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CONTRIBUTION TO THE PROBLEM OF NANOTUBE’S INTERACTION WITH METAL CONDUCTORS

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ABSTRACT
Nanotechnology grabs with rapid steps, but there are not a lot of voices asking questions about safety and about interaction with other systems and environment. Due to recent advances in nanotechnology, NEMS can be expected to play very important role in industry, construction, shipbuilding, transportation, medicine, space exploration, military, etc. NEMS can be consisted (either partly or totally) of carbon-based nanotubes (CNT). How CNT interacts with the environment is vital in future building of more complex systems and also in interaction between nanotechnological and “normal” parts of equipment or environment. This part is not well covered and researched. Since many objects and equipment consist of metal conductor, it is interesting to see what happens when metal is in the nanotube’s proximity. This paper describes such case. The contribution of this paper is in showing that nanotechnology product can make material damage or even endanger human lives if we do not standardize safety requirements. These requirements should cover every thinkable way of making damage or endanger lives.
Keywords: NEMS, electrostatic charge, carbon nanotube, capacitance, safety.

1. INTRODUCTION
Nanotechnology will impact entire transportation technology, including marine and naval technology. Although, there is carbon nanotube (CNT) nanotechnology, molecular nanotechnology also exists and it assumes manufacturing of nanosystems at molecular level [1]. Many experimental molecular elements exist today [2]. These are molecular conductors, insulators, diodes, transistors, resistors, switches, etc. The two mentioned nanotechnologies are not compatible, because the worst characteristic of CNT is their chemical inertia, which is not the case in molecular nanotechnology based on organic molecules. NEMS can be build by any nanotechnology. Key elements of NEMS, therefore, can be carbon-based nanotubes. NEMS can be nanotweezers, RAM, nanoreleys, rotation actuators, feedback-controlled nanocantilever, etc [3 - 7]. Crucial characteristic of nanotubes is cold emission of electrons. If we have nanotube attached to the surface of conductive substrate (thin film), the phenomena occurs when voltage is applied between film and metal electrode. Electron flow in this case can be compared to hot emission in cathode-ray tube. Possible application is obvious: development of paper-weight TV, emission of electrons, measurement, etc. However, we will show that there are dangers also. Nowadays, there are three major ways of manufacturing nanotubes. The disadvantages of these ways are very diverse length range of produced nanotubes, a lot of defected specimens and different technological and electrical characteristics. All of these occur because of the limitations of the nanotube manufacturing [8].

This article deals with electrostatic charge distribution on CNT as a vital part of onboard nanotechnological devices. Charge is expressed in the simulation as line charge per length (λ) of CNT. Since, electric charge can be a trigger to initialization of fire in different types of merchandise ships, it is obviously dangerous to use nanodevices without deep investigation on safety requirements.

2. PROBLEM DESCRIPTION

To model electromechanical characteristic, the elastic forces, the electrostatic forces and van der Waals forces have to be taken into count. The classical continuum mechanics theory is applicable for elastic forces to CNT devices. The electrostatics forces are computed by capacitance model. For the van der Waals forces, a model based on Lennard-Jones potential theory was employed in [9]. Every ship must have grounding. Ship's hall is, therefore, object of reference potential. Zero-value potential is, therefore, potential of ship's hall, or, to be more precise, metal part of it. To evaluate interaction between CNT (as part of future ship's device) and ship's hall, and reduce possibilities for "galvanic" corrosion (differential of potential between two conductors made from different materials causes unwanted current flow if both are in the second type conductor, i.e. see water), we will simplify model with several assumptions. Freestanding conductive CNT is in the three-dimensional space. CNT of radius R and length L is spaced from ground plane by a distance H. Usual length is between 1000 and 4500 nm, usual radius R = 20 nm and distance from the ship's hull between 500 and 1500 nm (for calculations in this article). Coordinate system as placed as in Fig. 1. In comparison to CNT dimensions, ship's hall can be seen as infinite plane of reference potential.

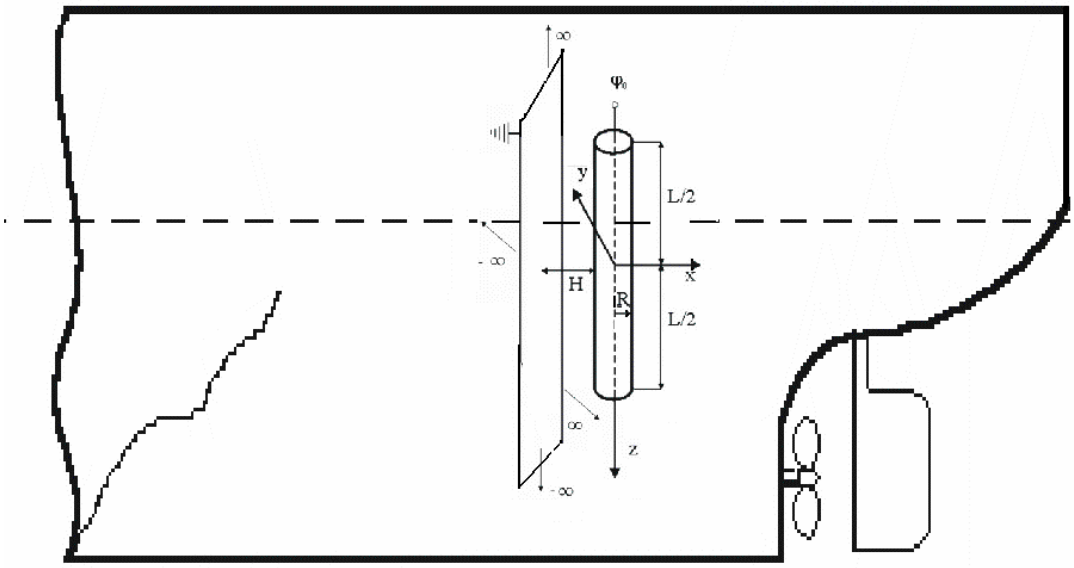


Figure 1. Geometry of the simplified problem.

For an infinitely long, perfectly conducting plane, which stands for grounded ship, the charge per unit length (λ) is expressed as [10, 11]:

$$\lambda = \frac{2\pi\varepsilon_0\varphi_0}{a\cosh\left(1+\frac{H}{R}\right)}. \qquad \ldots (1)$$

where φ_0 is the potential, ε_0 permittivity of vacuum (permittivity of the air is approximately equal to the permittivity of the vacuum). Boundary element method can be used to solve the electrostatic governing equations, similar as in methods in [12 – 15]. The electrostatic potential in given by:

$$\nabla^2\varphi = 0\,. \qquad \ldots (2)$$

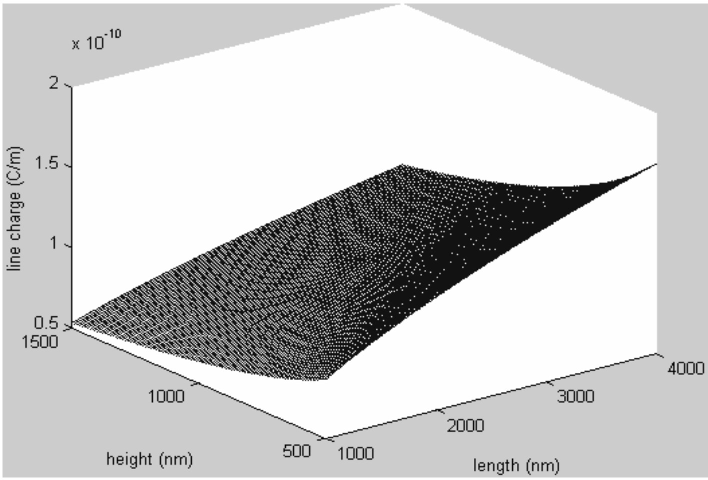
where φ is the potential and the region of interest belongs to the domain exterior to the conductor and its image. Since $\vec{E} = -grad\ \varphi$ and $\rho_A = \varepsilon_0 \vec{E}\vec{n}$, where $\vec{n}$ is unit vector in perpendicular direction to the observed point. The total electric charge on the nanotube is:

$$Q = \oint_A \varepsilon \cdot \vec{E} \cdot \vec{n} \cdot dA . \qquad \text{... (3)}$$

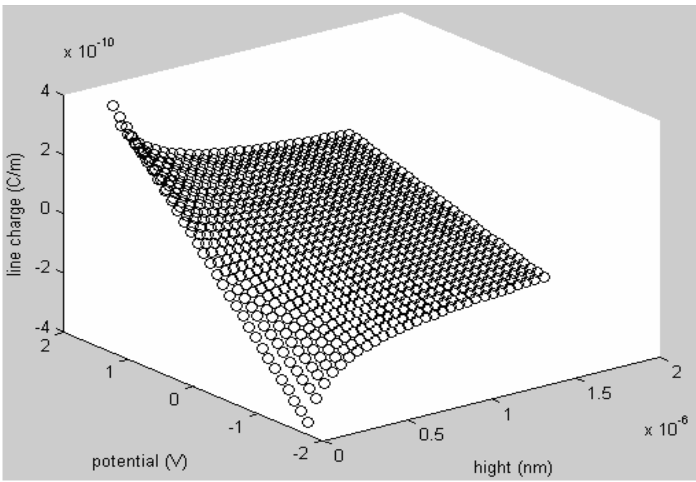
where A is the total surface area of the nanotube cylinder.

3. RESULTS

Results are obtained in Matlab 7 program package for numerical integration of (3) and numerical simulation of line charge. Results are partly comparable with [14, 15]. References shows 2-D graphs, which cannot be of use if more variables are present. Moreover, we showed dependencies on potential, while in references potential is unitary voltage.



a)



b)

Figure 2. Results of numerical simulation: a) line charge dependence on distance from the hull and length of the CNT, b) line charge dependence on potential and distance from the CNT.

Designation height in Fig. 2 means the distance from the ship's hall. We took distances ranged from 500 to 1500 nm. Fig. 2. shows that CNT cannot be safely placed on the ship's hall or in the close proximity of the hull. Triples of distance to the hull, CNT's length and line charge are shown in Fig. 2.a. The Fig. 2.b. shows potential's contribution to line charge with dependence to distance from the hull. The goal is to warn and to, eventually, predict some problems in future development of technology.

4. CONCLUSIONS

Future advances in technology lead to application of nanotechnology and its interaction with the environment. There are a lot of uncertainties regarding CNT interaction with the environment and the possible dangers [16]. Electrical charge from the CNT can be cause of shortcuts, fires or discharges, which can endanger human lives and the environment. There is no need to tell the details about what happens if that occurs aboard chemical or oil tanker. This area, therefore, must be standardized in the close future. The CNT can be trigger for dangerous Galvan corrosion of ship's hull also. Additional danger is in the cold emission from CNT, which was not mentioned in the article due to space available.

We used simplified model where infinite plane stands for metal conductor/construction element, and finite length cylinder stands for freestanding CNT. So, the charge distribution on a biased finite length CNT cylinder above an infinite grounded plane is investigated. The relationship between distance from reference plane and electric charge is studied by classical electrostatics.

It is shown on the small example that could occur that we must be very careful in implementation of nanotechnology. The contribution of this paper is in showing that nanotechnology product can make material damage or even endanger human lives if we do not standardize safety requirements. These requirements should cover every thinkable way of making damage or endanger lives. So we employ colleagues to take attention to these everyday situations.

5. REFERENCES

[1] Vujović, I., Kulenović, Z., Kuzmanić, I.: Present Limitations in Application of Nanotechnology for New Design Solutions in Industry, Proceedings of RIM 2003, Bihać, BIH, pp. 775-780., 2003.,

[2] Jaram, V.: What is nanotechnology? (in Croatian), Glasilo HZN, Vol. 1, No. 2, pp. 12-13., 2005.,

[3] Akita, S. et al.: Nanotweezers Consisting of Carbon Nanotubes Operating in an Atomic Force Microscope, Applied Physics Letters, Vol. 79, pp. 1691-1693., 2001.,

[4] Rueckes, T. et al.: Carbon Nanotube-Based Nonvolatile Random Access Memory for Molecular Computing, Science, Vol. 289, pp. 94-97., 2000.,

[5] Kinaret, J., Nord, T., Viefers, S.: A Carbon-Nanotubes-Based Nanorelay, Applied Physics Letters, Vol. 82, pp. 1287-1289., 2003.,

[6] Fennlmore, M. et al.: Rotational Actuactor Based on Carbon Nanotubes, Nature, Vol. 442, pp. 408-410., 2003.,

[7] Ke, C.-H., Espinosa, H. D.: Feedback Controlled Nanocantilever NEMS Device, Applied Physics Letters, Vol. 85, 2004, pp. 681-683

[8] Vujović, I.: Materials in Electrotechnics - Lectures, http://www.pfst.hr/~ivujovic/pred06.ppt,

[9] Dequesnes, M., Rotkin, S. V., Aluru, N. R.: Calculation of Pull-in Voltage for Carbon-Nanotube-Based Nanoelectromechanical Switches, Nanotechnology, Vol. 13, pp. 120-131.,

[10] Hayt, W., Buck, J.: Engineering Electromagnetics, 6th edition, McGraw-Hill, New York, 2001.,

[11] Ke, C., Espinosa, D. H.: Numerical Analysis of Nanotube-Based NEMS Devices – Part I: Electrostatic Charge Distribution on Multiwalled Nanotubes, Journal of Applied Mechanics, Vol. 72, 2005.,

[12] Spyrakos, C. C.: Finite Element Method in Engineering Practice, Algor Publishing Division, Pittsburgh, PA, ISBN 0-9652806-0-8, 1996.,

[13] Spyrakos, C. C., Raftoyiannis, J.: Linear and Nonlinear Finite Element Method in Engineering Practice, Algor Publishing Division, Pittsburgh, PA, ISBN 0-9652806-2-4, 1997.,

[14] Vujović, I., Kulenović, Z., Kuzmanić, I., Kezić, D.: Stress Intensity Factor, Energy Distribution and Forces Acting on Crack in Piezoelectric Robots' Sensors, Chapter 52 in DAAAM International Scientific Book 2006, B. Katalinic (Ed.), Published by DAAAM International, ISBN 3-901509-47-X, ISSN 1726-9687, Vienna, Austria, DOI: 10.2507/daaam.scibook.2006.52,

[15] Kuzmanić, I., Kulenović, Z., Vujović, I.: Nanotubes in NEMS – Impact to the Marine Technology, Proc. of the 48th ELMAR-2006, pp. 243-246., Zadar, Croatia, 2006.,

[16] Shelley, T., "Nanotechnology, New Promises, New Dangers", Global Issues, Zed Books, London, UK, ISBN 1-8-4277-686-X, 2006.