Parametric Design and Mechanical Analysis of Beams based on SINOVATION

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Abstract. In engineering practice, engineer needs to carry out complicated calculation when the loads on the beam are complex. The processes of analysis and calculation take a lot of time and the results are unreliable. So VS2005 and ADK are used to develop a software for beams design based on the 3D CAD software SINOVATION with C++ programming language. The software can realize the mechanical analysis and parameterized design of various types of beams and output the report of design in HTML format. Efficiency and reliability of design of beams are improved.

1. Introduction
Beam structure is a common component in engineering structure, such as the beam of the crane, the lathe spindle, etc, which can be simplified as a beam structure. To analyze the design of beams under external load, such as, shear force, bending moment, deflection, rotation, bending stress, bending shear stress, torsional shear stress and tensile stress etc, large amount of calculations are needed. For these reasons, software systems are developed, for examples, Xu Y 2013, developed one parametric design system of crane girder based on UG [1]; LU J J. et al, developed a crane beam CAD system[2]. Fu K W. et al, developed a bridge parametric design and analysis system for main beam machine based on Pro/E [3]; Han Ling developed a bridge crane design system based on AutoCAD [4]. In this paper, a beam design software is developed based on SINOVATION, which can be used to analyze the mechanical properties of the beam under various loads in various forms, and the parametric design of the beam, the results of the analysis can be put forward in the form of report.

2. Mechanical Analysis of Statically Determinate Beam
In this paper, the parametric properties of the different beams are analyzed, for the the simply supported beam, cantilever beam, fixed end and movable hinge support beam and beams with two fixed ends, etc. A freely supported beam with three radial force is shown in fig. 1. In order to get the shear value at the point A of the beam, the superposition method is utilized. Firstly, the single shear value at A point, with a single load is calculated[5], then, the supposition shear value at A point, with supposition loads are calculated one by one, shear at A with all the individual load values are obtained, i.e. the actual shear A value. Similarly, at any position on the beam, the moment, angle, deflection, bending stress, bending shear stress, torsional shear stress and tensile stress value can be calculated.
The parametric calculation is simple, for the simply supported beam and the cantilever beam. Calculation of parameters of beams supported by a fixed end and movable hinge, or by two fixed ends, are complex. The following is one calculation example for beam deflection. As shown in fig. 2, the beam is supported by a fixed end and a movable hinge, the beam is under one uniform loading due to self-weight \( q \), at the same time, loaded by the radial force \( F_1 \), \( F_2 \), and the concentrated couple \( M_1 \) and \( M_2 \). The concentrated couple \( M_1 \) has the end distance of \( L_1 \), \( M_2 \) has the end distance of \( L_3 \). The radial force \( F_1 \) has the distance \( L_2 \), the radial force \( F_2 \) has the fixed distance \( L_4 \).

The calculation of the deflection of the beam with a distance of \( x \) from the fixed end is as follows.

When \( 0 \leq x < S \),

\[
\omega_1(x) = \frac{q x^2}{2AEI} \left( x^2 - S^2 + 6L4 \right) + \frac{q x^2}{48EI} \left( S^2 - 4L4 + 6L4 \right) \left( 3S - x \right) 
\]

(1)

When \( S \leq x \leq L \),

\[
\omega_2(x) = -\frac{q x^2}{2AEI} \left( S^2 - 4L4 + 6L4 \right) + \frac{q S}{8EI} \left( S^2 - 4L4 + 6L4 \right) \left( \frac{x}{2} - \frac{S}{6} \right) 
\]

(2)

When \( 0 \leq x < L_2 \),

\[
\omega_3(x) = \frac{F_1 x^2}{6EI} \left[ \frac{L_2^2}{2S^2} \left( 3S - L_2 \right) \left( 3S - x \right) - 3L_2 + x \right] 
\]

(3)

When \( L_2 \leq x < S \),

\[
\omega_4(x) = \frac{F_1 L_2^2}{12EI} \left[ \frac{x^2}{2S^2} \left( 3S - L_2 \right) \left( 3S - x \right) + 2L_2 - 6x \right] 
\]

(4)

When \( S \leq x \leq L \),

\[
\omega_5(x) = \frac{F_1 L_2^2}{4EI} \left( 3S - L_2 \right) \left( 3S - x \right) - 3S + x 
\]

(5)

When \( 0 \leq x < S \),

\[
\omega_6(x) = \frac{F_1 x^2}{12EI} \left[ \frac{3L_4 - S}{S} \left( 3S - x \right) - 6L_4 + 2x \right] 
\]

(6)

When \( S \leq x < L_4 \),

\[
\omega_7(x) = \frac{F_1 x^2}{12EI} \left[ 3L_4 - S \left( 3S - x \right) - 2x \right] 
\]

(7)

When \( L_4 \leq x \leq L \),

\[
\omega_8(x) = \frac{F_1 L_2^2}{12EI} \left[ 3L_4 - S \left( 3S - x \right) + 2L_2^2 - 6L_4^2 \right] 
\]

(8)
\[ \omega_x(x) = \frac{M_1 x^2}{AEI} \left[ \frac{L_1}{S^3} (2S - L_1)(3S - x) - 2 \right] \]  

When \( L_1 \leq x < S \),  
\[ \omega_y(x) = \frac{M_1 x}{AEI} \left[ \frac{x^3}{S^3} (2S - L_1)(3S - x) - 4x + 2L_1 \right] \]  

When \( S \leq x \leq L \),  
\[ \omega_z(x) = \frac{M_1 L_1}{AEI} \left[ \frac{3}{S^3} (2S - L_1)(x - S) + 4(x - S) \right] \]  

When \( 0 \leq x < S \),  
\[ \omega_{x2}(x) = \frac{M_2 x^2}{AEI} \left( S - x \right) \]  

When \( S \leq x < L_3 \),  
\[ \omega_{x3}(x) = \frac{M_2 (S - 2x)(x - S)}{AEI} \]  

When \( L_3 \leq x \leq L \),  
\[ \omega_{x4}(x) = \frac{M_2 L_3}{AEI} \left[ \frac{S (3x - S)}{3} + 2L_3 (L_3 - 2x) \right] \]  

The calculation of the deflection of the beam with a distance of \( x \) from the fixed end is as the follows.  
\[ \omega(x) = \omega_x(x) + \omega_y(x) + \omega_{x2}(x) + \omega_{x3}(x) + \omega_{x4}(x) \]  

As shown in figure 3, the beam is supported by two fixed ends, the beam is under one uniform loading due to self-weight \( q \), at the same time, loaded by the radial force \( F_1, F_2 \), and the concentrated couple \( M_1 \) and \( M_2 \). The concentrated couple \( M_1 \) has the end distance of \( L_1 \), \( M_2 \) has the end distance of \( L_3 \). The radial force \( F_1 \) has the distance \( L_2 \), the radial force \( F_2 \) has the fixed distance \( L_4 \). The calculation process of the deflection from the left distance for \( x \) cross section values on the beam are as follows. The length of the beam is \( L \), the elastic modulus of the beam is \( E \), and the moment of inertia of the cross section to the \( Z \) axis is \( I \), and the deflection value of the uniformly distributed load \( Q \). The deflection of the beam caused by radial force: The radial force causes the deflection of the beam to be similar, The deflection of beams caused by the concentrated couple. Concentrated couple caused by beam deflection and beam deflection is similar. From the left distance for \( x \) section is as the follows. Other parameters, such as shear force, bending moment, rotation angle, bending normal stress, bending shear stress, tensile normal stress and torsional shear stress, are similar to those calculated by deflection method, superposition addition are utilized.

2.1 Software Development.

Development platform and tools: The beam design software module is developed, which are embedded in the domestic CAD software SINOVATION in the form of DLLs (Dynamic Link Libraries). The programs are based on the SINOVATION ADKs and Visual Studio 2005, C++ platform [6]. SINOVATION is a three-dimensional CAD application software system, with advanced hybrid modeling, parametric design, rich feature modeling function, is the Alex Hua Tian software in the country’s support and cooperation with foreign companies [7]. API(Application Program Interface).

ADK is the development kit provided by SHANDDA Hua Tian software co, in the form of API(Application Program Interface).

2.2 Software Interface Design.
Tab Control, Picture Control, Group Box, List Control, Button, Edit Control, Combo Box, Radio Button and Static Text in the MFC (Microsoft Foundation Classes) are utilized in this software. The design parameters are put in the design parameter interfaces of the beam, the supporting parameters and the load parameters are shown in fig. 4.

![Figure 4. “parameter” interface](image)

![Figure 5. The calculation results](image)

The type of beam section are categorized as circle, ring, square, hollow square, rectangle, hollow rectangle, hexagon, triangle, trapezoid, work shape, L shape and C shapes etc. After Modification of the section size of the beam sections, the corresponding area, moment of inertia and the coefficient of cross section will automatically be changed; After modification of the support type and support distance, the top icon of the supporting types are also automatically changed; Adding or removing of the load/load from, and changing of the load distances, etc, the corresponding icon will also be changed. In the design process of the software interfaces, one functionality need to be developed in the List Control, i.e. When the left mouse button clicked, a drop-down box appeared. For example, the section types are displayed and could be selected in the design parameter interface, when the left mouse button is clicked. Because List Control itself does not have such this function, so, NM_CLICK is utilized in the List Control messages. The "calculation results" page is shown in Fig. 5.

There is a red solid line in upper part of the software "calculation results" page, and the location of the vertical coordinate and the parameter value is shown in the bottom part of the page below Edit Control. When the mouse slides on the parameter graph, a solid red vertical line will move with the mouse, the vertical coordinate parameter in the Edit Control and the corresponding parameters will be changed simultaneously. Select a different button or select different parameters, such as the XY plane, XZ plane, the results of the calculation page will show different parameters. The elastic modulus and density of the beam are changed by selecting different materials, the material in the drop-down box including plain carbon steel, cast steel, nickel steel, stainless steel, gray cast iron, cast iron can be broken, copper, aluminum, magnesium alloy and custom materials.

2.3 Parameter graph drawing.
In the "results" page of the software, the algorithm flow chart of parameter drawing is shown in Fig. 6. The maximum parameter values of the parameters are firstly calculated, each pixel value corresponding to the logical unit is then calculated, lastly a line is drawn from the left most beam to the current point, \((d_x, * \text{the parameter value line})\). With the increase of \(d_x\), the line segments are drawn in turn until the right end of the beam, finally, all the segments are combined to form the parameter graph. By using the OnMouseMove message dialog box, the red line moves with the mouse function in the “calculation results” in the parameter map.

The flow chart of this function is shown in fig. 7. The RECT in the client area of the Picture control is obtained and is saved in the variable rc, rc is then mapped to the dialog box coordinates, Then determine whether the current mouse coordinates are in the variable rc, if they are in in the variable rc, then a red line is drawn in the parameter map in the mouse location, if not, the procedure ended. drawing in the calculation result page

2.4 Parametric design of beam.
The type of the beam and the size of the profile are selected in the "design parameter" page of the software. Click on the "create" button to create a three-dimensional model of the beam directly. The parametric design of beam is realized, the modeling process of beam is to draw the beam profile, the three-dimensional model of the beam can be obtained by pulling the model section.
2.5 The output report.
There is a "output report" button in the lower part of the "calculation result" page of the software. Click this button, a hybrid report with text, tables, pictures and other forms of HTML etc, will be automatically created and is opened. The report contains the creation time of the report, the creator, the criteria used, the current design parameters, and the results of the calculations etc. Algorithm flow of the output report is as the follows, firstly a folder is created, a HTML file is then created, and is saved in the same fold. And then the design of the beam and the results of the calculation of all the parameters are stored in the folder, All design parameters and calculation results are saved in a CString variable str, Finally, the contents in the str into a good HTML file, after the report was created, use the Web browser to open the report. The HTML report created by the software is shown in Fig. 10.

3. Application cases
The size of a lathe spindle and the force diagram is shown in fig. 8, The spindle is supported by A, B, C three supports, under normal circumstances, B support does not work, Only when the bending deformation of the main shaft B is greater than the clearance between the main shaft and the B support, the B support can play a supporting role.

The helical gear driven by the main shaft of E is subjected to external force. F=396N, =860N.
Cutting force at the cutting edge of position H, indirectly make the lathe spindle under a concentrated force couple at D position. Where, \( M_{D_2} = 432N\cdot m \), \( M_{D_2} = 810N\cdot m \), and, \( l_1 = 0.18m \), \( l_2 = 0.55m \), \( l_2 = 0.17m \), \( a = 0.15m \), \( b = 0.18m \).It is known that the cross section of lathe spindle is hollow, the outer radius of the cross section is 70mm, inner radius is 50 mm, the shaft material is 45 # cast steel.

The following calculation is to find the dangerous section of spindle, and calculate the bending deformation of the B section of the spindle. The above design parameters are input to the software design parameters page, Click the "calculate" button, The shear diagram, bending moment diagram, deflection diagram, deflection diagram, bending normal stress diagram and bending shear stress diagram are obtained. As shown in fig. 8, fig. 9, fig. 10. The shear diagram, bending moment diagram and deflection diagram of the lathe spindle are displayed.

Figure 6. Flow chart of parameter

Figure 7. Red line moving with mouse.

Figure 8. Shear diagram

Figure 9. Bending moment

Figure 10. Deflection diagram
4. Conclusions
In this paper, the beam supported by simply supported beam, cantilever beam, fixed end and movable hinge support and two fixed end supports are analyzed. Under multiple external loads, to get the shear force, bending moment, deflection, bending normal stress, shear stress, torsional shear stress etc. The parameter analysis and calculation schemes and software development are put forward. Based on SINOVATION software, Using VS2005 and ADK to develop the beam design software, The mechanical analysis and parametric design of the beam are realized, the design efficiency and reliability of the beam design are improved. The development method and development process used in this paper can provide reference for the other development of CAD systems.

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