1. Manufacturing Automation Laboratory

The Manufacturing Automation Laboratory (MAL) has been conducting research on the mechanics and dynamics of metal cutting operations, machine tool vibrations and CNC design since 1986. Currently, MAL has 11 Graduate assistants, 2 Postdoctoral fellows, 3 visiting students, 2 visiting professors and 2 research engineers. The current research projects include micro-milling, five axis machine tool control, trajectory generation, real time spline interpolation, active damping of feed drive vibrations, spindle dynamics, thin wall milling, mechanic and dynamics of five axis milling, virtual turning and milling, multi-body dynamics of machine tools, machining of implants, and chatter stability with process damping.

MAL has been publishing articles primarily in ASME, CIRP and Machine Tool Research journals. Our academic articles receive over 400 external citations annually.

Research facilities include a five axis Mori Seiki CNC Machining Center; a Mori Seiki CNC Mill Turn; a vertical research machining center equipped with our own CNC and spindle; a Hardinge Super Precision CNC turning center; Mitutoya CMM; Multi-Functional Micro-Machining Center from Mikrotool; an in-house built micro-milling center with 20000 rpm air spindle; a SIEMENS linear motor driven drive; a low speed-large scale XY table, high speed ball-screw driven table; ultra-precision piezo actuators; tool holder testing stands and shrink fit station. The laboratory is fully equipped to conduct research in all aspects of machine tool and machining engineering. Sample instruments include table, lathe and rotating dynamometers from Kistler; tool microscopes; surface finish analyzer; Laser Interferometer, laser displacement sensors, laser vibrometer, capacitive-inductive probes, modal testing kits with a variety of hammer and accelerometer sets, and shakers; Fourier Analyzers, data acquisition sets, dSpace high speed control system, scopes and analog filters.

2. Research Products

MAL conducts fundamental research and publishes the findings in open literature. Advanced research algorithms are integrated to industry friendly software systems owned by the university and marketed by a university based spin off company MAL Inc. (www.malinc.com).

2.1 Machining Process Analysis and Simulation Software—CUTPRO

MAL has been studying the micro and macro mechanics of metal cutting to predict cutting forces, torque, power, surface form errors, and vibrations in milling, turning, drilling and boring operations. The cutters are modeled using generalized geometry and mechanics, hence any milling, turning, boring and drilling tool can be modeled and process can be simulated. The chatter stability models are based on frequency and time domain analysis methods developed in the laboratory. The algorithms are embedded in CUTPRO advanced process simulation software. CUTPRO has measurement and analysis modules. MALDAQ is the data acquisition module with adjustable filters, FFT and chatter diagnosis functions. It also has a Kalman filter to compensate the dynamics of dynamometers for cutting force measurements at high cutting speeds. MALTF is an impact modal test module which accepts displacement, velocity, acceleration and force sensors with automated measurement quality control. Modal module
has one and two dimensional modal/mode shape analysis features. Machining simulation modules allow run-out, variable helix and pitch and any user defined cutter geometry. The cutting force coefficients can be entered by the user to simulate specific materials and tool geometries. CUTPRO is used to predict the optimal cutting conditions and tool geometry to prepare NC programs which do not lead to chatter and overloading of the machine tool while achieving optimal material removal rates (see Fig. 1).

2.2 Virtual High Performance Machining—MACHPRO
MAL has been investigating the simulation of machining physics in CAM environment. MACHPRO can read the NC programs and CAM files using standard data structures. It predicts cutting forces, torque, power, vibrations and optimizes the NC program by modifying the speed and feed fields automatically (see Fig. 2).

2.3 CNC Design and Analysis Research—Virtual CNC
MAL conducts research on the trajectory generation: interpolation and feed drive control methods to obtain smooth motion profile along up to five axis tool paths. The feed drive research aims to increase the contouring accuracy of the machine tool at high speeds while damping the structural vibrations transmitted to the drive table.

2.4 Spindle Design and Analysis Research—SpindlePro
MAL develops the structural dynamic models of spindles. The system predicts the angular contact bearing stiffness under preload, and calculates the mode shapes and FRFs at any point along the spindle shaft including at the tool tip. The FRF can be used in CUTPRO to predict the chatter stability performance of the spindle in machining various materials with different tools. The vibrations and bearing loads can be predicted under desired cutting conditions by SpindlePro which is used to optimize the spindle dimensions during the design stage (see Fig. 4).

3. Conclusion
MAL conducts fundamental research in machining, and publishes the details of the algorithms in journals. The sophisticated algorithms are integrated to user friendly software products which are released to industry and research centers. MAL enjoys friendly and social atmosphere while conducting research on machine tools and machining (see Fig. 5).

The algorithms are tested on our open architecture, in house developed CNC system. The system has a complete simulation module called Virtual CNC, which allows testing of various control-feed drive design models in time and frequency domain. Virtual CNC allows simulation of NC programs to predict the cycle times and tolerance violations contributed by the CNC (see Fig. 3).