◎ 논 문

A Research on Predicting Dynamic Behavior of Door Locking System for Side Impact Safety

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Key Words : Equations of motion, Runge-Kutta 4th order method, Characteristic factor, Door locking system properties

ABSTRACT

The main purpose of this research is to predict dynamic behavior of door locking system for side impact safety and the design process to avoid door opening is introduced. The equations of motion that represent the system are obtained from the energy equation. From them, the motion of door handle is predicted by using Runge-Kutta 4^{th} order method and the simulation result is compared with the real crash data. Also, the design guide to define the properties of door locking system from the standpoint of avoiding door opening phenomenon is introduced.

1. Introduction

There are some causes to bring about door opening problems in side impact test, but the countermeasures of opening issues due to the inertia force generated by dynamic crash energy exerted on the door locking system are based on the statics. However, it cannot be represented as the real response of the door opening behavior because time domain is not considered on statics. Therefore, in order to predict the behavior of door locking system in the side impact test, it should be based on dynamics. On the contrary, the traditional analysis based on statics can be more efficient even though there are unnecessary margins to interpret door opening phenomenon.

In this paper, the equation of motion that describes the real behavior of side impact crash and the process to determine the design parameters to avert door opening problem are introduced. Also, the design guide to define the properties of door locking system from the standpoint of avoiding door opening phenomenon is suggested. Finally, the analysis results based on statics and dynamics are compared, and the design strategy to embody robust system is suggested.

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2. Main Subject

2.1 Derivation of Equation of Motion

2.1.1 Dynamics Perspective

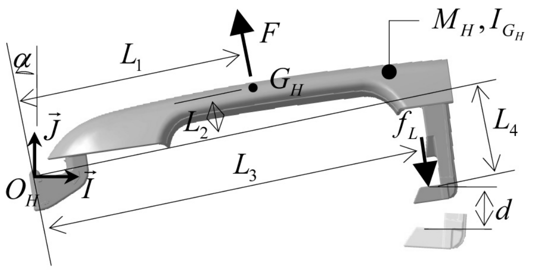


Fig. 1 Free Body Diagram of Door Handle

Fig. 1 shows a free body diagram of door handle system.

Fig. 2 shows a free body diagram of door handle lever system. It consists of lever & spring, and the door latch reaction force f_R which is proportional to the angle β is exerted on the linkage position on the lever. Also, the static deflection angle of spring δ is defined, which retains the closing status of door handle.

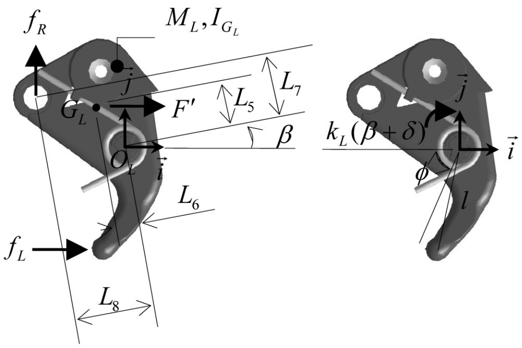


Fig. 2 Free Body Diagram of Door Handle Lever

From the free body diagram as depicted in Fig 1 and 2, one kinematic constraint and two equations of motion are obtained as follows. [1][4][5][8][9]

$$\beta = \cos^{-1}\left[\cos\phi - \frac{L_4(1-\cos\alpha) + L_3\sin\alpha}{l}\right] - \phi \tag{1}$$

$$\frac{d}{dt}\left(\frac{\partial L}{\partial \dot{\alpha}}\right) - \frac{\partial L}{\partial \alpha} = \left[M_H(L_1^2 + L_2^2) + I_{G_H}\right]\ddot{\alpha} = Q_\alpha \tag{2}$$

, where

$$Q_\alpha = L_1 M_H a(t) - L_3 f_L(t)$$

$$\frac{d}{dt}\left(\frac{\partial L}{\partial \dot{\beta}}\right) - \frac{\partial L}{\partial \beta} = \left[M_L(L_5^2 + L_6^2) + I_{G_L}\right]\ddot{\beta} + k_L(\beta+\delta) = Q_\beta \tag{3}$$

, where

$$Q_\beta = M_L a(t)(L_6\sin\beta - L_5\cos\beta) + f_L(t) l \sin(\phi+\beta) + f_R(-L_7\sin\beta - L_8\cos\beta)$$

It should be noted that the non-linearity of equations of motion is resulted from the kinematic relationship of generalized coordinate system, and it leads to difficulties to obtain the solution of differential equations. Therefore, Runge-Kutta 4th order method to solve the equations above needs to be used. From this numerical method, the following relationship is obtained. [2]

$$\dot{\alpha}_{i+1} = \dot{\alpha}_i + \frac{1}{6}(k_1 + 2k_2 + 2k_3 + k_4)\Delta t$$

,where

$$k_1 = f(\dot{\alpha}_i),\ k_2 = f(\dot{\alpha}_i + 0.5k_1\Delta t),$$

$$k_3 = f(\dot{\alpha}_i + 0.5k_2\Delta t),\ k_4 = f(\dot{\alpha}_i + 0.5k_3\Delta t)$$

$$f(\dot{\alpha}) = Q_\alpha / \left[M_H\left(L_1^2 + L_2^2\right) + I_{G_H}\right] \tag{4}$$

From Eq. (1), (2), (3), and (4), the handle motion resulted from the impact of barrier can be predicted numerically. [2][6][7]

2.1.2 Statics Perspective

From the standpoint of statics, the variables with respect to time are not considered. Therefore, the α and β terms are zero, so the following relationship is obtained. [3]

$$a = \frac{k_L\delta + f_R L_8}{L_1 M_H l\sin\phi / L_3 - L_5 M_L} \tag{5}$$

As expressed in Eq.(5), it can be seen that the spring moment and the reaction force of door latch are proportional to the inertia resistance which is represented as the acceleration *a*. Furthermore, the inertia resistance can be enhanced through the reduction of door handle and the upper shift of the center of gravity of lever. However, it should be noted that the acceleration of inertia resistance obtained from the statics perspective cannot represent real motion because time domain is not considered. In other words, the maximum magnitude of acceleration that blocks door opening is relatively smaller than that of dynamics perspective because the mass moment of inertia is not considered in statics.

2.2 Door Opening Behavior Prediction

2.2.1 Correlation with Side Impact Test Data

Fig 3 shows the schematic diagram to measure the acceleration data at the moment of side impact crash. The displacement of door handle during the crash can be obtained from the differences of each integrated data of accelerometer.

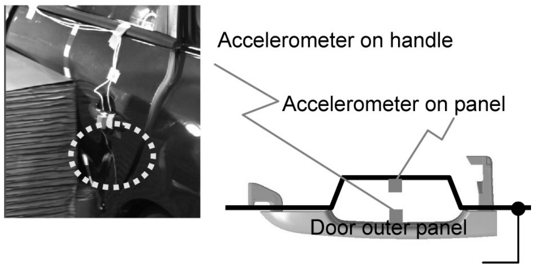


Fig. 3 Schematic Diagram to Measure the Acceleration Data at Moment of Side Impact Crash

Fig 4 shows the plot of acceleration & door handle opening angle versus time in real side impact case.

As expressed in Fig 3 & 4, the acceleration data are obtained from the accelerometers attached on the door panel and handle, respectively. Also, the displacement of door handle is defined as the discrepancy between door panel and handle movement, and it is calculated by integrating those accelerations with respect to time twice.

The door handle travel from the side impact test

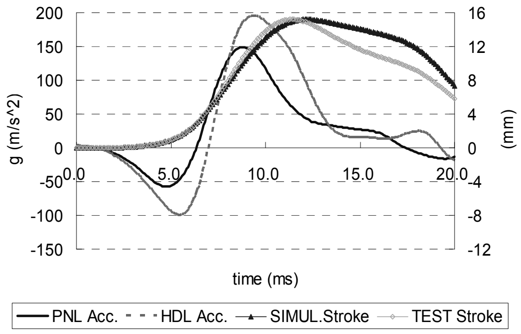


Fig. 4 Plot of Acceleration & Door Handle Opening Stroke vs. Time (Release Stroke=12.6mm)

is expressed as TEST Stroke in Fig 4. From this figure, it is seen that the maximum stroke is 15.2mm which is over the release stroke of 12.6mm, and the door is open at 9.5ms. Also, it is obviously seen that the simulation stroke obtained from Eq.(1), (2), (3), and (4) has the similar trend of test stroke. It should be noted that the characteristic factor needs to be defined to correlate test data as follows.

$$Simulation \quad stroke = C.F \times \alpha \tag{6}$$

, where *C.F* = *Max. Test Stroke / Max. Simulation Stroke*

Characteristic factor is dependant upon each side impact pulse, so it is considered as the unique value for each vehicle and impact test. Generally, characteristic factor has the value from about 2 to 4, but it can exist in different range for what the pulse is given to the system. In this study, the characteristic factor is calculated as 3.83.

Table 1 Increasing Properties of Outside Handle Lever

Property	Unit	Before	After	Increasing Rate
L_5	mm	7.8	11.5	54 %
L_6	mm	6.8	7.6	18 %
M_L	g	83	104	25 %
I_L	kg mm^2	15.2	21.6	45 %

There are several property changes to improve door opening problem such as increasing spring stiffness & outside handle lever. In this case, the properties related outside handle lever are increased as shown in Table 1.

Fig 5 shows the plot of acceleration & door handle opening stroke.

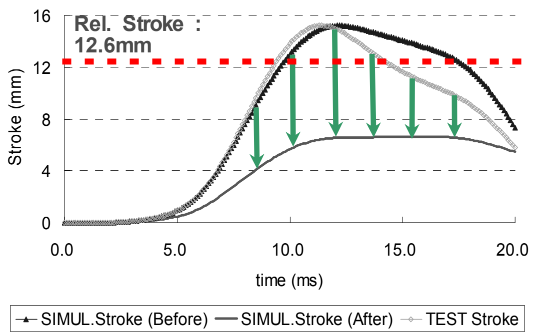


Fig. 5 Plot of Acceleration & Door Handle Opening Stroke vs. Time (Increasing Balance Weight)

As described in Table1, the inertia resistance for door locking system in raised through increasing balance weight, and it is clearly seen that the door opening stroke is reduced to 6.6mm, which is about half of release stroke. Of course, the stroke can be more reduced if the spring moment is raised.

2.2.2 Comparison with Statics and Dynamics Perspective

Interestingly, the inertia resistance analyzed from statics is typically used because the method is more intuitive and simpler than that of dynamics perspective. However, it seems that there are different evaluation results by different criteria.

Table 2 shows the criteria & judgment comparison for statics & dynamics analysis. From Table2, it is obviously seen that the criteria for statics and dynamics is inherently different from each other. It should be noted that the time dependant variable properties cannot be considered in statics perspective. Therefore, the dynamic behavior can be

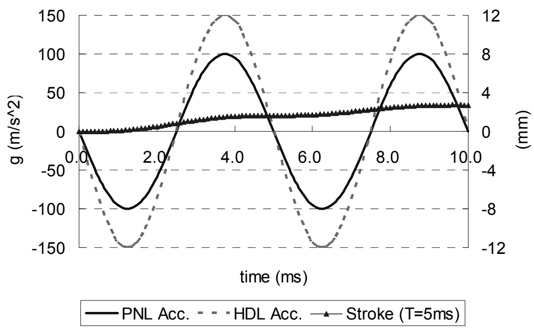
Table 2 Criteria & Judgment Comparison for Statics & Dynamics

	Statics	Dynamics
Criteria	Max. Acc (150g)	Max. Rel. 12.6mm
Before	N.G. (68g)	N.G. (15.2mm)
After	N.G. (122g)	O.K. (6.6mm)

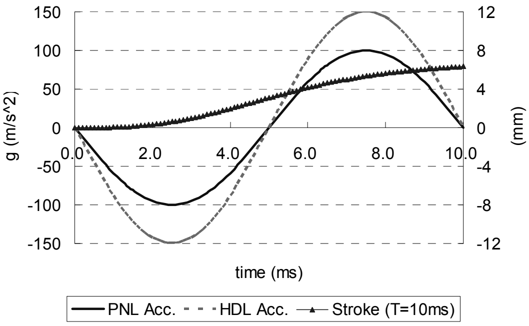
obtained from the equations of motion from Eq.(1) to (4). Also, even though the balance weight is increased as discussed before, the judgment result from statics is N.G. On the contrary, the result from dynamics is O.K. In other words, the analysis result from statics is more sensitive and gives more conservative answers. From this point of view, it seems to be difficult to say that the judgment result obtained from statics perspective is incorrect. Instead, it seems to be more reasonable process to set up the final target through dynamics perspective after the conservative target is established from the statics perspective. However, it is more difficult to satisfy the criteria from statics as the weight of handle is raised by embedding electronics inside of the handle.

2.2.3 Case Study of Response from Input Pulse Period

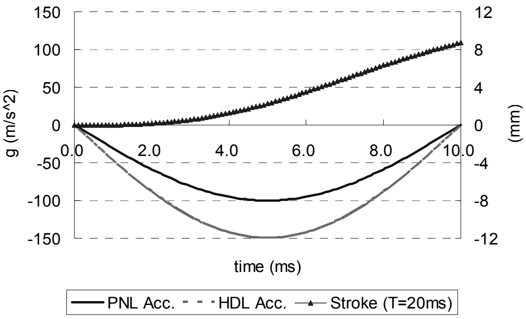
In order to more easily understand the response from input impact pulse period, the simulation result is introduced as follows.



(a) Stroke at Period(T)=5ms for given Input Pulse



(b) Stroke at Period(T)=10ms for given Input Pulse



(c) Stroke at Period(T)=20ms for given Input Pulse

Fig. 6 Stroke for Different Sine Input Pulse

Fig 6 shows the door handle stroke for different sine input pulse. It is observed that the maximum stroke is different for each input pulse. Also, it should be noted that, even if the maximum acceleration is same for all simulation cases, the output stroke is changing for each input. In other words, the statics perspective has the limitation that does not lead to the real stroke output.

Fig 7 shows the plot of stroke versus time for different period input of impact pulse. It can be observed that as the input period is increasing, the maximum stroke is also increasing. However, if the period is increasing more than 20ms, the maximum stroke is decreasing because the input energy that is represented by pulse is decreasing at the same time.

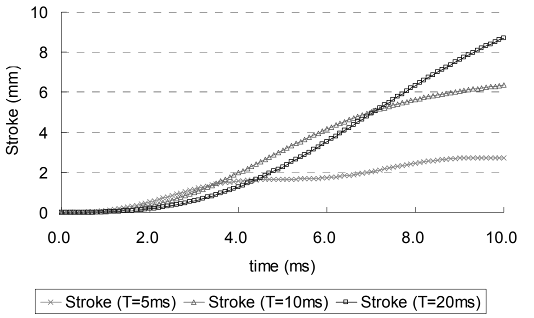


Fig 7. The Plot of Stroke vs. Time for Different Period Input of Impact Pulse

3. Conclusion

In this paper, the equations of motion that represent real dynamic behavior due to side impact pulse are derived by using Lagrange equation. Also, the solution of differential equations is obtained from Runge-Kutta 4^{th} order method numerically, and they are correlated with the displacement in real side impact case. Basically, the trend of the numerical solution corresponds to that of test result, and the characteristic factor to correlate the solution is considered. It should be noted that the characteristic factor is the unique correlated constant for the side impact test and simulation result.

In addition, typical statics perspective that analyzes the door opening phenomenon is compared with the dynamics perspective. In this discussion, it is seen that the analysis result from statics gives more conservative criteria. However, the weight of handle is raised by embedding electronics inside of the handle recently. Thus, it seems to be more reasonable to set up the final target through dynamics method after the conservative target is established from the statics perspective.

Finally, the case study of response from input impact pulse period is introduced. In this study, the maximum stroke is increasing as the input period is increasing because of the different input energy level. In other words, the limitation of typical statics analysis process is simply shown in this case, so time and frequency domain needs to be considered to obtain realistic dynamic behavior of door locking system for side impact safety.

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