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PERFORMANCE EVALUATION OF EXCAVATOR CABIN MOUNTING SYSTEM CONSIDERING NONLINEAR STIFF-NESS CHARACTERISTICS

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In order to fulfill NVH requirement, excavator cabin is isolated from the main structure by using flexible mount. For the bigger reduction of shock and vibration, highly damped rubber mount filled with hydraulic oil is usually adopted. Design point of view, nonlinear characteristics which is mainly caused by fluid viscosity makes difficulties when evaluating shock and vibration responses. This paper investigates calculation scheme of static and dynamic responses. By taking the mount stiffness with corresponding mount deflection, the accuracy of evaluation increased. Based on the suggested method, the sensitivity of design variables such as stiffness and location of an excavator cabin mounting system is analysed.

Keywords: excavator, cabin, mounting system, nonlinear

1. Introduction

Recently the interest of residential quality of cabin in earthmoving industries as well as automobile industries is increasing continuously. The residential quality of construction equipment is affected by several performances such as the interior noise level, the seat vibration exposure, and HVAC performance for an operator. All these performances except HVAC are related to NVH characteristics. That means the vibration isolation is major design point to satisfy such design re-

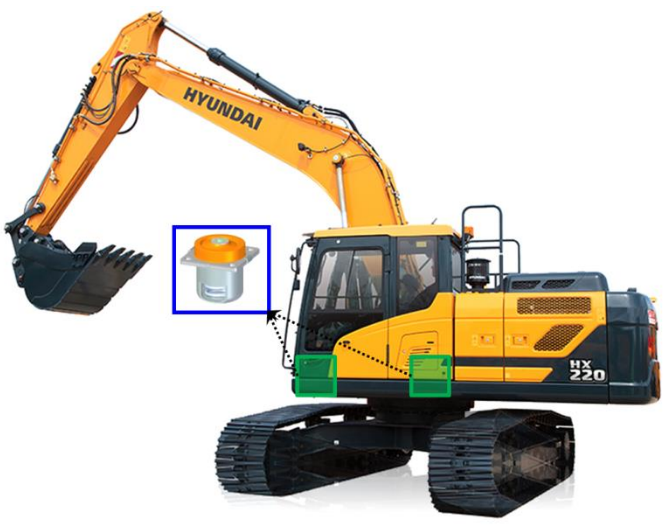

Figure 1.1 A view of excavator cabin mounting system

quirements. For the vibration isolation, as shown in Fig. 1.1, highly damped rubber mount filled with hydraulic oil is usually installed between the cabin bottom and the upper frame of vehicle[1]. Generally, lower stiffness is preferred for the vibration reduction. However, reducing stiffness may cause the mount to have an excessive shock deflection. In order to avoid this situation, cabin mount should be designed to have higher stiffness at high displacement range[2]. Therefore mount stiffness has nonlinear characteristics and it makes difficult to evaluate cabin responses.

In this paper, calculation scheme of dynamic responses as well as static responses is investigated. To consider the nonlinearity of mount stiffness, simplified stiffness model is suggested. By taking the mount stiffness with corresponding mount deflection through iteration, the accuracy of evaluation increased. Based on the suggested method, the sensitivity of design variables such as stiffness and location of an excavator cabin mounting system is analysed through a global optimization technique. All of these methods are implemented in Microsoft Excel file which is very easy to use in design stage. The results of this program are discussed in more detail for the typical excavator cabin mounting design.

2. Cabin mount model

2.1 Stiffness characteristics

An excavator cabin mounting system should satisfy shock requirement as well as vibration requirement. Therefore usually, cabin mount has a nonlinear force-displacement curve, which decreases at low displacement near static equilibrium about which the mount oscillates and increases at high displacement due to shock. Fig. 2.1 shows general force-displacement curve of cabin mount, where stiffness slope increases at high displacement range.

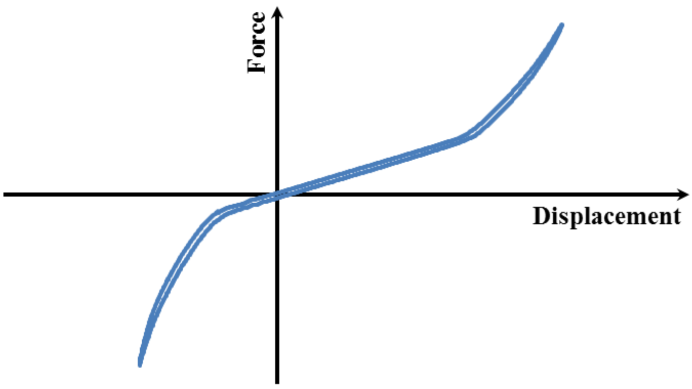

Figure 2.1 Relationship between force and displacement of mount

2.2 Stiffness simplification model

In order to evaluate cabin responses, it is necessary to consider nonlinearity of mount stiffness. However, nonlinear vibration problem cannot be solved analytically except a few cases. Therefore we considered simplified stiffness model which can be used in linear solutions.

The simplification model is prepared based on following assumption:

- Static and shock responses are affected by global stiffness
- Vibration response is affected by local stiffness at static equilibrium
- Local stiffness can be defined at static equilibrium condition
- Damping is same regardless any parameters such as frequencies, amplitudes, etc.

Considering the trend of stiffness change, mount stiffness can be dived into three parts regarding its displacement. So we simplified nonlinear stiffness to three parts of linear stiffness. Suggested stiffness simplification model is described hereafter and it shows in Fig. 2.2:

$$K_{mount}=\begin{cases}K_1 & (0\le d\le d_1)\\ K_2 & (d_1\le d\le d_2)\\ K_3 & (d_2\le d)\end{cases} \tag{1}$$

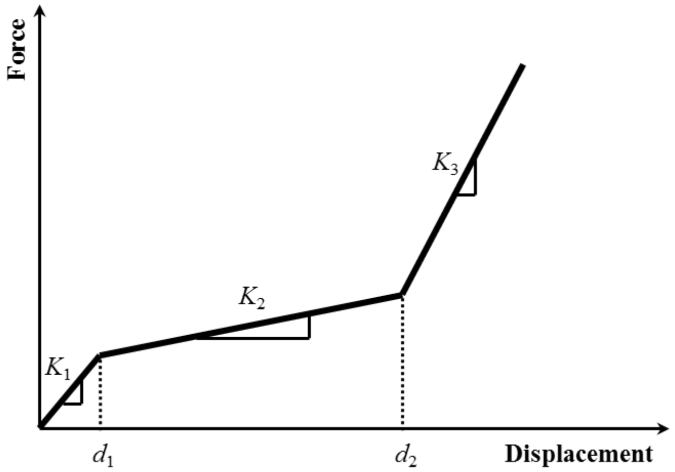

Figure 2.2 Relationship between force and displacement of simplified stiffness model

3. Analysis of cabin response

3.1 Static response

The static response of cabin can be determined from the equations of force & moment equilibrium and maintaining a plane of cabin bottom given by Eqs. (2)~(5).

$$\sum_{i=1}^{4} x_i F_i = 0 \tag{2}$$

$$\sum_{i=1}^{4} y_i F_i = 0 \tag{3}$$

$$\sum_{i=1}^{4} F_i = Weight_{cabin} \tag{4}$$

$$\sum_{i=1}^{4}\left((-1)^i \sum_{j=i}^{i+2} x_{(j\bmod 4)+1}\left(y_{(j+1\bmod 4)+1}-y_{(j+2\bmod 4)+1}\right)\right)z_i = 0 \tag{5}$$

In order to use simplified stiffness model suggested in Section 2 with these formulas, the iterative scheme shown in Fig. 3.1 is adopted. From calculation results shown in Fig. 3.2 we found that three iterations are enough for the typical excavator cabin mounting design.

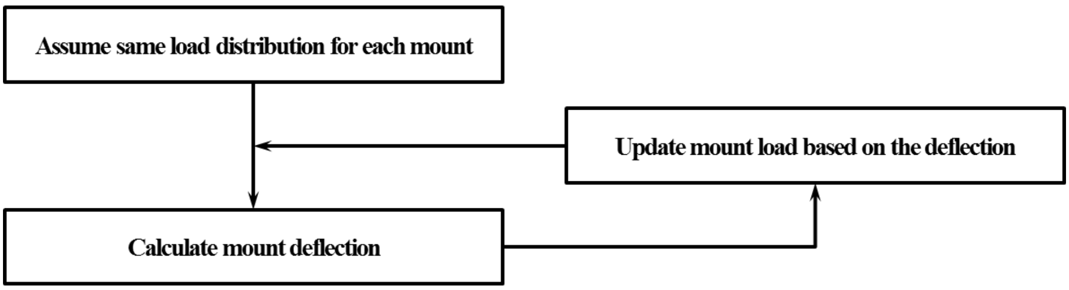

Figure 3.1Iteration scheme for calculation of mount deflection using simplified stiffness model

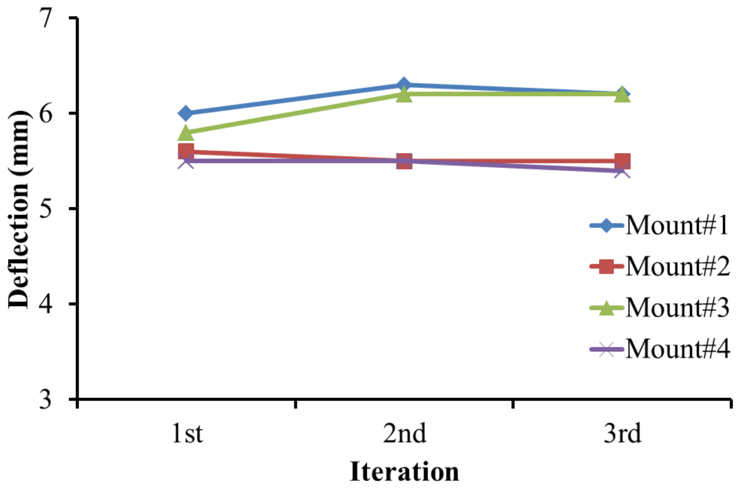

Figure 3.2 Calculation results of mount deflection with iteration

3.2 Vibration response

Excavator cabin excited by engine vibration transmitted through vehicle frame during normal operating condition. Therefore vibration response of excavator cabin can be solved by the analytical theory of base excitation problem given by Eq. (6).

$$z_{j,grms} = \frac{1}{4\pi^2}\sqrt{\sum_{i=1}^{N}\frac{QQ_j^T m}{\left(f_i^2 - f_j^2\right)^2 + \left(2\xi f_i f_j\right)^2} PSD_{base}\Delta f} \tag{6}$$

3.3 Shock response

For the shock response of excavator cabin it can be solved by the same methods as in Eq. (6), because it is excited by frame vibration which is generated by shock during work operation.

4. Design evaluation method

4.1 Evaluation tool

All of these analysis methods described in Section 3 are defined and programmed in Microsoft Excel file shown in Fig. 4.1. This Excel file is programed to check necessary design requirements and it is very easy to use. Design requirements regarding static, vibration and shock responses are defined in the program and their details are described hereafter:

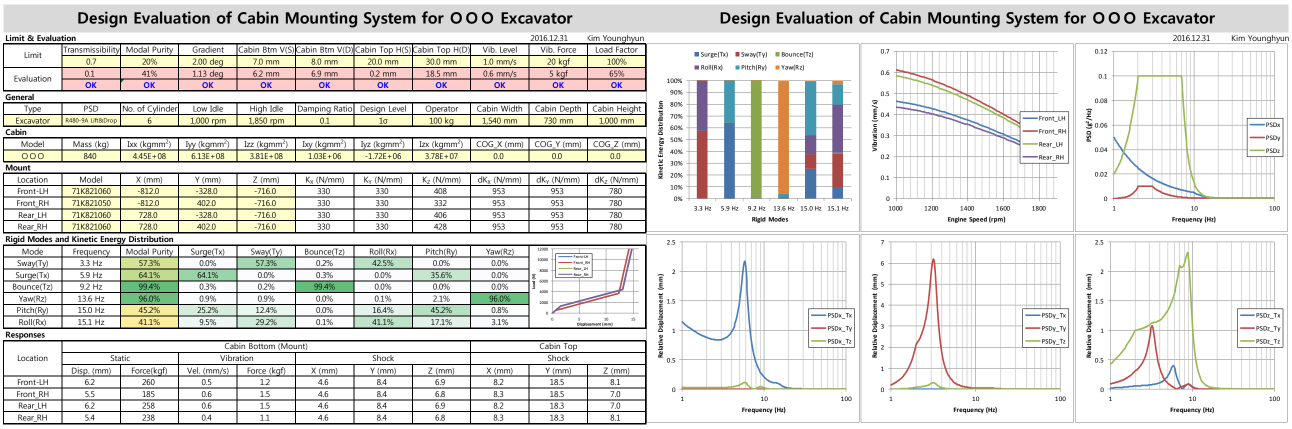

Figure 4.1 A view of cabin mounting evaluation program

- Static responses
  - Vertical deflection and related loading of each mount
  - Horizontal deflection of cabin top
  - Gradient of cabin bottom
- Vibration responses
  - Transmissibility
  - Kinetic energy distribution
  - Vibration of cabin bottom and related force
- Shock responses
  - Vertical displacement of cabin bottom
  - Horizontal displacement of cabin top

4.2 Optimization method

Because the evolutionary algorithm which is robust optimization method for global optimization search is already existed in Microsoft Excel program, we used this method.

In order to include all design requirements in the optimization, the object function is defined as follows:

$$Object = \sum \left(Weighting\ factor \cdot Evaluation\ result \right) \quad (7)$$

5. Design evaluation

A design evaluation of typical excavator cabin mounting system is performed. The design properties are summarized hereafter:

- Cabin properties
  - Mass(kg): 940
  - Moment of inertia(kgmm^2): 4.45×10^7(Ixx), 6.13×10^7(Iyy), 3.81×10^7(Izz)
- Mounting location and stiffness(@equilibrium)
  - Front left(mm, N/mm): (-812, -328, -716), 408/780(static/dynamic)
  - Front right(mm, N/mm): (-812, 402, -716) , 332/780(static/dynamic)
  - Rear left(mm, N/mm): (728, -328, -716) , 406/780(static/dynamic)
  - Rear right(mm, N/mm): (728, 402, -716) , 428/780(static/dynamic)

5.1 Evaluation

The evaluation results of initial mounting design are shown in Table 5.1. Based on these results, a study on design sensitivity and optimization were performed.

Table 5.1 Evaluation results of initial design

Rigid body modes(frequency / modal purity)						Static		Shock Disp.	Object
Surge	Sway	Bounce	Roll	Pitch	Yaw	Grad.	Def.		
5.9 Hz	3.3 Hz	9.2 Hz	15.1 Hz	15.0 Hz	13.6 Hz	1.13°	6.2 mm	6.9 mm	9.572
64.1%	57.3%	99.4%	41.1%	45.2%	96.0%				

5.2 Sensitivity analysis

For the front-left mount, the effect of location change has been studied. The change of location was determined from the initial location with a step of 10 mm.

The sensitivity results are shown in Figs. 5.1~5.3. These figures explain the most sensitive design parameter for each evaluation. Summarized results are as follows:

- For the roll mode, the change of Z location is most critical
- For the modal purity of roll mode, the change of Y location is most critical
- For shock, the change of Y location is most critical

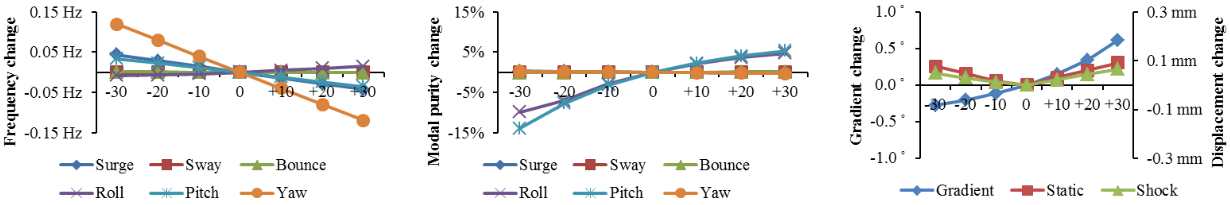

Figure 5.1 Sensitivity relative to the X location

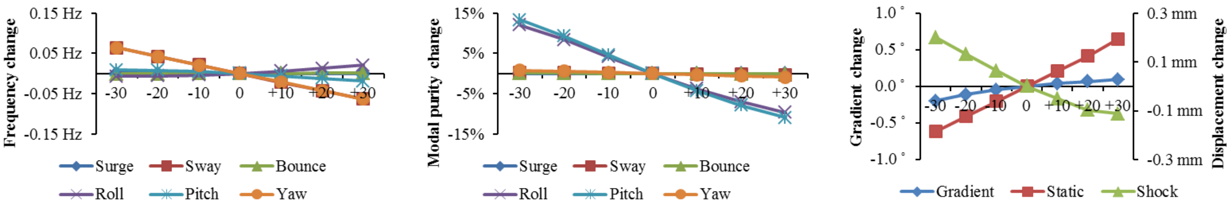

Figure 5.2 Sensitivity relative to the Y location

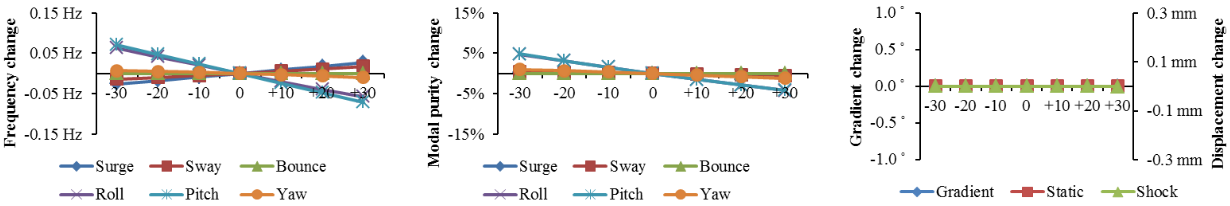

Figure 5.3 Sensitivity relative to the Z location

5.3 Optimization

The optimized results are shown in Table 5.2. Compared to the results of initial design shown in Table 5.1 the object function decreases from 9.572 to 7.745. Among the evaluation results, the modal purity of roll mode is increase greatly. Therefore, in this case, the increase of modal purity of roll mode is helpful to the design optimization.

Table 5.2 Evaluation results of optimized design

Rigid body modes(frequency / modal purity)						Static		Shock Disp.	Object
Surge	Sway	Bounce	Roll	Pitch	Yaw	Grad.	Def.		
5.8 Hz	3.5 Hz	9.2 Hz	15.2 Hz	15.0 Hz	13.7 Hz	0.00˚	5.8 mm	7.2 mm	7.745
63.9%	58.4%	99.6%	58.3%	63.5%	97.9%				

6. Conclusion

The design evaluation scheme of excavator cabin mounting system is investigated. In order to consider the nonlinearity of mount stiffness, simplified stiffness model is suggested. By taking the mount stiffness with corresponding mount deflection through iteration, the accuracy of evaluation increased. For the typical case, the sensitivity of design variables such as stiffness and location of an excavator cabin mounting system is analysed through a global optimization technique. After optimization, the modal purity of roll mode increases more than 40% which is helpful to improve cabin mounting system performances.

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