Modal Analysis Comparison on Dipstick Holding Bracket with and without Use of Vibration Isolator

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Abstract: ***The paper discusses use of damper (vibration isolator) on Dipstick holding bracket in an Automobile application such as off highway Excavator vehicle. Is it necessary to use isolator or not? An excavator is heavy machine used to dig earth mantle, hence it has to undergo very high vibrations. All parts of excavator should sustain these vibrations and perform function with desired efficiency. The dipstick of Excavator is generally very long and needs to be supported at more than one location on engine cylinder body. In general, all excavators use vibrations isolator along with P-Clip and Bracket at holding locations away from Engine Base (in some case Chassis) because intensity of vibrations is higher at parts away from Base. But this is observed that Modal Analysis of upper holding bracket with and without the use of Vibration Isolator didn't differ much and hence Vibration Isolator can be removed finally resulting in cost reduction and optimization of system***

Keywords: Dipstick, Modal Analysis, Vibration Isolator, P-Clip, Bracket (Brace Tube)

1. Introduction

Engine Mounting Bracket plays very important role to support the engine structure. They provide rigidity and strengthen system again sudden loads, vibrations. They also provide flexibility to repair, remove and for other operational modes. One such mounting bracket is used to hold Dipstick in all Automobile applications. The endurance of Brackets is analyzed by Modal Analysis. It calculates the natural frequencies of system to know which frequencies can be destructive and dangerous for it.

Destruction of system happens when it enters in resonance with the frequency of the input loading which means when the frequency of the input load is equal to the frequency of the system. It is absolutely critical to be able to calculate the resonance (natural) frequency of a system.

Modal analysis calculates the natural frequencies of the system alone. It isn't related to a loading at this stage but only to the geometry. Resonance frequencies change due to the shape of model and the way it is constrained only.

Modal analysis is a Dynamic analysis in which the system is cyclic loaded. Cyclic loads have a certain frequency, period and intensity. They are transient loads. When there is cyclic loading on a system and force excitation input is given to system, the system responds. If excitation load has a frequency which becomes close to natural frequency of system, the oscillation increases. This is the condition of "resonance".

Mounting Brackets of Engine are designed to give firmness but vibration and fatigue has been continuously a concern which may lead to structural failure if vibrations are excessive and system enters resonance condition it may turn into catastrophic failure. Finite Element Analysis on Brackets is done to minimize risk of such failures and make system reliable.

The Dipstick mounting assembly for FEA includes cylinder block at which one end of dipstick is fixed, P-Clips and Brackets (Brace Tube) at two supporting locations. The lower P-Clip is mounted without vibration isolator for analysis. Upper P-Clip is mounted with and without vibration isolator respectively to decide its significance on natural frequency of each mode.

2. Literature Survey

Practically the system under consideration is discrete system with Multi Degrees of Freedom. The discrete dynamic equation used in FEA is the following:

$$[M]\{\ddot{x}\}+[C]\{\dot{x}\}+[K]\{x\}=\{F\}$$

Where [M] is the mass matrix, [C] is the damping matrix and [K] the stiffness matrix. All three matrices are constant in linear dynamics.

$\{\ddot{x}\}$, $\{\dot{x}\}$ and $\{x\}$ are respectively the acceleration vector, velocity vector and the displacement vector. {F} is the load-vector. All three vectors vary as a function of time.

If we neglect damping for the moment, the equation becomes:

$$[M]\{\ddot{x}\}+[K]\{x\}=\{F\}$$

Damping can be neglected for a large class of problems because the amount of damping for most structures is well below 10%, which means slow damping of vibrations in the system.

For first solution of free damping (to determine the normal and modal properties) put {F}=0, equation becomes

$$[M]\{\ddot{x}\}+[K]\{x\}=\{0\} \qquad \text{-equation (1)}$$

Assuming the solution be in the form-

$\{x\}(t)=\{X\}e^{i\omega t}$

$\{\ddot{x}\}(t)=-\omega^2\{X\}e^{i\omega t}$

Where, {X} is a constant vector, and $e^{i\omega t}$ represents the time-response which is simply a sine wave. ω is the radial frequency of the sine wave. {ẍ}(t) is obtained by differentiating {x}(t) twice.

Substituting above values in equation (1), we get
$- \omega^2[M]\{X\}e^{i\omega t}+[K]\{X\}e^{i\omega t}=\{0\}$

Dividing whole equation by $e^{i\omega t}$, we get
$([K]- \omega^2[M])\{X\}=\{0\}$

Where, ω^2 is the eigenvalue and {X} the eigenvector. The solution to this equation is the vector {X} with a corresponding frequency ω. If {X} is scaled by any real number, the scaled {X} is still a solution to the eigenvalue problem. For this reason, it is more convenient to think of {X} as a "shape". It is also why it is called a "mode shape". It is the shape that the structure oscillates within at frequency ω. Said in less technical terms: If we deform the structure statically into the mode-shape, then set it free, it will oscillate between the initial deformed shape and the negative of the initial deformed shape at a frequency ω. True – Over time it will dampen out, but for low amounts of damping it will slowly decay in amplitude.

Another important point to remember is that there are multiple modes for a structure. Each mode shape occurs at a very specific frequency called the natural frequency of the mode. It is entirely possible for a structure to have multiple modes at the same frequency.

Note also that, each mode shape oscillates at the natural frequency of that mode. In other words, multiple modes, each at their own natural frequency will be present in the results.

Mode: A mode is a shape with a corresponding natural frequency at which the structure will absorb all the available energy supplied by an excitation. A mode is a property of a structure since it is calculated without any load applied to the structure. A mode is not a displacement at a certain natural frequency – rather it is a shape and it is not the structural response due to an input loading since it is calculated without any load.

The results of a modal analysis, such as displacement, stress, strain and velocity, are not representative of the stress in the structure under dynamic loading: This is because the relative values between any two (or more) points in the structure have meaning, not the numerical values of any of the results. The purpose of a modal analysis is to find the shapes and frequencies at which the structure will amplify the effect of a load.

3. Problem Statement

The current design of Excavators is using Vibration isolators at upper mounting location of Bracket (brace tube). Why vibration isolators are used at only upper mounting location? We analyzed if upper isolator is removed does it affect the natural frequency of several mode shapes and does the system enters into resonating condition.

4. Methodology & Approach

Under dynamic condition, structure components will be excited. If excitation frequency matches with natural frequency of the structure, then resonance takes place. Due to this structure oscillates excessively and may lead to failure. Modal Analysis is one of the major techniques to obtain natural frequency of structure and also to obtain different frequency modes. It can be done virtually by using software such as Ansys or Creo. This helps to reduce design time since multiple iterations can be done on design concept without ordering physical components for test. This virtual validation also saves the cost of development since few number of prototypes are required for physical validation.[1]
A fluid level measuring device also referred to as a dipstick, for measuring the fluid level in a fluid reservoir or tank, such as an oil pan or transmission reservoir in an internal combustion engine. It has a calibrated blade attached to a flexible cord with the help of end connector. This Calibrated blade indicates level of oil present in oil sump whether oil level is in permissible range between high and low or oil sump under filled/overfilled. It is used in all vehicles till now but with some modifications. Now-a-days dipsticks are obsolete from engines. New generation vehicles are having electronic oil-level gauge in place of a traditional dipstick. This switchover is started with a handful of European luxury vehicle manufacturing companies (Audi, BMW and Porsche), and is gradually making its way down market.
Traditional Oil dipsticks come in different sizes and designs. Most of those shapes are to make the dipstick easy to slide down the tube if it has bends in it. The twist at the end helps keep the tip from digging in as it goes around corners.

Figure 1: Traditional Dipstick

Traditional fluid level indicator systems typically consist of a two piece system with a holding tube and a dipstick. Today's engines, transmissions, and machinery designs are smaller, more compact, and of less weight than traditional engines, transmissions, and machinery. Therefore, fluid level indicator systems must be smaller, more compact, and lighter weight. A crucial need for a fluid level indicator system allowing access to the fluid compartment while assuring a secure, sealed closure of the access when fluid level determinations are not being made or additional fluid is not being added. This sealed closure would prevent unnecessary loss of the fluids during operation as well as supply level pressurization. Moreover, a positive indication that the dipstick is securely in place is desirable.

The locking mechanism eliminates expulsion of dipstick handle under transmission pressure utilizing a bolted in sealed pan fitting. The fluid level measuring device includes a stationary tube assembly in which a rotatable dipstick assembly is disposed. The dipstick assembly includes a fluid level indicator measuring blade attached to an elongated shaft that is molded into a plastic handle assembly. The plastic handle assembly includes a locking mechanism for locking the handle to the stationary tube assembly. A compressible seal forms a pressurized seal between the stationary tube assembly and the handle. One such illustrative example of Dipstick with handle has positive locking mechanism from Orscheln is shown in figure 2

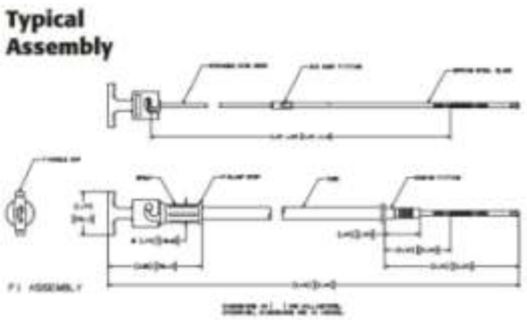

Figure 2: Orscheln F1 Assembly Dipstick (Positive Lock) [2]

Above diagram illustrates components used in dipstick **(Orscheln F1 Assembly Dipstick)** and **same model is used for analysis work in this paper.**

Positive Locking mechanism solves problems associated with conventional fluid level measuring systems by providing a handle associated with a dipstick that is free to swivel or rotate freely within a plastic handle. By being able to rotate (e.g., while being inserted through a non-linear tube and into an engine component), the dipstick can accommodate travel along non-linear routes without binding or being permanently deformed.[3]

Experimental analysis includes comparison of Modal Analysis (Structural Integrity) on Brace Tube (Holding Bracket) of New Oil level gauge of an off highway Excavator with & without the use of Vibration Isolator.

Dipstick is holded at two locations. Inset A shows Upper clamping location of Dipstick. Inset B shows Lower clamping location of Dipstick.

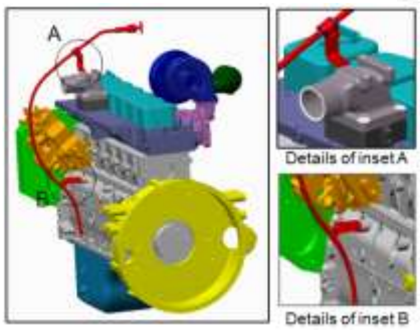

Figure 3: CREO 2.0 designed model of Dipstick (Assembly)

Dark blue colored part in inset A is vibration isolator. Upper Brace Tube is clamped on Air Intake Connection. P clip used here is X. Clip without isolator in inset B is used at bottom clamping position. Lower Brace Tube is clamped on Cylinder Block. P clip used here is Y. Isolator used in inset A is removed for analysis of system without Vibration isolator. Hence clip used at upper brace tube changes to X.

Material Engineering Review: The Material used for each component under analysis is given in table below

Table 1: Material Engineering Review

S. No.	Part Name	Material Name	Density (kg/m^3)	Young's Modulus (GPa)	Poisson Ratio	Tensile Yield Strength (Mpa)	UTS (MPa)
1	Clips X & Y	Low Carbon Steel	7858	206.8	0.3	155	310
3	Isolator, vibration	Valox 420 PBT	1530	9.3	0.35	-	-
4	Tube Oil Gauge	Nylon	5068.6 adjusted	11.115	0.4	-	-
5	Brace tube	Low Carbon Steel	7860	200	0.32	165	276
6	Air Intake connection	Aluminium Die Cast	2541 adjusted	72.39	0.33	-	-
7	Cylinder Block	Grey cast Iron	7060	96.6	0.25	123.5	190

Acceptance criteria: Acceptance criteria for Modal Analysis is the first mode natural frequency should be more than 1.1 times of engine firing frequency at high idle speed.

No. of cylinders = 6, High Idle speed = 2750 rpm
Target frequency = 1.1 times Firing frequency at High idle
= (1.1 * high idle speed * (no. of cylinder/2)/60)
= 151.25~ 151 Hz

Element Description: Tetrahedral element is a higher order 3-D, 10-node element. It has quadratic displacement behaviour and it is well suited to modelling irregular meshes & shapes (such as those produced from various CAD/CAM modules). The element is defined by 10 nodes having three degrees of freedom at each node: translations in the nodal x, y, and z directions as shown in figure 4[4]

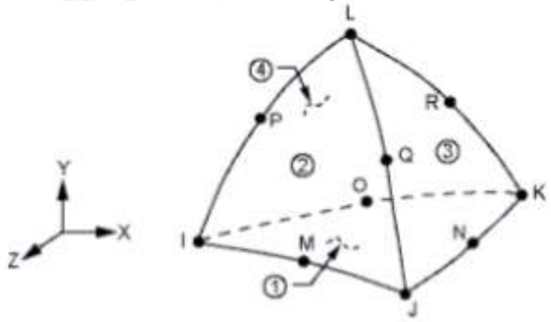

Figure 4: 3-D 10-Node Tetrahedral Structural Solid

Boundary Condition: The cut portion of model is considered for analysis, as shown in figure 5. Bonded contact formulations are generated between the mating surfaces. Boundary conditions are applied at the cut faces of cylinder block is fixed in normal direction and having Frictionless support. The bottom face of Engine and mounting face of air transfer connection is fixed in all DOF. No external load is considered for modal analysis.

Figure 5: Sliced portion of model used in Analysis

The calculated mass of Dipstick is 0.2535 kg. Mode shape plots of 10 modes have been calculated for both cases individually. A result of mode shape plots for both cases shown below

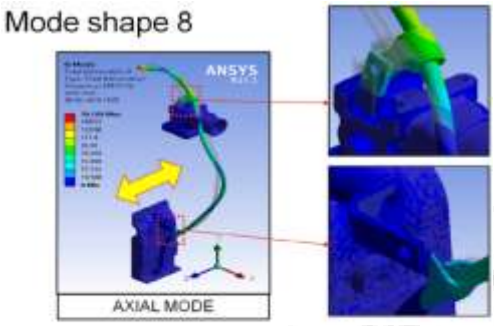

Figure 6: Mode shape 8 with Vibration isolator

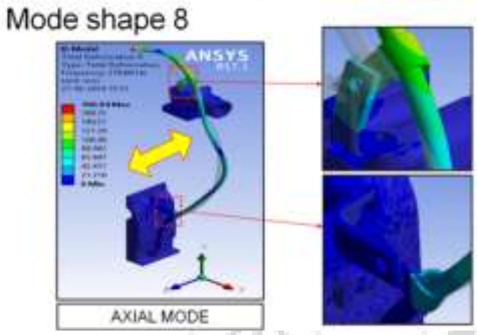

Figure 7: Mode shape 8 without Vibration isolator

The above figures show that for mode shape 8 with & without Vibration Isolator the frequencies are 248 Hz & 280 Hz (approx.) respectively. A slight change in frequency and is well above the Resonance Frequency of the system for both the cases.

5. Results & Discussion

The table shown below depicts comparison of Modal Analysis for Dipstick Upper Brace tube with Vibration Isolator & without Vibration Isolator-

Mode No.	Support bracket Frequency (Hz) With Isolator	Support bracket Frequency (Hz) Without Isolator	Mode Details
1	40	42	Local Mode
2	91	96	Local Mode
3	102	107	Local Mode
4	107	114	Local Mode
5	118	119	Local Mode
6	195	204	Oblique Mode
7	203	219	Axial Mode
8	248	280	Axial Mode
9	275	301	Oblique Mode
10	305	326	Mixed Mode

6. Observations of Result

1) First five modes are local mode i.e. observed on Dipstick therefore, they are not considered for modal analysis.
2) **6th to 10th modes are observed on dipstick tube brackets**, its frequency is more than target frequency **(151 Hz)** which is meeting modal analysis acceptance criteria.
3) Above observations are true for both cases (with & without vibration isolator).

7. Conclusion

Dipstick assembly meets modal analysis acceptance criteria, with Vibration Isolator & without Vibration isolator. Hence same dipstick bracket, caps screw and P-clip are used for the same application. Upper Brace Tube can be used with and without Vibration Isolator. Removal of Vibration Isolator will result in slight change of frequency of each mode but results will remain under acceptance criteria of Modal Analysis. If Vibration Isolator is removed from Upper Brace tube, previously used P-Clip X is to be replaced by P-Clip Y.

8. Future Scope

Modal Analysis of both Brackets using different materials can be performed in future. This will help in choosing appropriate material used for Brackets which is much lighter in weight and less costly.

A new study of research analysis for system can be done that includes Static Structural Analysis & Design of Bolt and Joint analysis (DBJ). This could be a new area of research.

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