COMPARISON OF OBJECTIVE FUNCTIONS FOR ENGINE MOUNTS OPTIMIZATION

Denis Blanchet and **Yvan Champoux**
Department of Mechanical Engineering
Universite de Sherbrooke, Boul. Universite, Sherbrooke
Quebec,Canada J1K 2R1. email : denis.blanchet@gaus.gme.usherb.ca

1 INTRODUCTION

Passenger's comfort is of prime importance in nowadays vehicule design. In order to improve this comfort, engine suspension design has to be based on comfort criteria describing passenger's perceptions. Acoustic pressure in vehicle cabin and vibration of components in contact with passengers are (seats, driving wheel, floor) typical examples. Using such an approach differs greatly from classical optimization techniques which only consider force injected into a rigid base structure. Considering only force functions limits the power of optimization techniques. In fact, passengers may not even feel the changes in perceptions between different configurations.

Futhermore, considering base structure as beeing rigid suppose that the mobility of the base is significantly different from that of engine mounts. However, in certains circumstances, mounts stiffness and structure impedance may coïncide and significantly alter engine's response to a determined excitation. In fact, at frame natural frequencies and for local mode, the mounts stiffness can even be higher than the attachment point frame stiffness.

On the other hand, transfer functions between force injected to the frame at engine mount locations and cabin vibration response or acoustic pressure often show high level peaks at specific frequencies. Cabin comfort can be compromise if there is energy transmitted at these frequencies from the powerplant. For all of these reasons, it is appropriate to adopt a design method which takes into account both structure flexibility and transfer path between engine attachment points and passenger's zone. The substructuring approach is well suited for these requirements.

Finally, classical optimization techniques usualy minimize a cost function for only one driving condition, typically idling. This can lead to undesired increase in noise and vibration levels at other driving conditions. This paper presents an optimization method which consider every steady state operating conditions of the engine.

2 GENERAL ASSUMPTIONS

This paper presents a straighforward method to model the behavior of an elastically supported engine attached to a rigid or a flexible structure. Model predicts sound pressure or vibration level that are directly linked with passenger's perception using a so called comfort criteria.. Each criteria is the sum in space and frequency of a cost function and optimization is based on these criterias. Cost functions studied are:

- Force injected into rigid structure
- Power injected into flexible structure
- Vibration in passenger's zone
- Acoustic pressure in passenger's zone

The engine is modeled as a rigid body. External force load acting on the engine's body is refered to as shaking forces, moments and torques [1]. This periodic load is due to the inertia of the moving parts. At first, Idling conditions are studied since external excitations frequencies and system's natural frequencies are much closer than in any other conditions. In a second step, a whole RPM range will be considered since higher order modes migth be ignored in the idle condition.

Mounts are made of rubber which dissipates energy and offers a wide range of possible stiffnesses. Structure is considered rigid or flexible depending on its stiffness relationship with mounts. All calculations are made in steady state conditions using a frequency based analysis. Figure 1 presents a schematic view of the system to model. For clarity, structure is not show.

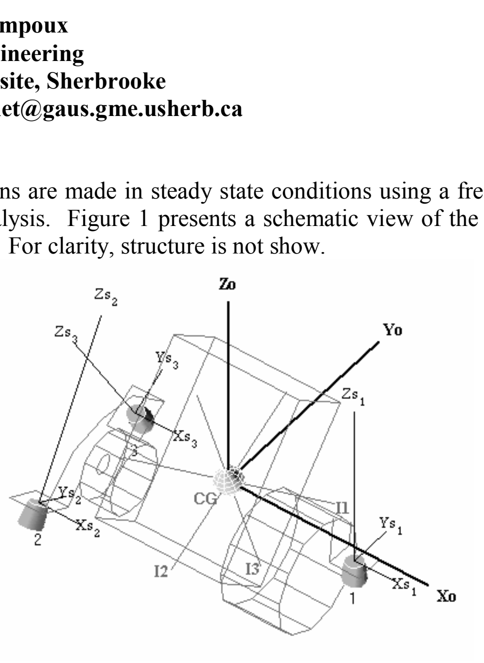

Figure 1 – Engine model with engine mounts principal axis of inertia.

3 EQUATIONS OF MOTION

The engine is modeled as a rigid body of mass m. Its center of gravity (CG), mass moments of inertia (Ixx, Iyy...) and principal inertia axes are considered known properties. The engine sits on n mounts with position x,y,z and orientation γ, τ relative to global coordinate system (CG,Xo,Yo,Zo) as illustrated in Figure 1. Since mounts are generally made of elastomeric material, dynamic complex stiffness is used to model hysteresis damping properties. All mounts properties expressed in local coordinate system (n_i,Xs_i,Ys_i,Zs_i) must be transformed into global coordinates system. Once engine and suspension are defined, the magnitude of the force applied to either rigid or flexible base structure can be estimated. These forces are then used to estimate several comfort criterias using the appropriate measured FRF.

A simple way to implement this approach is to combine a substructuring model [2] which assembles all components into a global system and a rigid body modelisation model [3].

$$\{f_s\} = \left(\left[H_{ss}^{A}\right] + \left[H_{ss}^{B}\right] + \left[K\right]^{-1}\right)^{-1} \left[H_{sp}^{A}\right] \{f_p\} \qquad (1)$$

where

$\{f_s\}$	Reaction forces in the connection points between engine and structure
$\left[H_{ss}^{A}\right]$	Compliance FRF matrix of the engine in free-free conditions at connection points
$\left[H_{ss}^{B}\right]$	Compliance FRF matrix of the base structure in free-free conditions at connecting points
$\left[K\right]$	Stiffness matrix containing the stiffness characteristics of the isolation elements
$\left[H_{sp}^{A}\right]$	Compliance FRF matrix describing tranfer in free-free conditions from excitation points to interface points
$\{f_p\}$	Input forces and moments at excitation points

Most of the preceeding FRF can be measured. The only FRF that can't be measured easely is [H_{sp}^{A}]. This FRF can be derived from the rigid body relations between excitation forces and interface points acceleration [6]. It is then possible to determine the force $\{f_s\}$ injected into rigid or flexible structure from eq (1). This force is used to evaluate all objective functions.

4 OBJECTIVES FUNCTION DEFINITION

4.1 Force injected in rigid structure

For a rigid structure, $\left[H^B_{ss}\right] \approx 0$, and eq (1) can be rewritten as :

$$\{f_s\} = \left(\left[H^A_{ss}\right] + \left[K\right]^{-1}\right)^{-1} \left[H^A_{sp}\right] \{f_p\} \qquad (2)$$

where $\{f_s\}$ corresponds to the objective function. In order to minimize this fonction, criteria φ_F is defined. This criteria corresponds to the total force injected into rigid base.

4.2 Power injected in structure

Power injected in a flexible structure is defined as [4]

$$P = \frac{1}{2}\,\mathrm{Re}\left\{f_s^* \cdot j\omega\left[H^B_{ss}\right] \cdot f_s\right\} \qquad (3)$$

where P corresponds to the objective function. In order to minimize this fonction, criteria φ_{Pw} is defined. This criteria corresponds to the total power injected into flexible base.

4.3 Acceleration at driver seat

Measured FRFs allow the computation of vibration levels in passenger's area. It is defined as :

$$\{a\} = \left[H^B_{as}\right]\{f_s\} \qquad (4)$$

where $\{a\}$ corresponds to the objective function. In order to minimize this fonction, criteria φ_{acc} is defined. This criteria corresponds to the total acceleration level of a specified region.

4.4 Acoustic pressure at driver's ears

Acoustic pressure may be computed using :

$$\{P_r\} = \left[H^B_{ps}\right]\{f_s\} \qquad (5)$$

where $\{Pr\}$ corresponds to the objective function. In order to minimize this fonction, criteria φ_{Pr} is defined. This criteria corresponds to the total pressure level over all locations considered as described in [5]

5 OPTIMIZATION

Let {X} be a vector of mount properties such as position, orientation and stiffness. It is necessary to minimize φ with respect to variable {X}. Implementation of this optimisation is done with Matlab's Optimization Toolbox functions. In order to run the optimization, upper and lower limits on {X} as well as constraints such as maximum engine displacement must be defined. Since the objective functions can be expressed in terms of single or multiple RPM values, the optimization Toolbox will solve for the specified RPM range of the objective function.

5.1 RESULTS

For simplicity and ease of interpretation, only positions of engine mounts are optimized. These mounts can move according to the geometry of the engine. In general, each mount may be moved up to 10 cm away from its original position.

In the next figures, results from optimization for a wide range of RPM are presented. These results suggest that from the starting configuration, each objective function taken separately can be well minimized. In fact, a significant gain of comfort can be experienced by changing the positions of the engine mounts.

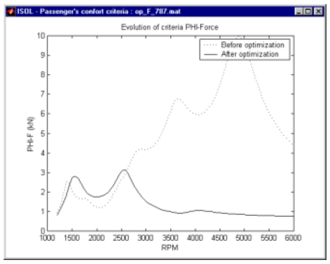

Figure 2 – Force criteria for force optimization

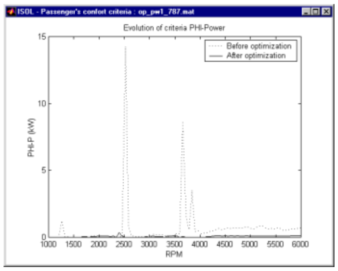

Figure 3 - Power criteria for power optimization

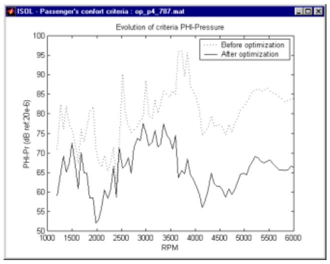

Figure 4 – Pressure criteria for pressure optimisation

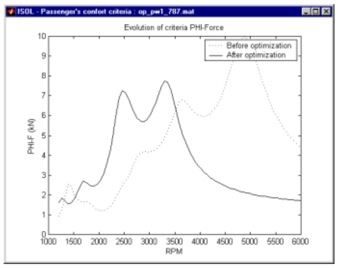

Figure 5 – Force criteria for power optimization

One should realise that optimization based on one criteria will not necessarily provide a good minimization of the other criterias. In other words, minimizing the power criteria will not necessarly minimize the force criteria. Figure 5 shows the level of minimization of the force applied to the rigid base when minimizing the power function. It is clear that minimizing for the power doesn't reduce injected force in the structure. These results can't be generalized since they greatly depend on vehicule FRFs, suspension availability and engine type. If the objective is to reduce vibroacoustic response at driver's location, it is useless to optimize with respect to the force injected into a rigid base.

Finally, in order to find the best suitable engine mount configuration, it is possible to combine certain criterias as defined before and to find the ideal position to minimize a weigthed sum of criteria according to the desired NVH vehicle quality.

6 CONCLUSION

A new approach in suspension optimization has been developped. It seeks to minimize passenger's perception of noise and vibration inside the vehicle. It allow designers to model structureborne noise generated by the engine. That is from the point of excitation on the engine chassis, throughout vehicle transfer path and up to the vehicle cabin. It was demonstrated that optimizing with flexible base structure, adequate structure FRFs and on a complete range of RPM is an efficient and promising approach. Optimization of the original position of the case study confirms that better positions can be found in order to enhance passengers comfort.

7 REFERENCES

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