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Characterization of machining quality attributes based on spindle probe, coordinate measuring machine, and surface roughness data

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Abstract

This study investigates the effects of machining parameters as they relate to the quality characteristics of machined features. Two most important quality characteristics are set as the dimensional accuracy and the surface roughness. Before any newly acquired machine tool is put to use for production, it is important to test the machine in a systematic way to find out how different parameter settings affect machining quality. The empirical verification was made by conducting a Design of Experiment (DOE) with 3 levels and 3 factors on a state-of-the-art Cincinnati Hawk Arrow 750 Vertical Machining Center (VMC). Data analysis revealed that the significant factor was the Hardness of the material and the significant interaction effect was the Hardness + Feed for dimensional accuracy, while the significant factor was Speed for surface roughness. Since the equally important thing is the capability of the instruments from which the quality characteristics are being measured, a comparison was made between the VMC touch probe readings and the measurements from a Mitutoyo coordinate measuring machine (CMM) on bore diameters. A machine mounted touch probe has gained a wide acceptance in recent years, as it is more suitable for the modern manufacturing environment. The data vindicated that the VMC touch probe has the capability that is suitable for the production environment. The test results can be incorporated in the process plan to help maintain the machining quality in the subsequent runs.

Keywords: Machining quality; Coordinate measuring machine (CCM); Design of experiment (DOE); Vertical machining center (VMC); Dimensional accuracy; Surface roughness

1. Introduction

Discrete part production using a computer numerically controlled (CNC) machine tool is common in modern manufacturing. Depending on the accuracy and surface finish requirements, the machining parameters, which have a significant influence on part quality, need to be set properly. The machining parameters are an important part of process plan, which can be determined from user experience, test experiments, and relevant reference materials. Improperly set parameters may induce unwanted complications in machining. For instance, chatter represents uncontrollable, excessive vibration, which produces unacceptable surface quality [1]. Vibration in machining can be minimized through the use of computer simulation tools. Simulation can project the optimal range of cutting speeds and feed rates for a chatter-free machining, hence producing less scrap and enhanced part quality. Since each machine tool exhibits different characteristics, such as stiffness, damping ratio, and natural frequency, the importance of pre-machining simulation is applied to each machine. Especially when the machine is newly acquired, the machine characteristics need to be tested and ascertained. In this study, CutPro® milling simulation software accompanied by a hammer test was used to generate a set of vibration free-cutting parameters. However, the simulation results do not provide a comprehensive picture when several material types are machined at the same time with varying parameters. The significant factors and potential interactive effects need to be ascertained to achieve a high level of quality in machining.

Equally important in machining is the confidence in the measuring instruments, from which part quality characteristics are ascertained. Part dimensional accuracy check has been largely based on a post-process inspection, such as a coordinate measuring machine (CMM). The downside of this technique is that non-conforming parts can be produced between inspections. To remedy the problem, a machine mounted touch probe has started gaining a popularity, which has the similar working principles of CMM. The probe enables the measurement of machined parts, while they are still

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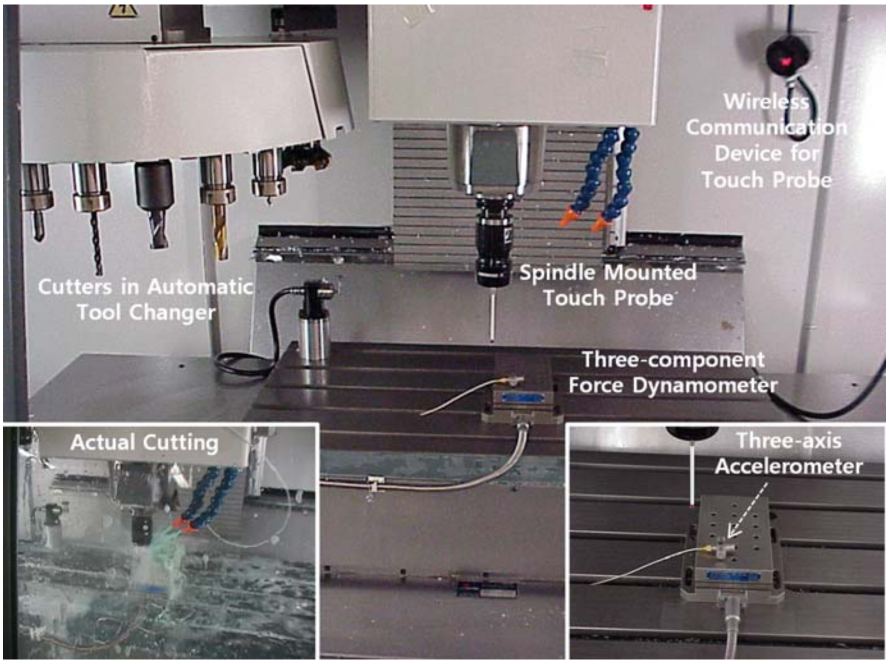

Figure 1. The experimental apparatus with the inlets showing the actual cutting and the accelerometer.

fixed on the machine (see Figure 1). By providing the part size or gauged information directly into a CNC controller, a closed-loop process control can be realized [2]. This is particularly important for a modern, computer controlled production environment, where a very little human intervention is expected during machining cycles. The accuracy of the probe, however, is affected by the machine tool's positional accuracy and positioning system. Therefore, the capability of the probe needs to be analyzed, and possibly, compared with the CMM measurements. CMMs are widely used in the manufacturing industry for precision inspection and quality control, and recognized as reliable and flexible gauges suitable for assessing the acceptability of machined parts [1, 2]. The comparison will offer insights towards the extent of measurement errors reflected on the touch probe. To characterize the machining quality attributes, a set of cutting experiments has been performed. The dynamic behavior of the machine tool structure was analyzed first to determine the range of chatter-free machining parameters (see Figure 2). During the actual cutting, the three-component force dynamometer continuously measured the X, Y, and Z directional cutting forces, while the three-axis accelerometer monitored and recorded the vibrations. The experimental data were analyzed, and it was found that the selected cutting parameters didn't induce any excessive vibrations or force signals. This vindicates that the cutting was conducted in a chatter-free condition. In this study, the tool wear effect was not considered in the DOE model, because an artificially induced tool wear couldn't be set for each cutting condition. In this study, the main contribution is as follows. Prior to the machining, an analytical test was performed to identify the stable, chatter-free machining conditions, and the DOE was conducted under the condition. Two critical machining quality characteristics are measured for three most common material types, and the most influential machining parameters were found, which would serve as a decision criterion for the subsequent process planning. In addition, the bore size was measured using two different gauges. The machine mounted touch probe acts as an online inspection tool, while the CMM is used for the post-process gauging. The readings from two types of gauges were compared to verify that which machining parameters have the most influence on the bore diameters. The findings from this study are expected to help develop a computerized process plan, which will be a mainstay of future production systems. The overall structure of this study is as follows. The first section is the introduction, delineating the purpose and the importance of the study. The second section illustrates the details of cutting experiments, while the third section elaborates on the data analysis. The conclusion is drawn in the fourth section.

2. Descriptions on cutting experiments

In this study a newly acquired, state-of-the-art Cincinnati Hawk Arrow 750 Vertical Machining Center (VMC) was used to conduct the DOE. Cutting experiments allow the production engineers to adjust the settings of the machine in a systematic manner and to learn which factors and interaction effects have the greatest impact on the part quality before the machine is put to use for production. This step is necessary, because in metal cutting, most process control models are based on the empirical data and no universal mathematical models exist [3-5].

In this study, three factors are selected. The levels of the