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'In-situ' inspection technologies: Trends in degradation assessment and associated technologies

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Abstract

The advent of advanced, innovative and complex engineered systems has established new technologies that are far more superior and perform well even in harsh environments. It is well established that such next generation systems need to be maintained regularly to prevent any catastrophic failure as a result of regular wear and tear. Non-destructive and structural monitoring technologies have been supporting maintenance activities for over a century and industries still continue to rely on such technologies for effective degradation assessment. Maintenance 'in-situ' has been adopted for decades where the health of system or component needs to be inspected in its natural environment, especially those safety critical systems that need in-field inspection to determine its health. This paper presents selective case studies adopted in the area of damage assessment that qualify for both field and 'in-situ' inspection. The future directions in the applicability of traditional and advanced inspection techniques to inspect multiple materials and in the area of inaccessible area degradation assessment have also been presented as part of this study.

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1. Introduction

Manufacturing in the 21st century has seen technological transformation whereby newer concepts are being adapted not just to increase production but also improve the quality of the product. With the introduction of complex technologies, the industries especially in the aerospace, automotive and locomotive sectors are now focussing on delivering next generation systems that are far superior and intuitive when compared with the age old counterparts. Concepts such as Industry 4.0 are the new drivers that control not just productivity but head to provide those factories of the future where the product quality is the top priority and the product is sold with a confidence factor to the customer, as part of their sales strategy [1] [2]. These concepts are completely data-driven; wherein much of the development has come from the digitisation of those critical manufacturing decisions that improve productivity. The high value manufacturing theme has now been embracing shift in service strategy where the responsibility of the system has fallen back to the manufacturers leading to next generation solutions such as industrial product service systems. Further, the shift in service responsibilities has led to the development of solution based approaches that monitor the whole-life cost of the product [3]. These solutions are based on those critical service decisions that accommodate the continuous and failure free operation of the system extending the life of the product. Thus maintenance is now a key aspect where end-users request for post-sales service packages as part of the sale.

With the ever increasing use of advanced materials into complex systems; the serviceability of the component has now become challenging, particularly in determining their maintenance requirements as dis-assembly and inspection is very expensive. Technologies such as non-destructive testing

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have been gaining importance over the last decade where determining the health of the component and or a system without causing further damage is vital [4]. Techniques such as thermography, ultrasonic testing and 3D x-radiographic computed tomography are gaining importance. However, the key aspect of full automation and 'in-situ' in field inspection (where the health of the system is determined in its natural working environment), hasn't matured in high value manufacturing (HVM) sectors and is currently being investigated to achieve connected factory type concepts [2] [5]. This paper presents those concepts that are currently being developed to address the areas of 'in-situ' in field maintenance scenarios capable of monitoring areas having limited or restrictive access.

2. State-of-the-art

Manufacturing technologies have matured over the last century with tremendous progress in developing high quality and high performance products without compromising productivity. The introduction of advanced materials has helped build complex systems leading way to high value manufacturing wherein maintenance requirements are constantly being evaluated and built alongside those developments. The current drive of Industry 4.0 is being derived in the context of digitisation of various activities in traditional manufacturing thereby establishing the next phase in industrial revolution. As part of this next-gen revolution, the concepts that are aiding connected factories of the future are defined with challenges such as large data handling, use of complex analytics, the interface between operator and machine and finally the transfer of digitally developed information into a physical form [1] [2]. With all of these perspectives comes the ability to maintain these systems in field where they are continuously monitored with advanced sensors that provide not just live but also those regular safety critical information that help prevent premature system failure. These activities suggest that regular in-situ monitoring together with digital decision making advanced analytical systems would be the future. Current technologies dealing with concepts of automated and in-situ inspection with the help of robotic probes and arms could improve in-field maintenance activities by characterising the health of the system in a fast and robust manner thereby providing those repair strategy decisions completing the entire maintenance decision activities in-field saving significant inspection downtimes [6] [7] [8].

This section presents the current in-situ inspection techniques covering three industrial sectors; machine tools, materials and transport sector.

2.1. *'In-situ' activities in machine tools industry*

'In-situ' is a term that is widely used to define the location of sensors as part of the system with the capability to provide functional measurements when the system is in its natural working environment. These sensors could be both rigidly placed or placed onto flexible parts that can inspect the system regularly. The measurements made are compared with a good working part so that any deviation in terms of geometry and or performance could be related to degradation and in turn help predict any impeding failure to the system. Vacharanukul and Mekid [9] reviewed various measuring techniques in the context of machine tools where both contact and non-contact methods were identified. Their study identified various limitations caused by both contact and non-contact sensors suggesting the need for an 'in-process' non-contact system, that is light, highly accurate, inexpensive and user friendly system.

The study on the sensors for in-process inspection classified the in-situ measurement methods into (a) contact methods and (b) non-contact methods [9]. The sensors for contact measurement are usually housed with the sensing surfaces that are in direct contact with the component. A typical example is a roller calliper measuring the diameter of the roller through friction where the accuracy of measurement is low [9]. The growth of contact based sensors has led to the introduction of highly refined probes with fine contact sensors especially in the machine tools environment where the accuracy is now dependent on the type of material leading to significant improvement in measurement accuracy [10]. Due to the limitations of accuracy and increased instrumentation, non-contact in-situ measurement sensors are being preferred.

A study on early technologies showed that the measurements of work pieces was done by photodiodes and or charge coupled devices (CCD) as early as 1984 and formed part of machine vision techniques where multiple sensors were located in fixed positions to inspect the workpiece [11]. Thus Vacharanukul and Mekid [9] further classified the non-contact methods into four categories (i) optical (ii) ultrasonic (iii) pneumatic and (iv) electrical methods (Fig. 1).

The paper reviewed a range of optical methods in conjunction with the machine vision to present the trend in in-situ measurement techniques. This classification was found to be in line with studies carried out by Yandayan and Burdekin

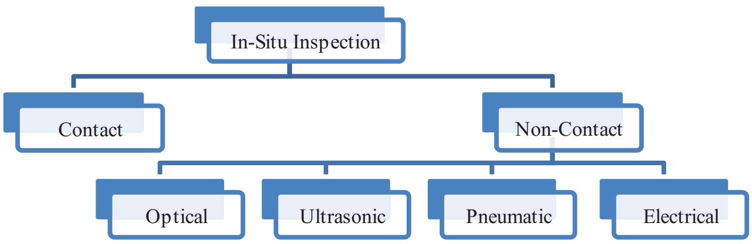

Fig. 1 Flowchart showing classification of in-situ inspection technologies in machine tools industry (based on [9])