Thi-Qar University Journal for Engineering Sciences, Vol. 6, No. 1 2015

Analysis of Cyclostationary CR Detector for OFDM signals

Hussian K. Chaiel

University of Thi-Qar /College of Engineering

Abstract:-

The cyclostationary based spectrum sensing algorithm is especially suitable for detection of orthogonal frequency division multiplexing (OFDM) signals that exhibit strong periodic correlation due to insertion of cyclic prefix between OFDM blocks. Normally, the cyclic prefix is used to remove the Intersymbol interference (ISI) and intercarrier interference (ICI) of the OFDM signal and so it eliminates a need for complex equalizer.

In this paper, simulation results demonstrate the normalized spectrum correlation function of the primary OFDM signal used in cognitive radio systems with different values of cyclic frequency. Two techniques are assumed to be used as PAPR reduction of OFDM transmitted signal. The results show that only one of them has no apparent effect on the correlation performance of the cyclostationary detector. Finally, it is found that a reduction of 30% in the implementation complexity can be taken by suitable choice of detector cyclic frequency.

Keywords:- OFDM, Cognitive Radio, Cyclostationary Detection, Dynamic Spectrum Sensing.

الخلاصة:-

تعتبر خوارزمية تحسس نطاق الترددات بالاعتماد على تقنية (cyclostationary) الأكثر ملائمة لكشف إشارات (OFDM) والتي تؤمن خاصية ارتباط متكرر عالية بسبب إدخال بادئة دورية بين رموزها. عادة، البادئة الدورية تستعمل للتخلص من التداخل البيني للرموز و الترددات الحاملة والذي يعني عدم الحاجة لاستخدام المصحح المعقد. في هذا البحث، نتائج محاكاة بالحاسبة لدالة ارتباط النطاق الترددي لإشارة (OFDM) للمنظومة الراديوية الإدراكية. تم افتراض تقنيتين لتقليل (PAPR) لتلك الإشارة. أثبتت النتائج أن أحد تلك التقنيات داعمة لخواص الارتباط لهذا الكاشف. أخيرا، تم الحصول من خلال البحث على تقليل ما نسبته (30%) من تعقيد بناء الكاشف عمليا عن طريق الاختيار المناسب للتردد الدوري للكاشف المعتمد في هذا البحث.

I. Introduction:

The policy of spectrum licensing and its utilization lead to static and inefficient usage of this spectrum and so it has become essential to introduce new licensing policies to enable dynamic and open way of utilizing the available spectrum efficiently. Recent studies on radio spectrum usage have given birth two concepts: Dynamic Spectrum Access (DSA) and

Cognitive Radio (CR) [1]. One of the most suitable techniques to guarantee a dynamic spectral occupancy of the transmitted signal (licensed signal) is the Orthogonal Frequency Division Multiplexing (OFDM) technique . On the other hand, Cognitive radio allows unlicensed users (secondary users) to access licensed frequency bands to reduce spectrum scarcity. Even after the beginning of the transmission, the bands must be continuously checked for any primary user entering to transmit in these bands. If so the secondary users should vacate the bands as quickly as possible and go on to some other empty frequency spectrum [1,2].

A number of schemes have been developed for detecting the presence of primary user in a certain frequency band. Energy detector and matched filter type are examples of such schemes. The first functions properly for high signal to noise ratio while the second complexity is very high. These constrains led to implement a detector which performed well under low signal to noise ratio and with complexity not as high as the matched filter detector. Such type is called cyclosationary detector. This detector is merely a Fourier transform of the correlated received signal and results in peaks at frequencies which are specific to the signal. The searching for these peaks helps in determining the presence of primary user [3, 4].

The rest of the paper is organized as follows; section II describes briefly the mathematical analysis of the cyclostationary detection for OFDM signal and discusses the challenges oppose the implementation of such detector. Section III presents computer simulation tests to show the correlation performance in the presence of techniques used to reduce the peak to average power ratio (PAPR) of the OFDM signal. This section includes also the hardware complexity to implement this detector. Finally, the paper is concluded in section IV.

II. Cyclostationary Detection of OFDM Signal

A. Mathematical Analysis

The mathematical development for cyclostationary analysis is based on Gardner's work [5] and it may be derived as:-

A complex random process $x(t)$ is said to be cyclostationary in wide-sense, if its mean $(E\{x\})$ and autocorrelation (R_x) in time domain are periodic:-

$$E\{X(t+T)\} = E\{X(t)\}$$

$$R_X(t+T,\tau) = R_X(t,\tau) \qquad (1)$$

where $R_X(t,\tau) = E\{x(t+T)x(t)\}$

Due to periodicity of autocorrelation, it can be expanded using Fourier series as:-

$$R_x(t+T,\tau) = \sum_{\frac{n}{T}} R_x^{\frac{n}{T}}(\tau)\, e^{j2\pi\frac{n}{T}t} \qquad (2)$$

where $\frac{n}{T}$ represents the cyclic frequency and can be written as α. The coefficients ($R_x^{\alpha}(\tau)$) represent a function, which may be called the Cyclic Autocorrelation Function (CAF), which may be represented by;

$$R_x^{\alpha}(\tau) = \lim_{T\to\infty} \int_{-T/2}^{T/2} R_x(t+T,\tau)\, e^{-j2\pi\alpha t}\, dt \qquad (3)$$

The cyclic Wiener relation states that the Spectrum Correlation Function (SCF) is then calculated using the Fourier transform of the cyclic autocorrelation function and its maximum value is directly proportional to the probability of detection and inversely proportional to the probability of false alarm [6]:-

$$S(f,\alpha) = \int_{\tau=-\infty}^{\infty} R_x^{\alpha}(\tau)\, e^{-2\pi f\tau} d\tau \qquad (4)$$

In this work, the primary signal ($x(t)$) is an OFDM signal, which may be represented as a composite N statistically independent QAM signal [7];

$$x(t) = \sum_k \sum_{n=0}^{N-1} \Upsilon_n e^{j\left(\left(\frac{2\pi}{T_S}\right)nt\right)}\, q(t-kT) \qquad (5)$$

Where Υ_{nk} is a complex sequence corresponds to a rectangular QAM signal point space, $q(t)$ represents a rectangular shaping pulse of duration T and T_s is a source symbol length.

The detection process based on the spectrum correlation function (Eq.4) may be implemented in three steps using the block diagram shown in (Fig.1) [6]:-

- The signal of interest is shifted by $\frac{\alpha}{2}$ and $\frac{-\alpha}{2}$.
- The shifted signals are multiplied after passing through sliding windows, where the symbol (*) represents the complex conjugate.
- Spectrum Correlation Function (SCF) is found by taking the Fourier transform of the multiplied signals .

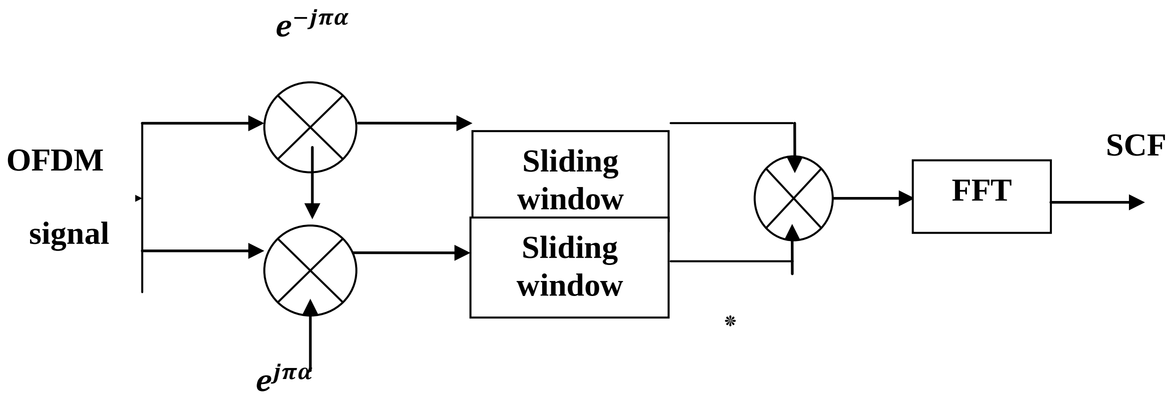


Fig.1 Block diagram of cyclostationary detector

B. Detection Challenges

However, there are two main challenges for using the cyclostationary detector in the OFDM systems. These challenges are [8-10]:-

- The first challenge is appeared due to the property of the IFFT used at the transmitter of the OFDM system, which is a high peak to average power ratio (PAPR) of the transmitted signal. This causing subcarrier intermodulation and undesired out- off band radiation. Such two drawbacks lead to inefficient amplification and a need to an expensive power amplifier. So it is important to use techniques to reduce the PAPR. These techniques may in turn reduce the correlation characteristics of the detector. [11] suggests a simple technique to reduce this ratio by mapping the QPSK symbols at the input of the IFFT of the transmitter with a certain formula. The results included in [11] show that the bit error rate performance is better than that of the conventional clipping PAPR technique. [12] proposed a tone reservation technique (operates with large number of subcarriers) reduces the ratio by a factor of nearly 5 dB. However the complexity is the main drawback of the technique proposed in [12], especially if large number of iterations are needed.
- The second challenge is merely the implementation complexity (number of arithmetic operations) of the cyclostationary detector. Many literatures analyze such issue, for example, problems of cycle leakage, aliasing and cycle phasing had been disused in [5]. In literature [13], the implementation is done mostly in angular domain to avoid complex operation (multiplication and addition/ subtraction). Finally, the signal is mapped back to Cartesian coordinates.

III. Computer Simulation tests

A. Detector performance

To examine the performance of the cyclostaionary detector (Fig,1), computer simulation tests have been carried out using Matlab software. In these tests, the signal to noise ratio is equal to -20 dB and $N = 32$. A sliding window of 32-width Hamming window is used, Firstly, the maximum normalized SCF of the envelop OFDM signal is plotted with different values of cyclic frequency (α). Such plot is shown in Fig.2.

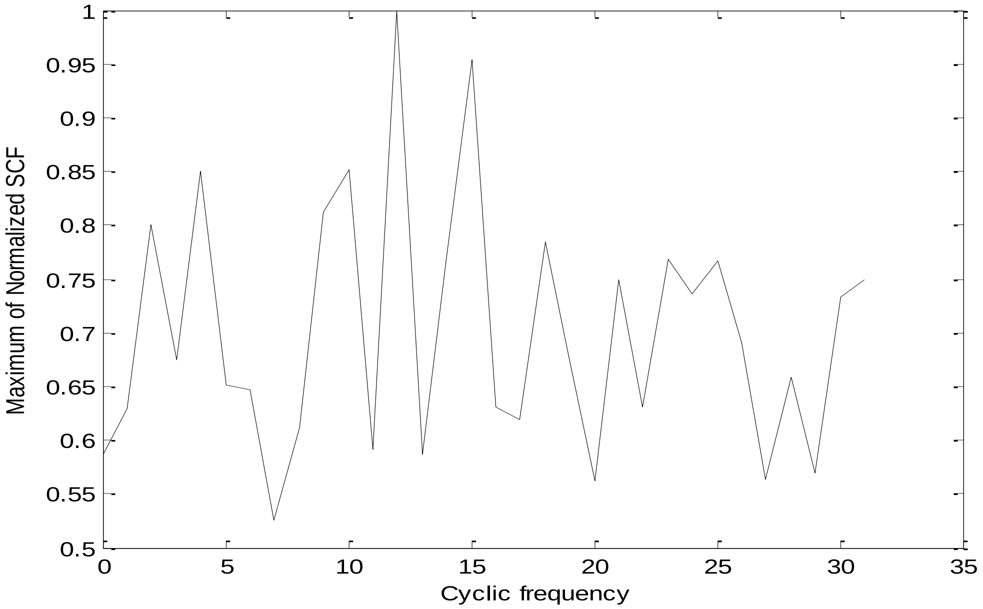


Fig.2 The maximum of SCF for different values of cyclic frequency

For $N = 32,$ Fig.2 shows that the normalized spectrum correlation function has its maximum value at cyclic frequency of 12 ($\alpha = (\frac{12}{32}T)$). According to this value, Fig.3 shows the ability for such detector to know the existence of primary OFDM signal with high probability of detection and low probability of false alarm (due to clear maximum value of SCF in this figure).

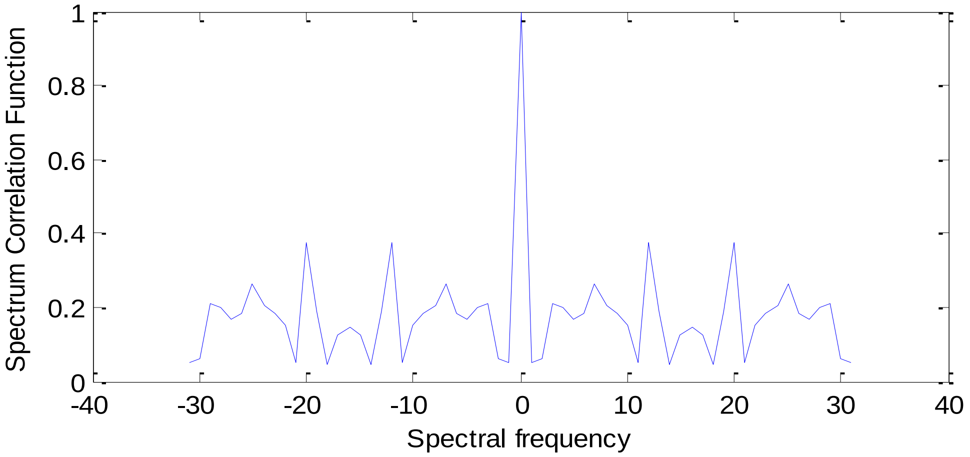
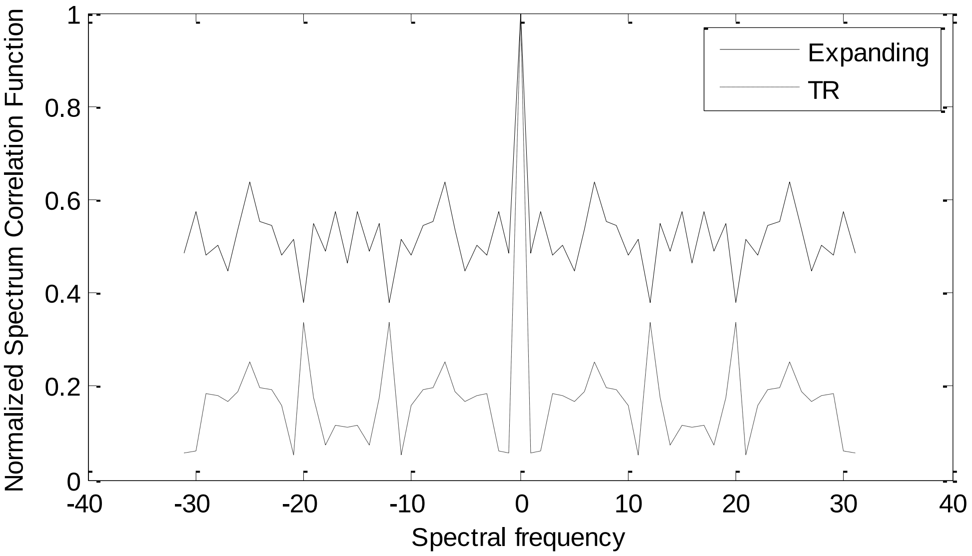


Fig.3 The normalized SCF of cyclostationary detector for OFDM signal

Extra tests shows that the correlation characteristics of the cyclostationary detector may affected when PAPR reduction techniques are used at the transmitter side of the OFDM system (first challenge in section II-B) . In these tests, symbol expanding technique [11] and tone reservation algorithm [12] are used. For an OFDM system with first technique, a reduction in the spectral correlation magnitude for the envelop of the OFDM signal is shown in Fig.4. This reduction makes the detection more difficult. In the other hand, the use of parallel search tone reservation method with memorized values enhances the cyclostationary features. It is clearly appears in Fig.4 that the difference between the maximum and the other values of the spectrum correlation function (SCF) in the tone reservation technique is higher than that of the symbol expanding technique. This means that an OFDM signal with tone reservation technique has better probability of detection and probability of false alarm than that of a same signal with symbol expanding technique.



Further tests are used to estimate the complexity of the cyclostationary detector (Fig.1). The complexity is calculated in terms of the number of addition/subtraction and multiplication operations of the detector algorithm. Table.1 shows the result of these tests with different values of OFDM symbols.

Table.1 The complexity of the cyclostationary detector for different values of OFDM symbols

	OFDM blocks	addition/subtraction	multiplication
1	16	96	204
2	32	192	396
3	64	384	780
4	128	768	1548
5	265	1536	3084
6	512	3072	6156

C. Proposed detector

As expected, Table.1 shows that the complexity of traditional cyclostationary detector is proportional with the number of OFDM symbols. To reduce the detector complexity, this paper suggests an algorithm to implement the cyclostationay detector. This algorithm is mainly based on the reduction of the number of the multiplication and addition / subtraction operations by choosing two suitable values of cyclic frequencies ($\alpha 1$ and $\alpha 2$). These values are used with the exponent function in the upper and the lower arms of the detector shown in Fig.1. As a result, the real or the imaginary parts of the exponent function is equal to zero or constant, so there is no need to more mathematical operations to implement such function. This idea behind this algorithm may be explained by the following two steps:-

- Step 1: for a certain value of N, the cyclic frequency (α) is chosen such that the SCF is maximum.
- Step 2: the values of $\alpha 1$ and $\alpha 2$ are calculated such that the sum of these values is equal to α and the real and imaginary parts of ($e^{j2\pi\alpha 1}$) and ($e^{j2\pi\alpha 2}$) are equal to zero or constant value.

Therefore, the complexity of the proposed detector is then calculated in terms of the number of mathematical operations for different values of OFDM symbols as tabulated in Table.2:-

Table.2 The complexity of the proposed detector for different values of OFDM symbols

	OFDM blocks	addition/subtraction	multiplication
1	16	80	134
2	32	160	262
3	64	320	518
4	128	640	1030
5	265	1280	2054
6	512	2560	4102

Finally, the estimated behavior of the traditional and the proposed detectors under multipath propagation is shown in Fig.5. Such behavior is represented by the probability of missed detection for different values of received signal to noise ratio. In this test, the received multipath signal is assumed to be a sum of the received signal with its delayed and attenuated version. The values of attenuation factor and normalized delay are assumed to have 0.75 and 15 respectively. The figure shows that the behavior of the traditional detector is better than that of the proposed detector (nearly 0.5 dB difference at probability of 10^{-4}) as a result of unbalanced values of cyclic frequencies used in the proposed detector.

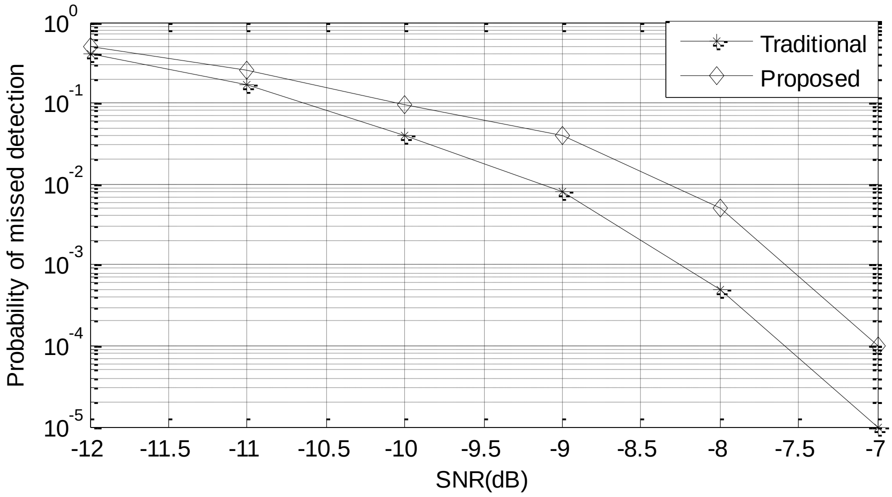


Fig.5 The behavior of the two detectors under multipath propagation conditions.

IV. Conclusion

Based on the correlation characteristics of the cyclostationary detection, this paper proves its ability to detect the OFDM primary signal. The results show the simplicity in the detection when a proposed tone reservation technique is used for reduction the PAPR of the OFDM signal. This work proposes also a method to reduce the complexity of cyclostationary detector in terms of number of arithmetic operations needed for hardware implementation. Further tests show that such hardware complexity reduction has an effect on the behavior of the proposed detector.

References

[1] Laser Berleman and Stefan Mangold, "Cognitive Radio and Dynamic Spectrum", John Wieley and Sons, 2009.

[2] Yulong Zou, Yu-Dong Yao and Baoyu Zhang, "Cognitive Transmission with Multiple Relays in Cognitive Networks", IEEE Transaction on Wireless Communication, vol.10, no.2, pp.648-659, February 2011.

[3] Harry Urkowitz, "Energy Detection of Unknown Deterministic Signals", Proceeding of IEEE, vol.55, no.4, April, 1967.

[4] S. Haykin," Cognitive Radio: Brain Empwered Wireless Communications", IEEE Journal on Selected Areas on Communications", vol.23, no.2, pp.201-210, 2005.

[5] William Gardner, "Measurement of Spectral Correlation", IEEE Trans. On Acoustics, Speech and Signal Processing, vol.34, no.5, pp.1111-1123, 1986.

[6] Manish Dave."Spectrum Sensing in Cognitive Radio: Cyclostationary Detector", M.Sc Thesis, National Institute of Technology, Rourkela, India, 2012.

[7] Kyou Woong Kim, "Exploiting Cyclostationary for Radio Environmental Awareness in Cognitive Radios", Ph.D Thesis, Faculty of Virginia Polytechnic Institute, Virginia, USA, 2008.

[8] Vladimir Sebeta, Roman Marsalek and Zbynek Fedra, "OFDM Detector Based on Cyclic Autocorrelation Function and its Properties", Radioenginnering, vol.20, no.4, pp,926-931, December 2011.

[9] Sina Maleki, Ashish Pandharipande and Geert Leus, "Two-Stage Spectrum Sensing for Cognitive Radio", IEEE International Conference on Acoustics, Speech and Signal Processing, pp. 2946-2949, March 2010.

[10] Paul D. Sutton, Keith E. Nolan and Linda E. Doyle, "Cyclostationary Signature in Practical Cognitive Radio Application", IEEE Journal on Selected Areas in Communication, vol.26, no.1, pp.13-24, 2008.

[11] Hussain K. Chaiel, "Sample Expanding Technique for PAR Reduction in OFDM Systems", Journal of Thi-Qar University, vol.5, no.3, 2009.

[12] Hussain K. Chaiel, Hassan A. Nasir, "Proposed Algorithm of Tone Reservation PAPR Reduction in OFDM System", Basrah Journal for Engineering Sciences, vol.10, no.1, 2010.

[13] V. Turunen, M, Kosunen, A, Huttunen, S. Kallioinen, P. Ikonen, A.Parssinen and J. Rynanen, " Implementation of cyclostationary feature detector for cognitive radio", In Proceedings of the 4th international conference on GROWNCOM '09, Hannover, Germany, pp.1-4, 2009.

Study Large Deformation Coil Spring Development For Robotics Submersible

Dr. Intessar A. Hadi

Lecturer

University of Technology

Machines & Equipment Engineering Department

Abstract

In this work the present a theoretical study for the free vibration of cylindrical, conical and helical springs. Circular cross sections, and non-circular cross section, namely elliptical, are considered as well for the investigating of the frequency characteristics of the springs. The equations of motion are derived mathematically for springs with different geometries. The mode shapes are numerically implemented by using COMSOL 4.2 software package for three dimensional solid elements. The mode shapes configurations are determined by applying different force loads and boundary conditions for different number of spring turns. The results show that increasing the number of turns leads to decrease the spring stiffness and vice versa. Also decreasing turn number is a good strategy to distinguish between different mode shapes. Springs stiffness is directly proportional to coil diameter. It is also shown that the configuration of cylindrical- elliptical spring is prone to the applied force where the stiffness is lower among all other spring types with the same number of turns.

دراسة التشوهات الحاصلة في النوابض الحلزونية للغاطس الآلي

الخلاصة

يقدم هذا العمل دراسة نظرية للاهتزازات الحرة لانواع من النوابض كالحلزونية والاسطوانية والمستطيلة متساوية ومختلفة المقطع كالمخروطية .تم اشتقاق المعادلات الرياضية للنوابض ذات المقطع المتساوي رياضيا اما الدوال الشكلية للنوابض تم حسابها عن طريق برنامج متطور يسمى كومسول (4.2) لعنصر ثلاثي الابعاد ووضع قوى مختلفة تراوحت بين 50 الى 150 نيوتن وتثبيت طرف من النابض واظهرت النتائج ان زيادة عدد حلقات النوابض يؤدي الى قلة جساءة النابض والعكس بالعكس. كما انها طريقة جيدة للتفريق بين الدوال الشكلية كما ان هناك علاقة بين كل من جساءة النابض وقطر الملف ويعتبر النابض الاسطواني افضل من النوابض الاخرى عن تسليط الاحمال بجساءة اقل ولنفس عدد الحلقات .

KEY WORDS

Helical springs; non-cylindrical; free vibration

Notations

$\acute{E}, \bar{G}, \acute{\upsilon}$ = Young's modulus N/m^2 ,shear modulus N/m^2 , Poisson's ratio
ρ = mass per unit volume of wire /kg/m^3
t = time / s
t,n,b = tangential, normal and binormal unit vector
χ, τ,h = curvature ,tortuosity and step for unit angle of the helix
M_t ,M_n ,M_b = torsional moment and bending moments, respectively
T_t ,T_n ,T_b = axial force and shear forces , respectively
U_t , U_n , U_b = Frenet components of displacement vector
Ω_t Ω_n Ω_b = Frenet components of rotational vector
J or I_t = torsional moment of inertia
A = cross sectional area
d, D = diameters of the circular cross- section and helix (R=D/2)
I_n , I_b = moment of inertias of cross –section with respect to n,b axes
C_t, C_n, C_b = the axial stiffness and the shearing stiffness's ,respectively
D_t D_n D_b = the tensional stiffness and the flexural stiffness’s respectively
p m = external force and moment vector per unit length
S = state vector

1. Introduction

Helical springs are commonly used in many engineering applications serving important mechanical tasks. The problem of helical springs is a classic mechanical problem that is subjected to many theoretical studies for decades. Performances of compressive springs working within dynamic envirments in mechanisms have become particularly important in recent years . Helical springs are amongst the most familiar engineering components and , as vital part of the automotive engine, they have been the subject of close scientific scrutiny . Cylindrical and non –cylindrical helical springs are common in many applications for wide variety of reasons, Figure (1) demonstrate the robotic fish design [7]. The number of paper present on the non–cylindrical coil springs is, yet, insufficient [3],[4],[5].The problem is described by six differential equations .These are second order equation with variable coefficients , with six unknown displacements. Three translations , and three rotations at every point along the member. A number of investigations were conducted in the field of vibration behavior of helical springs with constant cross section [6]. However, there is no paper published on the vibration analysis of the helical springs with variable cross section.

Although, there are some studies of the problems of free vibration of cylindrical coil spring [4], there have been only a few studies on the free vibration of helical springs with irregular shapes . Yildirim[5] investigated the free vibration frequencies of cylindrical springs by the transfer matrix method .Nagaya et al. [1] have determined the free vibration frequencies of non-cylindrical helical springs both experimentally and by the method of Myklestad. For this purpose, they have used the static element transfer matrix, where they derived the closed form solution with taking into account only the axial deformation for circular cross sections . Yildirim [1] used both the Myklestad method and the complementary functions methods , and presented the free vibration of non-cylindrical helical springs taking into account the effects of axial and shear deformation together with the rotary inertia . The free vibration problem of helical spring by the transfer matrix method .Yildirim employed the transfer matrix and the complementary functions to compute the eignvalues on non-cylindrical helical springs.The applications that use the helical and other types of springs are in continuous developments starting from the micro scale applications to huge civil engineering structures. The frequency characteristics of the helical springs can be implemented as a substitution for some continuous system applications. For instance, the robotics fish, is the interest of many researchers and companies around the globe. Due to highly need of such application, many models for robotics fish have been suggested in the last ten years. Some of these models are based on purely mechanical design , and some are based on using of smart materials. In general, the thrust mechanism stills the main challenge in the size and design of submersibles. Recently, it has been shown that the fluid-conveying pipes are a powerful technique for the thrust of submersibles .The mode of fluttering depends on the pressure inside the pipe , and it is found that higher pressure leads to fluttering with higher modes.

In this study we extend the work presented by Aren [7] who designed a robotics fish that works on the fluid inducing mechanism for the thrust force, he used relatively long hollow tail made of latex, see figure (1). The tail conveys water that is pumped from the head of the fish and flows through the latex tail and induces the tail to flutter and result in thrust force moves the fish forward. We investigate replacing of the long latex tail by a short helical spring that does the same function.the objective of the work is to replace the long latex tail by short coiled spring, than studying the igenfrequencies of the coiled spring under the effect of internal flow along the main axis,we investigate the effect of the internal pressure on the mode shapes for different types of coiled springs. Using of suitable type of coiled spring as a substitution for the latex tail of the submersible

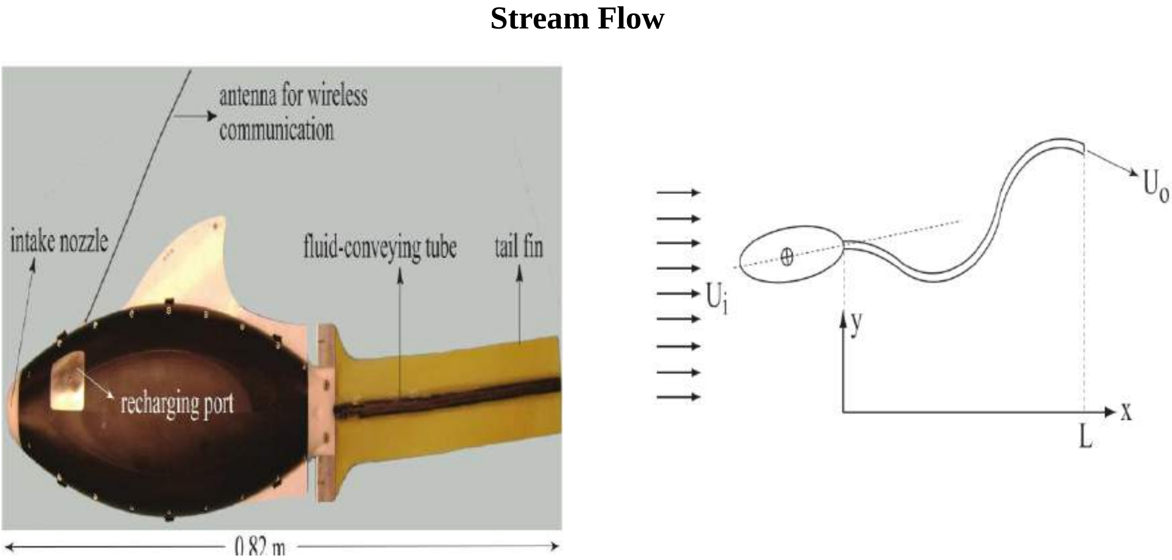


Figure (1). (a)The robotic fish design / (b)The free body diagram [7]

2. Free Vibration Formulation of cylindrical Coil Springs

The cylindrical helical coiled springs has the simplest mathematical model among the other types. The equation of motion for the 12-degree for free vibrations springs in (t, n ,b)[1,2]:-

$$\frac{\partial \mathring{U}_t}{\partial s} = X \mathring{U}_t^n + \frac{\mathring{T}_t}{C_t} \tag{1}$$

$$\frac{\partial \mathring{U}_n}{\partial s} = X \mathring{U}_t + \tau \mathring{U}_b + \mathring{\Omega}_t + \mathring{U}_n / C_n \tag{2}$$

$$\frac{\partial \mathring{U}_b}{\partial s} = -\tau \mathring{U}_n - \mathring{\Omega}_n + \frac{\mathring{T}_b}{C_b} \tag{3}$$

$$\frac{\partial \mathring{\Omega}_t}{\partial s} = X \mathring{\Omega}_n + \frac{\mathring{M}_t}{D_t} \tag{4}$$

$$\frac{\partial \mathring{\Omega}_n}{\partial s} = -X \mathring{\Omega}_t + \tau \mathring{\Omega}_n + \frac{\mathring{M}_n}{D_n} \tag{5}$$

$$\frac{\partial \mathring{\Omega}_b}{\partial s} = -\tau \mathring{\Omega}_n + \frac{\mathring{M}_b}{D_b} \tag{6}$$

$$\frac{\partial \mathring{T}_t}{\partial s} = X \mathring{T}_n - \mathring{P}_t + \rho A (\partial^2 \mathring{U}_t / \partial t^2) \tag{7}$$

$$\frac{\partial \mathring{T}_n}{\partial s} = -X \mathring{T}_t + \tau \mathring{T}_b - \mathring{P}_n + \rho A (\partial^2 \mathring{U}_n / \partial t^2) \tag{8}$$

$$\frac{\partial \mathring{T}_b}{\partial s} = -\tau \mathring{T}_n - \mathring{P}_b + \rho A (\partial^2 \mathring{U}_b / \partial t^2) \tag{9}$$

$$\frac{\partial \mathring{M}_t}{\partial s} = X \mathring{M}_n - \mathring{m}_t + \rho J (\partial^2 \mathring{\Omega}_t / \partial t^2) \tag{10}$$

$$\frac{\partial \mathring{M}_n}{\partial s} = \mathring{T}_b - X \mathring{M}_t + \tau \mathring{M}_t - \mathring{m}_n + \rho I_n (\partial^2 \mathring{\Omega}_n / \partial t^2) \tag{11}$$

$$\frac{\partial \mathring{M}_b}{\partial s} = \mathring{T}_n - \tau \mathring{M}_n - \mathring{m}_b + \rho I_b (\partial^2 \mathring{\Omega}_b / \partial t^2) \tag{12}$$

3. Modeling tools

COMSOL Multiphysics 4.2 simulation environment was used to make this analysis , COMSOL 4.2 is a complete problem-solving tool. MATLAB interface allowed somewhat straight forward modeling of a complex three dimensional helical geometry without resorting to CAD modeling .The analysis was also rather fast ,with meshing and analyzing taking less than 10 seconds .A three dimensional helix was created and meshed in COMSOL . eigenfrequency analysis was conducted to identify the first five vibrational modes along with their frequencies.

4. Case study analysis

A three dimensional helix was created in COMSOL4.2.to get deformation shape for different types of coiled springs. Figure (2) demonstrate different types of coiled springs , figures (3), (4) and (5) illustrate deformed and undeformations shapes for cylindrical, conical and elliptical springs for five mode shape .Table 1 records the results of COMSOL 4.2 when implemented for cylindrical, conical and elliptical springs .

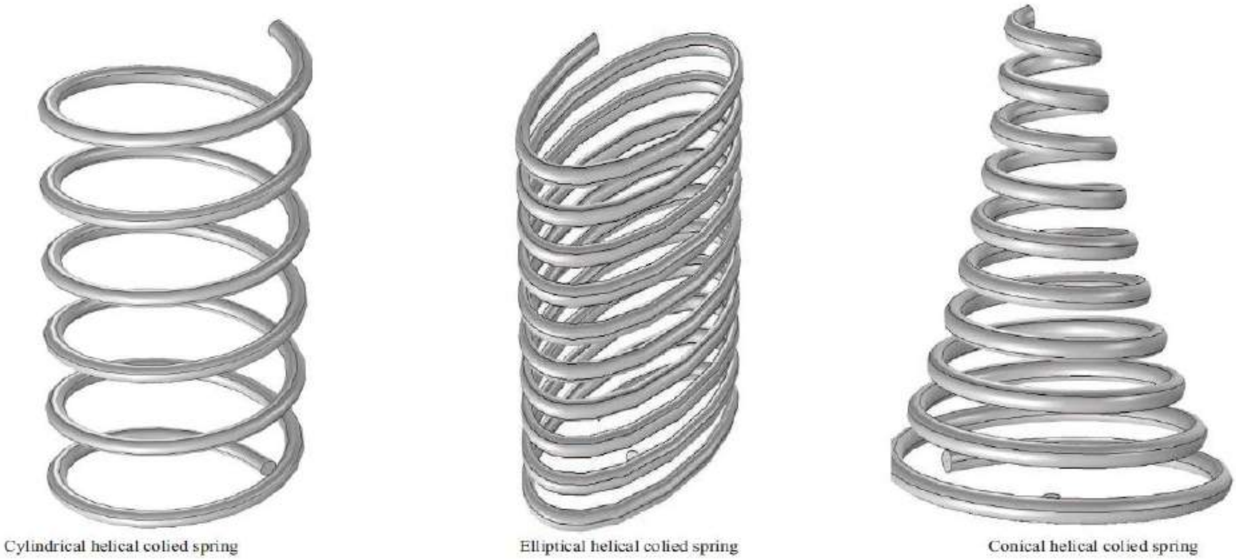


Figure (2).Different types of coiled springs

4.1. Cylindrical Spring analysis

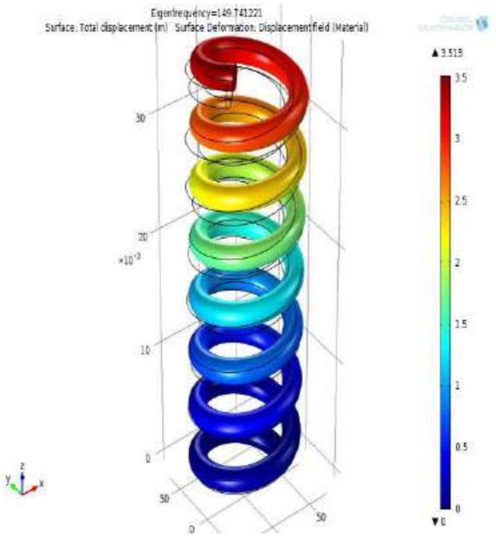
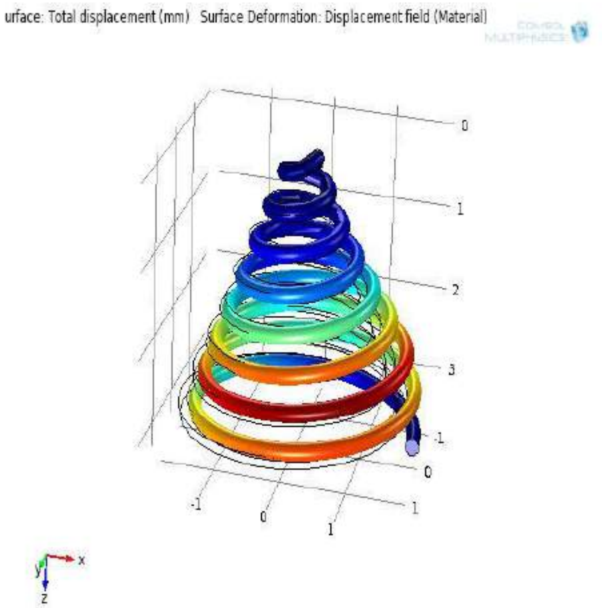


Figure (3). Cylindrical spring deformed & undeforormed.

4.2. Conical Spring analysis



Figure(4). Conical spring deformed & undeformed.

4.3. Elliptical Spring analysis

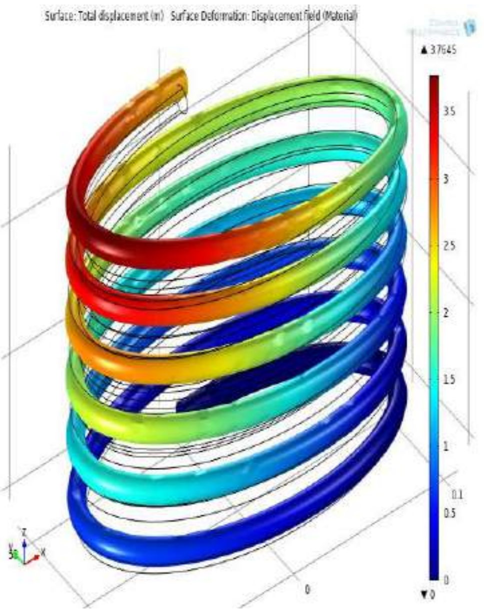


Figure (5).Cylindrical spring deformed & unreformed.

Table. (1). Application for spring steel AISI 4340 (n=6 ,E=2.0610^{11} N/m^2 V =0.3, d =0.005 m, a =0.001,α =0.00468 ,ρ =7900Kg/m^3).

Type	Mode1	Mode2	Mode3	Mode4	Mode5
Cylindrical/ PS	19.005	19.019	29.115	32.89	64.72
Yildirim[1]	36.52	36.544	150.627	165.616	201.82
Elliptical/ PS	23.646	25.587	31.500	32.888	53.765
Yildirim[1]	25.402	28.356	31.444	42.171	45.783
Conical/ PS	3.246	3.7.26	4.672	5.170	5.056
Yildirim[1]	3.200	3.121	4.556	5.443	5.508

PS=Present study

5. Results and Discussions

In this work, the equation of motion in helical spring was, derived from Timoshenko beam theory and Frenet formulae, after applying suitable boundary conditions by fixed one end. The software has been applied to the large deformation analysis of helical springs under axial loading. The Eigen frequency analysis was run across various values of the number of turns n, the wire diameter, and the helix diameter D.This paper presents theoretical analysis of vibration problem of coil springs of arbitrary shape by using COMSOL 4.2 .The results can be summarized five mode shape for cylindrical and elliptical springs as shown in figures (10,11) and table (2). For cylindrical spring . Figures (12,13) and table (3) for elliptical spring.

5.1. Cylindrical Spring

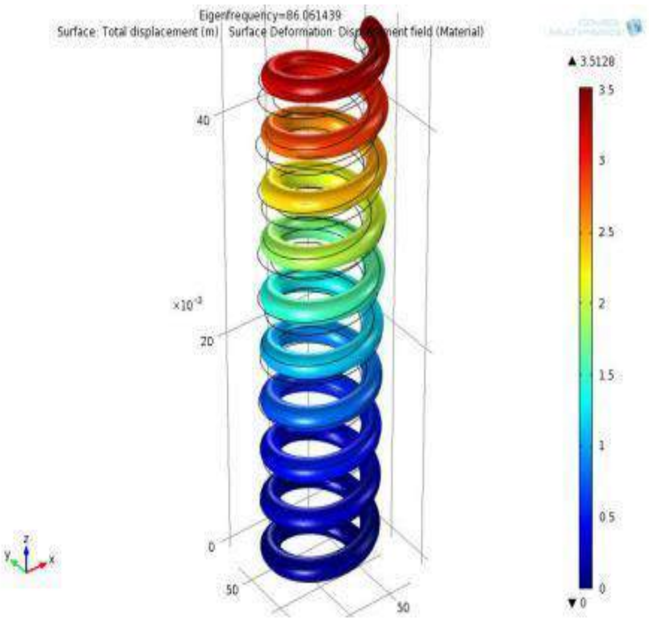
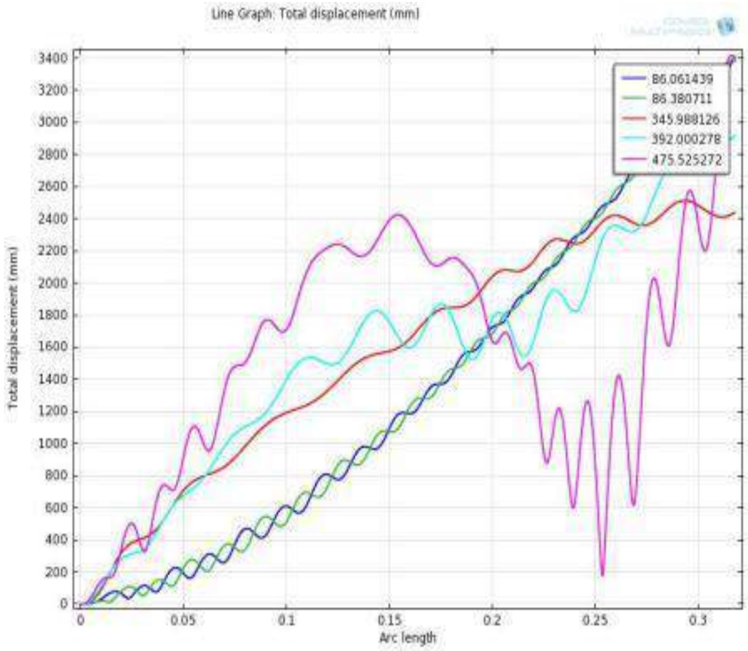


Figure (6). Deformed& unreformed of cylindrical spring

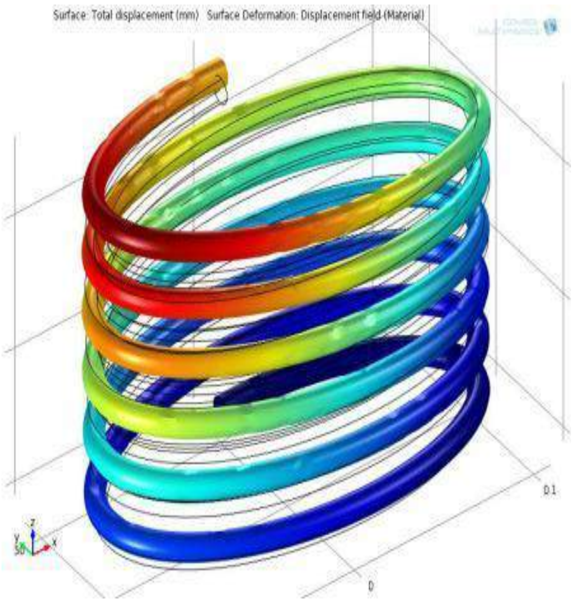


Figure(7). Fifth mode shape of spring fixed one end

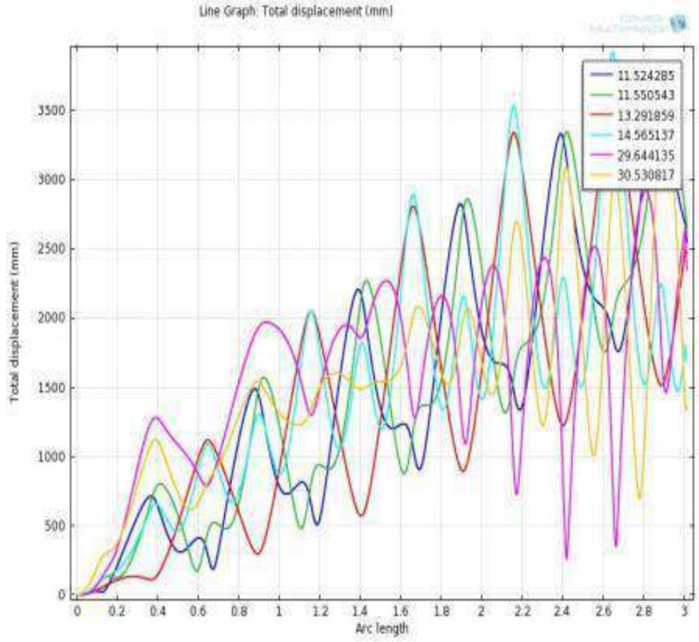
Table (2). Example for a cylindrical spring free vibrations, second with body load =50-150 N, Eigenfrequency for(5) mode shape number of turns =6.

Load	Mode 1	Mode 2	Mode 3	Mode 4	Mode 5
X=y=z=0	459.304	509.359	526.678	532.339	906.888
Y=0	107.84	108.153	238.845	268.833	474.070

5.2. Elliptical Spring



Figure(8). Deformed & undeformed of elliptical spring fixed one end



Figure(9). Fifth Vibration mode shape of elliptical springs fixed one end

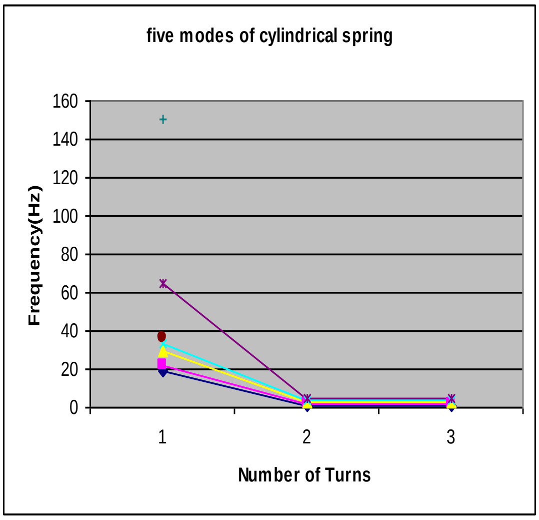
Table (3). Example of an elliptical spring with out load , second with body load, Eigenfrequency for (5) mode shape number of turns =6 .

Load	Mode 1	Mode 2	Mode 3	Mode 4	Mode 5
Y=0	11.524	13.294	14.565	29.644	30.538
X=y=z=0	25.402	28.356	31.444	42.171	45.783

6- Conclusions

The following notes can be extracted from the research results :-

1. Increasing spring turns number (n) will decreases spring stiffness and all resonant.
2. Decreasing spring turn number (n) is a good way to achieve separation between five mode and others.
3. Increasing diameter of the spring wire (d) will increase spring stiffness and increasing all resonant frequencies.
4. Springs having the same material and geometrical properties for elliptical type is more rigid than others types.
5. Some natural Frequencies are very close to each other for the elliptical type as illustrated in figures (14 ,15 ,16) below , which explore the effect of vibrational mode frequencies on spring number of turns(n) for constant pitch angle.
6. Figure (13) shows comparison of vibrational mode frequencies for Conical spring between this study and Yildrim



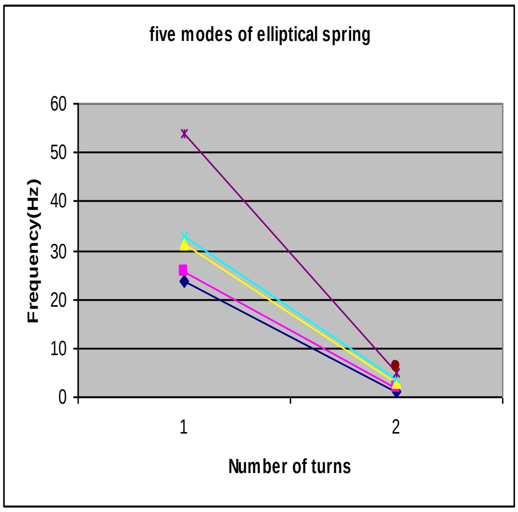
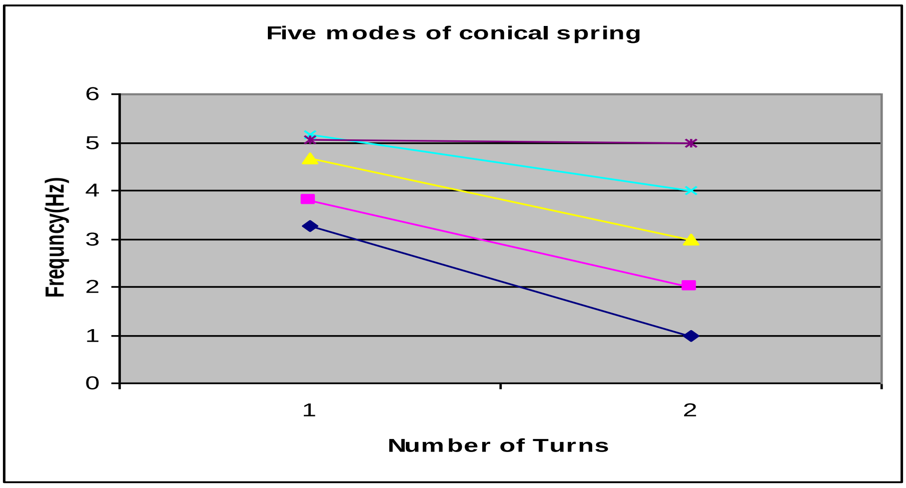
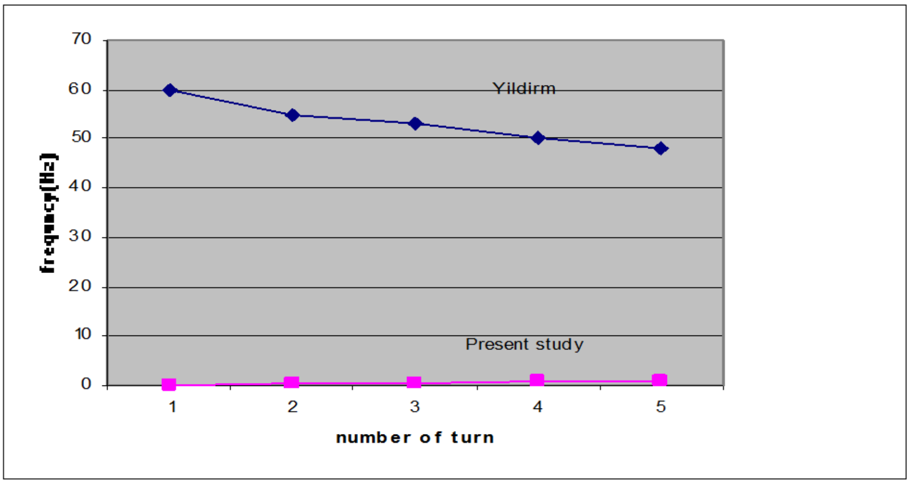


Figure.(10).Vibration mode frequencies on number of turns =6 of cylindrical spring

Figure(11).Vibration mode frequencies on number of turns=6 of elliptical spring



Figure(12).Vibrational mode frequencies on number of turns=6



Figure(13) comparison of vibrational Mode frequncies for Conical springs between this study and Yildrim.

References

1. Yildirim “ Investigation of parameters affecting free vibration Frequency of helical springs” Turkey Vol.39,99-114(1996).
2. Wisam Busool”Free vibration of helicoidal Beas of Arbitrary Shape and Variable Cross section” JULY2002 ,Vol.124/397.
3. Pratheev Sreetharan"Eigenfrequency Analysis of helical spring Electrode" Dec.16 ,2008.
4. A.M. Yu,Y.Hao"Free Vibration analysis of cylindrical springs noncircular cross- sections"J.of sound and vibration 330(2011).
5. V.Yildirim "Free vibration analysis of non-cylindrical coil springs by combined use of the transfer matrix and the complementary function methods"Vol.13,487- 94(1997).
6. Kosuk,Nagaya and Takeda ,Sadahiko, “Free vibration of coil Springs of Arbitaray Shape “Int.J.Numer Method Eng..32.pp1081-1099(1986)
7. Aren "Modeling and simulation of fluttering bioinspired submersible "Ph.D thesis 2011 MSU.
8. V.Yildirim, N. Ince. Natural frequencies of helical springs of arbitrary shape,Journal of Sound and vibraton 204 (1997) 311-29.
9. COMSOL "Introduction to COMSOL multiphysics "2011”.