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Tutorial Title

Bearingless Motors: Fundamentals and Current Status

Instructor Team

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Abstract

Magnetically levitated systems are becoming increasingly popular in the pumps, compressor, transportation, process industries etc. Bearingless motors are magnetically levitated systems with combined motor and levitation functions. The goal of this tutorial is to provide the fundamentals of the bearingless motor construction, operation, measurement system and control via lectures and hands on experience. Participants will also learn about the state of the art and recent developments in various conventional and non-conventional bearingless motor configurations. In the first part of the tutorial, we will discuss motivation, fundamental of operation and scaling laws of the bearingless motors. This will include the separate and combined winding configurations for motor and suspension function in bearingless motor. Participants will also learn about the basics of mechatronics surrounding the bearingless motors. The position measurement is an integral part of the bearingless motor, and the unstable nature of the electromagnetic suspension makes it an interesting control problem. We will discuss about the position sensor and control in brief to provide a complete picture to audience. First part of the tutorial will conclude with the state of art with commercially available magnetically levitated systems. In the second part, participants will learn about the variety of bearingless motor configurations. This will include the motors with various conventional and non-conventional topologies, associated working principles and motor configurations for various power levels. This section will cover the recent developments in the bearingless motors such as AC homopolar motor, interior permanent magnet motor, magnetically geared motor, vernier motor, induction motor and flux reversal motor. The non-conventional features of some of these bearingless motors like the geometry, airgap harmonics, etc. allows us to gain some desirable features like ease of control, force independent of rotor angle, reduced power electronics switches etc. This will provide a landscape of the bearingless motor configurations, applications and the research trends in this area. Participants will also learn about the drives for these motors. There are application dependent challenges associated with the bearingless motors. One such challenge is passive stiffness for pump operation and we will discuss the method to enhance passive stiffness in PM motors. The final part of the tutorial is a hands-on exercise. We have a complete experimenter's kit including the bearingless motor, power electronics, measurement system, controller and debugging interface. The kit is reconfigurable to work as various bearingless motor topologies as well as winding reconfigurable as combined winding or separate winding. The participants will learn to commission the motor, tune the suspension and motor controller (will be provided), perform the levitation and test the motor upto 2000 rpm. If time allows, we can test the motor with separate and combined windings as well.

Instructor Team Biographies

Wolfgang Gruber received the Dipl.-Ing. (M.Sc.) degree in mechatronics and Dr. techn. (Ph.D.) degree in technical sciences from Johannes Kepler University (JKU), Linz, Austria, in 2004 and 2009, respectively. Since 2012, he has been an Assistant Professor, since 2018 an Associate Professor and since 2021 Full Professor with the Institute of Electrical Drives and Power Electronics of JKU. Since 2004, he has also been a Senior Researcher with the RD company Linz Center of Mechatronics GmbH (LCM), Linz, Austria. He has developed the bearingless segment motor, reluctance motor, fluxswitching motor, and PM Vernier motor. His research interests include new topologies for bearingless slice motors, their design, setup and control. Prof. Gruber was the recipient of the international Nagamori Award in 2015.

Krishan Kant received B.Tech. degree from the National Institute of Technology Kurukshetra in 2012, M.Tech. degree from the Indian Institute of Technology Delhi in 2014, S.M. and PhD degrees from the Massachusetts Institute of Technology, USA in 2019 and 2023, all in electrical engineering. After that, he worked as a PostDoctoral Associate in Precision Motion Control Lab at MIT till Dec 2023. Currently he is working in General Electric global research center as a Research Engineer working on electromagnetic and power electronics design. Prior to his PhD, he worked at Exicom Power solutions Gurugram as an Assistant Manager in Power Electronics R&D Department, where he was involved in design and development of active power filter and multiport ac-dc converter. His research interests are electromagnetic actuators/motors design and control, bearingless motors and power electronics converter for mechatronics systems.

Eric L. Severson (Senior Member, IEEE) received the B.Sc. and Ph.D. degrees in electrical engineering from the University of Minnesota, Minneapolis, MN, USA, in 2008 and 2015, respectively where he was also a Post doctoral Associate till 2016. In 2017, he joined the Electrical and Computer Engineering Faculty, University of Wisconsin-Madison, Madison, WI, USA, where he received tenure and was an Associate Director of the Wisconsin Electric Machines and Power Electronics Consortium and a Fellow of the Grainger Institute for Engineering. In 2023, he joined the University of Minnesota's Mechanical Engineering Department, where he is currently an Associate Professor. His research interests include design and control of electric machines, bearingless motors, magnetic bearings, torque-dense machinery, off-highway vehicle electrification, and flywheel energy storage. Dr. Severson was the recipient of the USA National Science Foundation CAREER Award in 2020, Department of Defense NDSEG Fellowship in 2009, and National Science Foundation Graduate Research Fellowship in 2009.

Minkyun Noh received the B.S. degree in mechanical and aerospace engineering from Seoul National University, Seoul, South Korea, in 2012, and the S.M. and the Ph.D. degrees in mechanical engineering from the Massachusetts Institute of Technology (MIT), Cambridge, MA, USA, in 2014 and 2018, respectively. He joined University of British Columbia (UBC) Canada as an Assistant Professor with the Department of Mechanical Engineering in 2019. In 2022 he joined Korea Advanced Institute of Science & Technology, South Korea as an Assistant professor with the Department of Mechanical Engineering with joint Professor appointment with Institute of Robotics and Cho Chun Shik Graduate School of Mobility. Prior to joining UBC, he was a Postdoctoral Associate with the Laser Interferometer Gravitational-Wave Observatory (LIGO) laboratory at MIT for a year. His research interest includes the design and control of precision mechatronic systems, with applications to biomedical devices, scientific

instruments, and manufacturing systems.