Analysis of Temperature Effect on the Mass Sensing Capabilities of Boron Nitride Nanotubes

Dinesh Deshwal1*, Monika Deshwal1, and Nitin Gaur1
1Mechanical Engineering Department, Shree Guru Gobind Singh Tricentenary University, Gurugram-122505.
*E-mail: dinesh_fet@sgtuniversity.org

Abstract. In the periodic table, it is mentioned that the closer atoms or just intermediate atoms to Carbon are Boron & Nitrogen. Now Scientists also confirmed that Boron & Nitrogen can form a perfect nanotube structure. Boron Nitride Nanotube (BNNT), possesses a similar tubular nanostructure as carbon nanotube (CNT) but it is composed of the B-N atoms hexagonally. BNNT possesses various properties & its properties can show different-different behavior according to the conditions & environment. Here we are discussing the temperature & its effects on the mass sensing capabilities. Along with this, the various configurations of the BNNTs are also discussed simultaneously. Due to their superior properties & high effectiveness, these are widely used all over the world.

Keywords: Boron Nitride Nanotubes; Tubular structure; Mass Sensing Capability; Carbon Nanotubes; Temperature effect.

1. Introduction
Boron nitride nanotubes (BNNTs) are best known as building blocks of carbon nanotubes (CNTs) but with advanced and advanced properties. Although BNNT has similar structural properties, they are very different in their physical and chemical properties [1]. Research into the field of nanostructures was carried out especially soon after the discovery of CNT in the 1990s by Iijima [2]. The main reason why the excessive interest in the nanostructure sector is because it is evident that when the size of the object decreases it goes to the Nano on the scale (Zeptogram scale) and shows a higher and distinct growth in its material properties [3]. Since 1990, after the discovery of many CNT studies, theoretical or experimental studies have been conducted on all aspects of carbon nanotubes.

In addition to the same structure, BNNT exhibits various physical properties such as CNT actions such as metals or semiconductors, and BNNT acts like an insulator with a large 6.eV bandgap [4]. BNNTs withstand high temperatures up to 8000 °C in an open area i.e. in the air. BNNTs are physically and chemically stable at high temperatures [5]. The effectiveness and possible use of BNNTs in composites and bio drugs at that time will be discussed. It is noteworthy that the electrical protection of BNNTs seemed to have delayed the use of systems in advanced switching when operating with metallic quantum and graphene dots. In any case, electrical gadget systems will not be tested here in this first phase of testing.

The properties of the hexagonal boron nitride (h-BN) & graphite and the core or parent material of CNT’s (carbon nanotubes) and BNNT’s (boron nitride nanotubes) are very similar [6]. Both of these are horizontal objects made up of a six-dimensional short section; Graphite has no carbon particles at all in the grid concentration, while h-BN is formed by exchanging boron ions with nitrogen. In the plane grid, the constant for graphite & h-BN is 2.46 Å & 2.50 Å respectively. The slightest difference between
these items is their layer of layers. In h-BN, the layers are well-engineered & aligned with the principle that boron iotas in a single layer are formally beginning within the arch of nitrogen particles in the neighboring layers and solid wire reinforcement. Stacking is acutely different in graphite, the hexagons are countervailed and don't lie on each other's head. Multi-player allocation estimates: 3.35 Å for graphite and 3.33 Å for h-BN [7].

In contrast to carbon nanotubes, we have electrical properties that state that they can be metal or semiconducting material depending on their structure [8]. BNNTs are required to have more than 4 band holes with a visible width of more than 1 nm. The fixed band structure of a (4,4) BNNT. This particular cylinder has a backhanded hole. The band structure is very similar to a single layer of h-BN but has one outstanding distinct difference. There is a band closes to the point at the lower part of the conduction band, which has the power to propagate near the free electron gas & this whole state has been named the "Nearly Free Electron" (NFE).

The nonlocal piezo elasticity tube-shaped shell hypothesis was utilized as an establishment and viscous liquid course through the double-walled boron nitride nanotubes (DWBNNTs) [9]. And afterward, the nonlinear vibration and insecurity of these inserted nanotubes were analyzed under limited conditions. In view of Winkler Pasternak, the versa medium is reenacted and it was assumed that the layers are interconnected by van der Walls (vdW) power which has been determined taking Lennard–Jones model as the establishment. Donnell's hypothesis was the establishment of the nonlinear strain. For accomplishing removal, differential conditions, and electric potential; Hamilton's rule was used.

To figure the critical liquid velocity and the nonlinear recurrence at the two finishes of the DWBNNTs, the Differential Quadrature Technique (DQT) was utilized. It was discovered that determinations, for example, viewpoint proportion, vdW power, nonlocal boundary, and flexible medium's modulus had enormously influenced the DWBNNT's vibration and shakiness while the liquid consistency had a trifling effect. Specialists could utilize the diagnostic arrangements discovered here for planning the nano and miniature electro-mechanical structures containing BNNTs through which thick liquid implanted in an elastic medium is streaming.

The Single-walled boron nitride nano-tubes-based ultrasensitive mass sensor was introduced taking reproduction dependent on the sub-atomic auxiliary mechanics into thought as shown in fig 1. SWBNNT's limited component model was shaped with 3-D (three-dimensional) pillar components and point masses. At that point, the organic items and compound atoms of the zeptogram scale were contemplated dependent on the mass and thunderous recurrence [10].

Figure 1. Example of Boron Nitride Nanotube.
The result of this strategy was confirmed with the effectively distributed results dependent on atomic mechanics. The reproduction dependent on sub-atomic auxiliary mechanics was beneficial for the recreation of the nanotube's nuclear structures. The mass sensor arrangement recommended here demonstrated colossal affectability at the atomic level which makes it best for utilizing continuously detecting for watching wellbeing.

To study the various properties of the boron nitride nanotube especially electronic properties when BNNTs interacting with different materials like gold metals, nickels, palladium & titanium. For this different configuration of BNNTs like, (3,3), (4,2), (5,2) & (6,0) & calculations based on the density functional theory. Interaction of metals with BNNTs different configurations is carried out via intercalation, nitrogen substitutional doping, boron substitutional doping & adsorption. The bandgap was studied & which state of orbital has high contribution is studied then it is concluded that BNNT possesses semi-metallic properties in interaction with these metals & d orbital has a higher contribution [11].

Various researches are going on for developing & discovering new material which has the exceptional properties. By continuing this, researchers are highly attracted to the BNNTs, it is the most interesting subject for research because of its exceptional properties which are known & lots more yet to be discovered. Herein another interesting property is discussed, which is that BNNTs have the capability to purify water.

In this process at the time of the synthesis of the BNNTs by laser ablation method, keeping temperature constant & the continuously supplying the CO$_2$ laser of 1000W & 10.6 μm on the Molten Boron Ball. Along with it supply nitrogen gas at a very high pressure of 6 -14 bar as a source of nitrogen. As an output we get boron fibers during this growth process, growth temperature at the tip of boron fibers is constant which was confirmed by the black body radiation calculations carried by Wien’s displacement law & Planck’s law of black body radiation [12].

This controlled growth of the BNNTs with a large number of walls was studied in this, by this growth kinetics of BNNTs we came to know that the surface area of the BNNTs increased to 278.2 m$^2$/g correspondings to the small wall no. & small diameter. Due to high-temperature sustainability, BNNT acts as the recyclable adsorbent for the purification of water with the efficiency of 94% of capturing the Methylene blue particles from water [13].

From the literature survey, it is concluded that most of the work is carried on the CNNTs and BNNTs comparison, their applications, their constructions methods, their linear behavior and properties like toxicity, tensile strength, etc. but only a few works have done on the Non-Linear properties/behavior and its effects on BNNTs and its applications. Also, there is less information about the mass sensing capabilities of BNNTs with temperature variations. As for how efficiently they sense the mass under the condition of minimum to maximum temperature range. This can provide Aids and excellent accuracy in Nanotubes. So, it can withstand various conditions and minimizes the errors due to Non-linearity.

In light of the literature review and the motivation presented above, the work will be extended to investigate the mass sensing capability of the Boron Nitride nanotube with temperature variations. Performing our work on the continuum model by keeping other conditions as per standard. With the help of the discretization method & analysis software analysis is to be done.

2. Methodology
We isolate the calculation or body into little parts or components in-finite component modeling to discover the relocations at a discrete point [14]. Here the calculation is separated into hexahedral components where every component has eight nodes as demonstrated in figure 2.
Figure 2. Example of discretization

In the three-dimensional issue, every node has three degrees of opportunity/freedom (DOF) since every node is dislodged in the three ways along the x, y, and z-axis. The nodal arrangements are put in a way that the three-dimensional matrix representing the total number of nodes and the three coordinates at each node.

2.1 A General Formulation of Stiffness Matrix:
The relationship between stress & strain for a linear material is obtained from the generalized Hooke’s Law. For isotropic material, there are two properties i.e., Young modulus (E) and Poisson Ratio (v).

As per Hooke’s Law relationship
Modulus of Rigidity (G), is given by

$$G = \frac{E}{2(1 + v)}$$  \hspace{1cm} \text{eq. (1)}

From Hooke’s Law relationship,

$$\varepsilon = \frac{(1 - 2v)}{E} \sigma$$  \hspace{1cm} \text{eq. (2)}

After putting the values of Strain (ε) and Stress (σ) in the above equation we got σ = Dε.

The material law σ = Dε is written as,

$$D = \frac{E}{(1 + v)(1 - 2v)} \begin{bmatrix} 1 - v & v & v & 0 & 0 & 0 \\ v & 1 - v & v & 0 & 0 & 0 \\ v & v & 1 - v & 0 & 0 & 0 \\ 0 & 0 & 0 & 0.5 - v & 0 & 0 \\ 0 & 0 & 0 & 0 & 0.5 - v & 0 \\ 0 & 0 & 0 & 0 & 0 & 0.5 - v \end{bmatrix}$$  \hspace{1cm} \text{eq. (3)}

Here, D is the symmetric (6x6) material matrix.

For the eight-node hexahedral element, we consider ξ, η, and ζ as natural coordinates as shown in fig 3.
Figure 3. Hexahedron Element in Global system

Where, the directions of node I of the component in the nearby framework are portrayed by ($\xi_i, \eta_i, \zeta_i$), which has appeared in Fig (3). Relocation ($u, v, w$) in the component are determined from nodal dislodging ($u_i, v_i, w_i$) utilizing shape capacities $N_i$ is given underneath

$$
\begin{bmatrix}
u \\
v \\
w
\end{bmatrix}_{8x1} =
\begin{bmatrix}
N_1 & 0 & 0 & N_2 & 0 & 0 & \ldots & N_8 & 0 & 0 \\
0 & N_1 & 0 & 0 & N_2 & 0 & \ldots & 0 & N_8 & 0 \\
0 & 0 & N_1 & 0 & 0 & N_2 & \ldots & 0 & 0 & N_8
\end{bmatrix}
$$

\{u\} = [N]\{d\} \quad \text{eq. (4)}

Where $N$ is the Shape work for the 3D hexahedral component and $d$ is the nodal removal vector which gives the estimation of the relocation relating to Eq. (4). On the ace component, Lagrange shape capacity can be composed as

$$
N_i(\xi, \eta, \zeta) = \frac{1}{8}(1 + \xi_i \xi)(1 + \eta_i \eta)(1 + \zeta_i \zeta) \quad \text{eq. (5)}
$$

where $I = 1$ to 8

For the hexahedral, there are eight nodes in the component. In the natural co-ordinate system ($\xi$, $\eta$&$\zeta$) the eight shape functions are
\[ N_1(\xi, \eta, \zeta) = \frac{1}{8}(1 - \xi)(1 - \eta)(1 - \zeta), \quad N_2(\xi, \eta, \zeta) = \frac{1}{8}(1 + \xi)(1 - \eta)(1 - \zeta), \]
\[ N_3(\xi, \eta, \zeta) = \frac{1}{8}(1 + \xi)(1 + \eta)(1 - \zeta), \quad N_4(\xi, \eta, \zeta) = \frac{1}{8}(1 - \xi)(1 + \eta)(1 - \zeta), \]
\[ N_5(\xi, \eta, \zeta) = \frac{1}{8}(1 - \xi)(1 - \eta)(1 + \zeta), \quad N_6(\xi, \eta, \zeta) = \frac{1}{8}(1 + \xi)(1 - \eta)(1 + \zeta), \]
\[ N_7(\xi, \eta, \zeta) = \frac{1}{8}(1 + \xi)(1 + \eta)(1 + \zeta), \quad N_8(\xi, \eta, \zeta) = \frac{1}{8}(1 - \xi)(1 + \eta)(1 + \zeta), \quad \text{eq. (6)} \]

Anytime in the entire math, in every component the entirety of all the shape capacities is solidarity.

By utilizing the uprooting Eq (4) the three-dimensional strain-relocation relations can be composed as

\[ \vec{e}_{(\xi, \eta)} = \begin{bmatrix} e_{xx} \\ e_{yy} \\ e_{zz} \\ e_{xy} \\ e_{yz} \\ e_{xz} \end{bmatrix} = \begin{bmatrix} \frac{\partial u}{\partial x} \\ \frac{\partial v}{\partial y} \\ \frac{\partial w}{\partial z} \\ \frac{1}{2} (\frac{\partial v}{\partial x} + \frac{\partial u}{\partial y}) \\ \frac{1}{2} (\frac{\partial w}{\partial y} + \frac{\partial v}{\partial z}) \\ \frac{1}{2} (\frac{\partial u}{\partial z} + \frac{\partial w}{\partial x}) \end{bmatrix} \]

\[ \vec{e}_{(\xi, \eta)} = [B](\xi, \eta) \overrightarrow{d}_{(\xi, \eta)} \quad \text{eq. (7)} \]

In which

\[ [B]_{(\xi, \eta)} = \begin{bmatrix} [B_1] & [B_2] & [B_3] & [B_4] & [B_5] & [B_6] & [B_7] & [B_8] \end{bmatrix} \]

\[ [B_1]_{(\xi, \eta)} = \begin{bmatrix} \frac{\partial N_1}{\partial x} & 0 & 0 \\ 0 & \frac{\partial N_1}{\partial y} & 0 \\ 0 & 0 & \frac{\partial N_1}{\partial z} \\ 0 & \frac{\partial N_1}{\partial z} & \frac{\partial N_1}{\partial y} \\ \frac{\partial N_1}{\partial z} & 0 & \frac{\partial N_1}{\partial x} \\ \frac{\partial N_1}{\partial x} & \frac{\partial N_1}{\partial y} & 0 \end{bmatrix} \quad \text{eq. (8)} \]

By applying the Chain rule of the Partial differentiation, the derivative in the matrix [Bi] in Eq. (8) is shown as

\[ \begin{bmatrix} \frac{\partial N_1}{\partial \xi} \\ \frac{\partial N_1}{\partial \eta} \\ \frac{\partial N_1}{\partial \zeta} \end{bmatrix} = \begin{bmatrix} \frac{\partial x}{\partial \xi} & \frac{\partial x}{\partial \eta} & \frac{\partial x}{\partial \zeta} \\ \frac{\partial y}{\partial \xi} & \frac{\partial y}{\partial \eta} & \frac{\partial y}{\partial \zeta} \\ \frac{\partial z}{\partial \xi} & \frac{\partial z}{\partial \eta} & \frac{\partial z}{\partial \zeta} \end{bmatrix} \begin{bmatrix} \frac{\partial N_1}{\partial x} \\ \frac{\partial N_1}{\partial y} \\ \frac{\partial N_1}{\partial z} \end{bmatrix} = [J] \begin{bmatrix} \frac{\partial N_1}{\partial x} \\ \frac{\partial N_1}{\partial y} \\ \frac{\partial N_1}{\partial z} \end{bmatrix} \]

Where [J] is the Jacobian Matrix and the transformation of the Jacobian Matrix is given as...
The expansion of the Jacobian matrix as shown in Eq. (10)

$$[J] = \begin{bmatrix}
\frac{\partial N_1}{\partial \xi} & \frac{\partial N_1}{\partial \eta} & \frac{\partial N_1}{\partial \zeta} \\
\frac{\partial N_2}{\partial \xi} & \frac{\partial N_2}{\partial \eta} & \frac{\partial N_2}{\partial \zeta} \\
\frac{\partial N_3}{\partial \xi} & \frac{\partial N_3}{\partial \eta} & \frac{\partial N_3}{\partial \zeta} \\
\frac{\partial N_4}{\partial \xi} & \frac{\partial N_4}{\partial \eta} & \frac{\partial N_4}{\partial \zeta} \\
\frac{\partial N_5}{\partial \xi} & \frac{\partial N_5}{\partial \eta} & \frac{\partial N_5}{\partial \zeta} \\
\frac{\partial N_6}{\partial \xi} & \frac{\partial N_6}{\partial \eta} & \frac{\partial N_6}{\partial \zeta} \\
\frac{\partial N_7}{\partial \xi} & \frac{\partial N_7}{\partial \eta} & \frac{\partial N_7}{\partial \zeta} \\
\frac{\partial N_8}{\partial \xi} & \frac{\partial N_8}{\partial \eta} & \frac{\partial N_8}{\partial \zeta}
\end{bmatrix}$$

The element strain energy in the total potential is given by

$$U = \frac{1}{2} \int_V \sigma^T \varepsilon dV$$

$$= \frac{1}{2} \int_V (D \varepsilon)^T \varepsilon dV$$

And we know that,

$$\varepsilon = Bd$$

$$= \frac{1}{2} d^T \int_B B^T Db dV$$

$$= \frac{1}{2} d^T K d$$

where element stiffness matrix $[K]$ is given by

$$[K] = \int_V B^T B dV$$

Matrix $[B]$ is spoken to in common organizes and it is needed to do the combination in normal arranges as well, utilizing the relationship

$$dV = dxdydz = \det[J] \, d\xi \, d\eta \, d\zeta$$

The constraint of reconciliation is - 1 to 1 in all indispensable. Thus, the stiffness matrix $K$ of a Hexahedral eight-node component is equivalent to

$$[K] = \int_{-1}^{1} \int_{-1}^{1} \int_{-1}^{1} B^T DB \det[J] \, d\xi \, d\eta \, d\zeta$$

Henceforth, the firmness network is resolved. On account of the hexahedral component, there are three degrees of opportunity per hub and there are eight hubs in the component. In this way, the request for the firmness grid is $K (24 \times 24)$. Gauss Quadrature 6×6 is utilized to incorporate Eq. (13).
For the mathematical combination of this kind of issue, Gaussian Quadrature has been demonstrated to be the most effective technique. This technique has ended up being generally helpful in limited component work. Expansion to integrals in two and three measurements follows promptly. Consider the n-point approximation

\[ I = \int f(r)dr = w_1 f(r_1) + w_2 f(r_2) + \cdots + w_n f(r_n) \]

Where, \( W_1, W_2, \) and \( W_n \) are the weights, and \( r_1, r_2, \) and \( r_n \) are the testing focuses or Gauss focuses. In Gaussian Quadrature \( n \) Gauss focuses and \( n \) loads gives the specific answer for polynomial \( f(r) \) of as enormous a degree as could be expected under the circumstances.

Presently\[30\] the expansion of Gaussian Quadrature to three-dimensional basic structures

\[ [K] = \iiint B^T DB \det(J) d\xi d\eta d\zeta \]

Follows readily

\[ [K] = \sum_{i=1}^{n} \sum_{j=1}^{n} \sum_{k=1}^{n} w_i w_j w_k B_{ij}^T B_{jk} \det(J)_{ij} \]

eq (14)

For the Hexahedral eight-node component we utilize 6-point Gaussian quadrature. In this way, we have to decide the co-ordinate of the quadrature point just as the duplicating factor by utilizing the table given underneath.

There are various software's used for modeling and analysis of 3-D objects. Among them, we have taken "ABAQUS software" for our research work. Abaqus FEA is a product component of limited component investigations and PC-based constructions, first introduced in 1978. A Complete Abaqus Environment is ABAQUS/CAE that provides a very simple platform, predictable & consistent interface to help the user to create finite models & do an analysis of those element models.

As it's very complex to carry out the thing on a large scale or large entity or component, so to avoid complicity & improve the quality of the work we use some techniques like Finite Element Analysis/Method (FEM). We decide our desired & essential properties for the experiment, make the list of those properties & convert all the units in a similar unit like we convert all units in nm (nanometer).

We use the Software “ABAQUS”, in this software we select the continuum model then we define our properties accordingly. Perform the analysis & then collect various results of temperature effects.

3. Result and Discussion

The parameters used in the simulation are stated in Table 1.

| S.No. | Properties             | Referred value                      | Considered value |
|-------|------------------------|-------------------------------------|------------------|
| 1.    | Tube Length            | 200,400,600,800 nm [15]             | 200 nm           |
| 2.    | Atomic radius          | 50%                                 | 50%              |
| 3.    | Chilarity (n,m)        | (10,0)                              | (10,0)           |
| 4.    | Bond width             | 50%                                 | 50%              |
| 5.    | Band gap               | 6 eV [16]                           | 6 eV             |
| 6.    | Mass density           | \( \rho = 7.2 \times 10^{-7} \times 2\pi /A \) [15] | \( \rho = 7.2 \times 10^{-7} \times 2\pi /A \) |
| 7.    | Wall thickness (t)     | \( t = 0.089 \text{nm} \) [15]     | \( t = 0.08 \text{nm} \) |
| 8.    | Shear modulus          | 7 Gpa [17]                          | 7 Gpa            |
| 9.    | Bending stress         | Between 100 -260 Mpa [18]          | Between 100 -260 Mpa |
| 10.   | Inner diameter         | 1-3 nm [19]                         | 3 nm             |
| 11.   | Thermal Conductivity   | 600*10^{-9} W/mm - K [20]           | 600*10^{-9} W/mm - K |
| 12.   | Young's modulus        | \( E = 1030 \text{Gpa} \) & \( E = 1180 \text{nN/nm} \) [21] | \( E = 1180 \text{nN/nm} \) |
| 13.   | Poisson’s ratios       | \( \mu = 0.25-0.3 \) [21]          | \( \mu = 0.3 \)  |
Cantilevered Boron Nitride Nanotube is considered to have a point load at the free end. The boundary condition and loading conditions are defined by providing constraints to rotation and translation at the fixed end. The load is applied in the y-axis direction as shown in figure 4.

![Figure 4](image)

**Figure 4. Providing Loading & boundary conditions.**

In figure 5, after applying boundary conditions, the nanotube is discretized and meshed into fine packets by defining the global seeding.

![Figure 5](image)

**Figure 5. The meshing of Boron Nitride Nanotube.**

The model is analyzed for the load $3 \times 10^{-7}$ kg having a temperature of 25°C. The deflection in x, y, and z-axis is shown in figure 6.
Figure 6. Displacement Curve of X, Y, Z-axis (at temperature 25°C under the load 3x10^{-7} kg).

The displacement curve is plotted with respect to time in the direction of the applied load. The deflection in the direction of load applied is shown in figure 7.

Figure 7. Displacement Curve in the Y direction (U2) (at temperature 25°C & under the load 3x10^{-7} kg).

Now, the model is analyzed for different loading and temperature condition. The output is calculated and plotted for the loading of 3 x 10^{-21} kg and 3 x 10^{-7} kg for different temperature range i.e. -4°C, -10°C, -15°C, 25°C, 45°C, 65°C, 100°C, 500°C. It is found that the deflection value under the different temperature conditions is not changing. In figure 8, the deflection of BNNT under the temperature condition of 45°C is shown.
Figure 8. The output of BNNT deflection at temperature 45\(^{\circ}\) C, under the load of 3x10\(^{-21}\) kg.

The deflection in the x, y, and z-axis because of point load under the temperature condition of 45\(^{\circ}\) C is shown in figure 9.

Figure 9. Displacement Curve of X, Y, Z-axis (at temperature 45\(^{\circ}\) C under the load 3x10\(^{-7}\) kg).

The deflection in the x, y, and z-axis because of point load of 3x10\(^{-7}\) kg under the temperature condition of 65\(^{\circ}\) C is shown in figure 10.
The deflection in the direction of the applied load is shown in figure 11.

The deflection of BNNT because of the point load of $3 \times 10^{-21}$ kg under the temperature condition of $500^\circ$ C is shown in figure 12.
Figure 12. The output of BNNT deflection at temperature 500°C, under the load of $3 \times 10^{-21}$ kg.

The deflection of BNNT in the x, y, and z-axis, because of the point load of $3 \times 10^{-21}$ kg under the temperature condition of 500°C is shown in figure 13.

Figure 13. Displacement Curve of X, Y, Z-axis (at temperature 500°C under the load $3 \times 10^{-7}$ kg).

The deflection of BNNT in the x, y, and z-axis, because of the point load of $3 \times 10^{-7}$ kg under the temperature condition of -150°C is shown in figure 14.
Figure 14. Displacement Curve of X, Y, Z-axis (at temperature -15° C under the load 3x10⁻⁷ kg).

The deflection of BNNT in the x, y, and z-axis, because of the point load of 3x10⁻⁷ kg under the temperature condition of -10° C is shown in figure 15.

Figure 15. Displacement Curve of X, Y, Z-axis (at temperature -10° C under the load 3x10⁻⁷ kg).

4. Conclusion
We concluded that BNNTs property to withstand at high temperature is justified, as we keep varying the temperature over a working range, it gives the same outputs. Our result gives us the idea that the mass-sensing capabilities of the BNNT are very high & it doesn’t change significantly with temperature variation. It also concluded that if the mass sensing capabilities of the BNNT are increased to Zeptogram level then also the temperature variation doesn’t make any significant change in sensing the mass. By software analysis, we can say that the BNNTs are Thermo-Mechanically stable.
References

[1] Choppra, N. G., Luyken, R. J., & Cherrey, K., 1995, Crespi VH, Cohen ML. Louie SG, Zettl A., Science, 269, 966.
[2] Aqel, A., Abou El-Nour, K. M., Ammar, R. A., & Al-Warthan, A. 2012 Carbon nanotubes, science and technology part (I) structure, synthesis and characterisation. Arabian Journal of Chemistry, 5, 1-23.
[3] Patel, A. M., & Joshi, A. Y. 2017 Characterizing the nonlinear behaviour of double walled carbon nanotube based nano mass sensor. Microsystem Technologies, 23, 1879-1889.
[4] Ishigami, M., Aloni, S., & Zettl, A. 2003 Properties of boron nitride nanotubes. In AIP conference proceedings (Vol. 696, No. 1, pp. 94-99). American Institute of Physics.
[5] Golberg, D., Costa, P. M., Mitome, M., & Bando, Y. 2009 Properties and engineering of individual inorganic nanotubes in a transmission electron microscope. Journal of Materials Chemistry, 19, 909-920.
[6] Ishigami, M., Aloni, S., & Zettl, A. 2003 12th International Conf, Koenraad and Kemerink eds. In AIP Conference Proceedings (Vol. 696, pp. 94-99).
[7] Wang, J., Ma, F., Liang, W., & Sun, M. 2017 Electrical properties and applications of graphene, hexagonal boron nitride (h-BN), and graphene/h-BN heterostructures. Materials Today Physics, 2, 6-34.
[8] Oh, E. S. 2011 Elastic properties of various boron-nitride structures. Metals and Materials International, 17, 21-27.
[9] Panchal, M. B., & Upadhyay, S. H. 2015 Boron nitride nanotube-based mass sensing of zeptogram scale. Spectroscopy Letters, 48, 17-21.
[10] Patel, A. M., & Joshi, A. Y. 2017 Characterizing the nonlinear behaviour of double walled carbon nanotube based nano mass sensor. Microsystem Technologies, 23, 1879-1889.
[11] Kayang, K. W., Nyankson, E., Efavi, J. K., Abavare, E. K. K., Garu, G., Onwona-Agyeman, B., & Yaya, A. 2019 Single-Walled boron nitride nanotubes interaction with nickel, titanium, palladium, and gold metal atoms-A first-principles study. Results in Materials, 2, 100029.
[12] Kim, J. H., Cho, H., Pham, T. V., Hwang, J. H., Ahn, S., Jang, S. G., ... & Kim, M. J. 2019 Dual growth mode of boron nitride nanotubes in high temperature pressure laser ablation. Scientific reports, 9, 1-10.
[13] Cho, H., Kim, J. H., Hwang, J. H., Kim, C. S., Jang, S. G., Park, C., ... & Kim, M. J. (2020). Single-and double-walled boron nitride nanotubes: Controlled synthesis and application for water purification. Scientific reports, 10, 1-10.
[14] Rao, S. S. 2005 Analysis of trusses, beams, and frames. The finite element method in engineering (Fourth Edition). Butterworth-Heinemann, Burlington, 309-356.
[15] Kang, D. K., Yang, H. I., & Kim, C. W. 2017 Geometrically nonlinear dynamic behavior on detection sensitivity of carbon nanotube-based mass sensor using finite element method. Finite Elements in Analysis and Design, 126, 39-49.
[16] Ishigami, M., Aloni, S., & Zettl, A. 2003 12th International Conf, Koenraad and Kemerink eds. In AIP Conference Proceedings (Vol. 696, pp. 94-99).
[17] Patel, A. M., & Joshi, A. Y. 2015 Detection of biological objects using dynamic characteristics of double-walled carbon nanotubes. Applied nanoscience, 5, 681-695.
[18] Golberg, D., Bando, Y., Huang, Y., Terao, T., Mitome, M., Tang, C., & Zhi, C. 2009 ACS Nano 4, 2979 (2010).
[19] Kim, J. H., Pham, T. V., Hwang, J. H., Kim, C. S., & Kim, M. J. (2018). Boron nitride nanotubes: synthesis and applications. Nano convergence, 5, 1-13.
[20] Belkerk, B. E., Ashour, A., Zhang, D., Sahli, S., Djouadi, M. A., & Yap, Y. K. 2016 Thermal conductivity of vertically aligned boron nitride nanotubes. Applied Physics Express, 9, 075002.
[21] Trivedi, S., Sharma, S. C., & Harsha, S. P. 2014 Evaluations of Young's Modulus of Boron Nitride Nanotube Reinforced Nano-composites. Procedia materials science, 6, 1899-1905.