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Control of deviations and prediction of surface roughness from micro machining of THz waveguides using acoustic emission signals

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ABSTRACT

By using acoustic emission (AE) it is possible to control deviations and surface quality during micro milling operations. The method of micro milling is used to manufacture a submillimetre waveguide where micro machining is employed to achieve the required superior finish and geometrical tolerances. Submillimetre waveguide technology is used in deep space signal retrieval where highest detection efficiencies are needed and therefore every possible signal loss in the receiver has to be avoided and stringent tolerances achieved. With a sub-standard surface finish the signals travelling along the waveguides dissipate away faster than with perfect surfaces where the residual roughness becomes comparable with the electromagnetic skin depth. Therefore, the higher the radio frequency the more critical this becomes. The method of time-frequency analysis (STFT) is used to transfer raw AE into more meaningful salient signal features (SF). This information was then correlated against the measured geometrical deviations and, the onset of catastrophic tool wear. Such deviations can be offset from different AE signals (different deviations from subsequent tests) and feedback for a final spring cut ensuring the geometrical accuracies are met. Geometrical differences can impact on the required transfer of AE signals (change in cut off frequencies and diminished SNR at the interface) and therefore errors have to be minimised to within 1 µm. Rules based on both Classification and Regression Trees (CART) and Neural Networks (NN) were used to implement a simulation displaying how such a control regime could be used as a real time controller, be it corrective measures (via spring cuts) over several initial machining passes or, with a micron cut introducing a level plain measure for allowing setup corrective measures (similar to a spirit level).

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1. Introduction

Micro machining is a necessary process for manufacturing astronomical instrumentation as very small geometries are required with a defect free and smooth surface finish. Micro machining is a difficult process to carry out as the tool structure is susceptible to unwanted vibration due to less stiffness (small diameter and large length), which can result in poor surface quality and out of tolerance dimensions. By using AE, the signal is directly related to the micro-mechanical activities of the cutting process. Due to AE being concerned with high frequencies (ultrasound, our model is sensitive in the range of 0.1–1 MHz) the lower-frequency machine vibrations and environmental noise can be filtered out at no great cost. AE has already seen uses in tool condition monitoring, detection of work piece surface defects and chip management [1]. As a continuous signal source, AE can be used to monitor the following [1]:

- Plastic deformation in the workpiece.
- Plastic deformation in the chip.
- Tool-chip sliding friction (frictional contact between the tool rake face and the chip resulting in crater wear).
- Tool-workpiece sliding friction (frictional contact between the tool flank face and the workpiece resulting in flank wear).

As a transient AE signal source the following can be monitored for:

- Collisions between the chip and tool.
- Entanglement of chips.
- Tool fracture.
- Chip breakage.

Micro machining processes for astronomical instrumentation are particularly sensitive to the surface roughness and, the precision of achieved machining geometrical accuracies.

The current tolerance of the tailored micro machine setup is optically measured as 4 µm (See Figs. 1 and 2). The idea behind using a precision sensing capability is to achieve a precision of 1 µm, as the specified precision of the used micro machine was 1 µm over small areas. However, the main problem with the current setup is that the initial zero machine table datum is provided by visual inspection via an optical microscope (similar to work referenced in [2]). Where the machine probe is used to give the X, Y Z 0 position and confirm the setup accuracy of the machined part. Gauge markers on the fixture are then used for repeat setup purposes. If an inaccuracy is found with the setup then the probe position should pick this up and by using the gauge markers and optical microscope to correct any found errors. Even with such setup methodologies there can still be an associated error which can increase if not corrected. The proposed idea: deduce information from Acoustic Emission (AE) measurements that could lead to identify errors in-situ and give corrective machine commands to counter balance against setup and other machining inaccuracies (Fig. 3).

This idea of using closed feedback control is particularly important as most machining platforms have associated in/decreasing setup errors due to environmental changes, technology use/access and tool condition to name a few [2]. The work discussed here was carried out at the University of Chile´s Astronomy Department´s Millimeter-Wave Laboratory at the top of a hill: Cerro Calán in Santiago (this environment is very dry and hot in the January months with occasional seismic activity that can add to increasing errors). Another problem obtained in CNC precision is that of achieved control versus desired control where actuator backlash, wearing of gears can all add to the problems of deviations. Other problems were obtained in micro milling where push off and vibrations occur which are based on the large tool length to small diameter ratios: such problems only add to the problems of increased geometrical inaccuracies. Finally, another problem to be considered is in terms of temperature gradients that can impact on material machining accuracy. In the carried out tests the micro machine working area was kept at a constant temperature through closed loop control/thermostat.

Another important reason for using AE sensor technology is to make sure that the process is free from mechanical disturbances like resonance vibrations. This is very important in micro-machining applications, where spindle speeds have to be very high due to

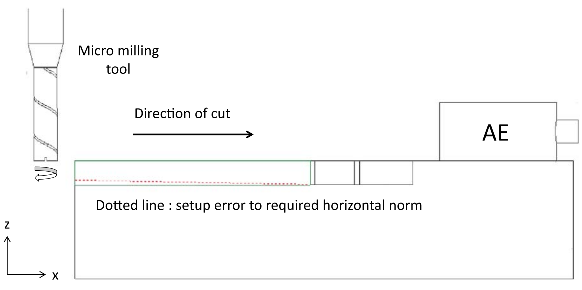

Fig. 1. A schematic of the machine setup and associated errors.