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ENERGY AND COST CONSCIOUS PROCESS ROUTING

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ABSTRACT

This paper presents the research work involved in development of an energy and cost conscious process routing system. Proposed system is based on total energy consumed by machine tools and manufacturing cost occurred during the manufacturing.Overall system is structured in the form of six different modules including modules for machine tool selection, cutting tool selection, time and cost estimation, energy estimation, impact assessment and process routing generation. Each module is designed by acquisition of technical information from different sources including published literature, catalogues, and consultation with domain experts. Artificial intelligence (AI) technique, state space search method is used to search all possible process routes and grey relational analysis is used to fix optimised process route in terms of energy and cost.Further a case study of a horizontal machining centre is demonstrated for developing the energy estimation models. Methodology followed in the present work for deriving energy estimation models are useful for any metal cutting industry and it does not require costly instruments. The usefulness of proposed system is tested in one medium scale industry having large variety of component and batch quantity manufacturing. The proposed system is helpful in reducing energy wastage and it provides a base for implementing potential energy saving strategies for sustainable manufacturing.

Keywords: *Energy,Cost, Process Routing, Metal cutting, Sustainable Manufacturing.*

1. Introduction

The industrial sector consumes 249 quadrillion Btu energy, which is more than 50% of the produced energy and dominates the commercial, residential and transportation [1].As a result, this sector’s energy impacts on the environment are much larger as compared to other sectors. Nowadays, growing cost of energy, increasing demand of consumer goods and environment issues are resulting in development of energy minimizing techniques. Reduction in overall energy requirement of various machining processes cause substantial benefits and is helpful for companies to accomplish green manufacturing. Nearly 99% of environmental impacts are caused due to the electrical energy consumed during metal removing operations. [2].The report of European Commission’s [3] highlighted that 10 to 40% potential savings are possible in energy consumption with the available technology. At manufacturing planning stage use of alternate process or machine tool with low energy consumption is a feasible solution. Such a small decisions made during process planning affects manufacturing cost and environment performance. This paper presents a computer-aided system developed for energy and cost conscious process routing for metal cutting industries. Proposed system is capable to reduce the impact of manufactured goods by suggesting the alternate process routes with different energy and cost.

The rest of the paper is structured as follows. In Section 2 relative literature is reviewed and Section 3 demonstrates energy estimation of a horizontal machining centre. Section 4 presents a framework of energy conscious process routing consisting five different modules. Section 5 discusses the validation of system. In Section 6, paper summarizes concluding remarks with contribution and advantages of developed system.

2. Literature Review

Various researchers have contributed in sustainable manufacturing by different ways. A brief literature review in the domain of energy estimation and energy conscious process planning is discussed as under.

2.1 Energy estimation

Metal cutting machine tools needs energy for operating its auxiliary components and for actual metal cutting. Dahmus et al. [4] and Vijayraghvan et al.[5] concluded that merely 15-25% of entire energy used by machine tool is required for actual metal removal operation. Gutowski et al. [6] have highlighted that energy-consuming components of every machine tool generate a specific energy consumption profile during the machining. Herman et al. [7] identified techniques to

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recognize and distinguish energy consumption profiles of different machine tools. Various researchers [8-11] have utilized specific cutting energy and metal removal rate (MRR) for the estimation of energy consumption. Weinert et al. [12] utilized machine level energy forecast considering the energy utilization of every machine tool and manufactured goods. Thiede et al. [13] studied two options for energy estimation like machine in built continuous meters or mobile meters. Park et al. [14] used discrete event simulations (DES) method to estimate energy consumption.

2.2 Energy conscious process planning

Sheng et al. [15] constructed environmental impact model that shows score of an each planned process. Srinivasan and Sheng [16] explored feature based environmental planning at the stage of selection of cutting tool parameters (micro planning) and feature sequencing with setup planning (macro planning). Dahmus and Gutowski [4] studied break up of energy usage with system level environmental analysis of different conventional and CNC machine tools. Software named Process Planning Support System for Green Manufacturing (GMPPSS) was developed by He et al.[17].Environment conscious multi objective CAPP mathematical model developed by Jin et al. [18] computes environmental scores of each operation to be carried out on different machines. Process planning systems is developed by Newman et al. [19]for CNC machining estimates the impact of any manufacturing process based on energy consumption. Shine et al. [20] developed algorithm for a green productivity based process planning system for a machining process. Dai M. et al. [21] proposed an energy-aware mathematical model for job shops, which integrates process planning and scheduling. Developed model aids in selecting energy efficient process plans.

The above literature review reveals that very few researchers have applied combined efforts on low cost energy estimation and process routing.

3. Energy Modeling

In present work total energy utilization of a machine tool is considered in form of fixed energy and variable energy (Fig.1). Combination of descriptive and actual power measurement method is used for energy modeling. The fixed power is determined by developing energy model for each machine by actual measurement. As an example, Horizontal Machining Centre MAZAK NEXUS 6000 is selected for energy modeling. Mecho Power Meter (Model: 3510PHW) is used to measure fixed power consumed during non-cutting condition. Reading are noted keeping non-productive modes ON, such as computer, fans, motor, coolant pump, hydraulic unit, general lighting system of machine and cleaning system etc. Power consumption readings are noted at no load condition and these are tabulated in Table 1. From this power consumption data the relation between spindle speed and power consumed at spindle is established. Fixed power of horizontal machining centre is approximated with a high coefficient of correlation using equation 1.

$$y = 0.00135x + 4.20536 \qquad (1)$$

Table 1.Sample Power Readings of Horizontal Machining Centre

Spindle Speed (RPM)	Power (kw)
500	5.36
1000	5.43
1500	5.62
2000	6.54
2500	8.06
3000	8.5
3500	8.95
4000	9.5

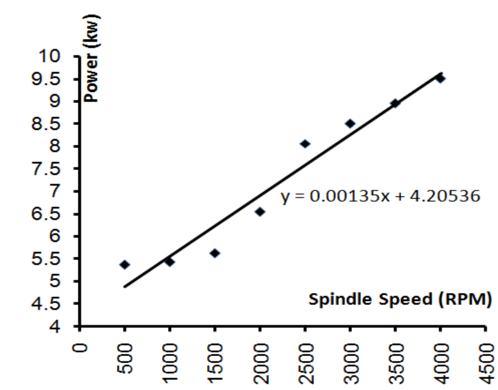

Fig. 1 Power Demand of a Machine Tool

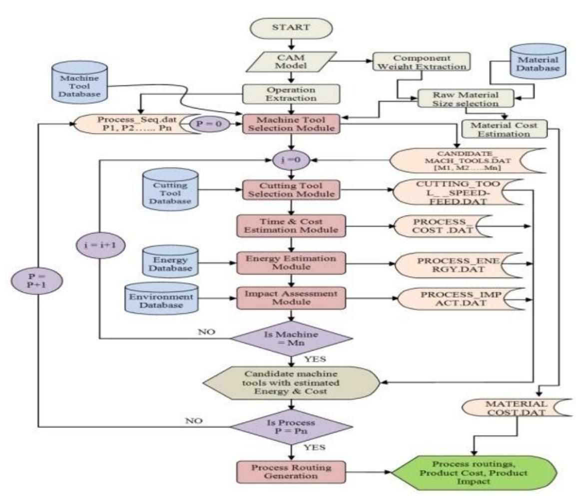

Fig. 2 Execution of Proposed System

4. Energy and Cost Conscious Process Routing

Technical information for the development of different modules is obtained from published research articles, catalogues and domain experts. The collected information is then converted in to user defined master database files and production rules (Table 2 and Fig. 3).

Table 2. A Sample of Rules used in Speed and Feed Selection

Sl. No	If	Then
1	Work material = plain Carbon steels & Hardness <=160 BHN & Depth of cut <=1 mm;	Feed = 0.3 mm/rev & Speed = 290 m/min
2	Work material = plain Carbon steels & Hardness <=160 BHN & 1 mm < Depth of cut <=3 mm;	Feed = 0.4 mm/rev & Speed = 350 m/min

	A	B	C	D
1	Material	Sub Class	Hardness	K_p
50	Alloy Steels	AISI 4023,4024,4027,402	241-260	2.18
51			261-280	2.29
52			281-300	2.38
53			301-320	2.48
54			321-340	2.62
55			341-360	2.73
56		AISI 1330,1335,1340,E52	160-180	2.16
57			181-200	2.27
58			201-220	2.38

Fig. 3 Sample of Material Master

To make the system industry specific, the user needs only to update specified information of available machine tools. Execution of the proposed system labelled as ECCPR is depicted in Fig. 2. Shop Document feature available in NX9 is used to extract manufacturing information from CAM model. After the execution of first five modules, last module prepares process routes with different energy and cost. These modules are briefly described as under.

4.1 Machine tool selection module

This system module is developed for selection of the most appropriate machine tool from the available machine tools. According to the input related to operations, selection of machine tool begins with comparison of process capability of candidate machine tool with required quality of workpiece. All the machine tools available in data base are related to achievable features on that particular machine. The module selects a machine tool on the basis of required tolerance, maximum workpiece size and maximum required cutting power. This complete matched machine tool is selected as a candidate machine for required operation. These candidate machine tools are temporarily stored in the system and are considered for next step of the system.

4.2 Cutting tool selection module

This system module is developed for selection of the most suitable cutting tool from the available data base files of cutting tools. For development of this module, technical knowledge is acquired from various sources including tooling catalogues and discussion with domain experts. While developing the module following points are mainly considered.

- ISO specification of tool holder
- insert material selection based on work-piece material hardness and production quantity
- maximum depth of cut that cutting edge or insert length will permit
- strongest shape of insert to achieve productivity

Insert grade selection is carried out on a nine squares matrix symbolizing different work piece materials and different machining conditions (Figure 4). Value of feed and nose radius affects the surface finish, which is determined here by the following formula [22]

$$Ra = \frac{f^2 \times 50}{r_e} \qquad (2)$$

Where,

$f = \text{feedrate}(^{mm}/_{rev})$ and $r_e = \text{noseradius (mm)}$

	Finish	Semi-Finish	Rough
Steel	P01-P10	P20	P30-P40
Stainless Steel	M01-M10	M20	M30-M40
Cast Iron	K01-K10	K20	K30-K40

Fig. 4 Nine Square Matrix

In example of turning operation, module displays the specification of selected turning tool giving all the details like tool holder (clamping system, approach angle, and cross section), Insert (shape, size, and nose radius) and Cutting data (speed, feed, and depth of cut).

4.3 Time estimation and cost estimation module

Activity-based costing (ABC) method is followed in the present study. Time and cost module is developed to evaluate the cost of a product on the basis of processing, handling and setup time. Material cost is calculated based on raw material suggested by system and it is added in manufacturing cost to find a product cost. Total time and cost for machining single component in batch production is given by equations [23-24].

$$T_{Tot} = T_{setup}/n + T_{Cut} + T_{Hndl} + T_{Insp} + T_{Alw} \qquad (3)$$

$$Cm = \sum_{i=1}^{n} \left(C^{i}_{pros} + C^{i}_{setup} + C^{i}_{handling} + C^{i}_{ins} + C^{i}_{o/h} \right) \qquad (4)$$

4.4 Energy estimation module

This system module is developed for estimation of total energy consumption of selected process and candidate machine tool. The total power consumed by machine tool is given by the following equation. [6]

$$P = Pf + Pv \qquad (5)$$

For estimation of fixed energy, total 52 energy modelsof different standard machine toolsare developed by authors and these are stored in database for the access.Variable power (P_v) is estimated by using in depth approach based on equation 6[25]. Many researchers have used only metal removal rate (MRR) for cutting power estimation which do not gives exact cutting power. In the proposed method work piece material, types of cutting, cutting tool condition are also considered along with the metal removal rate.

$$Pv = Kp \times C \times Q \times W \qquad (6)$$

Finally module displays total energy consumed by the each candidate machine tool. For the new machine tools other than database, user has to develop the energy consumption model by following the procedure shown in Section 3.

4.5 Module for Impact assessment

This module is designed to estimate the impact of operations carried out by the selected machine tools. Only the energy consumed by machine tool during a process is considered for impact assessment. System estimates direct and indirect emissions of green house gases (GHG) caused by energy production. Direct emission is of Co_2gas and indirect gases like Carbon Mono-oxide (CO), Sulphur di-oxide (SO_2) and Nitrogen monoxide (NO). This module is based on emission coefficients as determined by Ghodke et al.[26]. Proposed module is designed considering energy mix of India and emission coefficients of Indian coal based power plants.

4.6 Generation of process routing

This system module is developed for preparation of process routings with candidate machine tools. As the number of operations and number of candidate machine tools for every operation goes on increasing, finding the possible process routings is difficult task with simple logic. In the present work AI technique called state space search method is used to find possible paths. This technique is able to find any number of combinations with operations and machines.

Selecting the process route based on only energy or cost is not useful to industries. Hence grey relational analysis technique is used to suggest the optimum process route in terms of energy and cost. System suggests all possible process routes with the ranking and this ranking helps manufacturing organization to take decisions for sustainable manufacturing.

5. Validation of Proposed System

Developed methodology is tested in medium scale industry which has 3200 variety of work pieces and follows the batch quantity production system in the machine shop. Machine shop consists of total 52machines including CNC machining centres, turning centres, SPM and conventional machines. Based on order received and lead-time, company has to rearrange the process routes to meet the customer requirements and it is done manually irrespective of cost and energy. Implementation of the proposed system is shown with the input and out of system in Fig. 5 and Fig. 6 respectively.

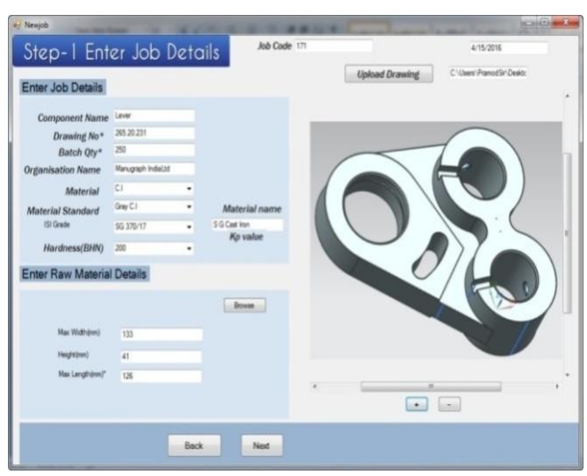

Fig. 5 Screen Shot of Part Input Window

Component Name - Lever
Drawing No.- U700A2550
Material – FG260
Job Code – 36
Product cost(Rs) – 556
Total Energy **0.76450**kWh/pc

Op. No	Machine	Operation	Cutting tool	Insert	Cutting Speed (m/min)	Speed (RPM)	Feed (mm/min)	Machining Time (min)	Process Energy (kWh)
10	TMC 1	Face Milling	Face mill- Ø 63 X 5 ASX400 (MITSUBISHI)	SOET12T308	120	540	315	1.8	0.08679
20	TMC 1	Face Milling	Face mill- Ø 63 X 4 ASX400 (MITSUBISHI)	SOET12T308	120	540	315	1.8	0.08679
30	V-655 MAZAK-M	Boring 42H7	Boring Bar A750 20CC06 90 (SECO)	CCMT0602	100	760	155	2.25	0.1221
40	V-655 MAZAK-M	Boring 30H7	Boring Bar A750 10CC06 90 (SECO)	CCMT0602	100	1060	215	2.1	0.10801
50	V-655 MAZAK-M	Boring 30H7	Boring Bar A750 10CC06 90 (SECO)	CCMT0602	100	1060	215	2.1	0.10801
60	V-655 MAZAK-M	Grooving 44.5	Circlip groove cutter Ø 30	HSS	30	320	50	2.76	0.13731
70	V-655 MAZAK-M	Slot Milling 30 Deg.	End mill Ø 11 X 4	HSS	22	560	80	1.9	0.079832
80	V-655 MAZAK-M	Slot Milling 15 Deg	End mill Ø 6 X 4	HSS	22	900	112	0.58	0.024031
90	D-34 HMT	Drilling Ø 6.75 Tapping 2 X M8 X 1.25	HSS Drill 6.75 Tap M8 X 1.25	HSS HSS	25 12	1180 475	180 594	0.25 0.35	0.00565 0.005985

Product GHG emission summary

CO_2 (gm)	CO (gm)	SO_2 (gm)	NO (gm)
756.862	3.042	6.612	1.834

Fig. 6 Process Plan Generated by the Proposed System

6. Conclusion

Combination of descriptive and actual power measurement approach used here gives better results with low cost solution. AI technique and Grey Relational Analysis used here simplified the work of finding possible process routings with optimum energy and cost. Clearly this is one of the prospective solutions to manufacturing organizations for savings in energy and cost due to optimum utilization of all resources.

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