

# TORQUE ROLL AXIS AND ITS INFLUENCE ON AUTOMOTIVE ENGINE MOUNTINGS\*

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Received on March 24, 1962

## ABSTRACT

In automotive engines the torque excitation does not occur about an axis parallel to any of the principal axes of the engine. This causes the roll movement of the engine to occur about an axis, known as Torque Roll Axis, and its accurate location becomes essential for the determination of the most favourable disposition of the engine mountings. The paper deals with the theoretical analysis to predict the location of Torque Roll Axis. The results of the analysis are applied to locate the Torque Roll Axis of seven automotive multi-cylinder engines for experimental verification. It is noticed that a judicious combination of the analytical and experimental methods would reduce considerably the time and effort involved in locating the torque roll axis. Further experimental work confirms the fact that the arrangement of mountings about the torque roll axis leads to the maximum isolation of engine vibrations.

## INTRODUCTION

An engine mounted on resilient supports has six natural modes of vibration. But under the influence of its inherent disturbances it will get excited in three of its natural modes of vibration, provided these disturbances are occurring along and about the principal axes of the engine and all the natural modes are decoupled. In a modern automotive engine the location of all the three principal axes  $xx$ ,  $yy$  and  $zz$  is as shown in Fig. I, and the ideal condition of decoupling of modes of vibration can be obtained by arranging mountings of equal stiffness symmetrically with respect to these principal axes. In practice it is not possible to attain this ideal arrangement and the mountings are generally fitted symmetrically about the vertical plane passing through axis  $xx$ .

This arrangement leads to some complications regarding isolation of rolling motion, because of the fact that torque excitation does not occur about axis  $xx$ . The interesting phenomenon arising out of this is discussed below.

In reciprocating engines of the automotive type the longitudinal principal axis  $xx$  is inclined to the crankshaft axis about which torque excitation occurs. Consequently the engine rolls about a third axis, called Torque Roll Axis, which lies between the crankshaft axis and the principal axis  $xx$ . If the foregoing arrangement of the mountings is modified so as to locate them about the Torque Roll Axis the engine mass will be excited in only one mode under the

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\*Extracted from the Thesis submitted to the Indian Institute of Science by Kailash Nath Gupta for the Degree of Master of Science of the Institute, July 1961.

influence of rocking torque and there will be complete decoupling. Further if the natural frequency of the engine mass on its mountings about this axis is substantially low as compared to firing frequency at low speeds, a very good engine installation will result.

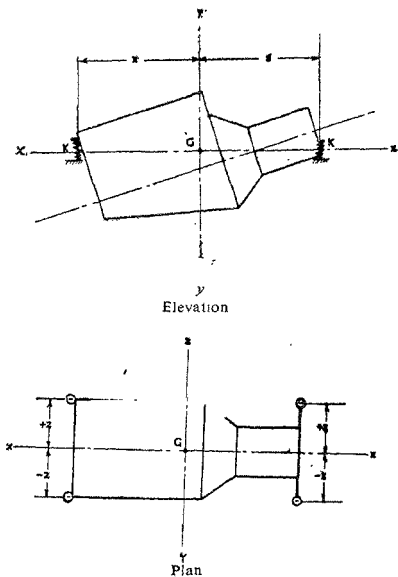


FIG. I  
Symmetrical Mounting arrangement of a Power Unit

It is the intention of the present investigation to devise a method for the easy location of Torque Roll Axis and to study its impact on engine vibration.

#### REVIEW OF PREVIOUS WORK

There was a belief at one time that roll took place about an axis parallel to crankshaft axis and passing through the centre of gravity of the engine. Hence emerged the practice of arranging the mountings about this axis. This was given up in favour of 'Floating Power Arrangement' as shown in Fig. 11, where the longitudinal principal axis was assumed to be the roll axis and the mountings were arranged about it.

The 'Floating Power Arrangement' did not, however, take into consideration the effect of non-coincidence of torque axis with principal axis  $xx$  on the engine roll movement. Den Hartog<sup>1</sup> and Iliffe<sup>2</sup> studied this effect and showed that torque excitation about an axis different from principal axis of inertia would also induce rotation about an axis at right angles to the torque axis, and the resultant motion would take place about an axis different from torque axis.

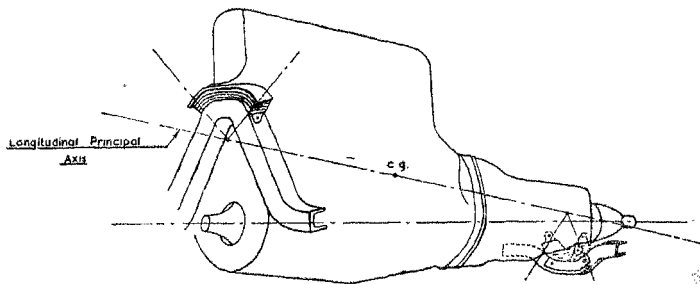


FIG. II

The Chrysler Floating Power System

Riesing<sup>3</sup> was the first to notice that engine roll took place about the Torque Roll Axis, which was in between the torque axis and the principal axis  $xx$  and recommended the location of the mountings about the Torque Roll Axis. But other workers such as Anon<sup>4</sup>, Harrison<sup>5</sup> and Horovitz<sup>6</sup> recommended the location of the mountings about the principal axis  $xx$ , since they considered that in a conventional engine (incorporating the gear box) the torque component along the principal axis  $xx$  would be much greater than that along the other principal axis  $yy$ . Though this was partly true yet Nicolaisen<sup>7</sup> showed that the torque component along the principal axis  $yy$  amounted to 30-40% of the total unbalanced torque and so argued that it was not justifiable to neglect it. Therefore if the unbalanced torque components along axes  $xx$  as well as  $yy$  were considered, the roll must take place about another axis namely Torque Roll Axis.

In view of the foregoing controversy regarding the roll movement of the engine and its influence on the location of engine mountings it was decided to carry out an analytical and experimental study of the disposition of the Torque Roll Axis and its impact on isolation of engine vibrations.

## ANALYTICAL INVESTIGATION

*Position of the Torque Roll Axis of an engine located in space:*—Consider an engine located in space, as shown in Fig. III. Let  $xx$ ,  $yy$  and  $zz$  ( $zz$  being perpendicular to the plane of paper) represent the principal axes of

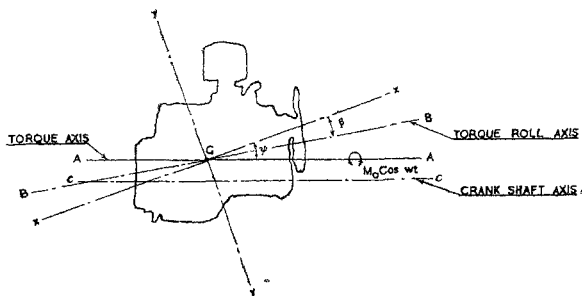


FIG. III

Torque roll axis location

inertia and  $G$  the centre of gravity. Let under the influence of torque  $M_0 \cos \omega t$  acting about the torque axis  $AA$  the engine roll about an axis  $BB$ , making an angle  $\beta$  with the principal axis  $xx$ . Then the following differential equations are derived.

$$I_x \ddot{\alpha} \cos \beta = M_0 \cos \psi \cos \omega t \quad [1]$$

$$I_y \ddot{\alpha} \sin \beta = M_0 \sin \psi \cos \omega t \quad [2]$$

where  $\alpha$  is the angular displacement of the engine about the axis  $BB$  at any instant, and  $I_x$  and  $I_y$  represent principal moments of inertia of the engine about axes  $xx$  and  $yy$  respectively. The equations [1] and [2] have a solution of the type  $\alpha = \alpha_0 \cos \omega t$ , which on substitution in these equations yields

$$\alpha_0 = - \frac{M_0 \cos \psi / \cos \beta}{I_x \omega^2} \quad [3]$$

and 
$$\alpha_0 = - \frac{M_0 \sin \psi / \sin \beta}{I_y \omega^2} \quad [4]$$

Equating equations [3] and [4] we have

$$\frac{M_0 \cos \psi / \cos \beta}{I_x \omega^2} = \frac{M_0 \sin \psi / \sin \beta}{I_y \omega^2}$$

$$\text{or} \quad \tan \beta = (I_x / I_y) \tan \psi. \quad [5]$$

The above relation establishes the location of axis  $BB$ , known as torque roll axis, with respect to the principal axis  $xx$ . For a given engine  $I_x$ ,  $I_y$  and  $\psi$  are constant. Therefore  $\beta$  is also a constant. The equation [5] can be written as

$$\tan \beta = C$$

$$\text{or} \quad (1/C) \tan \beta = 1 \quad [6]$$

where  $C = (I_x / I_y) \tan \psi$  is a constant for a given engine.

The following inferences can be drawn on the basis of equation [5] for an actual engine where the possibility of  $I_x = I_y$ ,  $\psi = 0$  or  $\pi/2$  is remote.

(a) The torque roll axis is independent of the magnitude and frequency of the exciting torque. This indicates that its position would remain unchanged under the influence of any periodic torque.

(b) Since  $I_x$  is always the minimum moment of inertia ( $I_x < I_y$ ),  $\beta$  will be less than  $\psi$ , i.e., torque roll axis will lie between the principal axis  $xx$  and torque axis  $AA$ .

(c) The inclination of torque roll axis to the torque axis depends upon the ratio of two principal moments of inertia  $I_x$ ,  $I_y$  and the angle between the principal axis and the torque axis.

*Position of Torque Roll Axis of an engine supported on flexible Mountings*:—Now consider the engine to be suspended resiliently such that all possible modes of oscillations are decoupled. Let  $K_x$  and  $K_y$  represent the torsional stiffness of the mountings about axes  $xx$  and  $yy$  respectively. Then, under the influence of periodic torque  $M_0 \cos \omega t$  the engine mass will be subjected to rolling motion about an axis  $BB$ . Resolving the torques acting on the engine mass along the principal axes, the following equations can be written for dynamic equilibrium of the engine mass.

$$I_x \ddot{\alpha} \cos \beta + K_x \alpha \cos \beta = M_0 \cos \psi \cos \omega t \quad [7]$$

$$\text{and} \quad I_y \ddot{\alpha} \sin \beta + K_y \alpha \sin \beta = M_0 \sin \psi \cos \omega t. \quad [8]$$

For steady state conditions the solution of the above equations may be assumed to be  $\alpha = \alpha_0 \cos \omega t$ , which on substitution in eqns. [7] and [8] gives

$$\alpha_0 = \frac{M_0 \cos \psi / \cos \beta}{K_x - I_x \omega^2} \quad [9]$$

and

$$\alpha_0 = \frac{M_0 \sin \psi / \sin \beta}{K_y - I_y \omega^2} \quad [10]$$

Equating equations [9] and [10] we obtain

$$\frac{M_0 \cos \psi / \cos \beta}{K_x - I_x \omega^2} = \frac{M_0 \sin \psi / \sin \beta}{K_y - I_y \omega^2}$$

or

$$(\tan \beta) / (\tan \psi) = (K_x - I_x \omega^2) / (K_y - I_y \omega^2)$$

$$= \frac{I_x}{I_y} \cdot \frac{\omega_x^2 - \omega^2}{\omega_y^2 - \omega^2} \quad [11]$$

where  $\omega_x$  and  $\omega_y$  represent the natural frequencies (rad./sec.) of the system about the axes  $xx$  and  $yy$  respectively. The eq. [11] can be written as

$$\frac{\tan \beta}{\tan \psi} \cdot \frac{I_y}{I_x} = \frac{\left(\frac{\omega_x}{\omega}\right)^2 - 1}{\left(\frac{\omega_y}{\omega}\right)^2 - 1}$$

or

$$\frac{1}{C} \tan \beta = \left\{ \left(\frac{\omega_x}{\omega}\right)^2 - 1 \right\} / \left\{ \left(\frac{\omega_y}{\omega}\right)^2 - 1 \right\} \quad [12]$$

where  $C$  is a constant for the engine equal to  $(I_x/I_y) \tan \psi$ .

The following inferences can be drawn on the basis of eq. [12].

(a) The position of torque roll axis for a particular engine installation is independent of the magnitude of the exciting torque, but it does depend upon its frequency.

(b) At  $\omega_x/\omega = 1$ , it occupies the position of the principal axis  $xx$  and at  $\omega_y/\omega = 1$ , it occupies the position of the principal axis  $yy$ .

(c) If mounting stiffnesses be so adjusted that  $\omega_x = \omega_y$ , the position of torque roll axis will be same as given by the relation [6].

(d) For values of  $\omega_x/\omega$  and  $\omega_y/\omega$  sufficiently small compared to unity the eq. [12] reduces approximately to eq. [6].

(e) In actual engine installations where vibration isolation is an important consideration, the ratio of any natural frequency of the system to the exciting frequency is less than  $1/3$ , which on squaring becomes sufficiently small compared to 1. Consequently eq. [12] reduces approximately to eq. [6], and eq. [6] defines approximately the position of the torque roll axis in actual engine installation.

A graphical study of the eq. [12] is also made. In Fig. IV the dimensionless quantity  $(1/C) \tan \beta$  is plotted against  $\omega_x/\omega$  with  $\omega_y/\omega$  as parameter. The dotted line in the figure represents eq. [6]. Within the practical limitations for values of  $\omega_x/\omega$  and  $\omega_y/\omega$  namely 0.33 one can conclude that the results obtained

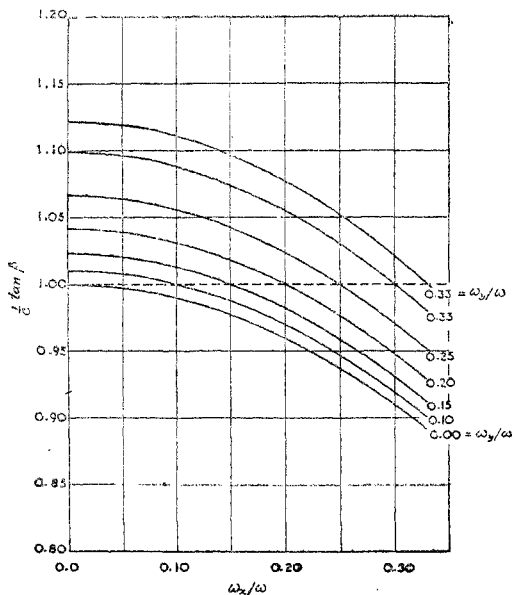


FIG. IV

Position of torque roll axis in a resiliently suspended engine for different frequency ratios

from eq. [12] do not deviate much from those from eq. [6]. The percentage error introduced by the use of eq. [6] in place of eq. [12] can be given as

$$\text{Percentage error} = \frac{1 - \left\{ \left( \frac{\omega_x}{\omega} \right)^2 - 1 \right\} / \left\{ \left( \frac{\omega_y}{\omega} \right)^2 - 1 \right\}}{\left\{ \left( \frac{\omega_x}{\omega} \right)^2 - 1 \right\} / \left\{ \left( \frac{\omega_y}{\omega} \right)^2 - 1 \right\}} \cdot 100$$

$$= \frac{\left( \frac{\omega_y}{\omega} \right)^2 - \left( \frac{\omega_x}{\omega} \right)^2}{\left( \frac{\omega_x}{\omega} \right)^2 - 1} \cdot 100. \quad [13]$$

The percentage error is plotted against  $\omega_x/\omega$  with  $\omega_y/\omega$  as parameter in Fig. V for values  $\omega_x/\omega$  and  $\omega_y/\omega$  ranging from 0 to 0.33. The maximum error as indicated by these graphs is 12.22% which occurs for values of  $\omega_x/\omega = 0.33$  and  $\omega_y/\omega = 0$ .

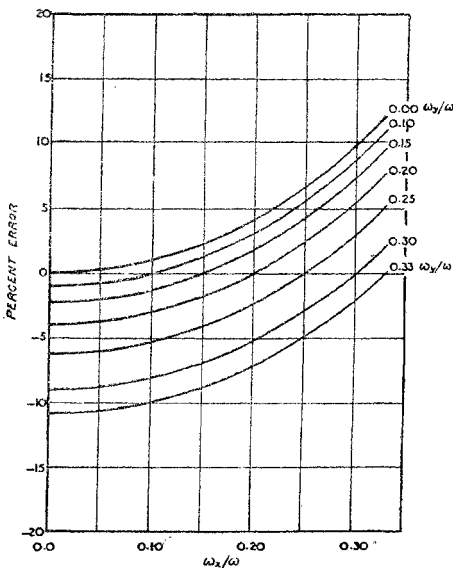


FIG. V  
Percentage error in assuming the engine to be suspended freely in space for different frequency ratios



In actual engine installations  $\omega_y/\omega$  cannot be zero, and it is a design consideration to keep all possible natural frequencies as low and as close as possible, under which condition the error becomes negligibly small.

On the basis of foregoing it can be concluded that the position of torque roll axis given by equation [6] would be in good agreement with practical results.

#### EXPERIMENTAL INVESTIGATION

The experimental investigation centred round several automotive engines available in the Internal Combustion Engineering Department and was conducted in the following stages:

(a) Determination of centre of gravity and principal axes and principal moments of inertia of the engine mass.

(b) With the help of the data obtained from (a) analytical determination of the position of torque roll axis.

(c) Experimental determination of the location of torque roll axis and comparison of the results with those got by the analytical method.

(d) A comparative study of the engine movement for different arrangements of the mountings.

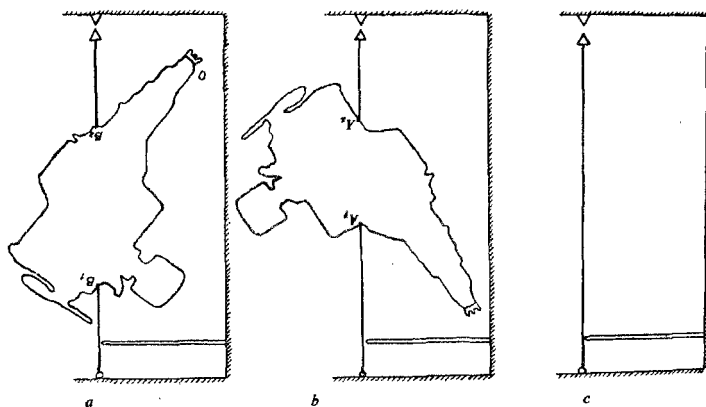
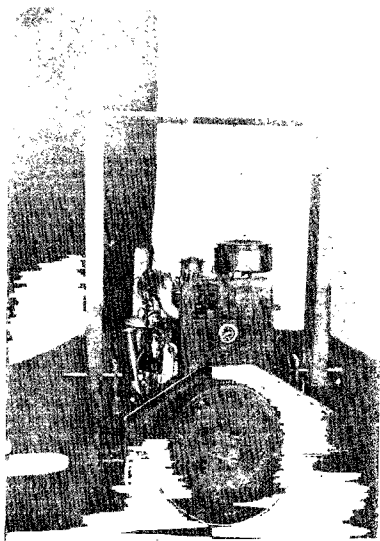


FIG. VI

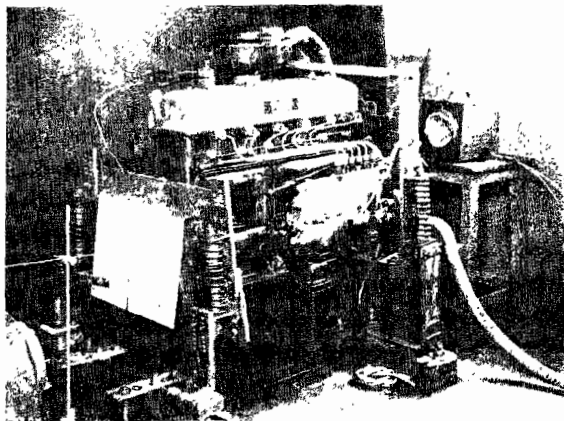
Determination of centre of gravity of engine mass

*Determination of Centre of Gravity:*— The method for determining the centre of gravity of the engine is illustrated in Fig. VI. The point of intersection of lines  $A_1 A_2$  and  $B_1 B_2$  would be the centre of gravity of the engine.



Quadrifilar pendulum with engine in suspended position

PLATE I



Test-rig for locating the torque roll axis

PLATE II

*Determination of Moments of Inertia and Principal Axes:*—A quadrifilar pendulum was used to determine the moment of inertia of the engine mass. The photograph of the test-rig is shown in Plate I. The test-rig had a provision to suspend the engine in such a way that the centre of gravity might lie on the centre line of oscillation of the pendulum formed with the engine and wires.

Since the centre of gravity of the engine mass lies generally on the plane containing the centre lines of the cylinders, a symmetry could be assumed about this plane, and an axis  $zz$  perpendicular to this plane and passing through the centre of gravity of the engine would be one of the principal axes. The other principal axes  $xx$  and  $yy$  would lie on the plane of symmetry.

By using the engine as a quadrifilar pendulum the moments of inertia of the engine about any three axes in the plane of symmetry were determined. From these values the location of the principal axes  $xx$  and  $yy$  and the moments of inertia about them could easily be determined. The procedure is explained in Ref. 4.

*Determination of Torque Roll Axis:*—

(a) *by the analytical method:*—The torque roll axis making an angle  $\beta$  with the principal axis  $xx$  was determined from the formula [5]

$$\tan \beta = \frac{I_x}{I_y} \tan \psi$$

and then its inclination to the crankshaft axis was obtained.

(b) *by the experiment:*—The photograph of the rig for locating the torque roll axis is shown in Plate II. The engine was suspended on four helical springs of suitable and equal rating such that the plane containing either the rear springs or the front springs was perpendicular to the torque roll axis already determined by the analytical method, and their mid-points adjusted to the level of the torque roll axis. The engine was started and its speed was adjusted to obtain large amplitude of oscillation in roll. The axis about which the engine was rolling was determined in the following way.

A plate painted white was attached to the front end of the engine, and a vertical line lying on the vertical plane containing crankshaft axis was marked on the plate. Under engine running conditions the vertical line was illuminated by a stroboscope and the point about which the line was rolling could be easily located and marked. The plate was then moved to rear end, and as before the point about which the roll was occurring was marked. This was further verified by mounting a stand on the floor which was carrying a pointer facing the end plate, as shown in Plate II. Under engine running conditions the relative movement between the vertical line and the stationary pointer end was observed. The position of the pointer was shifted so as to obtain least relative movement and the point opposite the pointer was marked on the plate.

The points thus located on the end faces of the engine would lie on torque roll axis. The location of the springs was adjusted with respect to this new torque roll axis if necessary. The engine was started and the foregoing procedure was repeated so as to get consistent results for the location of torque roll axis. In most cases it was found that the correct location of the torque roll axis was obtained in the first attempt.

To know the influence of lubricating oil mass on moments of inertia and torque roll axis experiments were conducted on two engines with and without wax substitution for lubricating oil. With the rest of the engines the experiments were conducted with wax substitution for lubricating oil.

*Comparative study of Engine Movement for Different Arrangements of Engine Mountings*:—The layout of the experimental set-up is shown in Fig. VII. Engine mountings were located symmetrically about the torque roll axis and

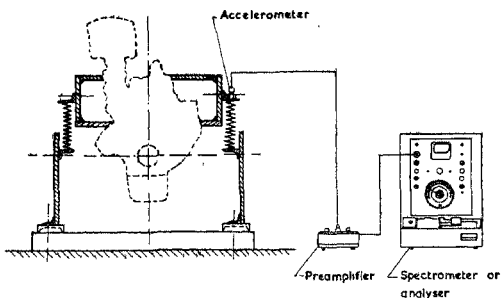


FIG. VII

Measurement of amplitude at the mounting point

displacements both in vertical and horizontal directions were measured at each mountings point for two speeds of the engine—630 and 1050 r.p.m. For measurement of displacements Bruel and Kjaer equipment was used, which consisted of an accelerometer, a preamplifier and an analyser.

Similar sets of readings were taken for the following arrangements of the mountings. Springs located

- (a) symmetrically about longitudinal principal axis  $xx$ .
- (b) symmetrically about an axis through the centre of gravity of the engine but parallel to crankshaft axis,
- (c) at the points recommended by the manufacturer.

In all cases the vertical planes in which front and rear mountings were located remained unaltered.

## RESULTS AND DISCUSSION

*Centre of Gravity*:— Table I presents the positions of centre of gravity and of the end points of crankshaft axis of various engines. While

TABLE I  
Centre of Gravity of Engine Mass  
*N.B.* : The units are in inches  
The order in which the values of co-ordinates are X, Y, Z  
Y Co-ordinates are in bold for clarity

Engine	Co-ordinates of		
	Centre of gravity	Crankshaft front end $O_1$	Crankshaft rear end $O_2$
1. Cheverolet (Master 85) engine with gear box assembly	26.63	50.69	-0.63
	<b>12.55</b>	<b>12.63</b>	<b>12.44</b>
	18.62	14.75	14.25
2. Mercedes Benz (OM 312) engine	22.3	41.94	6.13
	<b>19.44</b>	<b>18.44</b>	<b>19.75</b>
	23.82	17.63	16.63
3. Mercedes Benz engine with wax being substituted for lubricating oil	22.76	4.5	40.44
	<b>18.89</b>	<b>17.5</b>	<b>19.5</b>
	37.22	30.88	31.13
4. Perkins ( $P_6$ ) engine	23.05	3.75	39.38
	<b>35.88</b>	<b>35.25</b>	<b>36.88</b>
	24.45	17.69	18.0
5. Perkins engine with wax being substituted for lubricating oil	21.33	39.94	5.06
	<b>21.46</b>	<b>22.38</b>	<b>20.5</b>
	23.48	17.25	17.88
6. Leyland (Commet 3) engine with wax being substituted for lubricating oil	26.31	48.56	5.63
	<b>17.87</b>	<b>17.56</b>	<b>18.25</b>
	21.31	14.0	16.88
7. Meadows (4DC330 MK2) engine with wax being substituted for lubricating oil	24.71	4.5	41.5
	<b>14.51</b>	<b>15.19</b>	<b>13.94</b>
	26.58	19.5	20.5
8. Fiat (1100) engine with wax being substituted for lubricating oil	12.73	24.25	2.81
	<b>17.10</b>	<b>16.38</b>	<b>17.13</b>
	17.06	12.63	12.19
9. Deutz (F4 L514) engine with wax being substituted for lubricating oil	22.06	45.7	4.70
	<b>12.89</b>	<b>11.50</b>	<b>13.25</b>
	22.23	18.38	16.06

measuring the co-ordinates of the points care was taken to keep the plane containing the centre-lines of the cylinders vertical, so that Y-coordinates of the centre of gravity might give an idea of its relative position with respect to this plane. A scrutiny of the Y-coordinates (in bold in the Table I) of the centre of gravity and the end points of crankshaft axis for each engine shows that these values are almost identical and therefore the centre of gravity does lie very close to the plane containing the centre lines of the cylinders. Hence the assumption of the symmetry about this plane, stated earlier, is justified. A study of the coordinates of centre of gravity for engines 2-5 also indicates that lubricating oil mass has little effect on the position of centre of gravity.

*Principal Axes* :—The determination of principal axes in a three dimensional body is very difficult and laborious. But the assumption of symmetry about the vertical plane containing crankshaft axis and passing through the centre of gravity simplifies the matter.

Table II presents the principal moments of inertia of various engines and the inclination of the longitudinal principal axis to the torque axis. The longitudinal principal axis is found to be inclined to torque axis in all the engines, and the variation in inclination ranges from  $9.3^\circ$  to  $19.4^\circ$  except in Fiat Engine, where the inclination is  $42^\circ$ . This high value in the case of Fiat Engine is due to the fact that Fiat Engine is very compact in longitudinal direction as compared to other engines.

*Torque Roll Axis* :—The inclination of torque roll axis to torque axis as obtained by the analytical and experimental methods is presented in Table II. There is a good agreement between the two results. Table II also shows that lubricating oil mass does affect appreciably the disposition of the longitudinal principal axis with respect to torque axis, and the consideration of its effect has enhanced the accuracy of the results obtained by the analytical method. But the change in the results thus brought about is very small. This can be explained on the following grounds :

(a) The mass of the lubricating oil is appreciably small compared to that of the engine, and hence the position of centre of gravity and moment of inertia values are not much changed.

(b) The inclination of the torque roll axis depends upon the ratio of the principal moments of inertia, and as is evident that if the numerator and denominator values change in the same direction by same magnitude, the quotient gets affected to a very little extent.

*Engine Movement for Different Arrangements of Mountings* :—Comparative values of amplitudes measured both in vertical and horizontal directions at mounting points are shown in Fig. VIII at two engine speeds 630 and 1050 r.p.m. for different arrangements of the mountings. It will be seen

TABLE II  
Principal axes, principal moments of inertia and torque roll axis

Engine	Principal moment of inertia lb. in. Sec <sup>2</sup>		Inclination of Torque Roll Axis with torque axis as determined by			
	$I_x$	$I_y$	Inclination of axis $xx$ with torque axis	Calcula- tion	Experiment	
1. Cheverolet (Master 85) engine with gear box assembly	87.45	339.05	12.4°	9.2°	10.2°	
2. Mercedes Benz (OM 312) engine	139.32	265.78	9.3°	4.4°	7.2°	
3. Mercedes Benz engine with wax being substituted for lubricating oil	175.5	310.5	15.1°	6.4°	7.2°	
4. Perkins (P <sub>6</sub> ) engine	136.1	295.3	13.2°	7.0°	10.4°	
5. Perkins engine with wax being substituted for lubricating oil	147.0	297.5	18.1°	9.0°	10.4°	
6. Leyland (Commet 3) engine with wax being substituted for lubricating oil	262.5	541.0	19.4°	9.64°	9.4°	
7. Meadows (4DC 330) MK2 engine with wax being substituted for lubricating oil	223.9	457.9	14.7°	7.4°	8.3°	
8. Fiat (1100) engine with wax being substituted for lubricating oil	22.7	30.53	42.0°	8.3°	7.9°	
9. Deutz (F4 L514) engine with wax being substituted for lubricating oil.	502.2	298.2	10.2°	4.1°	4.7°	

from the figure that the arrangement of locating the mountings about torque roll axis results in producing minimum amplitudes of vibration at all stations in vertical and horizontal directions.



The horizontal displacement indicates the side thrust coming on the mountings. The mountings are, generally, less stiff in this direction and they should be subjected to least side thrust. The arrangement of the mountings about torque roll axis fulfils this requirement to the maximum extent.

It is observed from Fig. VIII that at front mounting points the amplitudes of vibration for different arrangements of the mountings differ appreciably. But it is not so at the rear mounting points. The axes about which mountings are arranged for various arrangements deviate to a great extent at the plane

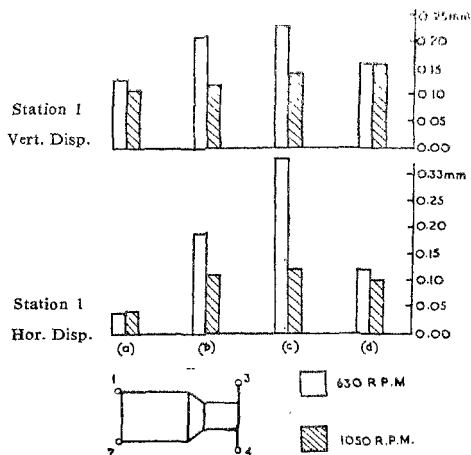


FIG. VIII

Comparison of amplitudes at stations 1, 2, 3 and 4 for different arrangements of spring mountings

Station 1 : Left hand front mounting point  
 Station 2 : Right hand front mounting point  
 Station 3 : Left hand rear mounting point  
 Station 4 : Right hand rear mounting point

- (a) Springs located about the Torque Roll Axis  
 (b) Springs located about the longitudinal principal Axis  $xx$   
 (c) Springs located about an axis passing through C.G. and parallel to the crankshaft axis  
 (d) Springs located at the points recommended by the manufacturer

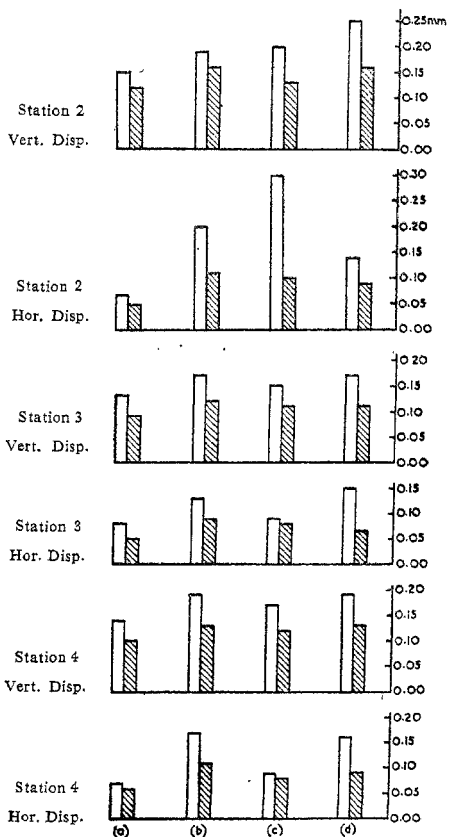


FIG. VIII (contd.)

Comparison of amplitude at stations 1, 2, 3 and 4 for different arrangements of spring mountings

containing front mountings, as this plane is at a greater distance from the centre of gravity of the engine than the plane containing rear mountings. This indicates that the arrangement of mountings about torque roll axis becomes more and more critical as the distance of the plane containing these mountings increases from the centre of gravity of the engine.

From the foregoing it is evident that maximum benefit is obtained by locating the mountings about the torque roll axis.

#### CONCLUSIONS

In all the automotive engines the torque axis does not coincide with any of the principal axes. Under such conditions roll takes place about an axis which lies in between the longitudinal principal axis and torque axis. This axis is called the Torque Roll Axis.

The position of torque roll axis can be located easily and quickly, by following the analytical cum experimental method used in this investigation.

The flexible mountings if located about the torque roll axis are subjected to least dynamic load and hence provide maximum isolation of vibration from the chassis.

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