Power consumption optimization strategy in micro ball-end milling of D2 steel via TLBO coupled with 3D FEM simulation

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Power consumption optimization strategy in micro ball-end milling of D2 steel via TLBO coupled with 3D FEM simulation

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Abstract

The present challenge in the manufacturing industry is to improve efficiency of production activities while reducing wastage of power consumption. Past research focused on multi response optimization of process parameters to improve performance of the process. The present study proposed an optimization-based strategy to reduce power consumption in micro ball end milling of D2 steel. As the power consumption is directly proportional to cutting forces, the process parameters such as cutting speed, feed and depth of cut were optimized to reduce cutting forces using teaching learning based optimization (TLBO) technique coupled with 3D finite element method (FEM) simulation. During the optimization, amplitude of cutter vibration and surface roughness were taken as constraints as 60µm (ISO 10816) and 2 µm (ISO 1302) respectively. Three best combinations of cutting speed, feed and depth of cut were obtained for minimum cutting force. Among them, combination of cutting speed of 15m/min, feed of 112.5 µm/tooth and depth of cut of 85.25 µm has low power consumption of 67W with tool vibration of 36.5 µm. However, remaining two combinations were also considered to be the next best optimal cutting conditions. Numerical simulation was carried out for the three best solutions and the cutting forces and amplitude of cutter vibration were predicted. There was good agreement between simulation results and experimental results that verified the acceptance of the simulation. It was also found that the three best candidate solutions were having same the cutting speed of 15m/min (minimum cutting speed). Hence, the induced stresses in the work piece were found to be with low values around 350Mpa.

Keywords: Power consumption, Ball end milling, Simulation, Optimization, TLBO, Tool vibration

1. Introduction

In the modern manufacturing system, all the production activities such as machining operations, material handling, tool change, assembly, storage and retrieval system and other activities are automated and they consume excess energy. Developing countries like India and China etc. keep the manufacturing sector as heart of the growth model, because the manufacturing sector has near about 25% share in the country total GDP. Based on the Energy statistics 2017, it was observed that the consumption of energy in the manufacturing sector was doubled since 2010. Production cost and emissions like Co, $C0_2$ and NO_X etc. are directly connected to power consumption in manufacturing [1-3]. At present, the core imperative of energy policy is to reduce the power consumption in manufacturing to reduce production cost and emissions. Hence, the researchers are concentrating on optimum utilization of power consumption and they have adopted different methodologies for optimization of process parameters.

Ball end milling is mainly used to meet demand in production of micro-feature-based miniaturized parts like biomedical devices, automotive industries, aerospace industry, and dies for forging and casting. Ball end mill cutters have additional advantage that they have ability to machine complex shapes with good surface quality [4]. But, there are fundamental challenges with the ball end mill cutters with respect to surface roughness, tool life, cutting forces and overall efficiency of the process [5 and 6]. In high speed ball end milling, cutting force is one of the important machining characteristics that has great influence on the other characteristics such as tool vibration, tool failure, machinability etc [7]. Effect of cutter rational speed, feed per tooth, radial depth of cut and