Evaluating Trade-offs of Green Machining Strategies and Technologies

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Motivation

- The growing demand to reduce environmental impacts has encouraged manufacturers to pursue various green machining strategies and technologies such as:
  - Minimum quantity lubrication (MQL) and dry machining
  - Process time reductions
  - Downsizing
  - Design and operation for the environment, though, has a direct impact on performance (i.e. availability, quality, service life, etc.) and cost
- So, it is important for decision makers to be able to evaluate the trade-offs between the environmental, performance, and financial impact of any potential technology or strategy choice

Experimental Approach

- This study applies a data acquisition approach to a “baseline” scenario (“machining as usual”) and other alternatives that reduce processing time to determine the true costs of this green strategy
- A Haas VF-0 vertical milling machine was used for machining tests

Energy Based Environmental Assessment

- Overall power demand of machine tool measured with a Yokogawa CW-240 wattmeter in a three-phase, three-wire, three-current setup sampling at 10Hz
- Total electrical consumption estimated using:
  \[ E_{\text{total}} = \sum \left( \frac{0.1P_k}{3600} \right) \]
  where:
  - \( E_{\text{total}} \) Total electrical energy consumed (in kWh)
  - \( k \) Total number of samples
  - \( P_k \) \( k^{th} \) measured real power demand
- Real power considered since power companies charge facilities based on real power component

Load Based Performance Evaluation

- Load profile on machine represented by cutting forces sampled at 1kHz using a Kistler 9257A three-component dynamometer and dual mode amplifier with sensitivity of 200N/V
- Probabilistic approach based on Weibull Cumulative Damage Model used to estimate change in cumulative damage caused by reducing processing time:
  \[ F(t, L) = 1 - e^{\left(W(t, L) f\right)} \]
  \[ W(t, L) = \sum_{j=1}^{m} \sum_{i=1}^{a} a_i \beta_i \]
  where:
  - \( F \) Probability of failure due to cumulative damage
  - \( t \) Time
  - \( L \) Load vector
  - \( W \) Normalized cumulative damage
  - \( a \) Model parameters
  - \( \beta \) Transformation of the load value

Cost Analysis

- Assumed that machine tool creates only test piece cost for 12 hours per day and 20 days per month with 30 second setup time
- Electricity costs based on PG&E pricing schedule (as of 11/10)
- Increase in summer months due to high price during peak/partial-peak hours
- Absolute costs low because of simplicity of test piece
- Haas VF-0 also does not have much auxiliary equipment, which means that processing power is relatively large portion of overall power
- Change in damage equals change in per part cost because of indirect relationship between damage and service life (measured in terms of parts)
- Increased cutting speed generally decreases maintenance costs
- Increased chip load generally increases maintenance costs

Conclusions

- Validated approach that considers environmental, performance, and financial impacts when evaluating green machining technology
- Initial results indicate that a process time reduction strategy may not work for machines with lower levels of automation like a Haas VF-0, but could be beneficial for larger and/or more automated machine tools
- Performance evaluation should be improved to provide greater detail on the extent to which increased loads affect individual machine tool components

Future Work

- Extend current approach to consider other environmental impacts (e.g. water, industrial fluids, compressed air) and tool wear
- Enable load and energy data collection on individual machine tool components
- Develop relevant metrics to feed decision making methodology