

ABSTRACT

Machining processes are key manufacturing activities which convert raw materials into finished products by consuming energy and other natural resources. Machining activities are responsible for one third of the global energy consumption and environmental emissions. The energy efficiency of CNC machine tools is less; therefore, there is high potential for reduction of energy consumption and environmental emissions. However, the machining energy analysis of modern CNC machine tools is a challenge for the researchers due to their complex structure and large number of energy consuming components.

This thesis aims to analyze the energy consumption and carbon emissions during milling process. It provides a systematic literature review on the energy consumption of machining processes. The machining energy characteristics are reviewed to address the four key research areas of machining: (i) energy classification (ii) energy modelling (iii) energy saving strategies, and (iv) energy efficiency evaluation. The energy consumption and carbon emissions during cutting (variable) and non-cutting (fixed) operational states are experimentally modelled and quantified; reduction techniques are also provided. A user-friendly, cost effective, and non-intrusive smart metering approach is developed for machining energy monitoring and quantification using a combination of load disaggregation algorithms (feature extraction, k-nearest neighbor, principal component analysis, and median absolute deviation).

Fixed and variable machining energy is analysed. A pragmatic multi-objective optimization model is provided for the reduction of variable energy consumption and carbon emissions while achieving the required surface finish. Therblig based micro analysis approach is used to analyze the fixed energy consumption. The proposed approach provides a clear visualization of the energy and carbon hotspots, which can be used by the practitioners in improving the process planning for higher energy, time, and carbon

efficiencies. The energy and carbon emissions of each activity provide better transparency of energy flow and carbon emissions information throughout the machining process.

The analysis of machining process is extended to cover the three dimensions of sustainability and a sustainability assessment index is proposed to quantify the economic, environmental and social performance of milling process. Fourteen performance indicators are identified from the literature to evaluate the sustainability performance of milling process. The indicators are either calculated empirically or determined experimentally; and the indicator weights are computed using analytical hierarchy process (AHP).

The environmental impacts of the machining activity are also analysed using life cycle assessment (LCA) approach. The LCA analysis has been carried out as per ISO 14040 standard using Umberto NXT software tool and eco-invent dataset version 3.0. The life cycle assessment of milling process quantifies its environmental performance in terms of aggregate and comprehensive indices. These quantified results are useful for the machine tool designers and users to identify the high impact processes, materials and resources used during milling process and take the corrective actions to improve the environmental performance.

The study is useful for providing better insights into energy consumption and environmental impacts of the machining processes and developing potential energy and carbon emissions reduction strategies to make machining processes greener.