Concurrent Engineering Project for MEM 688 – Agitator Design

Drexel University, Winter 2010/11

MEM 688 Manufacturing Processes II

Final Project

Introduction

Concurrent engineering is the simultaneous or parallel consideration of all facets of the product development process (including design, analysis, manufacturing, testing, quality control and marketing) for reducing the time to market, cutting down cost, and improving quality.

Students from the MEM 688 course were asked to design a part using the concurrent methodology. This project is meant to display how a project team applied CE's methodology to a project and utilize some of the IDEAS based approach throughout our design, See Figure 1.



Figure 1: Comprehensive approach to ensuring proper utilization of software programs to help design components from start to final product.

Scope and Project Goals

The team took on designing an agitator shaft assembly complete with dual impellers, which consists of 6 blades, plus top shaft and lower quill design requirements. The top shaft would hold both impellers and would be exposed to the inside content of a 5,000L Bioreactor, (see Figure 3). The bottom quill would be designed to properly turn the agitator by interfacing with a gearbox and sit inside a of the mechanical seal assembly. The project goal was to reduce the product development time, by utilizing the concurrent engineering methodology. The project was broken down into the following phases and timelines as can be seen in the attached CE Wheel, (see Figure 2). These phases were agreed by all team members to meet the intent of the MEM 688's final project requirements.



Figure 2 Concurrent Engineering wheel for agitator design

The software platform chosen for this assignment was SolidWorks. This CAD software is universal and will convert files as STL for rapid prototyping or STEP files for use with a finite element analysis (FEA) to determine if the shaft and quill design could take the stress and strains created by the spinning of the dual impeller design. The software chosen for the FEA was ABAQUS, as this was readily available in the MEM Computer Labs.

Purpose of a Bioreactor

Cell Growth: A bioreactor is meant to allow the growth of cell culture or fermentation of microbial culture within a sterile and controlled environment. The environment is controlled by temperature, pressure, agitation and supply of gases to the liquid.

Clean Design: A Bioreactor used in manufacture of drug products is typically a sterile environment, which requires smooth surfaces to reduce and minimize the growth of objectionable organisms such as bacteria and/or viruses on all contact surfaces. The growth of these organisms could harm or reduce the productivity of cell or microbial culture. Typically a 316L Stainless Steel, is electropolished to <15 Ra to meet the surface criteria for a clean design and minimize growth of these

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3 | Pageof19
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objectionable organisms. The bioreactor and agitator must be self-draining and prevent water from pooling at any point in the reactor. Pooling of water will allow growth of objectionable organisms.

Mixing and Mass Transfer: The Bioreactor requires continuous agitation. The right agitation will allow more or less gas transfer to meet the oxygen demands by the cell culture. The agitation allows a homogeneous mixture so all nutrients in the media can be equally shared by all of the cells growing in this environment. A homogeneous mixture is usually achieved by having the most turnovers in the shortest blend time possible.

Thus agitation is critical for creating the maximizing the bioreactor's capabilities to ensure proper mixing and optimizing gas transfer to each cell within the culture. A dual marine impeller design with a 28" diameter can yield approximately 3.3 turnovers < 30 seconds of blend time. The typical weight of the one set of the three blades is approximately 145 lbs. Thus, the shaft will now have to be designed to fit into a bioreactor see Figure 3. Having a dual marine impeller with 6 blades, that are turned down allows for improved mass transfer as well. Additionally, this marine impeller design was able to use the least amount power per unit volume to achieve the required mixing and mass transfer required for the bioreactor.



Figure 3: Bioreactor

Execution of CE Wheel from Project Scope

Design Parameters

At the beginning of the project, the team determined that the following parameters would be used throughout the design:

- Poisson's ratio n= 0.31 for 316L stainless steel
- Surface Finish: electropolished <15 Ra or better
- Young's Modulus E = 150 GPa, or 21.75M75 x 10^6 lbs./in²
- Geometric Dimensions and Tolerance must be +/- 0.010"
- Design would be smooth and sanitary to prevent any type of pooling of water as this would need to be used in a sterile bioreactor
- Agitator would spin up to 100 RPM using a 3 hp motor.
 - 1. Agitator would fit into Bioreactor, see Figure 3 and fit into Mechanical Seal and Gear Box.
- The forces imposed on agitator and mechanical seal while in splash zone (e.g. liquid level is in the midway point of the impeller and excessive waves or extra splashing and slapping of the impellers puts undue stress on shaft, mechanical seal and impellers) would be neglected and these instructions would be written in the Operating and Instruction manuals and provided to any owner:

"Do not attempt to fill the reactor or run the agitator such that the liquid level is only halfway in the impeller. Ensure to complete submerge the lower or upper impeller to avoid excessive damage and undue stress to the mechanical seal, impeller or shaft. Any operation of the agitator with this "splashing" condition will null and void the warranty of agitator"

Detailed Drawings and Assembly

General Layout Drawings for a 5,000L Bioreactor were furnished from other vendors, but no detailed drawings existed of the agitator shaft and assembly (See Figure 3)

The team decided to develop detailed drawings for the agitator. These drawings must show the quill (or bottom of the agitator) to fit into a universal gearbox. The lower portion of the shaft, which connects to the quill, was designed to fit into any universal mechanical seal, with the upper shaft holding two impeller assemblies.

First, an initial solid model was made using SolidWorks software. The model was saved as a STEP file (see Figure 4), which was used for finite element analysis of the part to demonstrate the sustainability of the design.

	Assembly (".asm;".sldasm) Assembly Templates (".asmdot) Part (".prt;".sldprt) Parasolid (".x_t) Parasolid Binary (".x_b) IGES (".igs) STEP AP203 (".step;".stp) STEP AP214 (".step;".stp)		
	ACIS (*.sat) STL (*.stl) VRML (*.wrl) eDrawings (*.easm) Adobe Portable Document Format (*.pdf) Universal 3D (*.u3d) 3D XML (*.3dxml) Adobe Photoshop Files (*.psd) Adobe Illustrator Files (*.ai) Microsoft XAML (*.xaml) Catia Graphics (*.cgr) ProE Assembly (*.asm) JPEG (*.ipo)		
File name:	HCG (^{*,} hcg) HOOPS HSF (*.hsf) Tif (*.tif)		Save 🗸
Save as type:	Assembly (*.asm;*.sldasm)	•	Cancel
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Figure 4: List of all type files saving options and saving the model as a STEP and STL file



Figure 5: Using of SolidWorks features to help simplifying the model for FEA and calculating the forces

After the model was proved to endure the applied momentum and the forces from the liquid (see Figure 5), detailed drawings were made of the Impeller Blades (Figure 6), Quill and Shaft (Figure 7) and Impeller Assembly (Figure 8). For convenience, the PDF are included with the report package.



Figure 6: Impeller Blades drawing



Figure 7: Quill and Shaft drawing



Figure 8: Impeller Assembly drawing

The final Quill and Shaft model was saved as STL binary file (Figure 4 and Figure 9) for future generating of rapid prototyping, CNC code and machining, which is not a part of the current project, because of the limited time and number of students involved.

S	SolidWorks		
ł	?	Triangles: 5358 File Size: 267984 (Bytes) File Format: Binary	
		Save C:\DOCUMENTS AND SETTINGS\MKOSTADINOVA\MY DOCUMENTS\PERSONAL\QUILL.STL?	
		Yes No	

Figure 9: Saving the STL file of the Quill and Shaft

Finite Elemental Analysis

For the FEM analysis, the first step was to create a simplied version of the shaft and the quill. This was done by creating a part under the model tab and sketching the geometry. Next, the material properties (Young's modulus, poisson's ratio) was defined and the section was assigned to the defined material. In the next step, the part was partitioned at a defined length to account for the shaft and quill geometry. To replicate the governing conditions, a set of boundary conditions was imposed on the part. The details of the Boundary conditions are given below

Boundary Conditions BC 1 U1=U2=U3=UR1=UR2=UR3=0 BC2 U1=U2=U3=0 Note that rod is along the y axis, i.e. the revolution is around y axis. A moment was applied at the location of BC1 and BC2. inc. (update this section with $\omega = 100$ radians/min = 1.667 radians/sec $v = r \omega = 0.97*1.667 = 1.616$ in/sec (if radius is in inches else ft/sec) $F_{max} = mv_{max} = 290lbs * 1.616 = 468.64psi$ Considering a safety factor of 2 The applied Moment from the agitator can be calculated as M = Fd = 226.98 lbs in/sec

The parts were then meshed using a 6 node triangular elements with mesh size 0.2 shown below (Include the mesh figure first). Based on the analysis, the displacement and stress contours were obtained and are shown below



DISPLACEMENT , Figure 10.

Though you see the colorful plot, note the displacement is of the order 10^{-4} in the red region which is very small and can be ignored as a design flaw. Additionally, a speed limiter could be placed on the motor to prevent running the agitator over the recommended maximum speed of 100 RPMs. Thus ensuring longevity of the agitator.

Enlarged Version of the stress points (You have major stress at the joint between the quill and shaft)



Stress, Figure 11.



Full Version of the Stress, Figure 12.



Figure 13: Mesh image prior to FEM Analysis Displacement

The following are snapshots of the animation of the shaft and quill. Figures 14-18.



Figure 14.



Figure 15.



Figure 16.



Figure 17.



Figure 18.

Discussion

Benefits of Concurrent Engineering

The team was able to develop detailed analysis and perform product development within 6 weeks, per the CE Wheel, See Figure 2.0. Typically, the time to develop a detailed agitator design is 12 weeks. Thus, the team has shown a 50% reduction in total product development time. The team was also able to show the true benefits of using one software program to generate the detailed drawings. SolidWorks was able to generate the detailed drawings and then convert these files to STL and STEP. By having STL file, saved by SolidWorks, allowed no loss of information during or translation into another software program for rapid prototyping or for the FEA.. This STL file can now be opened in any rapid prototyping machine and a small-scale version could be generated. Additionally, the STEP file was used in ABAQUS for finite element analysis of the part. Having one software program to generate all the necessary files for proper analysis ensures clear communication, 100% quality improvement and reduction of errors by using the correct files. Since only three people were required to do a product development of this agitator, the cost was approximately \$25,200. Typical costs for this effort range approximately \$35,000. Thus, the team was able to save \$9,800 for a 28% reduction of costs to any potential client. The typical costs to manufacture an agitator are \$65,000, but this design integration method projected costs are \$55,000, a 15% reduction. The typical time to manufacture is 16 weeks and this CE effort put forth a new projected time to manufacture of 11 weeks, thus creating a 31% reduction of time for the client. The total scrap and re-work was reduced by 10%.

Problems you encountered

Issue: While using ABAQUS to perform the FEA, the ".STEP" files generated too many nodes. The licensed ABAQUS software to the MEM Computer lab was not able to handle >2,000nodes. Thus the amount of nodes that were needed to generate a smooth mesh design for the agitator were drastically reduced and the surface mesh was not as smooth as desired.

What did you learn?

The project group encountered the following problem during the generation of FEA using ABAQUS: the STEP files generated too many nodes, so reduction of the nodes was done to fit the capabilities of the student version of the software.

Having the due date in mind is critical for defining the project deliverables. Additionally, it is even more critical to ensure that the proper software and the software's capabilities and compatibilities are resolved prior to start of work. Thus, having conversations about what software, versions, etc. should be a topic on any project team. Typically, this is overlooked and this could delay any good project plan.

In the future, it would be good for teams to be challenged by actually having to make a smallscale model through rapid prototyping. This would allow flushing out of smooth down other issues related to project execution.

References:

- 1. Kalpakjian S., S. Schmid, Manufacturing Processes for Engineering Materials, Fifth Edition, 2008
- 2. Zhou J., Manufacturing Processes II, Winter 2010-11, Lecture Notes