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Machinability and performance analysis MMT with EWMA

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Abstract : There is a growing demand for highly accurate micro-scale parts from various industries including medical, biotechnology, energy, consumer, and aerospace. Mechanical micro-machining which is capable of fabricating three dimensional micro-scale features on a wide range of engineering materials such as metals, polymers, ceramics and composites is a viable micro-manufacturing technique to electively address this demand. Miniature machine tools (MMTs) are developed and used in mechanical micro-machining since their small size improves the accuracy and efficiency of the process. The output quality of the product manufactured on an MMT depends on choosing the optimum machining parameters.
However, the full potential of micro-machining cannot be achieved due to challenges that reduce the repeatability of the process. One of the most sign cant challenges in micro-machining is the deterioration of output quality due to the MMT vibrations. This thesis demonstrates the development of a three axis miniature machine tool, the performance evaluation of its micro-scale milling process, and the characterization of its dynamic behavior using finite element simulations and experiments. The MMT is designed and constructed using precision three-axis positioning slides (2 micrometers positioning accuracy, 10 nanometers positioning resolution, 60 mm x 60 mm x 60 mm workspace), miniature ultra-high speed spindles (ceramic bearing electrical spindle with maximum 50,000 rpm rotational speed and air bearing air turbine spindle with maximum 160,000 rpm rotational speed), a miniature force dynamometer, and a microscope. Three dimensional finite element simulations are performed on the developed MMT to obtain the static and dynamic characteristics of the spindle side.

Introduction

There are several benefits of miniaturization such as reduction in space, material, and energy requirements and improved eficiency. Highly accurate miniature components with micro-scale features are increasingly in demand for various industries such as medical, biotechnology, consumer, aerospace and energy for using the advantages of micro-scale .

Miniaturization is very promising for medical and biotechnology applications which require micro-systems for interacting with molecules, proteins, cells and tissues. For instance, with the recently developed micro-/nano-manufactured devices, cancer agent molecules like PSA, CA can be detected at early stages of the cancer. Miniaturizing the cancer detection devices will reduce the cost of cancer monitoring and save many lives. Furthermore, to avoid tissue damage during surgeries, most implants and surgery equipments are required to be miniature. Miniature medical equipments including probes, stents and fiberoptic cameras have been increasingly used in surgeries, and their market is expected to grow rapidly .

While miniaturization is a necessity in biotechnology and medical applications such as the ones described above, it is advantageous to use miniature components in other applications. With miniaturization, products with more functionality is achieved. For example, today a cell phone not only provides mobile communication, but also has wireless internet connection, global positioning service, camera for high quality pictures, audio/video player and video games. Digital data storage systems (hard-disc drives) that include miniature mechanical components get smaller and store more data. Researchers are working on developing miniature fuel-cells which will be replaced with batteries in portable devices.

Mechanical micro-machining

Mechanical micro-machining is one of the viable micro-manufacturing techniques for fabricating micro-scale features and components with three-dimensional complex geometries on metals, polymers, ceramics and composites. It is the scaled down version of the traditional metal cutting techniques such as drilling and milling where the material is removed mechanically using microscale cutting tools. Although it might be possible to perform mechanical micro-machining on traditional precision machine tools, it is generally performed on miniature-machine-tools (MMTs) to achieve a better control in dimensional and thermal errors, and to reduce the required space, power and cost for operation. Miniature machine tools are equipped with high precision positioning stages, ultra high speed spindles, and measurement devices such as dynamometers and microscopes to monitor the process.

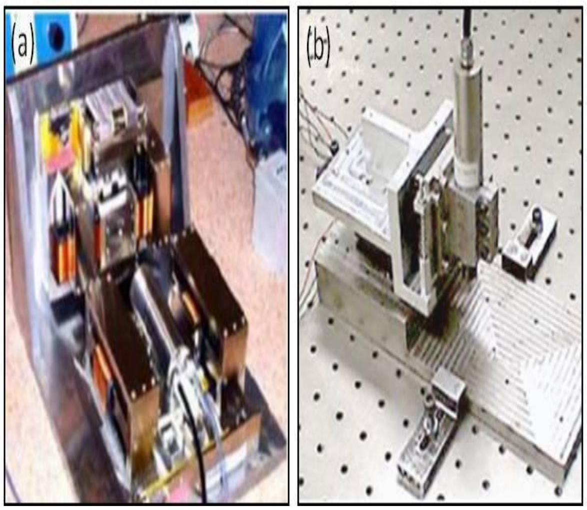


Figure 1.2 shows some examples of miniature machine tools.

Challenges of mechanical micro-machining

However, the full potential of mechanical micro-machining cannot be achieved due to the challenges that reduce the repeatability of the process.

The challenges include non-ideal micro-cutting tool geometry, uncertainty arising from micro-structure of the workpiece, lack of knowledge in micro-machinability of materials, and vibrations due to periodic machining forces and rotating unbalances. These issues have to be investigated and eliminated for successful application of micro-manufacturing. There is a fundamental limitation of how sharp the cutting tools can be made in micro-scale due to the limitations in the tool manufacturing process (grinding) so, the micro-cutting tools cannot be considered as ideally sharp. The edge radius (sharpness) of the tools in micro-machining is in the order of machining parameters such as feed rate and uncut chip thickness, which makes the cutting edge "blunt". Bluntness of the cutting edge makes mechanics of the process complicated. It renders the process ploughing (rather than shearing) dominated, in which a large portion of the material is deformed and pushed under the tool.

Dynamics of conventional machine tools

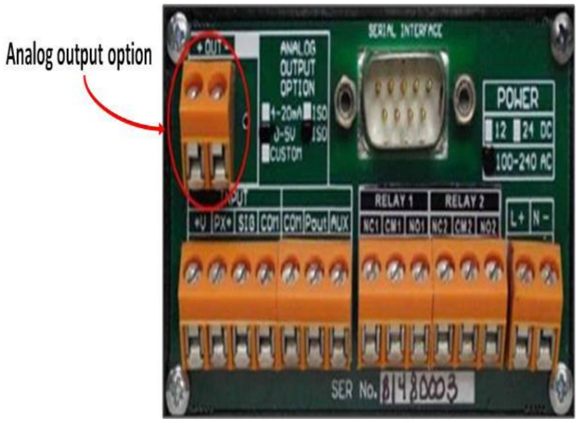
Dynamic characteristics of machine structures have been widely studied for conventional machine tools in order to enhance their machining performance. Research on dynamics of conventional machining processes show that in most cases, cutting tool and spindle are the main source of vibrations and they should be investigated to prevent chatter instability which causes the deterioration in the output quality of the process.

Accurate prediction of the tool point frequency response functions is significant to obtain stable cutting conditions. The negative real part of the tool point frequency response function can be used to obtain optimal cutting parameters that will maximize the chatter-free material the tool point frequency response function over the frequency range of interest, can be used to obtain stability lobe diagram which defines regions of stable and unstable cutting zones as a function of depth of cut (bcritical) and spindle speed (60*frequency). Then, this stability lobe diagram can be used to select appropriate machining parameters to improve output quality and productivity of the machining processes.

Design and Construction of MMT

To address the increasing demand in miniature components, an ultra-precision miniature machine tool (MMT) was designed and developed at Advanced Microsystem Technologies Laboratory of Bilkent University (see Figure 3 (a)). This MMT includes precision three-axis nano-positioning slides with 60 mm x 60mm x 60 mm workspace, high positioning accuracy and positioning resolution, miniature ultra high-speed (UHS) spindles with maximum 160,000 rpm rotational speed, a miniature force dynamometer, and a microscope. This presents the procedure we followed to design and build a 3-axis miniature machine tool that is capable of achieving significantly higher cutting speeds and producing three dimensional features in metals, polymers and different materials. First, the major subsystems of the designed MMT are introduced.

Next, static and dynamic finite element analysis to design mechanical parts for integration of the spindle is presented. Finally, integration of the machine components using computer aided drawings and precision alignment method are discussed.



Although this tachometer is capable of measuring 1 to 999,990 RPM range, it is also possible to adjust zero scale (0SCALE) and full scale (FSCALE) values of this tachometer according to the type of application. PM Remote Tachometer software and RS232 to RS232 serial interface can be used to adjust these values. The standard analog output has 32,000 steps from zero to full scale. This full scale value is the value at which the analog outputs are at a maximum, 5Vdc and this zero scale value is the value at which the analog outputs are at a minimum, 0Vdc, and the spindle speed will be linear between 0SCALE and FSCALE. Since the number of steps between 0SCALE and FSCALE is constant, increasing the difference between these values will decrease the resolution. Therefore, the measurement range of the tachometer is usually set to give a reasonable working range for the analog input.

Investigation of MMT Dynamics

The geometric and surface quality of precision parts manufactured on a MMT are highly dependent on the dynamic performance of the miniature machine tool, which is determined by the interrelated dynamics of machine tool mechanical structure and cutting process. Machine tool vibrations led to tool-work piece relative displacements play an important role in determining the dynamic performance of miniature machine tools.
Of the key components described in chapter 3, spindle side is the most important structural loop in the designed miniature machine tool. Spindle includes the exile bearings and holds the micro-cutting tool with relatively reduced stiffness. Due to flexibility of these parts, when subjected to the cutting forces during the machining process, expected vibrations on the spindle will be higher than those of precision stages side. Therefore, the dynamics of micro-machining processes and the vibration generated during micro-machining are directly affected by the spindle side dynamics.

Conclusions

This demonstrates the development of a 3-axis miniature machining center, the performance evaluation of its micro-milling processes and characterization of its dynamic behavior. In this research, a 3-axis miniature machine tool tested was designed and developed using precision three-axis positioning slides (2 micrometers positioning accuracy, 10 nanometers positioning resolution, 60 mm x 60 mm x 60 mm workspace), miniature ultra high speed spindles (a miniature UHS ceramic bearing electrical spindle with maximum 50,000 rpm and a miniature UHS air bearing air turbine spindle with maximum 160,000 rpm), a miniature force dynamometer, and a microscope. Based on the experimental study on the test-bed, performance evaluation of the developed MMT was achieved particularly focusing on its dynamic behavior.
Micro-milling was proposed as a novel method for fabricating three dimensional PMMA and PLGA polymer micro-needles. Due to the lack of knowledge in micro-machinability of polymers, the micro-machinability of PMMA and PLGA polymers was investigated experimentally to study the parameters (cutting speed and feed) that inuence the quality of the machined components. During the micro-machinability study, a group of 3 mm length and 100 firm depth slots using 50,000 and 100,000 rpm spindle speeds with different federates.

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