tools**
 Song, C-K.; Lee, C-H. (Korea Institute of Machinery & Materials (KIMM));
 Dinh, P. V. (Korea University of Science and Technology). 474
- 55. Software-Based Compensation of Vibration-Induced Errors of a Commercial Desktop 3D Printer**
 Yoon, D.; Duan, M.; Okwudire, C. E. (University of Michigan). 478
- 56. Decouplable Coarse-Fine Stage for Improved Precision and Efficiency in Point-to-Point Positioning**
 Yoon, D.; Zeng, B.; Okwudire, C. E. (University of Michigan) 483

Micro and Nano Technologies

- 57. Microassembly Development for an Advanced Micromirror Array**
Enstrom, K. G.; Uphaus, T. M.; Panas R. M.; Harvey, C.
(Lawrence Livermore National Laboratory) 489
- 58. Fabrication of Polycrystalline Diamond Molds by Micro EDM**
Kasai, S.; Yan, J. (Keio University); Sodetai, T. (Seiko Instruments, Inc.) 494
- 59. Numerical and Experimental Investigations into Production of Hierarchical Textures**
Patel, D. S.; Thalkar, M.; Jain, V. K.; Ramkumar, J.
(Indian Institute of Technology Kanpur) 498
- 60. Wafer Scale Exfoliation of Monocrystalline Micro-Scale Silicon Films**
Ward, M.; Cullinan, M. A. (The University of Texas at Austin) 504
- 61. Development of Micro Ball Forming to Process Micro Structure on Curved Surface**
Yamaguchi, K.; Nakano, T.; Kakutani, S.; Ota, M.; Egashira, K.
(Kyoto Institute of Technology) 508
- 62. Design and Modelling of a Bidirectional MEMS Thermal Actuator**
Zhao, C.; Ladner, I. S.; Cullinan, M. A. (The University of Texas at Austin);
Song, A.; Hopkins J. B. (University of California - Los Angeles) 514

Precision Manufacturing Machines and Technologies

- 63. Investigation in Micro-EDM Techniques for Laser Target Application**
Andre, J.; Barnay, N.; Gregoire, A.; Chicanne, C.; Theobald, M. (CEA) 520
- 64. Mechanical Machining Processes for Laser Target Manufacturing**
Andre, J.; Schunck, J.; Gregoire, A.; DeDemo, G.; Chicanne, C.;
Theobald, M. (CEA) 524
- 65. Precision Hard Turning on a Lathe Retrofitted with an Oil Hydrostatic Spindle**
Arneson, D. A.; Knapp, B. R. (Professional Instruments Company) 528
- 66. Thermal Errors of a Large 5-Axis Machine Tool Due to Cutting Fluid Influences - Evaluation with Thermal Test Piece**
Blaser, P.; Wiessner, M.; Wegener, K. (Institute of Machine Tools and
Manufacturing ETH Zürich); Hernandez-Becerro, P.; Mayr, J. (inspire AG) 531
- 67. Stability in Modulated Tool Path Turning**
Copenhaver, R.; Ziegert, J. C.; Schmitz, T. L. (University of North Carolina-Charlotte) 537
- 68. Fundamental Experiments of Additive Manufacturing Method by Selective Solidification Using Electrical Discharge**
Furutani, K.; Tsuchiya, T.; Yamagishi, H. (Toyota Technological Institute) 543
- 69. Effect of the Additive Manufacturing Process on Cutting Forces in Hybrid Manufacturing**
Gomez, M.; Honeycutt, A.; Schmitz, T. L. (University of North Carolina-Charlotte);
Heigel, J. (National Institute of Standards & Technology) 547

70. Precision Manufacturing of Internal Involute Gears Using 5-Axis Milling Center	Groover, J.; Goch, F. G. (University of North Carolina-Charlotte)	553
71. Force Measurement in Diamond Micro-Chiseling	Gurganus, D. K.; Sizemore, N. E.; Owen, J. D.; Davies, M. A. (University of North Carolina-Charlotte).	558
72. An Examination of Surface Location Error and Surface Roughness for Period-2 Instability in Milling	Honeycutt, A.; Schmitz, T. L. (University of North Carolina-Charlotte).	562
73. Fixed-Free Beam Dynamics Prediction for Thin Rib Machining by RCSA	Honeycutt, A.; Schmitz, T. L. (University of North Carolina-Charlotte).	568
74. The Challenges and Consequences of Material Uncertainties in Metal Laser Powder Bed Fusion	Jared, B. H.; Boyce, B.; Madison, J. D.; Ostien, J.; Rodelas, J.; Salzbrenner, B.; Swiler, L. P.; Underwood, O. D.; Saiz, D. J. (Sandia National Laboratories)	574
75. Analysis of Hydrophobicity of Micro-Channel and Micro-Pillar Patterns of Polymer for Orthodontic Retainer Fabricated by Mechanical Machining Process	Je, T-J.; Jeong, J-Y.; Lee, J-R; Jeon, E-C; Choi, D-S. (Korea Institute of Machinery & Materials (KIMM)).	578
76. Multi-probe Error Separation	Keller, E. E.; Marsh, E. R.; Arneson, H. D. (The Pennsylvania State University); Knapp, B. R.; Arneson, D. A. (Professional Instruments Company)	583
77. Measurement of Dynamic Characteristics of Hydrostatic Spindle Against Radially Applied External Forces	Kirigaya, R.; Nakao, Y. (Kanagawa University); Hayashi, A. (Kanazawa Institute of Technology) Fedorynenko, D. (Chernihiv National University of Technology).	585
78. Laser Augmented Diamond Drilling Operation Using A Rotating Tool Design	Mohammadi, H.; Patten, J. A. (Western Michigan University)	589
79. UPC 300 Ultra Precise Diamond Turning Machine Optimized for Freeform Production	Niehaus, F.; Huttenhuis, S. (Schneider GmbH & Co. KG); Gauch, D. (Schneider Optical Machines, Inc.)	593
80. Dry Planarization Method Using a Transpport of Reactive Species	Ryokume, R.; Miyazaki, T.; Matsuyama, S.; Sano, Y.; Yamauchi, K. (Osaka University)	597
81. Manufacture and Assembly of Precision Planar Samples for Experiments at the National Ignition Facility	Savage, L; Castro, C.; Vargas, R. J.; Seugling, R. M.; Nikroo, A. (Lawrence Livermore National Laboratory); Lament, M. (Schafer Livermore Laboratory)	602

82. M-Uber: Uber-Type Assignment for Distributed Operator Machining Operations	Schmitz, T. L.; Ziegert, J. C. (University of North Carolina-Charlotte); Greas, N (University of North Carolina-Chapel Hill)	606
83. Milling of High-Alloyed Steel Molds for Precision Injection Molding of Microfluidical Parts	Schmuetz, J. (Beuth University of Applied Sciences)	609
84. Fiber Based Tools for Precision Polishing Applications	Shahinian, H.; Hassan, N.; Cherukuri, H. P.; Mullany, B. A. (University of North Carolina-Charlotte).	615
85. On Gyroscope Mechanism for Mobile Machining Machine	Shim, J.; Heo, S.; Hwang, J.; Ro, S-K. (Korea Institute of Machinery & Materials (KIMM))	620
86. Material Behavior in Ultra-Precision Flycutting of Germanium	Sizemore, N. E.; Shanmugam, P.; Owen, J. D.; Davies, M. A. (University of North Carolina-Charlotte); Meyer, D. (Foundation Institute of Materials Science)	624
87. How to Realize the Self-Protective Tool During Cutting of Difficult-Cut Material?	Song, X.; Takahashi, Y.; Ihara, T. (Chuo University)	630
88. Precision Polishing Technology of Ferroelectric PMN-PT Single Crystals for Smoother Surfaces	Takahashi, H.; Suzuki, H. Y.; Namba, Y. Y. (Chubu University)	636
89. Temperature Measurement of Burnishing Process by Electro-Conductive Tool	Tanaka, H.; Tanaka, H.; Sakamoto, H. (Sophia University)	642
90. Inverted Diamond Cutting of Right Triangular Retroreflectors: Surface Quality and Cutting Forces	Tauhiduzzaman, M.; Bordatchev, E. V. (National Research Council of Canada); Milliken, N.; Tutunea- Fatan, R. R. (Western University)	647
91. Fundamental Study on Thermal Stability of Micro Milling Spindle Supported by Water Hydrostatic Bearings Under Spindle Rotation	Yaguchi, T.; Nakao, Y. (Kanagawa University); Hayashi, A. (Kanazawa Institute of Technology).	651
92. Laser Cutting Out Process for Semiconductor Substrates Applying Laser Slicing Method	Yamada, Y.; Saitama T.; Ikeno, J.-I. (Saitama University)	657
93. Improving Surface Quality of Thin-Walled Double Side Aspheric Component by Machining Process and Measurement Optimization	Zha, J.; Chu, J.; Chen, Y.; Li, Y. (Xi'an Jiaotong University)	663