MODELING AND BEAM DYNAMIC VISUALIZATION IN CYCLOTRON VIRTUAL PROTOTYPING*

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Abstract

Cyclotron virtual prototype improves design quality, reduces the number of costly physical cyclotron prototypes and the time of product development, and delivers innovative new designs faster. This paper describes the overall lifecycle models of cyclotron via CAD system, which can be used in cyclotron virtual design, virtual assemble, virtual manufacture and other relevant domains. The 3-dimension models with physical information help designers in the research of cyclotron construct, and empower designers with the flexibility of parametric or alternative design. This paper introduces applications in virtual assembly and automated modeling and describes particle moving animation and beam dynamic analysis result visualization expression in cyclotron virtual prototyping.

INTRODUCTION

Traditional cyclotron design is based on a mass of experimentation. People first work from conception design to decide general performance of the cyclotron, then distribute performance features to the components of the cyclotron for technology design, finally, after having decide the parameters of the components, they would work at detail design, manufacture of trial-components, and validation by testing. In this process, it has been a tendency to study individual components in isolation, with relatively little emphasis on the often-intimate relationships between the various components, and the detection of the problems lied in the design mainly depends on testing. Because the testing of each components of the cyclotron hardly can reflect the actual situation of the whole cyclotron, the interaction of all the components can be found only after the whole is tested. Thus, the traditional design, including design, manufacture, testing, modification, remanufacture etc, is generally a very long process which makes developing cyclotrons with high cost and risk.

Virtual prototyping (VP) Technology is a digital-design way of developing products, based on computer simulation models. These digital models or virtual prototypes simulate the appearance, functions and activities of real objects. Thus virtual prototypes can be used to replace physical prototypes for realizing innovative design, manufacture, testing and evaluation. Due to optimization possibilities, main working functions of the designed objects can be enhanced.

The use of VP of products and devices has heavily influenced other industries, for example, in automobile and aircraft design, here we introduce this technology into developing cyclotrons. Our goal is to develop a VP system for cyclotrons, in which we can design, analyse, manufacture, assemble, control, and debug virtual cyclotrons in computer environment. It is necessary to validate the capability of this technology through rigorous and extensive comparison with data for known situations of real cyclotrons to confidence in its reliability for developing new type cyclotrons. It is unlikely that VP will ever totally replace traditional methods, but it certainly can reduce their cost by identifying the best approaches before building actual hardware.

Modeling and simulation visualization are very important in the whole VP architecture. VP model should be involved in product overall lifecycle of development and support applications in different domains. Science data visualization techniques are used to allow better understanding of VP performance.

VIRTUAL PROTOTYPE MODELING

The virtual prototype is defined as a function, photo realistic, and three-dimensional digital model. Besides visualization, designers need to know the physical attributes, such as dimensions, weight and material [1]. Our cyclotron virtual prototype models are generated from CAD system since the current CAD system has had a very long developed history with a powerful capacity. Although they are often not as accurate as physical ones, improvement in CAD system is narrowing the gap, which can provide enough of key features to allow analysis, testing, and manufacture for the requirements of developing cyclotrons.

Modeling Characteristics

In modeling environment, we can directly build three-dimension cyclotron models according to the imagination of the designers. They have some basic characteristics including:

- Feature-based modeling;
- Parametric driving;
- Uniform database.

In product overall lifecycle, there are different types of information, for example, design information, manufacture information, management information, etc. We require cyclotron models include not only geometric data but also other data. The feature-based modeling is a way of expressing information, and the use of feature allows the association between the shape and functionality. For example, a shape feature is a special shape composed of a group of geometric elements with topological relationship such as cylinder and cone, an

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assembly feature describes the information of assembling parts, an attribute feature may express mass and material, and a technological feature may express design tolerance. Actually, A model is composed of all kinds of features, which can create high-level representations of product.

The primary model is generated from the conception of designers, and in product overall lifecycle, it need continually to be modified and consummated by experts from different disciplines together, because the same model can be expanded later as more detail is required. The modeling is the process that all kinds of features are continually created and modified according to planning feature tree.

As mentioned above, each model can be disassembled into finite types of features. But each type of feature can be constrained by finite parameters in the same way. That is a parametric driving characteristic. In three-dimension CAD system, we constrain the dimensions of cyclotron parts by parameters, so a desired new model will immediately be product only by changing the value of these parameters. In this case, cyclotron models are more easily and quickly modified and controlled, and the ideas of designers are expressed better.

Model data is managed by uniform database, which make a model be shared in modeling environment. It means that in modeling process, when designers modify a model in any place, all data associated with the model will refresh. For example, if a sector pole changes, the cyclotron assembly will show the change at one time. It is clear that we must do more work in limited time for shorting the cycle of developing product. The database management supports concurrent design that allows several engineers to take part in modeling together by local area network (LAN).

We express abundant product information by the greatest extend, which meets the needs in different phases of developing cyclotrons. The same model in different application domains has consistent information description for share. The modeling way also supports top-down and down-top designs.

Applications of Cyclotron Models

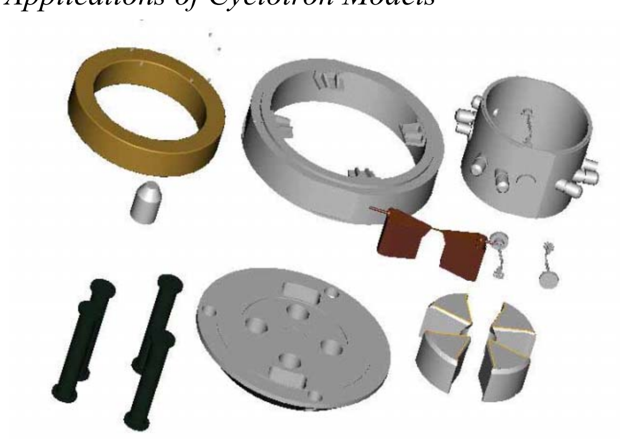

Figure 1:10MeV cyclotron parts.

We have built cyclotron parts (see figure 1), and a proficient CAD engineer can almost create any complicated part. For convenience of other researchers, we have created program automated modeling based on model feature-program. If we reedit it, it can automatically create the same type of models without trouble drawing. Therefore, an ordinary researcher can also create a complicated part only by inputting some parametric value in interactive interface. Due to similarity of one type of parts, we can conveniently create a serious of part family. Therefore, it avoids a great deal of work of repeated modeling and provides a possibility of multi-project comparison and evaluation with a serious of similar models.

An assembly is a collection of bodies (also called parts or subassemblies) in some given placements. We have assembled parts together with constraint relationships, and finally become a cyclotron VP assembly model (see figure 4). Designers have often made a mistake in product assembly before. They couldn't find the problem until products were manufactured. With virtual assembly technology, we can simulate assembling process, check interference and optimize assembly planning in computer. Now we can ensure the validity of design early in design phase.

We can research cyclotron from different viewpoints by the VP model. In VP environment, the model should support design, analysis, manufacture, and simulation. When we project tree-dimensional solid models to plane for drawing, we can get all kinds of drawings such as section drawing, assembling drawing, detail drawing and perspective drawing. And besides, we input technological data and explanation in these drawings in order to meet the engineering requirements completely. In cyclotron analysis, there are mainly magnetic analysis, RF analysis and beam dynamic analysis, which all use three-dimension solid models to replace hardware analysis. For example, in magnetic analysis, the main body model is meshed into a lot of grids and then we analyse magnetic field in ANSYS. Through feedback from these analyses, we evaluate the virtual prototype, then if we dissatisfy it, we may modify and analyse it again. The satisfied VP model will continue to research his feasibility of manufacture. For example, we may simulation the manufacture process in computer environment. Therefore the cyclotron model should support the product overall lifecycle management (see figure 2).

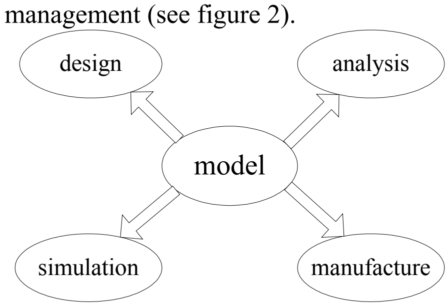

Figure 2: Cyclotron modeling framework.

We have already known that VP system is composed of these application modules above. Each module needs to utilize the VP model. It brings a question: How the model data can be exchange into each module? Because currently each module is independent relatively with own data format, the preferred technology for exchange of product model is based on using a neutral format, which is capable of capturing design intent, or in more recent terminology, product model [2]. STEP, the international standard for external representation of product data, aims to represent a compatible and integrated model data with a neutral format in product lifecycle, which is independent of any CAX system. We have used it to exchange model data between CAD module and other modules, and proven reliability of STEP. For example, figure 4 shows the VP model in simulation module.

BEAM DYNAMIC VISUALIZATION

Experimental methods remain the primary source of design information. On the other hand, because of the advance in computational technology, numerical predictions of cyclotron performance have become feasible and are beginning to produce results consistent with experiments. Appropriate visualization methods are needed to monitor and verify the results from numerical simulation. It transforms numerical data into computer-generated images. It includes three-dimensional computer graphics rendering, time series animations, and interactive display on computers. An example of beam dynamic visualization is introduced here.

We first import the cyclotron model into simulation module. Through beam dynamic analysis software, we obtain the numerical results of beam acceleration. To designers, the most concerned result is total phase excursion of beam, which shows a tendency chart with sector pole radius in Fig. 3.

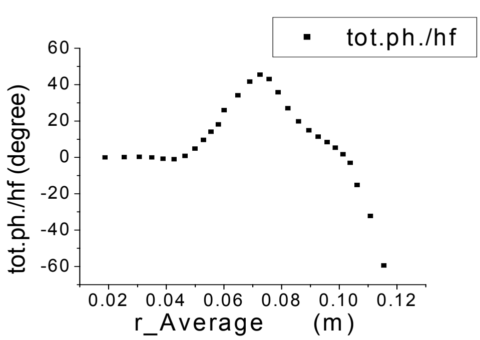

Figure 3: Total phase excursion

It is hard to create a actual motion equation of beam in beam dynamic simulation. Considering we don't take care of any special velocity and acceleration of beam, it become simply by beam track. In simulation module, beam is driven by the track spline. We can observe beam accelerate process in three-dimensional environment. Meanwhile, the total phase excursion change is displayed in graphic way. The figure 4 is a picture of beam movement, in which we can see a total phase excursion.

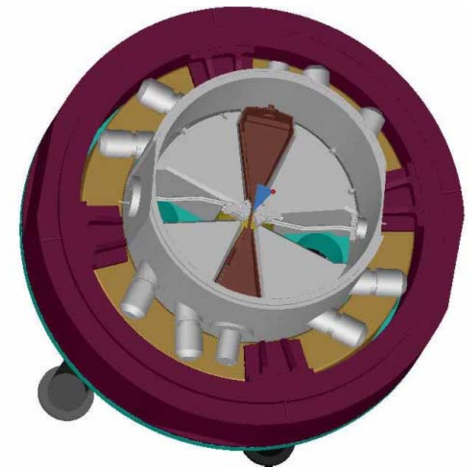

Figure 4:Beam dynamic visualization.

However, we purposely chose an imperfect result that most of beam cannot accelerate final energy in this simulation because of too large total phase excursion. It obviously shows the magnetic field of the cyclotron should be shimmed to close the isochronous. We should modify the sector pole edge for the magnetic field adjustment in modeling environment, and evaluate the performance again to get the most promising cyclotron. It also expresses an advantage of evaluating cyclotron with virtual prototypes.

CONCLUSION

This paper mainly describes CAD and visualization aspects in Cyclotron VP system. Modeling technology has already met the requirement of developing cyclotron. Visualization provides an aided method for understanding design intent better. Future work will focus on verifying VP with measurement data of real cyclotrons.

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