The New Digital Engineering Design and Graphics Process

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Abstract

With current computer-aided design technology, the traditional tasks of a designer, drafter, analyst, and prototype maker are all performed by a single engineer using modern digital engineering design tools. These digital tools include computer systems with 3-D solid modeling software, seamless links to engineering analysis and manufacturing simulations, and digital interfaces to rapid prototyping machines. While these new technology tools have been developed and are commercially available, they have not yet been integrated into mainstream engineering graphics education as the contemporary curriculum. This paper will summarize the digital engineering design process using current software that is widely available for the educational setting.

Introduction

The discipline of Engineering Design Graphics has been a cornerstone for engineering education for almost a century. During the majority of that time, the curriculum has centered on instruction in graphical techniques to solve spatial problems and to make orthographic engineering drawings. The past two decades have witnessed dramatic changes in the types of tools and techniques used by engineers to solve graphical problems. The field has gone from using drafting boards, to computer-aided design and drafting systems, and now to 3-D featured-based solid modeling. The power of this latest digital design paradigm is only now being realized as low-cost analysis, simulation, and rapid prototyping software and hardware systems are becoming available for educational use (Ault, 1999; Barr, 1999; Cole, 1999; Newcomer, McKell, Raudebaugh, & Kelley, 2001; Tennyson & Krueger, 2001).

Computer Sketching

Sketching is a natural element of creative ideation, and is the beginning of the engineering design process. Modern parametric modeling software starts with a 2-D sketch on a planar grid. While computer sketching may be more accurate than manual freehand sketching, computer sketching still retains a certain creative feeling. To aid in this computer sketching, the software offers a variety of 2-D primitive selections, such as line, circle, rectangle, arc, spline, and ellipse. In order to complete these 2-D profiles, the software includes 2-D editing functions such as extend, trim, mirror, offset, and array. Parametric dimensions and other geometric constraints are then added to the sketch to initially fix the geometry. When a 2-D sketch profile is complete, such as shown in Figure 1, it is then either extruded or revolved to form the 3-D base of the part.

Feature-Based Solid Modeling

The base part, such as shown in Figure 2, is usually not a finished model. Additional material removal and/or material thickening may be needed to accurately represent the final 3-D geometry. Different workplanes can be positioned in the modeling space, more 2-D sketches can be created on these workplanes, and these secondary profile sketches can then be used to cut through the base part or to add more material. Also, common design features, such as fillets, rounds, chamfers, ribs, bosses, cuts, and holes, can be created with simple commands that do not require sketches. A finished part of an automotive piston, with all needed features, is shown in Figure 3.

Modification of Parametric Solid Models

Sometimes it is necessary to modify the geometry of a completed 3-D geometric model.

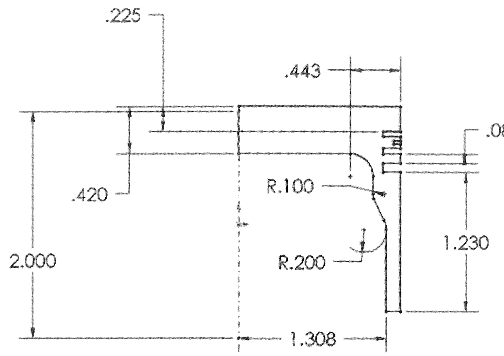

Figure 1 *A 2-D Parametric Computer Sketch*

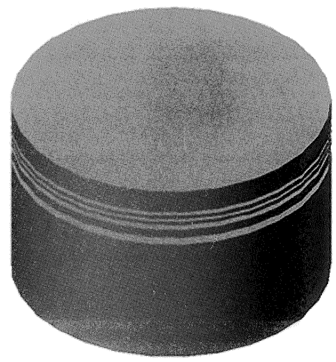

Figure 2 *The Initial 3-D Base Solid Model*

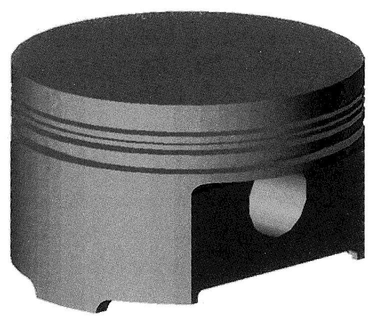

Figure 3 *The Finished 3-D Solid Model of the Cylinder Head with all Features Added*

With parametric modeling software, these modifications are simplified. For example, to change the dimension of a particular design feature, the user can simply revise that dimension on the 2-D sketch that created the part, and then re-build the model. Ability to quickly re-adjust dimensions of a designed part is one of the major advantages of parametric modeling software.

Analysis of Solid Models

One of the advantages of the new digital design approach is that physical properties and behavior of the solid material can be analyzed without actually embodying the part. One example is mass properties analysis. Once the model is built, the user can assign a material (or density) to the part, and then select the appropriate command to generate a "Mass Properties Report" (MPR). The report can be saved in a file and, if needed, imported into a technical document. Typical parameters included in this MPR are: mass, volume, surface area, center of mass, and moments of inertia. A typical MPR report for the part in Figure 3 is shown in Figure 4 for a density of 0.281 pounds per cubic inch.

Another analysis amenable to the solid modeling environment is Finite Element Analysis (FEA), which is quickly becoming a powerful tool for computer-aided mechanical analysis and design. In many cases, the FEA software can now be accessed inside the parametric solid modeling software command structure. To start, the user builds the solid model part,

Density = 0.281 pounds per cubic inch
Mass = 1.264 pounds
Volume = 4.499 cubic inches
Surface area = 49.272 square inches
Center of mass: (inches)
X = 0.000
Y = 0.542
Z = -0.001
Principal axes of inertia and principal moments of inertia: (pounds * square inches)
Ix = (0.000, 0.001, 1.000) Px = 0.894
Iy = (1.000, 0.000, 0.000) Py = 1.018
Iz = (0.000, 1.000, -0.001 Pz = 1.442
Moments of inertia: (pounds * square inches) Taken at the center of mass and aligned with the coordinate system.
Lxx = 1.018 Lxy = 0.000 Lxz = 0.000
Lyx = 0.000 Lyy = 1.442 Lyz = -0.001
Lzx = 0.000 Lzy = -0.001 Lzz = 0.894

Figure 4 *A "Mass Properties Report" for the Cylinder Head Solid Model* such as the piston. The user then invokes the FEA software and starts a study. First, the user applies fixed restraints and uniform pressure loading vectors to the solid model (Figure 5). Next an FEA mesh is applied using a specified quality of resolution (Figure 6). Finally, the results of the FEA study can be seen by plotting the Von Mises stress distribution on the model (Figure 7). The use of a color gradient scale on these stress plots offers an excellent visualization tool for the engineer to view the computer-generated results, all in essentially a real-time environment.

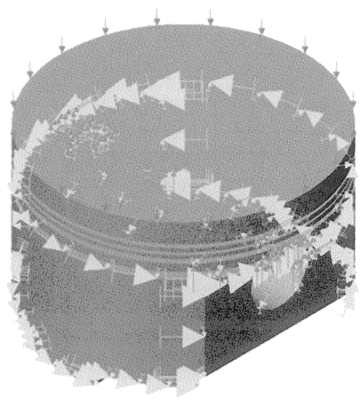

Figure 5 *Fixed Restraints and Uniform Pressure Loading Vectors are Applied to the Model*

Assembly Modeling

Most engineering products are not single parts, but rather are a collection of parts that mate together to perform a desired function. Modern parametric solid modeling software allows not only the creation of individual parts, but also the creation of an assembly of parts. An assembly model can be created by importing individual parts into an assembly file. For the piston assembly example, the remaining parts (connecting rod, rod cap, and wrist pin) are built. The first part is then imported into the assembly file and it becomes the base part of the assembly. Subsequent parts are imported and then mated together. In the mating process, a number of constraints can be attributed to the mated parts. Some of the common constraints used for mating the piston assembly (Figure 8) include coincident, concentric, and parallel features. Once the parts are mated properly in the assembly model, tolerance checks for clearance and interference can be made.

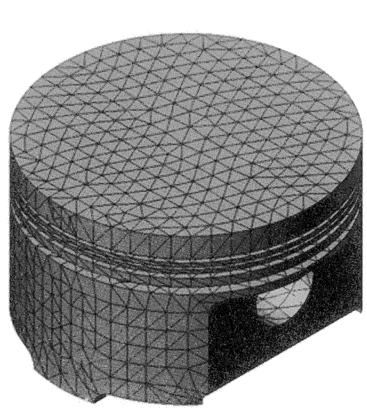

Figure 6 *A Mesh is Generated Over the Solid Model for the FEA Study*

Kinematics Simulations

While assembly models may show how the parts fit together, they are still only static images. With current solid modeling software, it is possible to study dynamic images through animations. For example, the piston assembly can be animated to show the motion of the piston head as it moves through a complete downward and then upward stroke.

Figure 7 *Results of the FEA Study Show the Von Mises Stress Distribution Over the Solid Model*

Rapid Prototyping of Solid Models

Once the 3-D geometry of the model has been constructed and verified through analysis, a rapid prototype of the individual parts can be made. The user saves each part individually as a stereolithography file (i.e. one with an .STL extension). The .STL file is then imported to any one of a variety of rapid prototyping machines. In the case here, the rapid prototyping machine is a Selective Laser Sintering (SLS) machine made by DTM Corporation. Basically, the .STL file-making process slices the model's geometry into very thin layers stacked one-by-one on top of each other, and then the SLS process sinters these layers together using fusible powder and a laser light beam. Example rapid prototypes of the piston assembly parts are shown in Figure 9.

Section Views of Solid Models

Sometimes solid model geometry becomes complex. Important features of the model may reside internally and not be visible from an external screen viewer. For example, two of the major features of the piston head are the internal bosses that support the wrist pin. In this case, the user may want to create a section view of the 3-D solid model. First, a cutting plane is positioned through the object. The plane could go through the middle of the object or be offset by a pre-defined value. Then a section view command is issued and the solid model is cut in half. Two examples of section views of the piston solid model showing internal features are depicted in Figure 10.

Generation of Engineering Drawings from Solid Models

Documentation has always been an important aspect of the engineering design process. Traditionally, this documentation centered around the generation of engineering drawings. As solid model databases become the mainstay of the digital engineering design enterprise, paper drawings are becoming less relevant. Nonetheless, most engineering companies will still require engineering drawings, if for no other reason than for legal matters. Fortunately, making an engineering drawing

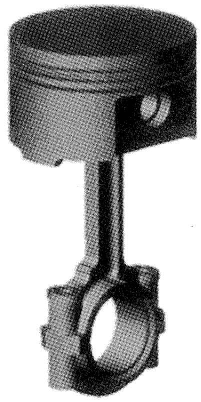

Figure 8 *The Piston Assembly Model*

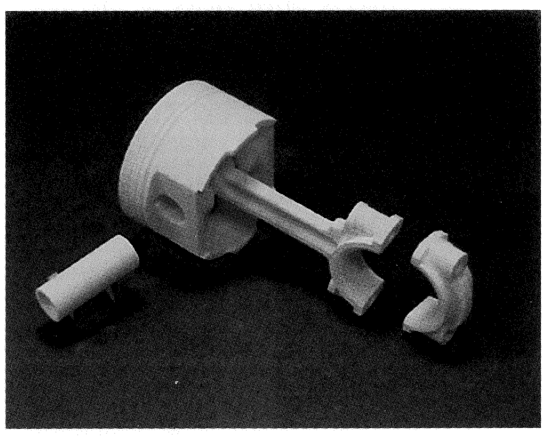

Figure 9 *Rapid Prototypes of the Individual Parts of the Piston Assembly*

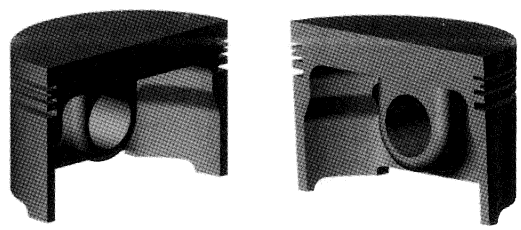

Figure 10 *3-D Section Views of the Piston*

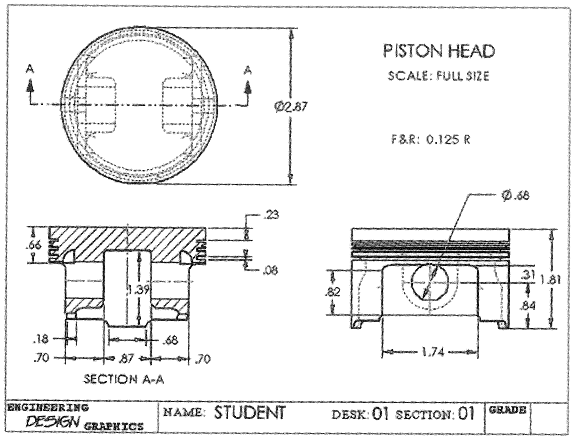

Figure 11 *An Engineering Drawing of the Piston Head Projected Directly from the Solid Model*

from a solid model is fairly straightforward. The user projects three views of the model onto a drawing sheet. Visible and hidden lines automatically come with the projection, but centerlines, dimensions, and notes must be user supplied. A typical student drawing of the piston model is shown in Figure 11.

Curriculum Laboratory Sequence

An Engineering Design Graphics curriculum outline, based on this digital engineering design process, is shown in Table 1. It consists of eight laboratory modules and a two-week design project. Outcomes of the curriculum include computer sketches, 3-D solid models of parts, assembly models, analysis results, kinematics animations, rapid prototypes, sections views, engineering drawings, and technical illustrations. The final design project involves reverse engineering of a mechanical assembly, a team project activity that has been successfully used as a capstone event in freshman Engineering Design Graphics courses (Barr, Schmidt, Krueger, & Twu, 2000).

Conclusions

Engineering Design Graphics curriculum content is at the threshold of a new era, a digital era where geometric computer models, and the attendant databases, are the center of instruction. The digital database starts with the building of a solid model from a 2-D sketch, and is then completed by adding 3-D design features. However, the true power of this approach is only realized when the solid model data is applied to analysis, simulation, prototyping, and design documentation activities. This paper has documented this digital engineering design and graphics process with realistic examples of freshman student exercises.

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Laboratory Sequence

Lab	Activities and Outcomes
1	**Computer Sketching:** Set up the sketch plane units and grid parameters; demonstrate all 2-D sketching primitives; demonstrate all line editing features; demonstrate the setting and editing of dimensions; set geometric constraints; make simple extrusions and revolutions to get 3-D geometry. Print hardcopies of 2-D sketches and simple parts for submission.
2	**Solid Modeling of Parts:** Create 3-D extrusions and revolutions of individual parts; use advanced sweep operations; add parametric design features; edit features and geometry in 2-D and 3-D; render the parts. Print color hardcopies for submission.
3	**Assembly Modeling:** Create individual parts; assemble parts as a mechanical assembly; mate features as appropriate; check for clearance and interference of parts; create color rendering of assembly. Print color hardcopy of the rendered assembly for submission.
4	**Analysis of Parts:** Perform mass properties analysis of 3-D parts. Perform an FEA study: set up applied forces, fix constraints, perform meshing, display color stress contours, visualize and interpret results. Print a mass properties report and obtain a color hardcopy of the FEA results for submission.
5	**Kinematics Simulation:** Create a mechanical assembly; mate the parts of the assembly, simulate motion of the assembly; generate an animation (.AVI) file; play the .AVI file externally on a suitable player. Print a rendered color hardcopy of the assembly and submit it along with the animation file.
6	**Manufacturing and Rapid Prototyping:** Create individual parts of a mechanical assembly; generate an .STL file of each part; send the .STL files to a prototyping machine; demonstrate mating assembly of prototype parts. Submit the rapid prototypes once finished.
7	**Section Views:** Create individual parts of a mechanical assembly; make different 3-D section views of the parts individually and as assembled; export acceptable color image files of the 3-D section views for presentation purposes. Make a 2-D section view of a model projection. Import the image files into a technical document page and submit printed hardcopies.
8	**Engineering Drawings:** Create a 3-D part and make a three-view orthographic drawing of the part; use a suitable sheet style template; add centerlines where appropriate; dimension the drawing; add a title block and appropriate notes. Print a black and white hardcopy for submission.
9-10	**Team Design Project:** Assign teams; acquire, study, and reverse engineer a common mechanical assembly; sketch shape and sizes of individual components; build computer solid models of parts and assemblies; perform appropriate computer analyses; make rapid prototypes of parts; generate drawings and other design documentation; propose design improvements. Submit final team project report.

Table 1

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