SIMULATION AND ANALYSIS OF TOUCH TRIGGER STYLUS PERFORMANCE

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Abstract. Over the last decades, *high accuracy and close tolerance requirements have introduced new paradigms in manufacturing industries. The coordinate measuring machines (CMMs) are a flexible and accurate measurement instrument that can contribute to achieve these requirements. These machines incorporates a touch trigger probe that provides the machine with the information from which the location of the surface of the part under inspection, relative to the machine's position. Accuracy and uncertainty of CMMs are influenced by the probe system performance as this system introduces systematic and random errors due to pre-displacement of the probe, at the time that sensor stylus undergoes significant deflection. This paper aims to investigate the performance of touch trigger probe stylus by using finite element method (FEM). The simulation and analysis were developed by using the software Nastran (NX 7.0, Siemens®). This analysis was developed by considering different configurations, geometries and kind of materials of the probe stylus in order to minimize the influence of the pre-travel errors of the probe system.*

***Keywords**: Coordinate measuring machines, touch trigger probe stylus, finite element method.*

1. INTRODUCTION

Coordinate measuring machines (CMMs) are in widespread use as an accuracy measurement tool over the last decades. These machines are very useful, particularly when the component to be measured has a complex shape. CMMS have attracted much attention due to their ability to measure geometrically complex workpieces efficiently and with higher dimensional accuracy (Silva et. al., 2009). Nowadays, one of the most difficult challenges on manufacturing system developments is to achieve total dimensional control of parts produced, creating statistical data analyses and part-to-part control (Guerra and Coelho, 2006).

The sensor, called Probe, is one of the most important factors influencing CMM accuracy, because it provides the connection between the object surface and the measuring system of the machine. This sensor is responsible to send a binary signal as a result of contact of the probe tip with a measurement, however, this signal response can be delayed because the deflection caused on the probe stylus. Because of imperfections of the touch trigger probe construction, the position of the probe during triggering is shifted from the position of an actual moment of its contact with workpiece surface. This displacement is called pretravel (Wozniak and Dobosz, 2005).

The probe system of CMM including probe and stylus has become the most critical part of the machine. Indeed, a probe sometimes has been described as the heart of a CMM. This is true not only because of its function in the machine, but also it produces larger errors than other parts of the machine (Salleh *et al.*, 2005). CMM users need good skills in selecting and configuring the probe, probe head, stylus, interface and accessories for a given application, and only well-trained users can establish efficient probe system for measuring tasks. Current practices have largely relied on choosing probes of better performance, selecting stylus configuration of shorter length and higher stiffness, using smaller probing forces, and careful sampling strategy. Even so, large probe errors can still be present in practical measurements due to the complicated operation of probes (Yang *et al.*, 1996).

This paper aims to investigate the performance of touch trigger probe stylus by using finite element method (FEM). The simulation and analysis were developed by using the software Nastran (NX 7.0, Siemens®). This analysis was developed by considering different configurations, geometries and kind of materials of the probe stylus in order to minimize the influence of the pre-travel errors of the probe system.

2. COMPONENT MODELING

There are various types of probes available which provide a wide range of functions and features. However, most CMM users continue to use the conventional ones (Kinematic contact) because of their low cost, adequate level of accuracy and performance. In this study, the structural model of probe and stylus, used in Coordinate Measurement Machines (CMMs), has been significantly simplified, although, in general, it is still carrying the important features. This model enhances the probe structure which consists of a vertical stem carrying a sphere in its tip. The stem is completely linked to three cylindrical arms, where each one of them serves as a supporting platform. These arms are positioned horizontally 120° apart. A spring that rests on the center top of the probe structure has as function to restore stem to its original position after deflection, fig.1. In order to determine the performance of the probe stylus by considering different design parameters, as it can be seen Tab. 1, the computer aided design software Nastran (NX 7.0, Siemens) was applied to modeling the probe structure.

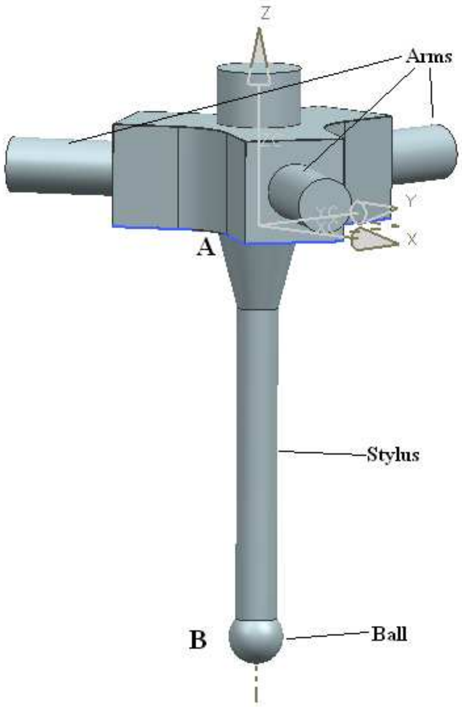


Figure 1. The simplified model of Kinematic contact probe system

In this research work, two different stylus lengths, 60 mm and 70 mm of different materials (Aluminum and Steel) were considered. Four sets of models were analyzed and for each one the stem displacement was calculated.

Table 1. Probe stylus design parameters.

Material	Aluminum 6061		Steel AISI 4340	
Length of probe Stylus	60 mm	70 mm	60 mm	70 mm
Mass	4. 916x10^{-2} kg	4. 993x10^{-2} kg	1. 424x10^{-1} kg	1. 446x10^{-1} kg
Moment of inertia	1. 620x10^{1} kg.mm^{2}	2. 041x10^{1} kg.mm^{2}	4. 691x10^{1} kg.mm^{2}	5. 911x10^{1} kg.mm^{2}
Young's Modulus	6.898x10^{7} kPa (20ºC)		1.930x10^{8} kPa (20ºC)	
Density	2.711x10^{-6} kg/mm^{3}		7.850x10^{-6} kg/mm^{3}	
Poisson's ratio	0.33		0.284	
Ball diameter	8 mm			
Stylus diameter	6 mm			

This methodology to determine the design parameters through modeling in CAD was used due to complexity of the component geometry and as it contributes to analyze different configurations and geometries of the probe. It is important to note that the length of probe stylus considered in this project comprises the distance between the points "A" and "B" highlighted in the Fig. 1, where "B" is located in the center of the sphere.

3. METHODOLOGY

The software NX is able to create the mesh of the model automatically and it was selected a structural and 3D Tetrahedral mesh. However, the mesh used by the software has a default size of 4.51 mm and it was not sufficient to represent the probe geometry appropriated. In consequence, the mesh size was optimized manually using a different value that was 1.50 mm.

According to Shen and Moon (1996), there is no trigger signal generated when the probe tip touches the workpiece. The probe will continue to move toward and the force between the probe tip and the workpiece will increase, causing a physical quantity to reach a threshold setting. A trigger signal is generated when the physical quantity exceeds a threshold limit in the sensing system. The travel distance between the touch instant and the trigger instant is known as probe *pre-travel*. That phenomenon was analyzed on the following way: for each length of probe stylus (60 mm and 70 mm) and material setting (Aluminum and Steel), respectively, with a force of 0.15 N in the center ball tip of 8 mm at the "Y" negative direction, where it is the maximum force direction. The Fig. 2 presents the top view enhancing both directions, the low and high ones. For all these simulations, the ball tip was considered as a rigid element and with same diameter.

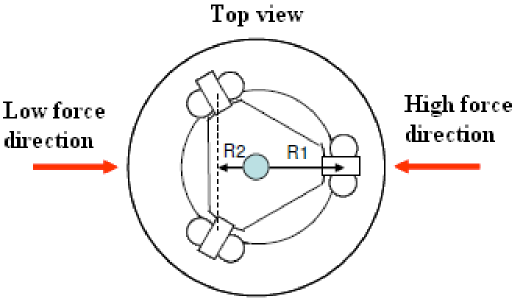


Figure 2. High and low force directions (Renishaw, 2003)

The constraints used for the simulations whereas the arms of the probe system should be fixed during the force application, what represents there is no the trigger signal instant, see Fig. 3. It is important to enhance the force applied on the simulations was in the same direction for all of cases.

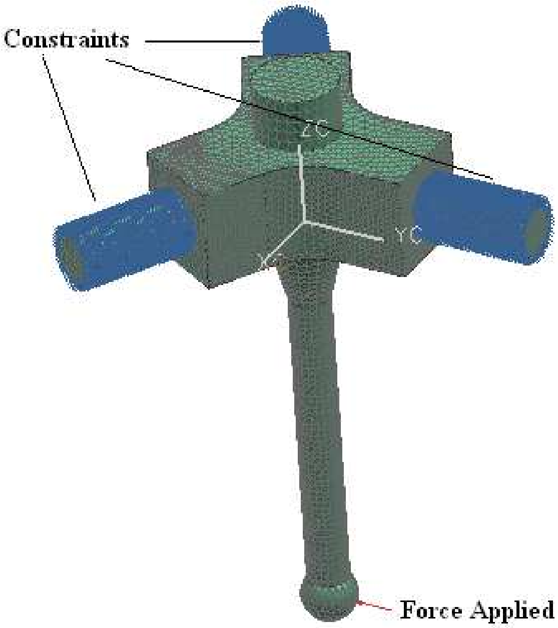


Figure 3. Mesh, load and constraint of the model

4. FUNDAMENTAL EQUATIONS

4.1. Pre-travel

When the stylus is in contact with the surface of the part to be measured a balance of forces is established. Before the trigger threshold is reached, these growing forces cause the stylus to bend. Since the machine is still moving, the amount of bending in the stylus that occurs before the probe triggers affects the latched position of the machine when the trigger is recorded (RENISHAW, 2003). This stylus bending prior to the trigger is known as *pre-travel*. Referring to Fig. 4, pre-travel (PT) depends on "Fc" and "L", as well as the stiffness of the stylus, according to the formula:

$$PT = F_c.L^3 / 3.E.I \tag{1}$$

Where "E" is the Young's modulus of the stylus stem material and "I" is the moment of inertia. An important point to be emphasized is that the Eq. (1) is the same used by a clamped beam with constant cross-section area.

Before the contact elements separate, the force balance is as follow:

$$F_c.L = F_s.R \tag{2}$$

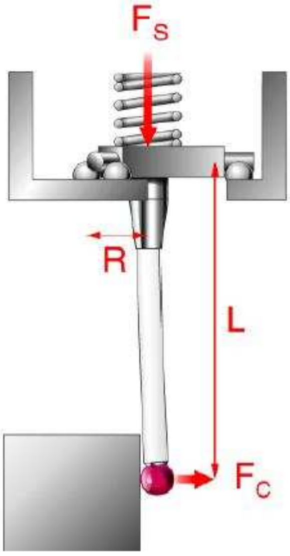


Figure 4. Force balance in a touch trigger stylus (Renishaw, 2003)

4.2. Numeric Method

The formulation of a static structural problem for solution by the displacement method is completely described by the matrix equation (NX Nastran, 2008):

$$[K]\{u\} = \{P\} \tag{3}$$

Where "K" is the stiffness matrix, "P" is the load vector and "u" is the independent displacement vector.

As mentioned before, the software NASTRAN was used to obtain the solution to Eq. (3). This method approaches the structural analysis and it is incorporated into the program NX 7.0, Siemens®.

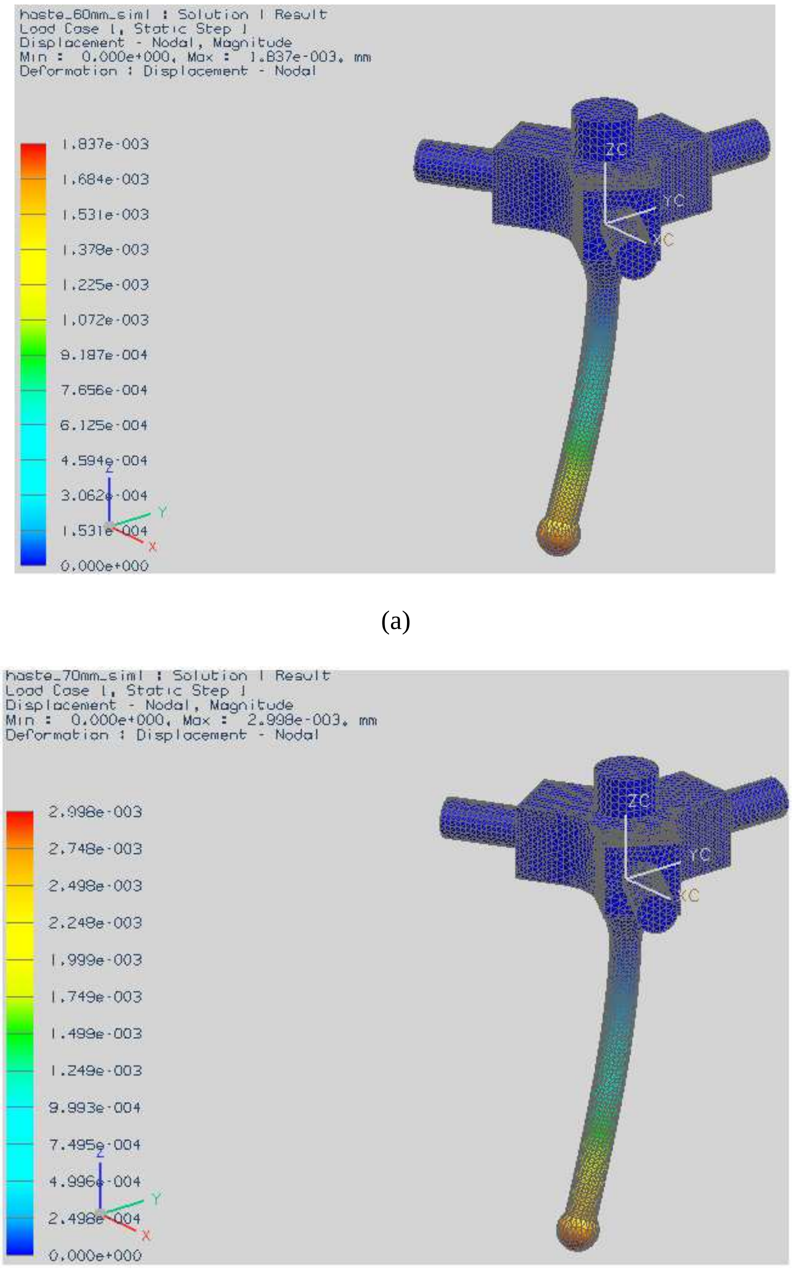
The distributed physical properties of a structure are represented by a model consisting of a finite number of idealized substructures or elements that are interconnected at a finite number of points. All input and output data pertain to the idealized structural model. In static analysis by the displacement method stiffness properties are input exclusively by means of structural elements. Mass properties (used in the generation of gravity and inertia loads) are input either as properties of structural elements or as properties of grid points. Solution of a linear static structural problem by the displacement method requires a set of preliminary operations which reduce the input data to the matrix form given in Eq. (3). Among these operations are the elimination of displacement components that are declared to be dependent by virtue of constrains and the transfer of all applied loads to the independent displacement components. Once Eq. (3) has been formed it is solved for each specific loading condition. Stress in the structural elements and other desired results are then obtained from "u" by a set of data recovery operations (NX Nastran, 2008).

5. SIMULATION RESULTS

This section will detail the results of the simulations with different materials and length of the probe stylus.

5.1. Material: Aluminum / Length: 60 mm and 70 mm

The probe system has been modeled with different stylus length, L1 = 60 mm and L2 = 70 mm, and both were applied with a force of 0.15N at the high force direction. For this purpose, a Finite Element Analysis (FEA) model was simulated on each case mentioned above, and the stylus displacement result of these models have been summarized in the Fig. 5.



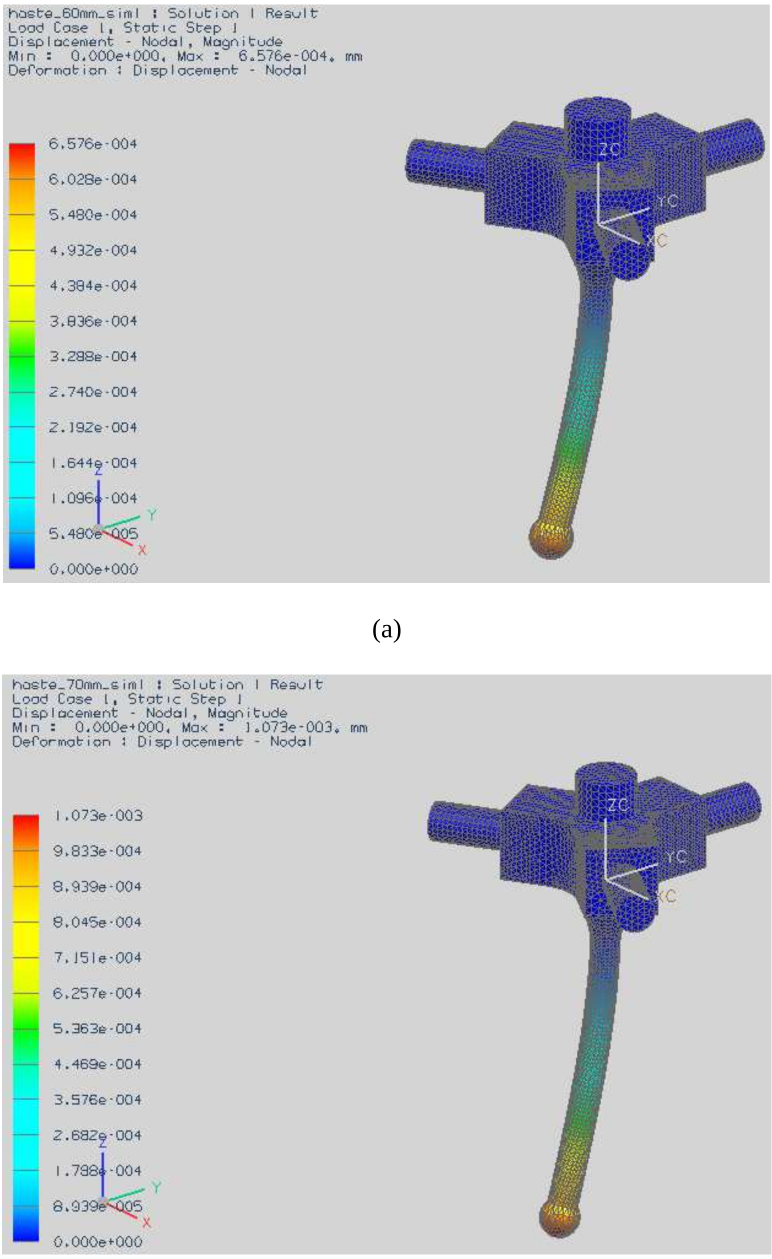
(a)

(b)

Figure 5. Probe stylus displacement to aluminum (a) 60 mm (b) 70 mm

5.2. Material: Steel AISI 4340 / Length: 60 mm and 70 mm

Modeling with different stylus length and both applied the same intensity of force (0.15N) of the first case, the Fig. 6 have been showing the displacement result of the simulation.



(a)

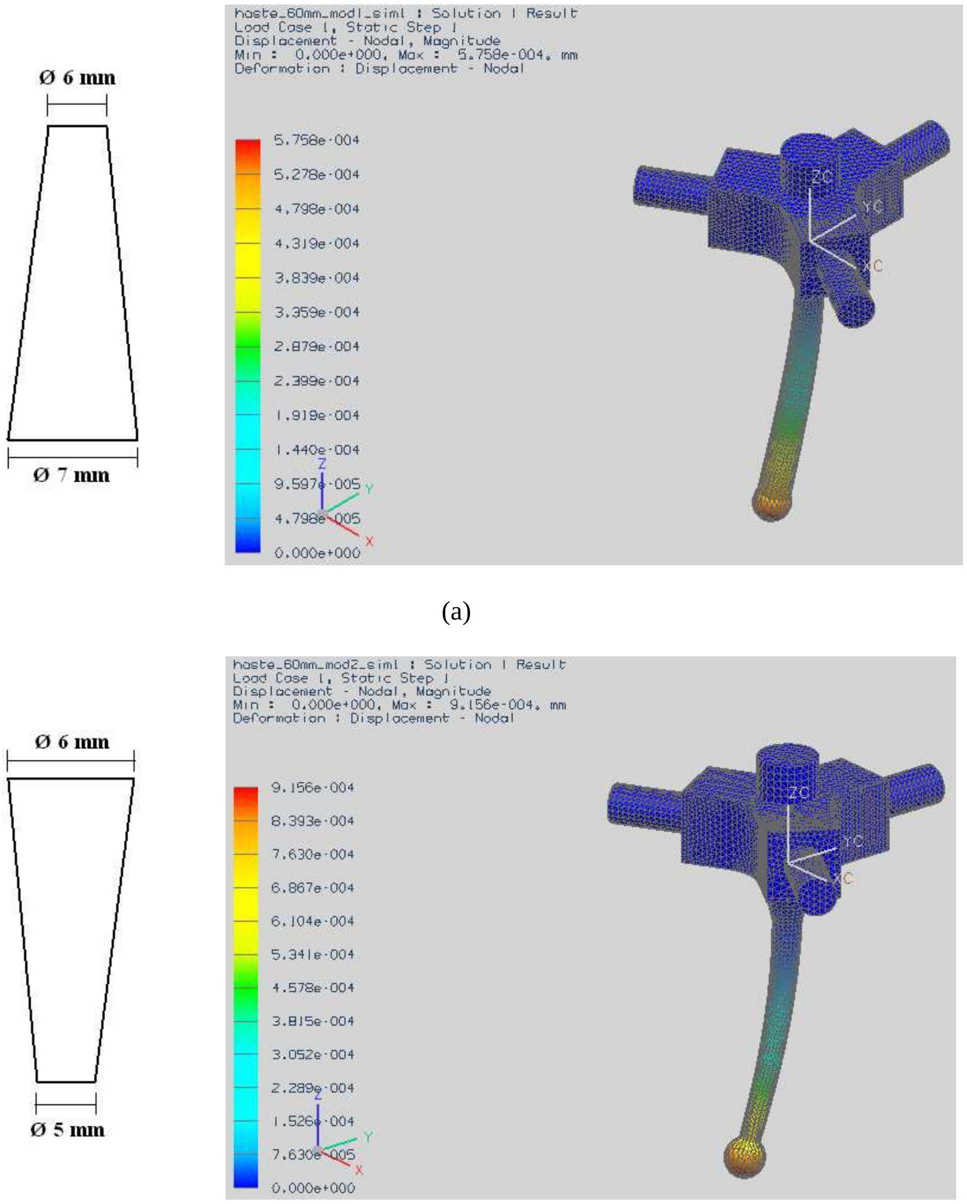
(b)

Figure 6. Probe stylus displacement to steel (a) 60 mm (b) 70 mm

According to the simulation results presented in Fig. 5 and 6, it can note that they are consistent with the analytical solution shown in Eq. (2) as the minimum displacement was found to the higher young's modulus of the material and to smaller length stylus, which are: material steel and length stylus 60 mm. The minimum displacement for this probe configuration was 0.6576 µm. After the validation process, it was studied two cases to evaluate the influence of varying the cross-sectional area of stylus in each case.

5.3. Simulations for stylus with different cross-section area

In order to analyze the influence of the geometry of the stylus were considered two case shown in Fig. 7, where the material and length of the stylus were steel AISI 4340 and 60mm, respectively. The Fig. 7 below shows the displacement of the stylus with a conical geometry. In the Fig. 7 (a) there was an increase in the diameter at the bottom of the stem, whereas in Fig. 7 (b) there was a reduction in the diameter at the same part.



(a)

(b)

Figure 7. Probe stylus displacement to steel with different cross-sectional area

After the new simulations, it was noted that the configuration shown in Fig. 7 (a) showed an optimization model, reducing the displacement with respect to the simulation with constant cross-sectional which was 0.5758 μm.

6. CONCLUSIONS

This paper has presented a displacement analysis of a probe stylus, used in coordinate measurement machines (CMMs), by applying finite element method (Nastran - NX 7.0, Siemens®).The influence of different materials, design configurations and stylus length on the displacement of the probe stylus were evaluated. From this analysis it is possible to conclude that the best performance, in terms of displacement, of the probe was obtained using steel, smaller stylus length and conical configuration. The proposed approach contributes for CMM users to change the design configuration of the stylus and estimating its displacement as an alternative to eventual lack of physical instrumentation, in the development and optimization of the measurement systems.

7. ACKNOWLEDGEMENTS

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9. RESPONSIBILITY NOTICE

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