CHAPTER 8

ENERGY-CONSCIOUS MILLING CUTTING PATHS TOWARDS SUSTAINABLE MACHINING

Abdul Rahman Hemdi, Umi Fatihah Mad Ali,
Azwan Rizal Ghazali, and Nor Hasrul Akhmal Ngadiman

8.1 INTRODUCTION

Energy consumption in the manufacturing industry is among the highest, particularly during production. 90 percent (%) of the electricity in industrial sector is mainly used for manufacturing processes such as machining, casting, and forging. The industrial sector in Malaysia consumed 33% of energy in 2015, which is the second-highest consumption after the transportation sector (Energy Commission, 2017).

Instead of using hydropower plants, Malaysia uses coal and diesel to produce its energy. Increased energy demand necessitates burning more coal and diesel, which releases harmful gases like carbon monoxide (CO) into the environment. To achieve sustainable manufacturing, the production and manufacturing activities must operate at an optimal energy level and high energy efficiency. Reducing energy demand and resource use in manufacturing or other sectors benefits the environment (Dambhare et al., 2015; Kopac & Pusavec, 2009).

Additionally, a life cycle assessment (LCA) study on machine tools revealed that the highest energy consumption occurs during the raw material extraction and usage stages (Goindi & Sarkar, 2017). Approximately 50% of all energy is consumed in the industrial sector, with manufacturing accounting for the largest share (Ma et al., 2014). Numerous studies have employed the LCA approach to analyse energy consumption. For example, Jiang et al. (2019) introduced an energy-based life-cycle assessment (EM-LCA) tool to measure sustainable manufacturing. The EM-LCA method was used to compare the sustainability of laser-engineered net shaping (LENS) and computer numerical control (CNC) machining in gear manufacturing. The results indicate that the LENS process demonstrates greater sustainability than CNC machining. Based on the EM-LCA findings, several countermeasures to improve sustainability were proposed.

Moreover, numerous studies have also focused on energy behaviour during the manufacturing process. Yun et al. (2019) compared the energy consumption of the high-temperature oxidation method and hybrid laser-waterjet technology in cemented carbide tools' scrap coating removal process. Using a multi-objective optimisation model, they found that the hybrid laser-waterjet technology consumed less energy than the high-temperature oxidation method.

In addition, Ben Jdidia et al. (2019) posited that machining efficiency is determined by the valuation of electrical energy demanded during the machining process. They investigated the influence of the dynamic performance of the machining system by measuring the cutting force dynamic response on the axis feed power prediction. They also introduced the model of emotional cutting power to predict machining energy.

The variation setting of the machining parameter also influences the energy usage. This is by research by Nasir and Cool (2019) on the influence of depth of cut, feed rate, rotational cutting speed, and chip thickness on the waviness and energy consumption during the wood cutting process. They observed that feed speed increases the waviness and cutting power while increasing rotational missing speed results in less waviness and increased cutting power. The study concluded that there is a trade-off between power consumption, quality and productivity, as energy efficiency can be achieved by lowering the cutting speed. On the other hand, increasing the cutting speed improves the cutting waviness.

Besides, Cui et al. (2019) relates the cutting force and specific cutting energy (SCE) to the material removal rate (MRR) during machining. The theoretical and experimental explorations have been conducted, and it was concluded that the large volume of MRR reduces the SCE value. In addition, the model for SCE, which can be used to identify the optimal setting for high sustainability, has been established.

The main concern of a manufacturer is the trade-off between lowering energy consumption and maintaining product quality, and these two goals appear to be at odds with one another. Camposeco-Negrete and de Dios Calderón-Nájera (2018) directed the trial study to enhance cutting boundaries in turning AISI 1045 steel. Their objectives were to lower the total specific energy consumed by the CNC machine tool while improving the surface roughness of the workpiece. response surface methodology (RSM) produces a regression interaction model between the machining parameter, electrical energy consumption, and surface quality. According to the study's findings, it is possible to maintain production and product quality while using a sustainable machining process.

Reduction of energy during machining involves many criteria that need to be considered, such as cutting parameters (feed, speed, depth of cut, etc.), cutting strategies, work material, tool material, and others. The cutting parameters, namely depth of cut, feed rate and spindle speed, may influence energy usage by optimising the parameters, consequently reducing energy consumption (Moradnazhad & Unver, 2016; Zhao et al., 2016; Zhong et al., 2016). When aluminium is face-processed using CNC processing, the feed rate is considered the most compelling factor in the utilisation of machining energy (Hemdi et al., 2020). Zhou et al. (2016) mentioned that energy utilisation for machine tools varies on part and tool features, process features, and machine tools' features. He concluded that the relationship between MRR and energy is non-linear