行政院國家科學委員會專題研究計畫成果報告

奈米級三次元量測儀結構之設計與分析(I)

Design and Analysis of A Nano-CMM Structure (I)

計畫編號：NSC 88-2212-E-002-033
執行期限：87年8月1日至88年7月31日
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1. Abstract

This project is the first sub-project of the integrated-project named "Design and Fabrication of a Nano-CMM(Coordinate Measuring Machine)" and is the first year of the whole three-year project. The main object of this year is to design and analyze a prototype of a Nano-CMM Structure. The measurement range of this machine would be 20mm, 20mm and 10mm in x, y and z axes respectively. The whole design process for the machine contains two design phases: preliminary design and detail design. In preliminary design, the first step would be to generate engineering specifications according to customer's requirements. Then, an expert system tool will be used to help the configuration design process such that the sizes of major components of the machine are determined. A parametric design process is also developed to automatically generate the solid model of the structure in a CAD software. In the detail design stage, a series of finite element analysis, such as static analysis and thermal deformation analysis, are carried out such that the detail sizes are modified to satisfy different structure requirements.

Keywords: Nano-CMM Structure, Expert System, Finite Element Analysis.

2. Introduction

In the recent year, Coordinate Measuring Machines(CMM)[1] are widely used for the 3D measurements of objects. In many cases, an accuracy of several nanometers(1 nm = 10^{-9} m) in stage positioning was required, especially for semiconductor lithography manufacturing. This project deals with the development of a new type of Nano-CMM by an expert system tool. After the solid model of Nano-CMM structure was generated, the finite element analysis was applied in static analysis and thermal deformation analysis.

3. Layout of the Nano-CMM structure

Specifications of the Nano-CMM are shown in Table 1 and its prototype is displayed in Figure 1. The main parts are granite base, bridge and x/y/z-stages. Each stage is driven by a Piezo Ceramic Linear Motor(PCLM) and was guided by a set of Cross Roller Guide. The main features of these components are stated as follows.

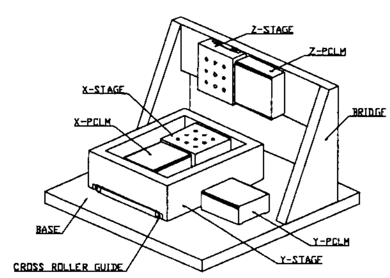

Figure 1. The prototype of Nano-CMM

Table 1. Specifications of the prototype of Nano-CMM

Size of machine, mm^3	300x300x300
Weight of machine, Kg	10
Measuring range, mm^3	20x20x10
Resolution, nm	10
Accuracy, nm	50

In order to reduce the effect caused by temperature change, the Invar material is used in the whole structure except the granite base. Invar, a 64%Fe-36%Ni alloy with the lowest thermal expansion coefficient of iron-nickel alloys, is commonly used as the structural material in precision measuring machines. Another material, Aluminum, was also used as comparison. The physical and mechanical properties of these two materials are given in Table 2.

Table 2. Physical and mechanical properties of materials

	Invar	Aluminum
Density, g/cm^3	8.1	2.7
Modulus of elasticity, GPa	150	71
Thermal expansion rate between 0 and 38°C, 10^{-6}m/m.K	0.877	22.2
Specific heat, at 25-100°C, J/Kg.°C	515	963
Thermal conductivity, at 20-100°C, W/m.K	11	203

All the three stages of the Nano-CMM structure are directly driven by PCLM. The PCLM system[2] consists of a motor and a drive amplifier to excite the motor. These two components are combined to create the piezoelectric effect. This effect converts electrical field to mechanical motion. The PCLM(Type SP-4) contains 4 piezo elements that play the important roll of operation. When the voltage is applied across the element in a precise sequence, the edge of the piezo element will generate an elliptical motion. This elliptical motion is then applied to the stage to create linear motion. Figure 2 and Table 3 shows the operation and specifications of PCLM.

Table 3. Specifications of PCLM

Motor Specifications	SP-4
Maximum Velocity, mm/sec	250
Maximum Force, Newtons	14.7
Resolution (Smallest Step), nm	5
Static Holding Force, Newtons	31
Standard Travels	To 300 mm

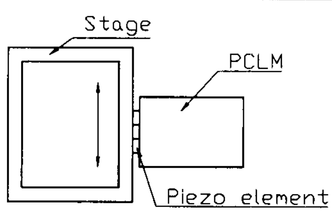

Figure 2. Operation of PCLM

The Cross Roller Guides are used in sliding parts of each stage. This guide increases the effective contact length of the rollers, and limits the linear motion of stage with high rigidity and high accuracy. The Cross Roller Guides[3] consist of the roller cage (type R) with a small roller pitch interval and the special V-rail (type V) with precision grinding after special heat treatment. This guide can provide a smooth movement without wear and with little friction.

4. Design of the Nano-CMM structure

An expert system that uses the technology of Object-Oriented Programming and Artificial Intelligence[4-10] is developed for the preliminary design of the Nano-CMM system. First, the Object-Oriented methodology is applied to build a system object model representing the composition relationships between components and subsystems of the Nano-CMM system. Different types of constraints for the system are established to form a dependency constraint network. Then, a constraint-driven reasoning algorithm will be applied to handle the constraint satisfaction process to find solutions that satisfy design specifications. Finally, the solid model of the Nano-CMM system is established automatically by an interface program in the AutoCAD software.

Before the design process, design requirements about the measurement range of Nano-CMM and the stage size are specified. It needs to find the feasible configuration for the Nano-CMM to meet design requirement.

The design requirements include the travel limits of guides in x/y/z directions, the size limits of the X/Y-stages and the material for the whole structure, including the base, bridge and stages.

The representing symbols of the Nano-CMM components are shown in Figure 3a,3b. In order to generate feasible designs in the expert system, the following steps are carried out sequentially.

The design procedures are : (a) Define the object model of the system for the expert system. (b) Define methods for parametric design. (c) Define the domain data for standard components.

(d) Define constraints for the system. (e) Set initial values for design parameters. (f) Start the inference process. After defining the previous data for the system model, the inference engine of the expert system can be started to find feasible solutions of the design parameters. The developed expert system can find all feasible solutions and display a pop-up dialog box to show the detail data for each feasible solution.

There are 6 feasible solutions for the Nano-CMM. Although these design results are different, each feasible solution satisfies all the specified design constraints.

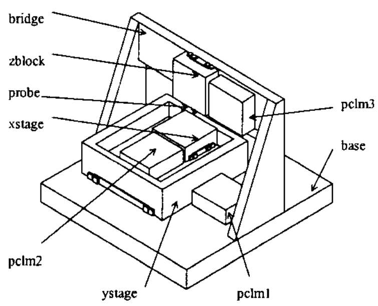

Figure 3a. Identification symbols of the Nano-CMM

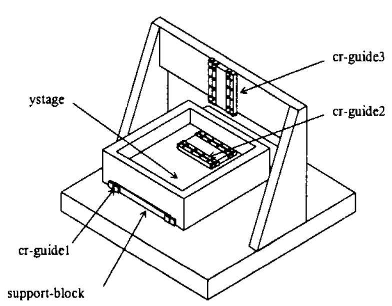

Figure 3b. Identification symbols of the Nano-CMM

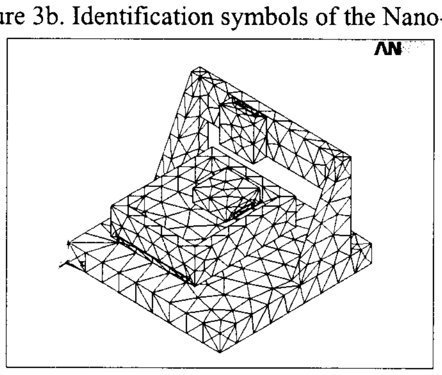

Figure 4. Finite element model of Nano-CMM

5. Analysis of the Nano-CMM structure

In the structural and thermal deformation analysis, the ANSYS software was used for finite element analysis. Figure 4 shows the Nano-CMM model meshed by 10 nodes tetrahedral solid elements. In this model, there are 2924 elements meshed by the ANSYS software automatically.

In static analysis, two materials, Aluminum and Invar, are used respectively to compare the deformations caused by gravity. Table 4 shows the results of static analysis. The maximum deformation in static analysis occurs near the center of Z-stage. Table 4 shows that Aluminum is better than Invar according to the results of static analysis.

Table 4. Static analysis results

Deformation (nm)	Aluminum	Invar
Maximum deformation	74.49	109.55
Center of X-stage	24.81	38.48
Center of Z-stage	65.83	97.66

In thermal deformation analysis, we also use two materials as comparison. The ambient temperature is set to 20°C. Figure 5 shows the temperature-time curves for thermal balance at the middle of Z-stage. It indicates that the temperature of Aluminum reach the steady state faster than Invar. Table 5 shows the thermal deformations of the structure as the temperature changes to 21°C. The maximum deformation dues to temperature change arise from the top of bridge Table 5 shows that Invar is better than Aluminum according to the results of thermal deformation analysis and thermal effect is more important in Nano-CMM.

Table 5. Thermal conduction analysis results

Deformation (nm)	Aluminum	Invar
Maximum deformation	3784.0	1401.85
Center of X-stage	3210.5	1009.1
Center of Z-stage	2381.5	372.22

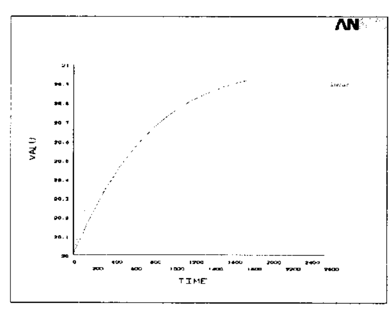

Figure 5. Result of thermal balance

For Aluminum, the maximum thermal deformation is 50.3 times larger than the maximum deformation in static analysis. For Invar, it is 12.8 times. It means that the low-expansion alloy, Invar, can reduce the effect of temperature change efficiently. Therefore, we use the Invar as the material of the Nano-CMM structure.

6. Conclusions

From the design and analysis of the Nano-CMM machine, the following conclusions are obtained: The x/y/z stages are developed with high resolution. Each stage is directly driven by a PCLM. Each stage is guided and supported by a set of Cross Roller Guide. The whole structure of Nano-CMM is made up of the Invar material except the granite base. There are 6 feasible solutions found by the developed expert system tool, each feasible solution satisfies the specified design constraints. The solid model of Nano-CMM structure is generated automatically. In the structural and thermal deformation analysis, the maximum deformation is 1401.85 nm which can be compensate by the software to meet the specifications of Nano-CMM.

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摘 要

本計畫為整合型計畫"奈米級三次元量測儀研製"之"子計畫一：奈米級三次元量測儀結構之設計與分析(I)."本年為三年計畫之第一年,主要目的為設計與分析一奈米級三次元量測儀結構之初型. 其量測範圍在 x 軸, y 軸及 z 軸方向分別為 20mm, 20mm 及 10mm. 結構設計部份可分初始設計和細部設計兩過程:初始設計階段首先根據產品之性能需求訂定產品規格, 接著經由專家系統之協助進行概念設計以決定結構主要尺寸. 並利用參數式自動繪圖技巧繪出概念設計結果之實體模型. 在細部設計階段則經由結構靜態分析及熱變形分析等, 利用調整細部設計尺寸使滿足各種結構特性要求.

關鍵詞:奈米級三次元量測儀結構, 專家系統, 有限元素分析.

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