Engine Mounts and its Design Considerations

Atul Adhau
PG Scholar, Dept of Mechanical Engineering,
AISSMSCOE, Pune University

Prof V Kumar,
Prof Mech Engg AISSMSCOE Pune
Pune University

Abstract

The purpose of this paper is to know more about the forming process, the material which can be formed, stresses coming on sheet metal during forming and defects of the sheet metal in forming operation.

Engine Mounting is one of the fundamental design characteristics of a motor vehicle. A vehicle's engine, in the particular way it is mounted to the vehicle's body, plays a major role in determining vehicle's vibration characteristic. A well designed mounting system needs to isolate the engine inputs from the vehicle body, and use the engine mass to minimize, not amplify, the effects of road/wheel inputs.

For an internal combustion engine, there exist two basic dynamic disturbances: a) the firing pulse due to the explosion of the fuel in the cylinder and b) the inertia force and torque caused by the rotating and reciprocating parts (piston, connecting rod and crank). The firing pulses will cause a torque to act on the engine block about an axis parallel to the crank. The directions of the inertial forces are both parallel to the piston axis and perpendicular to the crank and piston axes. For a multi cylinder engine, the components of the engine-unbalanced disturbance depend on the number and arrangement of the cylinders in the engine. These engine disturbances will excite the engine six degree of freedom vibration modes.

The engine is the largest concentrated mass in the vehicle, and if it isn't properly constrained and isolated it will cause vibrations in the body and front end sheet metal.

There has been lot of study been done by many vehicle designers for engine mountings through the years and developed certain "rules of thumb'' that generally lead to good mounting systems. These are the rules that are applied to engines six rigid body modes: frequency targets, coupled vs decoupled modes etc. It is very indirect and difficult to apply these modes as engine mounts differ with different types and its mounting. While the real goal is to minimize the vibrations felt by the passenger and rule of thumb apply to the engine modes. The engine mounts are designed with optimum stiffness so as to reduce the system vibration and avoid resonance phenomenon.

This paper discusses the problems of mounting a engine on elastic mounts to minimize the vibrational disturbance to the vehicle. Mount configurations that permit decoupling of modes are described. A method is described for measuring the dynamic rate and damping of the rubber mounts.

Keywords: Sheet Decouple, Elastic Centre, Centre of percussion

1. Introduction:

The Mounting of the powerplant (engine-transmission assembly) receives great care in the design and development of a new vehicle, and the mount specifications of the production parts are carefully guarded by reliability inspectors. This attention is required to deliver a satisfactory vehicle to the customer.

The power plant is the largest concentrated mass in the vehicle, and if it isn't properly constrained and isolated it will cause vibrations in the body and front end sheet metal.

The engine is subjected to various vibratory disturbances some external to it others internal. Random shocks from the road, transmitted through suspension, shake it, so do periodic shaking from the universal joints in the propeller shaft. Any rotating unbalances in the engine, transmission or engine mounted accessories are exciters. The mounts must isolate all of them, in addition, they must support the static weight of the engine and restrain it from fore and aft movement during acceleration and braking.

This paper will discuss the problems associated with the low frequency, or rigid body, modes.

The major functions of the engine mounting system are to support the weight of the engine and to isolate the unbalanced engine disturbance force from the vehicle structure. For an internal combustion engine, there exist two basic dynamic disturbances: a) the firing pulse due to the explosion of the fuel in the cylinder and b) the inertia force and torque caused by the rotating and reciprocating parts (piston, connecting rod and crank). The firing pulses will cause a torque to act on the engine block about an axis parallel to the crank. The directions of the inertial forces are both parallel to the piston axis and perpendicular to the crank and piston axes. For a multi cylinder engine, the components of the engine-unbalanced disturbance depend on the number and arrangement of the cylinders in the engine. These engine disturbances will excite the engine six degree of freedom vibration modes as shown in fig 1.

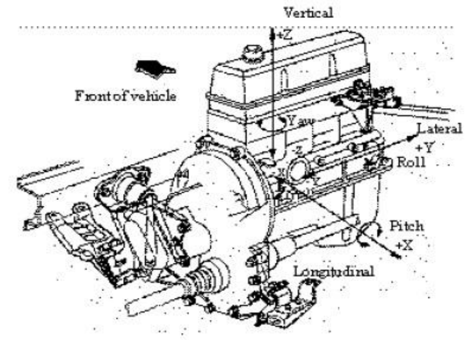

Fig.1Engine and Gearbox

In order to obtain a low transmissibility, the natural frequency of the mounting system in a certain direction must be below the engine disturbance frequency of the engine idle speed to avoid excitation of mounting system resonance during normal driving conditions. This means that the engine mount stiffness coefficient should be as low as possible to obtain a low transmissibility. If the elastic stiffness of the engine mount is too low, then the transient response (of the engine mount system) can be problematic for the shock excitation. Shock excitation would be a result of sudden acceleration and deceleration, braking and riding on uneven roads. So from this point of view, high stiffness and high damping are required to minimize the engine motion and absorb engine shake and resonance.

Thus from the above discussion, it can be easily inferred that to isolate the engine vibration in a relatively high frequency range, the engine mount are required to be soft-low elastic stiffness and low damping and to prevent engine bounce in the low frequency range, engine mounts should be hard-high elastic stiffness and high damping. Elastomeric mounts can be designed for the necessary elastic stiffness rate characteristics in all directions for proper vibration isolation. They are compact, cost effective and maintenance free.

The engine mounts can be optimized by tuning the natural frequency of the engine mounting system to some desired range to avoid resonance and to improve the isolation of vibration and noise and shock excitations.

2. Engine Mounts:

Motor mounts (engine mounts) are used to connect a car engine to the car frame. They are usually made of rubber and metal. The metal portion connects to the engine on one side and to the frame on the other. The rubber is in-between to provide some flexibility (so engine shake doesn't cause the car to shake). Newer cars may use slightly different mounts; however, there purpose is the same. Provide the connection from the engine to the car frame. The number of motor mounts varies from vehicle to vehicle.

Fig 2 Engine Mount

Fig 3 Engine Mount

3. Working of Engine Mount:

Fig 4 Engine Mounted on Engine Mount

Engine mounts are what separate you from the nasty vibrations and harmonics created by the internal combustion engine. Without these simple items, you would feel exactly how rough the engine in your vehicle really is, even when running properly. Engine mounts are basically rubber isolators that are mounted between the engine in a vehicle and the frame. They hold the engine in place while absorbing the vibrations caused by the engine, creating a quiet, smooth feeling inside the vehicle. They are made of rubber to absorb vibration without transferring it, but some manufacturers have tried using a liquid (oil) filled mount to dampen vibration with some success. In some performance applications polyurethane or solid steel mounts are used, these mounts transfer vibration, but can withstand the abuse and high-horsepower applications seen in racing where a comfortable, smooth ride isn't really an issue.

Besides holding the engine in place, motor mounts also keep the surrounding steel that vibrates around the engine from shaking that car. One end of the engine mount is bolted to the engine and the other to the vehicle frame. The mounts clamp everything down and allow the car to accelerate more smoothly and without vibration. In a rear wheel drive vehicle there are usually two engine mounts, one on either side of the engine. Front wheel drive applications may incorporate more mounts to help control the torque of the engine, usually one on both sides and one in the front center. Front wheel drive mounts are engineered differently from rear wheel drive due to the fact that the engine is sometimes hanging on them due to space constraints in front wheel drive vehicles whereas a rear wheel drive engine is usually sitting on top of the mounts. Front wheel drives sometimes incorporate a "dog bone" or torque mount, its sole job is to control the torque twisting of the engine so that the other mounts aren't stressed as much. These torque mounts are a common failure on vehicles that use them.

When an engine mount breaks; usually you will hear and feel a heavy clunk when accelerating, this is the engine moving around in the engine compartment. Other times the engine vibration may become more pronounced due to the mount collapsing, this will transfer the vibrations of the engine to the frame, thus the interior of the vehicle. This situation can cause the failure of hoses or anything that is mounted to the frame from the engine. It can also cause the throttle to stick on older vehicles with mechanical linkages instead of cables. In front wheel drive vehicles, a broken mount can cause the axle to fail or pop out of the transmission, causing the vehicle to stop moving.

When one mount breaks it adds more stress to the remaining mounts, and should be taken care of as soon as possible. Many things: oil contamination, hard shifting (manual transmission), excessive high idle, or the combination of age and engine compartment heat can cause engine mount failure. To inspect your motor mounts, lift and support the vehicle. Use a flashlight to see if the rubber has deteriorated or collapsed from the weight of the engine or if they are obviously torn, if so you will need to replace them. If they are oil soaked from an engine or transmission oil leak, the leak should be repaired as well or it will cause the new mount to fail as well.

4: If Engine mounts are not installed or are damaged:

Following issues or problems will occur if there are no engine mounts or if engine is rigidly mounted:

4.1. Excessive Engine Vibration:-

One of the most common symptoms of bad motor mounts is excessive engine vibration, especially under heavy acceleration and/or engine revving, when engine movements are most pronounced. Motor mounts serve to stabilize and reinforce a vehicle engine; bad motor mounts allow excessive engine movement to occur, movement that is pronounced when excessive engine power is created. Bad motor mounts allow excessive engine movements to cause vehicle chassis vibrations that can travel into the passenger compartment of a vehicle, where the vibrations can often times be both felt and heard.

4.2. Excessive Engine Rattling:-

Engine rattling is another common symptom of bad motor mounts. Depending on how many motor mounts are bad, an engine can shake and shimmy in an odd manner, sometimes even bumping against neighboring mechanical parts, all of which can cause engine rattling. Engine rattling due to bad motor mounts is usually more pronounced during times of engine idling. Engine power at this point is low, and an engine is allowed to rock back and forth under normal power, when engine rattling is more easily discerned than under heavy engine power or heavy acceleration.

4.3. Abnormal Engine Position:-

An engine that appears lopsided or out of alignment, relative to its normal position, is normally an engine with broken or severely damaged motor mounts. In addition to securing an engine within the vehicle hood compartment and stabilizing its movements, motor mounts serve to keep an engine aligned and positioned properly to allow for adequate engine operation, and adequate operation of all of the supporting mechanical devices underneath a car's hood.

4.4. Engine Damage:-

In rare cases, broken motor mounts can cause damage to various engine parts, such as to the exhaust manifold or the valve cover gaskets, both of which are located on the lateral aspect of a vehicle engine. Severely broken motor mounts can allow a vehicle's engine to shift and turn violently, especially during rapid engine acceleration, and/or during high speed driving. This can cause physical damage if the engine turns far enough to one side to allow contact between the engine and the sides of the vehicle engine compartment. Engine parts can become cracked, broken or dented as the result of broken motor mounts.

4.5. Broken Engine Belts and/or Hoses:

In addition to causing damage to vital engine components, broken motor mounts can also cause damage to various engine drive belts and engine hoses. Severely damaged or broken motor mounts can cause engine belts and hoses to break and/or snap if the engine is allowed to rotate or turn excessively. Belts and hoses, especially water pump and power steering belts and radiator hoses, can be stretched abnormally and severely damaged or broken. As is the case with damage to engine parts caused by bad motor mounts, broken engine belts and hoses are rare occurrences that only happen as the result of severely broken or damaged engine motor mounts.

5. Causes of driving a car with no engine mounts:

While the engine and transmission will both operate without motor mounts, driving without engine mounts may cause damage and create a safety hazard.
Following Problems will occur if a vehicle is driven without engine mounts:

5.1. Safety Concerns:-

Without motor mounts, the motor will be free to move farther than designed. This can cause additional stress to the throttle linkage, which may result in unintended acceleration. The engine's movements may also damage the brake lines, which could cause the power brake system to fail. The exhaust system may become damaged from the engine's movements, allowing exhaust gases to vent under or near the passenger cabin.

5.2. Engine and Transmission Damage:-

Without motor mounts, the engine and transmission may become damaged from striking other components or from the stress of the movement. The cooling lines for the engine and transmission may become also become damaged, causing both to overheat.

5.3. Other Problems:-

The excessive movements of the engine and transmission due to the missing motor mounts may cause damage to other parts of the automobile as well. The body of the vehicle may become damaged from the engine and transmission striking it, stress will be added to the suspension components and the vehicle will have an increase in noise and vibration.

6. Design Considerations

There are many good reasons to resiliently mount an engine and/or transmission. One increasingly important reason is to reduce structure borne noise and vibration generated by the engine and transmitted to the vehicles operator compartment. Resilient mounting will also provide longer life for frame and engine block mounting brackets, suspended components and transmission by attenuating transient shock inputs and operating torque loads.

6.1. Disturbances:-

a) Torsional dynamic pulses due to variations in cylinder gas pressure.
2 cycle engine – fd (disturbing frequency) = RPM x no. of cylinders
4 cycle engine – fd (disturbing frequency) = RPM x no. of cylinders/2

For Practical mounting solutions isolate the fundamental first order or RPM

2 cycle – isolate RPM
4 cycle – isolate RPM/2

b) Imbalance forces due to reciprocating or rotating masses within the engine

1. cylinder engine – isolate the primary vertical and horizontal inertia forces.
2. cylinder engine – isolate the secondary rotating inertia forces.

6.2 Centre of Percussion Mounting:-

A rigid body has a centre of gravity and three inertia axes that are orthogonal to each other. The body may translate in any of the three directions or rotate about any of the axes. Thus we say it has six degrees of freedom. If the mass is free in space and an oscillating force is applied to the mass at its centre of gravity, the mass will translate without rotation in the direction of the force. But, if the force is not applied at the centre of gravity there will be rotation as well as translation and there will be a ''centre'' of oscillation. This centre is the centre of percussion for that particular force location. Thus if a disturbance is applied to the front engine mount we would like to have the rear mount located at the centre of percussion so there would be no reaction forces on it. Fortunately the centres are reciprocal so this location will also make the front mount the centre of percussion for the rear mount. These centers can be easily determined if the mass moments of inertia of the engine are known

$$A \times B = J/M$$

Where,
A = Distance between front mount to centre of gravity
B = Distance between rear mount to centre of gravity
J = Engine mass moment of inertia about a principle axis
M = Engine Mass

6.3. Torque Axis:-

If an oscillating torque is applied to the mass along an axis parallel to one of the three principle axes, the mass will oscillate in rotation about that principle axis. But if the axis of the torque is not parallel to a principle axis it is effectively resolved into its components parallel to the principle axes and simultaneous oscillation about all of the axes occur. The amplitudes of the oscillations depend on the mass moments of inertia.

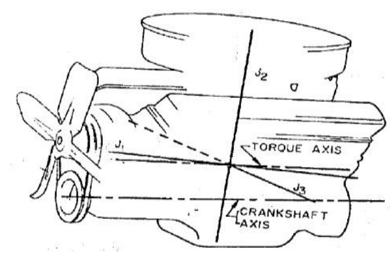

Fig.5 Torque Axis

These simultaneous oscillations produce an axis of oscillation that will generally be different from the axis of torque application and from any of the three inertia axes.

In an engine the axis of torque application is the crank shaft and it is seldom parallel to a principle axis. The output torque has periodic oscillations that cause the engine to oscillate in reaction. We can minimize the disturbance to the rest of the car by allowing the engine mass to oscillate about this natural ''torque axis''.

6.4. Coupling of Vibration Modes:-

Since the engine mass has six degrees of freedom it will have 6 vibratory modes viz 3 in translation and 3 in rotation. If an excitation is applied to the mass we must expect the mass to respond by oscillating. However, we do not expect a torsional excitation to result in the mass bouncing, yet this can easily occur. In fact, a vertical shaking force can cause the mass to respond by vibrating in all 6 modes. We say that the modes are coupled together. With a little care in the design stage it

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is possible to decouple most of the modes or to at least make the coupling "weak''. The requirement for decoupling is to make the elastic centres of the mounts coincide with the centre of gravity of the engine.

After the theoretical mount locations have been chosen we are faced with the difficulty of attaching the mounts at these points. In general, the ideal locations will lie inside the mass of the powerplant. Fortunately a pair of mounts can be placed exterior to a mass and have an elastic centre inside the mass. This is possible because a mount also has six degrees of freedom and its deflection is a function of the spring rates about its principle aces and the orientation of the load relative to them.

6.5. Elastic Centres:-

A rigid body on elastic supports has an elastic axis. If a force is applied to the body along this axis the body will translate without rotation and if a couple is applied about the axis the body will rotate without translation. The location of this elastic axis is dependent on the location, orientation and stiffness of the supports. Fig6 shows system mounted on two supports inclined to point to the centre of the mass. The elastic centre of this pair of mounts is a point on the elastic axis. The elastic centre will always lie below the geometrical intersection of the mount axes. This is illustrated in the following 3 cases:

Case 1 – Fig 6 For Two mounts symmetrically oriented

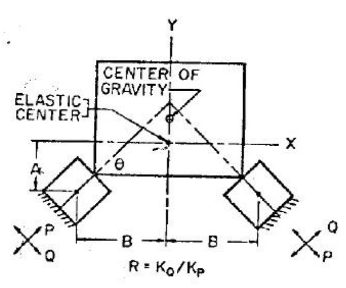
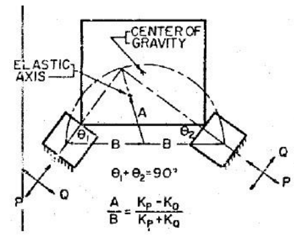
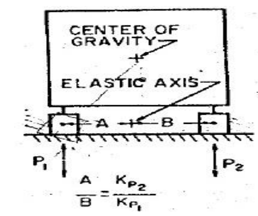


Fig 7. Two equal mounts with axes normal to each other
Fig 8 Two vertical mounts with different rates

Let P and Q be principle axes of mounts





Let Kp and Kq be stiffness of mount in directions P and Q
Case 2 – Fig7 for 2 mounts with axes perpendicular to each other

Case 3 – Fig8 For 2 vertical mounts with different rates

6.6. Dynamic Rates of Rubber Mounts:-

After the designer has finished his job of locating the mounts and specifying their rates, the development engineer takes over. His first problem is to measure the rates of the mounts to see if they are to specifications. Offhand this appears to be a trivial problem; a spring rate is determined by measuring the slope of a load-deflection curve. However, for rubber the load-deflection curve is not linear, so he has to know the point on the load deflection curve at which to measure the slope. After all of this is done he still doesn't have the information he needs because rubber stiffness changes with temperature and speed of loading and the dynamic rates of rubber are different from static rates. Since the decoupling of the vibration modes and the location of the elastic centers are dependent on the ratio of rates, it is essential to have a method of measuring the mounts under the proper load and dynamic conditions.

7. Practical mounting Considerations

a) Mount Locations: The engine is not a rigid mass but actually a free-free beam in space. Mounts should be positioned at the nodal points.
b) Stability: Mounts should provide stability for the following conditions:

Fore-aft: up to 7g's, Lateral: 1g, Vertical: 3-4g's

Torsional: Engine Manufacturers rated torque x 2

c) Frame and bracket stiffness: The stiffness of attached mounting brackets and support frame are important to the performance of the mounting system and should be designed to be as stiff as possible. The effective stiffness of the mounting system, when the

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support structure is less than 10 times stiffer than the solators, can be determined from the following formula:

$K_{effective} = (K_{support} \times K_{mounts}) / (K_{support} + K_{mounts})$

This effective stiffness should then be used to determine the performance of the spring mass system.

8. Practical Solutions

a. Automotive – 1957 Buick "Nodal Point" Engine Mounting System. Note that the engine mounts are located at the bending nodal points of the engine.

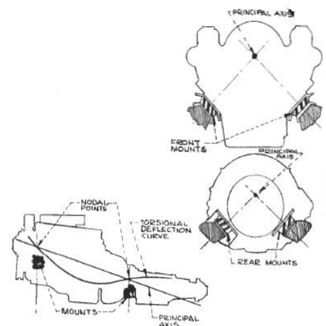

Fig 9 Engine mounts 1957 Buick

b. Industrial vehicles – Three Point Mounting

This system was designed to accommodate easy engine removal and maintenance. Due to badly coupled condition, the roll frequency is increased and poor isolation results at idle and low operating speeds.

c. Automotive – Generally used focused three point mounting system

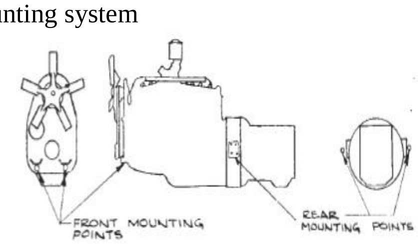

Fig 10 Focus 3 mounting system

Focused mounts provide decoupled stable response but the mount locations do not limit engine bending.

9. Selection of engine Mounts

There are three normal loading conditions which must be considered when selecting engine mounts. They are:

Static loads – weight of engine and accessories

Dynamic loads – transient shock levels

Torque loads – manufacturers ratings

Torque loads can be determined from the following formula manufactures ratings are not available:

$$T \text{ (in-lbs)} = 63000 \times HP/RPM$$

HP = engine horse power

RPM = output of transmission

10. Summary

Design considerations can be summarized as follows

a) Torque axis – The first step in mounting an engine is to establish the torque axis. This will be the elastic axis.

b) Centre of percussion – Select the planes for the front and rear mounts. The distance from the centre of gravity to these planes should meet the requirement of centre of percussion.

c) Mount Configuration – Arrange the mount in their planes so that the elastic centers will fall on the torque axis. Establish the relation between compression and shear rates of the mounts.

d) Decouple the pitch and bounce mode – This is achieved by making the product of front mount vertical rate and the distance along the elastic axis to the cg equal to the similar product for the rear mount.

e) Specify the values of the dynamic product rates in compresson and shear for each of the mounts.

f) Make the final tuning on the complete vehicle by variation in the rubber specification.

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