Form 2

Dissertation Abstract

Report no.	(Course-based) No. 1104	Name	Md Helal An Nahiyan
Dissertation title	**Multi-Dimensional Force Measurement Instrument Using Zero-Compliance Mechanism** (ゼロコンプライアンス機構を利用した多分力測定装置の開発)		

Abstract

This dissertation presents the research work conducted for the degree of Doctor of Philosophy (PhD). The research is entitled "Multi-Dimensional Force Measurement Instrument Using Zero-Compliance Mechanism".

Force measurement is immensely important in many industrial applications and scientific researches, especially in the development of new materials, where the assembly of materials and molecules is essential. Measuring microforce is inevitable in the current technical world of micro-assembly and micromanipulation. Most of the traditional force measurement methods estimate force from the displacement of the point of force which causes change in gap between the source of force and the point of force. In this research, a novel multi-dimensional force measurement instrument is designed and developed for measuring force in mN (millinewton) and μN (micronewton) range. To avoid the change of gap between the source of force and the point of force, force is measured by considering the basic principle of zero-compliance mechanism in every direction. The thesis consists of three major parts: theoretical analysis, development of the instrument and demonstration of experimental results.

Zero-compliance principle is implemented in force measurement by using double series magnetic suspension system. In the double series magnetic suspension, a single electromagnet levitates two floators. The control current of the electromagnet directly controls the movement of the first floator and the permanent magnet attached under the first floator regulates the motion of the second floator. Thus, the second floator is indirectly controlled by the electromagnet. Following the similar structure of double series magnetic suspension system, multi-dimensional force measurement instrument is developed by connecting two suspensions in series in every direction. One of the suspensions (first floator) is denoted as detection point and the other one (second floator) is denoted as point of force. In each axis, both the detection point and the point of force are suspended from the base frame through leaf springs to restrict their motions in single dimension and to prevent the rotation of the point of force. In such levitated condition, when external force is applied at the point of force, it displaces from its original position. The effect of applied force on the point of force is cancelled to maintain its

position by displacing the detection point in the same or opposite direction of the applied force. The motion of the detection point is controlled in such a way that it displaces proportionally to the applied force. Thus, applied force is estimated from the displacement of the detection point and zero-compliance is accomplished at the point of force.

For vertical axis force measurement operation, an electromagnet is affixed at the top base frame to directly control the motion of the detection point. A permanent magnet is installed under the detection point. The attractive force of the permanent magnet operates the movement of the point of force. In contrast to the electromagnet used for vertical direction force measurement, voice coil motors are used in the force measurement of the two lateral directions. Voice coil motors are used as linear actuator to reduce the nonlinearity effect of the permanent magnet in force measurement but to avoid excessive structural complexity, electromagnet and permanent magnet are used only in the vertical direction. In each axis, two voice coil motors are used to control the movement of the detection point and the point of force. The control system is designed and implemented to control the movement of the point of force and the detection point in the vertical and two horizontal directions force measurement. To accomplish zero-compliance at the point of force of vertical axis, PID control is applied to the point of force and PD control to the detection point to make the system stable. In contrast to the vertical direction, there is no permanent magnet in the lateral directions to generate negative stiffness. Thus, an additional PD control is imposed in between the detection point and the point of force to act as virtual spring with positive stiffness. As a result, the detection point displaces in the direction of the applied force in the vertical axis force measurement and in the horizontal direction force measurement, the detection point displaces in the direction opposite to the applied force.

The effectiveness of the proposed instrument in multi-dimensional force measurement is demonstrated by the experimental results of the horizontal and vertical direction force measurement. Force is measured in mN (millinewton) and μN (micronewton) range and in static and dynamic condition. The experimental results validate the zero-compliance condition at the point of force and demonstrates that force can be estimated from the displacement of the detection point with good linearity and one direction measurement has almost zero interference with the other directions.