Rapid Prototyping for Manufacturing Engineering Technology Program

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Abstract

Development, presentation and evaluation of a Rapid Prototyping class for Manufacturing Engineering Technology (MET) students at Minnesota State University, Mankato is presented. The two credit (400/500 level) class has been designed as an open-ended one-semester project in which students work in small groups following the typical stages of product development - designing, prototyping and manufacturing - in one continuous project. Students are required to apply in practice what they have learned from other classes. CAD, Manufacturing, Automation and Management classes are prerequisites. In-class instruction is limited. Students will often independently follow class guidelines but must meet the all milestones of the project. One goal is to train students to approach and solve problems on their own, with guidance from an instructor as needed.

1. Introduction

Manufacturing Engineering and Engineering Technology Programs are challenged with a rapidly changing industrial environment, emerging new technologies, and new methods of production. MET graduates are faced with a demanding work environment at the shop floor, in the designing office, and on a management level. To meet the mission of these programs, and the expectations of graduates and industries, universities need to prepare “industry-ready” students as much as it is possible. This is not an easy task, because of the wide variety of different industries in which graduates may be employed. Recent surveys show [1] that knowledge of new processes and technologies, and the ability to work in teams, are the most often mentioned competency gaps of engineering and engineering technology graduates. Some reasons are obvious. In traditional classroom teaching, industrial projects can be analyzed theoretically but simulated only to a certain extent, never fully reflecting the complexity of conditions existing in industry. Additionally, traditional classroom teaching focuses narrowly on subjects directly related to the class currently being taken, and it is difficult to incorporate a wide range of knowledge and experience from other courses, even the prerequisites. Particular difficulty is encountered in the format of class assignments. Rather than following the conventional linear instruction, in the Rapid Prototyping class it is desirable to simulate a more real-world working and learning environment where students must develop their own methods to meet class guidelines in the most effective way. To be successful they have to use many technical tools from different areas. In introducing this class, we had two major goals. The first was to prepare students to work in teams to solve open-end designing and manufacturing problems and to develop the necessary skills for using modern computer integrated manufacturing in an industrial environment. The second goal was to develop a course so closely linked to local industry that current projects could be picked by students directly from problems submitted by the cooperating companies.

Incorporating the Internet, and the latest developments in computer technology, provide great opportunities to improve the students' preparation for industry. Well established "live links," plus cooperation between the university and participating industrial companies, will bring current problems directly to the university labs. This synergy will provide dividends for all: a fresh look at problems and methods of solving the open-ended problems similar to those encountered in industrial settings for students, and industrial and student access to the advice and expertise of faculty for participating industries.

Nationally, the need for this type of arrangement is generally understood by everyone involved, and there is an increasing realization that return on investment in training and development can be significant [2]. Educational initiatives sometimes have a very large scale. Six large, diverse manufacturers and three state universities are working together cooperatively to define industry education needs and jointly design new experience modules [3].

A large employer has developed an education program which teaches the concept of short-cycle manufacturing and how to improve their operation. It helped the company to achieve significant improvements in reducing work-in-progress inventory, cycle times, and costs [4]. However, the main role in these initiatives belongs to educational institutions, especially the engineering departments of universities. The general trend is to move away from traditional one-subject, in-class instruction to interdisciplinary hands-on engineering programs, which pool resources with other academic institutions, and partner with industry or government institutions [5]. Some universities have developed courses, which involve mechanical, industrial, electrical, and material engineering students. Accounting, marketing, and information students are integrated into some teams as well. [6,7].

2. Why Teach a Rapid Prototyping Class in a Manufacturing Program?

Rapid prototyping by definition is a technology used for generating physical parts (prototypes) directly from technical documentation, usually in an early stage of new product design. In practice, however, it is much more. Effective use of rapid prototyping requires a higher-level use of computers, computer-aided design and engineering, and on-line communication across an enterprise. [8] Rapid prototyping also requires developing systematic cooperation among various specialists ranging from art and engineering designers, and marketing specialists, to those people directly involved in production preparation and manufacturing. Product development starts when market research indicates that there is need for a new product or for improving an existing one. Product information can come from such different sources as the market research group, to product users in the form of a manual sketch, photo image, technical drawing, computer file or a physical object. These data must first be transferred into precise technical documentation, then into a series of prototypes. Rapid prototyping allows engineers to create both physical models and full technical documentation of a product in a matter of days rather than weeks or months. These prototypes are used by engineers to verify the *form, fit* and *function* of the design. This enables them to detect problems earlier in the design process, and to bring products to market faster and with a lower design cost. Costs of designing and developing a new product often represent a significant part of the total cost of the product. Rapid prototyping can reduce this component of overall cost as well as reduce significantly the time-to-market factor. [9]

From an engineering and engineering technology educational viewpoint, the rapid prototyping projects will allow students to use their own creativity to arrive at a unique solution to a problem.

3. Rapid Prototyping Class Project

The RP class project for engineering technology seniors is as an open-ended project which enhances the Manufacturing Engineering Technology students' preparation while teaching them to invent their own problem solutions. Students must have successfully completed the prerequisite courses (Computer Aided Design, Manufacturing and Manufacturing Automation, Strength of Materials and Industrial Design) to be admitted to the RP class. Students work in small groups (typically three members per group) on all stages of the project.

Project Description

A description, intentionally general, of a sample RP project which was given to the students follows. The emphasis is on "things to do" to create an efficient problem-solving method rather than on the specifics of the problem.

Students were told to design a mechanism which is a part of packaging machinery. The mechanism has to provide a 90 degree indexing of the output shaft when the input shaft makes one full revolution. The indexed shaft should stay locked until the next impulse from the input shaft comes. Frequency of indexing is at least 60 times per minute, and expected torque on the output is 2.5 inch-pounds. Space is not limited and the input shaft is parallel to the output shaft. One hundred mechanisms will be needed to support one year of production.

Suggested problem approach

- Analyze the situation and come up with more than one possible technical solution. Choose one and justify why it is the best.
- For the selected design, produce complete technical documentation going from the hand sketches to the fully dimensioned CAD files.
- Perform the computerized stress-strain analysis of the crucial elements of the design to check the mechanical stress and deformation under normal working conditions, and when the mechanism is suddenly overloaded.
- Correct the documentation files if any changes are necessary.
- Make physical, fully functioning prototypes to verify form, fit, and function.
- Analyze the prototype for design and functional flaws.
- Make corrections in the basic documentation if any changes are necessary.
- Prepare a set of product documentation including marketing illustrations, catalog data and standard technical documentation.
- Prepare production documentation for the product, including CNC programming, selection of tools, fixture or pallet design, material selection and treatment, and methods of inspection.
- Prepare the final model and report to turn in, and give a public presentation.

Project Assumptions

- Designing, prototyping and manufacturing facilities are at different locations and a system of communication has to be used to set up the working links between these locations.
- Work-in-progress should be accessible by all the participating team members. A proper file management system has to be developed and used.

- Project evaluation is based on quality and completion of listed “things to do”. Students’ statements are required to say what was the involvement of each member of the group.
- Each project should begin with work scheduling; Microsoft Project software is recommended to accomplish this. Meetings with faculty are scheduled bi-weekly (or by appointment) to analyze work-in-progress.

A brief orientation introduces students to the equipment, manuals, on-line help, and technical support available from technicians to run the CNC equipment and informs them that laboratory facilities are available to students outside scheduled class times. (Fig.1).
At the beginning of the semester all students have assigned accounts at the local server. “Contact boxes” are created for the teams to make the work available for all group members. Students have to demonstrate proficiency in the use of e-mail, ftp, and web viewers for communication before working on projects. A training session is provided by the network manager.

Sample Project Details

After an open discussion session, the Geneva Mechanism was selected from two other possibilities. Criteria used for evaluation were fewer moving parts, and the possibility to confine the mechanism to protect it from dust and to reduce noise. First sketches confirmed that the mechanism met the basic requirements of the project. The team started the project with a hand sketch to show the idea of the mechanism and its location in the machinery. (Fig.2). An Internet search of results for similar objects was required for this part of the project.

Documentation - project documentation required use of a CAD package. Students used AutoCAD because they knew the system from prerequisite CAD classes. R2000 and Mechanical Desktop programs were available to them. The required documentation format was an assembly drawing as a solid model, and a detailed 3-D drawing file as the necessary technical documentation for prototyping, manufacturing, inspection, and production preparation. (Fig.3). All documents were stored on the local NT Server so all participants could access and review them. AutoDesk!Whip software was used to view the drawings on the web. Optionally, drawings could be viewed using Unix Show Me software on Sun workstations in the lab [Fig.4].

Stress-strain analysis – a parallel path to prototyping was computer simulation of the load-stress-deformation of the object. This option is used only when the objects are subjected to the loads, which in return can affect functions or performance if loads are excessive. Due to the limited exposure to mathematics required for engineering technology students, we chose to adopt the Design Space package from ANSYS [10] rather than the full Finite Element Analysis approach. This Finite Element Analysis based package is designed for analysis of stress and thermal deformation, and vibration of mechanical elements. It was used only during the design process. The Design Space system provides immediate solutions to the questions relating to the type and shape of deformations and stresses of the elements under working conditions. Students working on prototypes can easily evaluate the weak points in the design and redesign some elements to prevent excessive deformations and stresses for normal and overload conditions. For the Geneva Mechanism, the Design Space package was used along with the Mechanical Desktop to provide the stress-deformation analysis of some parts of the mechanism [Fig.5]. The results of the stress-strain analysis were available before the physical objects were made. Manufacturing students can easily learn the software, and usually one class period demonstration of software results in a basic working knowledge, although interpretation of the results of calculations will take longer. The Design Space report was the subject of an open discussion to discover the weak and strong points of the design. [Fig.6]. Documentation changes necessary were made at this time, and the documentation files were prepared for prototyping.

Prototyping - the next step was prototyping, or making physical models. Students used two methods: additive and subtractive. Using additive method plastic objects were built on the Actua ThermoJet Solid Object printer [11]. This machine builds precision objects layer by layer. One disadvantage, however is that objects produced have a very low strength, which makes assembly and running of the whole mechanism difficult. This method is useful for shape and fit evaluation, however. [Fig.7]. Using subtractive method students also milled the model on a Roland prototyping mill, which is a scaled down CNC milling machine. This method required more preparation operations, but the objects can be made out of much more durable material. The stronger parts could be assembled and mechanism operated. [Fig.8] There were two important issues in this stage of the project. The first was the conversion of file formats from one CAD system to another, and the second issue was to teach students how to use, the file management system. Problems with CAD file conversion from one format to another have not yet been completely solved in industry and students could see some conversion limitations. Manufacturing students in the RP class knew two CAD/CAM systems, AutoCAD (Mechanical Desktop) and MasterCAM, from other classes. A third file format, stereolithography (STL files), was created for use by the Actua ThermoJet printer. When conversions were done, the new formats were inspected for possible errors before proceeding with prototyping. This stage of the project was left to the students. They were free to search the Internet, system help files, or even contact support technicians. The goal was to develop some “self-help” skills, specifically important when the software environment is changing very fast. The file management system was used to transfer files at different stages of the project. A Windows NT server was used as well as resources, communication and storage from any location on campus or from outside analysis of the model-elements and assembly. Analysis at this stage of the project concentrated on two elements: design flaws: fitting parts together, and possibilities of design improvements by reducing the weight and material selection, as well as developing a concept of manufacturing and adapting the design to the process requirements. Three basic manufacturing processes were considered for this project: injection molding, casting or CNC machining. The following aspects were considered: manufacturing equipment available, overall costs, product durability, and number of products required per year. For the sample project, CNC machining was selected, which best met the considerations listed above. Design materials analysis resulted in selection of high density polymer for the housing of the mechanism, and hard aluminum for the remaining parts of the mechanism.

Production preparation - this stage of the project required development of the CNC programs and design of adequate tooling for milling and turning operations [Fig.9].The plan of operation included specification of tools and materials, and material preparation. The required documentation format included the electronic data file, and a hardcopy print of the files containing the CNC machining code ready to download to the CNC controller.

Part Production and Inspection

The CNC equipment was run (under supervision of faculty or technician) to produce some parts. [Fig.10]. These were assembled and operated. Following mechanism operation shop floor inspection station a CMM was used to evaluate the parts.

Post-class evaluation

All students completed their prototypes, which were assembled and operated. Following the course, a focus session with students revealed great enthusiasm for the course. Every student suggested new uses for rapid prototyping. Most stated that this should be a required course, with more time and projects. Other comments included: an enhanced understanding of Internet potentials, better appreciation of lead-time reduction, a good cap-stone course for manufacturing, and a desire to learn more. Students related the value of rapid prototyping to many areas including communication, ergonomics, and concurrent engineering. While the students were generally very pleased with the course, there was a consensus that a more comprehensive guide book would be valuable, and that more time (and credit) would be worthwhile. The Industrial Advisory Board for the College of Science and Engineering strongly endorsed the subject of rapid prototyping.

5. Conclusions

We found this rapid prototyping class to be a powerful and attractive method of teaching advanced manufacturing. However, the class requires extensive preparation time from faculty and staff, and strong departmental support. Equipment, computer networks, and software must be purchased, prepared and made accessible for students. Our main goal is to let students work in small teams, optimize their time, enjoy the work, and provide their solution to the problems; this can be achieved when the right teacher-student links are set up, and students know the evaluation criteria at the beginning of the class so they can prepare their work accordingly. The RP class still has much room for improvement. The following are some ideas being considered for introduction in next editions of the class:

- Increase class time to 3 credits;
- Write an operational guidebook;
- Introduce parametric CAD system for some projects which will make it possible to create much more advanced CAD documentation;
- Use more current problems from local industry, get students more involved, and possibly continue some projects as internships;
- Introduce elements of cooperation and competition between the teams.

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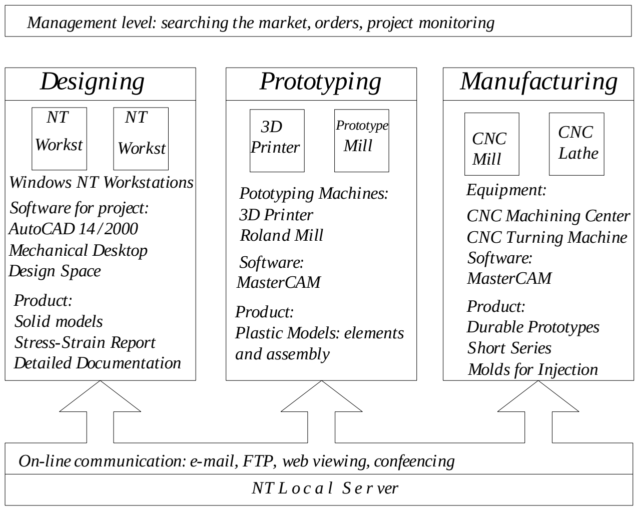

Fig.1. Rapid Prototyping Lab Configuration

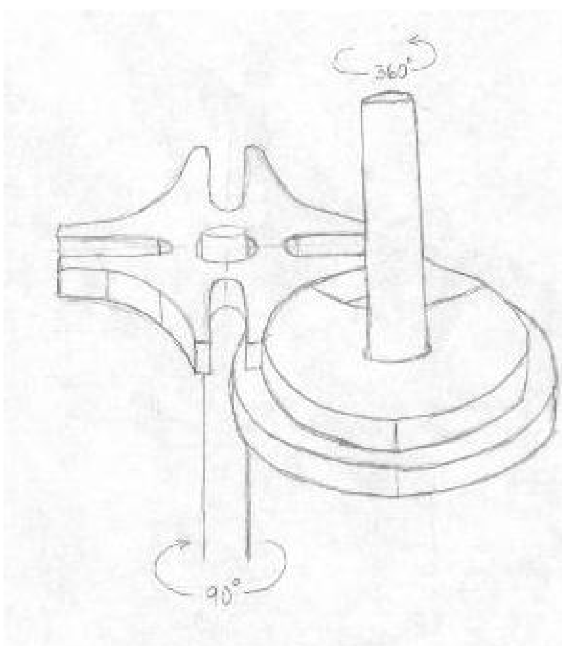

Fig. 2. A “Concept” Sketch of the Mechanism

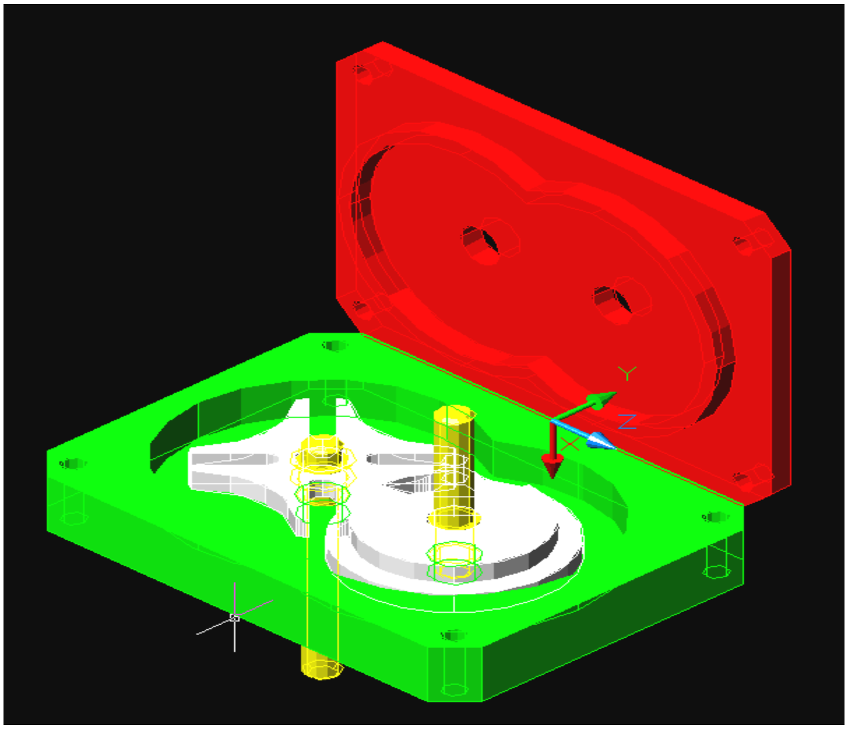

Fig.3. Solid Model of the Mechanism (Mechanical Desktop)

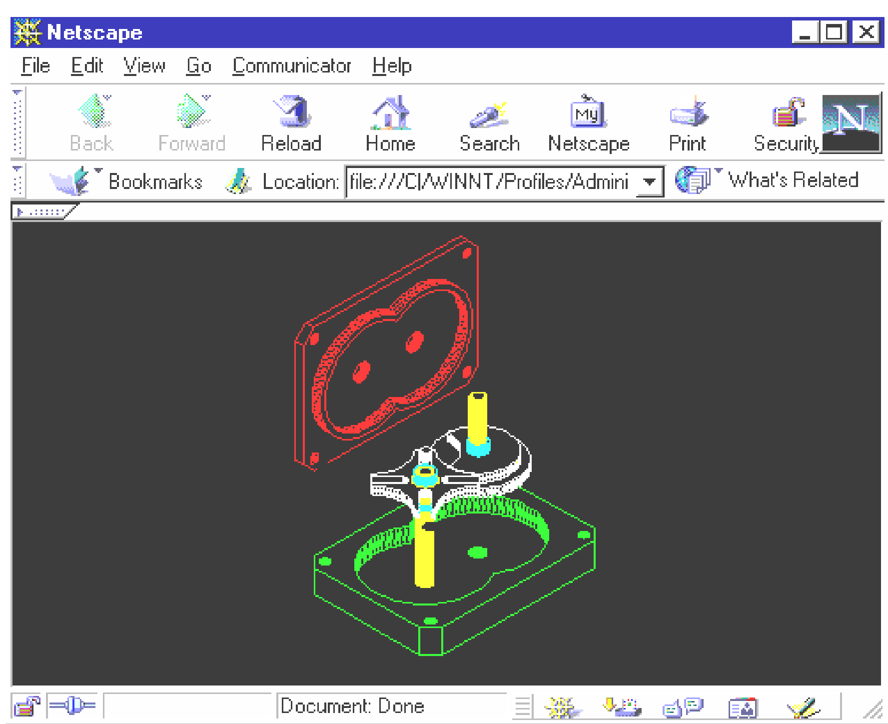

Fig. 4. Viewing an Assembly Drawing on the Web

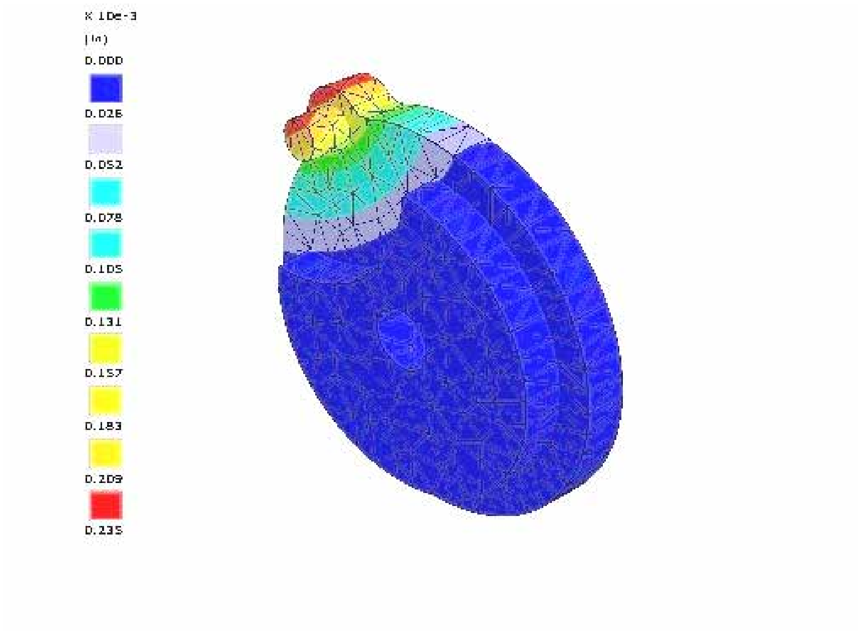

Fig. 5. Deformation Analysis Results (Design Space)

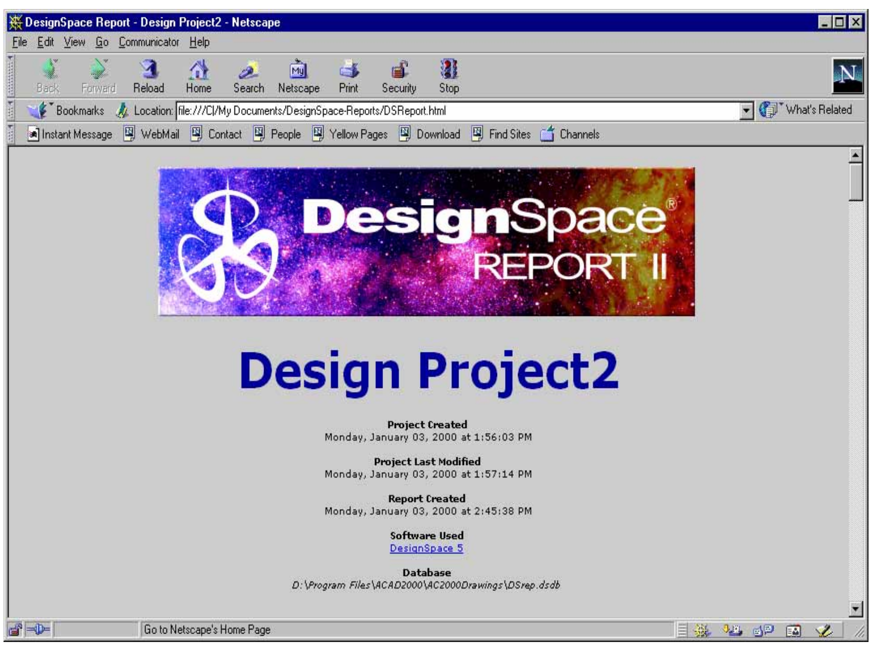

Fig. 6. Design Space Web Format Report Containing Results of Stress and Deformation Analysis

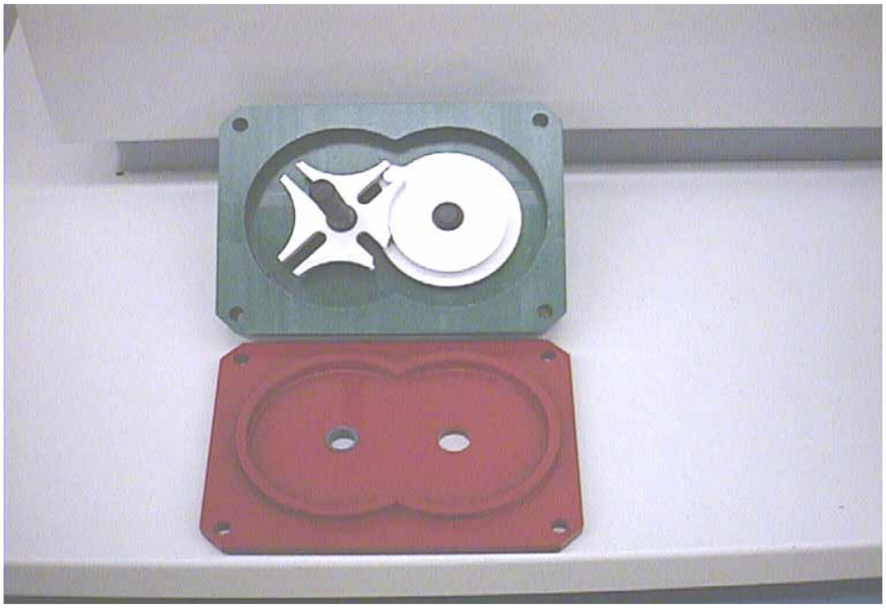

Fig. 7. Plastic Prototype of Geneva Mechanism made on the Actua ThermoJet Printer.

Fig. 8. Machining Case out of Plastic on the Roland Prototyping Mill

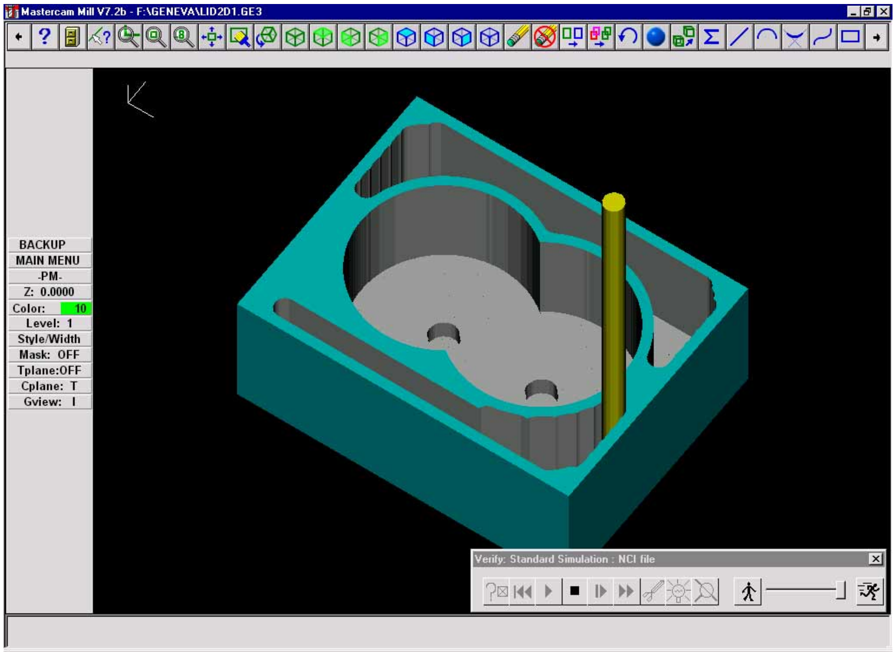

Fig. 9. Tool Path Generation (MasterCAM System)

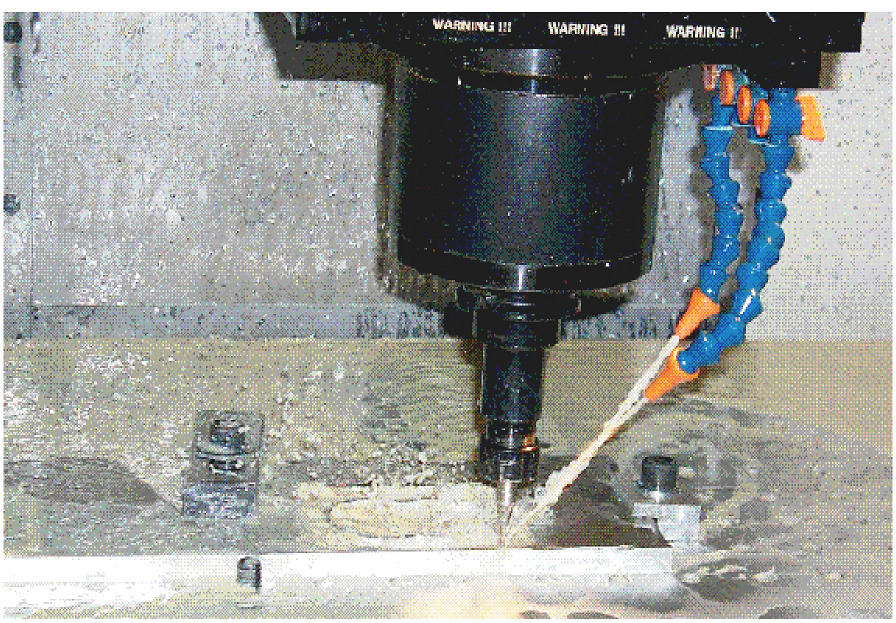

Fig. 10. Final Milling of the Case on Machining Center