Integrated CAD/CAM Software for Steel Tubular Truss Structures

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Abstract. Using ObjectARX, an integrated CAD/CAM software for steel tubular truss structures has been developed based on AutoCAD platform and Visual studio.Net environment. The design ideas and the application effects are introduced in this paper. Because of different data requirements in different design stages of steel tubular structures, i.e., the whole structure design and the detail design, a wireframe model and a solid model were adopted in the software, respectively. Joint lofting is the key point in manufacturing of complex tubular trusses. To solve this, 3D solid model was constructed by self-defined solid objects, which were designed with inheritance of class AcDb3dSolid in ObjectARX, and Boolean operation was used to realize 3D end lofting of branch pipes. Based on the lofted solid model, the G-codes can be generated automatically. At last, an actual tubular truss structure was designed and lofted by using the software. The proposed software package realizes the integration of CAD/CAM and it can greatly reduce the cost and time of design and fabrication, improve the quality of construction.

Introduction

In recent ten years, steel tubular truss structures have been popularly applied in variety fields of long-span space structures, such as large sports stadiums, railway stations and airports. For its good mechanical properties and aesthetic effect, direct intersection joints are more and more widely used in steel tubular truss structures. Generally in an intersection joint of tubular truss structures, the end of a branch pipe should be produced along the intersecting line, and then it is welded to external surface of the main pipe. This joint processing technology used to be considered difficult in manufacture. However, with the development of Computer Numerical Control (CNC) Machine Tools, all kinds of intersecting curves can be cut on branch pipes. The application of direct intersection joints of circle-hollow-section (CHS) in steel tubular truss structures has been strongly enhanced by CNC technology. Traditional structural engineering software is generally suitable for mechanical analysis. On the other hand, the structural design data has to be transferred to components blueprint, then the blueprint needs to be converted into cutting G-codes manually, which is required by CNC machine tools. It is considered as a very time consuming process [1] (shown as Fig.1(a)). Therefore, the integration of design and manufacture of steel tubular truss structure has been one of the most attractive issues in steel structural engineering. As a low cost, efficient, good manageable process, CAD package integrating to CAM system is well suited for steel tubular truss structures. Lots of manual operation for data converting could be saved in the CAD/CAM integrated design process shown as Fig.1(b).
Here in the study, an architecture is designed to develop an integrated CAD/CAM framework in Section 2, and some issues are taken into consideration: (1) How to solve different data requirements in design and manufacturing stages of tubular truss structure?. Data information needed by a structure design task is abstract member axis and load information. Neither joint dimensions nor groove data can be given according to the abstract structure model, which is necessary in the detailing design and manufacturing stages. The discussion will be presented in Section 3. (2) How to develop lofting method for complicated pipe joints, such as spherical joints? The traditional lofting method of web member ends are usually adopted solving the intersecting lines of cylindrical surface. Some complicated pipe truss joints could not be handled. This will be discussed in section 4.

The Framework of the Software

The architecture of the software. The architecture for the CAD/CAM integration software is set up to meet the requirements of both truss structure design and manufacturing process simultaneously. The existing CAD systems lack sophisticated data management facilities. This has contributed to little effective communication with CAM systems. CAD systems have also been unable to handle a large volume of information required for manufacturing process activities [2].

As shown in Fig.2, the integrated CAD/CAM software has various function modules, such as model-builder, structure analysis module, NC data generation module, etc. The most important part of such framework is the kernel data model, which is independent to outer function modules. The kernel data model for CAD/CAM integration, however, provides various interfaces for function modules to access the data [3]. And different module has different grade of limits of authority.

ObjectARX is used as the elementary tool to do secondary development based on AutoCAD. Engineering objects, which describe structural characteristics and components relationship of each
other, have been implemented as first-level objects in graphic database of AutoCAD. The composition of the software developing environment is shown in Fig.3.

**Object-oriented Analysis of Truss Structure Components.** An object-oriented method has been employed to define types of elementary components. Different kinds of structural components in tubular truss usually share some attributes. Thus, a base class may be set up to manage these attributes. The core data structure of the software system is built based on ObjectARX. The objects, which only have engineering properties without graphic representation, are inherited from the class AcDbObject or AcDbDictionary [4]. Other truss components, which need graphical representation, are inherited from the class AcDbEntity or AcDb3dSolid with 3D geometric entities and corresponding structure attributes.

Accordingly, these base classes will manage various properties of truss components, such as material type, style, size and direction of cross-section, and other commonly shared properties. The system has several predefined sorts of material types, including different grade concrete, and steel. Commonly used cross-section types, such as circle-hollow-section, circular, H-shaped, etc., are also predefined. In addition, user-defined section types are supported. Each type will have a corresponding code in the system, making an access to these types easier and faster.

Any given kind of structural component can be defined as a component class, derived from the base class. Top main chords, bottom main chords and web members are examples of simple components that can be directly derived from the base class without making many changes. Given the axial line that passes through the central point of its cross-section, any object of these three classes will be fully determined if the length or height is also specified. Its shape is obtained through the extrusion of the cross-section, implemented by a member function supported by the class AcDb3dSolid. Spherical joints, strengthening casing pipes and other structural components can be defined in a similar way except that their geometric parameters are more complicated.

**Data Storage Management.** A mass of data will be produced in the process of tubular truss design and fabrication. The data storage rationality becomes a key problem. If all engineering data were stored in the database of AutoCAD, the DWG file of the model would be too big to read and write efficiently. Therefore the database of AutoCAD and outer file system are utilized together to store the engineering model data. Graphic data, such as node and element objects, are stored as block table in AutoCAD database. Some data of the model without graphic representation are stored in Named Object Dictionary (NOD), which is a mapping from a string to an object. And these NOD objects can also be stored in another NOD of AutoCAD, forming a tree data structure. For other data of design results, such as internal forces and displacements of structures, will be stored in a series of files out of AutoCAD. The section and material libraries, which are often modified by users, will also be stored in outer files. The Data storage structure of the software is shown as Fig.4.
Mechanical Analysis Model to Detailing Design Model

The design and manufacture integrated procedure of tubular truss structure is consist of three stages, the integral design stage, the detailing design stage, and the pipe cutting preparation stage. Each working stage has different requirements about model data and functions. In the mechanical analysis model of integral design stage, the truss main chord is represented by its axis position, with its section and joint size omitted. Whereas in the latter two stages, the section and joint size is very important in the detailing design model. Even the weld groove shape and size data of every web member are needed in the cutting preparation stage. Therefore, two types of data model are adopted in the software. The two model relationship is shown as Fig. 5.

![Fig. 5 Two types of data model](image)

The mechanical analysis model is an axis wireframe model and can be transferred to a solid model needed in detail design and cutting preparation stages. Based on the solid model, web rod eccentricity and weld groove of cutting ends can be handled correctly.

Pipe Lofting and Manufacturing

The traditional methods for intersectional pipes end lofting are usually based on analytical solution of intersecting lines of cylindrical surface [5, 6]. The application scope of these methods is limited because complicated joints such as inserting plate joints and spherical joints can not be handled. In the proposed CAD/CAM software, a solid model for spatial multi-pipe intersection is established, and Boolean operation method is used for lofting branch member ends. This joint lofting method and procedure has good accuracy and high efficiency. And all kinds of sophisticated truss joint types can be processed including inserting-plate joint type and spherical joint type, shown as Fig.6.

![Fig. 6 Complicate stadium truss handled by software](image)
Summaries
Using ObjectARX, based on the AutoCAD platform and Visual studio.Net environment, the framework of integrated CAD/CAM software is presented. The run of this CAD/CAM software indicates it can work correctly. An actual stadium tubular truss is used as an example to showcase the power of the system, in which the computer aided design stage and manufacture stage can be performing seamlessly.

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