

Consideration for High-Accuracy 6-DOF Vibration Contribution Analysis Method utilizing Operational TPA and Virtual Point Transformation

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In this study, we considered a combined method of virtual point transformation (VPT) and operational transfer path analysis (TPA) to understand accurate contribution of 6 DOF input force at a point where direct measurement is hard such as inside of a structure, to the response point. In the method, the vibration characteristics (vibration, transfer function and input force) at the center of the target structure, where the direct measurement is impossible, are estimated by VPT employing vibration characteristics at around the target structure obtained directly. The vibration at the VP was estimated from the vibrations measured at three reference points using the VPT. The estimated vibration is then used to calculate the input force. Operational TPA is applied between the estimated input force and the measured response-point vibration to obtain the operational transfer function. The 6 DOF (three translational and three rotational) input-force contributions are calculated by multiplying the input force by the operational transfer function. The proposed method was applied to a simple vehicle model to evaluate the contributions of the 6 DOF motor input forces to the vehicle floor vibration, as shown in Fig. 1 (a). For the improvement of the VPT estimation accuracy, an additional validation point was introduced as shown in Fig. 1 (b). The vibration characteristics at the validation point were compared between the estimated characteristics by VPT and actual characteristic as shown in Fig. 2 (a). This figure shows the point inductance along up-down direction at the validation point. The result illustrated that the accuracy was not enough high from 30 to 50 Hz band. Then, we considered the main reason was the slight offset of the VP position from the actual gravity center along front-back direction. Then, we modified the VP point inductance matrix $[Y_{qm}]$ from Eq. (1) to Eq. (2) by considering the influence the VP point inductance was recalculated.

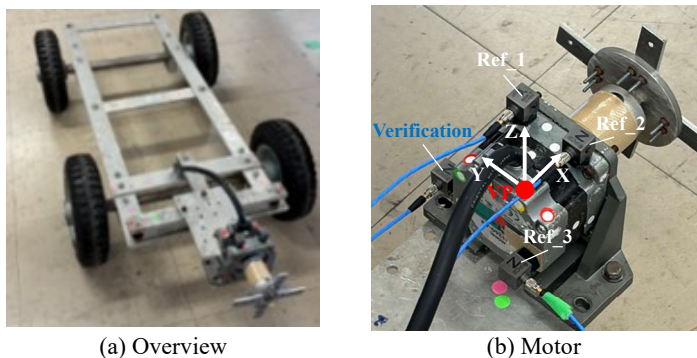
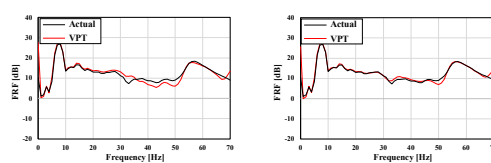


Fig. 1 Employed simple vehicle model

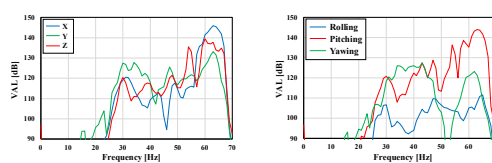
$$[Y_{qm}] = \begin{bmatrix} Y_{qtx_mtx} & Y_{qtx_mty} & Y_{qtx_mtz} & Y_{qtx_m\theta x} & Y_{qtx_m\theta y} & Y_{qtx_m\theta z} \\ Y_{qty_mtx} & Y_{qty_mty} & Y_{qty_mtz} & Y_{qty_m\theta x} & Y_{qty_m\theta y} & Y_{qty_m\theta z} \\ Y_{qtz_mtx} & Y_{qtz_mty} & Y_{qtz_mtz} & Y_{qtz_m\theta x} & Y_{qtz_m\theta y} & Y_{qtz_m\theta z} \\ Y_{q\theta x_mtx} & Y_{q\theta x_mty} & Y_{q\theta x_mtz} & Y_{q\theta x_m\theta x} & Y_{q\theta x_m\theta y} & Y_{q\theta x_m\theta z} \\ Y_{q\theta y_mtx} & Y_{q\theta y_mty} & Y_{q\theta y_mtz} & Y_{q\theta y_m\theta x} & Y_{q\theta y_m\theta y} & Y_{q\theta y_m\theta z} \\ Y_{q\theta z_mtx} & Y_{q\theta z_mty} & Y_{q\theta z_mtz} & Y_{q\theta z_m\theta x} & Y_{q\theta z_m\theta y} & Y_{q\theta z_m\theta z} \end{bmatrix} \quad (1)$$

$$[Y_{qm}] = \begin{bmatrix} Y_{qtx_mtx} & 0 & 0 & 0 & 0 & 0 \\ 0 & Y_{qty_mty} & 0 & 0 & 0 & 0 \\ 0 & 0 & Y_{qtz_mtz} & 0 & Y_{qtz_m\theta y} & 0 \\ 0 & 0 & 0 & Y_{q\theta x_m\theta x} & 0 & 0 \\ 0 & 0 & Y_{q\theta y_mtz} & 0 & Y_{q\theta y_m\theta y} & 0 \\ 0 & Y_{q\theta z_mty} & 0 & 0 & 0 & Y_{q\theta z_m\theta z} \end{bmatrix} \quad (2)$$

Fig. 2 (b) shows the point inductance along up-down direction in case the VP matrix changed from Eqs (1) to (2). As shown in Fig. (2), the accuracy of VPT was observed to be improved. Subsequently, Operational TPA was applied between the accuracy improved 6 DOF input (Blocked Force: BF) at the VP, calculated by dividing the vibration acceleration at the VP by the modified VP point inductance, and the vibration response measured at the center of the vehicle. The result is shown in Fig. 3. As the result, the contribution of the pitching rotational force was found to be significantly higher than the other contributions from 55 to 70 Hz band. As the verification of the contribution analytical result, simple countermeasure was implemented by shortening motor mounting position along the front-back direction to decrease the pitching contribution. As the result, the response point vibration could be decreased largely as shown in Fig. 4. From the result, the proposed VPT-based operational TPA was observed to obtain accurate 6 DOF input-force contributions.



(a) Full matrix (b) Modified
Fig. 2 Accuracy validation



(a) Trans. direction (b) Rot. direction
Fig. 3 Calculated contribution

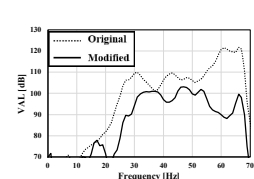


Fig. 4 Response signal