Abstract

Environmental sustainability is now a goal not only for the nations but also for industries and local communities worldwide. Diverse roots and implementations of sustainability have emerged due to both regulatory considerations and adoption of new development paradigms by policy makers. The changes and trends towards the goal of sustainability are now clearly visible in the field of manufacturing too. Manufacturing is often seen as economy-oriented activity and in many cases attaining functional requirements through manufacturing processes often overlooks the environmental dimension of sustainability. A tradeoff between the economic and the environmental dimensions can be achieved only through intense research and adopting alternate paradigms of manufacturing. When it comes to sustainable manufacturing, conservation of energy has been one of the key areas of focus. The present research work is concerned with the development of new strategies to reduce energy consumption in machining.

Machining is an indispensable manufacturing process which is energy intensive. The need to increase productivity and reliability of machining has led to the development of high-performance machines that are often characterized by high energy demands. Modeling and optimization of energy consumption in machining not only helps in reducing environmental impact but also in reducing the cost and improving productivity. Minimizing energy consumption in machining has been an active area of research during the last two decades, and there have been two approaches to address this issue. One approach is to use more eco-friendly energy sources while the other one being, reducing energy consumption in machining processes by process planning. The second approach has an additional advantage of cost savings and is the subject of present research.
Considering milling as a case, the thesis addresses four aspects of research pertaining to energy efficient machining. The thesis starts with addressing the need for a generic and comprehensive energy assessment predictive model. The proposed model is complete as it incorporates all energy sources due to machine tools and machining process. Energy consumption due to machining process is estimated by modeling cutting forces accurately. The proposed model is validated by carrying out machining experiments and measuring actual energy consumption on machines.

Role of machine tool and its contributing components and subsystem to energy consumption is analyzed next. Dissection of energy consumption sources facilitates in identifying key energy contributors. Machine tool related factors such as machine tool selection, machine tool efficiency, machining direction and effect of coolant have been studied and salient results are presented. This knowledge would be extremely helpful for machine tool designers in building lean machines which consume less energy. More importantly, it helps process planners in both selecting appropriate machine tool for a given application as well as in taking essential machine tool related process planning decisions.

This newly developed and experimentally validated model is used to study various process planning issues in the third part of the thesis. Selection of tool paths and cutting parameters and their effects on energy consumption is considered in detail and significant reductions in energy consumption due to appropriate choices are presented. Both rectilinear and curvilinear paths are analyzed and superiority of curvilinear paths over rectilinear paths is demonstrated. The study has been extended by taking actual and sufficiently complex industrial parts as case studies.
Optimizing energy consumption together with other criteria in terms of machining time and cost is attempted in the last part of this thesis. Trade-offs, if any, between minimizing machining time and minimizing energy consumption is attempted from process planning perspective. It is shown that the objective of energy-efficient machining is mostly not in conflict with high-productivity machining. Overall this thesis presents multiple aspects of process planning which affect energy consumption in milling process. It has been shown that significant energy savings are possible by making the right process planning decisions and choices. The finding of the thesis would immensely help both process planners and machine tool designers.