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A Modified Method to Calculate the Pelvis Trajectory of Crash Dummies during Frontal Impact

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Abstract： It is conducive to understand the movement of the dummy, the analysis of dummy injury curves and restraint system matching by studying on the trajectory of dummies. By viewing the crash video is difficult to quantitative analysis of dummy motion, so how to get the dummy trajectory through the test data is the urgent thing to solve the problem for engineers. This paper studied the relationship between the pelvis rotation angle and the pelvis acceleration based on the restraint system simulation model and the vehicle test data, used mathematical analysis method to conclude the mathematical formula, and summarized the method that dummy pelvis acceleration transforms into pelvis trajectory. This method provided thebasis and foundation for the matching and parameter optimization ofrestraint system.

Keywords: pelvis rotation angle; pelvis trajectory; pelvis acceleration; mathematical analysis

1 Introduction

It is important for restraint system engineers to find the trajectory of crash dummies as it helps to improve the accuracy of optimization solutions for restraint systems and gain high C-NCAP scores[1]. During crash testing, pelvis trajectory cannot be observed because vehicle doors hinder vision. Image analysis can be used to calculate the position of points on the crash dummies [2], but it is only available for sled testing. A mathematical analysis method was introduced to calculate the pelvis trajectory of a crash dummy during frontal impact.

2 Methods

Demerits of current calculation method were analyzedand a modified calculation method was proposed.

2.1 Current Calculation Method

The pelvis acceleration of a crash dummy can be obtained in a vehicle crash test (Fig. 1).

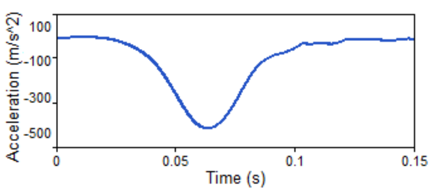

Fig. 1. Pelvis acceleration X.

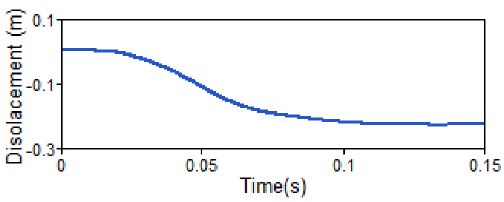

Fig. 2. Pelvis relative displacement X.

In the current calculation method, the pelvis displacement can be calculated as Equation (1):

$$D_P = \iint a_p(t) \tag{1}$$

where D_p is pelvis displacement (m) and a_p is pelvis acceleration (m/s^2).

Using Equation (1), the pelvis displacement X can be calculated. This displacement is absolute displacement, which refers to ground. Relative displacement x (Fig. 2) is pelvis displacement X minus vehicle displacement X.

There are two problems with the current calculation method. One problem is that the displacement is larger than the real result. Fig. 2 shows the maximum pelvis displacement X is 225 mm. However, the displacement between the dummy's abdomen and the steering wheel's lower rim is only 195 mm, which would means the steering wheel rim would embed into the abdomen. In fact, there was no contact between steering wheel and abdomen. The other problem is the shape of the displacement curve. Fig. 2 shows pelvis relative displacement is about 220 mm at 0.15 s, which means the dummy is still in contact with the steering wheel. In fact, the dummy has moved far from the steering wheel. Usually, the shape of pelvis relative displacement is a parabola.

2.2 Modified Calculation Method

Pelvis has been rotated during the crash test. To obtain the relative displacement, it is necessary to convert the pelvis acceleration from local coordinates to a global coordinate system. The conversion equation is:

$$ax_G = ax_L \times \cos\theta + az_L \times \sin\theta \tag{2}$$

$$az_G = ax_L \times \sin\theta + az_L \times \cos\theta \tag{3}$$

where ax_G and az_G is pelvis acceleration x and pelvis acceleration z are referenced to global coordinate system, ax_L and az_L is pelvis acceleration x and pelvis acceleration z are referenced to local coordinate system, and θ is the rotation angle of pelvis body referenced to global coordinate system.

In Equations (2) and (3), θ is an unknown variable and it is difficult to measure from crash test data. To obtain θ, a method of mathematical analysis was used. The relativity on θ with pelvis acceleration x and pelvis acceleration z was studied using five groups of crash test results. The significant levels' P-Values were 0.0034, 0.0022, 0.0105, 0.0138 and 0.0056, respectively. This means that the relationship is significant ($P< 0.05$), and there is a set of mathematical formulae to describe the relativity on θ with pelvis acceleration.

Regression analysis is a statistical analysis method used to determine the quantitative relationship between two or more variables [3].Theoretically, there should be a correlation between pelvis angular acceleration and pelvis acceleration. Using pelvis angular acceleration as a function (y) and pelvis acceleration (X and Z) as independent variables (x), the quadratic regression models were used to describe the correlation. If pelvis angular acceleration can be calculated, pelvis rotation angle θ can be obtained by pelvis angular acceleration double integral for time. Furthermore, to improve the fitting accuracy of pelvis angular acceleration, time series forecasting method is used to supplement and improve the above regression model [4]. Time series forecasting method is based on statistical techniques and it can be applied to estimate the future development trend of the prediction index [4]. By the two methods mentioned above, the Equation is as follows:

$$\begin{aligned}\ddot{\theta}(t) = \sum_{i-0}^{n} & a_1 \cdot ax_L{}^2(t-i) + a_2 \cdot az_L{}^2(t-i) + a_3 \cdot as^2(t-i) + a_4 \cdot ax_L(t-i) \cdot as(t-i) + \\ & a_5 \cdot az_L(t-i) \cdot as(t-i) + a_6 \cdot ax_L(t-i) + a_7 \cdot az_L(t-i) + a_8 \cdot as(t-i) + a_9\end{aligned} \tag{4}$$

where $a_1, a_2, a_3\ a_4, a_5, a_6, a_7, a_8$ are constant, as is vehicle crash pulse X, i is regression number , t is time.

3 Initial Findings

To verify the validity of the formulae, a simulation model was set up and correlated with crash test results. The pelvis rotation angle was output from the simulation model and compared with θ calculated according to Equation (4) (Fig. 3). The pelvis relative displacement was also compared with the simulation result (Fig. 4).

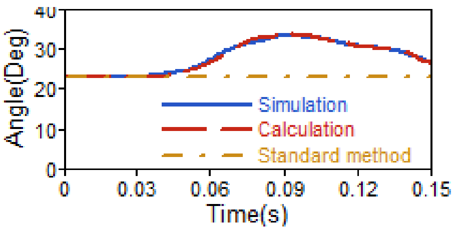

Fig. 3.Comparison of pelvis rotation angle.

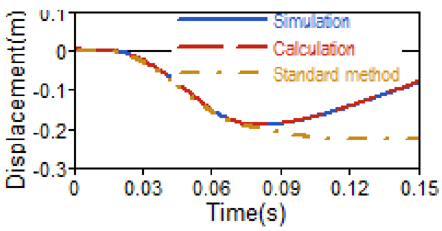

Fig. 4. Comparison of pelvis relative displacement

Fig. 3 and Fig. 4 show high similarity between simulation and calculation results, which means that the modified calculation method is an effective way to calculate the pelvis trajectory of crash dummies. In addition, the maximum relative displacement X (Fig. 4) is 189 mm and therefore lower than the displacement between abdomen and steering wheel of 195 mm. Meanwhile, the shape of pelvis relative displacement is a parabola.

4 Discussion

With regression analysis and the time series forecasting method, the relativity on θ with pelvis acceleration can be expressed by Equation (4). The accuracy of Equation (4) depends on the sampling rate.To increase the robustness of the Equation, more samples need to be researched. Pitch phenomenon can be found in frontal impact load case for some vehicles. In those load cases, pelvis rotation angle θ should be modified by the rotation angle of vehicle body. Detailed information needs to be collected through future research.

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