IOSR Journal of Engineering (IOSR JEN) **www.iosrjen.org**
ISSN (e): 2250-3021, ISSN (p): 2278-8719
PP 28-35

Modal Analysis of Titanium Nitrite Coated Stainless Steel Hip Joint Implant

S . L. Gavali[1, 2], H. V. Vankudre[3], K. N. Vijayakumar[4]
[1](Department of Mechanical Engineering, Sinhgad College of Engineering - Research Center, S.P. Pune University, India)
[2](Department of Mechanical Engineering, Cusrow Wadia Institute of Technology, Pune, India)
[3] (Department of Mechanical Engineering Vidyavardhini's College of Engineering & Technology, Mumbai University, India)
[4](Department of Mechanical Engineering, Dwarkadas J. Sanghvi College of Engineering, Mumbai University, India)

Abstract: *In this paper modal analysis of Hip joint implant used in Total Hip Replacement (total hip arthroplasty) is made. Objective of performing the modal analysis was to decide structural analysis of hip joint in static loading or in dynamic loading condition. Material used for Hip joint is Stainless steel 316L coated with Titanium nitrite. As coating is not contributing significantly to improve the mechanical properties of the implant but helps to improve the biocompatibility of hip joint. Modal analysis is the study of the dynamic properties of systems in the frequency domain. Modern day experimental modal analysis systems are composed of sensors such as transducers (typically accelerometers, load cells), or non contact via a Laser vibrometer, or stereo-photogrammetric cameras, data acquisition system and an analog-to-digital converter at front end and host PC to view the data and analyze it. The results of Modal analysis is considered for to decide static or dynamic structural analyses of hip joint implant for further study.*
Keywords: *Biocompatibility, Titanium Nitrite Coating, Hip Joint, ANSYS, FFT Analyzer*

I. Introduction

The Wear particles from total joint replacements are thought to play a critical role in implant failure by generating periprosthetic bone lysis phenomena, as a result of a debris-induced macrophage inflammatory response [1,2,3]. Since the discovery of the shape memory properties of nickel-titanium inter-metallic alloy (NiTi) in the early1960s, the alloy has been proposed for various practical applications, in most of which corrosion problems wear of no concern. Over the last decade, however, NiTi alloy has been increasingly considered for use in external and internal biomedical devices, e.g. orthodontic wires, self expanding cardiovascular and urological stents, bone fracture fixation plates and nails etc. [4,5,6]. Increased durability of a hip replacement therefore appears to be related to the reduction of the artificial joint wear [8,20,21]. The homogeneous solution of the damped equations of motion is a complex eigenvalue problem, and the damped system complex frequencies may be determined numerically by various finite element or matrix transfer procedures as outlined by Ruhl [7], and Lund [9,10,11].The determination of the damped system complex frequencies is a considerably more difficult problem than the determination of the un-damped modes by the Prohl-Myklestad matrix transfer method [14]. For rotor systems with a large number of mass stations, the complex eigenvalue procedure may run into numerical difficulties [16]. On the other hand, the mode shapes associated with the natural frequencies and the forced response analysis of distributed mass rotor systems have seldom been discussed in the literature. In reference [17] modal analysis is applied to an Euler-Bernoulli rotor model (without the gyroscopic terms). The difficulties in modal analysis of rotor systems arise from the fact that the resulting eigenvalue problems are characterized by the presence of skew-symmetric matrices with differential operators as elements, due to rotation and/or damping, resulting, in general, in a non-self-adjoint eigenvalue problem [18,19].

II. Modal Analysis

With the results of Modal analysis and testing one can decide that whether the first natural frequency of hip joint observed is much more than the maximum possible loading frequency. Generally when loading frequency is in a range of ± 30 of the first natural frequency, resonance is not said to have effect on the results of dynamic analysis. On the basis of this there is no need to go for full dynamic fatigue instead static analysis the results will be as good enough.

III. Theory of Modal Analysis

The modal analysis theory helps in vibration analysis to determine how the structural parameters such as mass, damping and stiffness relate to the impulse response function (Time domain), frequency response function (Frequency domain) and transfer function (Laplace domain) for a single degree of freedom and multi degree of freedom systems. A technique is used to determine vibration characteristics of structure as, Natural frequencies, Mode shapes and Mode participation factors (how much a given mode participates in a given direction). Figure 1 shows the theoretical procedure of vibration analysis. It displays the three phase procedure of the theoretical vibration analysis. First with the description of the physical properties of the structures, usually as its mass, stiffness and damping characteristics.

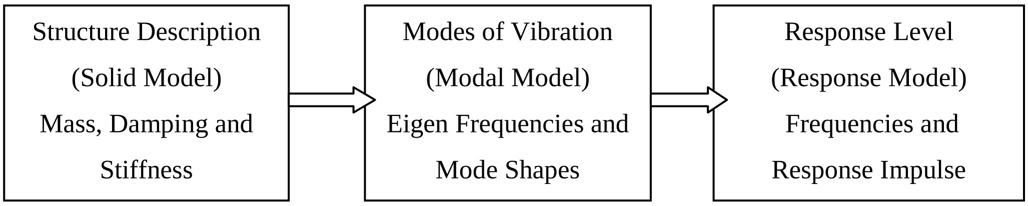

Fig. 1: Theoretical Procedure of Vibration Analysis

IV. Analytical Modal Analysis

For Analytical Modal Analysis (AMA) Finite Element Method (FEM) is used. The finite element method (FEM) is the conventional numerical tool used for the vibration analysis of composite engineering structures. For modal analysis, ANSYS14.5 Workbench is used. ANSYS workbench has ability to solve static and dynamic structural analysis.

HIP JOINT DETAILS:

Hip Joint is modeled in CATAI V5R20. Figure No.2 shows the CAD Modal of Hip Joint. Hip joint used for study is of 49 mm ball diameter and proportionate neck angle, femur length, width of the femur as per human body anatomy.

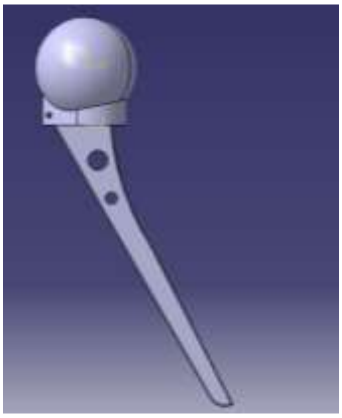

Fig. 2: CAD modeling of Hip Joint using CATIA

FINITE ELEMENT MODAL ANALYSIS

Finite Element method (FEM) simulates material behavior of part by breaking down the complete geometry into a number of elements and by applying boundary conditions. Uses of proper boundary conditions are very important and strongly affect the results of the finite element analysis. Finite Element modal Analysis of hip joint is performed to determine the natural frequency of the Hip Joint. The modeling of hip joint is done using CATIA software and the hip_joint.step file of model is imported in ANSYS14.5 workbench. The material used for hip joint Stainless steel 316L coated with Titanium Nitrite. Material properties hip joint is as shown in the table 1.

Table 1: Material Properties of Hip Joint Implant

Material	Stainless Steel 316L (Titanium Nitrite coated)
Density	7860 kg/mm3
Poison's Ratio	0.3
Young's Modulus	20000 N/mm2

LOADING AND BOUNDARY CONDITIONS:

The geometry is meshed in mechanical model window of an ANSYS 14.5. The hex dominant method is applied for the geometry. This method is used for applying maximum hexahedron elements to complicated geometry. The body sizing is applied for the whole geometry and element size is taken as 5 mm. The FE model of the hip joint geometry is meshed with hexahedral elements, with the global element length of 5 mm and local element length of 0.342 mm. The figure 3 (a) and (b) shows the meshed model and fixed support boundary condition.

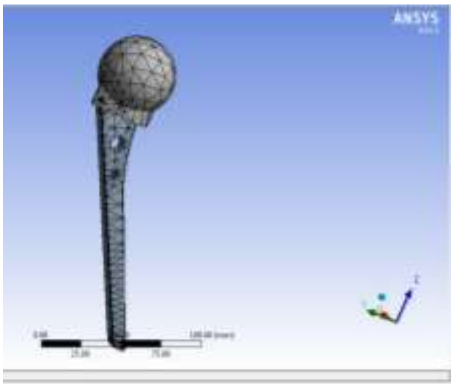

Fig. No 3(a): Meshed Model

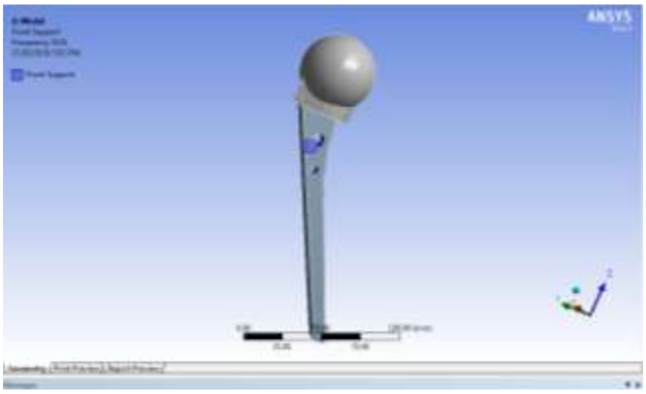

Fig. No 3(b): Fixed support boundary condition

FEA SOLUTION:

In the Finite Element Modal Analysis of hip joint three modes are extracted. The figure no. 4, figure no. 5 & figure no. 6 show the three modes of natural frequency of hip joint. The FEA solution results are tabulate and shown in the Table 2.

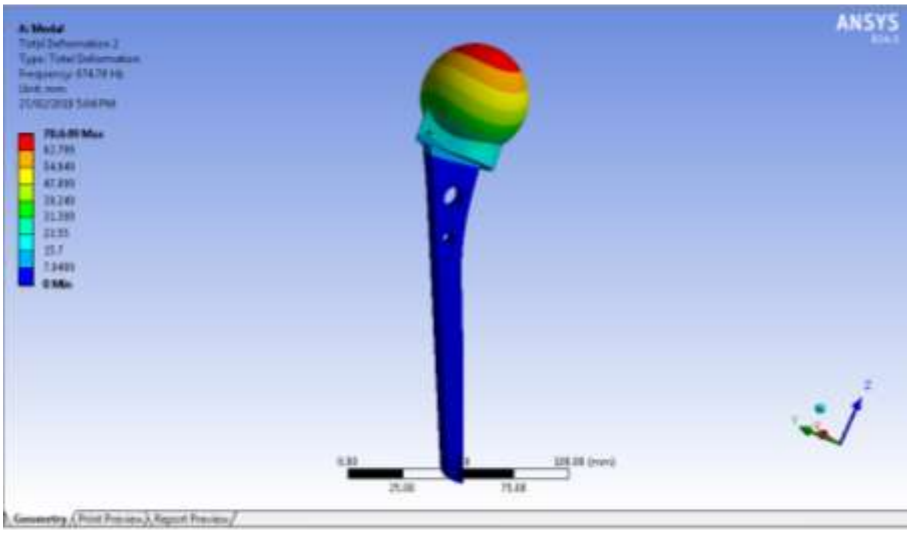

Fig . 4: First Natural Frequency

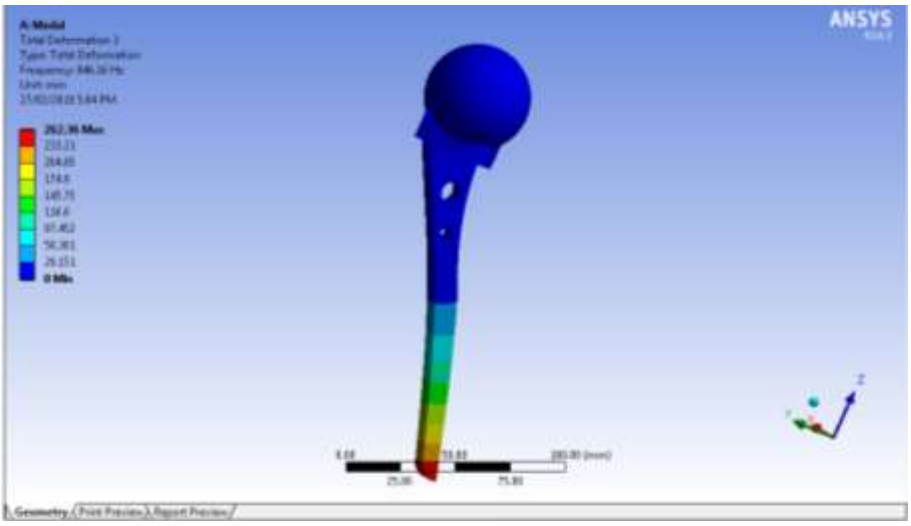

Fig . 5: Second Natural Frequency

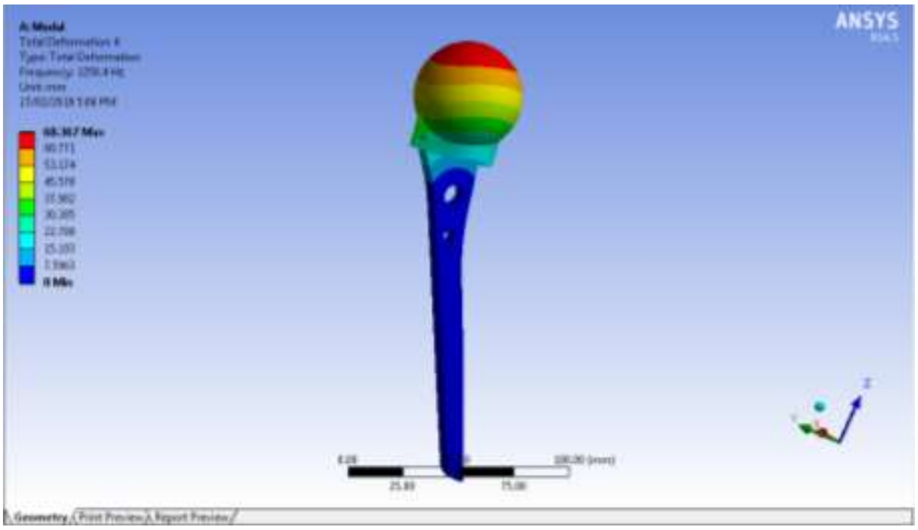

Fig. 6: Third Natural Frequency

Table 3: Analytical Modal Analysis (FEA) Results

Natural Frequency	**Analytical Modal Analysis (FEA) Result**
First Natural Frequency (F1)	588.51 Hz
Second Natural Frequency (F2)	846.16 Hz
Third Natural Frequency (F3)	1358.40 Hz

V. Experimental Modal Analysis:

To validate the results obtained by Analytical Method, experimentation is performed. Experimental modal analysis (EMA) is a process of determining the modal parameters (natural frequencies, damping factors, modal vector and scaling) of a linear, time invariant systems by the way of an experimental approach. Figure No. 3 shows the procedure of Experimental modal analysis (EMA)

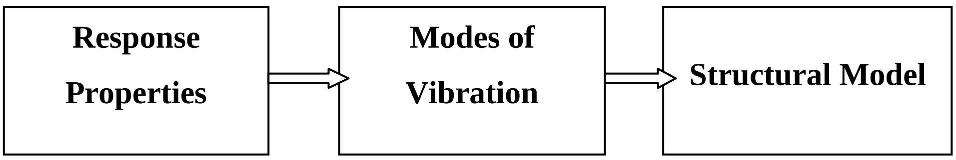

Fig. 7: Stepwise procedure for Experimental Modal Analysis

The process of determining the modal parameters from experimental data involves Modal analysis theory, Experimental Modal Analysis Theory, Modal Data Acquisition, Modal parameters Extraction Methods and Modal DATA Presentation. In experimental modal analysis to estimate the modal parameters, frequency response function methods approach is commonly used. In this method the frequency response functions are measured using excitation at single and / or multiple points. Four testing configuration can be used i.e Single Input and Single Output (SISO), Single Input and Multiple Outputs (SIMO), Multiple Inputs and Single Output (MISO) and Multiple Inputs and Multiple Outputs (MIMO). These four testing conditions mostly depend upon the number of acquisition channels and excitation sources. In present study Single Input and Multiple Outputs (SIMO) configuration is used and excitation method used is Roving hammer. In roving hammer method, a single response point is fixed and structure is excited at different points. The forms of excitations are possible for measurements of frequency responses for modal analysis is impact excitation.

BASIC ASSUMPTIONS IN EXPERIMENTAL ANALYSIS:

There are four basic assumptions are made in order to perform an experimental modal analysis.

1) The structure is assumed to be linear i.e. the response of the structure to any combination of forces, simultaneously applied, is the sum of the individual responses to each of the forces acting alone.
2) The structure is time invariant, i.e. the parameters that are to be determined are constants.
3) The structure obeys Maxwell's reciprocity, i. e. a force applied at degree of freedom p causes a response at degree of freedom q that is the same as the response at degree of freedom p caused by the same force applied at degree of freedom q.
4) The structure is observable i. e. the input output measurements that are made contain enough information to generate an adequate behavioral model of the hip joint as shown in fig. no. 2.

EXPERIMENTAL SETUP:

Experimental setup for modal analysis of Titanium Nitrite Coated Stainless Steel Hip Joint Implant is as shown in Figure No. 8. It consists of data acquisition system, accelerometer, roving hammer for excitation and FFT analyzer and desktop computer. Table No 4, 5 and 6 shows the details and specification of data acquisition system, accelerometer and roving hammer.

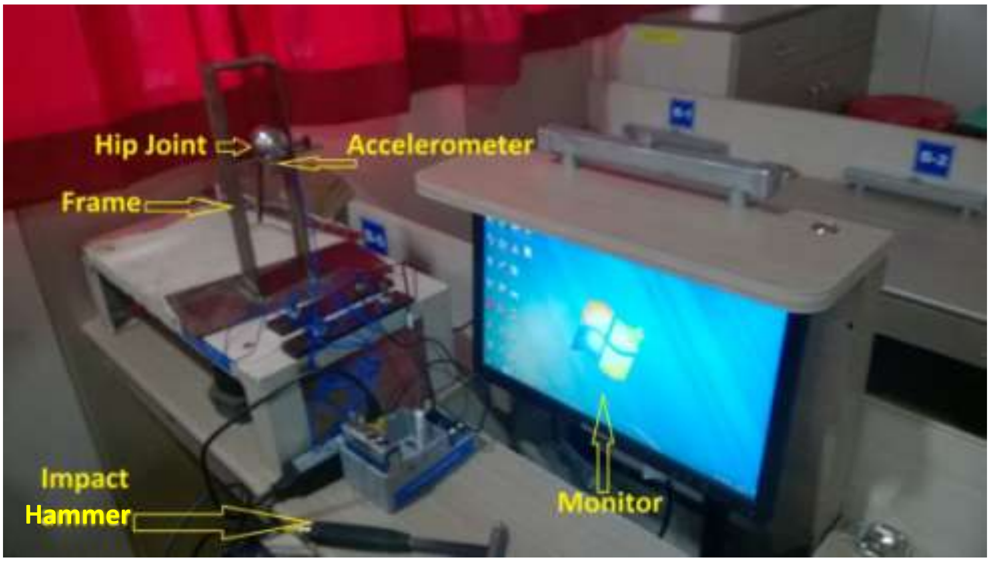

Fig. 8: Experimental set up for modal analysis.

Table 4: Specification of Data acquisition system

Sr. No.	Parameter	Specification
1.	Brand Make	National Instruments
2.	Number of channel	4
3.	Maximum sampling	51.2 ks/s per channel
4.	Voltage input	5V
5.	Dynamic range	102 DB

Table 5: Specification of Accelerometer

Sr. No.	Parameter	Specification
1.	Brand Make	National Instruments
2.	Model No.	PCB352C33
3.	Voltage sensitivity	100 mv/g
4.	Frequency range	0.3 to 12000 Hz
5.	Electrical connector	Type/location 5 – 44 coaxial/side

Table 6: Specification of Roving Hammer

Sr. No.	Parameter	Specification
1.	Brand Make	National Instruments
2.	Model No.	PCB086C03
3.	Voltage range	10 DB
4.	Sensitivity element	Material / Type Quartz / Epoxy
5.	Electrical connector	Type / Location BNC / Bottom of handle handle

PROCEDURE OF EXPERIMENTATION:

1) Hip Joint is mounted on the fixed frame which is fixed on table.
2) One end of the cable is connected to the accelerometer and other end to the Adapter. Similarly one end of the cable is connected to the Impact hammer and other end to the Adapter. The adapters are connected to the respective channels of FFT hardware.
3) In-pulse software is used for preparation of set for modal analysis.
4) Magnetic base is used to mount Accelerometer on Hip Joint Implant.
5) The power connections of hardware and computer display are made on.
6) The necessary arrangements in software are done to collect the frequency response function's (FRFs).

EXPERIMENTAL MODAL ANALYSIS RESULT:

Experimental modal analysis of a system, deals with determination of natural frequencies, damping ratio, and mode shapes through the vibration testing. In the case of forced vibration, the analysis includes the study of acceleration, velocity and displacement responses of the systems. The central idea involved in modal analysis is that when the forcing frequency is equal to its natural frequency, the structure or machine or any system is excited, its response exhibits a sharp peak at resonance, provided that the damping is not present or negligible.

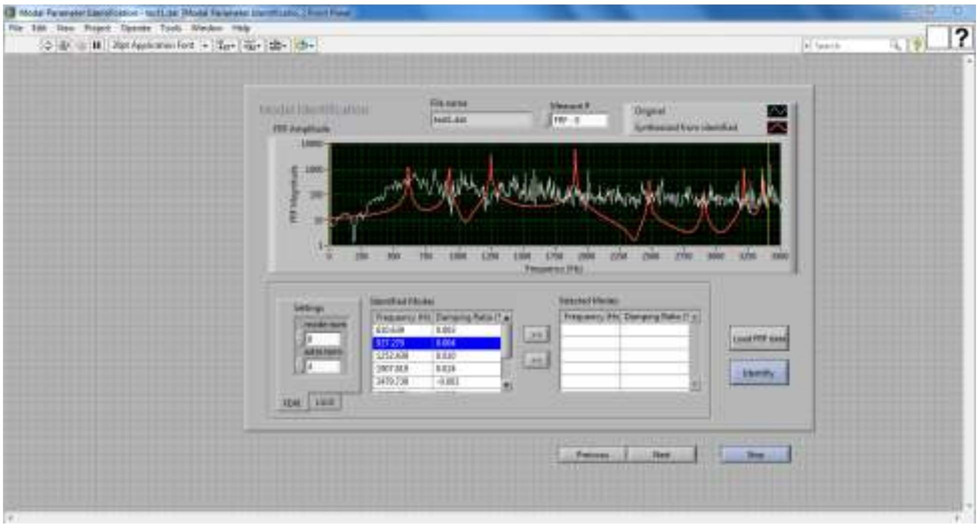

Fig. 9: Fast Fourier Transform (FFT) Analyzer Result.

Table 7: Experimental Modal Analysis Results

Natural Frequency	Experimental Modal Analysis (FFT) Results
First Natural Frequency (F1)	610.63 Hz
Second Natural Frequency (F2)	927.27 Hz
Third Natural Frequency (F3)	1252.43 Hz

Figure No. 9 shows the image of the Frequency Response Function. The first three natural frequencies of modal analysis are shown in the window. The results are tabulated in table 7. Impact testing is performed such that responses are measured with roving sensor (number of response points) or roving hammer with one or more fixed excitation points.

VI. Results and Discussion

Comparison between Analytical Modal analysis result and Experimental Modal Analysis results is as shown in Table No. 8 and figure No.10 shows the graphical representation comparison between Analytical Modal analysis and Experimental Modal Analysis results. The natural frequencies obtained in experimentation and from numerical analysis are found to be in close agreement.

Table 8: Comparison between Experimental and Software Results

Natural Frequency	Analytical Modal Analysis (FEA)	Experimental Modal Analysis (FFT)	Difference
First Natural Frequency (F1)	588.51 Hz	610.63 Hz	5.96 %
Second Natural Frequency (F2)	846.16 Hz	927.27 Hz	7.78 %
Third Natural Frequency (F3)	1358.40 Hz	1252.43 Hz	4.85 %

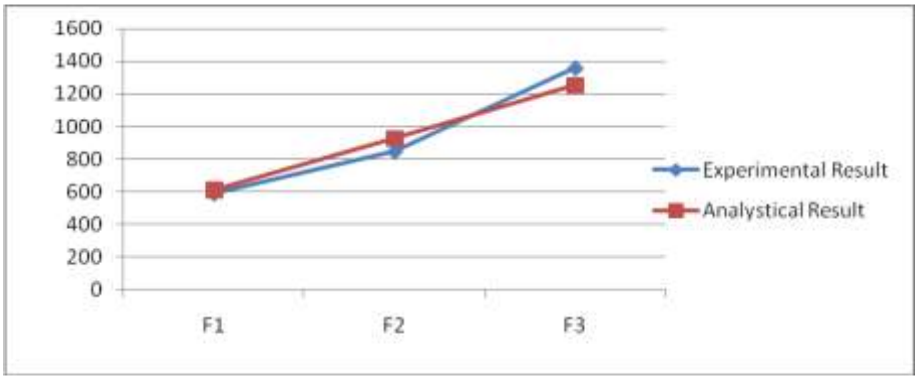

Fig.10: Comparison between Analytical result and Experimental results

The difference between first natural frequency by Analytical method and Experimental method is about 5.96% shown in figure No. 10. The first mode of vibration is the important mode. If forcing frequency of any harmonic component is close to the natural frequency of first mode of vibration, resonance occurred. At this condition the part is said to be running at critical speed. Three modes are extracted during modal analysis. The difference between first natural frequency by Analytical method and Experimental method is about 5.96%. Forcing frequency of hip joint is 610.63 Hz is very less than natural frequency of hip joint. As a result static structural analysis of Titanium Nitrite Coated Stainless Steel Hip Joint Implant is to be performed for further study.

Conflict of interest The authors declare that there is no conflict of interests regarding the publication of this paper.

References

[1]. Harris WH. The problem is osteolysis. Clin Orthop 1995; 311:46 - 53.
[2]. Brummitt K, Hardaker CS, McCullagh PJ, Drabu KJ, Smith RA. 'Effect of counterface material on the characteristics of retrieved uncemented cobalt -chromium and titanium alloy total hip replacements'. *Proc Inst Mech Engng [H]* 1996; 210: 191-5.
[3]. Harman MK, Banks SA, Hodge WA. 'Wear analysis of a retrieved hip implant with titanium nitride coating'. J Arthroplasty 1997; 12: 938-45.
[4]. Rodriguez D, Gil FJ, Planell JA. 'Wear resistance of the nitrogen diffusion hardening of the Ti6Al4V alloy'. *J Biomech 1998*; 31(Suppl. 1):49.
[5]. Yachia D, Beyar M. New treatment modality for penile urethral strictures using a self-expanding and self-retaining coil stent: *UroCoil. Eur Urol 1993*;24:500-4.
[6]. Wroblewski BM. Wear of the high-density polyethylene socket in total hip arthroplasty and its role in endosteal cavitation. *Proc Inst Mech Engng [H]* 1997;211:109 -18.

[7]. R. L. Ruhl and J. F. Booker, "A Finite Element Model for Distributed Parameter Turbototor Systems", J. Engng. Industry, Trans. ASME, Series B, Vol. 94, No. 1, pp. 126-132, Feb. 1972.
[8]. Kadoya Y, Kobayashi A, Ohashi H. Wear and osteolysis in total joint replacements. *Acta Orthop Scand Suppl* 1998;278:1-16.
[9]. D. Starosvetsky, I. Gotman, 'Corrosion behavior of titanium nitride coated Ni - Ti shape memory surgical alloy' *Biomaterials 22* (2001) 1853-1859.
[10]. Castelman LS, Motzkin SM. The biocompatibility of nitinol. In: Williams DF, editor. 'Biocompatibility of clinical implant materials'. *Boca Raton, FL: CRC Press*, 1981. p. 129 -54.
[11]. J. W. Lund, "Stability and Damped Critical Speeds of a Flexible Rotor in Fluid-Film Bearings", *J. Engng. Industry, Trans. ASME,* , May 1974, pp. 509-517.
[12]. C. W. Leer, R. Katz, A. G. Ulsov And R. A. Scott, 'Modal Analysis Of A Distributed Parameter Rotating Shaft', *Journal of Sound and Vibration* (1988) 122(1), 119-130.
[13]. Katz, C. W. Lee, A. G. Ulsoy And R. A. Scott , 'The Dynamic response of a rotating shaft, subject to a moving load', Journal of Sound and Vibration 1988 - 122,
[14]. M. Z. Prohl. "A General Method for Calculating Critical Speeds of Flexible Rotors", *Trans. ASME, Vol. 67, J. Appl. Mech. Vol. 12,* , 1945, P. A-142
[15]. E. J. Gunter, K. C. Coy And P. E. Allaire, 'Modal Analysis of Turbo-rotors Using Planar Modes-Theory', *Journal of The Franklin Institute, Vol.3 05,No.4* ,A pril1 978.
[16]. P. De Choudhury, S. J. Zsolcsak and E. W. Barth, "Effect of Damping on the Lateral Critical Speeds of Rotor Bearing Systems", J. Engng. Industry, *Trans, ASME, Paper No. 75-DET-38,* 1975.
[17]. G. M. L. GLADWELL and R. E. D. BISHOP 1959, *Journal Mechanical Engineering Science* 1, 195-206. The vibration of rotating shafts supported in flexible bearings.
[18]. L. MEIROVITCH and L. M. SILVERBERG 1985, *Journal of Optimization Theory and Applications* 47, 77-90. Control of non-self-adjoint distributed-parameter systems.
[19]. Nikos G. Tsagarakis, Stephen Morfey, et. al., 'Compliant Humanoid COMAN: Optimal Joint Stiffness Tuning for Modal Frequency Control', 2013, *IEEE International Conference on Robotics and Automation (ICRA) Karlsruhe, Germany,* May 6-10, 2013
[20]. Agins HJ, Alcock NW, Bansal M, et al. 'Metallic wear in failed titanium-alloy total hip replacements'. *A histological and quantitative analysis. J Bone Jt Surg [Am]* 1988; 70: 347-56.
[21]. B. Subramanian, C.V. Muraleedharan, et al. 'A comparative study of titanium nitride (TiN), titanium oxy nitride (TiON) and titanium aluminum nitride (TiAlN), as surface coatings for bio implants', *Surface & Coatings Technology* 205 (2011) 5014–5020.