Institution: The University of Huddersfield

Unit of Assessment: 15 General Engineering

Title of case study: Advanced machine tool accuracy measurement and improvement

1. Summary of the impact (indicative maximum 100 words)

Research by the University of Huddersfield has produced an in-depth understanding of the factors that contribute to machine tool inaccuracy. This has led to predictive methods for assessing the capability of machines to produce specific components and the development of a low-cost electronic compensation system that can increase machine tool accuracy by a factor of 10, with significant cost savings for factory temperature control. A contract has been signed to market this system globally. Rapid calibration techniques have been developed, in collaboration with a UK world-leading aerospace manufacturer, reducing timescales from days to less than one hour.

2. Underpinning research (indicative maximum 500 words)

The accuracy of machine tools is fundamental to the quality of the products they make. A better understanding of why errors occur and how to minimise them is vital to ensuring higher standards of manufacturing and increased productivity. For the past two decades researchers at the University of Huddersfield's Centre for Precision Technology (CPT) have delivered significant improvements in measuring and compensating for machine tool inaccuracies.

D Ford and S Postlewaite began research in 1992 under EPSRC grant SHAFT (graded Excellent) to increase precision of machines and improve quality of work-pieces. Further work under EPSRC grant RECOVER (graded Excellent) developed a real-time compensation system using scaler cards (Renishaw ipr) and a PC-based pre-calibrated compensation system (VCS) for correcting quasi-static geometric errors of 3-axis and later 5-axis computer numerical control (CNC) machine tools.

Both environmental and machine-induced temperature variations cause significant changes of size and distortion of shape of machine tool structures, producing sufficiently serious work-piece errors that a specific standard (ISO 230-3) has been introduced to facilitate the assessment of these errors. Research into compensating for the thermal errors present in CNC machine tools began in 1993 with a PhD undertaken by J Allan, initially concentrating on the main spindle (1). Subsequent PhDs by Simon Fletcher and Andrew White targeted all significant thermal errors. In 2001 a new thermal compensation system was created and incorporated into the existing VCS.

Further research, carried out by Andrew Longstaff under EPSRC grant CAPM (2001-2004, graded Excellent), implemented combined geometric and thermal compensation software inside the Siemens 840D machine tool controller. A special compile cycle was developed in collaboration with Siemens for real-time interface with the controller. This reduced the hardware cost but limited the application scope to machines with specific controllers (2,3).

A unique virtual reality machine tool program, VirMach (2003 onwards), was later created (Dr S Fletcher, Senior Research Fellow) to assist in measurement and installation of compensation systems in industry.

In 2005 Alan Myers became Technical Director of the CPT overseeing further research and development of the compensation system. Under the guidance of Prof. Myers a UoH-funded project (2008-2011) enabled the design and production of a new Machine Tool Compensation (MTC) system unit with all the capability of the VCS and affordable bespoke hardware for universal integration on to new and existing machine tools. This system has been shown to reduce geometric errors by 90% and thermal errors by 75% giving more accurate parts, with better functionality, less wear, longer life, less re-work, fewer scrapped parts and lower unit costs, which in turn reduced the need for inspection, significantly lowered assembly times and enhanced inter-changeability of parts.

The underpinning technology of rapid geometric calibration and high-accuracy temperature measurement using thermal imaging and unique flexible temperature-sensing strips, combined with physics-based models of the machine with emphasis on thermal characteristics. Specialist software, TempSpy, was written to calibrate sensors and record large amounts of data and also went on to become a key tool in the FP7 Project SOMMACT (2009 to 2012). Within this project Virmach also evolved to simulate and communicate machine errors for customer reports and became a further key tool for the compensation.

Finite element analysis (FEA) has played a significant role in more recent research, carried out in PhD work from 2007-2011 by Naeem Mian, using new techniques to model more accurately the thermal behaviour of complex structures. This reduces the amount of empirical work required to optimise model variables. FEA has also been used to understand the often-ignored elastic effects when traversing the machine. Automatic procedures are used to estimate the non-rigid effects, which are then measured using state-of-the-art equipment (4).

3. References to the research (indicative maximum of six references)

1. Postlethwaite SR, Allen JP, Ford DG, "The Use of Thermal Imaging, Temperature and Distortion Models for Machine Tool Thermal Error Reduction", Proceedings of IMechE, Vol. 212, Part B, pp. 671-679, 1998. DOI: 10.1243/0954405981515932. Won the I.Mech.E. Thatcher Bros. prize 1998.

2. Longstaff AP, Fletcher S, Myers A, "Volumetric compensation for precision manufacture through a standard CNC controller", 20th Annual Meeting of the American Society for Precision Engineering, 2005. (University Repository http://eprints.hud.ac.uk/3774/ available on request).

3. Fletcher S, Longstaff AP, Myers A, Ford DG "Practical compensation of all significant thermal errors in machine tools", 3rd Int. Congress on Precision Machining, pp109-117, 2005. (University Repository: http://eprints.hud.ac.uk/3769/ available on request).

4. Mian, Naeem S, Fletcher, Simon, Longstaff, Andrew P. and Myers, Alan (2011) Efficient thermal error prediction in a machine tool using finite element analysis. Measurement Science and Technology, 22 (8). 085107. ISSN 0957-0233. DOI: 10.1088/0957-0233/22/8/085107.(Downloaded 396 times from IOP Science http://iopscience.iop.org/0957-0233/22/8/085107)

4. Details of the impact (indicative maximum 750 words)

The predictive methods and novel techniques developed by the University of Huddersfield's research into machine tool accuracy have benefited a range of end-users in industry, both nationally and internationally, throughout the impact period.

Leading UK employers such as BAE systems and Rolls-Royce (RR), as well as major local employers such as Yorkshire-based Micro Metalsmiths, were among the first beneficiaries of PC-based compensation systems (VCS) and have continued to use increasingly advanced versions of the technology since 2008. In the case of RR VCS was initially introduced because two large vertical turning lathes, designed to manufacture jet engine casings, did not meet the accuracy specification required by the company. RR still depends heavily on CPT's compensation system to produce its fan casings to the required tolerances.

Collaboration with Siemens on developing the compensation system for industrial CNC has led to a number of high-profile installations on machine tools requiring new levels of accuracy for the Joint Strike Fighter (JSF) programme, the $1.1trn development and acquisition programme intended to replace a range of existing military aircraft used by the UK, the US and their allies. The programme validated the system and required that any manufacturers supplying parts for the JSF should use machines fitted with the VCS. Companies using VCS-equipped machines for the JFS programme include Rambaudi, Lockheed, Northrop Grumman, GKN Aerospace and Delcam. As a result of its collaboration with CPT, Siemens has produced a commercial compensation system and actively marketed it globally.

The aforementioned compensation work at Rambaudi, a machine tool builder in Italy, also resulted in CPT being invited by Renato Ottone, then director of the company, to be a partner in the SOMMACT FP7 project (2009-2012), which used and enhanced both the TempSpy and VirMach systems. SOMMACT's main aims were a 50% reduction in product dimensional errors, a 10-30% reduction in total manufacturing time and a 70% reduction in post-machining inspection for single-batch production. Alesamonti, the SOMMACT co-ordinating company, is now implementing many aspects of the project into its product range of high-accuracy facing and boring machine tools (i). A patent application has been submitted for the KinLoc six-degrees-of-freedom, high-accuracy sensor developed by CPT.

Under a TSB grant in collaboration with AsquithButler Ltd, the UK's only manufacturer of very large machine tools, the error compensation system, now known as Machine Tool Compensation system (MTC) has recently been integrated into a PowerCentre 500, 5-axis horizontal ram, moving-column machining centre (c). The volumetric error (geometric) was reduced by 90% as a result. AsquithButler is now considering installing the system on other machines within its holding company, the Kingsbury Group. AsquithButler Managing Director, Paul Hinchliffe, has remarked that the system is "extremely desirable from a sustainability aspect" (d). Since 2011 the MTC system has been part of a licensing agreement with Dapatech System Pte Ltd., whose managing director, Alexander Ponfoort, has commented that "the system will bring benefits to the global machine tool industry" (a,b).

CPT was also selected to be a fundamental contributor to Rolls-Royce's SAMULET project (Strategic Affordable Manufacturing in the UK with Leading Environmental Technology, 2011-2013). The objective was to develop a rapid calibration strategy for machine tools and reduce the average time for full 3-axis machine calibration from several days to less than one hour. This has been successfully demonstrated in CPT's CNC Laboratory and on machines in R-R facilities. CPT has been complemented on the outcome, and a further contract is now being negotiated to incorporate the process into RR workshops at Barnoldswick. In addition, further collaboration between CPT and Renishaw has produced a prototype laser capable of measuring six degrees of freedom simultaneously. This system is currently being Beta-tested in advance of commercial release (f).

The thermal compensation research was key to CPT becoming a participant in the FP7 project ADAMOD (2009-2011). The project needed a thermal compensation system with higher levels of accuracy than achievable in any literature. The University of Huddersfield successfully completed the project by data fusion of on-machine strain measurement with temperature into the thermal compensation system. This has led to a further FP7 grant, EASE-R3, which commenced July 2013.

The use of CPT's new methodologies throughout the industry has led to a series of industrial training courses, developed and delivered in collaboration with Machine Tools Technologies Ltd and aimed primarily at maintenance engineers employed in advanced manufacturing (e). Between 2008 and 2010 four five-week courses were run for engineers from R-R, BAE and AWE. Additional shorter courses for on-site training have also been provided. The University benefits from income (approximately £15k per course for an average of six engineers) and the strengthening of links with industry. These courses also help reinforce collaboration between CPT and its industrial partners, with management and personnel who attend training often requesting further work (e.g. appraisal of machine tool purchase).

From 2011 CPT staff have helped shape policy in the area of machine tool metrology through membership of the Manufacturing Technologies Association technical committee and active involvement in BSI and ISO standards committees (MTE1-2 and ISO TC39 SC02 respectively). As chair of the BSI machine tool standards committee, Prof. Myers has an overview of all BSI and ISO standards relevant to machine tool accuracy.

5. Sources to corroborate the impact (indicative maximum of 10 references)

a. Dapatech System Pte Ltd, five-year licensing agreement for MTC.

b. Dapatech System Pte Ltd reference letter of support provided by Alex Ponfoort, Managing Director.

c. AsquithButler Ltd contract Purchase Order.

d. AsquithBulter Ltd reference letter of support provided by the Managing Director, Paul Hinchliffe.

e. Machine Tool Technologies Ltd reference letter of support provided by Peter Willoughby, the Managing Director.

f. William Lee, Director, Renishaw plc

i. Alesamonti s.r.l. reference letter of support provided by Renato Ottone, the Technical Coordinator for SOMMACT EU Framework Programme 7 project and ISO committee member.