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An Integrated Cloud CAE Simulation System for Industrial Service Applications

JIACHENG XIE[1,2], XUEWEN WANG[1], ZHAOJIAN YANG[1], AND SHANGQING HAO[2]

[1]College of Mechanical Engineering, Key Laboratory of Fully Mechanized Coal Mining Equipment, Taiyuan University of Technology, Taiyuan 030024, China
[2]Taiyuan Mining Machinery Group Co., Ltd., Taiyuan 030032, China

Corresponding author: Xuewen Wang (wxuew@163.com)

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ABSTRACT The cloud-based computer-aided engineering (CAE) technology expands the application scope of CAE, solves the problem of uneven distribution, and improves the efficiency of the simulation resources. Consequently, various industries are turning to cloud CAE technology to design their products. However, to utilize this technology fully, we must overcome problems, such as impracticality, inability to handle complex analysis objects, poor data transmission, and compatibility, and poor industrial applicability. Based on the ASP.NET, VB.NET, and ANSYS Parametric Design Language, this paper establishes an integrated cloud CAE simulation system for industrial service applications. The system: 1) connects the dispatching manager through the network and 2) clusters the servers according to their load and usage before dispatch, thereby enabling users to access the ANSYS software remotely. The model can be built either by inputting the dimensions of the parametric model through the page or by uploading a three-dimensional computer-aided design (CAD) model that meets the format requirements. The material parameters and the boundary conditions also input through the page. Thus, clients can input their own parameters and analyze the server CAD. Finally, the CAE analysis results can be invoked by a page operation, saving meaningful results on the server to be accessed directly by users. The proposed simulation system serves the needs of users both quickly and efficiently. In the large-scale industrial application trials, enterprises responded favorably to the system. In particular, it properly solves the CAE analysis problems of small- and medium-sized machinery and equipment enterprises.

INDEX TERMS Integrated design, APDL, CAE, digital design, load balancing, service platform.

I. INTRODUCTION

Modern design is evolving rapidly toward multi-disciplinary integration [1], distributed collaborative design [2], knowledge-based design [3] ,and cloud design [4]. Gradually, different design links are being integrated and designed on the Internet [5]. The integration and development of flexible architectures and collaboration models based on cloud design simulation, direct user-oriented designs, multi-link data interactions and management, and complex product-oriented designs, is an accelerating trend [6].

As a maturing technology, computer-aided engineering (CAE) is widely used in aerospace, construction, machinery, and civil engineering. It has also become an important tool for structural analysis and optimization at the stage of product design and development. However, practical engineering applications are currently too complex and computationally expensive for CAE. Therefore, there is an urgent need for high-performance servers and other hardware support for CAE, which is also limited by high investment, high technical requirements, and high idle cost. Moreover, small and medium-sized enterprises (SMEs) can find CAE technological simulations quite difficult. However, cloud-sharing CAE technology promises to resolve the mismatch between high-end and low-end enterprises and improve the efficiency of resource utilization.

Cloud CAE combines parametric modeling with finite-element analysis and web technology. First, data are shared among the software by means of secondary development tools of related software and relevant CAE software modules. Next, parametric remote designs and an analysis platform are constructed using web development technology

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(such as ASP.NET), component technology (such as Component Object Model (COM) components and Java applets), and database technologies (such as Structured Query Language (SQL) servers) [7]. Specifically, users can perform analyses and calculations on a group of remote high-performance servers equipped with relevant commercial computer-aided design (CAD) and CAE software and construct a related integrated-design network platform that handles internet requests from different users. The load balance is maintained by real-time perceptual scheduling, enabling remote calling by the end users at any time and place.

Theoretical researches on cloud CAE are numerous in the literature. Cheng and Fen [12] proposed a three-tier distributed problem-solving environment for structural topology optimization and pollutant-transport simulation in coastal waters. Shi *et al.* [13] developed a tool for remote glass-service providers. The tool comprises the master server, a job scheduling program, a unit for simulating the pressing process, and user interface modules. The collaborative modeling and simulation platform of Wang *et al.* [14] includes the infrastructure of the distributed communications, a mechanism that runs the interaction, and an abstract representation of the simulation systems. Hamri *et al.* [15] proposed a new approach based on hybrid shape representation, which reduces the gap between computer-aided design (CAD) and CAE software. Using an improved sequential approximation optimization algorithm, an integrated commercial CAD and CAE software greatly reduced the calculation cost [16]. Deng and Zhang [17] integrated heterogeneous CAE software into a CAE application encapsulation template (CAE-APT) technology for developing parallel CAE systems. Integrating CAE and virtual reality technologies would create a simple data exchange link between the two technologies, enabling integrated engineering analysis tasks in an immersive environment [18]–[20].

Considering the complexity of current objects, Yu *et al.* [21] proposed a remote CAE collaborative design system for complex products based on a design resource unit. They enhanced the product analyzability in the mold design process by an integrated CAD/CAE system [22]. Using an integrated design system approach, Karayel *et al.* [23] established a mixed-design environment that integrates artificial intelligence methods, CAD/CAM technology, and technical computing packages. Within this environment, they designed a helical gear-one speed gearbox. A hybrid CAD and CAE software platform enables tasks that are not possible in traditional design, such as the fast generation, exploration, and evaluation of large design spaces with geometrically complex solutions [24].

Using intelligent agent technology and Web services technology, Kuk *et al.* [25] managed and transferred cloud CAE simulation data, thereby integrating various engineering resources distributed in different places. This approach supports the collaboration and coordination of engineering activities. Kim *et al.* [26] conceptualized Web Services for CAD (WSC) for effective interactions based on XML files. To improve the data reusability among different modules, Gujarathi and Ma [27] built a common data model that uses the parameter information required for both CAD modeling and CAE analysis. Jia *et al.* [28] effectively integrated CAD, dynamic finite element analysis and fatigue analysis. Their system supports data exchange and transmission in multi-domain analyses, enabling integration and information exchange of various software to a certain extent. Xia *et al.* [29] proposed a unified representation architecture that resolves the incompatibility between a CAD system and the data structure of a CAE system model. By combining CAD and CAE into an organic entity, they greatly reduced the redundancy in the grid-generated data. Liu *et al.* [30] combined computer-aided circuit design with CAD and CAE into a framework for the design, modeling and optimization of fiber-reinforced plastic parts. Their framework achieves multi-stage optimization in a semi-automated manner. Ma *et al.* [31] extracted features from SolidWorks and mapped them to a finite element analysis model in real-time for parallel machine tools. Imaging methods and data structures can provide large-scale cloud CAE services [32]. A service-oriented data exchange architecture for cloud-based design and manufacturing can replace the traditional functions of feature-based data exchange between heterogeneous CAD systems [33].

Within a framework that integrates commercial CAD/CAE software, the design, analysis, and redesign processes are automatic and seamless, removing the need to interact with designers [34]. Yu *et al.* [35] investigated the integration and dynamic dispatching methods of several commercial software packages (Pro/E, HyfMype and ANSYS), and designed an integrated system for railway vehicle bogies, which facilitates the design of complex products. Ma and Ling [36] selected the most effective web services among various alternatives using quality-of-service-aware scheduling with real-time adaptive and countable parameters. Their system maintains load balance, enabling remote access to the CAE software anytime and anywhere. The quality and efficiency of product design can be greatly enhanced by introducing knowledge-based design and multi-stage optimization into the CAD/CAE integration technology [37]. Component-reuse technology can improve the software productivity and quality, and has achieved very good results.

The above literature review revealed the following five main problems in current cloud CAE research.

(1) The research on web-based CAE technology is expanding continuously, with most interest being on (i) integrating distributed CAE resources and (ii) collaborative CAE [8], [9], with a strong emphasis on theory. However, web-based applications of CAE software are relatively scarce [10], [11], and most CAE studies investigate the analysis processes rather than the complete analysis itself. Consequently, the technology is not guaranteed to be practical.

(2) Current design platforms are intended mainly for either simple small-scale products or parts of complex products and are unsuitable for designing large-scale complex equipment.

(3) Each link is designed independently, and the data transmission and compatibility in the internet are poor. The data integration or transfer is limited to simple cases, the cloud data management is not perfect, and the data management plan is incomplete.

(4) No analysis has yet considered the customer perspective: how to conduct online and offline analyses, upload models, generate grids, and view and save results.

(5) Previous analyses were relatively simple and could not simulate various models continuously.

To solve the aforementioned problems, the present paper presents an integrated cloud-based CAE simulation system for industrial service applications. Among its various functions, the system generates the parts for the CAD model, sets the material parameters and boundary conditions, constructs the grid, and analyzes and post-processes the data to solve the problem.

Within enterprises of all sizes, there is an urgent need to establish a cloud CAE analysis system that is suitable for less-experienced operators and that can analyze large-scale equipment and its components. The system should (i) offer a complete solution for preserving and managing processing data, (ii) be applicable to many types of CAE analysis in enterprises, and (iii) be closely integrated with industrial applications. In addition, due consideration should be given to usage pressures within the enterprise to ensure that a sufficient number of designers can use the platform simultaneously.

The present paper is organized as follows. After analyzing the application and development of cloud CAE technology in detail, an integrated cloud CAE simulation system for industrial service applications, which can solve these problems, is proposed based on modern mechanical design technology. Sections 2 and 3 introduce the overall architecture of the system and the key technologies. Sections 4 and 5 illustrate the parametric-modeling and model-importing subsystems, respectively. The system performance is tested and analyzed in Section 6, and Section 7 concludes the study.

II. OVERALL ARCHITECTURE

As shown in Fig. 1, the overall architecture of the system is divided into three parts, namely (i) user operation, (ii) remote response, and (iii) results processing. Via the webpage on the computer, the user-operation part remotely receives the user's instructions and tasks to be realized; it includes the graphic parameter inputs, assistant professional-knowledge query browsing, display and download requests for the results, and similar items. The remote-response part is based on the web server supported by an Internet Information Services (IIS) server; it responds to user instructions such as calling the server software for analysis, completing the analysis results, and waiting for data invocations. The results-processing part performs the analysis, display, storage, and download of the data through the program call processing results, thereby satisfying the direct needs of users.

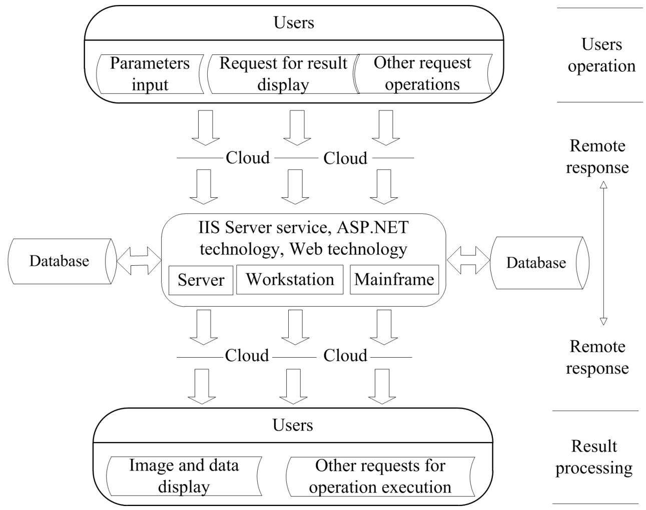


FIGURE 1. Platform system architecture.

The system comprises two subsystems: the parametric modeling subsystem and the model importing subsystem. The analysis can be static, non-prestressed modal, prestressed modal, harmonic response, or transient. The main language is an interpretive text language based on the ANSYS Parametric Design Language (APDL). The ANSYS command is organized by APDL and the parameterized user program is compiled to realize the whole process of the finite element analysis.

The overall technical route is shown in Fig. 2. The main parts are narrated below.

Remote ANSYS invocations are realized by remotely invoking the ANSYS BATCH module. ANSYS is controlled by APDL files, which can be written when the ANSYS program is opened by VB.NET. The ANSYS software version emphasizes the need to configure the environment and correctly set up the work path.

APDL file generation part:

(1) The command flow of the parametric modeling subsystem proceeds as follows: establish a new blank document → parameterize and assign the model → establish the result-saving path → parameterize the model APDL file → preprocess the APDL file → solve and post-process the APDL file. The parameterized assignment part of the model is inputted by the page and passed to the APDL file. The result-saving path saves the analysis results under a folder dedicated to the specific analysis type for users to call and view. The APDL file of the parameterized model is the command flow file generated after the model has been parameterized in ANSYS. The assigned part is excluded by the original command flow, and the preprocessing APDL file includes the settings. The command-flow file determines the analysis type, chooses the element type, sets the material parameters, divides the grid, sets the boundary conditions, and loads the APDL file. The solution and post-processing APDL file is a command flow file that includes solving, generating and invoking the specified analysis results.

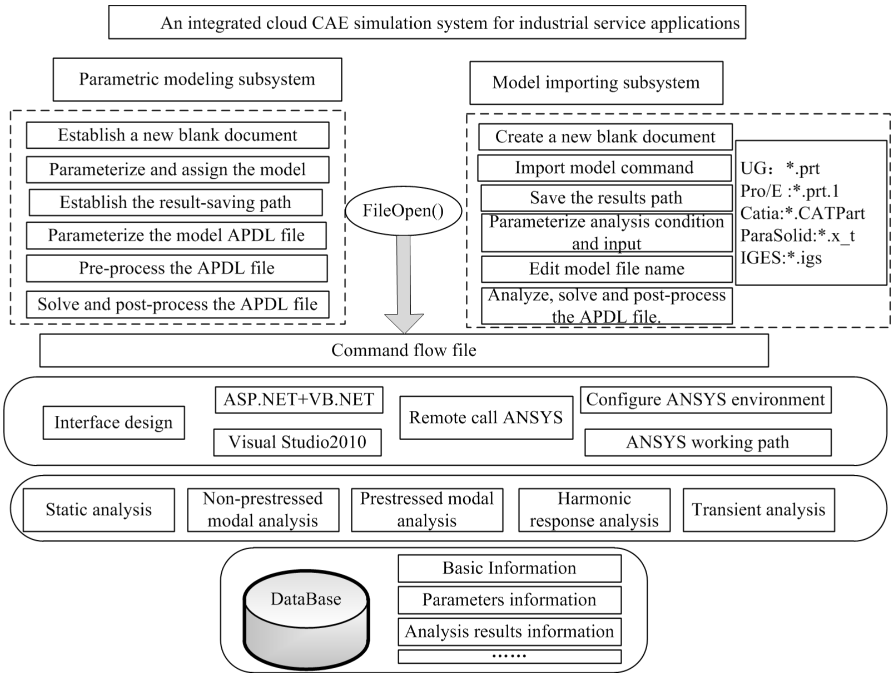


FIGURE 2. Technology roadmap.

(2) The command flow of the model importing subsystem proceeds as follows: create a new blank document → import model command → save the results path → parameterize analysis condition and input → edit model file name → analyze, solve and post-process the APDL file. The model is imported by different parts, not by repeating the above process and parameterization of the modeling subsystem. Specifically, the 3D entity model is imported into the background server through the page. The file path is then extracted and written into the command flow of ANSYS. The conditional parameterization is analyzed by inputting the preprocessing APDL file part to the parameterized modeling subsystem, but with a higher (relative to the standard input procedure) command flow of the grid partition type selection part. The file name is extracted from the imported three-dimensional entity model and written into a separate saved document.

(3) APDL file generation depends on an important function called FileOpen (). The output mode creates new documents and writes content in the chosen writing style to the Open-Mode mode. The Append mode writes overlapping content. Both modes cooperate with the final implementation to generate a complete command-flow file.

(4) The command flow is not called as a whole, but is written as separate parts. The reasons are as follows: first, the parameterized part needs to transfer the parameters in real time by inputting them to the page; second, each part needs to be controlled by corresponding controls, and the separate foreground page designs must cooperate to realize the whole analysis. Third, for different types of analysis, the specific contents of the command flow must be divided into several parts while retaining the same write part. Different parts need to establish other corresponding files.

(5) The two parts of the different analysis processes differ in their order of writing the command flow of the APDL file, the content of the command flow that implements the analysis, and the saved contents of the result information.

III. KEY TECHNOLOGIES

A. REMOTE CALL ANSYS

To conduct a remote web-based call analysis, the remote call interface of the ANSYS analysis component must be connected correctly. For this purpose, an ANSYS Parametric Design Language (APDL) file is written to the open ANSYS program by VB, thereby controlling the ANSYS adequately.

(1) Configure ANSYS, select ANSYS Batch for Simulation Environment, select ANSYS MultiPhsics for License, set the working path and the input-and-output file path, click Run to enable the Batch function with the background call function.

(2) Edit the APDL file of parameterized parts.

(3) Retrieve the APDL file call by the following procedure:

Dim sss As String

Dim ttt As New Diagnostics.Process

sss = "-p ane3fl -dir C:\Program Files\ . . . \data -j input -s read -l en-us -b -i C:\Program Files\ . . . \data \input.txt -o C:\Program Files \ . . . \data \output.txt"

ttt.StartInfo.FileName ="C:\Program Files \ . . . \ ansys140.exe"

ttt.StartInfo.Arguments = sss

ttt.Start()

Here, the variable SSS is the return value of VB calling the ANSYS program, C:Program Files\\\\ ANSYS 140.exe is the installation directory of ANSYS, -p ane3fl is the characteristic code of the ANSYS Multiphsics module, -j represents the setting of the Job name of the ANSYS project file, whose input will generate the input.db file in the project directory, -i and –o denote the path of the input file and output file, respectively, and the variable ttt mediates the access to the remote process.

B. FILEOPEN () FUNCTION

The system pages include front-end display pages and back-end function pages. The main functions must be implemented by back-end function codes. Specific function codes are compiled for the CAE analysis process and the order of writing the command flow during the APDL file generation. The functionalities include (but are not limited to) page parameter transfer, APDL file generation, and calling ANSYS interfaces. The important function FileOpen () is formatted as

FileOpen (1, filename, OpenMode.Output),

where "1"is the file number, "filename" is the name of the open file, and the MapPath () function returns the file path. Optional modes for OpenMode are Append, Binary, Input, Output, and Random. The Append mode opens in a superimposed manner, with each write superimposed after an existing file, or in other forms. All modes overwrite source files and generate new files.

The following code implements some functions through the FileOpen () function.

(1) Write the parameters passed by the page to the file.

```
Dim LA, LB, LC, DB, DC As String
Session("LA") = TextBox1.Text ! Passing page input parameters to temporary memory
Session("LB") = TextBox2.Text
......
LA = Session("LA") ! Assigning parameter values in temporary storage to variables
LB = Session("LB")
......
FileOpen(1, Server.MapPath("./data/input.txt"), OpenMode.Output)
! New document, write data, and close after completion.
PrintLine(1, "LA =", LA)
PrintLine(1, "LB =", LB)
......
FileClose(1)
```

(2) Write the contents of an existing document to the file.

```
FileOpen(2, Server.MapPath("./data/Adress_jingtai.txt"), OpenMode.Binary)
Do While Not EOF(2)
  s = LineInput(2)
  PrintLine(1, s)
Loop
FileClose(2)
```

When file 1 is open, the above code opens file 2 under the server. When file 1 is open, MapPath () path is using the Do When () statement. Loop then writes all contents of file 2 into file 1 in binary form, overlaying the contents of both files.

C. TIMER CONTROL AND TASK SCHEDULING

Depending on the load and usage, the remote connection dispatch manager clusters the servers and dispatches the clusters through the network, enabling remote calls of ANSYS software by users. The user requests are queued by the order of their arrival, and task completion is judged by the remote connection dispatch manager (Fig.3).

Component CAE analysis is generally a time-intensive process (requiring several hours), during which the analyst cannot always manually refresh the page. Once the analysis prompt is completed by a special program, the user is given a page prompt, enabling timely access to the complete information of the analysis and progression to other operations. The task network scheduling involves the following processes: perform regular page refreshes using the Timer control and Update Panel control, which are added to the page, set the refresh time with the Interval property, open and close the Timer with the Enabled property at the beginning of the analysis and after the analysis prompt, respectively, and reduce the additional burden of page running.

D. DATA PRESERVATION

The system saves and retrieves parts based on the CAE analysis. The saved information includes the basic information of the parts, the CAE analysis parameters, and results of the CAE analysis. The most important part is the database operation, which performs the saving and retrieving.

The three categories of the saved information are described below:

The basic information of parts includes the part name, analysis software name, analysis type, analysis name, analysis time, and the two-dimensional and three-dimensional drawings of the parts.

The information of the CAE analysis parameters includes the element type, material name, elastic modulus, Poisson's ratio, material density, dimension parameter, mesh mode, mesh grade, mesh size, and the constraint and load descriptions.

The result document of the CAE analysis presents the displacement and stress curves for each coordinate axis and the whole system, the vibration mode diagram of each order, the mesh quality diagram of the parts, and the strain diagram, which is convenient for subsequently expanding the functions of the system.

The files generated after the CAE analysis are saved in a result-saving folder named by part name + analysis type(Fig.4). The part name is manually input to the page by the user, and the analysis type is selected from a popup menu. The result-saving function of this system saves the analysis result twice with the same part name, and the third save replaces the first analysis result.

IV. PARAMETRIC MODELING SUBSYSTEM

The parametric modeling subsystem generates the entity model in real time by calling ANSYS on the web. The main

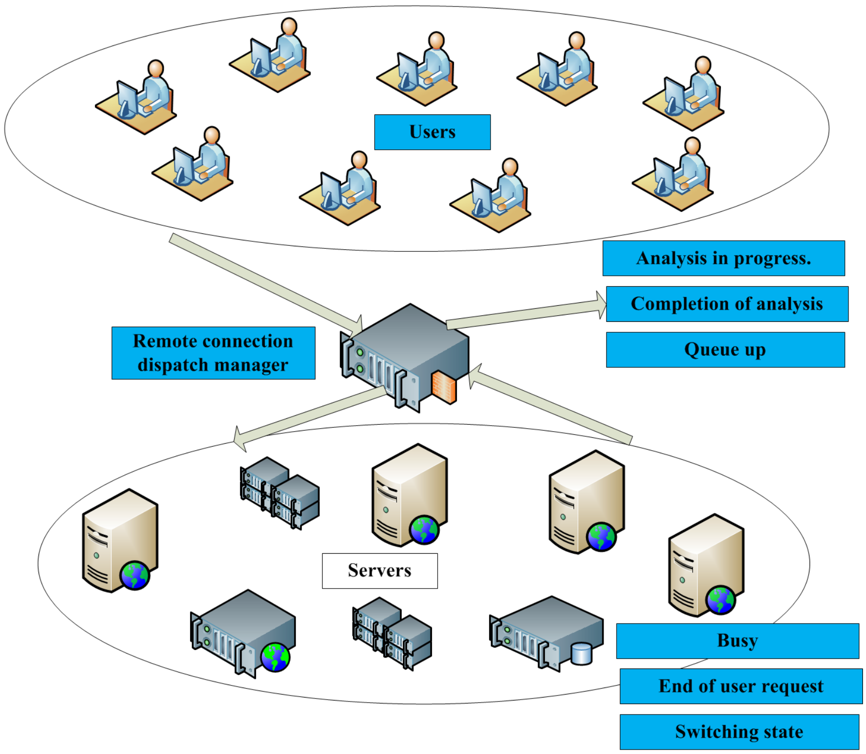


FIGURE 3. Task network scheduling.

processes are parameterization of the entity model, extraction of the ANSYS analysis command flow, and remote calling of the ANSYS and system page technologies.

A. PARAMETERIZATION OF ENTITY MODEL

To perform a CAE analysis of a given part but of different sizes, one must parameterize the size of the solid model by resizing the parameterized model. The parametric model is established using the Unigraphics (UG) software, and its outputs are displayed in a spreadsheet. To ensure that changing a parameter value then changes the associated part dimension, there should be correspondence among (i) the parameter name, (ii) the input expression of the parameter value, and (iii) the corresponding parameter of the modeling operation. Parts with a complicated structure should be simulated by a UG modeling function; for example, a cycloid tooth profile should be simulated by a point-fitting function.

B. EXTRACT THE APDL COMMAND FLOW

Once the entity model is parametrized, the necessary CAE analysis types are selected. To illustrate the production process of a parameterized command flow, we perform a static analysis of the first axis of the cutting unit (Table 1).

The web parameter data are manually inputted through the front-page function, and the APDL documents are written by the back-end function. The save paths of the results are designated by their paths and the result of each analysis type.

The modeling command flow, including the modeling of the spur gears, involute splines and other parts, is extracted from the analysis results of these parts in ANSYS. Different analysis types require different boundary conditions and material parameters. The parameters are input from the page and expressed by their corresponding parameters. Transferred data are represented in the form of the inputted Web parameter part data. The parameters and contents of the five analysis types are shown in Table 2.

The post-processing command flow extracts the different analysis results by recognizing their different types, thereby recovering the meaningful results of the analysis problem. The analysis results extracted from the five analysis types are shown in Table 3.The command flow of a non-prestressed modal analysis can be generated in two ways. In the first approach, the non-prestressed modal analysis of the truncated axis is carried out by classical ANSYS, and the ∗.log file in the working path is extracted and processed. The second approach alters the previously determined command flow of the static analysis of the truncated axis. To convert the loading position of the static analysis into a constraint for the non-prestressing modal analysis, a command flow into modal analysis, modal order definition, modal expansion order and frequency range is added. The two approaches generate different outputs of the post-processing part. The first method requires researchers to master the relevant instructions of the classical ANSYS analysis and the corresponding command flow. Although this method achieves an accurate

TABLE 1. The first axis of cutting unit static analysis command flow.

Content	Command flow	Explanation
inputting of web parameters	D1 = 160 D2 = 130	Assign values to parameterized dimensions.
Results save path	/cwd,D:\CAEAnalysisSystem\CAEAnalysisSystem\jieguo_jingtai	Save the result to the specified path according to the analysis type.
Parametric definition and modeling of cylindrical spur gear	*SET,m,6 *SET,z,30 *SET,angle1,20*pi/180.0 ……	Definition of modulus Number of teeth Initial deflection angle
Definition and modeling of involute inner spline parameters	*SET,c,0.2 *SET,r,0.5*m*z *SET,rb1,r*cos(angle1) *SET,ra,0.5*(z+2*c+1)*m *SET,rf,0.5*(z-1)*m *SET,angle2,180.0/z ……	Top clearance coefficient Indexing circle radius Base circle radius Radius of the addendum circle
Other parts modeling	…… *get,area0,area,6,area /UNITS,MKS ET,1,SOLID185 ……	Extract the area of 6th face. Set up the unit system. Elastic modulus parameterization
Preprocessing part	SMRT,C3 … *get,num,node,,count …… ASEL,S,AREA,,256 …… ASEL,S,AREA,,6,122,4 SFA,ALL,1,PRES,F/area0 …… ASEL,A,AREA,,125 ……	Smart grid division Extract surface nodes Plus Z constraint in A, B datum Load on spline surface Add constraint
Solving part	SOLVE FINISH /POST1 …	Solve Finish Start
Post-processing part	/show,jpeg,, eplot PLNSOL, U,SUM, 0,1.0 PLNSOL, S,EQV, 0,1.0 /show,close	The result is saved as JPEG format. Save displacement nephogram Save stress nephogram

TABLE 2. Parameters contrast of the different analysis results.

Parameters \ Analysis type		Static analysis	Non-prestressed modal analysis	Prestressed modal analysis	Harmonic response analysis	Transient analysis
Elastic modulus	C1	√	√	√	√	√
Poisson's ratio	C2	√	√	√	√	√
Grid density	C3	√	√	√	√	√
Material density	C5	√	√	√	√	√
Loading force	F	√		√	√	√
Gravity	G	√		√	√	√
Modal order	C6		√	√	√	√
Frequency end value	C7				√	√
Step length	C8				√	√
Stationary time	t1					√
Unloading time	t2					√
Termination time	t3					√
Substep number	bc					√

result, it is difficult, time-consuming, and inefficient. In contrast, the second method is convenient, fast, and easily mastered (requiring only the correct constrained position and direction), but compromises the accuracy. Errors introduced by this approach can lead to failure of the whole analysis.

TABLE 3. Results contrast of the different analysis type.

Analysis type	Analysis results
Static analysis	Grid graph, Displacement nephogram, Stress nephogram
Non-prestressed modal analysis	Grid graph, Formation maps of from modal order 1 to modal order 12
Prestressed modal analysis	Grid graph, Formation maps of from modal order 1 to modal order 12
Harmonic response analysis	Grid graph, Formation maps of from modal order 1 to modal order 12
Transient analysis	Grid graph, X-Direction displacement curve, Y-Direction displacement curve, Z-Direction displacement curve, X/Y/Z displacement comparison diagram, Displacement nephogram, Stress nephogram

Changing the command flow of the non-prestress modal analysis automatically alters the command flow of the prestress modal analysis, because the two analyses differ only by the presence or absence of prestress. In a static analysis, the loading-force position in the prestress analysis changes under the constraints imposed by the non-prestress analysis, whereas the other parts are unchanged. A command flow for prestress modal analysis is provided.

A harmonic response analysis requires a different command flow from that of the non-prestressed modal analysis. After solving the non-prestressed modal analysis, the harmonic response analysis is carried out under relevant pre-settings.

A transient analysis is more realistic than static analysis because it accounts for the temporal load changes. The command flow of a transient analysis cannot be directly obtained by adjusting other types of command flow, so must be extracted by first performing a correct transient analysis. However, the main parts of the command flow can be derived by a transient analysis of the command flow of the same part with different constraints and load components.

For the convenience of user selection, the output results of the post-processing part include not only the stress and displacement nephograms, but also the unidirectional displacement curves in the X, Y and Z directions, the three-dimensional displacement contrast graphs, and the stress curves. All curves display the results of the most dangerous nodes on the parts. The displacement and stress curves show the changes from the maximum displacement and maximum stress change at the most vulnerable node, respectively.

V. MODEL IMPORTING SUBSYSTEM

The model importing subsystem constructs the solid model using three-dimensional (3D) modeling software and uploads it to the server. The model is then imported into ANSYS by page instructions, and the subsequent CAE analysis is completed as required.

A. MODEL IMPORTATION

The 3D modeling software builds the user-imported model based on the design requirements of the key components, including the structural and size requirements. Because the modeling method and the definition format of the primitives of the 3D CAD software are incompatible with ANSYS, the model must be simplified by (i) removing the chamfering, (ii) modifying the small parts, and (iii) removing interferences of the body, surface, lines, and other features. Without these modifications, errors in the follow-up operation of ANSYS are inevitable. The model can be either parameterized or not, but to ensure repeatability and scalability, a parameterized model that facilitates size changes is recommended.

1) FORMAT SUPPORTS

ANSYS software supports the direct import files UG, Pro/E, CATIA, Parasolid and other software model formats, including two intermediate formats (IGES and SAT).

The intermediate conversion format of IGES is:

IGESIN,'∗∗∗','igs','D: CAEAnalysis System\ CAEAnalysis System \\\\\\\\\\\\\\\\

where ∗ ∗ ∗ is the file name of the uploaded file, D:\ CAEAnalysis System\... is the file uploaded to the server's save path. After testing by the above instructions, this file is uploaded to the server's IGES model file and successfully imported into ANSYS, where it completes the next CAE analysis.

2) UPLOAD THE MODEL

The FileUpload control uploads the local model files to the server and saves them to the path specified by the server.

B. EXTRACT THE APDL COMMAND FLOW

The command flow is extracted from ANSYS by the extraction method employed in the parametric modeling subsystem, but the structures and contents of the APDL files differ between the two extractions. Specifically, the different modes of model generation require different modes of model generation and processing.

The CAE analysis command flow is shorter in the model importing subsystem than in the parametric modeling subsystem, mainly because in the former, the complex ANSYS

TABLE 4. Comparison of parameters of different analysis types.

Parameters	Analysis type	Static analysis	Non-prestressed modal analysis	Prestressed modal analysis	Harmonic response analysis	Transient analysis
Elastic modulus	C1	√	√	√	√	√
Poisson's ratio	C2	√	√	√	√	√
Grid density	C3	√	√	√	√	√
Grid shape	C4	√	√	√	√	√
Grid size	C5	√	√	√	√	√
Loading force	C6	√		√	√	√
Material density	C7	√	√	√	√	√
Modal order	C8		√	√	√	√
Frequency end value	C9				√	√
Step length	C10				√	√
Stationary time	t1					√
Unloading time	t2					√
Termination time	t3					√
Substep number	bc					√

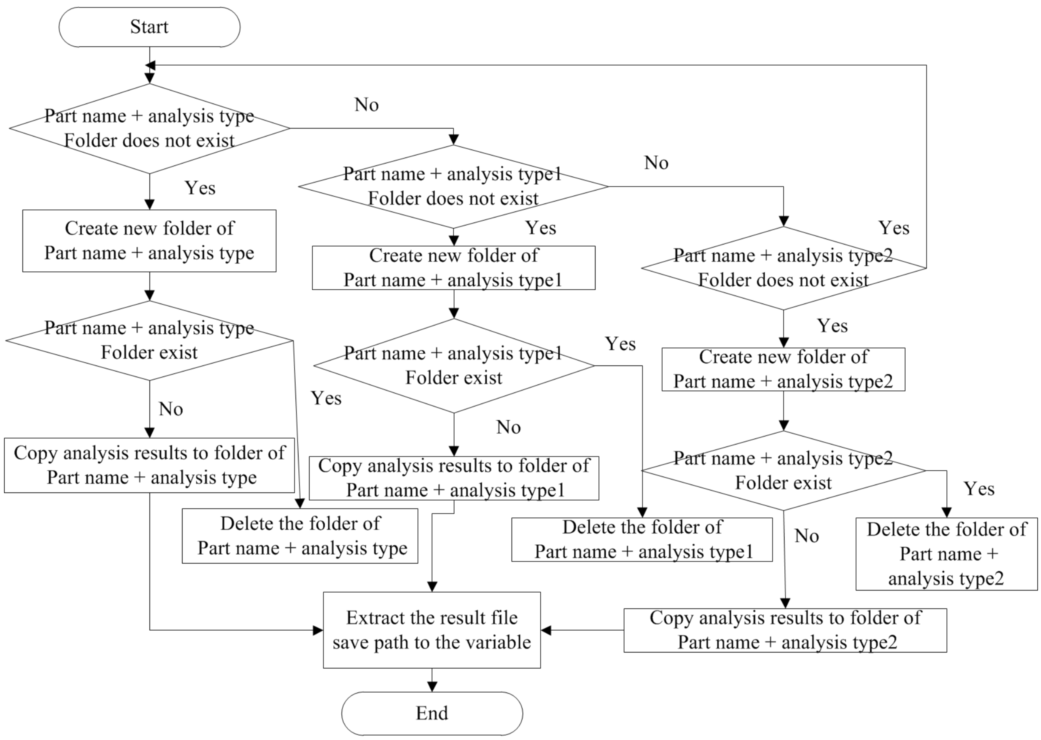


FIGURE 4. Flow chart of Results save and folder creation.

modeling command flow is replaced by part the import command flow. However, this part of the command flow is also complex and divides into the Web parameter input, the result-saving path, the model import command, and preprocessing. The main elements are the material parameter input, mesh generation, constraint load and solution, and post-processing. The solution and post-processing is accomplished by the same command flow as the parametric modeling subsystem.

The web parameter needs to be manually input through the page and written to the APDL document by the background function. As the parameters must be manually input for the five analysis types, the different analysis types are uniformly named and inherit the same parameterized modeling subsystem, accounting for the special functions added by the system. The comparison of parameters is shown in Table 4.

Table 4 lists the parameters of C3 to C6 in the command flow. Based on the function distributions of the preprocessing material parameter inputs and the preprocessing grid settings, the other parameters are written directly into the command flow by the VB.NET program in the page background.

The preprocessing material parameter input takes the values of the material parameters that are directly inputted to

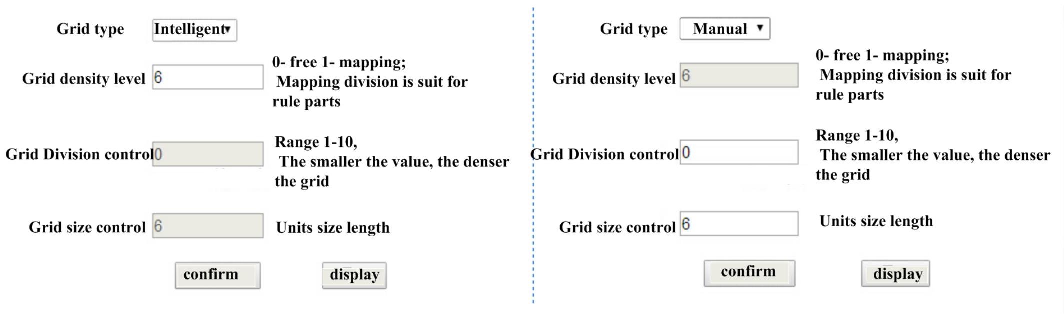


FIGURE 5. Comparison of mesh selection methods.

TABLE 5. Commend flow contrast of the different meshing type.

Intelligent mesh generation	Manual partitioning (Free mesh)	Manual partitioning (Mapping mesh)
SMRT,C3 MSHAPE,1,3D MSHKEY,0 VMESH,ALL	ESIZE,C5 MSHAPE,1,3D MSHKEY,0 VMESH,ALL	ESIZE,C5 MSHAPE,0,3D MSHKEY,1 VMESH,ALL

the page, and writes them into the APDL command flow file through the VB. NET program.

The elastic modulus (C1), Poisson's ratio (C2) and material element selection values entered by the user are assigned to variables, and the complete command flow is written directly to the APDL file through the FileOpen () function. The parameterized modeling subsystem transfers the values of the parameterized variables through the command flow. Before generating the command flow, the parameter values are assigned to variables by instructions in the system. Therefore, there is no parameter transfer in the input part of the material parameters pre-processed in the generated command flow.

C. GRID TYPE

As shown in Fig. 5, this system generates the chosen mesh either automatically(intelligent mesh generation)or manually(manual mesh generation). Intelligent mesh generation requires only the mesh density level; the text boxes of mesh generation control and mesh size control are deactivated. In contrast, when the user selects a free mesh or mapping mesh and inputs the size control of the input grid, the text box of the intelligent grid density level is deactivated. Manually creating a uniform, dense, and high-quality grid will yield a more accurate analysis result. Table 5 compares the command flows of the different grid types.

D. GRID PREVIEW

To ensure that users understand intuitively the quality of the grid partition, the system also previews the grid diagram of the parts. By opening the preview window on the page, users can modify the parameters until the grid is partitioned to the required quality. Fig. 6 compares the meshing results of 23T gears on (i) smart meshes of grades 3 and 10 and (ii) a 20-mm free mesh. The grid quality is highest with the grade-3 smart grid and relatively poor with the grade-10 smart grid.

VI. TEST OF THE SYSTEM PERFORMANCE

A. PERFORMANCE TESTING

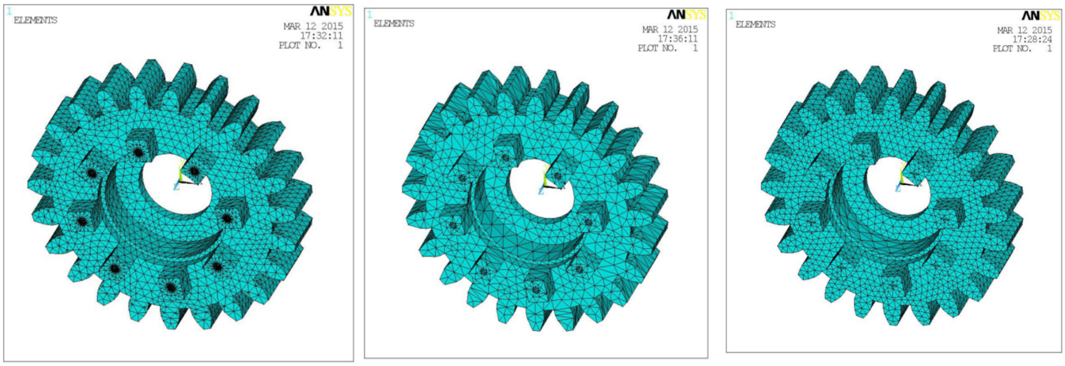
A pressure test is among the most important tests of system performance. Here, the pressure is tested in the actual network environment after the system has been published on the Internet (Table.6). The test verifies whether the system can simultaneously respond to a large number of users, and whether each user can transmit a large amount of personalized data, such as CAE analyses of large parts. The results can be downloaded for long-term use.

B. PARAMETER MODELING SUBSYSTEM

On the main page of the system, the user clicks the parameterized modeling subsystem to enter the parameterized modeling subsystem page. The operation process of the system is demonstrated on the sun wheel gear of the inner traction part of a shearer. The sun wheel gear is entered to the CAE analysis interface. The system CAE analysis proceeds through the following steps:

1) STATIC ANALYSIS

The parameterized dimension values corresponding to the parameterized two-dimensional drawings of the parts are input to the CAD modeling part. The parameters recommended in the text box of the input page provide a reference.



(a) (b) (c)

FIGURE 6. Different meshing mode effect contrast of 23T gear. (a) Smart grid level 3. (b) Smart grid level 3. (c) Free mess size 20.

TABLE 6. Performance test of system.

Number	Test 1	Test 2	Test 3
Name	Connection speed test	Load test	Pressure test
Test conditions	Response time of the system is tested under different clients and different network speeds.	The number of user visits in web system and the number of allowing users to handle the same functional requirements are tested.	The test site is enterprise intranet and internet.
Validation step	The CAE analysis pages of a part are opened on different clients and CAE analysis is carried out. The number of tests is not less than 100 groups.	The CAE Analysis page of a part is opened on different clients and CAE analysis is carried out. The number of tests is ten groups.	Log on to a page at the same time on different clients and operate on the page to see how the page responds to different clients.
Actual results	It runs well on all clients and can respond to CAE analysis requests in about the same amount of time. The page display requests of different clients can be quickly responded to and executed.	It can display requests on different client response pages, perform CAE analysis on corresponding clients first, and wait in queue according to requests.	It can respond to different client operations smoothly.

After inputting the values, the button that opens the CAE analysis section changes from gray to black (that is, becomes clickable by the user).

The appropriate analysis type is selected by sliding the mouse to the left or right. The static analysis page is displayed by default. A static analysis requires the relevant parameters of the CAE analysis (the elastic modulus, Poisson's ratio, and other mechanical properties). Based on the recommended values in the text box of the page reference, the user is presented with hints in the middle of the page after completing the input. When the gray button of the CAD modeling part turns black, the user can click refresh, as shown in Fig.7.

When the CAE analysis is completed and a new page prompt appears, the user clicks the button that releases the result-display buttons. All buttons of the result operation then change from gray to operational black. The user can now display page calls, and download and save the CAE analysis results.

When the user clicks on the results display section, a separate analysis-result display page pops up. Clicking on the button will pop-up the download window on this page, as shown in Fig.8.

By clicking on the associated buttons, the user then pops-up the saved result page, and saves the result of the CAE analysis.

After clicking the reload button, the page is reloaded, and the parameters can be changed for a re-analysis.

Clicking the return button restores the next level, that is, the parameterized modeling subsystem, on the page.

2) NON-PRESTRESSED MODAL ANALYSIS

After a modal analysis without prestressing, the interface is displayed by refreshing the page.

The trigger results (viewed by clicking) are consistent with the static analysis. When clicked, another button displays the modal shapes of the inputted order on a new page. Fig.9 show the first four-order modal shapes selected for display. The next-order modal shape is viewed by clicking on a picture or on the scroll bar underneath.

As the prestressed modal analysis and harmonic response analysis belong to the same analysis type as the non-prestressed modal analysis, the interface styles and result calls of all three analyses are very similar, but the pages of the parameter input parts differ slightly among the three contents. This difference is not elaborated here.

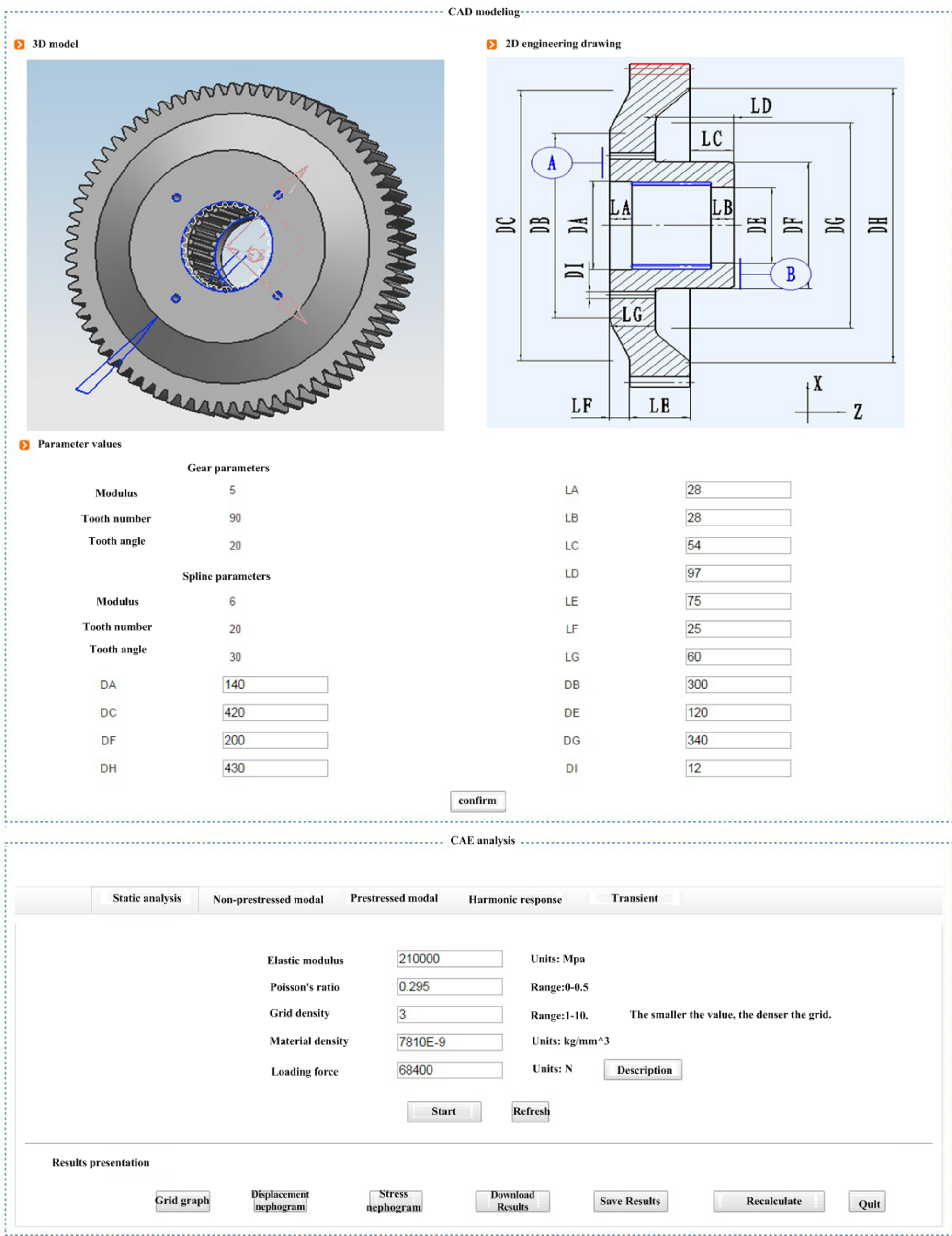


FIGURE 7. **CAE Analysis interface of Sun gear.**

3) TRANSIENT ANALYSIS

The transient analysis completes the interface displayed after a refresh. The trigger result (viewed by clicking) is consistent with the static analysis. Another button pops-up the page displaying the interface of the displacement diagram generated under the settings, as shown in Fig.10.

The equivalent stress diagram is displayed on a separate pop-up page.

C. MODEL IMPORTING SUBSYSTEM

From the main page of the system, the user clicks "model importing subsystem" to open the model importing subsystem page. Taking the design of the transmission gear of the cutting part of the shearer as an example to analyze, the analysis interface is shown in Fig.11.

The user clicks on the sixth-shaft of the external traction unit and enters the sixth-shaft CAE analysis interface. The system CAE analysis proceeds by the following steps:(Fig.12)

The system displays the transient analysis page by default (Fig.13).

(1) The user clicks the associated button, selects the file with the specified path, and displays the file name. Clicking the button again will upload the file to the server. Files

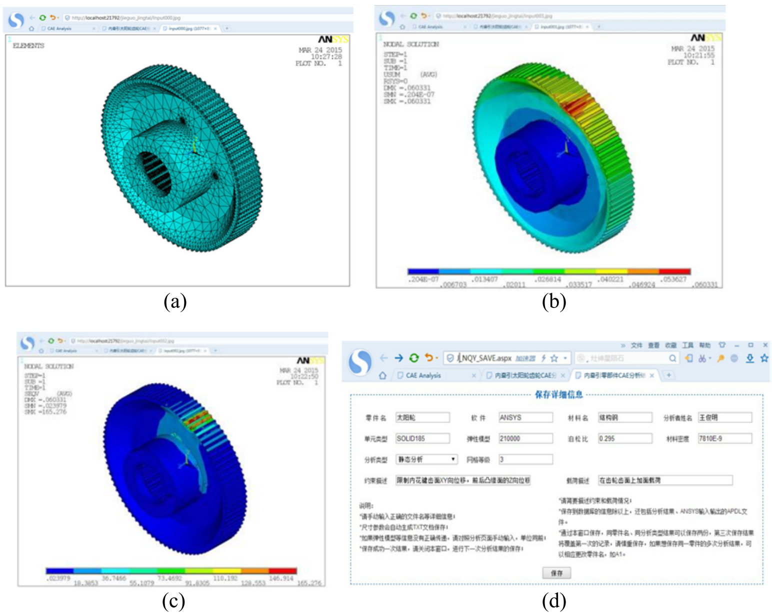


FIGURE 8. Results of static analysis. (a) Grid graph. (b) Stress nephogram. (c) Displacement nephogram. (d) Save Results.

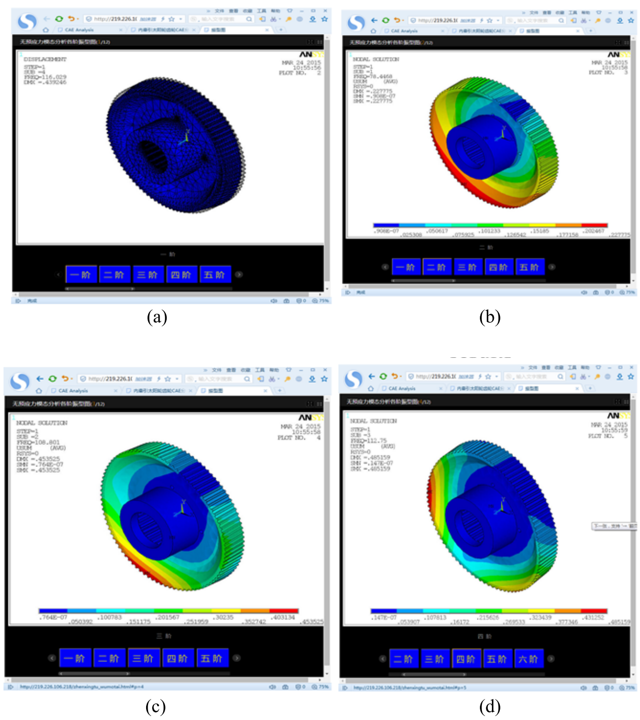


FIGURE 9. Results of Non-prestressed modal analysis. (a) First-order modal analysis results. (b) Two-order modal analysis results. (c) Three-order modal analysis results. (d) Four-order modal analysis results.

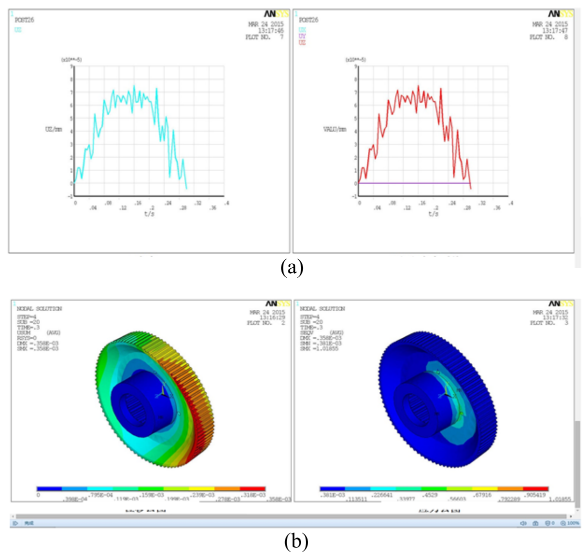


FIGURE 10. Results of transient analysis. (a) Force diagram of transient analysis. (b) Stress analysis and starin diagram for transient analysis.

that meet the file format and file size requirements will be prompted for uploading to the server.

(2) The user clicks on the drop-down list box of unit types, and selects a required material unit type. Among the solid parts, the system prefers the SOLID185, SOLID186, and SOLID187 units. Two input parameters are required: the elasticity modulus and Poisson's ratio.

(3) The user selects the grid partition method in the drop-down list box of grid types, inputs the corresponding parameter values, and clicks on the grid pre-partition, thereby activating the button on the right image-preview box. Clicking this button displays the pre-partitioned grid quality. If the quality is unsatisfactory, the parameters can be modified and the grid re-partitioned until the standard are met.

After entering the loading force, the user clicks the button to start the CAE analysis and solve the problem. When the

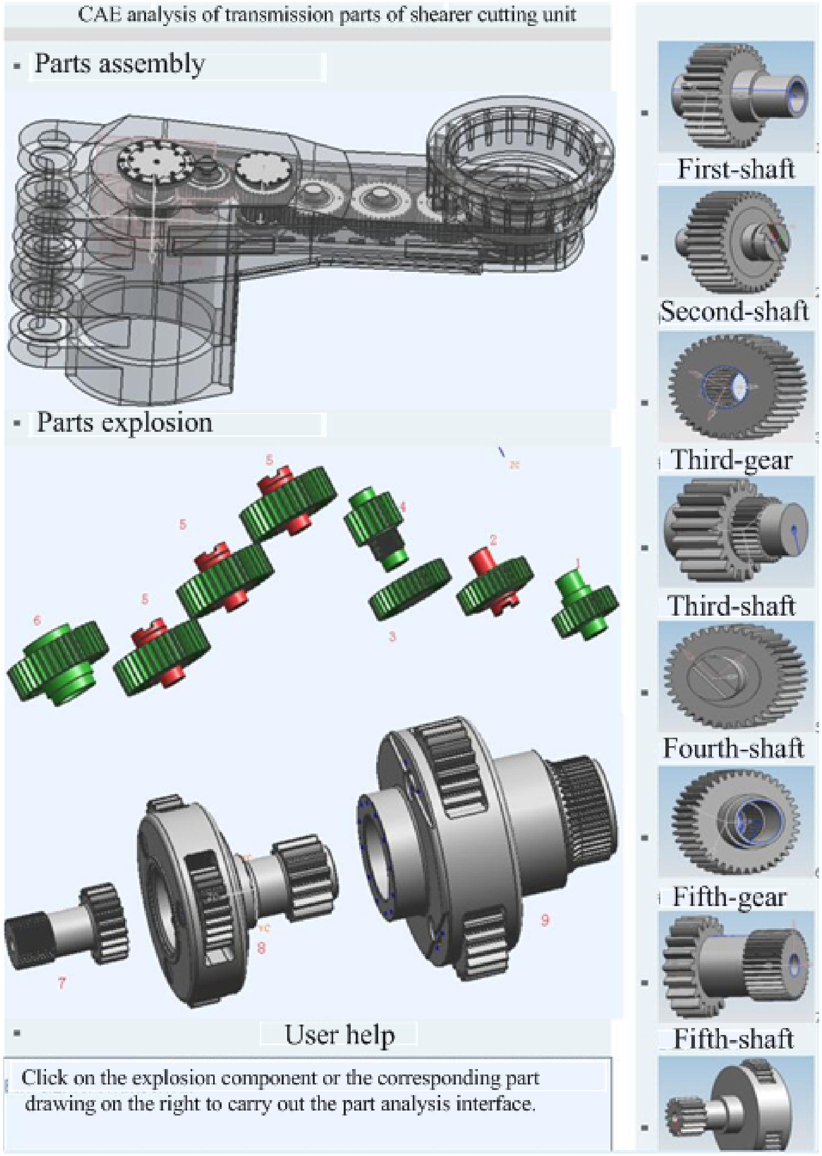


FIGURE 11. Interface of model importing subsystem.

prompt changes, the user clicks the button that activates the result section, and all buttons of the result operation change from gray to black. The user can now display page calls, and download and save the CAE analysis results.

D. TEST CONCLUSION

Opening a browser on any client allows the system to be entered normally, a CAE analysis of the key components to be realized on the web, and the analysis results to be displayed on the page. The meaningful analysis results can be saved to the database without the support of the ANSYS software or the database SQL server, thereby ensuring the system's extensive application and operational independence. The test results show that the function modules of the system are integrated effectively, the design style of the system pages is unified, the interface is friendly, the links between pages are quick and accurate, the function calculation results are correct and reliable, and the software requirements for CAE analysis can be realized by users, thereby meeting the design expectations.

E. DISCUSSION

Many equipment manufacturing enterprises and design institutes have welcomed this platform after it was the implemented therein, and obvious economic benefits have been achieved. It has good application prospects to improve design efficiency, reduce production costs, shorten the development cycle of new products, promote enterprise knowledge innovation, improve the design environment, and improve the technological innovation ability and market competitiveness of application enterprises. In SMEs in the field of mechanical

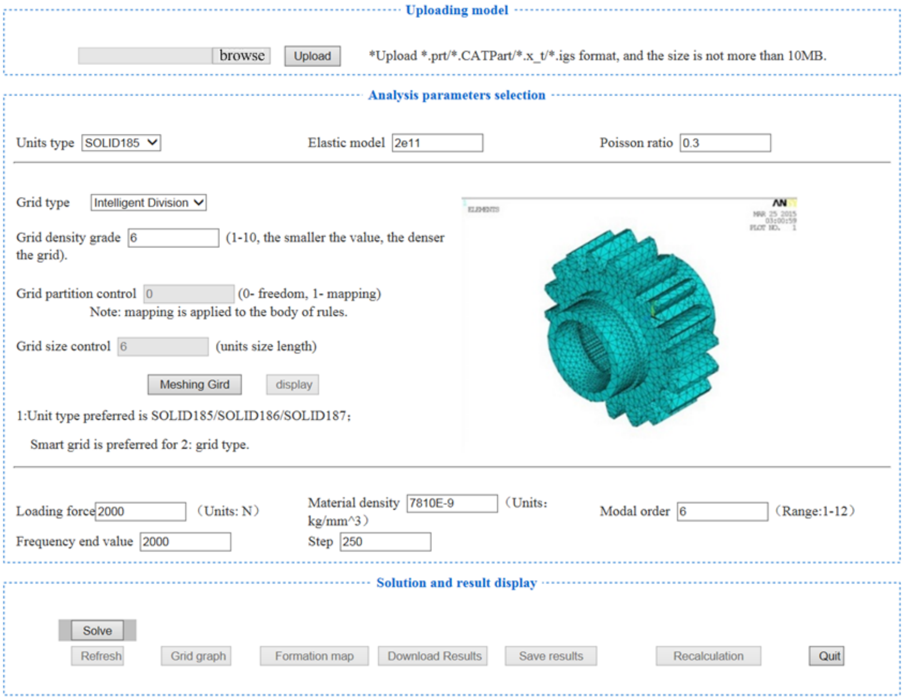
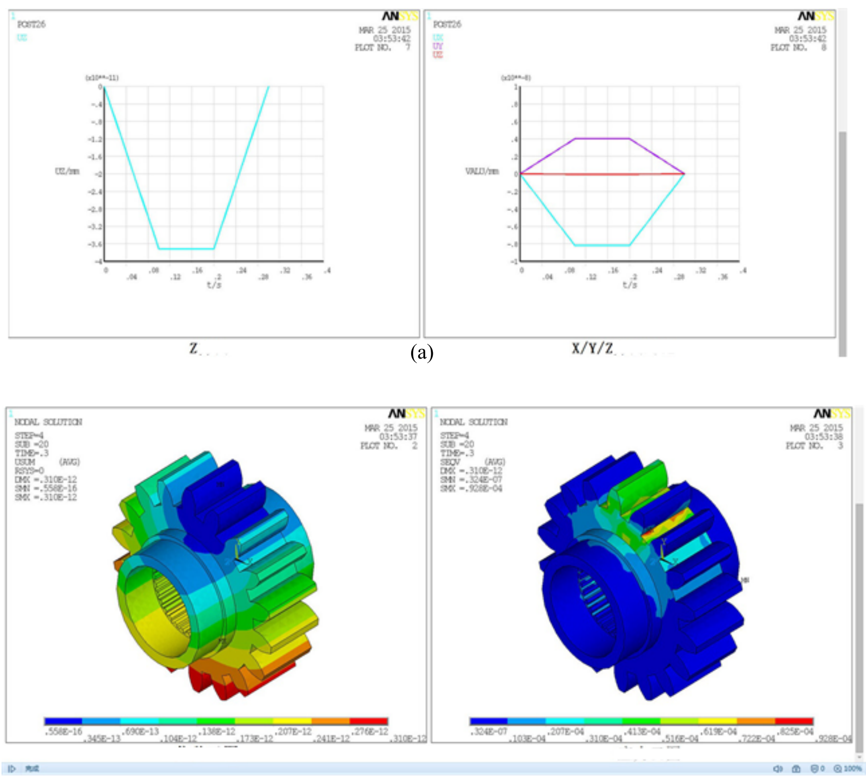


FIGURE 12. Interface of model importing subsystem.



(a)

(b)

FIGURE 13. Results of transient analysis of model importing subsystem. (a) Stress curve chart of transient analysis result. (b) Displacement curve chart of transient analysis result.

manufacturing in particular, the technical force is relatively weak. However, the technical services provided by the present design platform can be used to carry out the design and CAE analysis of mechanical products without the need for a thorough understanding and mastery of modern design theory and methods.

VII. CONCLUSIONS

The main conclusions are as follows:

(1) The system generates an APDL command flow for the parameterized model by extracting a CAD parameterized entity model + ANSYS combination, and it regulates the generated sub-modules of the command flow. The system has an effective human–computer interface, and it considers the problem from a user perspective. Because all links can be processed in the cloud, the proposed CAE analysis is applicable to industry.

(2) Because of the complex large-scale equipment design—including parametric-modeling and model-importing subsystems—a single component of the CAE analysis process can be analyzed in various ways.

(3) By means of its complete data management and interaction solution, the system properly allocates and uses the resources of the group server, improves the efficiency of use, and selectively saves the results of the CAE analysis to the database.

This effectively improves the research and development ability of an enterprise regarding its products. The function is more perfect, more problems are found in the use process, and positive improvements are made. The next goals are to (i) continue to integrate all the various types of design resources and process data within the enterprise and (ii) integrate with other functions in a wider and more application to further develop the internet + enterprise design.

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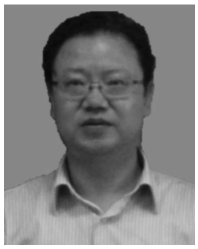
JIACHENG XIE received the B.Eng., M.Eng., and Ph.D. degrees from the Taiyuan University of Technology, Taiyuan, China, in 2012, 2015, and 2018, respectively, all in mechanical engineering, where he is currently a Lecturer in mechanical engineering. He has done many works mainly associated with virtual reality and modern design in coal mine equipment, such as virtual assembly and simulation system of mining, driving, and transporting equipment.

XUEWEN WANG is currently a Full Professor of mechanical engineering with the Taiyuan University of Technology, Taiyuan, China. He has conducted a lot of national and provincial research projects. He has supervised a lot of master's and Ph.D. students. His research interests include modern mechanical design theory and method, virtual reality design of mechanical product, and mechanical CAD/CAE.

ZHAOJIAN YANG is currently a Full Professor of mechanical engineering with the Taiyuan University of Technology, Taiyuan, China. He has held various positions in both the academic and the administrative field and has conducted a lot of national and provincial research projects. He has supervised a lot of master's and Ph.D. students. His research interests include modern mechanical design theory and method, mechanical equipment status monitor and fault diagnosis, and mechanical dynamics.



SHANGQING HAO is currently a Professor-Level Senior Engineer of mechanical engineering with Taiyuan Mining Machinery Group Co., Ltd., Taiyuan, China. He has held various positions in both the academic and the administrative field and has conducted a lot of national and provincial research projects. He has been engaged in professional technology and management work in the field of coal mine machinery for a long time.