INFUSING MANUFACTURING ANALYSIS IN THE MANUFACTURING ENGINEERING TECHNOLOGY CURRICULUM USING CAD

Radha Balamuralikrishna[1] & Clifford R. Mirman[2]

Abstract – Arguably, computer-aided design has emerged as the most significant change agent in manufacturing during the past decade. The switch from constructive solid geometry based solid modeling systems to parametric solid modeling has positively impacted manufacturing industries worldwide. Solid modeling technology has now advanced to a stage where it has become the precursor to a wide array of engineering analyses including finite element analysis. These recent developments suggest that we can make a case for a mandatory course in solid modeling enabled manufacturing analysis for all manufacturing engineering and technology majors. Until recently, the manufacturing engineering technology degree program at Northern Illinois University did not require students to take a course in solid modeling or kinematic analysis. This paper describes the efforts made by the authors to fill this void that existed in the curriculum. We pose a rationale for establishing a new course and describe the planning and specific implementation details of the resulting three-credit course in solid modeling and manufacturing analysis.

INTRODUCTION

The manufacturing education plan disseminated by the Society for Manufacturing Engineers (SME) specifically identified computer-aided design (CAD) as a key competency for manufacturing engineers and manufacturing engineering technologists (MET) [1]. Nationally recognized professional licensure (Principles and practice of engineering with manufacturing as the area of specialization) and certification exams (SME's certified manufacturing engineer and certified manufacturing technologist) have identified CAD and its downstream applications as a body of knowledge that defines proficiency in manufacturing. It is not an exaggeration to say that CAD is at the forefront of the computer integrated manufacturing (CIM) environment [2]. Although the basics of engineering analysis still has its roots in the fundamental sciences such as physics and mathematics, CAD has significantly revolutionized the engineering design and manufacturing process. More specifically, solid models of parts and assemblies created using any one of several popular CAD packages form the basis for various kinds of engineering analyses that establish and verify proposed designs. CAD models serve as the starting points for allied manufacturing technologies including rapid prototyping, computer-aided process planning, computer-aided manufacturing, and computer-aided inspection [3]. Selected examples of popular CAD packages for the modeling of mechanisms and parts/assemblies for the machine tool industry are AutoCAD™, SolidWorks™, and Pro/Engineer™. CAD standards continue to evolve and are being continuously fine-tuned for interoperability and exchange of data from one platform to another.

Higher education's approach in dealing with this shift in manufacturing paradigm has so far been both reactive and incremental. This paper describes the efforts made by the authors to ensure that all Manufacturing Engineering Technology (MET) majors at Northern Illinois University were provided with an opportunity to establish their skills in CAD and downstream applications of solid models with a special focus on manufacturing component analysis. The authors have recently designed a course at the junior level that includes eight weeks of instruction on key CAD topics using a state of the art 3-D modeler. This is followed by another sequential eight-week instructional segment that emphasizes various aspects and tools of computer-aided manufacturing component analysis. Through this paper, the authors hope to highlight and share how manufacturing educators can incorporate design and analytical tools that are fast becoming essential competencies for entry level manufacturing engineers and technologists.

GENERATING CONTENT FOR A NEW COURSE

It is reasonably well known that engineering programs across the country have designed courses (even at the senior level) with a primary focus of providing their graduates with computer skills in solid modeling. It appears that educators who once frowned upon the large emphasis placed to software usage in a design course have now relented and recognize that the complexity of modern day design packages can not be mastered by the average student without proper guidance and instruction [4]. The NIU Department of Technology's existing curriculum in Manufacturing Engineering Technology did not have a required course in either solid modeling or manufacturing analysis. The

[1] Radha Balamuralikrishna, Department of Technology, 206 Still Hall, Northern Illinois University, Dekalb, Ill., bala@ceet.niu.edu
[2] Cliff Mirman, Department of Technology, 204 Still Gym, Northern Illinois University, Dekalb, Ill., mirman@ceet.niu.edu

student could however select these courses as electives. As a result several of our past graduates had only a cursory knowledge of solid modeling and little or no skills in using a CAD system to produce parts and assemblies. This deficiency proved to be a barrier for the departmental graduates in dealing with basic manufacturing analysis. Recognizing the growing importance of solid modeling and manufacturing analysis, the department has now concluded that these skills be required of all MET majors. The input of industry representatives serving on the department's Industrial Advisory Board played a key role in this decision-making. In addition, the students in this area typically experienced the need to utilize kinematic analysis and/or solid modeling skills in completing their mandatory senior design projects. Over the years, the initial design of many of the assigned projects were carried out using solid modeling (shown in Figures 1 and 2),

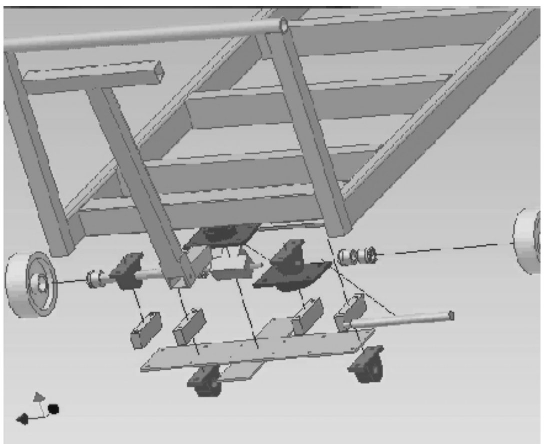

FIGURE. 1
SENIOR PROJECT DESIGN USING SOLID MODELS

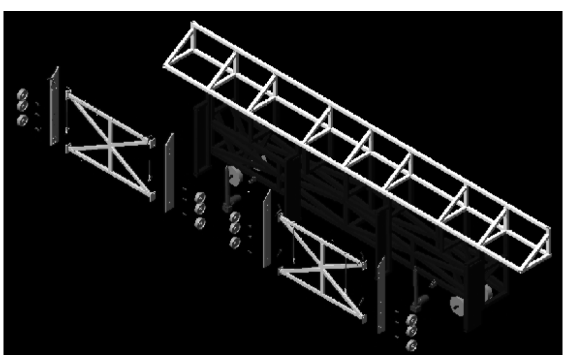

FIGURE. 2
SENIOR PROJECT DESIGN USING SOLID MODELS – ANOTHER EXAMPLE

These project teams were able to develop solid models mostly "by chance" with the contribution coming exclusively from one student member of the team who had acquired these skills elsewhere or by probably electing to take a course in solid modeling. Many projects called for the design groups to develop gear trains and cams. These design tasks were handled on an individual basis, and the information was not presented to the group as a whole. Clearly, the students were asked to climb a steep learning curve in the area of solid modeling and manufacturing analysis during their senior project term and the department decided to act to correct this situation.

Within the next two years, the Manufacturing Engineering Technology program will be seeking the initial ABET accreditation. To this extent, the Department has been working with our industrial advisory board to develop and redevelop both the curriculum and laboratory infrastructure in this area. At the present time, an MET graduate is required to successfully complete courses in the following areas:

Tech 175 - Electronics Fund.
Tech 211 - Computer-Aided-Design
Tech 262 - Machine Production Process
Tech 265 - Manufacturing. Processes
Tech 295 - Visual Basic Programming
Tech 310 - Statics & Dynamics
Tech 326 - Fluid Power
Tech 342 - Manufacturing Component Design
Tech 362 - Numerical Control Systems
Tech 369 - Strength of Materials
Tech 391 - Industrial Quality Control
Tech 393 - Properties of Materials
Tech 420 - Computer-Integrated-Manufacturing
Tech 423 - Automation
Tech 425 - Programmable Logic Controllers
Tech 443 - Engineering Economy
Tech 477/478 - Senior Projects I & II

The reader should note that the TECH 342 course, the central subject of this paper, was a recent addition. In addition to the above courses, the students are required to take four technical electives within the various areas that comprise manufacturing.

Like many other Universities and Departments, the Department of Technology at NIU is looking at how courses are offered, and the resources needed in delivering the programmatic course content [5]. In addition, the total number of credits needed for graduation is closely monitored, and thus, the program cannot exceed a total of 126 credits. As emphasized earlier, there was an overwhelming need for the departmental MET graduates to have a knowledge base in the areas of solid modeling and mechanism analysis, or kinematics. To both satisfy the educational need of the program and meet the administrative constraints, it was decided that a combined course covering the areas of kinematics and solid modeling would be developed and added into the MET curriculum. The proposed course, Tech 342 (shown in the above list) would be a three-credit course covering solid modeling during the first eight weeks and engineering analysis, or kinematics, during the subsequent eight weeks. To enter the course, the student would be required to complete three pre-requisite courses addressing the following subject areas:

- ✍ Calculus
- ✍ Computer-aided design (basic engineering graphics principles and 2-D CAD)
- ✍ Strength of materials

It should be noted that the Statics and Dynamics course is a prerequisite for the Strength of Materials course, and therefore, the students will have the required knowledge in the area of dynamics. The prescribed prerequisite courses should provide the instructors and students with the proper platform required to provide relevant instruction in solid modeling and engineering analysis.

The idea of combining two distinct areas like solid modeling and kinematics within one course is both novel and difficult. The novel aspect is that the instructors can select components of both areas that meet the specific programmatic goals of the NIU MET program. The difficult part of the task is to determine which components are important and should be covered. Following extensive research and debate, it was decided that the following topics would be covered in the proposed course:

Solid Modeling

- ? Solid modeling concepts
- ? Parametric solid modeling and its applications
- ? Part modeler and Assembly modeler using SolidWorks™

Kinematic Analysis

- ✍ Position, velocity, and acceleration analysis
- ✍ Gear trains
- ✍ Cams
- ✍ Mechanism synthesis

The preceding course topics were developed based upon the need for the program to cover the following learning objectives,

- ✍ Ability to design parts using solid modeling and identify downstream applications
- ✍ Knowledge and application of parametric solid modeling techniques
- ✍ Knowledge and skills in the usage of Solid Works™
- ✍ Ability to determine position, acceleration and velocity for a 4-bar mechanism
- ✍ Ability to analyze a compound and epicyclic gear trains
- ✍ Ability to design and analyze cams
- ✍ Ability to synthesize and analyze a 4-bar mechanism
- ✍ Ability to utilize knowledge in a open-ended design project

It should be noted that while this material fulfills needed subject matter expertise for several allied courses in the MET curriculum such as computer-integrated manufacturing, manufacturing process, and machine production processes, perhaps the greatest impact will be noticed in the quality of the culminating open-ended senior design projects that all students are required to complete prior to graduation.

SOLID MODELING

It was determined at the initial stage of discussions that a key desired outcome of TECH 342 would be that the students should be able to develop a skill base in the area of solid modeling using a specific design package. Therefore, SolidWorks™ was selected as the design package for instruction in solid modeling techniques based on the growth in popularity of this CAD package during the past five years, particularly in the region served by Northern Illinois University. This design package has earned industry-wide recognition and acceptance because of its functionality, ease of use, and wide range of support services offered including partnerships with creators of allied applications for manufacturing and engineering analysis. The reader is urged to explore the Solid Works website at ***http://www.solidworks.com*** for more information in this regard. The first eight weeks of lectures would focus on newer CAD concepts such as parametric and feature-based modeling using SolidWorks™. The approach would be hands-on where the instructor demonstrated the functionality of the software through relevant examples. Students were required to acquire mastery through the completion of specific part and assembly modeling assignments and design projects. Specific topics covered in this section included but were not limited to sketching functionality, using relations to capture design intent, create placed features, extrusion, revolution, sweep, loft, and assembly modeling. It was expected that this instruction would provide the student with a solid background to create fairly complex parts and define simple assemblies. Examples of typical individual parts that students were challenged to model using SolidWorks™ are provided in Figures 3 and 4. In the part shown in Figure 3 the student was required to apply the following concepts to create the part:

- ✍ Fairly complex sketching
- ✍ Applying geometric relations (such as tangencies) to sketches
- ✍ Creating feature patterns
- ✍ Use the hole wizard and copy features
- ✍ Extruded boss

In order to model the part shown in Figure 4, the student would be required to extend the skills learnt from the previous example and also apply additional concepts including:

- Creating a revolved feature
- Inserting new sketch planes
- Placing fillets

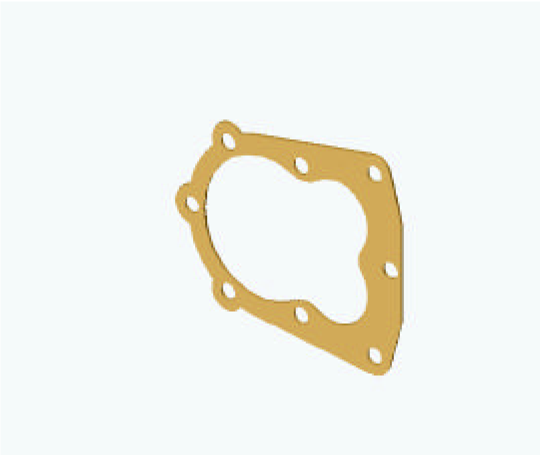

FIGURE. 3
PART MODELING EXAMPLE – GASKET WITH INTRICATE FEATURES

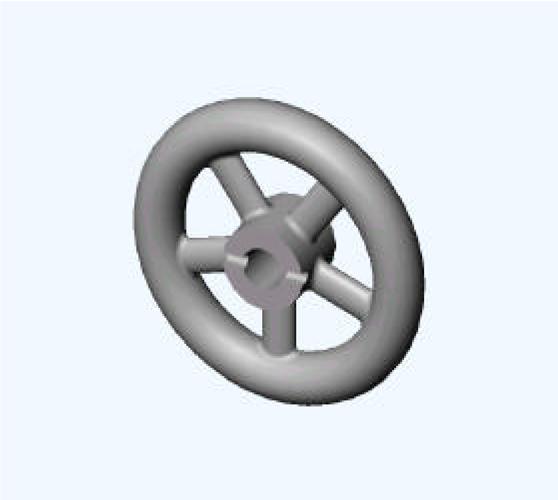

FIGURE. 4
PART MODELING EXAMPLE – HANDWHEEL WITH ELLIPTICAL SPOKES

The assembly model example shown in Figure 5 clearly illustrates that various constraints had to be specified in order to obtain correct mating of parts. We should mention that the tutorial activities that are embedded in the SolidWorks™ package proved to be a useful pedagogical tool. In particular, the U-joint assembly exercise was used very early on in the assembly model instructional process and it was observed that students developed a significant degree of confidence in applying mating relationships after the completion of this activity.

With this background, the student may reasonably be expected to pick up the higher order skills much more easily than if she had little or no exposure to using a CAD package. More importantly, the students now have the basic skills vital to the study of more complex manufacturing engineering analysis.

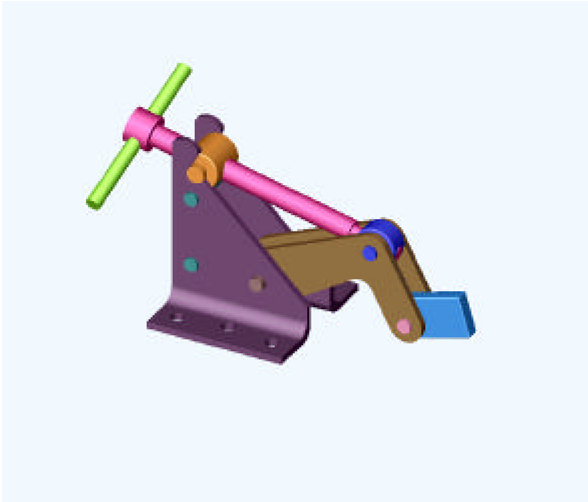

FIGURE. 5
ASSEMBLY EXAMPLE - CLAMP

KINEMATICS

Within the manufacturing industry, the usage of kinematic analysis is commonplace. Therefore, graduating students in this area must have a knowledge base in the applied areas of kinematic design, analysis, and implementation of systems that provide motion, such as cams, gears, and mechanisms. Given the short time-frame (8 weeks) for this section of the course, the material that is presented must be concise and have an applied component [6]. Within this time frame, the students learn about basic linkage design and how to classify and determine the transmission angle of 4-bar mechanism. In addition, the students must learn about 2-position and 3-position linkage synthesis and how to determine if the given mechanism can provide a solution to the design goal, as shown in Figure 6. In addition, the course covers kinematic analysis of various types of gear trains, including epicyclic and compound trains, as shown in Figure 7. The course also covers the design and analysis of cams, including selection of precision points, development of displacement, velocity, and acceleration profiles, and cam development based upon follower selection. Within each section of this course, the students work on several short applied projects to obtain a detailed understanding of the various concepts within solid modeling and mechanism and cam analysis. At this point in time, the instruction of the various topics within the kinematics course will be through application of theory and through utilization of a CAD program. Looking into the future, various components will be added which will take the course in the direction of computer applications. However, this development will be over several course offerings. It should be noted that the SolidWorks™ partner packages for manufacturing analysis do not readily sell student versions of their software, and this makes it difficult to make a seamless transition from design to analysis. Until this issue is resolved, we shall continue to rely on neutral file formats such as ***iges*** to make the transition possible.

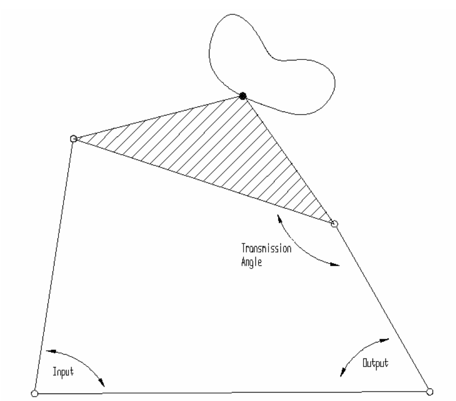

FIGURE. 6
4-BAR LINKAGE AND COUPLER CURVE ANALYSIS

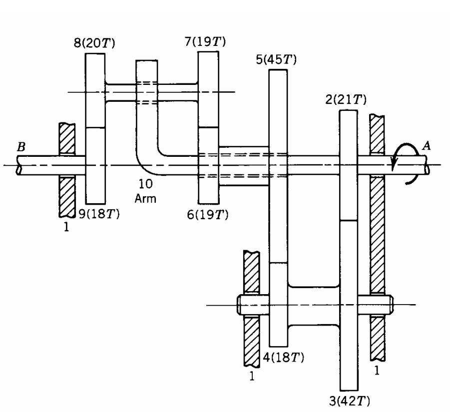

FIGURE. 7
PLANETARY GEAR TRAIN ANALYSIS

CONCLUSION

More and more industries are addressing the challenges of compressed product life cycle and development times. Similarly, in an era of explosion of knowledge, educators have to introduce more concepts without extending the duration of a four-year undergraduate program. This essentially is akin to a "compressed cycle time challenge" in teaching and learning at universities. Creativity, innovation and experimentation are the vital keys in discovering new approaches that enhance efficient and effective preparation of manufacturing engineering technology graduates. In order to minimize "re-invent the wheel" syndrome, it is also essential for faculty members to quickly share and promote widespread dissemination of teaching experiences of specific content matter. This is the case within the Northern Illinois University Department of Technology. Based upon industrial input, it was determined that there existed a void in the knowledge base which was not filled with the currently offered curriculum, and additional course components could not be inserted into the courses being taught. Thus, creativity was utilized in the development of a new "hybrid" kinematic/solid-modeling course. In the course development, since only eight weeks was allotted to each segment, important areas of knowledge were developed in each area. The result of this development was a course that combines the applications oriented components from each area. The course utilizes short projects in each area to allow the students to develop the analysis and modeling techniques in a practical setting. It should be noted that this course is being offered for the first time during the Spring 2003 semester.

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RADHA BALAMURALIKRISHNA
Radha Balamuralikrishna (Bala) received his Ph.D. degree from Iowa State University in 1997. As a Naval Architect, he completed several projects in structural design of ships and offshore structures during the late 1980s. He is currently an Assistant Professor in the Department of Technology at Northern Illinois University teaching courses primarily in the CAD area. Dr. Bala is actively involved in professional societies including the American Society of Engineering Education (ASEE), Society of Manufacturing Engineers (SME) and the National Association of Industrial Technology (NAIT).

CLIFFORD R. MIRMAN
Clifford R. Mirman received his Ph.D. degree from the University of Illinois at Chicago in 1991. From 1991 until 1999, he was a member of the Wilkes University Mechanical Engineering Department. He is currently the Chair of the Department of Technology at Northern Illinois University. During his tenure at Wilkes University, he was active in the areas of CAD, Finite-Element-Analysis, and kinematics, both securing grants and writing publications. Dr. Mirman is actively involved in the American Society of Engineering Education (ASEE) and Society of Manufacturing Engineers (SME).