# 乘車 시뮬레이션을 위한 路外車輛 運轉者의 模型化

## Modeling of Off-Road Vehicle Operator for Use in Ride Simulation

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## 要 約

路外車輛의 乘車 시뮬레이션을 위한 着席 狀態의 運轉者 모델을 開發하였다. 運轉者 모델은 머리, 몸체, 臀部로 크게 나누어 自由度 3의 振動体로 假定하고 머리와 몸체, 몸체와 臀部는 각각 목과 臟器를 나타내는 彈性体로서 연결하였다. 또한 人体의 解部學的 構造와 一致하도록 머리와 臀部사이에는 脊椎部分을 포함시켰다. 모델의 각 變數들은 既存의 實驗 結果를 利用하여 머리부의 振動이 實驗 結果와 一致하도록 시뮬레이션 方法으로 決定하였다.

## I. Introduction

Since the human body is a very complex physical structure, it may be impossible to completely describe the body system by mathematical or mechanical methods. Therefore, in order to formulate the human body as a vibratory system, some assumptions, generally acceptable as valid idealizations, must be made. One such assumption has considered the human body a very complicated system of interconnected masses, elastic elements, and viscous dampers (Coermann et al. 1960). In a limited frequency range, the human body has been also considered a linear system (Pradko et al. 1965). Both assumptions have been the bases for modeling the human body, even though neither is a particularly valid idealization. Once a human model is developed, the model must display dynamical characteristics of the body system as closely as possible, and it must resemble the human anatomy for further validity of the model. In addition, the model to be used for ride simulation is also required to be compatible with seat suspension model at the seat/operator interface when the two models are combined. In this study, it was intended to develop a human model which will be used for the ride simulation of off-road vehicle operator incorporating with seat suspension models.

## II. Model Development

Nomenclature

Shown in parentheses are the units of the parameters in terms of force (F), length (L), and time (T).

- $m_h$ = mass of the head ($FT^2/L$)
- $m_b$ = mass of the body ($FT^2/L$)
- $m_p$ = mass of the pelvis ($FT^2/L$)
- $k_h$ = spring constant of the neck (F/L)
- $k_b$ = spring constant of the visceral path (F/L)
- $k_v$ = spring constant of the spinal path (F/L)
- $c_h$ = damping coefficient of the neck (FT/L)
- $c_b$ = damping coefficient of the visceral path (FT/L)
- $c_v$ = damping coefficient of the spinal path (FT/L)
- $x_h$ = absolute vertical displacement of the head (L)
- $x_b$ = absolute vertical displacement of the body (L)
- $x_p$ = absolute vertical displacement of the pelvis (L)

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y = absolute vertical input displacement (L)

j = $\sqrt{-1}$

To develop a mathematical model of an off-road vehicle operator for use in ride simulation, a three degree of freedom system was chosen as a vibratory model of a sitting man. The anatomical description of the model, which was originated from Muksian and Nashs' (1976) work, included the head, body, and pelvis as shown in Figure 1. The body

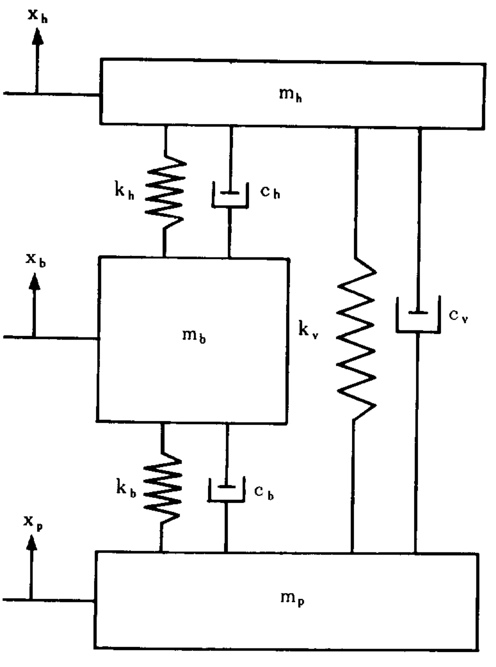


**Fig. 1. A model of off-road vehicle operator**

in the model represented the part between the neck and pelvis, which is containing the chest, abdomen, and arms. The head and body were assumed being coupled by the neck, and the visceral path was included between the body and pelvis. The model also included the spinal path between the head and pelvis so as to increase resemblance of the model to the human anatomy.

From Newton's second law, equations of motion for the model of vehicle operator were derived as follows:

$$m_h\ddot{x}_h+(c_h+c_v)\dot{x}_h-c_h\dot{x}_b-c_v\dot{x}_p+(k_h+k_v)x_h-k_hx_b-k_vx_p=0,$$
$$m_b\ddot{x}_b-c_h\dot{x}_h+(c_h+c_b)\dot{x}_b-c_b\dot{x}_p-k_hx_h+(k_h+k_b)x_b-k_bx_p=0,$$
$$m_p\ddot{x}_p-c_v\dot{x}_h-c_b\dot{x}_b+(c_b+c_v)\dot{x}_p-k_vx_h-k_bx_b+(k_b+k_v)x_p=0, \quad (1)$$

In a sitting position, the pelvis was assumed to be excited by the input motions. Then, the output motions of the head and body could be given by the first two of Equation (1). Let $x_p$ be a given input displacement, y(t), and expressing the first two of Equation (1) in matrix form

$$[M]\{\ddot{x}\}+[C]\{\dot{x}\}+[K]\{x\}=\{F(t)\}, \quad (2)$$

where

$$[M]=\begin{bmatrix} m_h & 0 \\ 0 & m_b \end{bmatrix},$$

$$[C]=\begin{bmatrix} c_h+c_v & -c_h \\ -c_h & c_h+c_b \end{bmatrix},$$

$$[K]=\begin{bmatrix} k_h+k_v & -k_h \\ -k_h & k_h+k_b \end{bmatrix},$$

$$\{F(t)\}=\begin{bmatrix} c_v\dot{y}+k_vy \\ c_b\dot{y}+k_by \end{bmatrix},$$

and $$\{x\}=\begin{bmatrix} x_h \\ x_b \end{bmatrix}$$

Let, $\{X(f)\}$ be the Fourier transform of $\{x\}$.

$$\{X(f)\}=\int_0^\infty \{x\}\, e^{-j2\pi ft}\, dt$$

Taking the Fourier transform of both sides of Equation (2),

$$\left[[K]-(2\pi f)^2[M]+j2\pi f[C]\right]\{X(f)\} = \left[\begin{bmatrix} k_v \\ k_b \end{bmatrix}+j2\pi f\begin{bmatrix} c_v \\ c_b \end{bmatrix}\right] Y(f), \quad (3)$$

where Y(f) is the Fourier transform of input displacement, y(t).

$$Y(f)=\int_0^\infty y(t)\, e^{-j2\pi ft}\, dt$$

Frequency response function of the model is given by the Fourier transform of the output displacement, $|x|$, to a unit impulse input displacement, i.e., $y(t) = \delta(t)$. Since the Fourier transform of a unit impulse displacement is unity, the frequency response function, $|H(f)|$, of the model is determined from Equation (3) as follows:

$$|H(f)| = [[K]-(2\pi f)^2[M]+j2\pi f[C]]^{-1} \left[\begin{bmatrix} k_v \\ k_b \end{bmatrix} + j2\pi f \begin{bmatrix} c_v \\ c_b \end{bmatrix}\right] \quad (4)$$

Using Equation (4), transmissibility and phase angle of the head and body response to the input motion were computed at the given frequency, f.

## III. Determination of Model Parameter Values

Using a weight distribution of the human body approximated by Hertzbeıg and Clauser (1964), masses of the operator model were determined as 5.44 kg for the head, 47.17 kg for the body, and 27.22 kg for the pelvis on the basis of a total mass of 79.83 kg. Evaluation of spring constants and damping coefficients was made by using a frequency response matching method. Frequency response function of the model, given by Equation (4), was computer programmed, and the parameter values were varied until the head transmissibilities showed the best agreement with the head to seat acceleration ratios measured by Pradko et al. (1965) for the input frequencies from 1 to 30 Hz. The determined parameter values were given in Table 1.

**Table 1. Parameter values of the operator model**

| Mass | Spring constant | Damping coef. |
|---|---|---|
| $m_h$ =5.44 kg | $k_h$ =10000N/m | $C_h$= 630N. s/m |
| $m_b$ =47. 17kg | $k_b$ =65000 N/m | $C_b$= 450N. s/m |
| $m_p$ =27. 22kg | $k_v$ =28000N/m | $C_v$=1700N. s/m |

Figure 2 shows the transmissibilities of the head and body of the model simulated in the frequency range of 1 to 30 Hz. The model displayed two resonance peaks at 5.5 and 18 Hz. The first resonance peak occurred at higher frequency than the experimental results by 1 Hz, which was in the range of difference exhibited in many experimental results. In the frequency region above 10 Hz, the head response of the model was in good agreement with the experimental results. Since no experimental data on the body response were available, the validity of the body response of the model could not be assessed and may still be necessary when those experimental data become available. It was noted, however, that the body response showed a similar trend to the shoulder response measured by Dieckmann (1947) in the shake table experiment. The experimental results of the head and shoulder response measured by Pradiko et al. and Dieckmann were also plotted in Figure 2.

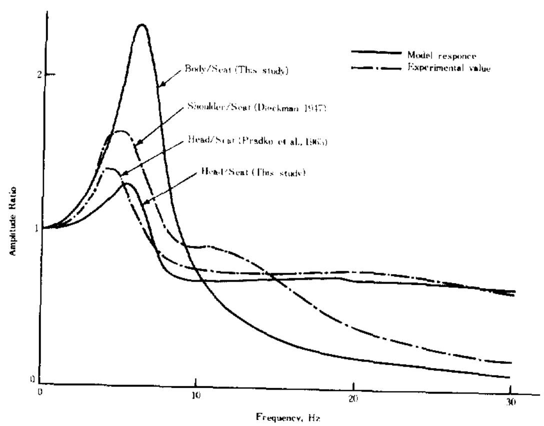


**Fig. 2. Transmissibilities of the head and body response of the model**

Phase angles of the head and body response were plotted as a function of input frequency in Figure 3. The head response lagged by a relatively constant phase angle of about 20 degrees to the input motion with the frequency higher than 10 Hz while the body response led by about 60 degrees in the same frequency range. In the low frequency region below 10 Hz, the body response showed fast phase shift.

## IV. Conclusion

A three degree of freedom, lumped parameter

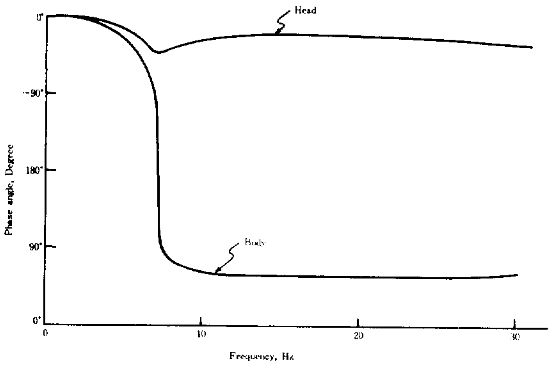


**Fig. 3. Phase angles of the head and body response of the model**

model of the human body in a sitting position was developed for use in ride simulation of off-road vehicle operator. The model response showed a good approximation of the human response obtained from the shake table experiments. The model response also exhibited two resonance peaks at 5.5 and 18 Hz. Since the model included the head and body of which response are most important in evaluating operator's comfort, the model may be most suitable for use in ride simulation purposes of off-road vehicle operator.

## References

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