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Finite Element Analysis of Two Stage Gear Pair to Finding Natural Frequencies with Effect of Design Parameters

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Abstract: ***Gearing is a very important term in automobiles, industrial, production and every place where power transmission requires. Gear is an important machine component in much mechanical power transmission system. It has a wide range of applications because of its high degree of reliability and compactness. Vibration induced by gear is a major problem in much power transmission system and has been widely studied; it is an important topic for further studies in engineering field. Natural frequencies and mode shapes are the important design parameters of a system. Mathematical modelling of system may be done to find the natural frequency & mode shape. In present work, the effects of design parameters on the natural frequencies are investigated.***

Keywords: 3D modelling, modal analysis: two stage gear-rotor assembly, natural frequency, mode shape

1. Introduction

Gear transmission has become the most common and important mode in today's mechanical world, due to its advantages such as compact structure, high drive efficiency, accurate transmission ratio and large power transmission range. With the rapid development of automobile, aviation, shipbuilding, mining and other industries, the demand of gear transmission has increased. Vibration is a major problem in many power transmission applications at higher operating speeds, have vibratory excitations is related to the gear transmission error. Most of the mechanical systems are subjected to dynamic loading which induces vibration in gears and leads to crack, fatigue and noise. In general the total effective work for the mechanical system is lowered. Reasons for such behaviour are type of loading, construction and conditions of work, where mechanical system operates.
The spur gear is the first choice for gear vibration analysis and parameters such as natural frequencies and vibration mode, can be calculated.

Modal analysis is a technique used to determine, improve and optimize the dynamic behaviours of the engineering structures. It can be used for determining the inherent dynamic characteristics of natural frequencies and mode shapes.

2. Literature Review

Akur Saxena, Anadparey and Manoj Chouksey[2016] studied the inherent dynamic characteristics of gear rotor system in the form of natural frequencies, damping factor and mode shapes using modal analysis. Modal analysis has been done using solid element in Ansys workbench. It is also found that the variation in bearing stiffness, affect the natural frequencies of the system.

FU Shengping, LUO Ning and LI Shengbo [2017], this paper comprehensively and deeply studied the dynamic characteristics under the multi boundary conditions. Generation mechanism of the multi-source excitations leads the gearbox vibration is analysed study provides the method of forecasting of gearbox dynamic response, as well as also provide the technical guidance for gearbox design and optimization.

Edward J. Dielhl and J. Tang [2016] proposed the systematic approach to modelling and analysis of two stage gear box to predict the fault. The research demonstrates that the modelling method in combination with HWT data analysis has the potential for facilitating successful diagnosis for gearbox system.

AnkurSaxena, AnandParey and Manoj Chouksey [2016] described the dynamic behaviour of the multi mesh geared-rotor system. Modal analysis technique is used to find the natural frequencies and force harmonic response of the system. It has been found that the position of the gear and coupling, affect the gear dynamic behaviour. Also show the effect of bearing stiffness on natural frequencies.

Kadam G. N. and Prof. Bajaj D.S.[2015],to reduce the weight of the gear system, the authors studied the effect of design parameters on natural frequency and vibration mode. To evaluate the alternative design choice, reduction in weight and tune of the system, modal parameters are often altered during the design phase.

ShoyabHussin[2015] studied the torsional vibration characteristic of multi rotor using finite element method. Outcomes is that the natural frequencies for any systems can help to avoid the failure. The results are compared with Holzer and Ansys 14.0 to establish the effectiveness of finite element method.

WANG Tao, XIE Chen, WANG Feng, HU XIAO-Rui and HU Li-ming [2014], aiming of this paper is that the static linear modal analysis methods fail to meet the working conditions of high and frequent variable speeds. This paper provides the guidance and reference data for design, use and maintenance. Jairo Alberto Ruiz-Botero, Juan Fernando Lopez and Hector FabiaQuentero- Riaza [2014], studied the detection of failure in two stage gear box and shows the variation on gear mesh stiffness for different amount of damage.

James Kuria and John Kithiu [2008], described the effect of time varying mesh stiffness, time varying frictional torque on vibration and stress level of multi stage gear box. This model can be used as a tool for optimum gear design parameter for any multistage spur gear train.

J. S.Wu and C.-H. Chen [2001] described a simple approach for eliminating the dependent torsional angles present in the gear branched system. This study also find the influence of shaft mass on the natural frequencies.

3. Methodology

1) Model development

Model of three shafts and two pairs of the gears in mesh is developed. The essential elements of the gear train model shown in fig. 1. Model contains two pairs of gear meshes each with a shaft stiffness, moment of inertia of gears, Moment of inertia of the input and output masses. Equivalent system is shown in fig.2. This yielded a six degree of freedom system which is modelled

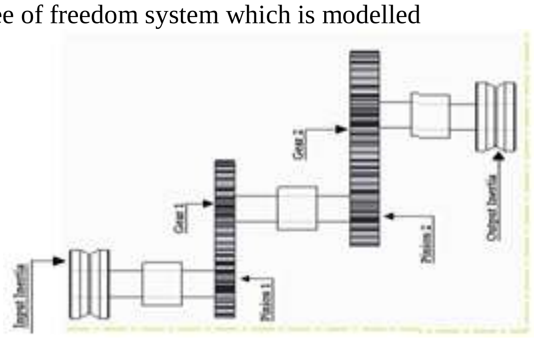


Figure 1: Schematic diagramof Gearbox

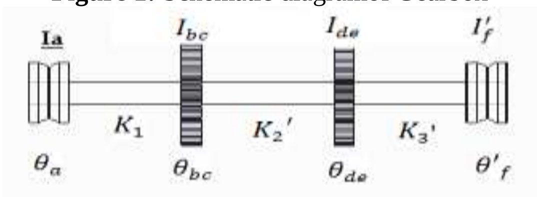


Figure 2: Equivalent System

Equations of motion for free un- damped vibration are derived-

$$I_a\ddot{\theta}_a + K_1(\theta_a - \theta_{bc}) = 0$$

$$I_{bc}\ddot{\theta}_{bc} + K_1(\theta_{bc} - \theta_a) + K_2'(\theta_{bc} - \theta_{de}) = 0$$

$$I_{de}\ddot{\theta}_{de} + K_2'(\theta_{de} - \theta_{bc}) + K_3'(\theta_{de} - \theta'_f) = 0$$

$$I_f'\ddot{\theta}_f' + K_3'(\theta'_f - \theta_{de}) = 0$$

Where: $I_{bc} = I_B + (G_1)^2 I_c$

$I_{de} = I_d + (G_2)^2 I_e$

$$I_f' = (G_1G_2)^2 I_f$$

$$K_2' = (G_1)^2 K_2$$

$$K_3' = (G_2)^2 K_3$$

Assumptions:

1) Gears are modelled as rigid disc and radius equal to the reference radius.
2) Mass of the shafts are ignored.
3) Backlash is not considered.
4) Teeth are perfectly involute.

Parameters Used in Gear Modelling:				
Parameter	Pinion1	Gear1	Pinion2	Gear 2
Module	2.5	2.5	2	2
Pressure Angle	20°	20°	20°	20°
No. Of teeth	18	26	20	35
Width(mm)	10	10	15	15
Moment of inertia (kg/m²)	1.35e-04	1.35e-04	2.90e-05	2.72e-04

Material properties

Material Properties	Unit	Value
Density	Kg/m³	7800
Young's Modulus	Gpa	210
Poison's Ratio	-	0.3

Shaft Stiffness

K1=K2=K3
K1 =6626.79 N-m/rad
K'2 =13826 N-m/rad
K'3 =20295 N-m/rad

4. Numerical Solution

Assuming the motion of the form of

$$\theta_i = A_i \cos\omega t$$

The equations of motion can be arranged in matrix form as,

$$M\ddot{\theta} + K\theta = 0$$

Where, $[M]$= mass matrix,

$[K]$=stiffness matrix

To find the natural frequencies and mode shapes of the two stage gear transmission system, two methods are used-

(I) Eigen values and Eigenvectors method

$$|\lambda I - C| = 0$$

Where, C=$[M]^{-1}[K]$, dynamic matrix and λ=ω^2

Mass matrix,

$$[M] = \begin{bmatrix} Ia & 0 & 0 & 0 \\ 0 & Ibc & 0 & 0 \\ 0 & 0 & Ide & 0 \\ 0 & 0 & 0 & I'f \end{bmatrix}$$

$$\text{Stiffness Matrix, } [K] = \begin{bmatrix} K_1 & -K_1 & 0 & 0 \\ -K_1 & (K_1 + K'_2) & -K_2' & 0 \\ 0 & -K'_2 & (K'_2 + K'_3) & -K_3' \\ 0 & 0 & -K'_3 & K'_3 \end{bmatrix}$$

Solution is done by using MATLAB Code to find the Natural frequencies and mode shapes.

(II) Holzer's Method,

For SHM we may substitute, $-\omega^2\theta = \ddot{\theta}$ in the governing equations and by assuming the suitable value of ω and $\theta_a = 1$

we get the deflections-

$\theta_a = 1$

$\theta_{bc} = \theta_a - (I_a\ \theta_a)\omega^2/K_1$

$\theta_{de} = \theta_{bc} - (I_a\ \theta_a + I_{bc}\theta_{bc})\omega^2/K'_2$

$\theta'_f = \theta_{de} - (I_a\ \theta_a + I_{bc}\theta_b + I_{de}\theta_{de})\omega^2/K'_3$

$If, \sum I\ \omega^2\theta = 0$ then we get the natural frequency

III) Finite Element Analysis

The spur gears are sketched, modelled and assembled in Creo-2.0.The IGES assembly file is imported to the finite element software (Ansys 16.0) for model analysis. By define contacts, meshing and applying proper boundary conditions and solve, we get the natural frequencies and mode shapes of the two stage geared system.

Figure 3: Model of Two Stage gear System

5. Results and Discussion

1) Comparison of Natural Frequencies

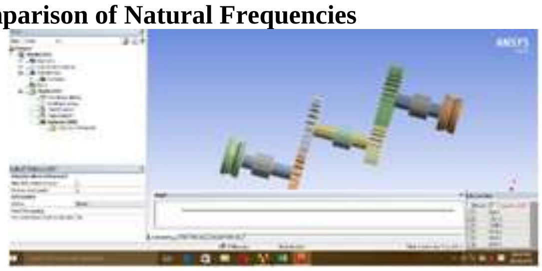


Figure 5: Model Solution

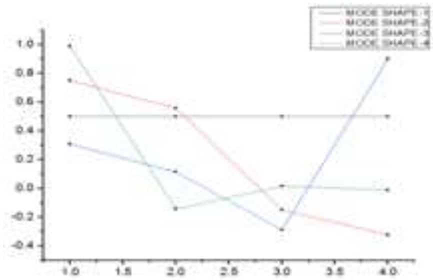
2) Natural Frequencies:

Natural Frequencies (Hz)				Difference (%)		
S.No.	Holzer Method	Eigen Method	Ansys	Holzer-Ansys	Eigen-Ansys	Holzer-Eigen
1	0	0	246	-	-	0
2	1110	1118	1231	9.83%	9.18%	0.70%
3	1740	1719.4	1808	3.76%	4.90%	1.10%
4	2342	2356	2434	3.78	3.20%	0.60%

Mode Shapes:

Following Mode Shapes were obtained at different natural frequencies of the system. The calculations were done on MATLAB program.

MODE SHAPE-1	MODE SHAPE-2	MODE SHAPE-3	MODE SHAPE-4
0.5	0.7505	0.309	0.9896
0.5	0.5575	0.1139	-0.1428
0.5	-0.149	-0.2879	0.0143
0.5	-0.3221	0.8994	-0.0103



Effect of gear design parameters on natural frequency

1) Effect of change in module

The effect of module of the gear on natural frequencies was investigated by changing the module from 2.0 to 2.5 and 3.0, while holding the pressure angle, width and number of teeth constant.

Natural Frequencies(Hz)			
Frequency/Module	module 2.0	module 2.5	Module 3.0
First	58	32	33.3
Second	1253	948.6	707.57
Third	2370.4	2288.5	2260.8
Fourth	2990.4	2473.2	2276.5

2) Effect of Change in pressure angle:

The pressure angle was increased from 14.5˚ to 20˚, while holding the module, width and number of teeth for various meshes constant.

Natural Frequencies(Hz)	Pressure angle	
	$\phi=14.5^0$	$\phi=20^0$
First	12.9	33.3
Second	279.3	707.6
Third	1110.8	2260.8
Fourth	2267.6	2276.5

6. Conclusion

The mathematical modal was developed to analyse the vibration characteristics of two stage gear transmission. The modal consists four equations of motion, which were solved using Eigenvalue& Eigenvector and Holzer's method. Modal analysis was done in finite element software (Ansys16.0). Parametric studies ware also conducted to examine the effect of two design variables, module and pressure angle .The following specific conclusions can be drawn from the study:

1) The results of natural frequencies and mode shapes are reported.
2) Increasing the module from 2.0 to 2.5 and 3.0, decrease the natural frequencies.
3) Increasing the pressure angle of the gears from 14.5˚to 20˚, increase the natural frequencies.
4) This type of study may be helpful in understanding modal behaviour of geared branched system and for proper gear design as per our requirement.

References

[1] AnkurSaxena, AnandParey and Manoj Chouckse y, "Study of Modal Characteristics of a geared rotor

system," Procedia Technology , vol.23, pp. 225-231, 2016 .
[2] FUShengping, LUO Ning and LI Shengbo, "Study on dynamic characteristics of vehicle gearbox under multi-boundary condions," J. Shanghai Jiao Tong univ. (Sci.), vol.22(1), pp 24-34, 2017.
[3] Edward J. Dielhl and J. Tang, "Predictive modelling of a two stage gearbox towards fault detection," Journal of sound and vibration, ID 9638325, volume 2016.
[4] AnkurSaxena, AnandParey and Manoj Chouksey, "Dynamic analysis of multi-mesh geared rotor system using modal analysis, "Prognostics and system Health management conference, 978-1-5090-2778-1/16, IEEE, 2016
[5] Kadam G. N. and Prof.Bajaj D.S., "Modal analysis of spur gear to determine the natural frequencies and its effect over the change in material properties," IJARIIE,VOL.1(5), PP. 526-530, 2015
[6] Hemantkori, and Akhileshlodwal, "Modelling and torsional vibration characteristics of Mechanical gearbox using FEA", Journal of scientific research and development, vol.4(4), 119-121, 2016.
[7] WANG Tao, XIE Chen, WANG Feng, HU XIAO-Rui and HU Li-ming, "Modal analysis of gear transmission system based on ANSYS," Journal of applied mechanics and materials, vol.635-637,pp. 519-522, 2014.
[8] VivekKaraveer, Ashish Mogrekar and T. PremanRenold Joseph, "Modelling and finite element analysis of spur gear," International journal of current engineering and technology,vol.3(5), pp. 2104-2107, 2013.
[9] Jairo Alberto Ruiz-Botero, Juan Fernando Lopez and Hector FabiaQuentero- Riaza,"Design, modelling and dynamic simulation of three double stage gearboxes with different module, mesh stiffness fluctuation and different level tooth breakage," Rev Fac. Ing. Uni. Antioquia, vol. 74, pp117-131, 2015.
[10] James Kuria and John Kithiu, "Modelling parametric vibration of multistage gear system as a tool for design optimization," journal of Aerospace and Mechanical Engineering, VOL.2:3, PP. 159-166, 2008.
[11] J. S.Wu and C.-H. Chen,"Torsional vibration nalysis of gear- branched systems by finite element method,"Journal of sound and vibration, vol. 240(1), pp. 159-182, 2001.
[12] ShoyabHussin, "Mode shapes and Natural frequency of rotor system with ansys14,"international journal of scientific &and engineering research," vol.6(5), pp. 11-14, 2015.

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