SIMULATION STUDY OF LEAD BALL CONTACT WITH PIEZOCERAMIC DISC TYPE ACTUATORS

K. VISWANATH ALLAMRAJU

Department of Mechanical Engineering, Institute of Aeronautical Engineering, Dundigal, Hyderabad, India

ABSTRACT

Vibration energy harvesting is playing a key role in generating electricity. It also acts as a cram to replace the lithium and lead acid batteries. It is one of the methods of self and continuous supply of electric energy to low power devices. When the piezoelectric transducers are in the direct piezoelectric effect phenomenon, it leads to generate electrical voltage. When the mechanical pressure is applied by external means, the contact stress should be within the limits of fatigue strength of transducer, therefore, in this paper presented the simulation study of lead cylinder contact with piezoceramic disc type actuator in relation to demonstrate the principal of direct piezo electric effect. Maximum contact stress is observed under very low deflection of the piezoelectric disc type actuator during simulation.

KEYWORDS: *Hertzian Stress; Electricity & Contact Stress*

Received: Jan 12, 2018; **Accepted:** Feb 02, 2018; **Published:** Mar 06, 2018; **Paper Id.:** IJMPERDAPR201854

INTRODUCTION

When the mechanical pressure is applied on the lead zirconate titanate, electric charge is generated as an output under the process of dynamic strain development. This is called the principle of direct piezoelectric effect. In 1881, Curie brothers discovered the direct piezoelectric effect on natural perovskite material such as quartz. In the 19th century, man-made piezoelectric materials were developed by the researchers for maximizing the power. Even though research work is done in generating the power by using clamped free beam type energy harvesters, but the generation of power is in micro level, therefore, it is a great concern for designing the energy harvesters to optimize the output power for charging the wireless sensor nodes. In relation to the design of energy harvester when the load impacts the lead zirconate titanate disc type actuator, electricity can be observed. The amount of generation of electricity depends on the contact stress. Erturk and D. J. Inman described the mathematical model of cantilevered energy harvester by using Rayleigh ritz method [1-4]. Y. C. Shu and I. C. Liende monstrated the optimal power analysis of AC-DC conversion for cantilevered energy harvester [5].

When two bodies with curved surfaces are in contact under a force, point or line contact between these bodies changes to area contact, and three-dimensional stresses are developed. These stresses are contact stresses. A knowledge of contact stresses is important in calculating the strength of bearings, gear and worm drives, ball and cylindrical rollers, and cam mechanisms. Typical failures are seen as cracks, pits, or flaking in the surface material. Calculation of stresses and corresponding deformation at a contact point between rolling elements and raceways employs elasticity relations established by Hertz in 1881. Hertz's theory considers the contact of two bodies with curved surfaces under force W. There is a theoretical point or line contact between the rolling elements and races. However, due to elastic deformation, the contact area between two curved bodies in point contact has an elliptical

shape. In machinery that involves severe shocks and vibrations, the contact stresses can be very high.

R. Pandiyarajan et. al presents to determine the contact stress of large diameter ball bearings using analytical and numerical methods [6]. The large diameter bearings (diameter >400mm) are of great importance in complex engineering mechanisms such as Aircraft gas turbines, Rolling Mills and Nuclear Reactor etc., in which varying load and critical environmental conditions lead to the failure of such bearings. This paper presents to determine the contact stress of large diameter ball bearings using analytical and numerical methods. In analytical method, the contact stress is found out using the Hertzian Elliptical Contact Theory. The finite element analysis is also performed to predict contact pressure in ball and raceway. Comparison of the results is made at the end. The comparison of the total deformation of thrust ball bearing & contact stress b/w ball & raceways & its effect on fatigue life of thrust ball bearing done by Prabhat Singh et al. [7-8]. When two components with curved surfaces are in contact under a force, point or line contact between these components changes to area contact, and three-dimensional stresses are developed. These stresses are contact stresses. The knowledge of contact stresses is important in calculating the strength of bearings, gear and worm drives, ball and cylindrical rollers, and cam mechanisms. Typical failures are seen as cracks, pits, or flaking in the surface material. Calculation of stresses and corresponding deformation at a contact point between rolling elements and raceways employs elasticity relations established by Hertz in 1881. Hertz's theory considers the contact of two bodies with curved surfaces under force W. There is a theoretical point or line contact between the rolling elements and races. However, due to elastic deformation, the contact area between two curved bodies in point contact has an elliptical shape. In machinery that involves severe shocks and vibrations, the contact stresses can be very high. Assumptions are as follows:

The size of the contact area is small compared with the size of the curved bodies.

- Both contacting surfaces are smooth and frictionless.
- The gap, h between the un-deformed surfaces may be approximated by an expression of the form $h = Ax^2 + By$ (e.g. the contact between spheres, cylinders, and ellipsoids).
- The deformation is elastic and can be calculated by treating each body as an elastic half space.

$$P_{max} = \frac{3 W}{2 \pi a b}$$

There are different types of contacts such as contact between a sphere and a half – space, contact between two spheres, contact between two crossed cylinders of equal radius, contact between a rigid cylinder with flat ended and an elastic half space, contact between a rigid conical indenter with flat ended and an elastic half space, contact between two cylinders with parallel axis and bearing contact.

Material properties

Body 1: Select material, Young's modulus: 14 GPa, Poisson's ratio: 0.42, Maximum stress: 18 MPa

Body 2: Select material, Young's modulus: 51 GPa, Poisson's ratio: 0.31, Maximum stress: 140 MPa

Dimensions and contact type

☐ Circular/elliptical contact

Body 1: Radius 1x: 4.4 mm, Radius 1y: Infinite, Roughness: 0 um, Length: 5 mm, D1: mm, D2: mm

Body 2: Radius 2x: Infinite, Radius 2y: Infinite, Roughness: 0 um

Results

Half contact width b: 7.675 um, Hertz contact stress: 11.4 MPa, Max. shear stress 1: 3.42 MPa, Max. shear stress 2: 3.42 MPa, Von Mises body 1: 5.99 MPa, Von Mises body 2: 6.31 MPa, Max. shear stress: Z=6.033 um, Max. Von Mises stress: Z=5.705 um

Contact

Normal: 0.6967 Newton, Traction: 0 Newton, ☐ Slip

Settings

Units: ☒ SI ☐ Imperial, Language: English

Figure 1: Parameters for Contact Stress Analysis of PZT Disc Transducer

In this paper, the contact between lead material cylinder with flat infinite radius body is considered. The classical theory of contact focused primarily on non-adhesive contact where no tension force is allowed to occur within the contact area, i.e., contacting bodies can be separated without adhesion forces. Several analytical and numerical approaches have been used to solve contact problems that satisfy the no-adhesion condition. Complex forces and moments are transmitted between the bodies where they touch, so problems in contact mechanics can become quite sophisticated. In addition, the contact stresses are usually a nonlinear function of the deformation. To simplify the solution procedure, a reference is usually defined, in which the objects (possibly in motion relative to one another) are static. They interact through surface tractions (or pressures/stresses) at their interface. The following assumptions are made in determining the solutions of Hertzian contact problems: The strains are small and within the elastic limit. The surfaces are continuous and non-conforming (implying that the area of contact is much smaller than the characteristic dimensions of the contacting bodies). Each body can be considered an elastic half-space. The surfaces are frictionless. In this paper presented the contact stress is developed when the impact mass touches the piezoelectric disc type actuator through simulation. Figure.1 describes the input parameters and output parameters during the contact of the lead cylinder to the piezoelectric disc type actuator. The lead cylinder is considered as body1 and the piezoelectric disc is considered as body2. The poison's ratio, modulus of elasticity and maximum stress of body1 are 0.42, 14 GPa and 18MPa. Whereas for body2 are 0.31, 51GPa and 140Mpa. The normal stress is plotted on X- axis and the deflection in micrometer is plotted in negative Y- axis. The behaviour of contact stress in relation to applied load and deflection is non-linear.

MATHEMATICAL MODELING OF ENERGY HARVESTER (EH)

Figure 2 shows the mathematical model of the lumped mass energy harvester.

Figure 2: Lumped Mass Model of EH

According to Hertz's theory, the equation of the pressure distribution in an ellipsoidal contact area in a ball bearing is

$$P_{max} = \frac{3W}{2\pi ab} \quad (1)$$

$$D = d\sigma + \varepsilon E \quad (2)$$

$$P(\omega) = \frac{mY^2\omega^3 \left(\sqrt{1 + \left(2\xi \frac{\omega}{\omega_n} \right)^2} \right)}{\sqrt{\left(1 - \frac{\omega^2}{\omega_n^2} \right)^2 + \left(2\xi \frac{\omega}{\omega_n} \right)^2}} \quad (3)$$

The equations (1) to (3) describes the contact stress under elliptical contact, output electrical discharge at definite stress and the input mechanical power.

RESULTS AND DISCUSSIONS

Figure 3: Hertz Contact Stress in Z Direction of PZT Disc Transducer

The radius of lead cylinder is 4.4 mm and the applied normal force 0.6867N. The observed Hertz contact stress is 11.4MPa. These values are shown through the graph of normal deflection in Z-direction and the Hertz contact stress in Figure.3.

Figure 4: Variation of Contact Stress Under Deflection of PZT Transducer

Figure.4 describes the Hertz contact stress's variation in relation to deflection of the piezoelectric disc type transducer. For calculating the contact stress, various input parameters and mechanical properties of PZT disc type transducer and impact mass are considered. Hertz contact stress is inversely proportional to the deflection of the piezoelectric disc type transducer. Mathematical relations are considered for stress calculation. Hertzian contact stress theory plays a very important role for understanding the contact mechanics of two bodies.

CONCLUSIONS

The simulation study of contact with lead cylinder with PZT disc type actuator is done in order to know the operating loads. Lead material is good at developing a more dynamic strain in the piezoelectric disc. If the contact stress is not within the limit of fatigue strength, which leads to develop the shear stresses between the bondage areas, thus leads to damage the actuators.

REFERENCES

1. Erturk and D. J. Inman, (2009). An experimentally validated bimorph cantilever model for piezoelectric energy harvesting from base excitations, *Smart material and structures*, 18, pp.1-20.
2. Erturk and D. J. Inman, (2008). A distributed parameter electromechanical model for cantilevered piezoelectric energy harvesters, *Journal of vibration and acoustics*, 130, pp.041002-15.
3. K. ViswanathAllamraju & SrikanthKorla, (2017). Design and Performance of a Prototype Clamped Free Beam Novel Energy Harvester for low power applications, *Materials Today: Proceedings* 4, pp. 3542–3548.
4. K. ViswanathAllamraju & SrikanthKorla, Review and scope of scavenging micro energy using piezoelectric materials, *International Journal of Advanced Materials Manufacturing & Characterization* Vol.4 Issue 2 (2014), pp.96-100.
5. Y C Shu and I C Lien, (2006). Analysis of power output for piezoelectric energy harvesting systems, *Smart Mater. Struct.* 15, pp.1499–1512.
6. Pandiyarajan. R, Starvin. M. S, Ganesh. K. C, (2012). Contact Stress Distribution of Large Diameter Ball Bearing Using Hertzian Elliptical Contact Theory, *Procedia Engineering* 38 pp.264-269.
7. Prabhat Singh, Prof. Upendra Kumar Joshi, (2014). Fatigue Life Analysis of Thrust Ball Bearing Using Ansys, *International Journal of Engineering Sciences and Research Technology*, pp.2277-9655.
8. TEDRIC A. HARRIS, (2001). *Rolling Bearing Analysis*, 4th edition, John Wiley and Sons Inc., New York.