E-ISSN: 2321–9637
Volume 1, Issue 5, December 2013
International Journal of Research in Advent Technology
Available Online at: http://www.ijrat.org

EXPERIMENTAL & FEA BASED MODAL ANALYSIS OF SCALED UP DENTAL PIN (PLUGGER): A CASE STUDY IN ENDODONTICS

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ABSTARCT:

Root canal treatment (RCT) is a treatment used to repair and save the tooth which is badly decayed or becomes infected. It is the process by which a dentist treats the inner aspects of a tooth called root canals which most commonly is referred as the nerve. It is a part of Endodontic (means inside tooth) treatment study. Obturation, a process during RCT, is the complete filling and sealing of 3D root canal space against further bacterial growth. The system under study is the dental pin, which forms a part of the device that can be handheld portable apparatus used during root canal obturation to heat, soften & cut excess gutta percha as filler material with ease and also fill it in root cavity without disturbing patient.

Modal analysis is the study undertaken to see the effect of frequency & mode shape during actual root canal obturation. The actual effect of vibratory pin in filling root canal cavities has not been studied. The current project will include vibration at the dental pin which will help to give a denser, more compact filling of the root canal space, and will enhance the obturation process to certain extent. Aim of the current study is to perform the modal analysis of the dental pin (plugger) of biomedical device that is modeled as a tapered cantilever beam model with the defined configuration by using analytical methods & verifying it using Finite Element Method model. This is undertaken to observe the effect of frequency & mode shape during actual root canal obturation. Also the experimental modal analysis on scaled up dental pin model has been carried out, and the FEA results are verified with experimental results.

Results for natural frequency of tapered pin are verified and found approximately same using analytical method, and FEM approach. Experimental modal analysis of scaled up (10 times) dental pin is carried out and acceptable agreement is seen between the experimental results and the FEA results which are within 9% for all the modes.

Keywords: *Root canal treatment, Obturation, gutta percha, Finite Element Method.*

1. INTRODUCTION

The tapered pin is a part of the device that can be handheld portable apparatus used during root canal obturation to heat, soften & cut gutta percha as filler material with ease and also fill it in root cavity without disturbing patient. Success of the current study will be beneficial to dental surgeons, dental experts, and in turns the common patients in terms of cost. Successful root canal treatment is based on diagnosis, treatment planning, knowledge of tooth anatomy, and the traditional concepts of debridement, sterilization, and obturation. Dentists can charge $300 to $400 for a Dental Filling in USA & Europe. It costs only $20 to $40 in India. A Root Canal is $3,000 in the West but only $100 to $200 in India. Dentures can cost $1000 overseas but only $200 in India. Thus it is required to highlight the effect of compacting Gutta Perch with mechanical vibration in root canal space during actual obturation phase, as it will directly contribute to the success in root canal treatment.

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2. LITERATURE REVIEW

Mário Tanomaru-Filho et.al [1] (2007), the author studied the force required to provide a significant increase in the diameter of heated gutta-percha specimens should be greater than 3 kg.

Maniglia-Ferreira C, et al [2] (2007), This paper briefs information of thermal properties of dental GP, plasticized by a heat carrier or by thermo-mechanical compaction, if used improperly may cause partial decomposition if the heat generated exceeds 100°C, according to the Merck index. Root canal filling techniques must use temperature control (between 53°C and 59°C) permitting the β-phase GP to the α-phase. GP in the β-phase begins the α-phase change when heat reaches the range of 48.6°C to 55.7°C.The α-phase changes to the amorphous phase when heated between 60°C and 62°C. Heating GP to 130°C causes physical changes or degradation.

Maurizio Ferrante et.al [3] (2010), It gives information on thermal analysis of GP Heating up to 130 °C causes chemical-physical changes of the gutta-percha; this is due to the presence of additives (70–80%), which alter the behaviour of the material. For this reason, the dimensional stability of the filling materials is not guaranteed.

Alvin Goodman, Herbert Schilder, Winthrop Aldrich[4] (1981), The maximum regional temperature determined for bulk GP in the body of the canal was 80° C., while the over-all peak temperature recorded in the apical region was 45° C.Thermal penetration of the GP was expectedly limited, with significant thermal effects rarely exhibited more than 4 to 6 mm into the material

Clifford Ruddle [5] (2006), This article is to describe an obturation technique that is safe, easy to use, and routinely fills root canal systems in three dimensions. The obturation technique that will be described is the vertical compaction of warm gutta percha.

The degree of endodontic success is directly proportional to a clinician's knowledge of, appreciation of, and respect for the root canal system anatomy and the techniques selected when performing treatment.

M. Venturi, R. Di Lenarda & L. Breschi [6] (2006), A plastic mass of GP forced to flow where compacting force applied to GP can have vectorial decomposition between two inclined planes. C into tangential force (t) and normal force (n). r, reaction force; f, friction force; R, resulting force. Any frictional force that would reduce the forward motion of the penetrating gutta-percha, would likewise be parallel to the canal wall. The compacting of heated amorphous gutta-percha is difficult to control, especially close to the apex (Clinton & Van Himel 2001). The main difficulty for the practitioner is to adjust the compacting procedure to the softening of the GP.

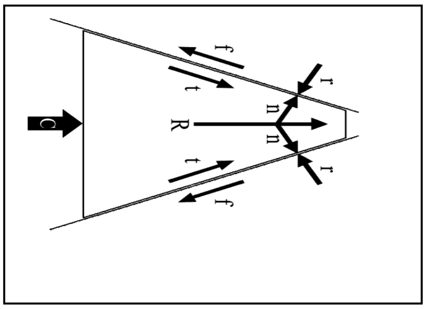

Fig.1. Compaction force analysis during obturation Process

Alex Wai-Kwok Chan [7] (2006), present study focuses to gather information on endodontic practice of general dental practitioners in Hong Kong.Endodontic is a dynamic, evolving discipline with considerable advances in techniques and materials.Lateral compaction of gutta-percha is a relatively simple and versatile technique that has produced good results and does not require expensive equipment. Thermo-plasticized gutta-percha is better adapted to the canal walls and may fill lateral canals better than lateral condensation

Ricardo Caicedo, Dr. Odon and Stephen M. Clark [8] **(2008),** Success in RCT is based on diagnosis, treatment planning, knowledge of tooth anatomy, and the traditional concepts of debridement, sterilization, and obturation. University of Missouri- Kansas City School of Dentistry showed that DownPak's combination of heat and vibration resulted in a denser, more compact filling of the root canal space. **Pagavino et al.(2006)** found that DownPak device with heat and vibration, when compared to heat only, resulted in a greater % of GP-filled area at the 1.25-mm level from working length with either a 0.4 or 0.8 taper, and at the 2.5-mm level with a 0.4 taper in simulated curved canals. **Wu et al.(2002, 2004)** compared the use of the System B & the DownPak with heat only, and the DownPak with heat and vibration. A significantly smaller percentage of gutta-percha-filled area was found after using the System B than than using the DownPak, either with heat and vibration or with heat alone.

John Whitworth [9] **(2005),** In technical terms, 'success' in obturation will be associated with root canals (prepared and) densely filled to within 2 mm of radiographic root end. Clinical studies and case reports have convincingly reinforced the view that warm vertical condensation techniques can enjoy comparable success to lateral condensation methods.

Stephen Cohen, Louis H. Berman & Gabriela Martin [10] **(2008),** Even after heating and compacting gutta-percha or Resilon into a canal system, there still may be voids in the obturation, to address this problem Martin developed a self-contained electronically heated spreader for warming and laterally compacting gutta-percha (Endotec, Medidenta International), increased the density of the obturation by approximately 15 percent. Subsequently the Touch 'n Heat (Sybron-Endo) and the System B (Sybron-Endo), expanded on this concept and were found to be successful for creating a more homogenous obturation of gutta-percha. The EndoTwinn (MDCL) used in Europe, is a hand-held, self-contained, heat-carrying instrument with spreader or plugger tips. Sonic vibration was also incorporated into this device to augment the compaction and obturation effectiveness. In early 2007, efforts to improve and refine the EndoTwinn led to the introduction of the DownPak (Hu-Friedy) is cordless and lightweight, with an ergonomically balanced hand-held grasp make it easier for the clinician to more effectively provide a three-dimensional obturation, also enables variable temperature settings and to use vibration feature, as desired.

Harris [11] **Vibration Handbook,** At 20 Hz and 30 Hz the head exhibits a mechanical resonance.

Ming-yong HU [12] **et.al (2010),** Vibration mode of the constrained damping cantilever is built up according to the mode superposition of the elastic cantilever beam. The control equation of the constrained damping cantilever beam is then derived using Lagrange's equation. Dynamic response of the constrained damping cantilever beam is obtained according to the principle of virtual work, when the concentrated force is suddenly unloaded. Frequencies and transient response of a series of constrained damping cantilever beams are calculated and tested. Influence of parameters of the damping layer on the response time is analyzed.

Saeid Bashash, Amin Salehi-Khojin, Nader Jalili [13] **(2008),** This paper presents a novel framework for forced motion analysis of Euler-Bernoulli beam with multiple jumped discontinuities in the cross section. Results indicate that the added mass and stiffness significantly affects the mode shapes and natural frequencies. This paper gives why Euler-Bernoulli Beam is used.

Dr S. Talukdar [14] Author gives various methods for vibration analysis of a continuous beam (to find the natural frequency, mode shape etc.) Equation of motion is derived by Hamilton principle. Also for nonuniform geometry the exact solution of differential equation is not obtained. Therefore Rayleigh-Ritz method &Galerkin method is described for non uniform geometry.

Dumitru I. Caruntu [15] **(2009),** This paper deals with free transverse vibrations of nonuniform homogeneous beams. Cantilevers of rectangular (or elliptical) cross-section with parabolic thickness variation, and cantilevers of circular cross-section with parabolic radius variation, are considered. Fourth order differential equations of transverse vibrations reduced into a pair of second order differential equations leads to general solutions in terms of hyper geometric functions.Exact natural frequencies and exact mode shapes are reported for sharp parabolic cantilevers of various dimensionless lengths.

H.H.Marbie & C.B.Roger [16] (1964), Free vibrations of nonuniform cantilever beams with an end mass have been studied, using the equations of Bernoulli-Euler. Two configurations of interest are treated: (a) constant width and linearly variable thickness; and (b) constant thickness and linearly variable width. Charts have been plotted for each case from which the fundamental frequency, the second harmonic, and the third harmonic can be easily determined for various taper ratios and ratios of end mass to beam mass.

MARC and Mentat [17], In this paper Mode shape and natural frequency is studied and derived for cantilever beam. The beam is assumed to be plane stress problem. Mode shape and natural frequency is found using nastran software total four finite elements are developed, three using one –D two noded thin beam element and one using 2-D four noded bilinear plane stress element.

J Eaton-Evans1et.al [18] (2007), Super elastic and shape memory capabilities of Nitinol are strongly dependent on the alloy composition, its heat treatment, and mechanical deformation history. The current paper presents a review of the behaviour of Nitinol and describes a characterization study conducted to determine the mechanical properties of the material.

Anamika S. Misty [19] (2011), The author studies the dynamic response of mini cantilever beam in viscous media. The dynamic response characteristic such as frequency, frequency amplitude in air and fluid media (water, oil) is measured using laser Doppler Vibrometer and compared as function like density, and viscosity of fluid media.

Le Ngoc Bich, Pham Thi Thu Hien, Phan Quoc Hung[22](2006), The experimental results and the computation results show that the difference between them is within 10% for all modes.

3. PHYSICAL PROPERTIES OF MATERIAL FOR DENTAL PIN

Table.1. Typical physical properties for 316 L grade stainless steels.

Grade	Density (kg/m^3)	Elastic Modulus (GPa)	Poisson's ratio (υ)
316/L/H	8000	193	0.27

4. LOADING CYCLE

There are two parts in the loading cycles

Manual compaction load of 15 N magnitude (gradual) in three vertical increments in the three regions of root canal , i.e. a. Cervical 1/3rd , b. middle 1/3rd and , c. apical 1/3rd.

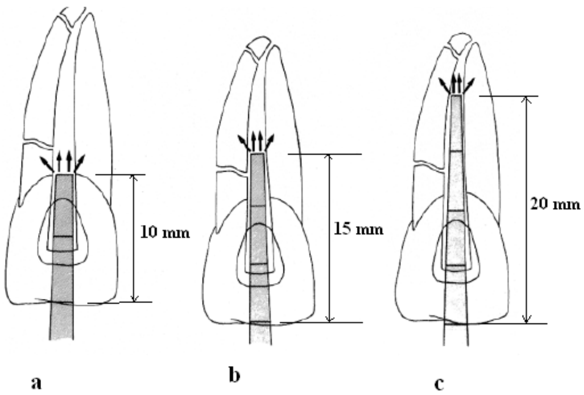

Fig. 2: Regions of root canal

E-ISSN: 2321–9637
Volume 1, Issue 5, December 2013
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The findings of preliminary studies showed that the force required to provide a significant increase in the diameter of heated gutta-percha specimens should be 3 kg. This is based on the American Dental Association specification No. 57 (for endodontic sealers) was adapted to gutta-percha testing. (ISO 6876:2002 – Dental Root Canal Sealing Materials). Transverse Vibration excitation at the base of tapered cantilever of 20 to 50 Hz. (As at about 200 Hz there will be resonance of lower jaw.)

5. STEPS IN MODAL ANALYSIS USING FEA

5.1 Eigenvectors and Eigen values:
5.2 Consistent Element Mass Matrices
5.3 Evaluation of Eigenvectors and Eigen values

5.1 Eigenvectors and Eigen-values:

The governing equation for structural dynamics provides general expression for structural mass and damping.

For a single element of volume V, this work balance becomes

$\int_e (U^T \rho \ddot{U} + U^T c\acute{U} + {}_\varepsilon{}^T \sigma)\, dV = \int_e U^T F\, dV$ .... (1)

Where

ρ= Mass density
c= Damping
k= Stiffness
F= External force

Finite element discretization provides

$U=N_{u,}$ $\acute{U} = N\grave{u},$ $\ddot{U} = N\ddot{u},$ $\varepsilon = Bu$ …… (2)

Shape functions N are functions of space while nodal degrees of freedom u are functions of time.

Combinations of eqs. (1) and (2).

$u^T [\int_e \rho N^T NdV\, \ddot{u} + \int_e c N^T NdV\, \grave{u} + \int_e B^T \sigma\, dV - \int_e N^T FdV] = 0$ ….. (3)

Where Consistent element mass matrix

$m_e = \int_e \rho N^T NdV$ ….. (4)

Damping matrix

$c_e = \int_e c N^T NdV$ ….. (5)

And stiffness matrix $k_e = \int_e {}_B{}^T \sigma\, dV$ ….. (6)

According to Newton's second law F = mü. For a multi element structure,

$M\ddot{U}+C\acute{U}+KU=F$ …. (7)

For Undamped Free vibration (F=0 and C=0),

$M\ddot{U}+KU=0$ ….. (8)

For the steady state condition, starting from the equilibrium state, we set

$U= X \sin \omega t$ …. (9)

Where

X = Vector of nodal amplitudes of vibration
$\omega = 2\pi f$ …. (10)

Where f is natural frequency in H_Z.

Substituting Eq. (9) into Eq. (8), we have

$KX= \omega^2 MX$ …. (11)

This is the generalized eigen value problem

$KX=\lambda MX$ … (12)

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Where x is the eigenvector, representing the vibration mode, corresponding to the eigen value λ. The eigen value λ is the square of the circular frequency ω.

5.2 Consistant Element Mass Matrices

The Consistent Mass Matrix for bar Element is given as follows
For bar element, the displacement vector and shape function are given by
$u = [u_1 \; u_2]^T$
$N = [N_1 \; N_2]^T$ …. (13)
Where $N_1 = \frac{1-\xi}{2}$ and $N_2 = \frac{1+\xi}{2}$
Now, Consistent mass matrix
$m_e = \rho \int_e N^T N A dx = \frac{\rho A L}{2} \int_{-1}^{+1} N^T \; N d\xi$
Where $dx = \frac{L}{2} d\xi$
On carring out the integration, we get
$m_e = \frac{\rho A L}{6} \begin{bmatrix} 2 & 1 \\ 1 & 2 \end{bmatrix}$ ...(14)

5.3 Evaluation of Eigenvectors and Eigen values

Eigen values and eigenvectors are evaluated using the following methods:
Characteristic Polynomial Technique
From Eq. (12) , we have

$$(K-\lambda M)X=0 \quad …. \quad (15)$$

If the eigenvector is to be non-trivial, the required condition is :

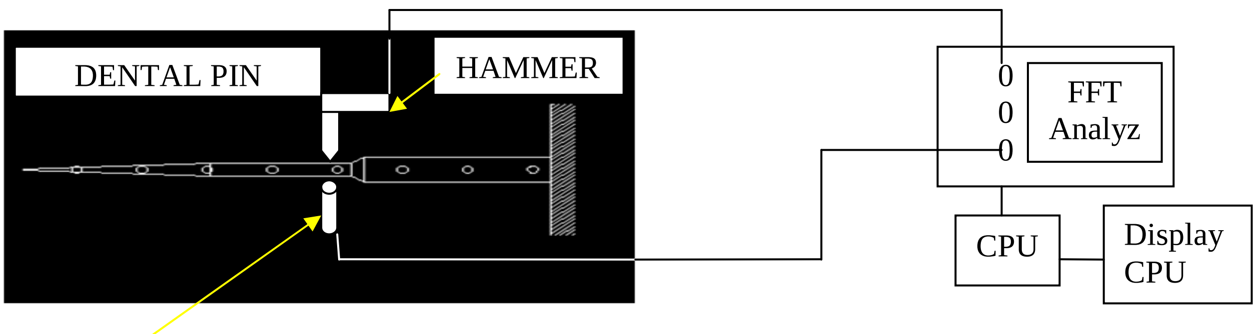
$$\det(K-\lambda M)=0 \quad … \quad (16)$$

This represents the characteristic polynomial in λ. The implementation of characteristic polynomial technique on computers is tedious.

6. MODAL TESTING CONCEPTS: [22]

Modal testing or experimental modal analysis is the process of determining the modal parameters (frequencies, damping factors, modal vectors and modal scaling) of a linear, time-invariant system by way of an experimental approach. The modal parameters may be determined by analytical means, such as finite element analysis, and one of the common reasons for experimental modal analysis is the verification/correction of the results of the analytical approach (model updating).

6.1 Experimental set-up:



ACCLEROMETER

Fig.3: Schematic Experimental setup

6.2 Apparatus: Following apparatus will be used to perform the real experiment:

a. Impact Hammer
b. Accelerometer
c. Multi-channel Vibration Analyzer (At least two-channel)
d. A PC or a Laptop loaded with software for modal analysis.
e. Test-specimen (A cantilever held in a fixture)
f. Power supply for the PC and vibration analyzer, connecting cables for the impact hammer and accelerometer, fasteners and spanner to fix the specimen in the fixture, and adhesive/wax to fix the accelerometer).

6.3 Geometric Scaling of Dental Pin:

Currently dental pin has been scaled up geometrically by 10 times , as it is not possible to conduct modal testing on actual pin.

Fig. 4: Test Specimen (Scaled up dental pin) with fixture

6.4 Software's and hardwares used:

Design – Pro-Engineer wildfire 4.0
Analysis – ANSYS Mechanical APDL10.0
Modal experiment – OROS Modal 2 with NV Gate software, FFT Analyzer, Impulse hammer, accelerometer etc.

6.5 Experimental Results

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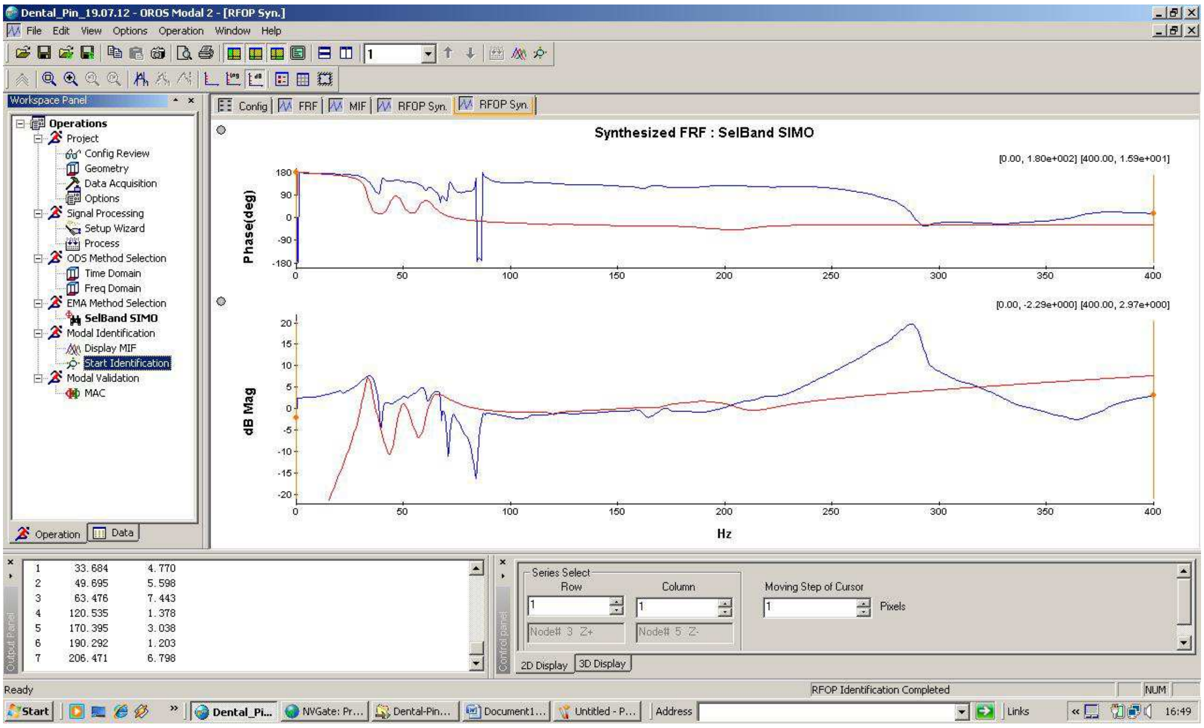

Fig.5. Trial 2 Frequencies upto 200 Hz, Points20

6.6 Results for Trial 2, upto 200 Hz, , Order 20

Identification Result	Freq.
1	33.684
2	49.695
3	63.476
4	120.535
5	170.395
6	190.292
7	206.471

6.7 Modal analysis using ANSYS 10.0:

Element Type: BEAM3 (2D Elastic 3)

- Material Properties (316 L)
  - Young's modulus: E = 1.93e5 MPa
  - Poisson's Ratio : 0.27
  - Density : 8e-6kg/mm^3 (8000e-9)
- Modal Analysis
- Subspace, 15 modes

6.8 Results:

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Volume 1, Issue 5, December 2013
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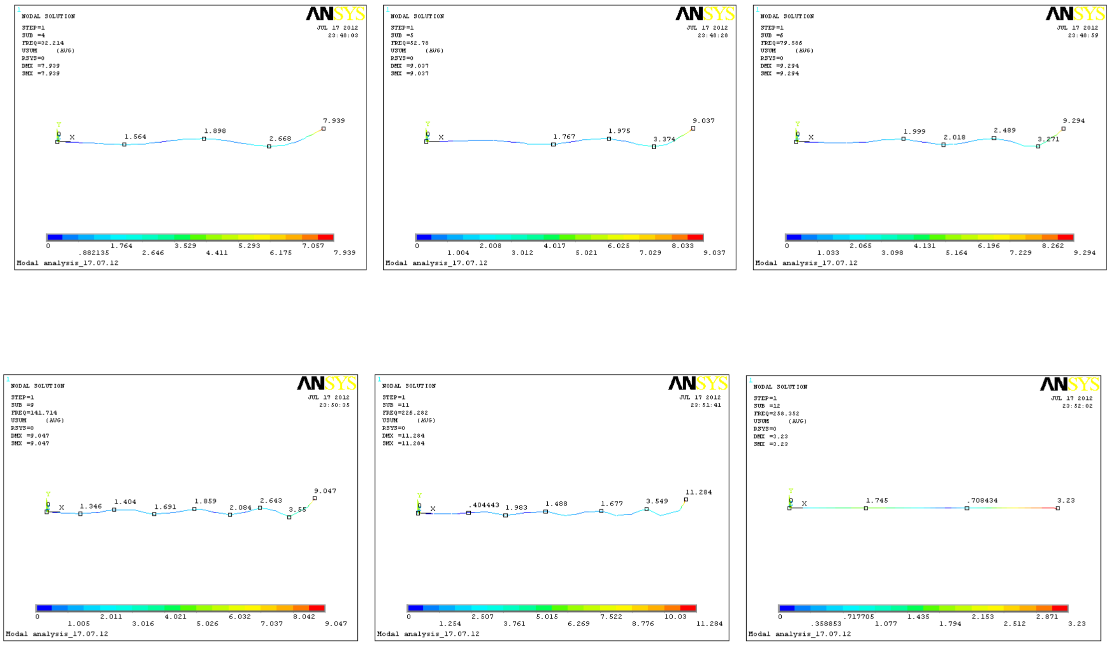

Fig.6. FEA Results (ANSYS10.0 plots)

Table.2. Selected modes out of FEA Results (using ANSYS 10.0)

Set	4	5	6	8	10	11
Frequency (Hz)	32.214	52.780	79.586	110.44	178.84	226.28

6.9 Error estimation:

(It is based on the Trial 2 which is found to be close to the FEA results)

For mode 4:

The FEA *result* f_{4fea} = 32.214 Hz

Experimental result f_{4ep} = 33.684 Hz

Error : $\varepsilon = \frac{f4fea - f4ep}{f4fea}$ *100 %

= ((32.2145 - 33.684/32.2145))*100% = **4.5623 %**

Similarly,

For mode 5: Error is **5.8450 %,** for mode 6: Error is **20.2422 %**, for mode 8: Error is **9.1407** %, for mode 10: Error is **4.7222** %, & for mode 11: Error is **8.7945** %

Table 3. Comparison between FEA result and Experimental result

Modes	Fea (Ansys10.0) Results (Hz)	Experimental Results, (Hz)	Error (%)
4	32.214	33.684	4.5623
5	52.780	49.695	5.8450
6	79.586	63.476	20.2422
8	110.44	120.535	9.1407

10	178.84	170.395	4.7222
11	226.38	206.471	8.7945

7. CONCLUSIONS

Acceptable agreement is seen between the experimental results and the FEA results which are within 9% for all the modes. This shows that the FEA results are validated based on experimental work.

Some of the intermediate frequencies have been neglected as seen in the limitations of modal analysis that few frequencies corresponds to the load data which is not correctly applied during hammer hitting also the point at which the accelerometer is attached, frequency at this point is omitted. In the process of data analysis we have omitted some low frequencies corresponds to some modes at 1, 2,3 --- but the results are considered to be good enough.

The results are suitable as for the actual model the theoretical resonating frequency should be less than 200 Hz (Resonance occur at 200 Hz for lower jaw) and it is found that the frequency goes on increasing as model size increases and for the scaled up model (10 times scaling), maximum modal frequency is found to be 206.471 Hz, can be used as results for predicting the frequencies of actual dental pin which would be definitely less than 200 Hz.

8. ACKNOWLEDGEMENT

Authors sincerely thank BCUD, University of Pune, for proving necessary financial support for the current study. It is a part of funded Research Project by BCUD, University of Pune during the year 2012-13 & 2013-14. Also special thanks to Prof. (Dr.) D.W.Pande, Professor in Mechanical Engg Department of COEP, Shivajinagar, for guiding in the experimental modal analysis.

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