Machining Process Optimization for RP Parts

Participants

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Project Objectives

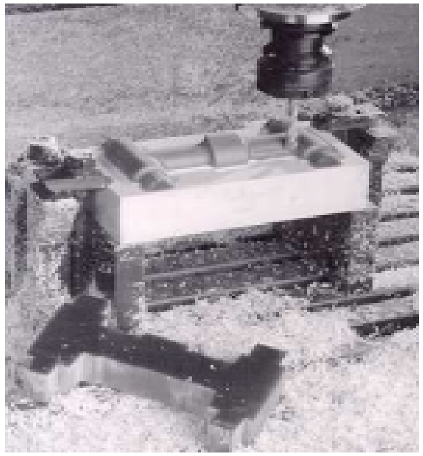
- Intricate parts manufactured by RP techniques (such as s***tereolithography)*** may not meet satisfactory surface finish and part integrity requirements for tooling and manufacturing.

- Additional machining processes may be required to improve the critical ***surface finish, tolerance and part integrity problems***, given the material and geometry of the part to be produced.

Project Objectives

- The research addresses this issue by investigating the capabilities of machining processes to ***optimize the quality and productivity*** of RP parts, mainly for injection molding processes.

- The objective is to develop an analytical ***process model***. The model should accurately predict the outcome of various manufacturing operations and the resulting part quality characterized by different process parameters.



Project Objectives

- This model will provide an insight of how a change in a process parameter will effect the end product. For any given task, it will be possible to identify the ***best possible set of operating conditions***.

- The ***sensitivity*** of part quality due to the varying operation conditions will be better understood. The model will serve as a guideline to optimize a specific end/face milling operation for ***best product quality***.

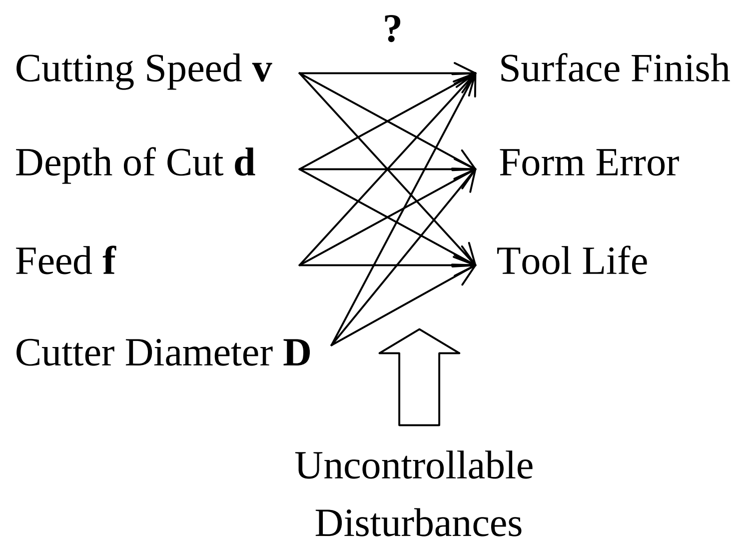
Research Activities

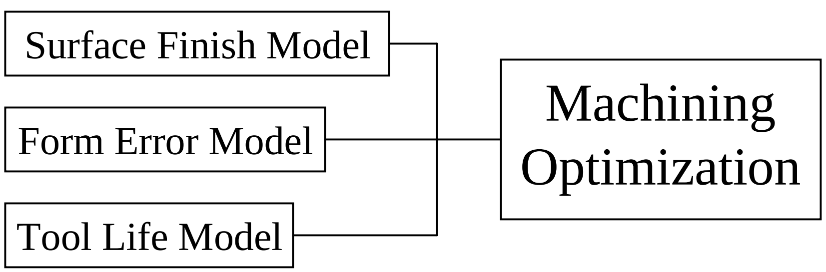
Last Semester:

- Background research on machining parameters (***cutting speed***, ***feed*** and ***depth of cut*** in particular) and their effect on critical part characteristics, such as ***surface finish***, ***form error*** and ***tolerances***.

- Investigation of the additional influence of these parameters on machining ***productivity*** and ***tool life***.

- Generation of ***mathematical models*** to be utilized in the optimization analysis that relate the controllable manufacturing factors to the investigated outcomes.



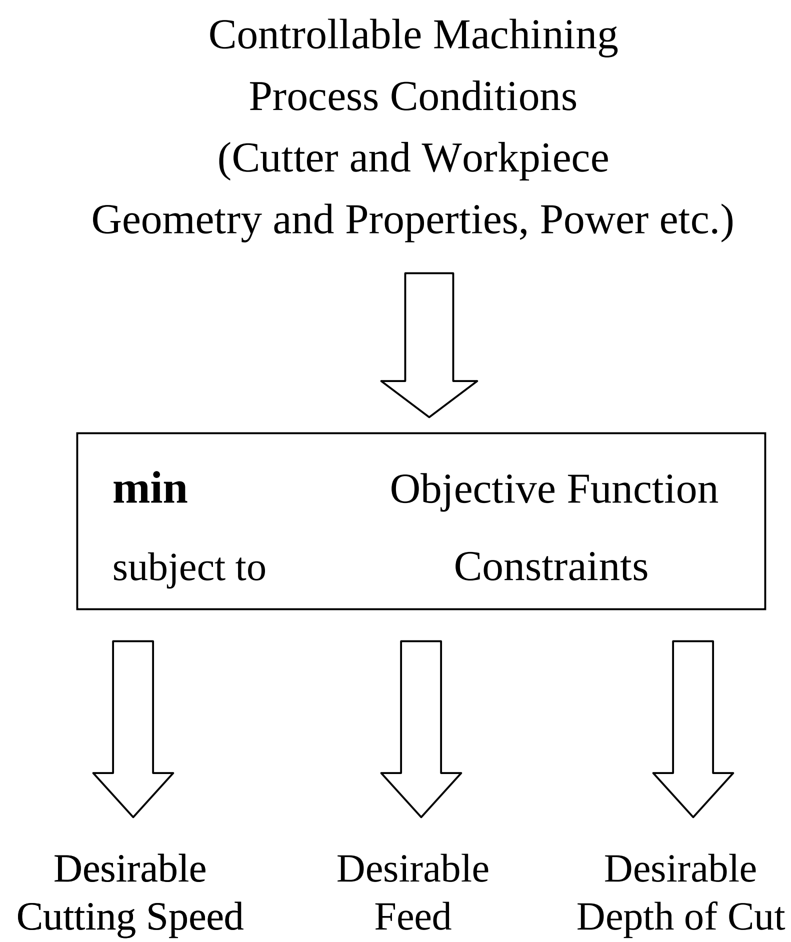


Research Activities

Last Semester:

- Feasibility study to select the appropriate optimization technique. Eventually, a ***computer aided analytical optimization*** method was chosen as opposed to experimental routines, such as genetic algorithms or neural networks.

- Lastly, an ***optimization program*** was developed that predicts the necessary cutting speed, feed and depth of cut of an end milling operation in order to obtain the best achievable outcome for the manufacturing characteristics that are of interest.



Research Approach

- Objective Function:
  - Floor and Wall Surface Roughness (**A/B**)
  - Form Error (due to deflection of end mill) (**C**)
  - Tool Life (**D**)
  - Production Time (**E**)

$$\min\left\{\begin{array}{l}\omega_1\cdot\left(\frac{(A_{max}-A)}{(A_{max}-A_{min})}\right)+\omega_2\cdot\left(\frac{(B_{max}-B)}{(B_{max}-B_{min})}\right)+\omega_3\cdot\left(\frac{(C_{max}-C)}{(C_{max}-C_{min})}\right)\\-\omega_4\cdot\left(\frac{(D_{max}-D)}{(D_{max}-D_{min})}\right)+\omega_5\cdot\left(\frac{(E_{max}-E)}{(E_{max}-E_{min})}\right)\end{array}\right\}$$

- Constraints and Boundaries:
  - Cutting Speed / Spindle RPM
  - Feed per Tooth
  - Depth of Cut
  - Machine Tool Power

subject to :

$$v_{min} \leq v \leq v_{max}$$

$$f_{min} \leq f \leq f_{max}$$

$$D_{min} \leq D \leq D_{max}$$

$$v \cdot f \cdot d \leq \frac{P_{max}}{p_s}$$

Research Approach

- <u>Procedure:</u>

  Concavity angle **K** and number of flutes of cutter N_t

  Modulus of elasticity of cutter material E

  Effective overhang of cutter ℓ_0

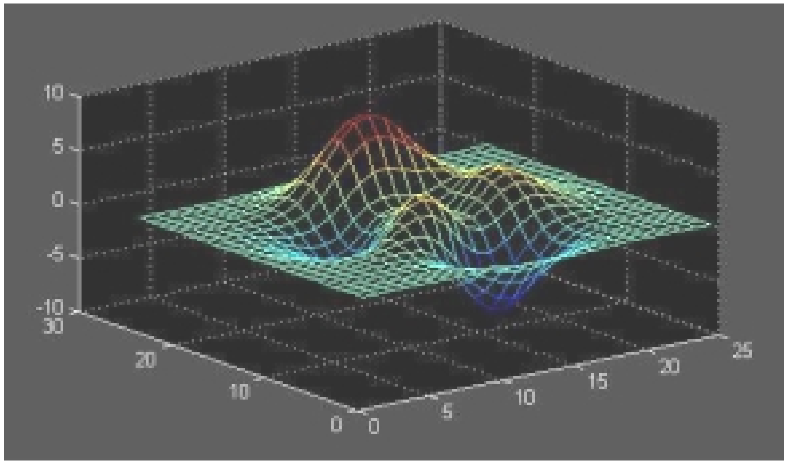
  Specific cutting energy of work material p_s

  Taylor's tool life constant C

  Maximum available machine power P

min Obj.Ft. ⇒ **v** **f** **d**

- The program employs a ***Sequential Quadratic Programming (SQP)*** line search method to solve the ***constrained nonlinear multivariable optimization*** problem.



Current Activities

- Characteristic material properties of the RP parts (***RenShape material*** in particular) are necessary as inputs to the program in order to expect any realistic results.

- Therefore, several machining operations need to be carried out to determine relevant properties, such as ***the specific cutting energy*** of the RenShape material and its effect on tool life (~***Taylor's tool life constant***)

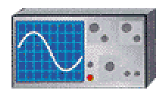
Current Activities

- <u>Experimental Plan (Specific Cutting Energy):</u>

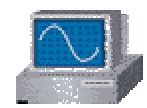
Slot Milling
RenShape Blocks
with **Fadal VMC 15**

Load Controls
UPC Powermeter

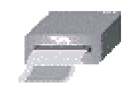
Oscilloscope



Multichannel charge amplifier



Personal Computer



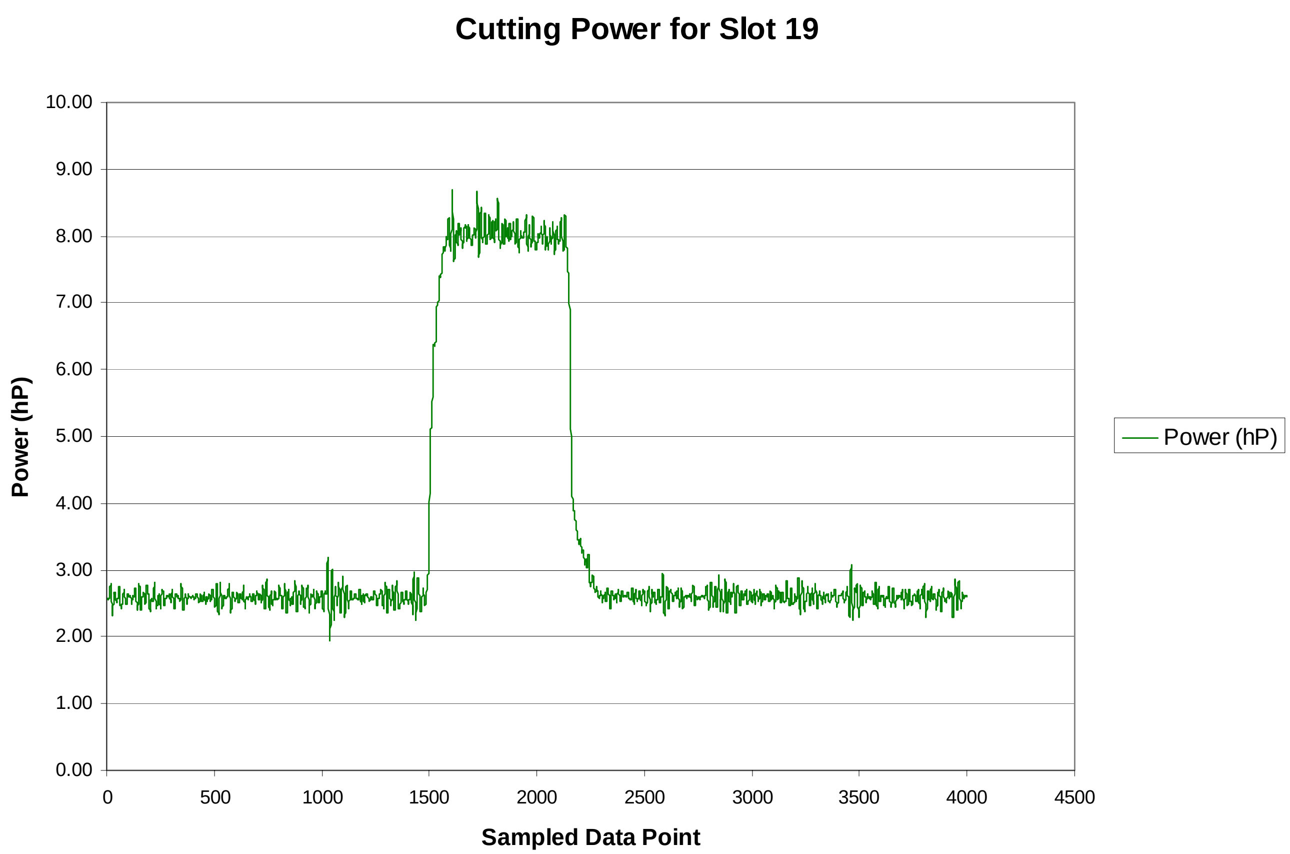
Printer/ Plotter

$$p_s = \frac{P}{MRR} = \frac{F_p \cdot v}{v \cdot f \cdot d}$$

	Spindle Speed N (RPM)	Feed rate f (ipm)	Depth of Cut (in)
Minimum Value	5600	24	0.2
Medium Value	6500	48	0.4
Maximum Value	7500	72	0.6

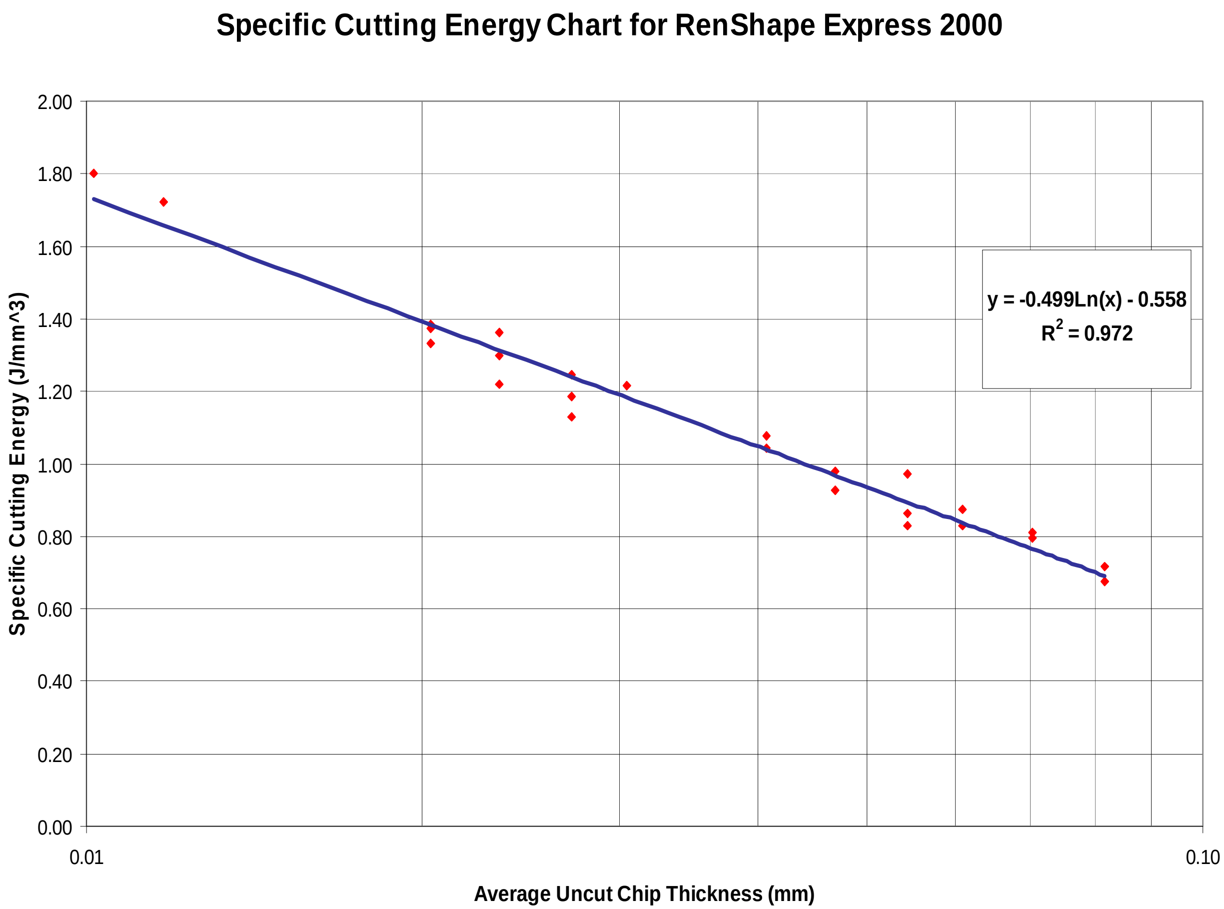
Current Activities

- A typical Power Consumption Chart for Slot Milling):



Current Activities

- Specific Cutting Energy vs. Average Uncut Chip Thickness:

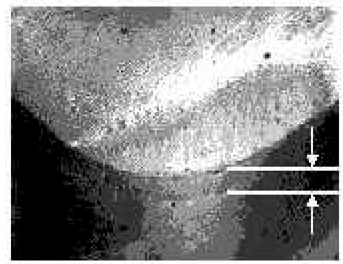


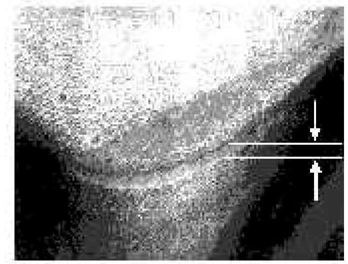
Current Activities

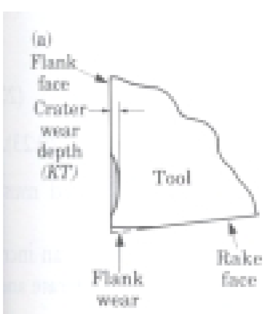
① <u>Experimental Plan (Taylor's Tool Life Constant):</u>

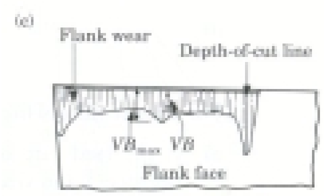
Milling on
Bridgeport Torq-Cut

Zygo Interferometer
Microscope

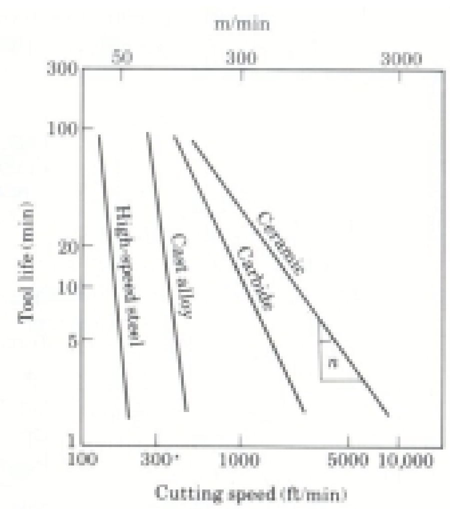








Flank wearland
measurements



Appropriate
Tool-life
curves

Future Plans / Summary

- The developed optimization algorithm is running properly without any complications. However, experimental results are necessary to verify the effectiveness and accuracy of the program.

- Using theoretical input values to the program, it has been observed that the overall objective function is relatively more sensitive to the ***feed*** of the machining operation. Similarly, it appears that the ***depth of cut*** and ***cutting velocity*** are relatively less responsive to given starting estimates for the program.

ω_1	ω_2	ω_3	ω_4	ω_5
1	3	5	7	9
0	2	0	2	0
2	0	5	0	10
10	1	2	0	100

d (mm)	**v** (mm/s)	**F** (mm/tooth)
9.909	500.35	0.05
9.999	500.00	0.05
10.000	500.37	0.05
9.228	500.33	0.05

d_0: 10 mm v_0: 500 mm/s f_0: 3 mm/tooth

Future Plans / Summary

- The results depend on the weights assigned for each constituent in the objective function and they will be compared in the future with the best possible set of experimentally obtained conditions.
- Several modifications and improvements may need to be made to the optimization algorithm so that it estimates true machining conditions more accurately. In that case, more complex mathematical models can be incorporated to the optimization scheme to meet the goals set for the process model.