Fitness of Spindle Systems for Machining Units

Still to date, machine builders rely on past experience to design spindles. These are driven by belts or gears, providing torsion, and thrust, to cutting tools that machine work-pieces. If a shaft within a spindle system is not properly sized, it can deflect under the action of the tangential cutting effort, resulting in a poor finish of the machined component (waves on the face of the finished product). Worse: if rotation of the tool approaches a natural frequency of the shaft, deflections of the spindle under the tangential load amplify, causing a fatal failure of the whole cutting unit. Replacing shafts during trials poses budgetary challenges (of going to the customer for more money), and delays the delivery of machinery.

Tri-Way has approached the *Industrial Research Assistance Program* (IRAP of the National Research Council), and WIDL, to:

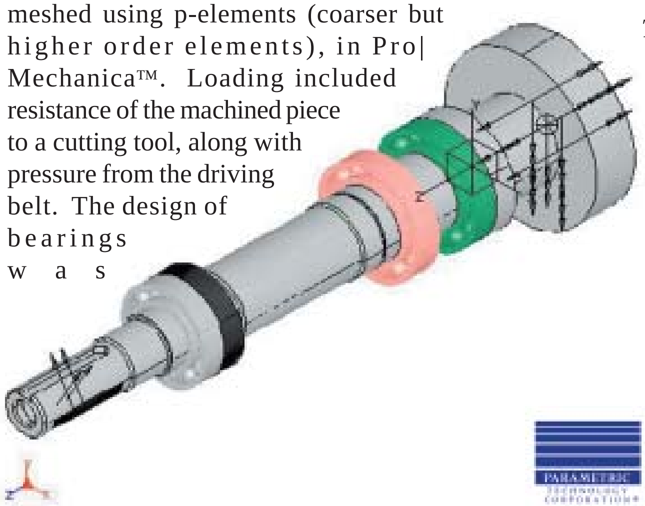
1. Search the literature for algorithms that could help the company design rotating shafts under lateral loads;

2. Build an analytical model of a spindle drive assembly case study, using Finite Element Analysis (FEA), and

3. Validate the calculations through testing at *Tri-Way* and *Ford Motor Co*.

Starting tasks at WIDL looked into 1/ the dynamics of spindle systems, 2/ thermal effects, and 3/ surface finish requirements on machined components.

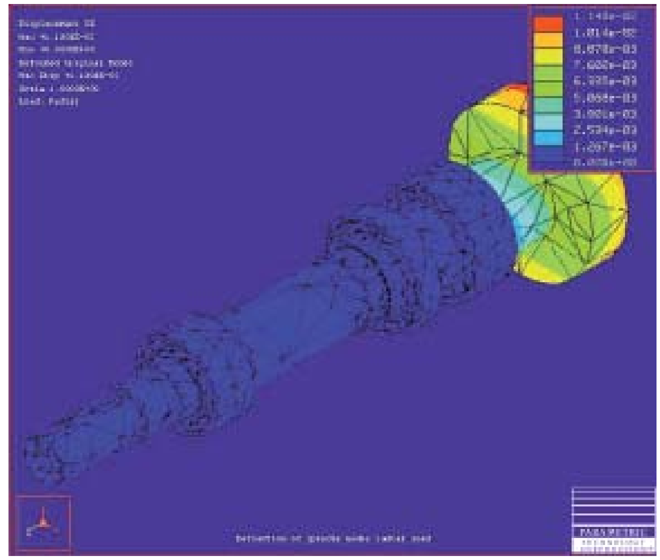
A 50-mm spindle made a case study, and drawings by *Tri-Way*, in Autocad™, (cf: http://www. autodesk.com) helped build parametric solids in Pro| Engineer™ (cf: http://www.ptc.com), at WIDL. The assembly was meshed using p-elements (coarser but higher order elements), in Pro| Mechanica™. Loading included resistance of the machined piece to a cutting tool, along with pressure from the driving belt. The design of bearings was borrowed from a catalogue by NSK-RHP.



Assembly of Tri-Way Spindle System

Materials properties, of components to the spindle assembly studied, were those of alloy 4130; properties of the bearings were pulled from the NKS-RHP catalogue.

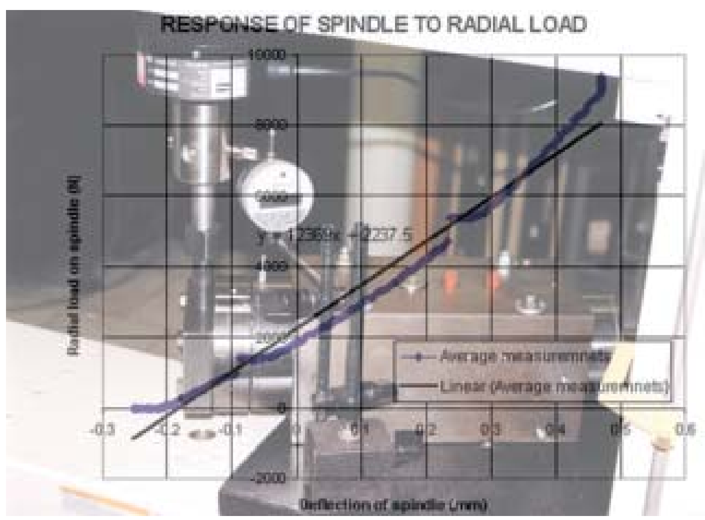
Boundary conditions fixed the spindle system to a milling machine. Several load cases were considered to establish the stiffness of the spindle in the axial and radial directions, along with belt loading.



Spindle Displacements under Radial Load of Cutting Tool

Several spindles were tested at WIDL, under quasi-static efforts of a load frame. The largest discrepancy between modeling and testing was 7%. Special holders and supports were machined, to test spindle components and assemblies by *Tri-Way*, under incremental loads.

Further modeling of spindles at WIDL was modal, in again, Pro| Mechanica™ by *Parametric Technology Corp*. Predicted natural frequencies using FEA compared to within 9% of hammer-impact measurements. The model built within this project assumed linear elasticity, for 1/ simplicity, and 2/ so that it could later be reproduced at *Tri-Way*. The model ignored nonlinear boundaries: (1) Interference between bearings and the housing, and (2) Contacts, rings to balls in bearings.



Testing Spindle Assembly under Radial Loads

Spindle System Testing and Analysis Results

Static Load	*Deflection (mm)* analysis	testing	error (%)
axial	0.0285	0.026	9
radial	0.1014	0.116	7
belt	1.1540	1.187	3
Dynamic Constraints	***Natural frequency (cycles/min)*** *analysis*	*testing*	*error (%)*
fixing bottom	10,073	9,474	6

Further testing and analysis of spindle systems by *Tri-Way* involved *Ford Motor Co* and NRC/IRAP. These were evaluated under accelerated machining. Collected vibration data later validated transient dynamic FEA models, built at WIDL.