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The Application of 3-D Solid Modeling to Reactor Vessel Internals

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SUMMARY

The process to develop a reactor internals design for an advanced pressurized water reactor using 3-D modeling techniques and the interface with analysis applications is presented. Examples are given of specific reactor internals components and a discussion of the model development is provided. A discussion of the component models is presented as a series of individual components with increasing levels of complexity consistent with the way the models were developed. The design process to optimize the design and the iterations to establish compatibility with interface components, engineering disciplines and manufacturing is discussed. The experience obtained between the 3-D design model and the interface with analysis applications is described including the lessons learned reinforcing the importance of concurrent engineering. The discussion concludes with a summary outline of the design models and how they are integrated into the overall system.

INTRODUCTION

In today's global infrastructure it is necessary to present design information in a precise unambiguous manner. Component design may be conducted at one location, analyzed at another, with manufacture and installation at still other locations. Considering the goal of constantly improving the overall plant schedule from first concrete to fuel load, the reactor internals design process consisting of design, analysis and manufacturing must be expedited to release the designs for material procurement and subsequent manufacture. The process of concurrent engineering is augmented by the quick turnaround time of design iterations that is afforded after model development. Configuration control is better maintained since the reactor internals design model is available to interface disciplines such as analysis and manufacturing. Availability of 3-D models of the components allows engineers in geographically separate locations to work on their portion of the design while reducing the margin for error since all the personnel are working from the same database. In order to meet these aforementioned challenges it was necessary to transition from a 2-D design to a 3-D design tool for reactor internals design.

The reactor internals are an excellent application for a 3 dimensional software application with design analysis capability since the reactor internals are complex precision structures that typically interface with many other components and engineering disciplines.

DEVELOPMENT OF MODELS

The objective is to optimize the design of the reactor internals components by use of a design model in conjunction with a design analysis application. The model is then available for use by the analytical engineers for further detailed analysis as part of design and analytical evaluation processes. In conjunction with this effort, the model is available for interface and manufacture evaluation. In order to meet the objectives, training was provided not only to the component designers but also to the analysis personnel. The decision for cross training was particularly beneficial when the designs were developed to the point that they were ready to be imported into an analysis application. It also became clear that all participants must contribute to the development of the model since it will assist interface groups in their use of the component design model.

Presently, the individual components, which make up the reactor internals, have been modeled without direct parametric links to each other. Dimensional features that are controlled from interface components are defined in the respective models. For a model, or component, the manner in which these interface dimensions are controlled is dependent on both the types of features and personal preferences. There are specific techniques that can be employed to control these interface dimensions. The same method, or specific file, that was used to control features in a specific model can be used to control features in multiple models.

The specific techniques employed were unique to the software package used (Reference 1). During the following discussions on the individual components, reference is made to two techniques. These techniques are a "map part" and "layout table". A "map part" is a frame model that has some non-solid, non-mass features to define key component features or interface geometry. The geometry can include parametric relations, relative to other geometry. The "map part" technique produces a pictorial representation of the frame model. The second technique, "layout table", also controls component or interface geometry but does so in a traditional table format. The table can include raw feature dimensions, or formulas that control a feature as a function of other features. Any component model that is affected by a feature or geometry defined in the map part can be parametrically linked to the layout table. It should be noted that these techniques are not specific software commands, but are methods of implementing various commands or processes that are unique to the 3-D solid modeling software used.

These control techniques offer some advantages over simply defining the respective feature or interface within each individual component. These are:

High level features / dimensions can be modified or controlled by a task manager or supervisor.

Often the features being controlled affect multiple components. These techniques minimize or eliminate redundancy by having one piece of data control multiple components / models.

One file (either the picture from the map part, or the table for layout table) conveniently defines the interface features / dimensions. Any or all of the data contained in this one file can be used in many component models, and by many designers. This speeds up the design process and simplifies the review process.

In addition to controlling interface features with these modeling techniques, they can also be used to define standard parts or even features. Additional details can be added, or modifications to the standard can be defined in the model of the specific component.

These techniques were used in developing the design from a top - down, or high level system information to detailed component level, approach. The opposite approach can also be used. There are tools within the 3-D solid modeling design package, which allow the designer to develop a component, and then later redefine the model to incorporate interface controls, or even parametric relationships. The following component model descriptions provide some specific examples of model development for reactor internals. The core support barrel was chosen as one of the first models because of its geometric simplicity relative to other reactor internals components.

CORE SUPPORT BARREL

Model Description

The Core Support Barrel (CSB), in a general sense, is a right circular cylinder with 2 horizontally opposed nozzles intersecting the cylinder, with upper and lower flange arrangements. In addition, there are key way bosses mounted on the outer surface. The overall dimensions vary depending on the size of plant, but for a typical application the diameter is 12 to 13½ feet by 31½ feet in length. The structure, although large, has a number of small radii and features that make up the component. See Figure 1 for an overall assembly view of the CSB component.

Modeling Technique

Various factors played a role in selecting the "map part" method for setting up the model for this component. Some of those factors included:

- An evaluation of the basic design shapes,
- consideration for how this component would be constructed,
- a knowledge of what interface features would impact the design, and,
- a desire to have a pictorial representation of the main controlling features / dimensions.

Model Geometry to Analysis Interface

The core support barrel model was used to transfer model geometry from the solid model to a finite element (FEM) analysis package. Traditionally, the core barrel flanges have been modeled using axisymmetric elements. In order to transfer this 2-D information from the 3-D model, a cross-section was taken and then exported to an IGES file. ANSYS® imported the IGES file and a meshed representation of the flanges was easily created. The purpose of the transfer of model geometry was to verify the ease of interface between the design and analysis application.

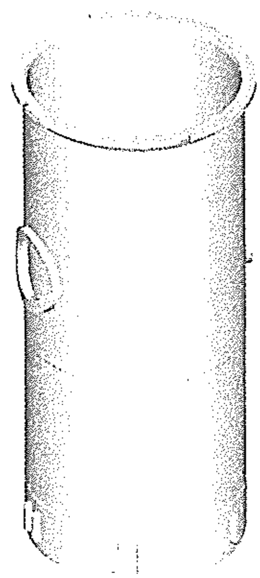

Figure 1
Core Support
Barrel Assembly

Model Benefits

Often 3-D features are difficult to properly visualize. In this example the component geometry is relatively simple however proper visualization of the less salient features of the component was achieved, including details of the inside surface of the nozzles and their intersections that consists of intersecting curved geometry. This information is useful for the fabricator and material supplier of the complex forged and machined shape.

LOWER SUPPORT STRUCTURE ASSEMBLY

Model Description

The Lower Support Structure Assembly is comprised of two major subassemblies, the Lower Support Structure (LSS) and the In-Core Instrument Support Structure (ICISS). Each is discussed separately. See Figure 2 for an overall assembly view of the Lower Support Structure Assembly.

The main function of the LSS is to provide vertical support to the reactor core. The main components are deep beams welded in a box like structure within a cylinder. The ABB CENP Reactor Vessel design features bottom entry In-Core instrumentation. Therefore, there are features in the LSS that interface with the support for this instrumentation.

The ICISS is comprised of the hardware that supports the In-Core Instrumentation. A support tube for each instrument provides a path from the nozzles in the Reactor Vessel Lower Head to a tube in the fuel assembly. The instrument tubes are supported from the LSS by a complex geometry of a flow plate and support structure.

Modeling Technique

The placement of the ICI beams is a complex 3-D problem. It is a goal to place the beams in an equally spaced manner on the ICI plate. Interference with the support tubes and their gussets must be avoided. In addition, the beams must interface with the bottom of the main beams. In developing the model, it was recognized that the locations of the beams would have to be mostly a trial and error process, so a method to easily change the beam locations was performed. The beam end locations were defined relative to datum points in the model. The datum point locations were controlled by a layout table, which controlled other components and features. Therefore, the data in the table controlled the beam locations, boss locations and plate hole locations.

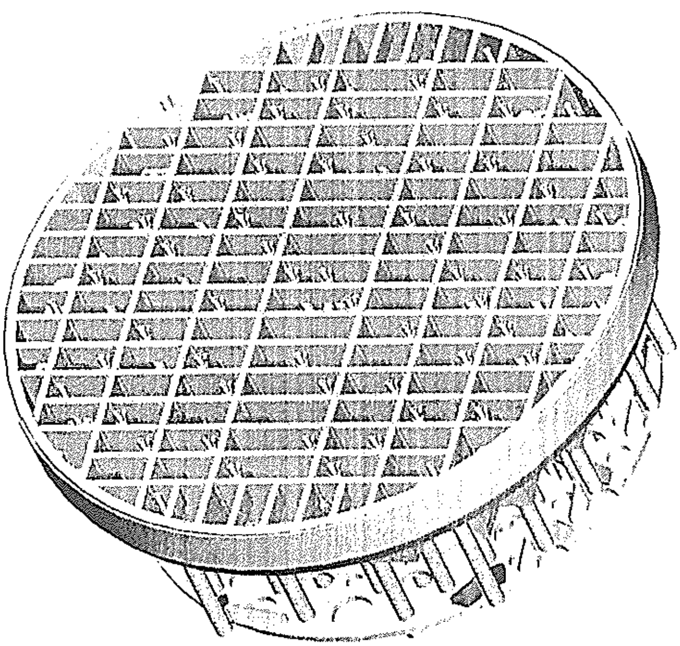

Figure 2, Lower Support Structure Assembly

Model Geometry to Analysis Interface

The ICI Plate was used to test the solid model to FEM interface. The ICI Plate has a number of flow hole sizes and is attached to the ICI Support Structure. A mid-surface compression representation of the plate suitable for shell modeling was created. The IGES file created was imported by ANSYS® and a shell model was easily created. This process is not only fast, but ensures that the analyst uses the latest plate geometry.

Model Benefits

A solid modeler provides various tools to obtain information about the model. One of these tools checks for interference or calculates minimum clearance between components. This tool, used with the layout table that allowed for fast model changes, facilitated the trial and error process of finding acceptable ICI beam locations. The process reduces cycle time of days to hours and also provides the hydraulic engineer the opportunity to evaluate the interface geometry with a reduced cycle time.

INNER BARREL ASSEMBLY

Model Description

The main function of the Inner Barrel Assembly (IBA) is to protect the Control Element Assemblies (CEA's) from cross-flow during reactor operation. The IBA is comprised of tubes and panels arranged in a grid type structure. The structure is supported by the Upper Internals. See Figure 3 for an overall assembly view of the Inner Barrel Assembly.

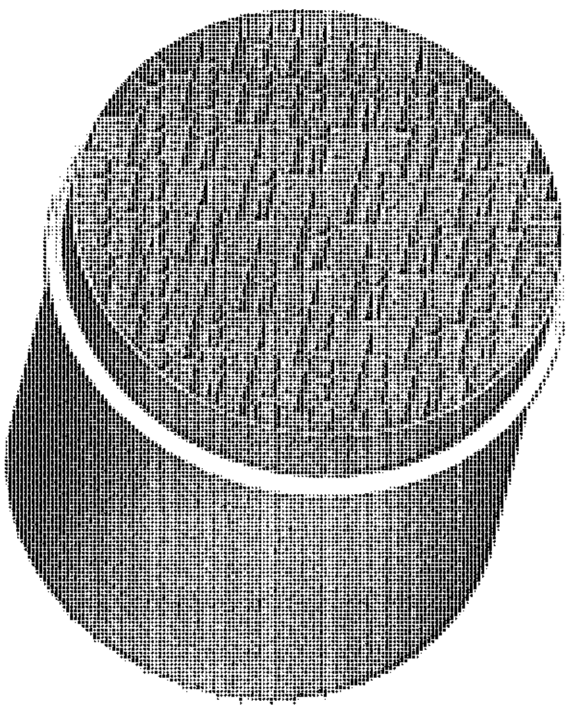

Figure 3, Inner Barrel Assembly
(top plate not shown)

Modeling Techniques

The top plate of the IBA, not shown in Figure 3, is of special modeling interest because of the complexity of the features. The features of the plate are symmetrical in four quadrants. Therefore, the features of one quadrant were created and mirrored to represent the features of one half the plate. However, because of the complexity of the features, the mirroring required about an hour of computer time. Mirroring the features of one half the plate to complete the model of the plate took about ten hours. This computation time is repeated each time a change to the model must be made and makes modeling and working with the top plate extremely difficult.

Model Benefits

The difficulty in modeling the top plate is an excellent example of how the specific methods of creating features affect the model. Identical features can be created with the solid modeler using various commands and techniques. The experience and knowledge of the design modeler can make a significant difference in how efficiently the computer processes the information.

CORE SHROUD ASSEMBLY

Model Description

The function of the Core Shroud Assembly is to provide a path for the coolant through the reactor core, minimizing the bypass flow. The core shroud components, being directly adjacent to the reactor core, is subjected to heating from the core. It is necessary to limit the thickness of the components of the core shroud to limit the thermal stresses. However, the core shroud must maintain structural integrity during the normal operational and postulated accident loads. These conflicting requirements make the design of this structure a particular challenge. The shroud is basically a folded plate structure reinforced by a series of rings, flanges and stiffeners as shown in Figure 4.

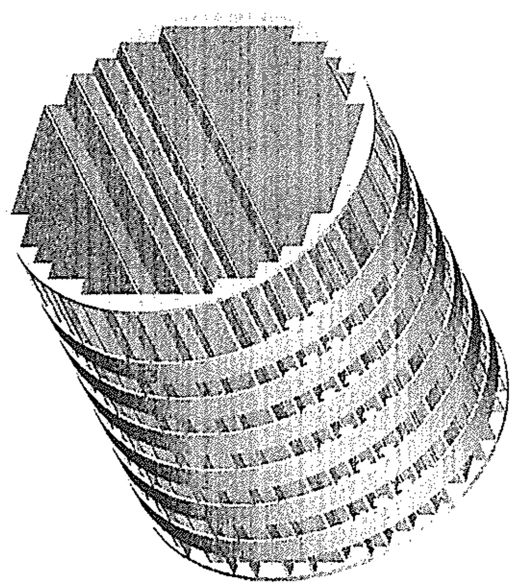

Figure 4, Core Shroud Assembly

Modeling Technique

A primary feature of the core shroud is the use of circumferential rings outside of the folded plate structure. The number of rings and their placement on the core shroud model is controlled by parameters in the layout table.

Model Geometry to Analysis Interface

A 3-D Core Shroud model was used to create a mid-surface representation of the shell model. First, simplification of the geometry was performed. This is common practice in FEM modeling. The designer was able to create what the analyst desired. However, as is often the case with complicated geometry, the information from the IGES file required some adjustments in ANSYS to obtain an acceptable meshed model. With proper communication between the designer using the solid modeler and the analyst using an FEM analysis tool, overall timesaving can be realized while ensuring accurate transfer of the geometry.

Model Benefits

Since it was recognized that due to the complexity of the task and the number of interfaces that there would be a number of design iterations to establish an acceptable design, the layout table was chosen. Parameters could be varied thereby providing iterations of the design for subsequent evaluation.

The use of this feature allows for fast and easy changes by the designer and interface engineering disciplines to assess the effect and significance of modifications to the design of the structure.

PROCESS ENHANCEMENTS

Parametric Control

The models that have been created at this juncture are basically stand alone for each of the individual reactor internals components. Future development of the design process for the reactor internals is to develop the models to the extent that changes made at the component level modifies the assembly accordingly. Similarly, changes to external interfaces would more readily be accommodated within the individual components.

Interfaces

One of the objectives of incorporating the use of the more advanced features of the software application is to augment the design and analysis process. As the interface between the various design entities becomes more interactive a better understanding of how a given model would be utilized becomes imperative. A model that is established by the designer and used for fabrication may be too detailed for structural analysis. There are techniques available in which features unnecessary for one group, such as analysis, can be suppressed. Incorporation of these types of features is important for the efficient development of a model. The model is least affected by the individual needs of the different disciplines if it is structured so specific features may be suppressed without requiring a re-definition of feature parent - child relationships.

An additional area for improving interfaces is when portions of a design are conducted in different companies, or even different countries. This adds additional complexities, but sharing of 3-D solid models can only improve the communication process. Utilizing a software package that is more universal among the entities improves the direct compatibility.

Standardization of Model Structure and Format

Because of the various techniques available to create a model, the approach used to model any given component could be quite varied. This can create problems when multiple individuals need to access, or modify, the same model. Time is lost if a user can not readily understand what controls the model, or how to modify the design without requiring major re-definition. A standardized approach to model structure, such as relationships, layer creation, datums, coordinate systems, and feature dependencies are more easily followed by all users.

Manufacturing Interface

Often it is very difficult to give quick quantitative assessments of a design modification that would make the design easier to manufacture. Many times the design goes through an iterative process that takes substantial evaluation time between discussions and eventual agreements. A task for further development is to have manufacturing become familiar with the 3-D solid modeling tool. The use of the 3-D model would greatly improve the understanding of the complexity of a component. A large benefit would be the ability for manufacturing to use the model, to create shop drawings, travelers, and other manufacturing related documents. Each of these would parametrically update as the designer updates the model.

Integrate Design Parameters with an Engineering Database Management System

This paper has described a number of methods for defining dimensions or features in one file and having them affect multiple models. Many of the dimensions or features originate from other sources outside of the solid modeler. Outside source input may originate from calculations, specifications, customer drawings, or other non-model documents. The control of this original data will eventually be within a Database Management System. Links or connectivity between the solid modeler and the Database Management System would expand the boundary of control of this information.

Besides the Database management, file management becomes an important issue in a 3-D solid modeling tool. The file manager needs to encompass various issues from naming conventions, access controls, file version locks, and write permissions.

CONCLUSIONS

It is clear that the design process requires the contribution from many individuals but the process can no longer be performed in a series operation and still meet program objectives relative to schedule. The designer, analyst and other entities must work together early in the process so that the total process is complementary. There remains many ways to improve and streamline this process, but in this early phase it is evident that a parametric 3-D solid modeler provide substantial benefits. Increased quality and reduced cycle time are only a few of many benefits.

REFERENCES

1. Pro/ENGINEER , *Introduction to Pro/ENGINEER, Release 20*, Parametric Technology Corporation, Waltham, Massachusetts