Session

FEA Application in Sheet-Metal Assembly Process As A Senior Team Project

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Abstract

As FEA software is becoming increasingly user friendly, it is feasible to utilize it in a team-based senior project. The underlying philosophy of the project is to introduce students to FEA that is currently used in manufacturing practice in the automotive sector. In particular, students are introduced to the FEA through a project evaluating the quality of an assembly process on the automotive sheet-metal panel. A real industrial part, an automotive front fender panel, is utilized in the project. This project tied much of the material from students' previous course work together, including mechanics of materials, machine design, and manufacturing process planning.

1. Introduction

Over recent years, many manufacturing engineering or technology graduates work in positions requiring familiarity with computer-aided engineering analysis as well as design and manufacturing process. They are asked to utilize commercial software for simple design/manufacturing analysis, such as performing Finite Element Analysis (FEA) in fixture and tooling design to ensure required function. The main reason for this shift is integration of analysis at early stages of product design and manufacturing process planning. This up-front design analyses by engineers in industry, such as using FEA, has also moved from engineers with Ph.D.'s to engineers at the M.S. or B.S. degree level. However, most manufacturing engineering students are not exposed to FEA as part of their educational process. It is especially true for manufacturing engineering technology curriculum at Wayne State University (WSU).

FEA is now considered by many to be a standard tool for many categories of engineers. The commercial FEA code is now a very common numerical tool in stress analysis of mechanical components, and is widely used in other types of engineering analysis, such as vibrations and thermals. Furthermore, the FEA plays an important role in the arena of integration of product design and manufacturing. The overall success of a product design is significantly affected by its manufacturing process and equipment, for an example that the rigidity of a fixture influences the dimensions and surface quality of the product [1,2]. Therefore, in a concurrent engineering environment, manufacturing engineers are expected to utilize the FEA technique to implement the robust manufacturing facility and process. However, Waldorf [1] focused on tooling/

machining fixtures and Liao[2] emphasized on research activities of machining fixtures (not on the curriculum development). This paper focuses on the assembly fixture for bolting sheet-metal panels and implementation of the FEA as a senior design project.

It seems reasonable to expect that manufacturing engineers in the 21st century will need to be comfortable with the use of FEA software in order to be effective in the workplace. As the FEA software is becoming increasingly user friendly, it became feasible to use it in a team-based senior project. The underlying philosophy of the project is to introduce students to the FEA that is currently used in manufacturing practice in the automotive sector. In particular, students are introduced to the FEA through a project evaluating the quality of an assembly process on the automotive sheet-metal panel. The students are given a brief introduction to the fundamentals of the finite element method, including basic theory and practical guideline for meshing, boundary conditions, and interpretation of simulation results. This project tied much of the material from students' previous course work together, including mechanics of materials, machine design, tooling, and manufacturing process planning. In this respect, the project can represent a capstone design project. The contents of this paper are based on the activities of senior design project course offered in winter term 2004.

2. Background

This section gives an overview of FEA courses or projects that have been implemented in undergraduate curriculum at several universities and colleges. A brief background of the Engineering Technology (ET) Division in Wayne State University is also described.

2.1 Overview of FEA Course/Project in Undergraduate Curriculum

FEA courses, including theory and software application, have been regularly delivered in engineering graduate curriculum for decades. In undergraduate curriculum, two approaches have been adopted in introducing FEA to students: 1) integration with other appropriate courses, and 2) term project-based. Since the real benefit in introducing the students to the FEA technology is the ability to solve more interesting, physically realistic problems in a short amount of time, both approaches use commercial FEA software as a teaching tool.

Integration of FEA with undergraduate engineering courses has been held in many schools. Any course involving applications of mechanics of materials is appropriate for integration with FEA [3-7]. However most of these integrated undergraduate courses are for civil and mechanical engineering (and engineering technology) curriculum, very few evidences have been found that introduce FEA in the manufacturing engineering (and manufacturing technology) curriculum. Waldorf[1] introduced FEA for fixture design analysis to the tool engineering course. He developed a series of FEA laboratory exercises to analyze and optimize fixture, mold, and die designs.

A project-based introduction FEA to student has also been successfully implemented in several schools. Miner and Link [8] outlined a project requiring the design of a bracket that must meet size, load, and deflection requirements. Students were grouped into teams to design, analyze (using FEA), and build the bracket. The brackets were tested to compare the teams' predicted results to actual performance, and to see which team achieve the highest strength to weight ratio.

2.2 Overview of Engineering Technology at WSU

The Division of Engineering Technology in the College of Engineering, Wayne State University, was established in 1973. Currently the ET Division offers a very strong program in both undergraduate and graduate technology education in mechanical, manufacturing/industrial, electrical, and electromechanical disciplines. The upper division programs complement community college education by providing an application-oriented curriculum that leads to baccalaureate degrees in engineering technology. In order to cater for the extensive functional opportunities from a wide variety of automotive and other industrial enterprises here in the world's motor capital, Detroit, the Division of ET offers the following areas of specialization: Mechanical Engineering Technology (MCT), Manufacturing/Industrial Technology, Electrical/Electronic Engineering Technology (EET), Electromechanical Engineering Technology, Product Design Engineering Technology and Computer Technology. The MCT and EET programs are ABET-accredited. Seven full-time and more than fifteen part-time faculty delivery instruction in Engineering Technology area courses. In general, our students are working and have associate degrees from community colleges.

An engineering technologist is expected to be well equipped with hands-on experience through the courses taken and laboratory practice. For the Division to keep up with technological trends, instructional effectiveness be increased. Thus, specific needs arise to revise, add, or delete courses from time to time. Currently there is no course offered in the subject of FEA in ET Division, however students have solid backgrounds in statics, mechanics of materials, and machine elements design. A senior project, involving design or manufacture of specific product, is also required for every student in his/her final semester to be eligible for graduation. It seems effective to utilize this senior project to introduce FEA to students. The project "FEA application in sheet-metal assembly process as a senior team project" is just one example how ET responds to the needs of industry.

3. Project Implementation

This section outlines the objective of the project, implementation of FEA tool in senior project course, and formation of student teams to carry out the project.

3.1 Project Description and Objective

Since each workpiece is subject to dimensional variation caused by manufacturing randomness, these individual variations in turn act on one another to compound distortion in the final assembled part. The dimensional variation of sheet-metal workpiece is mainly resulted from its preceding manufacturing process, such as stamping, transportation, and subassembly. Therefore, the initial matching gap may be generated between the workpieces at each bolting pair. The gaps between the workpiece and bolts are forced to close during bolting action and accordingly undesirable structural deformation results. This is especially true in the compliant, non-ideal sheet-metal assembly process. In addition, the variations of sizes and locations on bolt holes also dominate the final assembly quality.

A real industrial part, an automotive front fender sheet-metal, as shown in Fig. 1, is utilized in the project. After press operation, this panel is placed in an assembly fixture for bolting operation. Due to bolts tightening and gravity effect, the panel will deform. The deflection due to bolting might result in out of tolerance specification in panel. The surface profile tolerance specification is ±0.7 mm in the panel outer flange and inner regions, according to geometry and tolerance specification. The fixture design (locator and clamp positions) is pre-determined by the industrial partner. The objective of this project is to determine the bolting sequence in the fixture, such that the deflection of the panel can be within tolerance.

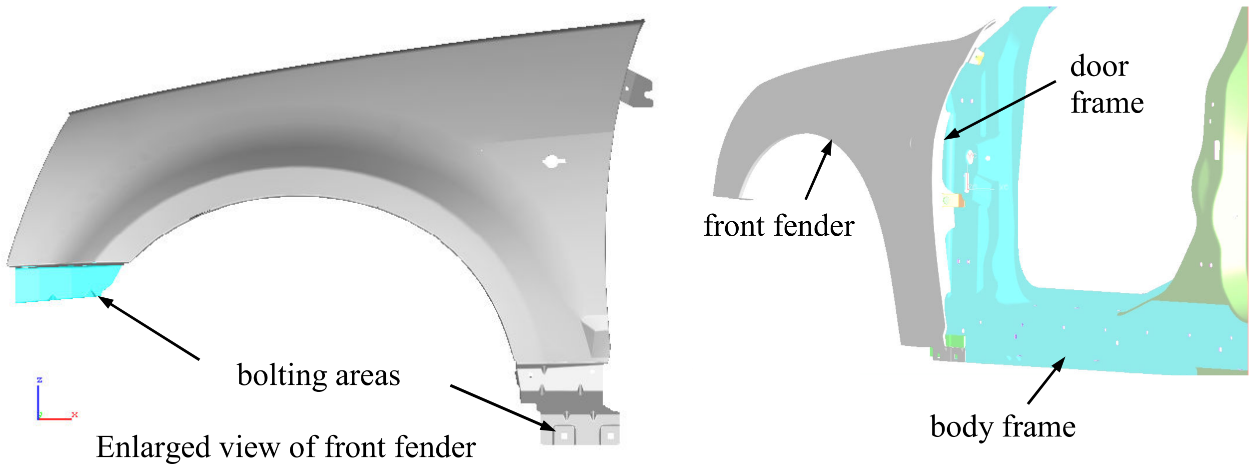

Figure 1. Front fender panel of an automotive

3.2 FEA Software as Senior Project Tool

3.2.1 Interface Between CAD and FEA

A CAD (Computer Aided Design) file of this panel was provided by an industrial partner. Hypermesh [9] was used as pre and post processors to build a finite element model from CAD file and to display simulation results. Nastran [10] was utilized as a solver to compute the panel deflection due to gravity.

3.2.2 Fundamental Theory of FEA

Commercial FEA software has become so user-friendly and powerful that a novice can perform complex analysis without having very much about the details of the analysis processes. To avoid “black box effect” [11], it must ensure that students have a basic understanding of the underlying principles. The fundamental theory of FEA was delivered in ten two-hour lectures. The topics included finite element principles, element geometries, element types, material properties, boundary and loading conditions, and accuracy and precision. Certainly, it is important to emphasize to the students the need to use engineering judgment to interpret ate the FEA results.

3.2.3 Application of Commercial FEA Software

Most commercial FEA codes (modeling and solver) can now be utilized effectively to illustrate concepts in a level of undergraduate course. However, the objective of this project-based course does not intend to teach or train students in specific FEA software, such as Nastran. Commercial FEA codes serve the dual purposes of assisting the students in learning the core material and demonstrating valuable tools which can be used in solving complex problems. The introduction of Hypermesh and Nastran were delivered in ten two-hour lectures.

3.3 Team Approach

Students were grouped into several teams. Each team consists of three or four students to carry out the project, which come from actual applications in automotive industry. This paper describes just one of the projects. Furthermore, this team project addresses the goal of improving the teamwork and communication skills within these senior design teams.

4. Simulation Results and its Implementation

The inputs of the analysis include FEA model of the fender panel, variations data of the panel and bolt holes. Figure 2 shows the FEA model of the fender panel with eight bolting areas. Figure 2 also illustrates the initial design of bolting sequence ($1 \rightarrow 2 \rightarrow 3 \rightarrow 4 \rightarrow 5 \rightarrow 6 \rightarrow 7 \rightarrow 8$). The panel deflection in the x-axis direction (the fore-aft direction of vehicle) due to gravity and gaps closed is displayed in Fig. 3. The maximum deflection is 2.6 mm in outer flange close to head light fixture area. Since the 2.6 mm deformation towards the rear end of the vehicle, or the positive x-axis direction, this deformation increases 2.6 mm gap between the fender front end and the headlight.

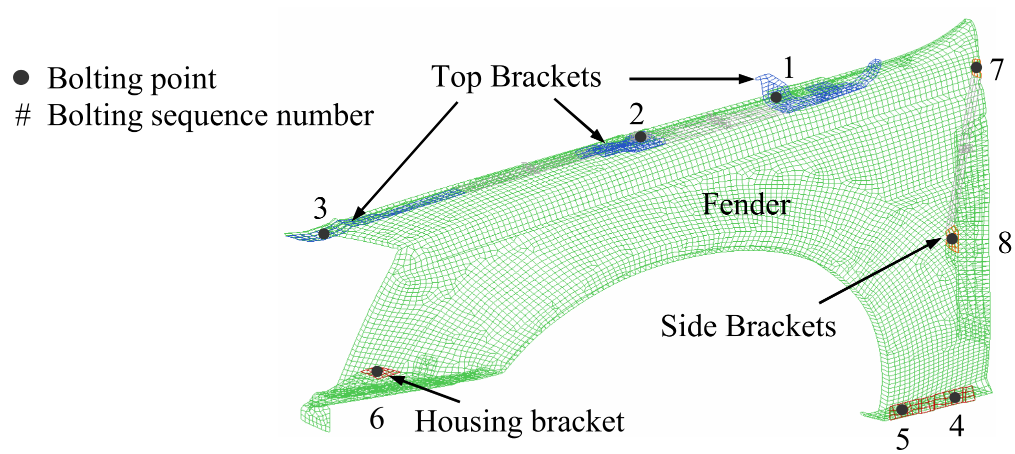

Figure 2. FEA model of fender panel and bolting areas

The panel deflection in the y-axis direction (the cross-car direction of vehicle) due to gravity and gaps closed is displayed in Fig. 4. The maximum deflection is 2.4 mm in outer flange close to hood area. Since the 2.4 mm deformation outbound of the vehicle, or the negative y-axis direction, this deformation increases the gap between fender top side and hood. Figure 5 shows the deflection in the z-axis (up-down direction of vehicle). The maximum deflection is 1.4 mm in outer flange close to headlight fixture area. Again, this 1.4 mm upward deformation increases gap between the fender front end and the headlight.

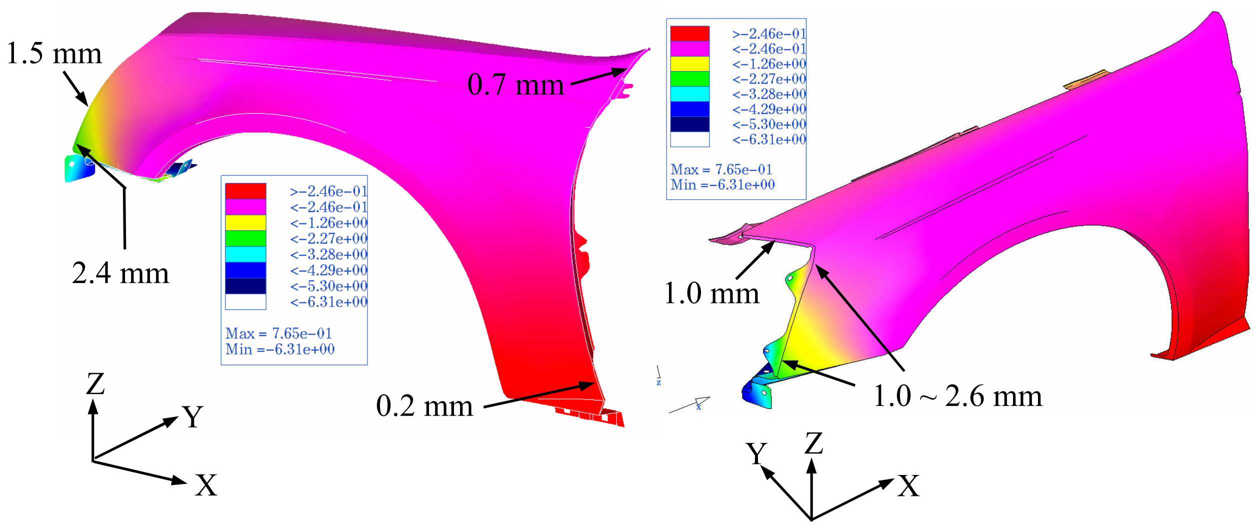

Figure 3. Deflection of fender panel in the x-axis direction

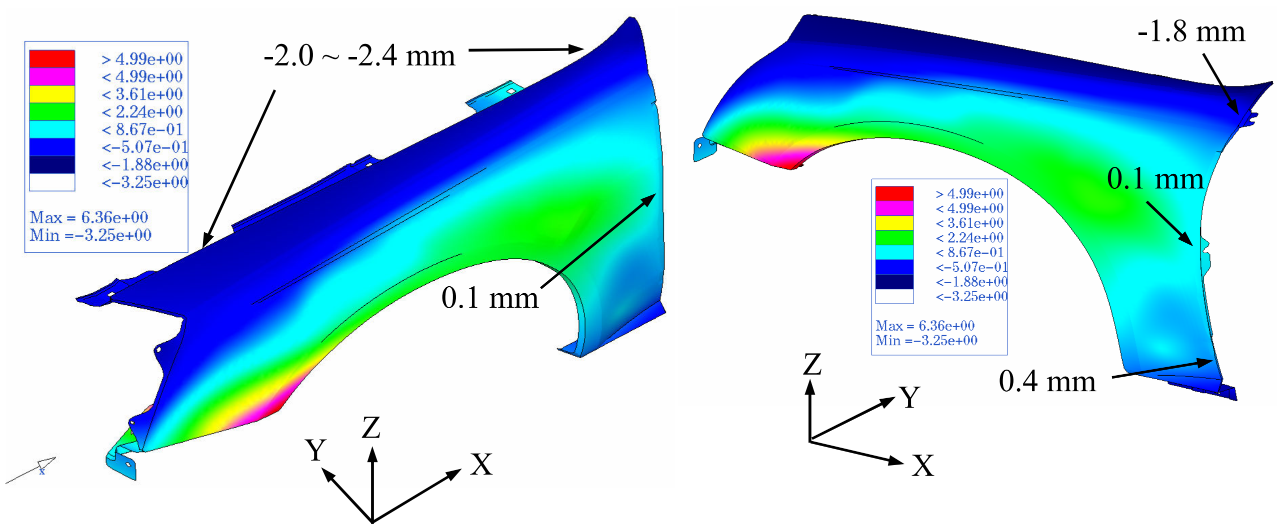

Figure 4. Deflection of fender panel in the y-axis direction

The algorithm developed for welding sequence optimization is utilized in this study [12]. The optimal bolting sequence was determined as 4 → 8 → 7 → 5 → 3 → 1 → 2 → 6 (referring to Fig. 2). Figure 6 illustrates the panel deflection in the x-axis direction as the optimal bolting sequence applied. The maximum deflection is 0.6 mm in outer flange close to door frame area. The fender deformations in the x-direction are within the tolerance specification. The panel deflection in the y-axis direction, as the optimal bolting sequence is applied, is displayed in Fig. 7. The 1.1 mm deflection in the inner region will cause non-smooth flashness on the assembled sheet-metal. The fender deformations in the y-axis direction are still out of the tolerance specification. Figure 8 shows the deflection in the z-axis as the optimal bolting sequence applied. The fender deformations in the z-axis direction marginally meet the tolerance requirement.

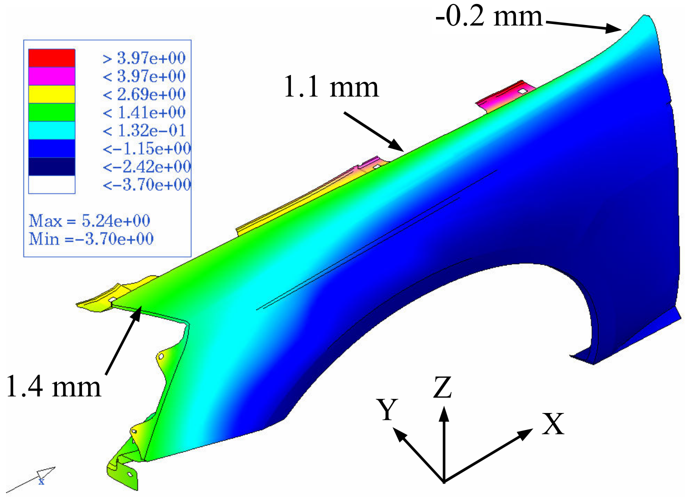

Figure 5. Deflection of fender panel in the z-axis direction

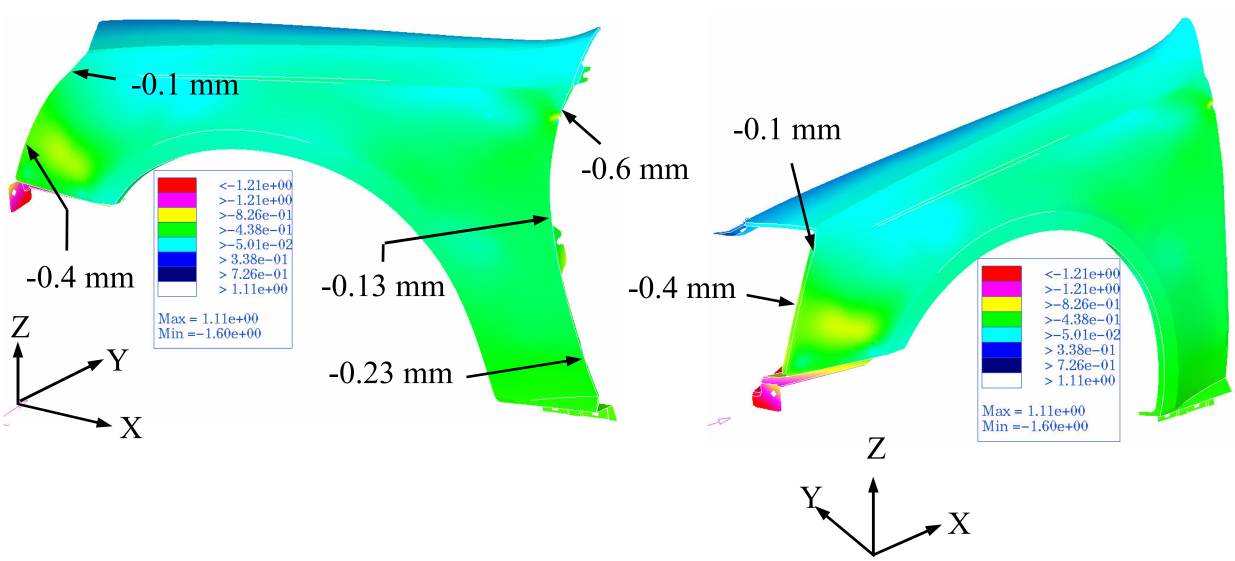

Figure 6. Deflection of fender panel in the x-axis direction with optimal bolting sequence

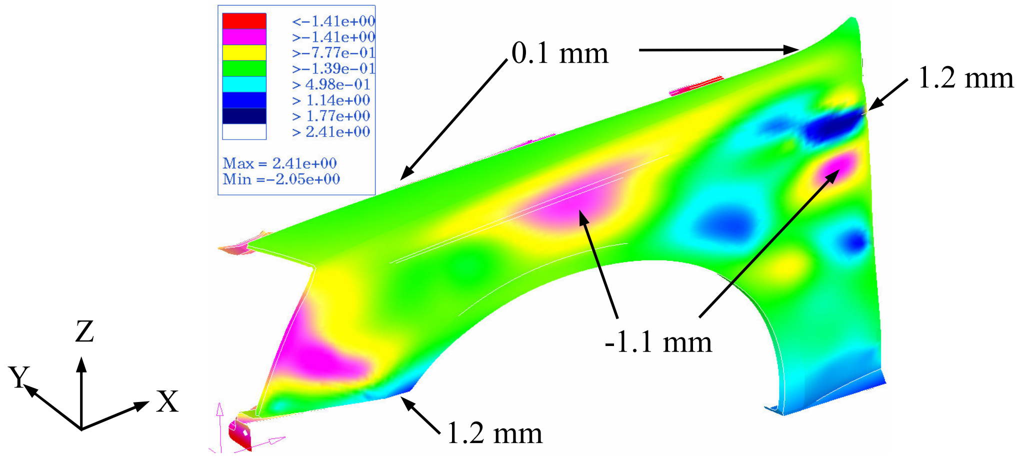

Figure 7. Deflection of fender panel in the y-axis direction with optimal bolting sequence

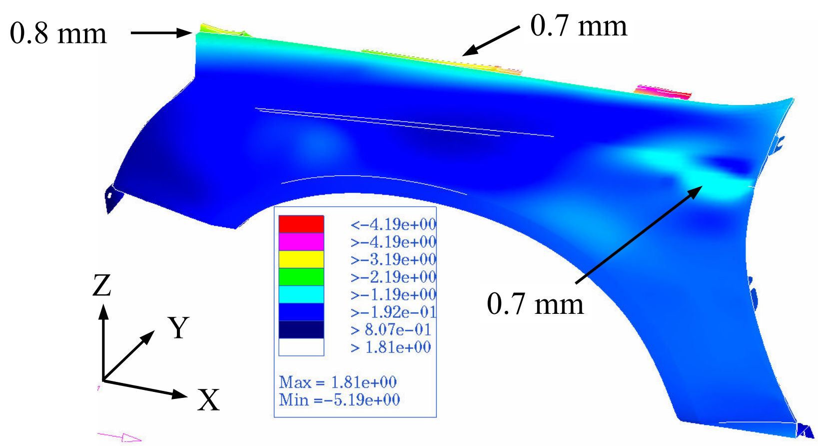

Figure 8. Deflection of fender panel in the z-axis direction with optimal bolting sequence

5. Conclusions

An overview was presented of an initial effort at the ET Division in WSU to include the use of commercial FEA codes, Hypermesh and Nastran, in senior projects. Through a project requiring the design of an optimal bolting sequence in an automotive sheet-metal panel, three purposes have been achieved: 1) to assist students in practicing an industrial project, 2) to introduce the capability of FEA in solving complex problems into the students, and 3) to emphasize the importance of team work and communication skills.

According to FEA simulation results of this project, the predicted optimal bolting sequence was implemented in a real production line. The shop floor measurement data has demonstrated the quality improvement of vehicle assembly. We are confident that this project-based FEA application in real industrial part will be beneficial to the graduating students. They will be better prepared for their career.

References

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