Manual Desktop Lathe Design and Manufacture

Group 1 Project Report
2.72 Elements of Mechanical Design

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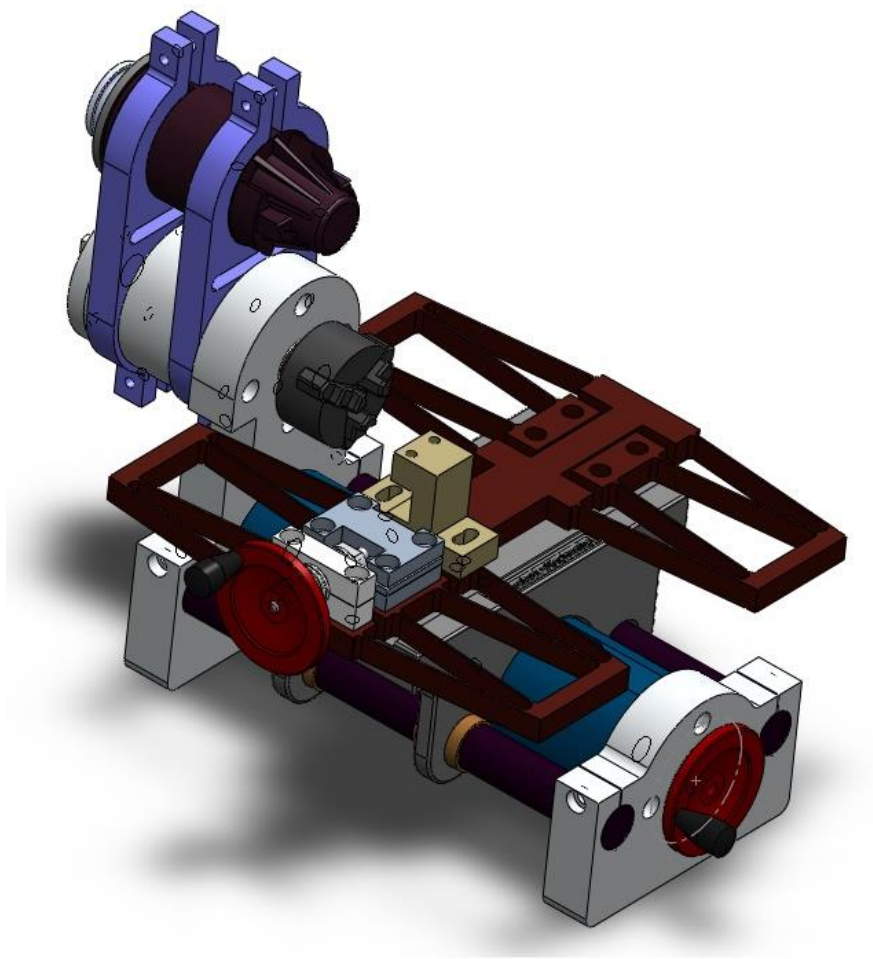

Tabletop Lathe Design

To apply core mechanical principles to a realistic engineering problem, a small bench-top lathe was rigorously modeled, designed, fabricated and tested. The machine was designed to cut within 50 microns (µm) accuracy and was produced in three months by a team of 6-8 senior mechanical engineering students within a $150 budget. Outlined in this report are some of the key concepts learned during the design and fabrication of the lathe: bearing fits and preloads, flexure design and FEA, HTM's and error modeling, and precision machining and measuring techniques.

Bearing Fits and Preloads

Bearing Fits on Seats

Part of the lathe design included determining appropriate fits for bearings in the lathe spindle: two Timken LM11949/LM11910 (cup/cone respectively) tapered roller bearings. For constraint management purposes, one bearing is fully constrained and has a tight fit, while the other bearing is allowed to slip, to allow for part expansions due to thermal heating during machine operation. Bearing fits were determined from recommended fits in tables available in the Timken catalog and *Mechanical Engineering Design*, by Shigley and Mishke.

Bearing	Fit Type	Reasoning
Motor Cone	transition (+0.0005/-0)	Accurate guiding of the shaft yet transition fit allows disassembly if needed
Pulley Cone	slip fit (+0/-0.0005)	Slip fit allows for expansion of shaft due to thermal expansion
Housing Cups	fixed fit (+0/-0.0015)	Press fit housing cups into housing

Table 1: Bearing Fits chosen for the Lathe Spindle

Bearing Pre-loads

Since radial and axial play are inherently present in ball and roller bearings, an axial force must be supplied to tapered and thrust bearings. This force, the preload, acts to eliminate unnecessary clearances, to control the rotational accuracy of the bearing, and to reduce the nonrepetitive runout that could occur because of play. According to calculations, decreasing the preload increases bearing life and decreases the running torque, thus the minimal preload which achieves accuracy of the bearings was determined for the three bearing sets in the system: the spindle bearings, cross-feed leadscrew bearings, and carriage leadscrew bearings.

To determine the preload for the spindle bearing, spindle runout was measured for a range of preload values. With this data, the optimal preload that gave the longest life, lowest running torque, lowest runout, and highest stiffness, was determined to be 7.3 lbs.

For the preloads on the thrust bearings of the carriage leadscrew and cross-feed bearing, preloads were determined based on the cutting forces acting against the bearings. The preload was estimated as the minimum normal force needed to hold the thrust bearing floating under normal cutting conditions.

Flexure Design and FEA

Constraints in a machine can be managed through the use flexure bearings, bearings that allow motion by bending a load element. Use of flexures reduce part count and result in less error due to assembly, while still allowing precise, smooth motion.

To determine the optimal design for the flexures, initially, straight beam bending calculations were done to get first order approximations of the flexure stiffness. Finite element analysis (FEA) was used as the primary design tool where inputs (beam thickness, length, and angles; fillet radius at beam roots; moving mass) were adjusted to obtain an ideal design. The design was then checked using mesh convergence which was based on differences in a quarter of the model with converged mesh and a full model with low-resolution mesh.

Three flexures (Fig. 1) were used in the lathe design: the cross-feed flexure, the lead-screw carriage flexure, and the rail carriage flexure. The cross-feed was designed with the following parameters in mind: a travel of 0.4-0.5” based on the max chuck size, a no yield condition, its frequency could not be near the driving frequency (or a multiple thereof), fundamental mode shapes could not lead to errors in part dimensions, and it had to have a low restoring force.   A modified “dancing man” flexure was used for the lead-screw carriage flexure to decouple the stiffnesses of the degrees of freedom of the part. The rail flexure on the carriage was modified to a double blade design to provide a linear constraint. Thicker elements were added to divert the load path from the thin flexure blades in case of high loads or impulses.

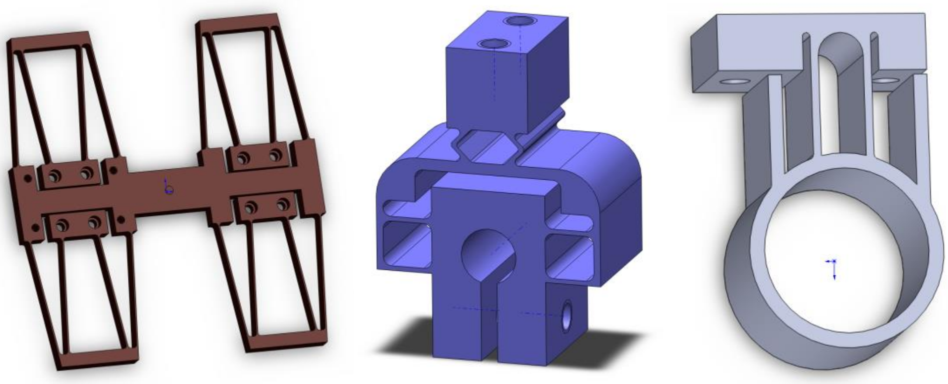

Figure 1: The cross-feed, dancing man and carriage rail flexures

Error Modeling using HTMs

To accurately predict how well the machine will cut, it is important to determine how different elements of the machine affect the error budget. Homogeneous transformation matrices (HTM’s) are a useful tool for determining the total error and how different design changes add or subtract from the error budget.

To determine the total error, the machine was divided into separate sections. Force paths were traced through each section to determine the set of HTM's for each section. Models and equations for each section were developed by hand, and the computational software program Mathematica was used to combine the HTM's of the different sections and to solve the matrix equations. Using HTM's, the team was able to double check modifications, guide design decisions, and determine error sensitivity to different sections of the machine. From the HTM error modeling, a total predicted error of (25 x, 2y,2z) microns was predicted for the machine.

Precision Machining and Measuring

For precision machining, several techniques and tools were used for accurately measuring dimensions including dial indicators, and Gauge R&R.

Dial indicators were used to measure concentricity of bearing seats and used to center the chuck for precise and concentric cuts on the for the bearing seats. The dial indicators were also used to determine the accuracy of the assembled spindle.

Gauge R&R, a measurement systems analysis technique, was used to gauge the variance of random effects of measurements on the bearing seats of the housing to ensure accuracy of critical diameters. To verify the critical dimensions of the housing, three different people each took three measurements of the same critical part and an average of the measurements was taken.

Conclusion (Lathe Performance)

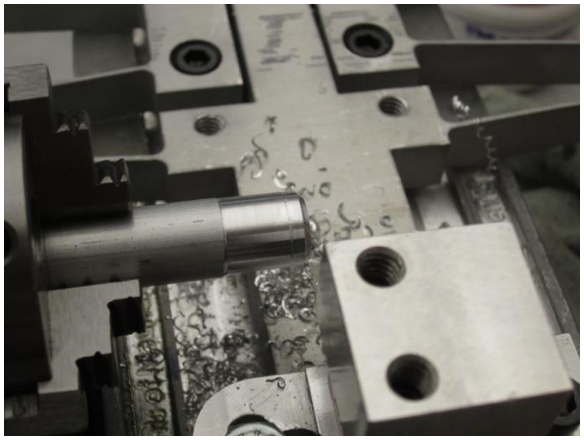

Figure 2: Cutting Aluminum with benchtop lathe

Use the key concepts learned about bearing fits and preloads, flexure design and FEA, HTM's and error modeling, and precision machining and measuring techniques, a desktop lathe was constructed that successful cut both metal and plastic stock. The lathe was able to turn half-inch diameter aluminum with a 0.03" depth of cut off the diameter (shown in Figure 2) and able to turn a half inch piece of Delrin with a 0.08" depth of cut off the diameter.