Materials Research Proceedings 44 (2024) 558-568 https://doi.org/10.21741/9781644903254-60

A customized design tool incorporating web and client functions for new mechanical presses

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Keywords: Mechanical Press, CAD, Knowledge-Guided, Multi-Link System, Structural Consistency

Abstract. To improve the design efficiency and consistency of many new mechanical presses developed by a few engineers, an application with two tabs was proposed to incorporate a web browser and a client window, respectively, for the press modification and the new press design. The press modification is based on the standardized press data in server while the new press design adopts the functions of Computer-Aided Design (CAD) and Word processing tools in local computers. For the press modification: (1) a case retrieval function was developed to find similar features of standardized press information that was then adapted to meet the new custom order; (2) some structural parameters and component selections were adjusted and checked by the calculation algorithms and material properties; (3) within the browser tab, design document was eventually reported. For the new press design: (1) besides the BOM templates, two dimensional (2D) sketch templates were summarized for non-standard parts or assemblies including the machine frame, crank, links, slider, work-table, etc.; (2) the slider movement design and dimensional allocation of press components were performed according to a series of interactive dialogs, answers and views with regard to the custom order; (3) the dot net framework was adopted to integrate Solidworks, Auto CAD and Word functions to generate parts, assemblies, drawings and the Bill Of Materials (BOM) from the 2D sketch and BOM templates using the dimensional allocations and the design results. Examples validated the feasibility of the proposed tool.

Introduction

Mechanical presses play a crucial role in manufacturing the parts made by steel or aluminum alloys that are widely used in automotive, rail transit, household appliance, aircraft and aero-engine industries, accounting for 76% the global market amount of metal forming machines [1]. In response to various specific working scenarios, the customized designs of new presses are not uncommon. For a large number of design tasks, many problems restrict the rapid and accurate response of metal forming machine manufacturer, such as the growing human cost, high-strength workload, and the inevitable diversity of design results [2]. Especially, every design result needs to be confirmed to meet the custom order and structural safety. To deal with this challenge, it requires to normalize the custom design that uses the knowledge of standardized presses, and performs interactive designs and analyses, from which the parts, assemblies, drawings, and Bill of Materials (BOM) will be yielded.

Over decades, web applications are usually applied to database managements while desktop applications are able to perform the Computer-Aided Design / Engineering / Manufacturing (CAD / CAE / CAM). For example, Siemens team center product lifecycle management is good choice for one source of standardized mechanical press (parts, assemblies, drawings, and bill of materials) shared by all the designers within a company [3]. These standardized mechanical presses are cases that would be used for new customer orders. In many theoretical researches, the case-based reasoning methods, which separately adopt the case retrieval [4], case adaptation [5], or expert experience [6], are usually applied to find an appropriate case or adjust a case to meet the new plan requirement. For the customized design of a new mechanical press, some components of different standardized mechanical presses are selected, adjusted and assembled together; this is a complex case retrieval and adaptation using a series of standardized mechanical presses with many components because of the complexities of various hierarchical component features within a product; it is seldom solved either by the case retrieval or by the case adaptation. To combine both the case retrieval and adaptation of standardized mechanical presses with their components, the new hybrid feature weights with the weight mean of design parameters are proposed, which make true the press modification for the customized design.

Recently about 10 years after the concept of Industry 4.0 was introduced [7], and despite that the cloud-based finite element modeling was developed and open [8], this still is a time-consuming and error-prone procedure when the manufacturers use the remote database or a solver in a server far away to perform the design generating two more solutions for each customer. Hence the desktop application is effective for the design of a brand-new new press. For the design of a brand-new new press, the kinematics and dynamics of the crank, link and slider system are analyzed firstly, the dimensional allocation are then performed which support the component design and check using CAD and CAE tools, and finally the CAD tool [9] outputs the parts, assemblies, drawings and the Bill Of Materials (BOM) for the further manufacture and test. A rapid product design system based on 3D CAD that uses the part templates and BOM templates is proposed with the application to a vehicle steering gear [10]; this system is based on the secondary development technology, XML data interface technology, and parameterized component design technology, but the hierarchical component features are not addressed. A rule-based and feature-based approach is employed in 3D CAD modeling to create a parametric design platform with integrated evaluation features, which is able to automatically determine the dimensions of spherical joints, effectively boosting their design efficiency and safety [11]; so it would be more efficient if the hierarchical component features were handled in assembly templates. Recently, an explicit template is referred to internal structure of functional geometries, subtractions, combination operations, replication features, and the localized modifications would significantly improve the robustness and reusability of feature-based CAD models, particularly in response to changes [12]. In light of the above advances, the templates of the 2D part sketches and the axis and point assembly templates with explicit functions of subtractions, combination operations, replication features, and the localized modifications are proposed for new press design.

Methodology

A New Architecture Incorporating Web and Client Functions. As shown in Fig. 1, it is comprised of five lines. The top line is the functions of the press modification and new press design. The second line is the workflow having two operational directions. The first operational direction is to modify a press, which starts from case retrieval and adaptation, and then involves the modification, calculation, save and report. And the other one is to perform dimensional allocation, 3D modeling, save and report. The third line is the user interface made up of web view, window files, dialogs and views, which accommodates the workflow. The fourth line is the subroutine functions written in Vue, Oracle, Java Script, C++, C#, and dot Net Framework. The subroutine functions written in Java Script provide services for the case retrieval, case adaptation, press data revision, design calculations for press forces and the dimensions of press components, the selection of motors, clutch and brakes, and the report. The subroutine functions written in C++ provide the calculation algorithms in DLL files and the subroutine functions written in C# and dot Net Framework provide the service of dimensional allocation and 3D modeling. The fifth line is for the recourses embedded in some of the upper tool line or stored in Oracle database. The recourses embedded in tool line are the work flow of the design, the rules of case retrieval and adaptation, the calculation algorithms, the templates of BOM and sketches, and related API of Solidworks, auto CAD and

Word. The recourses stored in Oracle database comprise the standardized presses and components, material properties, and the user information.

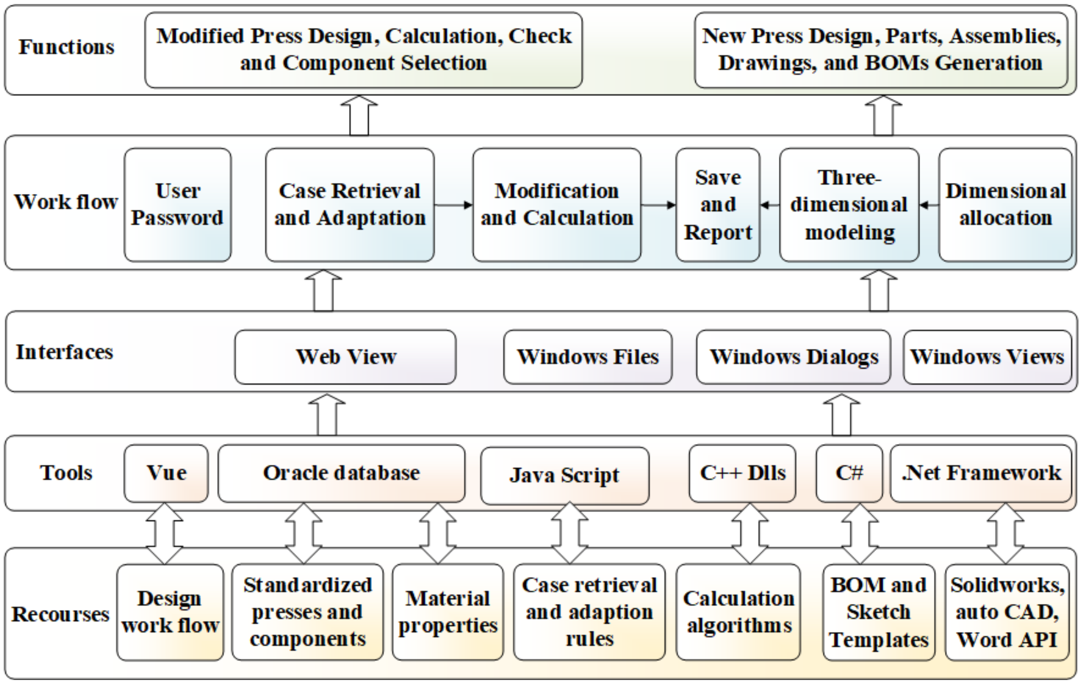


Fig. 1. The architecture with web and client functions.

For the top two functions, the press modification is based on the Oracle database in server while the new press design adopts the functions of Computer-Aided Design (CAD) and Word processing tools and 2D sketch templates in local computers. The novelty of this new architecture lies in the case retrieval and adaptation as well as the parametric assembly design of mechanical presses from the templates. This is due to the factors that the calculation algorithms and BOM templates can be found in any textbook or obtained from the experience summarized by any press manufacturer.

Case Retrieval and Adaptation of Standardized Mechanical Presses. Each case is represented as a vector containing m question and n solution attributes, thus the cases can be represented as Eq. 1.

$$\mathbf{C}_k = \left\{p_{k1},\ p_{k2},\ ...,\ p_{ki},\ ...,p_{km},\ s_{k1},\ s_{k2},\ ...,\ s_{kj}\ ...,\ s_{kn}\right\}\ \ 1 \le i \le m;\ 1 \le j \le n \quad (1)$$

where $\mathbf{C}_k$ is the k-th case, p_{ki} is the i-th problem attribute, s_{kj} is the j-th solution.

Let $\mathbf{C}_0$ be the vector of a new case, thus its vector of question attributes is $\{p_{01}, p_{02}, \dots, p_{0i}, \dots, p_{0m}\}$. According to Eq.1, a series of similarities can be calculated by the comparison between the new case question attributes $\{p_{01}, p_{02}, \dots, p_{0i}, \dots, p_{0m}\}$ and one of $\mathbf{C}_k$, i.e., Eq. 2.

$$sim_i = \sum_{j=1}^{m}\left[1-\left|q_{ij} - p_{0i}\right|\right] \times w_{\mathrm{h}j} \Big/ \sum_{j=1}^{n} w_{\mathrm{h}j}\ , \quad (2)$$

where sim_i is the similarity that take a higher value to demonstrate a higher similarity, p_{0j} is the new problem attributes, q_{ij} that satisfies Eq. 3 is the element of the normalized problem matrix $(q_{ij})_{k\times m}$, and $w_{\mathrm{h}j}$ of is the element of the proposed hybrid weight matrix $(w_{\mathrm{h}i})_{k\times m}$.

$$q_{ij} = p_{ij} \Big/ \sum_{i=1}^{m} p_{ij} \quad , \tag{3}$$

where p_{ij} is the problem attributes in Eq. 1.

Element $w_{\mathrm{h}j}$ combines both the subjective and objective weights, i.e., $w_{\mathrm{s}j}$ and $w_{\mathrm{o}j}$, is obtained by the optimization in form of Eq. 4.

$$\begin{aligned} &\min \ \sum_{i=1}^{m}\sum_{j=1}^{n}\left[\left(w_{\mathrm{h}j}-w_{\mathrm{s}j}\right)p_{ij}\right]^2+\sum_{i=1}^{m}\sum_{j=1}^{n}\left[\left(w_{\mathrm{h}j}-w_{\mathrm{o}j}\right)p_{ij}\right]^2 \\ &\text{s.t.} \ \sum_{j=1}^{n} w_{\mathrm{h}j}=1, \ w_{\mathrm{h}j}\geq 0. \end{aligned} \tag{4}$$

As shown in Eq. 5, element $w_{\mathrm{s}j}$ in $(w_{\mathrm{s}i})_{k\times m}$ is generated from the judgment matrix $(\alpha_{ij})_{k\times m}$ defined by experts according to the analytic hierarchy process (AHP) [13].

$$w_{\mathrm{s}j} = \overline{w_{\mathrm{s}j}} \Big/ \sum_{j=1}^{n} \sqrt[n]{\prod_{j=1}^{n} \alpha_{ij}} \quad , \tag{5}$$

where n is the number of features, $w_{\mathrm{s}j}$ is the j-th weight of features, α_{ij} represents the importance of criterion i compared to criterion j, $\alpha_{ij} > 0$, $\alpha_{ii} = 1$, and $\alpha_{ij} = 1 / \alpha_{ji}$.

As shown in Eq. 6, element $w_{\mathrm{o}j}$ in $(w_{\mathrm{o}i})_{k\times m}$ is yielded from the entropy method [14] and the normalized problem matrix $(q_{ij})_{k\times m}$.

$$w_{\mathrm{o}j} = \left(1+\frac{1}{\ln m}\sum_{j=1}^{m} q_{ij}\ln q_{ij}\right) \Big/ \sum_{j=1}^{m}\left(1+\frac{1}{\ln m}\sum_{j=1}^{m} q_{ij}\ln q_{ij}\right) . \tag{6}$$

According to Eq. 2, a number of top-ranked cases would be selected for the case adaptation. Without lose generality, k top-ranked cases are selected and denoted by the superscript in form of Eq. 7.

$$\mathbf{C}_s = \left\{p_{s1}^{(1)},\ p_{s2}^{(1)},\ ...,\ p_{si}^{(1)},\ ...,p_{sm}^{(1)},\ s_{s1}^{(1)},\ s_{s2}^{(1)},\ ...,\ s_{sj}^{(1)}\ ...,\ s_{sn}^{(1)}\right\} \ \ 1\leq i\leq m;\ 1\leq j\leq n \quad . \tag{7}$$

As shown in Eq. 8, a hybrid weighted mean w_{kj} is proposed to covers similar case problems p_i, the utility of each candidate case u_i, the gray relationship between each candidate case problem and solution r, and the feature adaptability of each case solution $a(C_{k,j}^{sol})$.

$$w_{kj} = a_{kj}\times\sum_{i=1}^{m} p_{ki}\times\left(\sum_{s=1}^{s}\frac{u_i}{\sum_{i=1}^{k} u_i} r\left(\frac{p_{si}^{(1)}}{p_{1i}^{(1)}},\frac{s_{sj}^{(1)}}{s_{1j}^{(1)}}\right)\right) . \tag{8}$$

Specifically, r is the coefficient of the gray relationship between similar problem $p_{\mathrm{s}i}^{(1)}/p_{1i}^{(1)}$ and solution $s_{\mathrm{s}j}^{(1)}/s_{1j}^{(1)}$,

$$u_i = \sum_{j=1}^{m} w_{hi} p_{si}^{(1)}, \tag{9}$$

$$a(C_{k,j}^{sol}) = w^S sim(case^P, case^C) + w^A a(f_p), \tag{10}$$

where w^S and w^A represent the weights that are both set to 0.5.

The solution to the new case $\mathbf{C}_0$ is adapted by the hybrid weighted mean and the k similar cases as shown in Eq. 11, which would be efficient and effective for the customized press design with a little modification compared to standardized presses.

$$s_{0j} = \sum_{j=1}^{n} w_{kj} s_{kj}^{(1)}. \tag{11}$$

Once the similar press is found and modified, the calculation algorithms will check whether the press modification is acceptable or not. If it is acceptable, it will be able to be saved and written in a report. Otherwise, calculation algorithms will provide some recommendation of improvement. In brief, Fig. 2 is the flowchart for the above procedure.

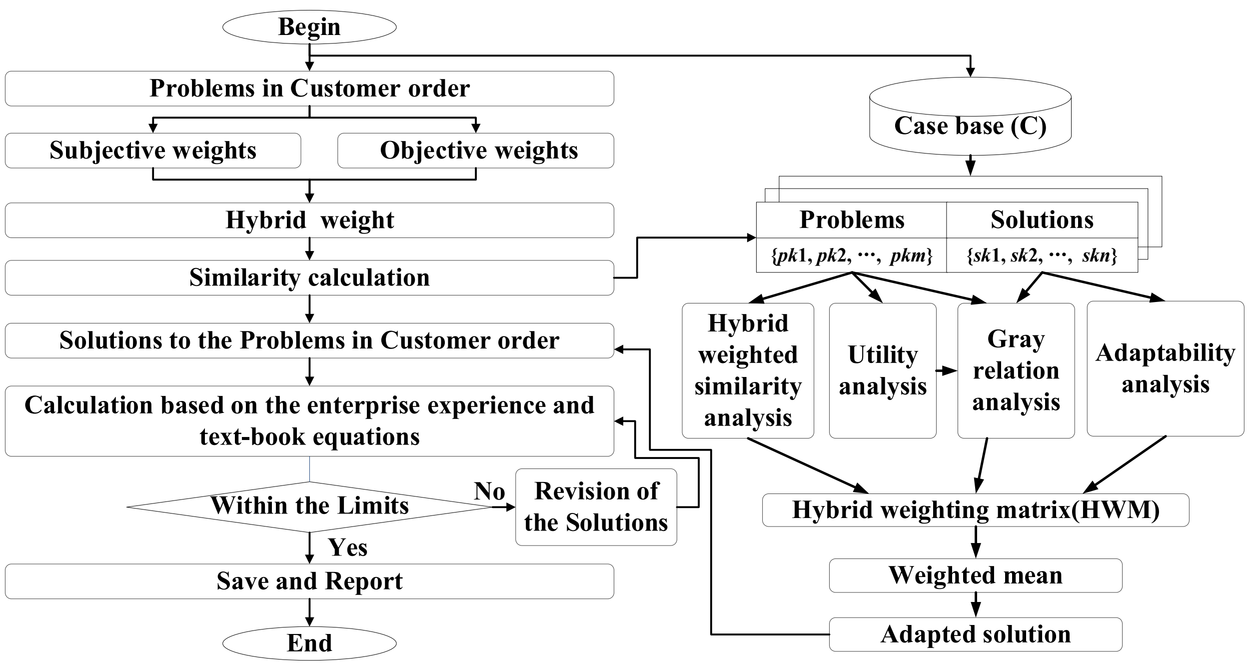


Fig. 2. Press Modification based on the Case Retrieval and Adaptation.

Parametric Assembly Design of Mechanical Presses from the Templates of Modeling. A set of parameters in 2D sketch templates are revised according to the dimensional allocation yielded from the kinematic analysis of multi-links that represent the dimension of crank, link, slider and wheel. Some points and axis in these 2D sketch templates that are never changed are defined especially for the location of parts in the assembly. On one hand, subroutine functions written in C# and dot Net Framework copy the 2D sketch templates in software template directory to a new part in working directory, and use the parameters in the result of dimensional allocation to generate all the features of a part in form of the shaft, link, slider, wheel, work-table, etc. On the other hand, the unchanged axis and points in the 2D sketches of the generated shaft, link, slider, wheel or work-table are helpful to locate the related parts with respect to the assembly platform. By combining the two folds, the press assembly would be able to obtained and save to a series of files

Materials Research Proceedings 44 (2024) 558-568 https://doi.org/10.21741/9781644903254-60

as well as the 2D drawing and BOMs. In a nutshell, the proposed parametric assembly design methodology of mechanical presses from the templates is summarized in Fig. 3.

In addition, Fig. 3 shows that the assembly would be able to be saved as STEP files that could be meshed and applied to related stress analysis, supporting a comprehensive structural validation before the production using the 2D drawings and BOMs.

Examples

The Customized Design Tool of New Mechanical Presses. According to the methodology, the customized design tool is developed as shown in Fig. 4. This design tool is an application with two tabs that incorporate a web browser (Fig. 4a) and a client window (Fig. 4b), respectively, for the press modification and the new press design.

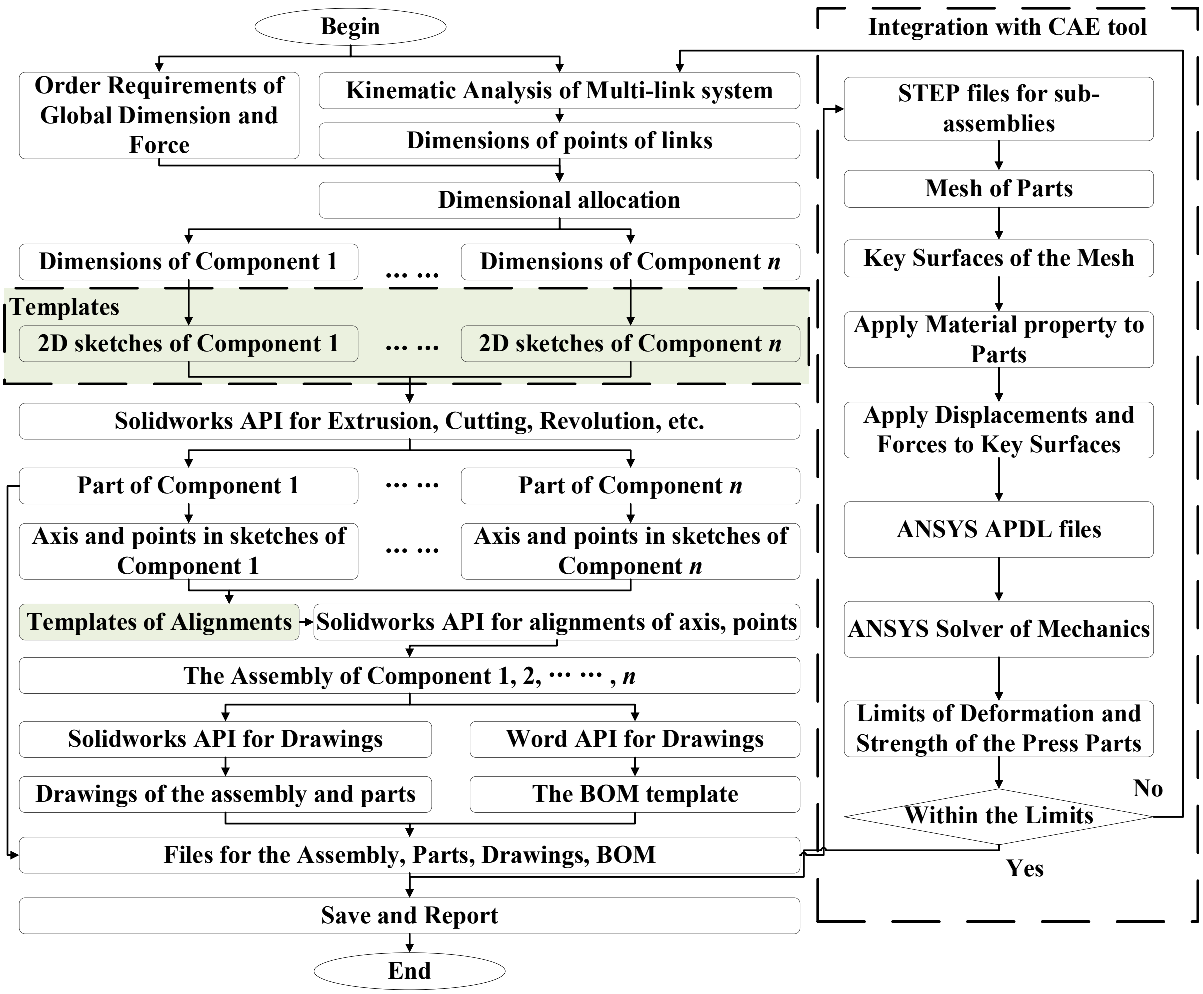
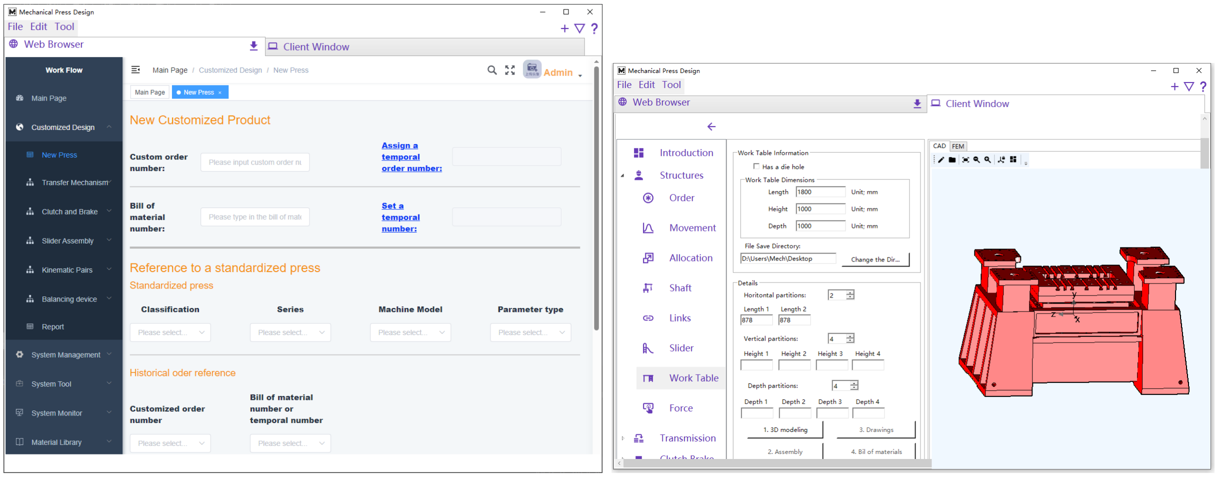


Fig. 3. The parametric assembly design methodology of presses from the templates.



(a) the web browser tab (b) the client window tab

Fig. 4. The web browser tab and client window tab of the proposed application.

The web browser is for the press modification. Especially the client window is not visible until the authorized user enters the correct password. In the web browser, the user could perform the case retrieval and adaptation for all the components in the standardized mechanical presses stored in the server database. The left side of the web browser comprises the modification for components in transfer mechanism, clutch and brake, slider assembly as well as the kinematic pairs. The left side also provides the report function if the modification is validated by the calculations performed in the web browser and server. The report function outputs a PDF file of all the design information of the new press. The administrator could see the system management, tool and monitor in the left side, and some managers are able to add, delete and search data in the material library and standardized mechanical press library.

The client window is for the new press design. It comprises three views, i.e., the left tree view, the middle form view and the right graphic view. For each node in the left tree view, there is a form view in the middle view. In the middle form view, the user could input related parameters, and click confirm and start the functions in Fig. 2. If the functions in Fig. 2 generate the assembly, part or drawings, the model would be displayed in the right graphic view.

The following sections is two specific examples of press modification and design using the customized design tool.

The Knowledge-guided Press Modification. As shown in Fig. 5, the knowledge-guided press modification is illustrated by the modification of a crank shaft.

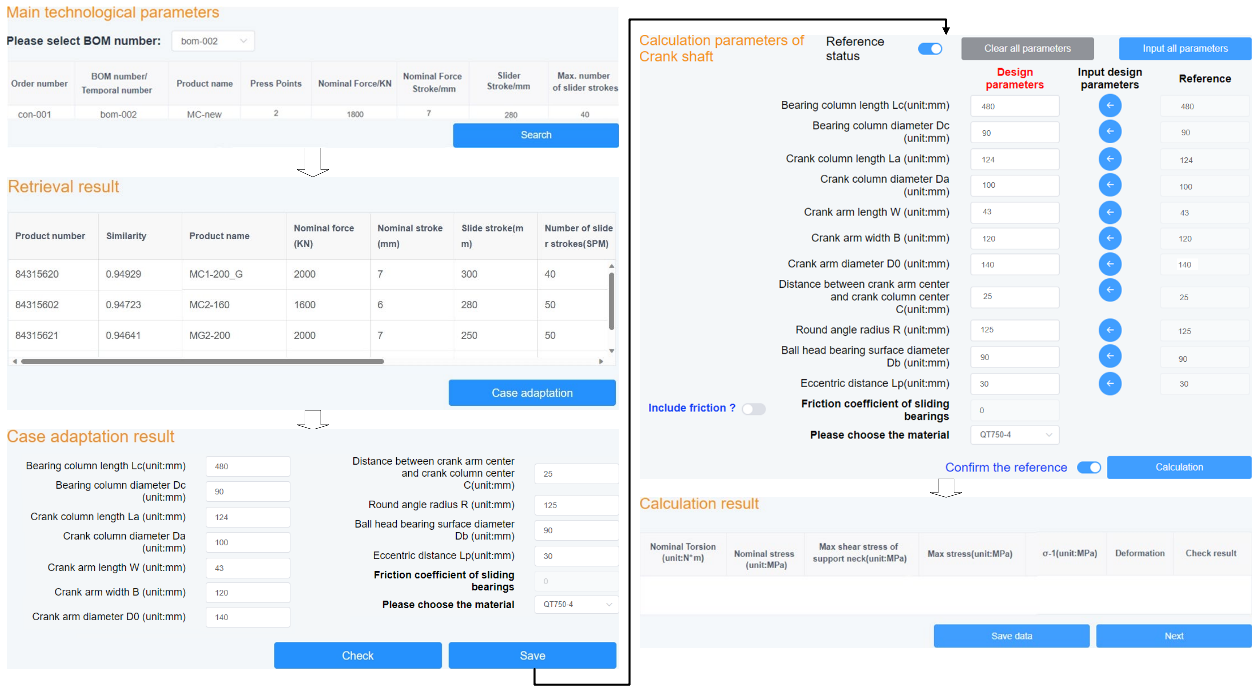


Fig. 5. Case retrieval, adaptation, calculation for a crank shaft of a customized press.

The top-left view in Fig. 5 is main technological parameters of a press required by a customer order, including press points, the nominal force, the stroke of nominal force, maximum number of slider strokes per minutes. When we click the button Search, the middle-left view is shown, and a set of similar cases are retrieved from the database of knowledge that contains many parameters of standardized presses. Then, if the button Case adaptation is clicked, the case adaptation result is shown as the bottom-left view. Then, as shown in top-right figure, if the button Input all parameters is clicked, all the adaptation result will be put into the textboxes of design parameters of the crank shaft. If we confirm the reference parameters and click the button Calculation, some equations of mechanics that are obtained from textbooks and experience of engineering practice will check the nominal torsion, stress and deformation, the result of which are listed in the bottom-right view of Fig. 5. Especially, the last column of Check result in the bottom-right view of Fig. 5 will show whether the new parameters of the crank shaft are acceptable or not.

The Template-driven New Multi-Link System Design. In this client window, a multi-link mechanism of six links is shown as example. In Fig. 6, a variation of eccentric wheel-link mechanism is calculated for the input coordinates of six points. After the length of crank shaft is allocated according to the length and width of the work-table required by the customer, the feature-based 3D modeling is performed for the crank shaft.

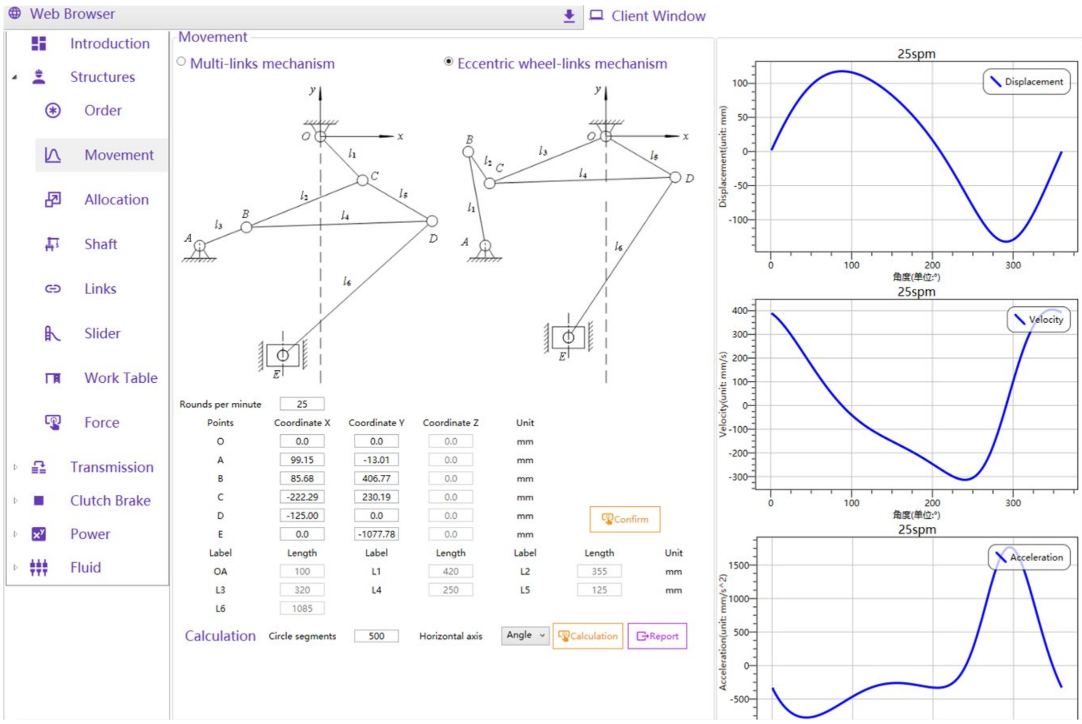


Fig. 6. Stroke curves of multi-link mechanism.

Fig. 7 shows the 3D modeling of the crank shaft starting from a series of 2D sketch templates by the modeling, assembly and drawing functions.

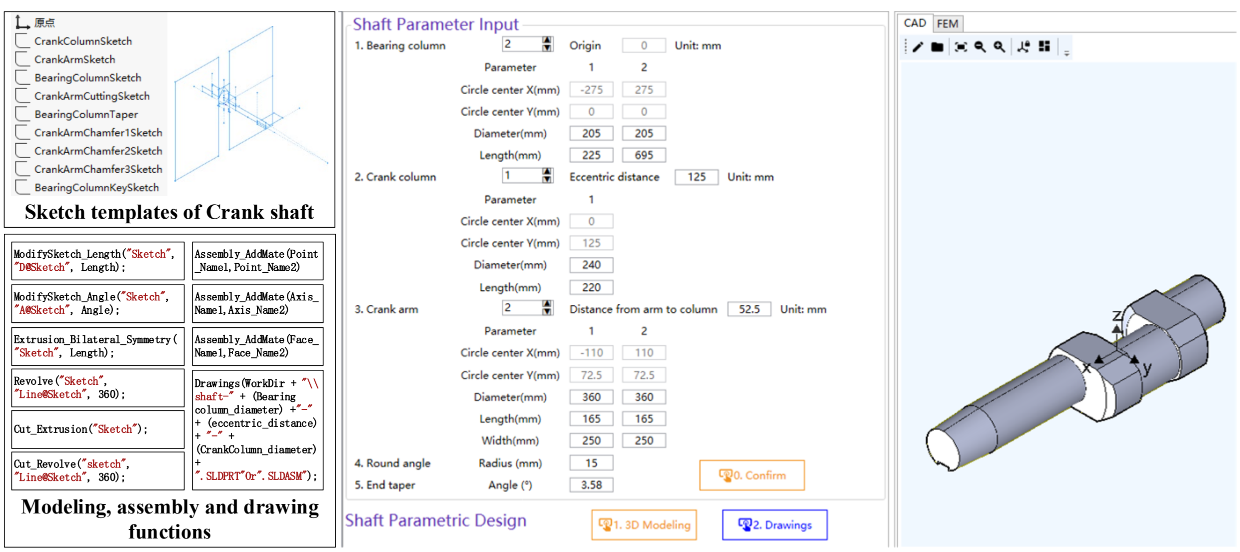


Fig. 7. Sketch templates and the parametric design view of crank shaft.

The left-top side figure in Fig. 7 is the designed sketch templates, the left bottom side figure in Fig. 7 lists modeling, assembly and drawing functions that take use of the solidworks API, and the right view shows the user interface made of a form view and a graphic view.

The modeling is achieved by the following process. The form view has many textboxes for each column of the shaft. Some of the textboxes are column and arm parameters especially for the position, length and diameter of all the columns as well as the position, length, width and diameter of the arms. Specifically, the bearing column will contact with the sliding bearings that support the shaft. The number of the bearing columns can be changed by the textbox with the up and down triangles according to the length of the press worktable, the simplest case of which is 2 bearing columns. The least crank column number is one, which will contact with the link. One crank column has two crank arms, the number of which can be automatically set when that of crank column is set. The textboxes of column and arm parameters increase as the number of columns and arms increase, i.e., the value of textboxes with up and down triangles. When all the column and arm parameters as well as the round angle and end taper angle are all confirmed, the shaft parametric design can be executed. By clicking the button 3D Modeling, we will obtain the part of the shaft as shown in the right graphic view, and the related part is saved in working directory.

Similar to the above process, the parts of all links and wheel components can be generated from the parameters set by the user. By automatically making some of the axis and points of different parts coincide with each other, the assembly of wheel, shaft and links will be completed as shown in Fig. 8. Similar to the assembly procedure of wheel link mechanism, the whole mechanical press will be assembled.

Fig. 8. The assembly of eccentric wheel-link mechanism.

Summary

This paper proposes a new architecture incorporating web and client functions for the modification and design of mechanical presses. The press modification is done in the web browser using the case retrieval, adaptation and calculating validation. The new press design is finished in the client window using modeling, drawing and assembling functions that integrate the Solidworks API. The cases used by the web browser is the knowledge of standardized presses and related BOMs and drawings stored in the server. Many templates including BOM templates and 2D sketches with mating feature (points, axis and faces) are defined for the report, modeling, drawing and assembling. By the proposed architecture, a customized design tool of mechanical presses is developed, the feasibility of which is validated by the modification and design of a multi-link system.

Acknowledgements

This work was financially supported by Jiangsu Provincial Department of Science and Technology, project BA2021067.

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