VEHICLES RIDE: TORSIONAL VIBRATIONS OF PROPELLER SHAFT

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Abstract

Torsional vibration of the propeller shaft when the vehicle is on motion was studied. Propeller shaft experiences dynamic behaviour known as vibratory motion, that is, single movement of part, to and fro, when the equilibrium of the parts has been disturbed. If the rate at which the propeller shaft oscillates about a certain equilibrium position increases, it has a great effect on the various vehicle parts, including the passengers and it can even lead to loss of life. Vibrations occur in many vehicle parts but this paper studied only torsional vibrations of propeller shaft. Basic vibrations theory was studied and some mathematical formulas were used to calculate the frequency, period and response and varying the length and diameter of propeller shaft. This paper also highlighted the causes, effects, and solutions of vibratory motion in propeller shaft. The graphs plotted show that torsional vibrations vary with the frequency and period of vibrations.

Introduction

The study of the relation between the motion of physical systems and forces causing the motion is a subject that fascinated the human mind since ancient times. Vibration motion, which is-very common in nature is the most fundamental vibration of one dimensional system. The motion of any part of the vehicle is said to be vibratory when it moves back and forth over the same path, motion being repeated at regular interval (Leonard 1986). In principle, the torsional natural frequencies of a drive line can be approximated by the analysis of a mode that includes point mass moments of inertia which are connected by a straight flexible shaft of zero mass. Some parts of the vehicle such as propeller shaft execute simple harmonic motion when it moves to and fro, about a fixed point, along a straight line path and repeats this motion periodically with acceleration which is proportional to displacement and is always directed towards the mean position (Lalanne, Berthier and" Hagopian, 3983). Torsional vibration refers to vibration of a rigid body about a specific reference axis. The displacement is measured in terms of angular co-ordinate and the restoring moment may be either member or to be the unbalanced moment of a force or a couple.

In a front engine rear-wheel drive, the propeller shaft connects the gearbox to the final drive unit and transmit the torque of the engine through the gearbox to the rear axle (Heinz, 1985). It has to withstand torsional stresses of the transmission torque and must be light and balanced to prevent vibration and whip at high speed. Some manufacturers split the propeller shaft and support it in the centre by bearing, in order to reduce the whip and vibration. The fitting of a divided propeller shaft necessitates additional cross members to support the mounting, as well as extra universal joints. The safe speed of the propeller shaft is inversely proportional to the mean diameter of the cross section (Beard, 1983). The propeller shaft consists of low carbon steel tube, either formed with rolled steel sheet which is then, butt welded along its seam or made from seamless drawn tubing.

This paper studied the behaviour of vehicle propeller shaft subjected to given excitations. The behaviour of the system is characterised by the motion caused by these excitations and commonly referred to as the system response. The motion is generally described by displacements and less frequently by velocities or accelerations. The excitation can be in the form of initial displacements or velocities or in the form of externally applied forces known as forced response. Torsional vibrations,

in the propeller shaft is of great hazard. As a result of these vibrations, various torsional strains appear in the propeller shaft body. These strains depend on the parameters of the vibrating material system; such as mass, rigidity and ability to absorb vibrational energy (Timoshenko, Young, and Weaver, 1974).

Small cars, short vans, and trucks are able to use a single propeller shaft with a slip joint at the front end without experiencing any undue vibration. However, the vehicles of longer wheel base require longer propeller shaft which tend to sag and under certain operating conditions would tend (o whirl and then set up sympathetic resonant vibrations in the body of the vehicle which cause the body to vibrate as the shaft whirls. According to BS6841 and ISO2631, the sensitivity of the human body to vibration varies throughout the frequency range which is-from 0.1 to 80Hz (Wesley, Tillman and Tillman, 1992). Vibrations in the frequency range of 0.1 to 0.63Hz are considered to be responsible for causing discomfort or acute distress (commonly known as motive sickness) in people who are exposed to them.

Objectives of the Study

The main objective of this paper is to study the causes, effects and the solutions of the torsional vibrations of propeller shaft.

Materials and Methods

In order to achieve the objectives stated above, the author acquired detailed knowledge'of torsional vibrations of propeller shaft through the literature review and interaction with related automobile industries and roadside mechanics. Some mathematical formulas were used to write a comprehensive computer program to calculate the frequency, period and response, varying the length and diameter of propeller shaft. The acquired raw data was documented for the purpose of plotting various graphs.

Causes **of Vibration in the Propeller Shaft**

Vibration in the propeller shaft are caused by the following:

(i) Bent rotating shaft,
(ii) Long shaft.
(iii) Shaft rotating at high speed,
(iv) Worn splines at sliding,
(v) Worn universal joints,
(vi) Worn needle with roller bearing.
(vii) Lack of lubrication.
(viii) Mis-aligned split propeller shaft.

Effect of Vibration during Vehicle Ride

The effects of torsional vibrations of propeller shaft are listed below:

(i) **Degraded health of the driver and passengers:** These includes back-ache and spinal damage resulting from exposure to vibration. Exposure can disturb the central nervous system and can affect the circulatory and urological systems.

(ii) **Vibration** of the **body/propeller shaft may affect visual perception:** Even small movement of the head (1mm) produces a similar movement of the retina of the eyes and can disturb the visual acuity. Sensations of touch and hearing may also be affected.

(iii) **Vibration can disturb** one's **comfort:** It reduces comfort boundary.

(iv) Low frequency vibration (less than about 0.5Hz) can cause the motion sickness syndrome characterised by pallor, sweating nausea and vomiting.

(v) Vibration can reduce driver's life-span if it leads to high blood pressure.

(vi) **Constant repair of vehicle:** When the vehicle is in motion and it vibrates, a lot of parts like body, engine seating, joints, bearing, etc. would be damaged. Therefore, the owner of the vehicle must spend unplanned expenses in repairing the vehicle, which can also lead to the reduction in life-span of the vehicle.

Torsional Vibration Theory and Analysis

The simplest form of mechanical vibration to consider is that based on a linear theory. When a shaft vibrates in torsional mode, the elasticity and inertia torques on a typical segment may be summed in accordance with d'Alembert's principle (Barber, 1992).

$$T + \frac{dT}{dx}dx - T - I_p dx \frac{d^2\theta}{dt^2} = 0 \ldots\ldots\ldots\ldots 1$$

Where

T= Internal torgue on the cross section at x \P = Polar moment of inertia of cross section $\backslash_r dx$ = Mass moment

of inertia of the segment

$$\frac{d^2\theta}{dt^2} = \text{Rotation acceleration}$$

substituting $T = GI_p \frac{d\theta}{dx}$ it becomes $\frac{d^2\theta}{dx^2} = \frac{1}{b^2} \frac{d^2\theta}{b^2\, dt^2}$ 2

When shaft is vibrating in one natural mode, $b = \sqrt{\frac{G}{\;}}$ 3

The frequency equation from which the frequencies of the natural modes of the torsional vibrations of the shaft can be calculates as

$$P_1 = \frac{i\pi b}{l}$$ 4

Where i is an integer, i.e i = 0, 1, 2, 3, ... ∞

We can obtain various modes of torsional motion. The mode of vibration can be expressed from the following equations

$$x_1 = C_1 \, Cos \frac{p_1 x}{b} = C_1 Cos \frac{\pi x}{L}$$

$$x_2 = C_2 \, \text{Cos} \frac{2\pi x}{L} \; ; \; x_3 = C_3 \, Cos \frac{3\pi x}{L}$$

Generally: $$x_1 = C_1 Cos \frac{p_1 x}{b} = C_1 Cos \frac{i\pi x}{L} \qquad \text{.............................5}$$

The general form of the vibrational solution is:

$$\theta i = \text{Cos} \frac{i\pi x}{L} \left(\text{Aicos} \frac{i\pi bt}{L} + \text{BiSin} \frac{i\pi bt}{L} \right) \qquad \text{...............................6}$$

Rayleigh's Quotients for torsional vibration are:

$$w_1 = 1.7719 \sqrt{\frac{GJ}{IL^2}} \qquad \text{..7}$$

$$w_2 = 4.7776 \sqrt{\frac{GJ}{IL^2}} \qquad \text{..8}$$

$$w_3 = 7.7254 \sqrt{\frac{GJ}{IL^2}} \qquad \text{..9}$$

7	17507.8	16285	15161.9	14183.7
8	20100.4	18611.5	17327.9	16210
9	22642.9	20937.9	19493.9	18236.2
10	25125.5	23264.3	21659.9	20262.5

TABLE 2
Receptance versus Period of Vibration

1	2.50173E-3	2.701868E-3	2.902007E-3	3.102145E-3	3.302284E-3
2	1.250865E-3	1.350934E-3	1.451003E-3	1.551073E-3	1.651142E-3
3	8.3391E-4	9.006229E-4	9.673357E-4	1.034048E-3	1.100761E-3
4	6.254325E-4	6.754671E-4	7.255017E-4	7.755363E-4	8.255709E-4
5	5.00346E-4	5.403737E-4	5.804014E-4	6.20429E-4	6.604567E-4
6	4.16955E-4	4.503114E-4	4.836678E-4	5.170242E-4	5.503806E-4
7	3.5739E-4	3.859812E-4	4.145724E-4	4.431636E-4	4.717548E-4
8	3.127163E-4	3.377335E-4	3.627508E-4	3.877681E-4	4.127854E-4
9	2.77978E-4	3.002076E-4	3.224452E-4	3.446828E-4	3.669204E-4
10	2.50173E-4	2.701868E-4	2.902007E-4	3.102145E-4	3.302284E-4

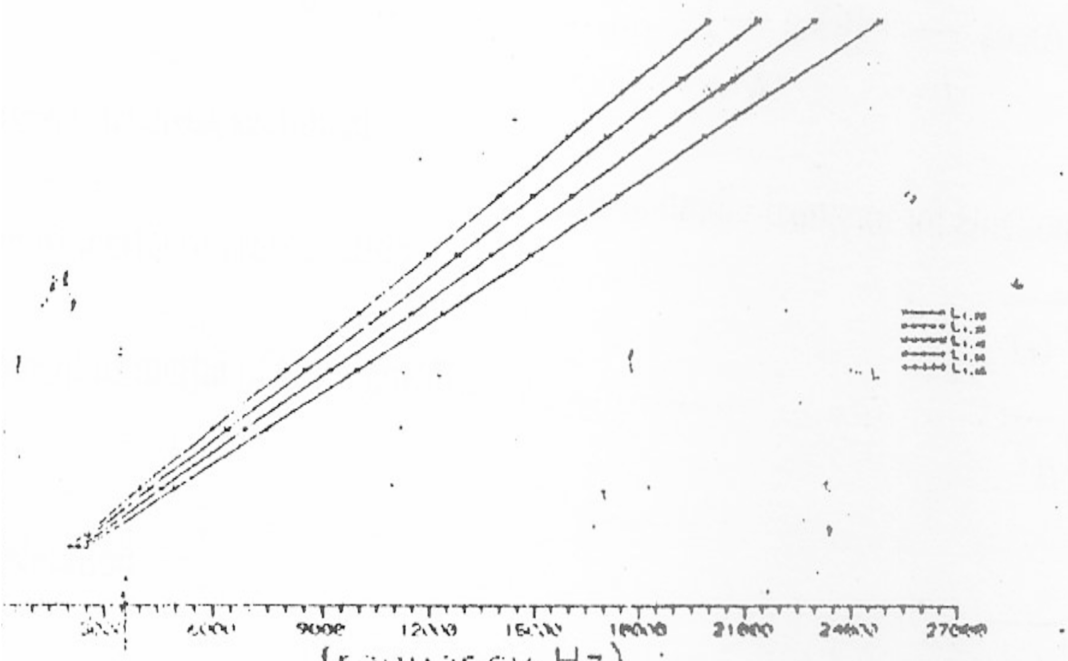


FIG 1

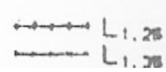


TABLE 3

Displacement Versus Receptance varying the length of the shaft

c=10, x=0.055

i	L1.25	L1.35	L1.45	L1.55	L1.65
0	10	10	10	10	10
2	9.61997	9.67389	9.71711	9.95229	9.7813
4	8.50878	8.71684	8.88446	9.02144	9.11477
6	6.75087	7.19125	7.54916	7.84365	8.08868
8	4.47985	5.19664	5.78674	6.27728	6.6888
10	1.86835	2.8631	3.69693	4.39913	4.99635
12	-8.85162E-1	3.428174E-1	1.30795	2.30457	3.08536
14	-3.57139	-2.19982	-9.801149E-1	9.505855E-2	1.01942
16	-5.98618	-4.59898	-3.30273	-2.11916	-1.05199
18	-7.94599	-6.69819	-5.41849	-4.2284	-3.09738
20	-9.30186	-8.36053	-7.26655	-6.12815	-5.0073
22	-9.95073	-9.47759	-8.68349	-7.72431	-6.69819
24	-9.8433	-9.97649	-9.60915	-8.93779	-8.09611
26	-8.98772	-9.82472	-9.99115	-9.70848	-9.13991
28	-7.44903	-9.03216	-9.80787	-9.99819	-9.78382
30	-5.34417	-7.6505	-9.0697	-9.79258	-9.99999
32	-2.83112	-5.76987	-7.8184	-9.10183	-9.77866
34	-1.067462E-1	-3.51291	-6.12475	-7.96016	-9.12962
36	2.62774	-1.02684	-4.08458	-6.42413	-8.08124
38	5.16251	1.5262	-1.81331	-4.56984	-6.6794
40	7.3049	3.97971	5.605425E-1	-2.48915	-4.98539
42	8.89208	6.17365	2.90268	-2.881413E-1	-3.07333
44	9.80341	7.96493	5.0806	1.93299	-1.02684
46	9.96963	9.23673	6.97107	4.05554	1.06456
48	9.3781	9.90609	8.46714	5.97682	3.10941
50	8.07379	9.92934	9.48416	7.60218	5.01824
52	6.15582	9.30502	9.9646	8.85091	6.70758
54	3.76998	8.07379	9.88127	9.66115	8.10353
56	1.0976	6.31597	9.23888	9.99277	9.14503
58	-1.6582	4.14622	8.07379	9.82933	9.78653
60	-4.28797	1.70604	6.45191	9.17893	9.99997

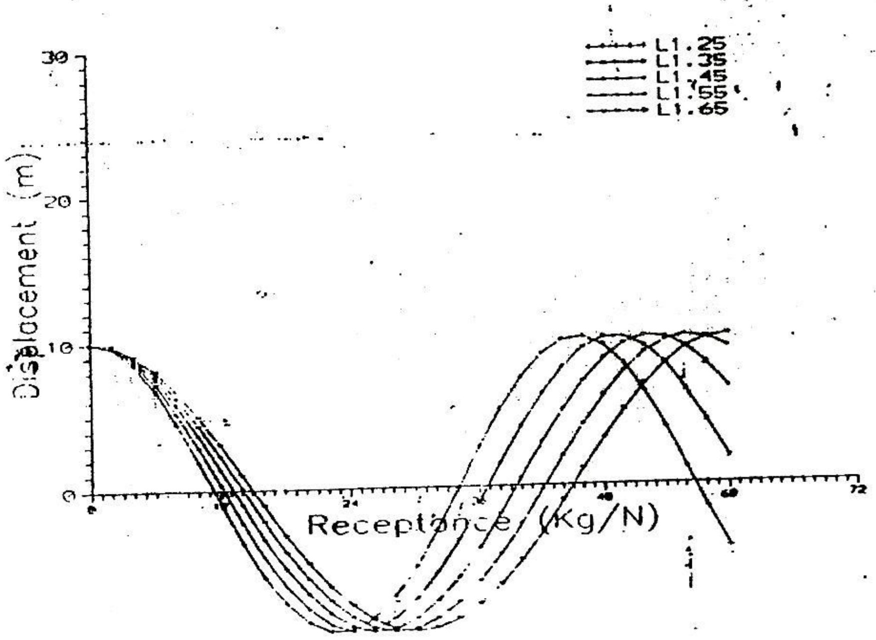


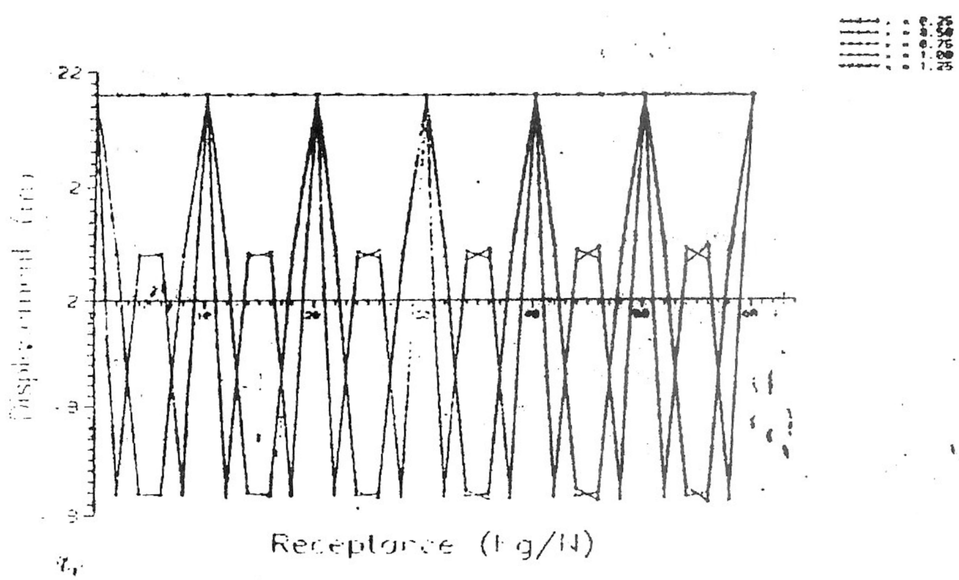
FIG 3

TABLE 4

Displacement versus Receptance

k=1.25, c=20

i	x=0.25	x=0.5	x=0.75	x=1.00	x=1.25
0	20	20	20	20	20
2	6.17072	-16.1922	-16.1625	6.21881	19.9999
4	-16.1922	6.21881	6.12259	-16.1326	19.9997
6	-16.1625	6.12259	6.26686	-16.2514	19.9994
8	6.21881	-16.1326	-16.2514	6.02622	19.999
10	19.9999	19.9997	19.9994	19.999	19.9984
12	6.12259	-16.5714	-16.0727	6.41077	19.9977
14	-16.2219	6.31487	5.97797	-16.0123	19.9969
16	-16.1326	6.02622	6.41077	-16.3685	19.9959
18	6.26686	-16.0727	-16.3194	5.833	19.9948
20	19.9997	19.999	19.9977	19.9959	19.9936
22	6.07442	-16.3101	-15.9819	6.60207	19.9923
24	-16.2514	6.41077	5.833	-15.8902	19.9908
26	-16.1027	5.92969	6.55431	-16.4839	19.9892
28	6.31487	-16.0123	-16.4264	5.6392	19.9875
30	19.9994	19.9977	19.9948	19.9908	19.9856
32	6.02622	-16.3685	-15.8902	6.79269	19.9836
34	-16.2808	6.5065	5.6877	-15.7666	19.9815
36	-16.0727	5.833	6.69747	-16.5976	19.9793
38	6.36284	-15.9514	-16.5125	5.44481	19.9769
40	19.999	19.9959	19.9908	19.9836	19.9744
42	5.97797	-16.4264	-15.7976	6.98262	19.9718
44	-16.3101	6.60287	5.54208	-16.6413	19.9691
46	-16.0425	5.73617	6.84024	-16.7096	19.9662
48	6.41077	-15.8902	-16.5976	5.24987	19.9632
50	19.9984	19.9936	19.9856	19.9744	19.96
52	5.92969	-16.4839	-15.7041	7.17184	19.9568
54	-16.3394	6.69747	5.39613	-15.5144	19.9534
56	-16.0122	5.6392	6.98262	-16.82	19.9499
58	6.45045	-15.8286	-16.6818	5.05439	19.9462
60	19.9977	19.9908	19.9793	19.9632	19.9425



FIG

Discussion

Computer programme was written, using equations 4, 5, 8, 9 and the raw data in Tables 1, 2, 3, and 4 were used to plot graphs shown in Figures 1, 2, 3, and 4 respectively.

The receptance-frequency graph in Figure 1 shows linear graph of four different lengths of propeller shaft. When the lorsional vibration increases, the frequency of vibration increases, causing both drivers and passengers to feel uncomfortable. The graph also shows that frequency varies with the length of the shaft. The longer the length, the higher the torsional vibration for the same frequency of vibration.

The five natural modes in receptance-period graph in Figure 2 shows that the torsional vibrations vary with the period of vibration. The higher the torsional vibrations of the shaft, the lower the time required for the shaft to complete one cycle of its motion. The graphs also show that the length of the shaft varies with the period of vibration. The shorter the length, the lower the torsional vibration of the shaft, for the same period of vibration.

The graph plotted in Figure 3 shows that the torsional vibration varies with the frequency of vibration, period of vibration and the number of nodes when different lengths of propeller shaft are considered. It can be seen from the graph that when the length of the shaft is reduced, the period of vibration reduces. Furthermore, we have more nodes with the shorter shaft, which implies reduction in torsional vibration as point of zero displacement increases.

Figure 4 shows the shape of vibration at various points on a particular shaft. A shaft of length 1.25m was considered at five different points. It was observed that at point 0.25 and 1m overlapped and at point 0.5m and 0. 75m overlapped, this means that torsional vibrations at the beginning of the shaft and towards the end of the shaft arc equal. Also, torsional vibrations are equal for a certain length at the middle of the shaft.

Recommendations

The following points are recommended:

(i) Fundamental frequency of the drive line should be increased, (ii) Low frequency absorber should be fitted to the propeller shaft.

(iii) Operating line should be arranged so that the engine avoids the critical region of operation, (iv) Cylindricity and concentricity of the propeller shaft should be checked as recommended by the manufactures.

(v) If long propeller shaft is used, centre bearings are required to support the shaft, (vi) Worn out splines and joints should be repaired immediately the owner notices the problem. (vii)Propeller shaft splines and joints should be lubricated as recommended by the manufacturer. (viii)Split propeller shaft should be properly aligned. (ix)Vibration absorber should be attached to the propeller shaft to reduce vibration to a minimum.

Conclusions

A common approach of increasing the rigidity of the propeller shaft is to extend either the rear end of the gearbox main shaft and housing or the final-drive pinion shaft and housing. The vibration problem can be solved by increasing the diameter of the shaft, but this would increase its strength beyond its torque-carrying requirements and at the same time increase its inertia which oppose the vehicle acceleration and deceleration. An alternative solution frequently adopted is the use of divided propeller shafts supported by intermediate or centre bearings.

Therefore, from the study of torsional vibration of propeller shaft, it was observed that in order to avoid unplanned expenses, accidents and to assure occupants comfort, it is advisable to reduce the torsional vibration (o a minimum by using short propeller shaft.

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