University of Huddersfield Repository

Shagluf, Abubaker, Longstaff, Andrew P., Fletcher, Simon, Denton, Paul and Myers, Alan

The importance of assessing downtime cost related factors towards an optimised machine tool calibration schedule

Original Citation

Shagluf, Abubaker, Longstaff, Andrew P., Fletcher, Simon, Denton, Paul and Myers, Alan (2013) The importance of assessing downtime cost related factors towards an optimised machine tool calibration schedule. In: Proceedings of Computing and Engineering Annual Researchers' Conference 2013 : CEARC'13. University of Huddersfield, Huddersfield, pp. 182-187. ISBN 9781862181212

This version is available at http://eprints.hud.ac.uk/id/eprint/19385/

The University Repository is a digital collection of the research output of the University, available on Open Access. Copyright and Moral Rights for the items on this site are retained by the individual author and/or other copyright owners. Users may access full items free of charge; copies of full text items generally can be reproduced, displayed or performed and given to third parties in any format or medium for personal research or study, educational or not-for-profit purposes without prior permission or charge, provided:

- The authors, title and full bibliographic details is credited in any copy;
- A hyperlink and/or URL is included for the original metadata page; and
- The content is not changed in any way.

For more information, including our policy and submission procedure, please contact the Repository Team at: E.mailbox@hud.ac.uk.

http://eprints.hud.ac.uk/

THE IMPORTANCE OF ASSESSING DOWNTIME COST RELATED FACTORS TOWARDS AN OPTIMISED MACHINE TOOL CALIBRATION SCHEDULE

A. Shagluf. A. P. Longstaff, S. Fletcher, P. D. Denton, A. Myers
University of Huddersfield, Queensgate, Huddersfield HD1 3DH, UK

ABSTRACT

Reducing downtime and assuring a high degree of accuracy of production machines, especially machine tools, have become increasingly important as the demand for higher production rates and closer tolerance continues to grow. The growing understanding of the importance of both calibration and maintenance in the evolving industrial scenario and the technological advancements of recent years has yielded the development of advanced metrology equipment and predictive maintenance programs. Predictive maintenance and similar programmes are tools that have been designed to reduce downtime by avoiding unpredictable machine failures. These programmes have been adopted in some industries to improve operational efficiency and reduce machine breakdown. However, extensive diagnostic procedures can take machines out of service for longer periods than are acceptable for some manufacturers.

Studies in the field of predictive maintenance have resulted in cost calculations for the downtime associated with machine failure. Models have been presented to determine optimal intervals between repairs by minimising global maintenance costs. However, very little work has concentrated on optimising the frequency of machine tool calibration by assessing the downtime cost considering the contribution of both technical and commercial factors.

This paper give an introduction to causes of machine tools failures with respect to production of non-conforming parts and the importance of calibration and then it addresses the key factors to a cost function parameters that forms the basis of a strategy for scheduling machine tool calibration which takes into account these influences on part tolerance.

Keywords: Machine tools; Predictive maintenance; Calibration; cost function.

1. INTRODUCTION

This paper considers the scheduling of calibration. This open question has been widely discussed in industry with machine tool owners over the last decade. One problem in determining an optimum calibration schedule for machine tools is that methods and practices developed in a laboratory environment are not necessarily acceptable in an industrial context. In the case of a machine in a research institute or metrology company's development area, calibration can be established with a higher degree of accessibility to the machine. This is not the case for those machines in industrial companies, especially those manufacturing with high levels of output or to a high level of accuracy, such as mobile phone, submarine, aircraft, military and nuclear systems manufacturing.

Papers consider models and solution algorithms that can be used to determine schedules that optimize optimal intervals between repairs [1]. However, very little work has considered the importance of assessing downtime cost in order to optimising calibration schedules [2].

This work identifies causes of machine tool failure with respect to production of non-conforming parts, the impact of calibration and the parameters that contribute to derive a downtime cost function that can be used to optimise the frequency of calibration to reduce unnecessary downtime while maintaining the machine at the required tolerance.

2. MACHINE TOOL CAUSE OF FAILURE

Machine tools, especially those manufacturing to a high level of accuracy, are required to operate within an accepted limits of tolerance. Limits of operating conditions are designed to maintain safe operation of the machine to ensure that the machine performs and produces parts within the required specification [3]. A machine is required to produce parts at a specified rate. Failure of a machine tool can be described as the inability of the machine tool to produce parts within the specified tolerance at the desired rate. Gradual wear of machine parts may be the main cause of failure. However, machine failure modes may be for a variety of reasons like: programming errors, excessive critical speeds, inappropriate maintenance, misalignment, mechanical looseness, installation errors, excessive demand, processing and deficiencies in original machine design [4]. This paper is mainly concerned with failure to produce parts to tolerance (non-conforming parts) and downtime for calibration (reduction in production rate), but builds on research into avoiding other failure modes that impact upon production rates such as mechanical or electrical breakdowns of the machine.

2.1 IMPORTANCE OF CALIBRATION

In recent years, the importance of the calibration functions, and therefore also of calibration management, has grown. Within manufacturing there are different views and opinions about calibration. Some people believe that calibrating the machine to understand and control its performance is the best approach. On the other hand, others believe that such data gathering exercises are too time-consuming and difficult to interpret so that reacting to quality control problems is the best for their production methods, instruments and tools. This argument about calibration is not clear enough for non-specialists to make an informed decision.

According to the International Organisation For Standardization publication entitled “International Vocabulary Of Metrology - Basic And General Concepts And Associated Terms” (VIM), calibration is the set of operation that, under specified conditions, in a first step, establishes a relation between the quantity values with measurement uncertainties provided by measurement standards and corresponding indications with associated measurement uncertainties and, in a second step, uses this information to establish a relation for obtaining a measurement result from an indication [5]. The National Physical Laboratory (NPL) defined calibration as “the comparison of an instrument or artefact against a more accurate instrument (or sometimes a well-controlled reference signal or other reference condition), to discover whether it meets the manufacturer’s specification” [6]. A certificate, which shows the instrument’s readings and compares them to a reference value or values with an associated value for the uncertainty of measurement, is then produced. Calibration ensures that a machine tool performs accurately and increases its reliability. Therefore, calibration is the process to maintain accuracy assessed, traceable to internationally recognised standards. Thus, calibration is an essential activity in any measurement process, especially in engineering companies those manufacturing to a high level of accuracy.

Furthermore, machine tool failures in industrial organisations interrupt production operations and cause production loss, which has a direct cost-to-business and potentially a significant detrimental impact to future production. Predictive maintenance is one approach that has been successfully applied to mitigate the effects of unexpected failure by scheduling controlled production stoppages [7], rather than reacting to a breakdown. Predictive maintenance is a tool that has been adopted in some industries to improve operational efficiency and reduce maintenance cost [8]. As a result, monitoring equipment that provides information about the condition of manufacturing systems has evolved rapidly over recent years [2].

Calibration is a fundamental process required to maintain the quality of measuring machines [9]. It can also be applied to the production process to help control output quality and maintain the credibility of the machine tool for measurement, such as in-process probing [10]. Full machine tool calibration requires measurement of a significant number of error sources, taking up to two weeks on large machines [11]. The reason for repeatedly calibrating an instrument, machine tool or any other machine is that their performance can drift over time and usage in both their mechanical and electrical response. When considering machine tool accuracy, bedding in, wear of components and collision are some reasons for this change. At present, the prescribed interval between calibrations tends to be subjective; a fixed “annual” calibration is sometimes adopted as part of a quality paper-trail, but more likely calibration is undertaken as a reaction to change in the consistency of the machine’s output. Building a database of inspection history by measuring the machine on a regular basis with relatively non-invasive methods will make the decision of scheduling the more extensive calibration a better-informed process [2].

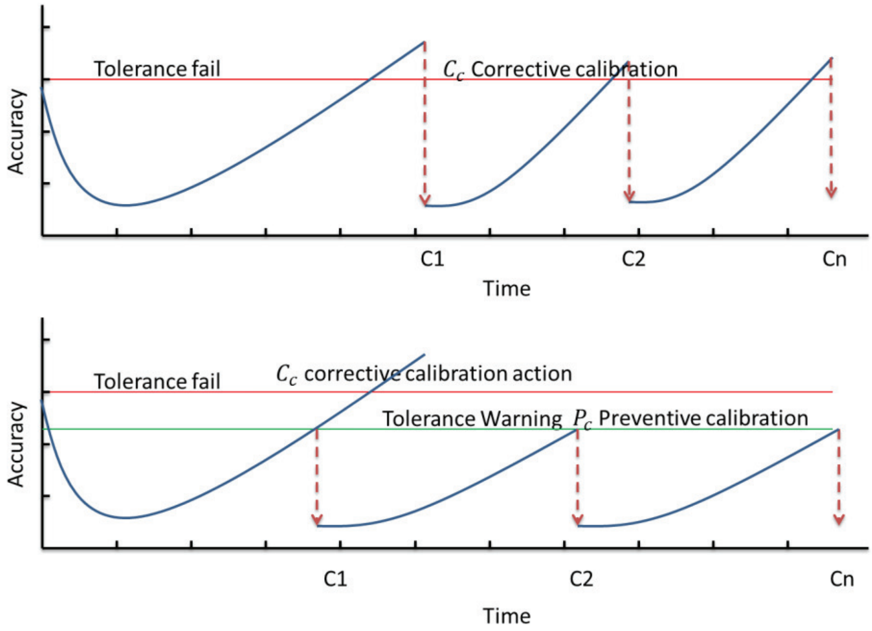

Figure 1 Illustration of degradation of machine tool accuracy and the need for calibration to maintain the required tolerance

The frequency of calibration is a compromise between the desire for a high production rate and the need to maintain quality. This situation is sometimes exacerbated when production and quality departments do not operate in tandem. This leads to a potential conflict of interests where machine tool calibration is perceived as lost production time (a reduction in short-term production rate) rather than an investment in time to allow consistent, long-term production quality and enhance the overall equipment effectiveness (OEE) [2].

2.2 THE IMPACT OF FALSE POSITIVES ON CALIBRAATION DECISIONS

There is a high probability that some calibration or maintenance intervention is based on wrong analysis of data. Analysing the results from a machine tool test requires deep thought about all the available scenarios. Experience and a theoretical knowledge are essential in order to interpret data correctly and not be misled by a single piece of data in isolation.

Condition-based maintenance (CBM) is generally concerned with detecting faults as they develop because it has the ability to identify faults early in their progression and then recommend specific maintenance activities. However, this is difficult to achieve if it were based on recommendation with false interpretation.

When looking at the reports from individual tests several observations should be made. Environment, metrology and operator skills are very important to consider for making decisions to take remedial action; the levels of uncertainty of measurement are directly influenced by these factors. A decision to take action following a false positive analysis could cause unnecessary cost.

3. INTRODUCING PREDICTIVE CALIBRATION

In some production, machine tool repairs are conducted only when the machine breaks down or otherwise ceases to meet its key performance indices (KPI’s). The strategy is more “do not fix it until it breaks” than maintenance and is known as Corrective Maintenance (CM). Although CM is an appropriate strategy in some businesses, reducing unexpected machine tool downtime and assuring quality have become increasingly important as the demand for higher volume of production and “just in time” manufacturing has increased. Consequently, the adoption of periodic maintenance has evolved.

One solution is Preventive Maintenance (PM), which replaces parts before they fail, often using a probability model. However, this technique can be wasteful since healthy parts will be discarded and downtime for replacement may not be optimised. Predictive Maintenance (PdM) or Condition Based Maintenance (CBM) is a strategy that includes feedback of the instantaneous condition of the machine and detects degradation before a fault becomes critical.

Predictive Calibration (PdC) is a new methodology proposed to be analogous with, or indeed a subset of, a PdM strategy. It is intended to be a formalised approach applied to machine tools to measure and monitor any degradation in the mechanical parts to assist with maintaining the KPI of positioning accuracy, while having the added-value of revealing other maintenance issues such as wear in ball-screws, guide-ways, impending bearing failure, etc. Although inspired by PdM, accuracy is difficult to monitor “live” with available technology so a periodic approach is required. It is therefore necessary to apply the necessary technical knowledge along with management strategies and decision making skills [12].

Establishing an optimised PdC strategy is a non-trivial task that must be rolled out as a controlled process programme, taking into account the available technology and their relative merits. PdC can be used as part of a hybrid maintenance strategy. However, the negative factors are the cost of the metrology equipment needed and the necessary skilled labour and training costs required to use them effectively. Additionally, such measurements can only be taken when the machine is not producing parts, thus the opportunity cost must be considered.

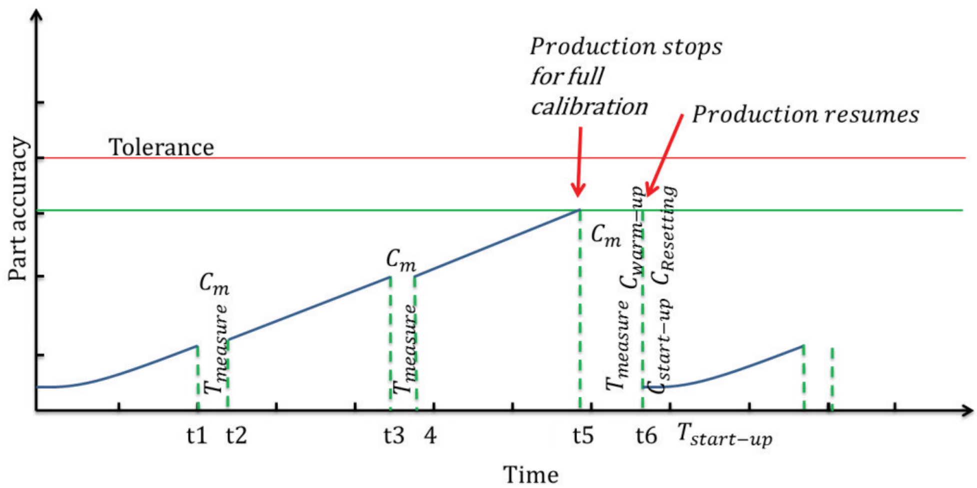

Figure 2 Predictive Calibration (PdC) methodology

4. COST OF FAILURE

The failure of machine tools is the termination of the ability of the machine tools to perform or function within specification. The machine gradually wears over time. Consequently, there will be an unpredicted drop in the quality and quantity of production. In this case, the machine tool needs to be mechanically adjusted or compensated to perform accurately again. The cost of downtime here is unpredicted.

Downtime costs are critical to estimate because they depend on production rate and commodity and even alternative production approaches. On the other hand, estimating it will benefit maintenance decision making by measuring the impact of the equipment failure on system efficiency, and also test any alternatives. Existing studies in the field of predictive maintenance have resulted in cost calculations for the downtime associated with machine breakdown [1]. It could be said that calibration and predictive maintenance are different applications, but that they can follow the same downtime cost calculation process to decide their applicability for a given asset.

The main objective of this work is to propose the key factors and parameters that could contribute to derive a mathematical model for downtime cost taking into account maintenance cost, loss of production and scrap/rework due to parts produced out of tolerance. These factors can lead to a model that can lead to better calibration decision-making on the relevance, or otherwise, of a PdC strategy and optimising the cycle of calibration process.

4.1 FACTORS BREAKDOWN

Breaking down the factors that contribute to determining the downtime cost is necessary to cover a broad range of machine tool assets, production types and scales. The more factors taken into account, the more universal the model would be.

Cost of downtime could include, Time to measure, resetting time, warm up and start up time, production time during steady state production and production time lost due to speed loss. This could be described as time not producing and/or producing scarp parts. This is shown in Figure 3 below.

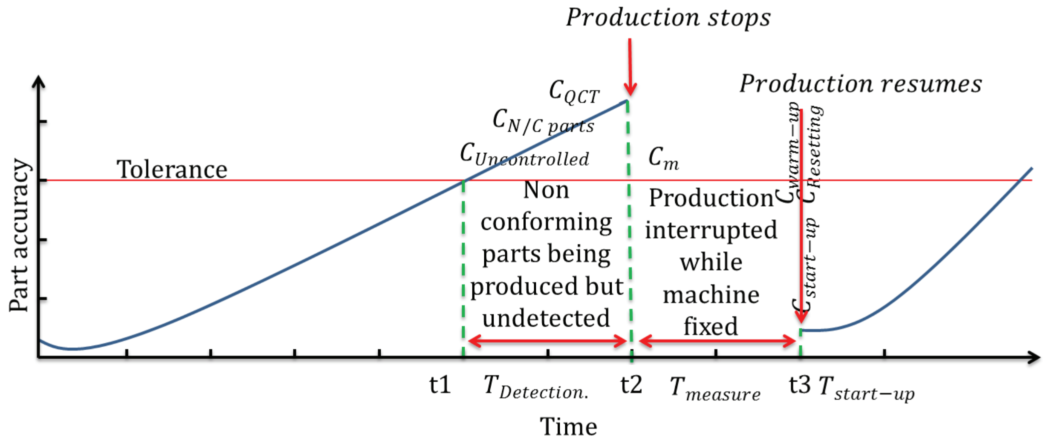

Figure 3 Machine tool run to fail scenario and the related costs

All the expected costs and their related factors illustrated in Figure 3 can be summarised in Table 1.

Event	Cost	Factors
Machine is out of service	The cost of measurement per unit time	• Time to measure • Cost of lost production during measuring and fixing the machine
	Cost of hire of service	• Hire cost of equipment • Labour cost
Production resumes	The cost due to resetting and warm up period	• Warm-up time • Resetting including all the adjustments
	The cost of start-up rejects	• Start-up rejects cost • Cost of scrap part • Cost of rework
Non-conformance parts being produced	Cost of uncontrolled production	• It includes the time spent to detect that the machine produces scrap and/or pieces that require rework due to the machine going out of accepted performing tolerance
	Quality control time consumed	• Time spent for identifying faults or trouble-shooting • Cost of material and replacement
Impact of producing rework/ scrap parts	The cost due to producing non-conforming part	• Shipping cost • Fines • Penalties

Table 1 cost function related factors and events

5. CONCLUSIONS

This paper starts with a brief introduction of machine tools cause of failures and the importance of calibration. It presents the consequences of false positives in decision making process, following this; it introduces the new concept of predictive calibration.

This paper also presents a summary of some of the key factors that can lead to derive a mathematical cost function that forms the basis of a strategy for scheduling machine tool calibration which takes into account both the commercial impact and the technical influences on part tolerance.

This work will ultimately lead to a development of an algorithm that will be a management tool that will optimise intervals of machine tool calibration actions for a given manufacturing process.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the UK’s Engineering and Physical Sciences Research Council (EPSRC) funding of the EPSRC Centre for Innovative Manufacturing in Advanced Metrology (Grant Ref: EP/I033424/1).

REFERENCES

[1] R. Pascual, et al., "On the Effect of downtime costs and budget constraint on preventive and replacement policies," Reliability Engineering and System Safety, Elsevier 22 September 2006.

[2] A. Shagluf, et al., "Towards a Downtime Cost Function to Optimise Machine Tool Calibration Schedules," in International Conference on Advanced Manufacturing Engineering and Technologies, KTH Royal Institute of Technology in Stockholm, Sweden, 2013, p. 10.

[3] A. Shagluf, et al., "Predictive Calibration-Based Tolerance Boundaries For Arresting Deterioration of Machine Tool Accuracy," in Manufacturing the Future conference 2013, Manufacturing at Cranfield University, 2013.

[4] C. K. Mechefske, "Machine Condition Monitoring and Fault Diagnostics," in Vibration an d shock Handbook, C. W. d. Silva, Ed., ed. Boca Raton: CRC press, Taylor and Francis Group, 2005, p. 35.

[5] I. O. f. Standardization, "International vocabulary of metrology-Basic and general concepts and associated terms (VIM)," J. m. organisations, Ed., 3rd edition ed: JCGM member organisations, 2008, p. 104.

[6] N. P. Laboratory. (2010). NPL-Beginners-Guide-to-Measurement. Available: ISSN: 1368-6550

[7] Y.-S. Shum and D.-C. Gong, "Development Of A Preventive Maintenance Analytic Model," in Fifth Asia Pacific Industrial and Management Systems Conference, Gold Coast Australia, 2004, pp. 38.5.1-38.5.12.

[8] L. Bin, et al., "Predictive maintenance techniques," IEEE Industry Applications Magazine, vol. 15, pp. 52-60, 2009.

[9] Renishaw. (2007, 2011). Evolution of the Renishaw Productivity System. White Paper [White Paper]. 1-12.

[10] R. Ahola. (2007, 03/2007) Traceable and efficient calibrations in the process industry. Calibration World. 1-17.

[11] S. Parkinson, et al., "Automatic planning for machine tool calibration: A case study," Expert Systems With Applications, vol. 39, p. 11367, 2012.

[12] F. Moe, et al., "Predictive Maintenance and Diagnostics of Machine Tools.," presented at the Virtual International Conference on Innovative Production Machines and Systems (IPROMS), Berlin, 2008.