SOLIDS MODELING IN REMOTE EQUIPMENT DESIGN

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ABSTRACT

Solids modeling is the most advanced method of three-dimensional (3-D) design. It allows locations on the surface of an object to be determined as well as locations inside or beyond the object's boundaries. This advanced technique for drawing permits sectioned views that show structure and shape anywhere within an object. Used as a remote equipment design tool, it gives an engineer greater flexibility for rapid changes and the capability for simulating objects, equipment, and facilities via a prototypic computer model. In addition it provides engineers with the capability to precisely locate components on equipment or to accurately position equipment in remotely operated facilities prior to actual fabrication.

INTRODUCTION

Solids modeling is the remote equipment design tool of the future. With this advanced design tool, designers and engineers can develop improved and more reliable remotely operated components.

APPLICATION

The mass properties for an assembly or for any individual part of an assembly can be determined from the solid model. From the model, the centroid, volume, mass, moments of inertia, radius of gyration, and surface area can be computed. The 3-D solid model can be transferred directly into many two dimensional (2-D) computer-aided-design (CAD) and finite element analysis (FEA). Commercially available software packages were used for all solid modeling.

This form of CAD has been used to design remotely operated equipment for use in Pacific Northwest Laboratory's (PNL) a shielded hot cells at Hanford, Washington. Computer-generated solid models were created for the installation equipment and operating equipment used for the bench-scale slurry-fed ceramic melter (SFCM) of the Hanford Waste Vitrification Project (HWVP). Disassembly equipment was modeled for the existing remotely operated radioactive liquid-fed ceramic melter (RLFCM).

A remotely operated SFCM was designed by modeling the assembly (Figure 1). The model was then imported into a 2-D CAD drafting program and fabrication drawings were produced. The time to fabricate the SFCM will be reduced significantly since the fit and function of all the components were analyzed prior to construction. Minimal modifications will be required during subsequent assembly and testing.

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FIGURE 1. Sharyed Ceramic Melted Solid Model (Upper Left: Stainless Steel Melted Outer Shell; Upper Right: Second Layer Thermal Barrier; Lower Left: Third Layer Low-Density Latticized Ceramic with Discharge Opening; and Lower Right: Fourth Layer High-Density Refractory Chamber).
and assembling the four subassemblies into the final model. After the solid model was created, 2-D fabrication drawings were produced. The mass properties were calculated for the whole assembly from the solid model. Finite element structural analysis and a thermal analysis was aided by incorporating the solid model into other software packages.

Computer-generated solid models were created for several specialized tools used to remove the refractory blocks which form the melter cavity in the RLFCM. A single cylinder refractory grapple was designed by modeling the assembly. The model was then imported into a 2-D CAD drafting program and fabrication drawings were produced. The time to fabricate the remote grapple was reduced significantly since the fit and function of all components were analyzed prior to construction. No modifications were required during subsequent testing of the grapple.

A. Conceptual Design of the Solid Model

Three restraints governed the conceptual design of the SFCM: the overall size, the size of the inner melt chamber, and the location of associated equipment in the hot cell. Four materials of different densities were used in the design. The outer shell was stainless steel (Figure 1). The other layers included a thermal barrier, a low-density castable ceramic, and a high-density refractory chamber (Figure 2). All four layers were individually modeled with separate components, and the size of each checked for form and fit. After each material layer was checked it was incorporated into the next material layer, and the fit between the two layers was confirmed. This process was repeated until the entire assembly had been checked. In the event that either the individual components or one material layer did not fit, changes could be readily made. Section views could also be generated to illustrate the internal relationship of each component of the assembly. Sectioning the solid model assembly allows the engineer to visually confirm the location and fit of each component.

B. Determination of Mass Properties

The advantage of constructing a 3-D solid model is that each part of the assembly can be assigned a particular material and density— in this case, 8.03 g/cm³ for the 304L stainless steel.

FIGURE 2. Slurry Fed Ceramic Melter Two Dimensional Fabrication Drawing.
stainless steel layer, 3.9 g/cm³ for the refractory chamber, 0.4 g/cm³ for the thermal barrier, and 2.8 g/cm³ for the castable ceramic layer. For remote installation and operation, it is vital to locate the assembly's center of gravity and all the lifting points. For irregularly shaped objects or entire assemblies, this calculation would be a lengthy manual process, but with solid modeling the program completes the calculation. Table I lists the mass properties generated from the SFCM outer shell solid model. The mass properties are calculated according to the materials associated with an assembly or solid. The calculations produced from the solid model are extents mass volume, surface area, radii of gyration, centroid, moments of inertia, products of inertia, principal moments, and principal axis. The extents calculation is very important in designing remote equipment, as it is the smallest possible box that will contain the entire assembly. The centroid location is the center of mass and reflects how the volume of the object is distributed, and locates a point around which lifting or support points can be located. The accuracy of the generated mass properties is dependent on the subdivision level and decomposition direction selected. The error estimation and standard deviation are calculated and shown in the generated calculations.

C. Solid Model to Fabrication Drawings

After establishing the exact size and shape of each individual component in the 3-D solid model, the entire assembly can be transferred to a 2-D CAD program (Figure 2) in one of two ways: 1) by creating either an International Graphics Exchange Specification (IGES) file or a Drawing Interchange File (DXF). Typically, these two types of files can be transferred from one software system to another without losing the integrity of the solid model; 2) by listing the exact surface and feature size of the individual components of the solid. For small models or models with smooth contours or features, this process could be used. Using a CAD program, each component can then be drawn in 2-D using orthographic projection.

When drawing the components and assemblies, the required tolerancing can be incorporated into the process. Once the equipment is drawn in 2-D, each component can be checked with its counterpart in the solid model. Any changes which may be required due to tolerance stack-up can be noted and changed on both the 2-D and 3-D solid model. After these confirmations and corrections are completed, the final 2-D fabrication drawing can be completed with confidence that each part will fit in its proper location.

### TABLE 1. Mass Properties Generated from the SFCM Solid Model

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass</td>
<td>706 lbm</td>
</tr>
<tr>
<td>Volume</td>
<td>2.4E+03 in³</td>
</tr>
<tr>
<td>Extents</td>
<td>X = -28.6 to 28.6 in Y = 0 to 54.5 in Z = -2.01 to 55.8 in</td>
</tr>
<tr>
<td>Centroid</td>
<td>X = -0.0111 in (5.60) Y = 116 in (41.5) Z = 63.6 in (34.4)</td>
</tr>
<tr>
<td>Mass</td>
<td>706 lbm</td>
</tr>
<tr>
<td>Volume</td>
<td>2.48E+03 in³ (425)</td>
</tr>
<tr>
<td>Approximate Surface Area</td>
<td>2.5E+04 in²</td>
</tr>
<tr>
<td>Moments and Products of Inertia</td>
<td></td>
</tr>
<tr>
<td>Moments of Inertia</td>
<td></td>
</tr>
<tr>
<td>lxX</td>
<td>1.25E+06 (4.12E+05)</td>
</tr>
<tr>
<td>lyy</td>
<td>4.86E+05 (1.19E+05)</td>
</tr>
<tr>
<td>lzz</td>
<td>9.71E+05 (3.97E+05)</td>
</tr>
<tr>
<td>Products of Inertia</td>
<td></td>
</tr>
<tr>
<td>Pxy</td>
<td>-109 (5.44E+03)</td>
</tr>
<tr>
<td>Pyz</td>
<td>3.82E+05 (9.07E+04)</td>
</tr>
<tr>
<td>Radii of Gyration</td>
<td></td>
</tr>
<tr>
<td>Rx</td>
<td>42 in.</td>
</tr>
<tr>
<td>Ry</td>
<td>26.3 in.</td>
</tr>
<tr>
<td>Rz</td>
<td>37.1 in.</td>
</tr>
</tbody>
</table>

Principal Moments (PM) and Directions (i j k) about centroid:

PM[1] = -1.12E+07 along [0.0000569 - .48 .877]  
PM[2] = 2.76E+05 along [8.15E-05 - .877 - .48]  
PM[3] = -1.11E+07 along [1 0.000345 - 0.00046]  

The values in parentheses indicate the estimated error with the corresponding property.

Property values are with reference to the modeling coordinate system.

RESULTS

At PNL, solid modeling has been used as the design basis for the fabrication drawings for the RLFCM disassembly tools and the IIWVP bench-scale SFCM. Based on the success with the single cylinder refractory grapple, zero or minimal design changes are expected during construction of the SFCM.

Solid modeling is clearly the remote equipment design tool of the future. It reduces design cycle time and helps to avoid costly changes. It permits more options to be considered before costly fabrication commitments are made. Most importantly, with this advanced design tool, designers and engineers can develop improved and more reliable remotely operated components.