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Modelling, analysis and control of linear feed axes in precision machine tools

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MODELLING, ANALYSIS AND CONTROL OF LINEAR FEED AXES IN PRECISION MACHINE TOOLS

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JEFFREY WILLIAM MOSCROP, BE (HONS.)

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CERTIFICATION

I, Jeffrey W. Moscrop, declare that this thesis, submitted in fulfilment of the requirements for the award of Doctor of Philosophy, in the School of Electrical, Computer and Telecommunications Engineering, University of Wollongong, is wholly my own work unless otherwise referenced or acknowledged. The document has not been submitted for qualifications at any other academic institution.

Jeffrey W. Moscrop

19th June 2008

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Abstract

The precision control of linear feed axes in machine tools is examined in this thesis. Although high precision in machining has been a focal point for engineers for over 200 years, the traditional solutions have often been based on complex mechanical designs. In this thesis, two aspects of feed axis controller design are examined: i) the use of appropriate mathematical models and ii) the significance of three of the most common performance limiting factors that have traditionally affected precision in linear feed axes. The three particular performance limiting factors considered are: i) dynamic stiffness, ii) torsional vibrations and iii) backlash.

The most effective way of obtaining knowledge about a control system is through appropriate mathematical modelling. A new two-body model for a simple motor-transmission-load system is presented in this thesis. This new model is shown to provide a more accurate representation of both the total inertia and lowest natural frequency of a system, when compared with the two-body model that is traditionally used by researchers and system designers. A new model to represent backlash in a two-body system is also presented. These new models are then extended to provide accurate mathematical models of four common linear feed axis drive configurations: i) a rotary motor driving a rack and pinion transmission, ii) a rotary motor directly driving a ballscrew transmission, iii) a rotary motor driving a ballscrew transmission via a synchronous belt, and iv) a linear motor directly driving the axis.

Different control solutions to the problems of dynamic stiffness, torsional vibrations and backlash are examined in this thesis, with each controller implemented on specially constructed test-beds. An approach using Quantitative Feedback Theory (QFT) is presented for systems with inherently low dynamic stiffness. This QFT approach is shown to provide a transparent design process, which results in high dynamic stiffness. Different controllers for torsional vibrations are compared both theoretically and experimentally, with many previously published solutions shown to be theoretically equivalent. A new backlash controller is also presented, which is shown experimentally to provide dynamic stability and good tracking performance at both high and low velocities.

The importance of treating these performance limiting factors simultaneously is also addressed in this thesis, with the control solutions developed to address some factors shown to also affect the other factors. The QFT approach is shown to provide a suitable integrated design process, where the implications of any compromises, on the control of each factor, are clearly visible.

Published Papers Arising From This Thesis

1. Jeffrey Moscrop, Chris Cook and John Turner, "Modelling and Control of Motor/Load Inertia Mismatch in Servo Systems," in Proceedings of the Fifth International Conference on Control, Automation, Robotics and Vision, Singapore, 1998, pp. 429-433.

2. Jeffrey Moscrop, Chris Cook and Fazel Naghdy, "Comparative Study of Feedback Sensor Locations for Servo Systems with Motor/Load Inertia Mismatch," in Proceedings of the Australian Conference on Robotics and Automation, Brisbane, 1999, pp. 202-207.

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7. Jeff Moscrop, Phil Commins and Chris Cook, “Torque Perturbations and Dynamic Stiffness of Linear Motors for Grinding Machines,” in Proceedings of the 6th International Symposium on Linear Drives for Industrial Applications, Lille France, 2007