

Investigating mechanical characteristics of styli for micro-CMMs

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Abstract

The mechanical characteristics of styli for micro coordinate measuring machines (micro-CMMs) is of importance because of the major effect the styli have on the performance and capability of micro-CMMs. Previous work has focussed on the design of the next generation of stylus systems for micro-CMMs, and several test styli have been manufactured. These test styli have sphere-tips and stylus shaft diameters of less than 70 μm and 40 μm respectively, and aspect ratios of greater than ten. The styli are manufactured using a novel hybrid manufacturing process. In this paper the results of tests designed to determine the mechanical properties of the test styli will be presented. The experimental setup and testing method has been enhanced from that of the previous work, especially with respect to the precision manipulation stages and control software. The main focus of the work presented here is to measure the stiffness of the styli shafts and the transverse force on the tip that causes initial plastic behaviour in the stylus. The results of the mechanical properties measurements are also compared to results from analytical models. The outcome of this work will lead to a better understanding of the development of tactile stylus systems for micro-CMMs, with the aim of developing micro-styli with sphere-tip diameters of the order of 10 μm or less.

Keywords: Mechanical properties, Micro styli, micro-CMM

1. Introduction

Recently, the development of styli with tip diameters below 100 μm , used for micro coordinate measuring machines (micro-CMMs) [1], has significantly increased due to the increasing demand for measuring miniature products. Using new manufacturing techniques, styli with tip diameters below 50 μm have been successfully manufactured [2]. However, the quality and capability of these styli is still not fully understood. To examine the capability of these styli, the strength characteristics under certain loads must be evaluated.

Experimental methods to study the mechanical properties of new styli with tip diameters of around 70 μm are proposed. The stiffness and "maximum safe tip force" of the styli (the transverse force on the tip that causes initial plastic behaviour in the stylus) will be investigated.

2. Design consideration and manufacturing processes

2.1. Design considerations for micro styli

A set of rules have previously been identified for the design of new styli for micro-CMMs [3], which can be summarised using five main categories: geometrical considerations, probing forces, stylus stiffness (coupled with effective mass and probing speed), surface quality of the stylus tip, and material selection. This work examines the stiffness and the maximum safe tip force of the styli.

The stiffness of the stylus shaft is an important parameter for micro-CMM measurement. During CMM measurements, the position of the stylus tip is subject to a systematic error due to the bending of the stylus shaft. Although this systematic bending error is considered during verification of the probing system, to minimise this error the stylus shaft should be as stiff as possible.

In contrast, the maximum safe tip force needs to be identified in order to avoid plastic deformation of the stylus. The forces exerted on the stylus can lead to errors of measurement, especially at the micrometre scale. The effects of static and dynamic contact forces could damage the surface of the stylus tip or the measured workpiece. The maximum safe tip force, therefore, defines the maximum limit of the working range of forces for the stylus.

2.2. Manufacturing process of micro styli

The test styli for this work were made by one of three variant hybrid manufacturing techniques, namely:

Manufacturing technique Type 1: The stylus shaft is manufactured by a wire electro-discharge grinding (WEDG) process while the stylus tip is produced on the end of the stylus shaft using a one-pulse electro-discharge machining (OPED) process [4], creating a monolithic structure.

Manufacturing technique Type 2: Assembly of the stylus using an adhesive material to attach the stylus tip sphere to the stylus shaft [5]. The stylus shaft is manufactured using WEDG (as with *Type 1 styli*) and a commercially available micro-sphere made from glass is used as the stylus tip. This type is analogous to most commercially available styli for micro-CMMs.

Manufacturing technique Type 3: A manufacturing technique similar to that used for *Type 1 styli*. However an electro chemical machining (ECM) process is introduced immediately after the WEDG process. The ECM process is expected to increase the stiffness of the stylus shaft by reducing the instance of pits, which are typical surface features of structures manufactured using EDM, therefore improving the stylus shaft surface and geometrical quality. The detail of this ECM process is well described in a previous paper [2].

Type 1 and *Type 2 styli* have been tested previously to investigate their ultimate yield strength [6], and further examples are re-tested in this work along with examples of *Type*

3 styli. The mechanical characteristics of all the tested styli types will be compared.

All the styli measured in this work have approximately similar stylus shaft diameters (between 40 μm and 42 μm). Meanwhile the effective lengths of the stylus are between 645 μm and 776 μm and the diameters of the stylus tips are between 62 μm and 85 μm . The mechanical aspect ratios are between 16 and 19.5.

3. Experimental setup

The experimental setup, shown in figure 1, is further developed from previously completed work [6]. The stylus is moved into contact in the vertical direction by a precision manipulation stage. A precision mass balance is used as a force sensor. A chromatic confocal point sensor records the movement of the precision manipulation stage. For the experiment of maximum safe tip force, the stage motion is only stopped after the stylus breaks.

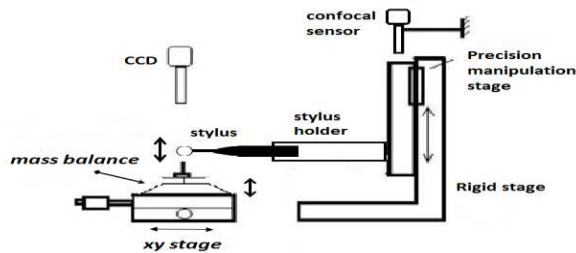


Figure 1. Experimental setup for stiffness and force measurement.

Enhancements to the setup beyond that used in [6], include better control of the precision manipulation stage and better integration of hardware and software components. The stiffness measurement of the styli has been improved by calculating the stiffness of the experimental setup, measured during the absence of the stylus. The stiffness of the experimental setup is then eliminated during the data analysis, resulting in a calculation of the stiffness of the stylus. The maximum safe tip force is identified at the point associated with the onset of non-elastic behaviour. The uncertainties for both measurement are analysed using standard methods [7]. The changes made to this experimental procedure are expected to enhance the accuracy and repeatability of the measurement result beyond that previously reported [6].

4. Result and discussion

The relationship between the experimental results for the stiffness of stylus, calculated from three repeated measurements, and its effective length are presented in figure 2. The theory of a simple cantilever [8] suggests that the stiffness will decrease as the length of the stylus increases with a relationship of $\frac{1}{l^3}$ where l is the effective length of the stylus. Of course, the tested styli have marginally different diameters, and, therefore, aspect ratios, so the theoretical trend shown in figure 2 are approximate and for indication only. The experimental results from all stylus types seem not to follow this relationship. The graph in figure 2 also shows a significant difference between the theory and the experimental results. In addition, the results also shows that the *Type 3 styli* have a lower stiffness compared to the *Type 1 styli*. This result contradicts the initial prediction that the *ECM* process will produce stiffer styli.

These results could be caused by imperfections in the surface quality of the stylus shaft caused by *ECM* process. Other factors such as non-optimised manufacturing process parameters and material properties could contribute. Further experiments are also needed with styli that have a wider range of mechanical aspect ratios.

Figure 3 shows the relationship between the effective length of the stylus and the maximum safe tip force, which can only be determined once per sample, owing to the destructive nature of

the test. In figure 3, *Type 2 styli* seem to have a low maximum safe tip force. This is because the strength of the *Type 2 styli* is determined by the strength of the adhesive materials between the stylus shaft and stylus tip. *Type 3 styli* shows reasonably constants result over the small testing ranges, while *Type 1 styli* demonstrate unpredictable results.

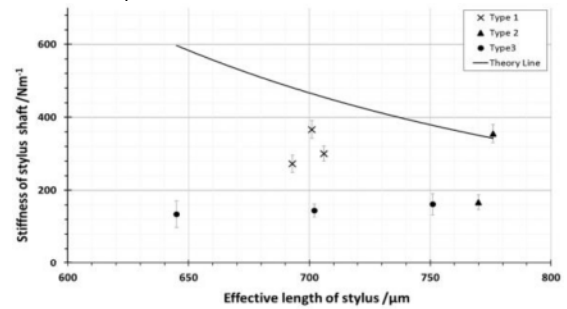


Figure 2. Graph of stiffness of stylus shaft vs effective length of stylus.

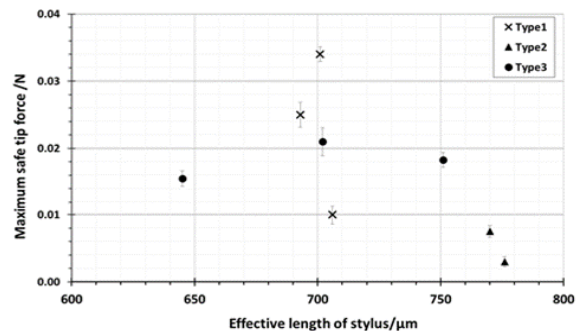


Figure 3. Graph of maximum safe tip force vs effective length of stylus.

5. Conclusion and future work

In conclusion, the mechanical properties of styli produced using each of three hybrid manufacturing processes have been tested and compared. From the experimental result, *Type 3 styli* have lower stiffnesses compared to *Type 1 styli*, but the maximum safe tip force shows a constant result over the small testing range. In contrast, *Type 1 styli* are stiffer than the *Type 3 styli* but the maximum safe tip force cannot be easily predicted. *Type 2 styli* seem variable in both stiffness and force limit. Significant differences between theoretically predicted stiffnesses and the experimental results strongly suggest continuing issues related to imperfections of the stylus shaft surfaces, manufacturing process control and, perhaps, material properties. The manufacturing process needs to be enhanced to achieve the optimum performance.

In the future, further investigation into increasing the stiffness of the styli is suggested for *Type 3 styli* (which are manufactured using the hybrid process of WEDG, ECM and OPED) using different in mechanical aspect ratios and smaller dimensions of stylus.

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