Evaluating Trade-offs of Green Machining Strategies and Technologies

LMAS

Moneer Helu   contact email: mhelu@berkeley.edu

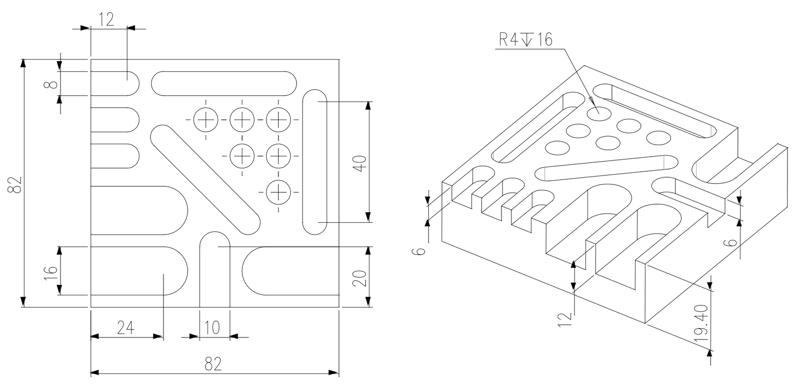
Funding Source: DTL/Mori Seiki and Industrial Affiliates of LMAS

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



Standard part made of 1018 steel used as baseline scenario (Behrendt 2010)

Baseline machining parameters:

- Cutting speed kept constant at 50m/min
- Chip load kept constant at 0.05mm/tooth except for face cut (0.1mm/tooth) and groove sets (0.05, 0.06, and 0.07mm/tooth for each subsequent groove)
- Depth of cut incrementally increased from 1mm to 2mm to 3mm for each of the three machining passes

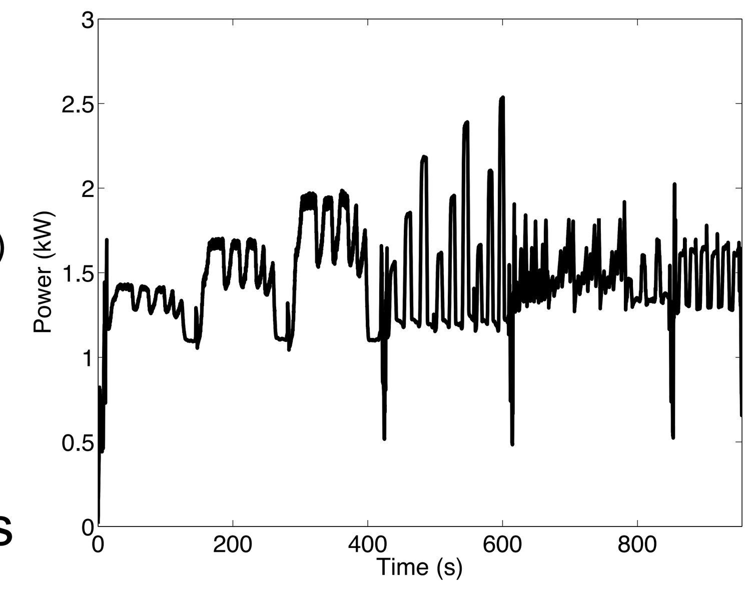
Energy Based Environmental Assessment

- 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:

$$E_{total} = \sum_{i=1}^{k} \left(\frac{0.1 P_i}{3600} \right)$$

E_{total} Total electrical energy consumed (in kWh)
k Total number of samples
P_i ith measured real power demand

- Real power considered since power companies charge facilities based on real power component



Measured power demand for the baseline scenario (a 2 second moving average is used to smooth the plot)

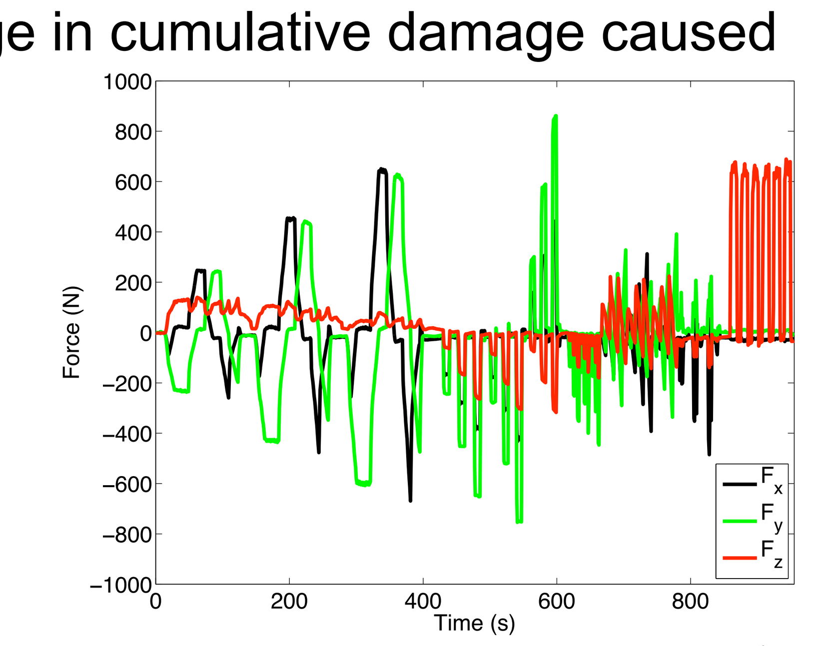
Load Based Performance Evaluation

- 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:

$$F(t,L) = 1 - e^{-(W(t,L))^{\beta}}$$

$$W(t,L) = \sum_{j} \left(e^{a_0 + \sum_i a_i X_{ij}} \cdot t_j \right)$$

F Probability of failure due to cumulative damage
t Time
L Load vector
W Normalized cumulative damage
β Shape parameter
a Model parameters
X Transformation of the load value



Measured load profile for the baseline scenario (a 5th order Butterworth filter with cutoff frequency 0.005Hz is used to smooth the plot

Environmental and Performance Impacts

	ΔE_{toal}	ΔP_{max}
Increased cutting speed scenarios		
10% increase	-26.0%	+5.6%
20% increase	-29.7%	+12.6%
Increased chip load scenarios		
20% increase	-31.0%	+7.6%
40% increase	-40.7%	+13.8%

	$\Delta Damage_x$	$\Delta Damage_y$	$\Delta Damage_z$
Increased cutting speed scenarios			
10% increase	-8.7%	-37.9%	+39.8%
20% increase	-12.5%	-39.8%	+33.2%
Increased chip load scenarios			
20% increase	+18.7%	-14.1%	+52.9%
40% increase	+31.2%	-0.2%	+113.2%

- Total electrical energy consumed during baseline scenario was 0.387kWh and maximum power recorded was 13.1kW
- As expected, reducing process time by increasing material removal rate decreased energy consumed and increased power demanded
- Cumulative damage decreased for increased cutting speed due to material softening caused by increased heat generation
  - Increase in Z-direction due to tool run-out
- Cumulative damage increased for increased chip load scenarios due to strong cutting force dependence on chip load

Cost Analysis

	Summer		Winter	
	ΔCost/Part	% Diff	ΔCost/Part	% Diff
Increased cutting speed scenarios				
10% increase	-$0.001	-0.2%	-$0.008	-16.4%
20% increase	+$0.010	+4.3%	-$0.009	-17.6%
Increased chip load scenarios				
20% increase	$0	0%	-$0.010	-19.9%
40% increase	+$0.004	+1.9%	-$0.013	-26.6%

- Assumed that machine tool creates only test piece 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

Berkeley
UNIVERSITY OF CALIFORNIA