APPLICATION OF NANO-CONTACT MECHANICS MODELS IN MANIPULATION OF BIOLOGICAL NANO-PARTICLE

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Abstract—Contact mechanics is related to the study of the deformation of solids that meet each other at one or more points. The physical and mathematical formulation of the problem is established upon the mechanics of materials and continuum mechanics. Contact mechanics gives essential information for the safe and energy efficient design of various systems. During manipulation process, contact forces cause deformation in contact region which is significant at nano-scale and affects the nano-manipulation process. Several nano-contact mechanics models such as Hertz, DMT (Derjaguin, Muller and Toporov), JKR (Johnson, Kendall, Roberts), BCP (Burnham, Colton, Pollock) MD (Maugis, Dugdale), COS (Carpick, Ogletree, Salmeron M ), PT (Pietrement, Troyon), and Sun have been applied as the continuum mechanics approaches at nano-scale. Recent studies show interests in manipulation of biological cells which have different mechanical properties. Low young modulus and consequently large deformation makes their manipulation sensitive. In this article contact mechanics models are used for biological cell, in air and liquid environment, then results will be compared with Tatara contact mechanics model. Since biological cells are mostly modeled as visco- or hyper-elastic materials, this model will be more compatible with their condition.

Keywords—contact mechanics models, biological cell, nano-manipulation, large deformation.

I. INTRODUCTION

It is now well known that biological cells sense the mechanical changes in their environment. The out coming response to mechanical changes is deterministic in controlling the cell’s action. Realizing the mechanical behavior of the cell, first needs a precise knowledge of both force and stress distribution within the contact area.

This feature is crucial since determining the force/stress of various types of load can dictate the mechanical cell response (Girot et al., 2006).

Pursuant to literature, much endeavor has been dedicated to recognize the mechanism by which the cell perceives the external mechanical actuations. In fact, many methods have been developed, whether to mechanically stimulate cells, sense force distributions or to determine the mechanical properties of the cells (Lukkari and Kallio, 2005). Among these methods, the most promising ones involve Scanning Probe Microscopy (SPM) techniques for the nano-scale level (Girot et al., 2006).

However, the Atomic Force Microscope (AFM) has become a commonly used tool in the field of bioscience.

The original work in contact mechanics dates back to 1882 with the publication of the paper “On the contact of elastic solids” by Heinrich Hertz. It gives the contact stress as a function of the normal contact force, the radii of curvature of both bodies and the modulus of elasticity of both bodies (Johnson 1985).

It was not until nearly one hundred years later that Johnson, Kendall, and Roberts found a similar solution for the case of adhesive contact. Johnson et al. model came to be known as the JKR model for adhesive elastic contact.

Further advancement in the field of contact mechanics in the mid-twentieth century may be attributed to names such as Bowden and Tabor. Bowden and Tabor were the first to emphasize the importance of surface roughness for bodies in contact. The works of Bowden and Tabor yielded several theories in contact mechanics of rough surfaces (Tatara 1991).

However, these developments are confined to the case of small deformation and based on point or line contact of half-space elastic body model and problems of large deformations in simple compression of elastic spheres as well as elastic bodies have remained unsolved. Tatara (1991) proposed a new model which was the extension of Hertz mechanics model for hyper-elastic material like rubber.

The organization of this article is as follows: interaction forces which are important in liquid environment are studied and their effects in contact mechanics models are applied. Then small deformation contact models for gold nano-particle and biological nano-particle will be compared. In addition Tatara large deformation model will be simulated for two different kinds of biological cells and its results will be compared with small deformation models.

II. THEORY

A. Contact Mechanics Models

Contact mechanics models are used in different literature. But since these models have been developed for special conditions their application in other situation would encounter problems and limitations. Most models are applicable in small deformations, but a large deformation model will be investigated in this paper which invokes a non-linear elastic response and a large deformation formulation. In this model the influence of adhesion and the effects of interfacial friction are not consid-