Dynamics Identification and Amplitude Control of a Wireless Side-Mounted Ultrasonic Tool Holder System under Minimum Impedance Resonance Frequency Tracking

Her-Terng Yau [1,2,*], Ping-Huan Kuo [1,2], Ting-Chung Tseng [1], and Hao-Yang Lin [1]

[1] Department of Mechanical Engineering, National Chung Cheng University, Chiayi 62102, Taiwan

[2] Advanced Institute of Manufacturing with High-tech Innovations (AIM-HI), National Chung Cheng University, Chiayi 62102, Taiwan

[*] E-mail: htyau@ccu.edu.tw

***Abstract*—Ultrasonic tool holders have been widely used in machining hard and brittle materials, but how to control the tool tip oscillation amplitude at the resonance frequency to guarantee the machining accuracy is very important. In this study, a system identification and control of a wireless ultrasonic tool holder was developed. The parameters and size of the piezoelectric ceramics was optimized to ensure that the vibration mode of the tool holder could match the desired resonance frequency. Feedback current of the actuator is used to track the resonance frequency under minimum impedance. A theoretical methodology was applied to obtain the transfer function, and an optimal time domain system identification with bilinear transformation was used to more precisely describe the real tool holder system at the resonance frequency. In order to control the oscillation amplitude of tool tip, an optimal controller with Harris hawks optimizer was used to implement control scheme. From the experimental results, it seen that the amplitude of tool tip can be controlled to desired value within 1 second to fit the requirement in industry.**

REFERENCES

[1] Z.Zhu, S.To, K. F.Ehmann, andX.Zhou, "Design, analysis, and realization of a novel piezoelectrically actuated rotary spatial vibration system for micro-/nanomachining," *IEEE/ASME Trans. Mechatronics*, vol. 22, no. 3, pp. 1227–1237, 2017, doi: 10.1109/TMECH.2017.2682983.

[2] L.Zheng, W.Chen, D.Huo, andX.Lyu, "Design, Analysis, and Control of a Two-Dimensional Vibration Device for Vibration-Assisted Micromilling," *IEEE/ASME Trans. Mechatronics*, vol. 25, no. 3, pp. 1510–1518, 2020, doi: 10.1109/TMECH.2020.2978209.

[3] W.LeZhu, Z.Zhu, Y.He, K. F.Ehmann, B. F.Ju, andS.Li, "Development of a Novel 2-D Vibration-Assisted Compliant Cutting System for Surface Texturing," *IEEE/ASME Trans. Mechatronics*, vol. 22, no. 4, pp. 1796–1806, 2017, doi: 10.1109/TMECH.2017.2693996.

[4] Yantao Shen, E.Winder, Ning Xi, C. A.Pomeroy, andU. C.Wejinya, "Closed-loop optimal control-enabled piezoelectric microforce sensors," *IEEE/ASME Trans. Mechatronics*, vol. 11, no. 4, pp. 420–427, Aug.2006, doi: 10.1109/TMECH.2006.878555.

[5] S.Park, J. W.Song, B.Lee, H.Yoon, Y. J.Lee, andS.Sung, "Autonomous Oscillation Control Loop Design for Amplitude Controlled, Frequency Read-Out-Type Resonant Sensors," *IEEE/ASME Trans. Mechatronics*, vol. 17, no. 6, pp. 1009–1020, Dec.2012, doi: 10.1109/TMECH.2011.2157352.

[6] L.Qiu, Y.Shi, J.Pan, B.Zhang, andG.Xu, "Positioning-Tracking Controller Design of A Linear Motion Control System Based on Vectorization Technique," *IEEE/ASME Trans. Mechatronics*, vol. 23, no. 4, pp. 1512–1520, Aug.2018, doi: 10.1109/TMECH.2018.2851980.

[7] M.Xiao, S.Karube, T.Soutome, andK.Sato, "Analysis of chatter suppression in vibration cutting," *Int. J. Mach. Tools Manuf.*, vol. 42, no. 15, pp. 1677–1685, 2002, doi: 10.1016/S0890-6955(02)00077-9.

[8] Z. C.Li, Y.Jiao, T. W.Deines, Z. J.Pei, andC.Treadwell, "Rotary ultrasonic machining of ceramic matrix composites: Feasibility study and designed experiments," *Int. J. Mach. Tools Manuf.*, vol. 45, no. 12–13, pp. 1402–1411, 2005, doi: 10.1016/j.ijmachtools.2005.01.034.

[9] D.Liu, W. L.Cong, Z. J.Pei, andY.Tang, "A cutting force model for rotary ultrasonic machining of brittle materials," *Int. J. Mach. Tools Manuf.*, vol. 52, no. 1, pp. 77–84, 2012, doi: 10.1016/j.ijmachtools.2011.09.006.

[10] "An introduction to ultrasonic motors," *Eng. Sci. Educ. J.*, vol. 4, no. 3, pp. 116–116, 1995, doi: 10.1049/esej:19950305.

[11] J.Gao andY.Altintas, "Development of a Three-Degree-of-Freedom Ultrasonic Vibration Tool Holder for Milling and Drilling," *IEEE/ASME Trans. Mechatronics*, vol. 24, no. 3, pp. 1238–1247, Jun.2019, doi: 10.1109/TMECH.2019.2906904.

[12] Z.Wang, Q.Zou, L.Faidley, andG. Y.Kim, "Dynamic compensation and rapid resonance identification in ultrasonic-vibration-assisted microforming system using magnetostrictive actuator," *ASME 2010 Dyn. Syst. Control Conf. DSCC2010*, vol. 1, no. 3, pp. 21–28, 2010, doi: 10.1115/DSCC2010-4140.

[13] J.Gao, H.Caliskan, andY.Altintas, "Sensorless control of a three-degree-of-freedom ultrasonic vibration tool holder," *Precis. Eng.*, vol. 58, pp. 47–56, Jul.2019, doi: 10.1016/j.precisioneng.2019.05.005.

[14] C. C.Peng andC. Y.Su, "Modeling and Parameter Identification of a Cooling Fan for Online Monitoring," *IEEE Trans. Instrum. Meas.*, vol. 70, 2021, doi: 10.1109/TIM.2021.3104375.

[15] J.Zhao, H.Wang, J.Zhao, Z.Pan, andR.Yan, "Precise Positioning of Linear Motor Mover Directly from the Phase Difference Analysis," *IEEE/ASME Trans. Mechatronics*, vol. 25, no. 3, pp. 1566–1577, 2020, doi: 10.1109/TMECH.2020.2980078.

[16] Kiam Heong Ang, G.Chong, andYun Li, "PID control system analysis, design, and technology," *IEEE Trans. Control Syst. Technol.*, vol. 13, no. 4, pp. 559–576, Jul.2005, doi: 10.1109/TCST.2005.847331.

[17] Y.Li, K. H.Ang, andG. C. Y.Chong, "Patents, Software, and Hardware for PID Control: An Overview and Analysis of the Current Art," *IEEE Control Syst.*, vol. 26, no. 1, pp. 42–54, 2006, doi: 10.1109/MCS.2006.1580153.

[18] Chun-Liang Lin, Horn-Yong Jan, andNiahn-Chung Shieh, "GA-based multiobjective PID control for a linear brushless DC motor," *IEEE/ASME Trans. Mechatronics*, vol. 8, no. 1, pp. 56–65, Mar.2003, doi: 10.1109/TMECH.2003.809136.

[19] K. K.Tan, Tong Heng Lee, andH. X.Zhou, "Micro-positioning of linear-piezoelectric motors based on a learning nonlinear PID controller," *IEEE/ASME Trans. Mechatronics*, vol. 6, no. 4, pp. 428–436, 2001, doi: 10.1109/3516.974856.

[20] X.Zhang, W.He, andC.Wang, "Self-Sensing Waveform Control for a Low-Frequency Electromagnetic Vibrator," *IEEE/ASME Trans. Mechatronics*, vol. 22, no. 2, pp. 785–793, 2017, doi: 10.1109/TMECH.2016.2635260.

[21] A. A.Heidari, S.Mirjalili, H.Faris, I.Aljarah, M.Mafarja, andH.Chen, "Harris hawks optimization: Algorithm and applications," *Futur. Gener. Comput. Syst.*, vol. 97, pp. 849–872, 2019, doi: 10.1016/j.future.2019.02.028.

[22] A.Altan, "Performance of Metaheuristic Optimization Algorithms based on Swarm Intelligence in Attitude and Altitude Control of Unmanned Aerial Vehicle for Path following," 2020, doi: 10.1109/ISMSIT50672.2020.9255181.

[23] A. F.Kamaruzaman, A. M.Zain, S. M.Yusuf, andA.Udin, "Levy flight algorithm for optimization problems - A literature review," in *Applied Mechanics and Materials*, 2013, vol. 421, pp. 496–501, doi: 10.4028/www.scientific.net/AMM.421.496.