COMSOL Multiphysics® for Simulation of Surface Response to Excitation Method for Manufacturing Process Performance Monitoring

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Introduction:
For many years structural health monitoring (SHM) techniques have been studied for improvement of reliability of engineering structures, reduction of periodical maintenance and prevention of unexpected failures. Electromechanical Impedance method (EMI) and Surface Guided Waves method are two major trends in high-frequency based structural health monitoring. Surface response to excitation method (SuRE) [1] monitors the health of structure using characteristics similar to EMI method.
In this study the implementation of surface response to excitation method via non-contact optic sensor is modeled using COMSOL. Manufacturing community has been using manufacturing process based on the data collected from work piece [2]. Methods similar to SHM techniques for tool condition monitoring (TCM). In this study part-based manufacturing process performance monitoring (PbPPM) was implemented using laser vibrometer.

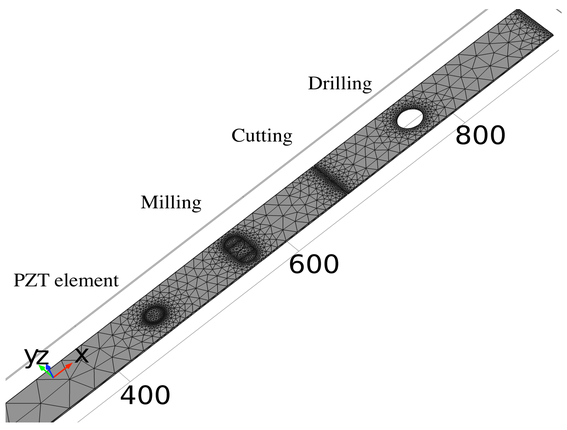

Figure 1. Meshed model with free tetrahedral elements.

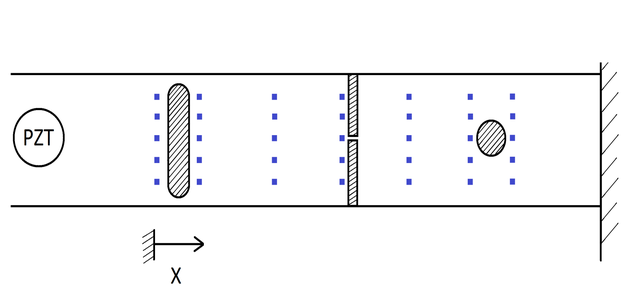

Figure 2. Schematic of aluminum beam with PZT exciter, scan probes and drilling, cutting and milling operations.

SuRE Algorithm: SuRE method creates a baseline measurement of surface response to sweep excitation in frequency domain. A SHM system based on SuRE method constantly measures these characteristics for all probe points and compares them to the values of baseline using the sum of the squared differences (SSD) index. If changes in SSDs exceed certain threshold the presence of damage to structure is speculated.

$$SD: D_{m\times n} = \left\| A_{m\times n} - R_{m\times n} \right\|^2$$

$$SSD: S_{1\times n} = \sum_{m} D_{m\times n}$$

In this study, COMSOL simulates laser vibrometer monitoring surface accelerations during various metal cutting operations through a grid of scan on an aluminum beam. The concept of SuRE method is based on the assumption of consistency of these spectrums in the absence of damages. In presence of a fatigue cracks the spectrum of probe points adjacent to crack will influenced more than the farther ones. This phenomenon is demonstrated in Figure 3 and Figure 4.

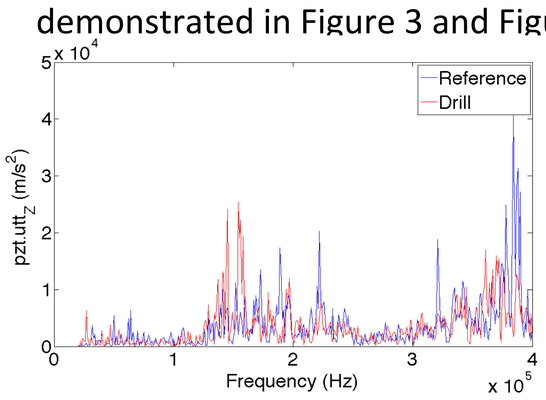

Figure 3. Spectrums of before and after the drill hole from a probe in 2nd column.

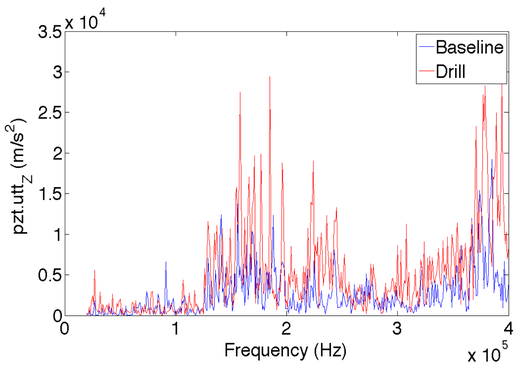

Figure 4. Spectrums of before and after the drill hole from a probe in 6th column.

Results: Since the study was a frequency domain study, the solution set includes a set of displacements for each frequency starting from 20[kHz] to 400[kHz] with 1[kHz] step. Figure 3 and Figure 4 shows the solution for displacements of the beam for the 1st frequency step, 20[kHz].
While there is significant vibrations in the vicinity of piezoelectric, no considerable local change in the oscillations close to hole has occurred for the 20[kHz]. The advantage of SuRE method is that it is not limited to a single frequency and a range of frequencies is examined.

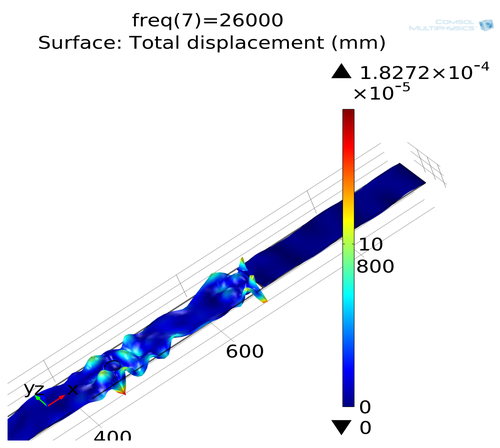

Figure 5. The cutting surface displacements solution for the 7th frequency step; 26[kHz];

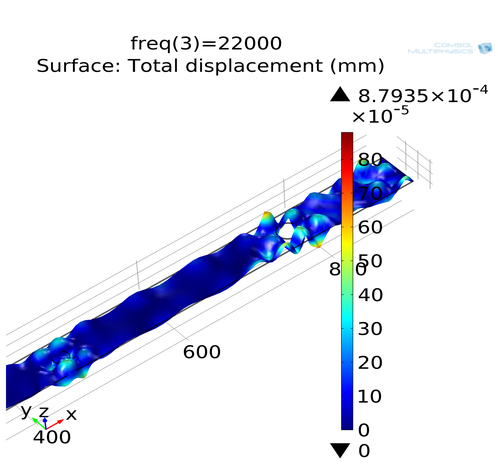

Figure 6. The drilling surface displacements solution for the 3rd frequency step; 22[kHz].

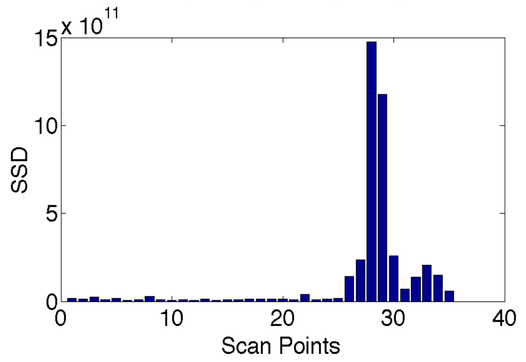

Figure 7. Bar diagram of SSD values vs. scan points for drilling.

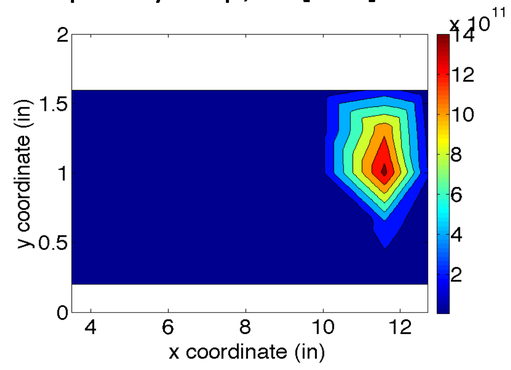

Figure 8. Color-map of SSD values vs. scan surface for drilling.

Conclusions: In this study, COMSOL was used to investigate the non-contact implementation of surface response to excitation method for monitoring manufacturing machining operations.
After each operation the maximum changes in manufacturing occurred in the vicinity of that operation. The existence, the shape and the location of the operation could be estimated with the contour maps. Also COMOL's surface displacement solution successfully revealed the difference cases of interaction of surface waves with the machining operation for each frequency.

References:
1.Inspection of the Integrity of a Multi-Bolt Robotic Arm Using a Scanning Laser Vibrometer and Implementing the Surface Response to Excitation Method (SuRE), "H. Fekrmandi, J. Rojas, J. Campbell, I. N. Tansel, B. Kaya, S. Taskin", International Journal of Prognostics and Health Management, Vol. 5 No. 1, 2014, pages 1-10.
2.Tansel, Ibrahim N., and Ahmet Yapici. "Part based process performance monitoring (PbPPM)." Journal of Manufacturing Processes 15.3 (2013): 329-337.