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Parametric optimization of ultrasonic machining process using gravitational search and fireworks algorithms

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Abstract Ultrasonic machining (USM) is a mechanical material removal process used to erode holes and cavities in hard or brittle workpieces by using shaped tools, high-frequency mechanical motion and an abrasive slurry. Unlike other non-traditional machining processes, such as laser beam and electrical discharge machining, USM process does not thermally damage the workpiece or introduce significant levels of residual stress, which is important for survival of materials in service. For having enhanced machining performance and better machined job characteristics, it is often required to determine the optimal control parameter settings of an USM process. The earlier mathematical approaches for parametric optimization of USM processes have mostly yielded near optimal or sub-optimal solutions. In this paper, two almost unexplored non-conventional optimization techniques, i.e. gravitational search algorithm (GSA) and fireworks algorithm (FWA) are applied for parametric optimization of USM processes. The optimization performance of these two algorithms is compared with that of other popular population-based algorithms, and the effects of their algorithm parameters on the derived optimal solutions and computational speed are also investigated. It is observed that FWA provides the best optimal results for the considered USM processes.

1. Introduction

Due to ever increasing use of advanced materials, such as carbides, ceramics and nimonics in aerospace, nuclear, automobile industries because of their high strength-to-weight ratio, hardness and heat resistant properties, it becomes essential to develop non-traditional machining processes that can efficiently machine those materials into intricate shapes along with improved dimensional features. Ultrasonic machining (USM) is such a non-traditional machining process

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for precision machining of hard and brittle materials, having many unique characteristics. This process is non-thermal, non-chemical, non-electrical and creates no change in the metallurgical, chemical or physical properties of the workpiece material. This process is characterized by low material removal rate (MRR) and almost no surface damage to the work material machined. It can be used for machining both electrically conductive and non-conductive materials preferably with low ductility and high hardness into complex shapes with good accuracy and reasonable surface finish. The process is particularly suitable to machine holes with a curved axis of any shape on the workpiece material.

In USM process, low-frequency electrical energy is first converted to a high-frequency electrical signal, which is then fed to a transducer. The transducer transforms the high-frequency electrical energy into mechanical vibrations, which are then transmitted through an energy-focusing device (horn/tool assembly). This causes the tool to vibrate along its longitudinal axis at high frequency (usually $\geqslant$20 kHz). For efficient material removal, the tool and tool holder are so designed considering their mass and shape that resonance can be achieved within the frequency range capability of the machine. A controlled static load is applied to the tool and abrasive slurry (composing of a mixture of abrasive materials, such as silicon carbide, boron carbide, alumina, etc. suspended in oil or water) is pumped around the cutting zone. The vibration of the tool causes the abrasive particles, held in slurry between the tool and the workpiece, to impact the workpiece surface causing material removal by micro-chipping. The schematic diagram of a typical USM setup is shown in Fig. 1. An excellent overview on the mechanism of USM process is available in [1–3].

As the USM process is characterized by low MRR, it is therefore extremely important to adopt proper steps so as to improve its rate of metal removal without affecting the surface finish of the workpiece. This can only be achieved through optimal selection of various machining parameters influencing MRR and surface roughness (SR) in USM process. A comprehensive qualitative and quantitative study on the material removal mechanism and subsequent development of relevant analytical models for MRR and SR is therefore necessary to achieve the optimal machining performance of USM process. Several attempts have already been made to investigate the influence of different process parameters on the two most important performance measures of USM process, i.e. MRR and SR.

2. Literature review

Singh and Khamba [4] deduced the relationship between MRR and other controllable machining parameters, i.e. power rating, tool type, slurry concentration, slurry type, slurry temperature and slurry size by using Taguchi technique for an USM process. Dvivedi and Kumar [5] studied the effects of workpiece material, grit size, slurry concentration, power rating and tool material on SR of an USM process. Taguchi method was applied to obtain the optimal parametric setting for that process. Jain et al. [6] optimized an USM process using genetic algorithm (GA), giving details of formulation of the optimization model, solution methodology used and optimization result. Singh and Khamba [7] selected tool material, power rating, slurry type, slurry temperature, slurry concentration and slurry grit size as the input parameters, and SR as the single response for an USM process. The outcome of a Taguchi method-based model was adopted for developing a mathematical formulation of SR using Buckingham's π-theorem. Jadoun et al. [8] applied Taguchi method for identifying the optimal settings for workpiece material, tool material, grit size of the abrasive, power rating and slurry concentration of an USM process. The effects of those process parameters on oversize, out-of-roundness and conicity were also studied.

Kumar and Khamba [9] determined the optimal combination of various input factors, such as type of abrasive slurry, their size and concentration, nature of tool material and power rating of an USM process applying Taguchi's multi-objective optimization technique. Kumar and Khamba [10] determined

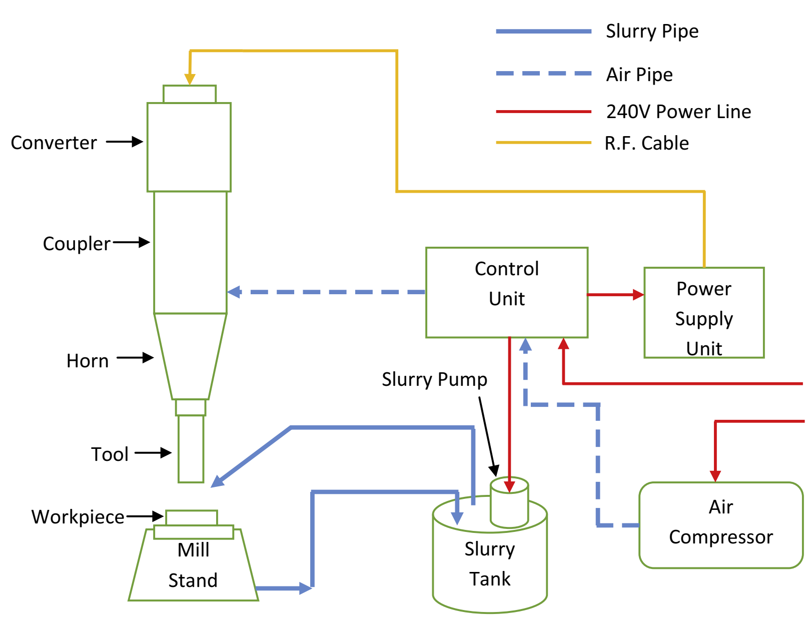

Figure 1 Schematic diagram of a typical USM setup.