ENGR 58 Final Project:
Thread-Cutting Dynamics Modeling in Simulink

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ENGR 58, 2011
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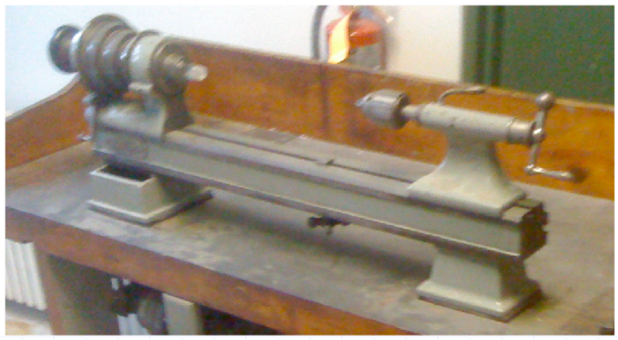
Introduction

- Project Outline
- Modeling
- Results
- Conclusion

Project Outline

- Goal: Create a Simulink model of a lathe performing a screw-cutting operation
  - Use to develop electronic "leadscrew" for smaller lathes



Determine whether or not sophisticated control systems are needed

Project Outline

- How screw-cutting works

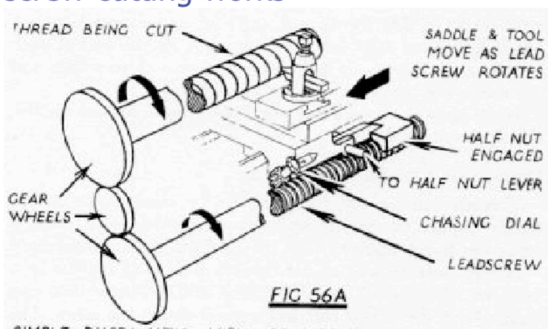
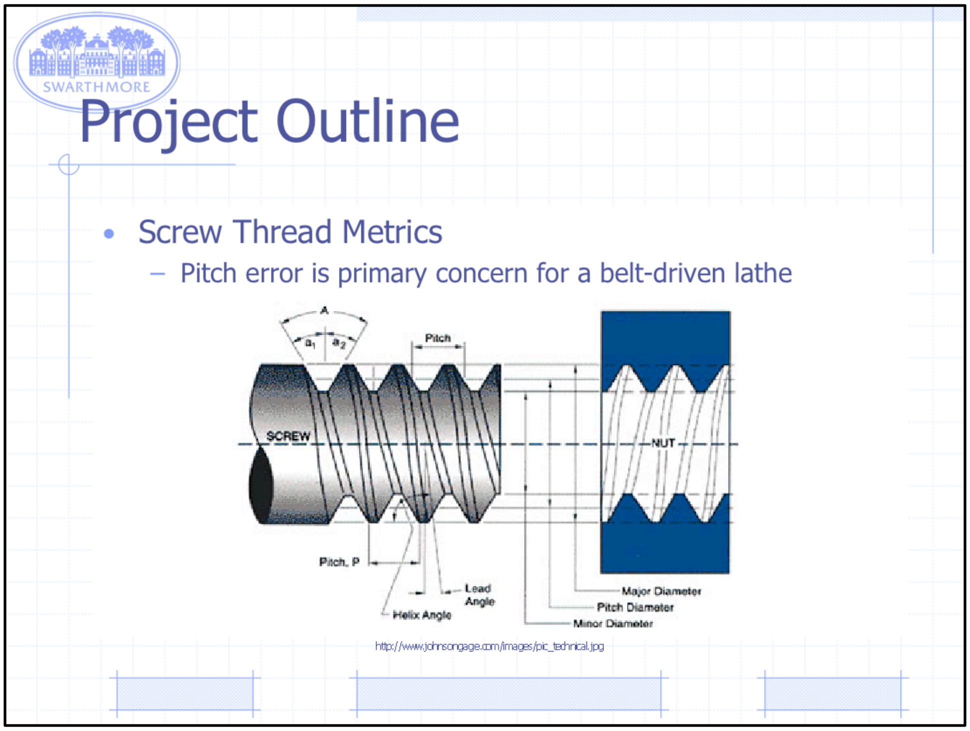


FIG 56A

SIMPLE DIAGRAMATIC VIEW OF SCREWCUTTING ON THE LATHE

http://www.autonopedia.org/crafts_and_technology/Metal_work/Metalworking-The_Basics/metalworking/13_fig56a.jpg

Need to replace gear wheels with electronic linkage



Lead = distance traversed by a single rotation of a screw

Pitch is same as lead for single-thread screw, which most screws are.

Modeling

- Requirements
  - Model lathe dynamics, including cutting dynamics
  - Model variations in spindle velocity – slipping belt
  - Output pitch error and TPI

Modeling

- State-Space Model

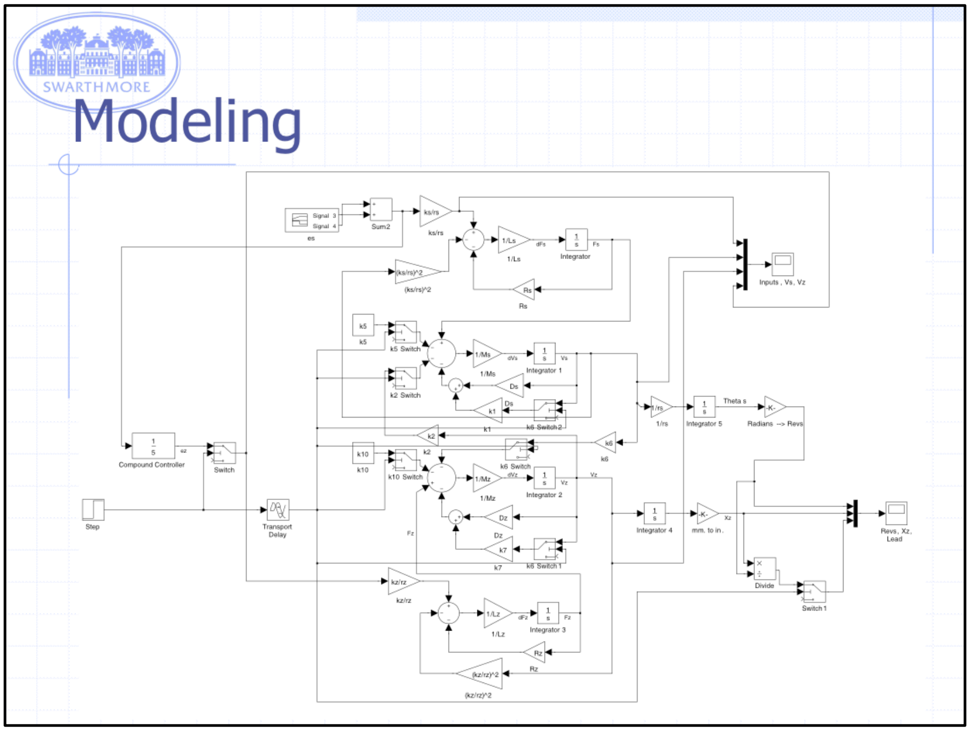
$$\begin{bmatrix} \dot{V}_s \\ \dot{F}_s \\ \dot{V}_z \\ \dot{F}_z \end{bmatrix} = \begin{bmatrix} -\frac{D_s+k_1}{M_s} & \frac{1}{M_s} & -\frac{k_2}{M_s} & 0 \\ -\left(\frac{k_s}{r_s}\right)^2 \frac{1}{L_s} & -\frac{R_s}{L_s} & 0 & 0 \\ -\frac{k_6}{M_z} & 0 & -\frac{D_z+k_7}{M_z} & \frac{1}{M_z} \\ 0 & 0 & -\left(\frac{k_z}{r_z}\right)^2 \frac{1}{L_z} & -\frac{R_z}{L_z} \end{bmatrix} \begin{bmatrix} \dot{V}_s \\ \dot{F}_s \\ \dot{V}_z \\ \dot{F}_z \end{bmatrix} + \begin{bmatrix} -\frac{1}{M_s} & 0 & 0 & 0 \\ 0 & \frac{k_s}{r_s L_s} & 0 & 0 \\ 0 & 0 & -\frac{1}{M_z} & 0 \\ 0 & 0 & 0 & \frac{k_z}{r_z L_z} \end{bmatrix} \begin{bmatrix} k_5 \\ e_s \\ k_{10} \\ e_z \end{bmatrix}$$

Ward, Ralston and Stottman 8

  - State variables: spindle and carriage velocity, spindle and carriage force
  - Incorporates cutting dynamics

In the interests of time, I elected to use an existing state-space model rather than develop my own – helps me avoid dealing with cutting dynamics.

State model taken from paper by Ward, Ralston and Stottman



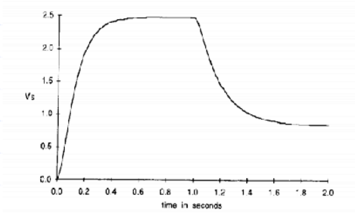
Zero-feedback system between spindle motor and carriage drive motor – carriage runs at simple proportional rate to spindle

Additionally, MATLAB code was written to calculate TPI and pitch error

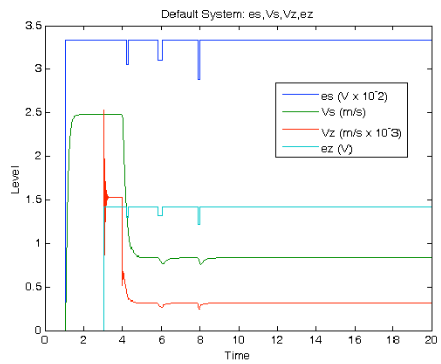
With model built, I now needed to determine how accurate the model was, how much I can control the "output" in terms of TPI, and what sort of thread error I could expect to see there

Results

- Comparison to expected results

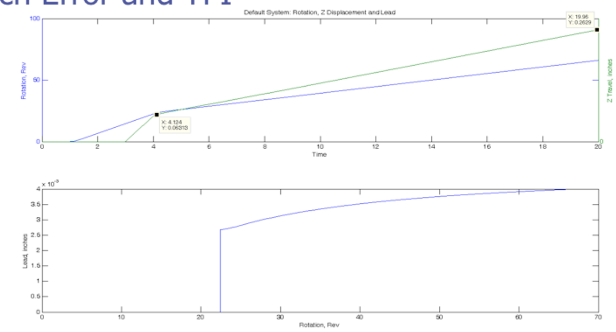


Ward, Ralston and Stottman 4

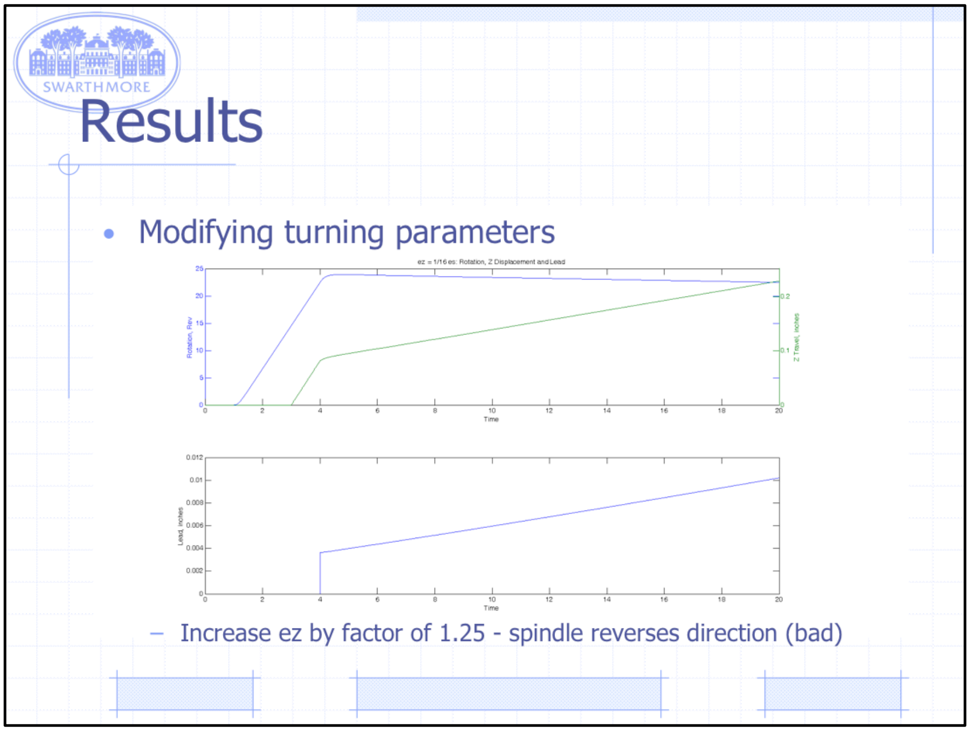


Results

- Pitch Error and TPI



  - Max pitch error = 7.15×10^{-5} in, but TPI ≃ 200

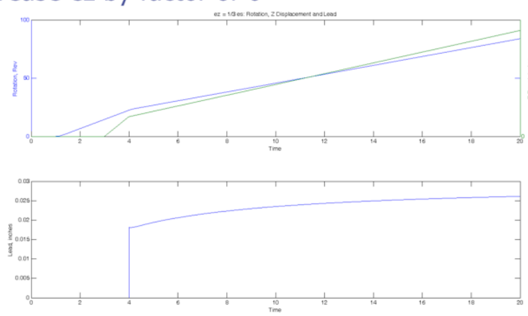


I then began modifying turning parameters to try to alter the cutting behavior.

As expected, increasing drive motor velocity exerts too much force on the spindle → makes it turn backwards, not a real result

Results

- Solution: lower cutting force, Fc, to 1/8 value
  - Increase ez by factor of 6



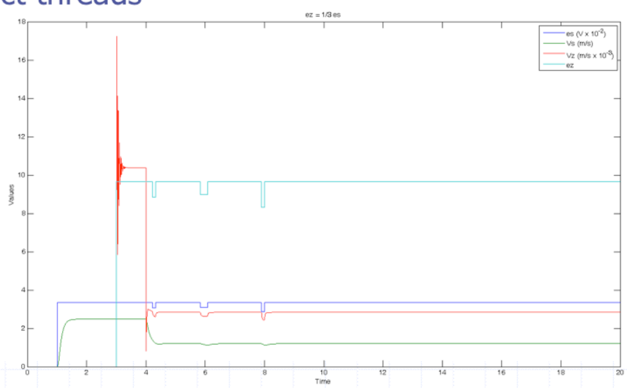
  - 32 TPI, max pitch error = 4.117×10^{-4} in, within allowable range for all but the finest threads

However, lowering cutting force (analogous to cutting depth) and increasing cutting speed works – what a real machinist would have to do

ASME Standard B1.1 specifies lower error for only 3A threads of 40 TPI and up

Results

- Fluctuations in rotational speed do not appear to affect threads



Conclusions

- Results
  - Simulation output is similar to other experiments
  - Lathe model is realistically "controllable"
  - Initial tests show that pitch error will be negligible for zero-feedback system
- Future Work
  - Simplify interface
  - Tune for my lathe
  - Determine relationship between Fc and depth of cut
  - Apply to building an electronic leadscrew!

Questions?

References

- ASME B1.1 – 2003. *Unified Inch Screw Threads (UN and UNR Thread Form)*. The American Society of Mechanical Engineers, 2004
- Ward, Thomas L; Ralston, Patricia A. S; Stottmann, Denise J. C. *Continuous-Time Simulation of Metal Cutting On A Lathe*. Computers in Engineering, 1991