Journal of Manufacturing Processes 15 (2013) 329–337

Contents lists available at SciVerse ScienceDirect

Journal of Manufacturing Processes

journal homepage: www.elsevier.com/locate/manpro

Technical paper

Part based process performance monitoring (PbPPM)

Ibrahim N. Tansel [a,*], Ahmet Yapici [b]

[a] Mechanical and Materials Engineering Department, Florida International University, 10555 West Flagler St., Miami, FL 33174, USA
[b] Mechanical Engineering Department, Mustafa Kemal University, 31040 Ataturk Caddesi, Hatay, Turkey

ARTICLE INFO

Article history:
Received 30 May 2012
Received in revised form 9 January 2013
Accepted 6 February 2013
Available online 11 March 2013

Keywords:
Monitoring manufacturing operations
Structural health monitoring (SHM)
Surface response to excitation (SuRE)
Lamb wave method
Metal cutting
Drilling
Composite patch
Welding

ABSTRACT

The performances of completed manufacturing processes were evaluated using the surface response to excitation (SuRE) and Lamb wave methods. Both methods used the same piezoelectric elements attached to the surface of the workpiece. The SuRE method and the Lamb wave method were used to identify the structural changes created by welding, drilling, coating, filling a slot with glue, and composite patching. This study indicates that the tested methods are feasible for part based process performance monitoring (PbPPM) which evaluates the quality of the completed process with the sensors attached to the workpiece.

1. Introduction

Inspection of a part's dimensions, integrity and added new features are highly desired in manufacturing. In the past, these inspections relied on the senses and intelligence of the machine operators. Unfortunately, automated manufacturing has not found a perfect solution to perform this task yet. Machine vision systems can inspect the features and dimensions without moving the part to a separate machine if the part is clean [1]. They have been widely used in chip assembly by electronic equipment manufacturers for many years [2,3]. The same success has not been observed in the metal cutting applications since the workpieces are covered with chips after most manufacturing operations and the camera resolution of the machine vision systems is generally not satisfactory for inspection. Coordinate measuring machines (CMM) perform the dimensional inspection accurately but require the part to be removed from the machine tool, cleaned and fixed onto their table. Even the on-machine inspection systems which use a laser beam require cleaning the part prior to inspection [4,5]. In this paper, the feasibility of the surface response to excitation (SuRE) [6,7] and Lamb wave [6,8,9] methods will be investigated for evaluation of the completed manufacturing operation. We will name the evaluation of the performance of the completed manufacturing operation using sensors attached to the workpiece "part based process performance monitoring" (PbPPM). In this paper, cutting, gluing, welding, drilling, coating and composite patching will be considered.

Since the early 1960s, the manufacturing community developed automated chatter detection [10–12] and tool condition monitoring (TCM) methods [4,13–26] to evaluate part quality indirectly during automated manufacturing. These methods worked well in laboratory conditions but have not been widely used on the shop floor [19]. False alarms, associated costs, space requirements and other limitations have discouraged manufacturers from implementing these methods.

Dynamically loaded parts quickly fail when very small defects such as cracks, corrosion, delamination and material losses reach a critical level. The changes of the dynamic characteristics of the part during the progress of these defects are very difficult to detect in the presence of noise and computational uncertainties. The structural health monitoring (SHM) community developed the impedance [27–29] and Lamb wave [8,9] methods for detection of these defects [29–31] and loose bolts at early stages [31]. Significant effort was also made for cost and space reduction. SHM methods have been successfully implemented in aerospace and civil engineering applications [7,30,32–38]. The potential of the SHM methods in manufacturing applications have not been fully studied yet. The precision of the SHM methods may not be compared with the specialized equipment such as CMMs but they

* Corresponding author. Tel.: +1 3053335180.
E-mail addresses: tanseli@fiu.edu (I.N. Tansel), yapiciahmet@gmail.com (A. Yapici).

1526-6125/$ – see front matter © 2013 The Society of Manufacturing Engineers. Published by Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.jmapro.2013.02.002

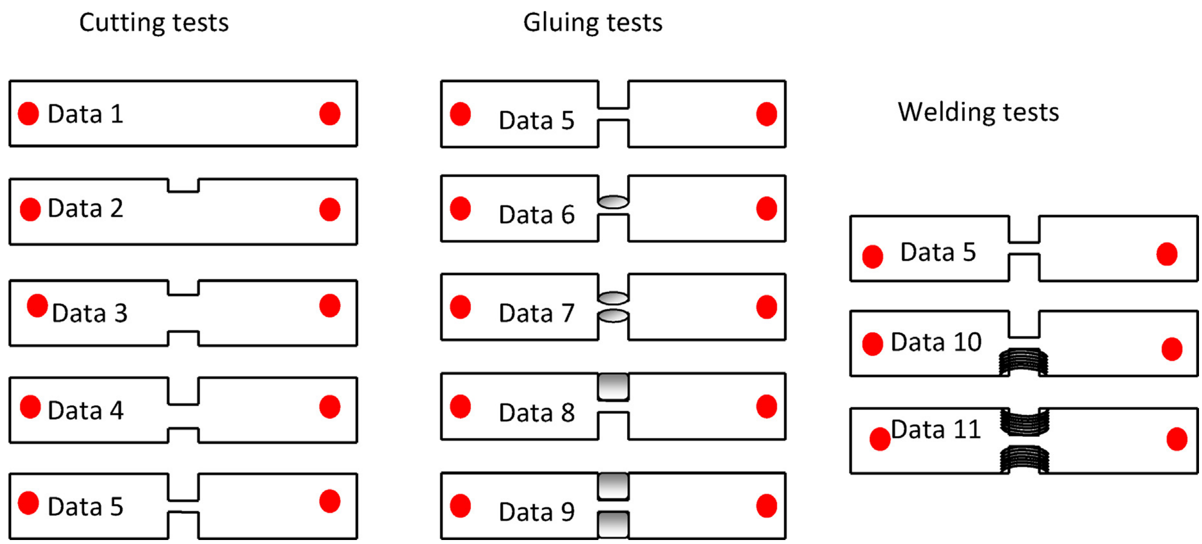

Fig. 1. The created slots slots (left column), gluing steps (center column) and welding stages (right column) at the tests. The dots are the location of the piezoelectric elements. The data #s refer to the test condition numbers presented in Table 1.

Table 1
The beam conditions when the cutting, gluing, welding and drilling was performed at the experiments. The slot depth was equal to beam thickness after the machining process. Where (c) cutting, (g) gluing, (w) welding, (h) hole.

Test condition	Length of the created slots		Length of the glue filling the slot		Length of the weld filling the slot		Hole diameter
	Upper	Lower	Upper	Lower	Upper	Lower	
1 (perfect)							
2 (c)	1 cm						
3 (c)	1 cm	1 cm					
4 (c)	1.5 cm	1 cm					
5 (c)	1.5 cm	1.5 cm					
6 (g)	1.5 cm	1.5 cm	0.5 cm				
7 (g)	1.5 cm	1.5 cm	0.5 cm	0.5 cm			
8 (g)	1.5 cm	1.5 cm	1.5 cm	0.5 cm			
9 (g)	1.5 cm	1.5 cm	1.5 cm	1.5 cm			
10 (w)	1.5 cm	1.5 cm			Full (1.5)		
11 (w)	1.5 cm	1.5 cm			Full (1.5)	Full (1.5)	
12 (h)	1.5 cm	1.5 cm			Full (1.5)	Full (1.5)	1.6 mm
13 (h)	1.5 cm	1.5 cm			Full (1.5)	Full (1.5)	7.1 mm
14(h)	1.5 cm	1.5 cm			Full (1.5)	Full (1.5)	9.5 mm
15 (h)	1.5 cm	1.5 cm			Full (1.5)	Full (1.5)	13 mm

can be used for the detection of missing features and evaluation of the integrity of the parts simultaneously just after the manufacturing process without any cleaning. The sensors may stay on the part for inspection of additional processes and/or SHM applications.

Previously, the authors' group showed the feasibility of impedance, SuRE and Lamb wave methods [6] for monitoring the tool wear. The behavior of the impedance and the SuRE methods were similar [39]. In this paper, the applicability of SuRE and Lamb wave methods will be discussed for manufacturing operations including gluing, welding, drilling, coating and composite patching. In the following sections, the theoretical background, PbPPM concept, experimental setup, results, discussion and conclusions are presented.

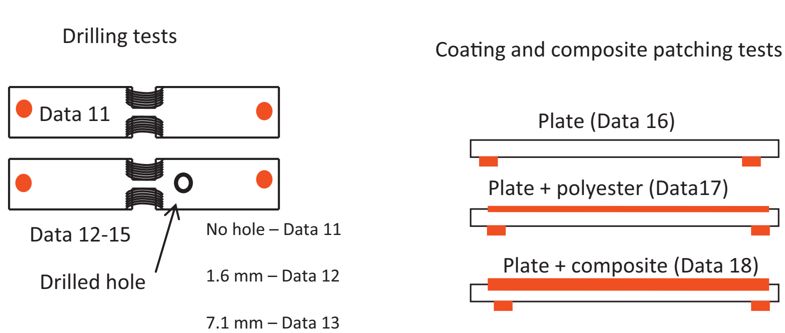

Fig. 2. The drilling (left column), coating and composite patching tests (right column).