A Kind of FEM Dummy Material Property Parameter Curve Optimization Method Based on Vehicle Collision Simulation

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Abstract: Based on full-size vehicle collision test, a new finite element dummy model (FEM dummy) was built in this paper, at the same time the corresponding dummy's material parameter curve optimization method was proposed. For the result of dummy simulation being in keep with that of full scale vehicle collision experiments, it was necessary to scientifically adjust the dummy's structural material parameters and parameters curve. Besides, optimized design of parameters curve was a more complex work. Therefore proposing a method of the curve approximate optimization to meet the design requirements was necessary. First, according to the variation of the curve, we cut it into segments, and redefined them as parameters. Then, using the parameter optimization method, the important parameters was selected which significantly affected the results of the simulation. Finally, using that method obtained the curve which made it consistent with the full-scale vehicle collision test results. In the paper, positive collision chest pressure test of a new FEM dummy as an example, to make sure simulation dummy' chest pressure peak and spring rate and so on were consistent with full-size vehicle collision dummy data, Use this method to optimization design someone material parameter curve. The result proved that the method could be used to improve the new FEM dummy to meet the needs of the full-scale vehicle collision test.

Introduction

[1]The full-size vehicle collision simulation is an important part in the process of product development, FEM Dummy as the evaluation index is particularly important. From the 80's, the FEM Dummy model has been established by industry and academia. Today, The III 50th Hybrid finite element model established by American LSTC Company and TNO uses a non-real solid finite element model to speed up the calculation. these two models have their own shortcomings. LSTC company in order to improve the performance of the model and the accuracy of the response has been increasing the calculation time. TNO's model is fast but not real solid finite element models. Besides, they both simulate the physical characteristics of people in western countries. The FEM dummy's research started late in our country. based on the human body mechanics and finite element method analysis the 95% FEM dummy model of Chinese body was established by Chen Shuang, Yuan Zhongfan et al. It has basically realized the simulation of mechanical structure and similarity of mechanical properties of the crash dummy. Cai Zhihua, Lan Fengchong et al established the finite element model of the humans' thorax based on automobile collision damage. The biomechanical response and damage mechanism of the chest in a crash environment are predicted and evaluated by it. But the model used in the test data is also a western data, and cannot fully reflect the Chinese people's biomechanical response.

Based on a new domestic FEM dummy model, this paper aims to solve the low calculation accuracy. For the result of dummy simulation being in keep with that of full scale vehicle collision experiments, it was necessary to scientifically adjust the dummy's structural material parameters and parameters curve. In this paper, a method of the curve approximate optimization meeting the design requirements is presented. In order to illustrate the method of application, positive collision chest pressure test of a new FEM dummy as an example, use this method to optimization design someone material parameter curve. The result proved that the method could be used to improve the new FEM dummy to meet the results of the full-scale vehicle collision test.

Objective curve optimization method

In engineering, a lot of optimization parameters and optimization goals are curve obtained mostly by experiment and simulation. Each curve cannot be expressed explicitly, and it is more difficult to express the relationship in function. The parameter fitting technique has been developed, but it is too complicated to the engineering problem currently. So it is necessary to put forward the optimization method of curve which can be used in engineering application.

First of all, From the point of parameter sensitivity, the parameter curve can be divided into several sections. Sensitivity of the results is affect by the slope and length of each segment. From the point of the optimization goal, the result may be the peak value, peak position or slope of the target curve, which can be directly observed and described.

So that, the parametric curve can be expressed in the form of parameterization, such as each line segment's length and slope. And the target curve can also be expressed in the form of parameterization, such as peak value and slope. As a result, the optimization problem of the curve can be described as a multi-objective and multi-parameter optimization problem.

Here is a brief introduction to the multi-objective optimization method used in this paper [8-10] .

First, consider the three functions $f_1(X),\ f_2(X),\ f_3(X)$, each function contains four independent variables $X=\left(x_1,x_2,x_3,x_4\right)$, omitted the higher order terms, the first order Taylor expansion is as follows.

$$\begin{cases} f_1(X)\approx f_1(X)-\dfrac{\partial f_1}{\partial X}\Delta X\approx a_1x_1+b_1x_2+c_1x_3+d_1x_4+e_1 \\ f_2(X)\approx f_1(X)-\dfrac{\partial f_2}{\partial X}\Delta X\approx a_2x_1+b_2x_2+c_2x_3+d_2x_4+e_2 \\ f_3(X)\approx f_1(X)-\dfrac{\partial f_3}{\partial X}\Delta X\approx a_3x_1+b_3x_2+c_3x_3+d_3x_4+e_3 \end{cases} \tag{1}$$

Thus,

$$df_1/dx_1\approx a_1,df_2/dx_1\approx a_2,df_3/dx_1\approx a_3 \tag{2}$$

When the increment of x_1 is

$$\Delta x_1=\left(df_1/dx_1\right)^{-1}=1/a_1 \tag{3}$$

The increment of the three functions in the formula (1) can be expressed as a formula (4), (5) and (6).

$$\Delta f_1\approx a_1\left(\frac{df_1}{x_1}\right)^{-1}\approx\left(\frac{df_1}{dx_1}\Big/\frac{df_1}{dx_1}\right)\approx a_1\left(a_1\right)^{-1}\approx 1 \tag{4}$$

$$\Delta f_2\approx a_2\left(\frac{df_1}{x_1}\right)^{-1}\approx a_2\left(a_1\right)^{-1}\approx\left(\frac{df_3}{dx_1}\Big/\frac{df_1}{dx_1}\right) \tag{5}$$

$$\Delta f_3\approx a_3\left(\frac{df_1}{x_1}\right)^{-1}\approx a_3\left(a_1\right)^{-1}\approx\left(\frac{df_3}{dx_1}\Big/\frac{df_1}{dx_1}\right) \tag{6}$$

Similarly, when the increment of x_1,x_2,x_3 and x_4 is

$$\Delta x_1 = \sum_{i=1}^{3} l_i \left(\frac{df_i}{dx_1} \right)^{-1} \tag{7}$$

$$\Delta x_2 = \sum_{i=1}^{3} l_2 \left(\frac{df_i}{dx_2} \right)^{-1} \tag{8}$$

$$\Delta x_3 = \sum_{i=1}^{3} l_i \left(\frac{df_i}{dx_3} \right)^{-1} \tag{9}$$

$$\Delta x_4 = \sum_{i=1}^{3} l_i \left(\frac{df_i}{dx_4} \right)^{-1} \tag{10}$$

The increment of the three functions in the formula (1) can be expressed as the formula (11), l_1, l_2, l_3 are given step size.

$$\begin{aligned} \Delta f_k &\approx \sum_{i=1}^{3} l_i \left(\frac{df_k}{dx_1} \Big/ \frac{df_i}{dx_1} \right)^{-1} + \sum_{i=1}^{3} l_i \left(\frac{df_k}{dx_2} \Big/ \frac{df_i}{dx_2} \right)^{-1} + \sum_{i=1}^{3} l_i \left(\frac{df_k}{dx_3} \Big/ \frac{df_i}{dx_3} \right)^{-1} + \sum_{i=1}^{3} l_i \left(\frac{df_k}{dx_4} \Big/ \frac{df_i}{dx_4} \right) \\ &\approx l_1 \sum_{i=1}^{4} \left(\frac{df_k}{dx_i} \Big/ \frac{df_1}{dx_i} \right)^{-1} + l_2 \sum_{i=1}^{4} \left(\frac{df_k}{dx_i} \Big/ \frac{df_2}{dx_i} \right)^{-1} + l_3 \sum_{i=1}^{4} \left(\frac{df_k}{dx_i} \Big/ \frac{df_3}{dx_i} \right)^{-1} i = 1,2,3,4 \qquad k = 1,2,3 \end{aligned} \tag{11}$$

If $\Delta f_1(X), \Delta f_2(X), \Delta f_3(X),$ is known to satisfy the condition of $\Delta X = (\Delta x_1, \Delta x_2, \Delta x_3, \Delta x_4)$.

Then it can be combined with the formula (12) to get a linear equation group, and a set of vectors l_1, l_2, l_3 is obtained. 1

$$\Delta x_i = l_1 \frac{df_1}{dx_i} + l_2 \frac{df_2}{dx_i} + l_3 \frac{df_3}{dx_i} \tag{12}$$

$$\begin{cases} \Delta f_1 \approx l_1 \sum_{i=1}^{4} \left(\frac{df_1}{dx_i} \Big/ \frac{df_1}{dx_i} \right)^{-1} + l_2 \sum_{i=1}^{4} \left(\frac{df_1}{dx_i} \Big/ \frac{df_2}{dx_i} \right)^{-1} + l_3 \sum_{i=1}^{4} \left(\frac{df_1}{dx_i} \Big/ \frac{df_3}{dx_i} \right)^{-1} \\ \Delta f_2 \approx l_1 \sum_{i=1}^{4} \left(\frac{df_2}{dx_i} \Big/ \frac{df_1}{dx_i} \right)^{-1} + l_2 \sum_{i=1}^{4} \left(\frac{df_2}{dx_i} \Big/ \frac{df_2}{dx_i} \right)^{-1} + l_3 \sum_{i=1}^{4} \left(\frac{df_2}{dx_i} \Big/ \frac{df_3}{dx_i} \right)^{-1} \\ \Delta f_3 \approx l_1 \sum_{i=1}^{4} \left(\frac{df_3}{dx_i} \Big/ \frac{df_1}{dx_i} \right)^{-1} + l_2 \sum_{i=1}^{4} \left(\frac{df_3}{dx_i} \Big/ \frac{df_2}{dx_i} \right)^{-1} + l_3 \sum_{i=1}^{4} \left(\frac{df_3}{dx_i} \Big/ \frac{df_3}{dx_i} \right)^{-1} \end{cases} \tag{13}$$

Bring l_1, l_2, l_3 calculated into formula (12), finally find out $\Delta x_1, \Delta x_2, \Delta x_3, \Delta x_4$, $i = 1,2,3,4$ (13).

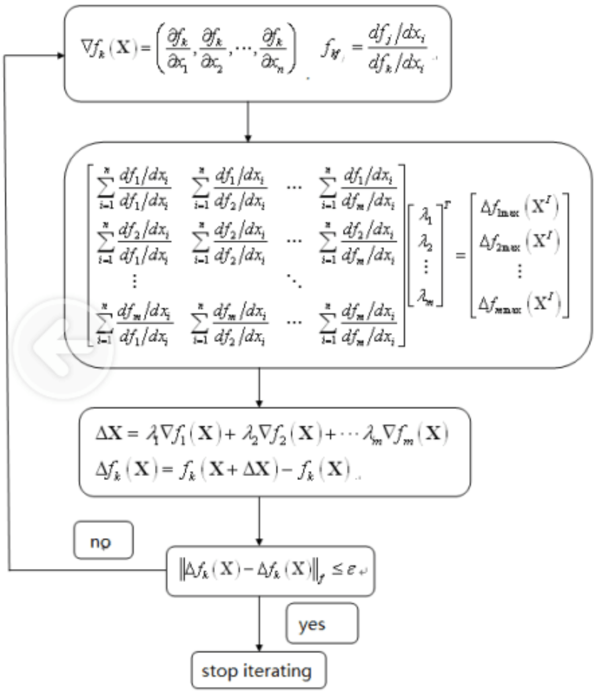

Fig1.Multi-objective optimization program flow chart

For m functions $f_1(\mathbf{X}), f_2(\mathbf{X}), \mathbf{L}, f_m(\mathbf{X})$ with n parameters $\mathbf{X}=(x_1, x_2, \mathbf{L}, x_n)$. If the deviation of the function Δf_k is regarded as a function $f_k(\mathbf{X})$.And it is the given value. The change of the interval parameter x_i is unknown. By using the above method, the Δx_i can be calculated.

Here, $(k=1,2,\mathbf{L},m)$, $(i=1,2,\mathbf{L},n)$.

Because the calculation problem of multi-objective optimization in engineering is very complicated, so it is difficult to calculate only one step to get the optimal solution. Therefore, this paper proposes to use this optimization method, The deviation of the actual value and the target value is divided into several sections. Calculate Step by step. Specific steps are as follows:

Step 1: Set a minimum value Δx, the sensitivity of the differential calculation function is

$$df_k/dx_i = \frac{f_k(x_1, x_2, \mathbf{L}, x_i+\Delta x, \mathbf{L}, x_n) - f_k(X)}{\Delta x} \tag{14}$$

Step two: Calculation

$$\frac{df_j/dx_i}{df_k/dx_i} \quad k, j=1,2,\mathbf{L}m \quad i=1,2,\mathbf{L},n \tag{15}$$

Step three: Using the following equations to solve the $l_1, l_2, \mathbf{L}, l_m$

$$\begin{bmatrix} \sum_{i=1}^{n}\frac{df_1/dx_i}{df_1/dx_i} & \sum_{i=1}^{n}\frac{df_1/dx_i}{df_2/dx_i} & \cdots & \sum_{i=1}^{n}\frac{df_1/dx_i}{df_m/dx_i} \\ \sum_{i=1}^{n}\frac{df_2/dx_i}{df_1/dx_i} & \sum_{i=1}^{n}\frac{df_2/dx_i}{df_2/dx_i} & \cdots & \sum_{i=1}^{n}\frac{df_2/dx_i}{df_m/dx_i} \\ \vdots & & \ddots & \\ \sum_{i=1}^{n}\frac{df_m/dx_i}{df_1/dx_i} & \sum_{i=1}^{n}\frac{df_m/dx_i}{df_2/dx_i} & \cdots & \sum_{i=1}^{n}\frac{df_m/dx_i}{df_m/dx_i} \end{bmatrix} \cdot \begin{bmatrix} l_1 \\ l_2 \\ \vdots \\ l_m \end{bmatrix}^T = \begin{bmatrix} \Delta f_1(\mathbf{X}) \\ \Delta f_2(\mathbf{X}) \\ \vdots \\ \Delta f_m(\mathbf{X}) \end{bmatrix} \tag{16}$$

Step four:

$$\Delta x_i = l_1\frac{df_1}{dx_i} + l_2\frac{df_2}{dx_i} + l_3\frac{df_3}{dx_i} \tag{17}$$

Step five:

$$\Delta f_k(\mathbf{X}) = f_k(\mathbf{X}+\Delta\mathbf{X}) - f_k(\mathbf{X}) \tag{18}$$

If $\left\|\Delta f_k(\mathbf{X}) - \Delta f_{k\max}(\mathbf{X})\right\|_f \le e$, stop calculation. Otherwise,

$$df_k/dx_i = \frac{f_k(x_1, x_2, \ldots, x_i + \Delta x_i + \Delta x, \ldots, x_n) - f_k(X)}{\Delta x} \tag{19}$$

Back to step two. Here e is a given threshold.

An example

Positive collision chest pressure test of a new FEM dummy as an example, the model is shown in figure 2. Reference the chest calibration method in CNCAP procedures of the trial and the United States National Highway Safety Administration regulations issued by the CFR Part NHTSA 572 [11-12]. A simplified positive impact test is established in this paper. To build a simplified seat model and place the finite element model of the dummy. 70mmx90mm rectangular pendulum, which quality is 10kg, is established in the central location of dummy's chest, impacted dummy FE model at the speed of 5.77 m/s, calculated by the software of LS-DYNA, view dummy's chest pressure curve. Calculated chest pressure curve is shown in Figure 4. Among them, K1 is a straight segment between the initial value and the peak value in this curve. Approximate calculated down slope of K1. Calculate K2 by the same way. The straight segment between the peak and the end of the thoracic pressure curve was extracted. To calculate the approximate rebound slope K2. Dmax indicates the peak value of the thoracic pressure curve. The initial value of the thoracic pressure curve is shown in Table 1 and figure 3.

Select a stress-strain curve of dummy chest material, as shown in figure 4. Will parameter curve is decomposed into four segments, there are eight characteristic parameters which reflect the characteristic of the parametric curve, the slope of the line AB, BC, CD and DE are respected with m1, m2, m3, m4, each line segment in the X axis projection respectively for n1, n2, n3, n4, each parameter initial value is shown in Table 2. The slope and peak pressure of the curve are optimizated using these eight parameters.

Design parameters: $m_1, m_2, m_3, m_4, n_1, n_2, n_3, n_4$

design target:

1. Peak chest pressure D_{max} is 30mm.
2. The descending slope K_1 and rising slope K_2 of the thoracic pressure curve.

$$D_{\max}(m_1, m_2, m_3, m_4, n_1, n_2, n_3, n_4) = 30 \tag{20}$$

$$K_1(m_1, m_2, m_3, m_4, n_1, n_2, n_3, n_4) = -2.5 \quad (21)$$

$$K_2(m_1, m_2, m_3, m_4, n_1, n_2, n_3, n_4) = 2 \quad (22)$$

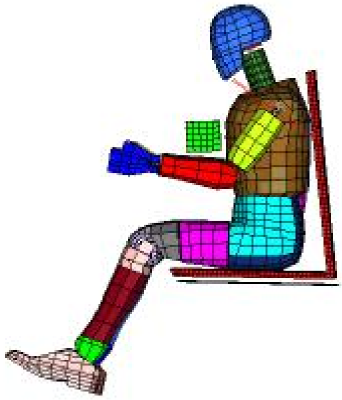

Fig.2positive collision chest pressure test

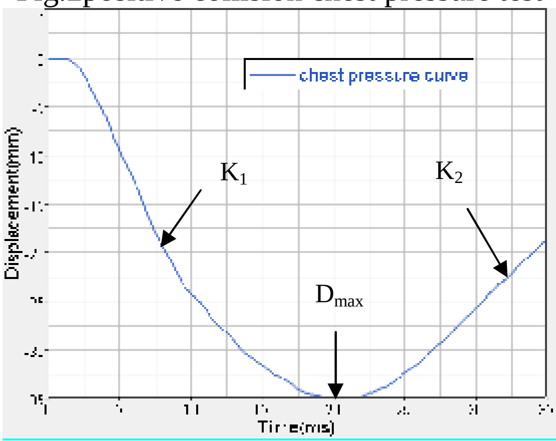

Fig.3positive collision chest pressure curve before optimization

Table 1 chest pressure curve evaluation before optimization

evaluating indicator	D_{max} /mm	K_1	K_2
Value	35.110	-3.311	1.169

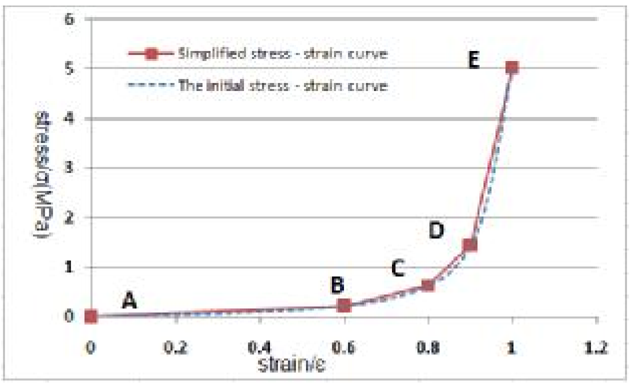

Fig.4 material parameter curve before optimization

Table 2characteristic parameter value before optimization

Parameter	m_1	m_2	m_3	m_4	n_1	n_2	n_3	n_4
Value	0.367	2.025	8.03	35.72	0.6	0.2	0.1	0.1

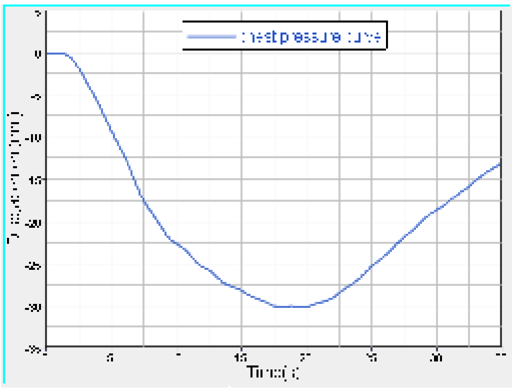

Fig.5 optimized positive collision chest pressure curve

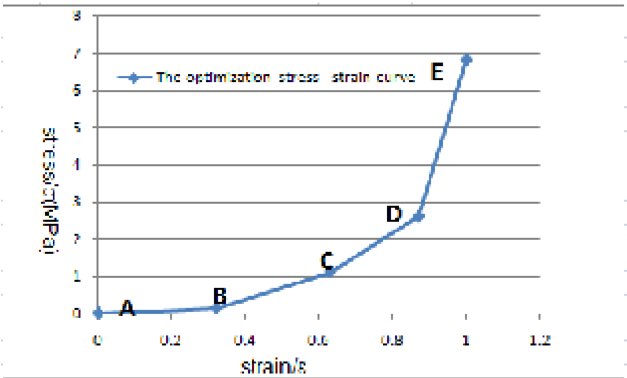

Fig.6 material parameter curve after optimization

Table 3optimized characteristic parameter value

Parameter	m_1	m_2	m_3	m_4	n_1	n_2	n_3	n_4
Value	0.432	3.175	6.132	32.432	0.32	0.31	0.24	0.13

Table 4 chest pressure curve evaluation after optimization

Evaluating indicator	D_{max} /mm	K_1	K_2
Value	30.08	-2.505	2.105

In this example, the curve optimization method is introduced in this paper. The optimization was carried out according to the optimized target value. Finally get the optimal solution, as shown in Figure 5 and table 3. The stress-strain curve after optimization is shown in Figure 6. The main characteristic values of stress-strain curves are shown in Table 4. From the optimization results, the optimal solution is very close to the design goal, which shows that the method can meet the requirements of optimization.

Conclusions

Based on full-size vehicle collision test, a new FEM dummy was built in this paper. And let these parameters represent the main features of the curve. The optimization problem of complex curve is transformed into a multi parameter and multi objective optimization problem. At the same time, the multi-objective optimization problem is linear piecewise, which makes the problem easier to calculate. In the optimization design of the result curve during independent research and development FEM Dummy, this method is very important. The method is further verified in the example. In summary, the optimization design method can be used for study on optimization of experimental curve based on full-size vehicle collision test.

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