Airbag ECU Vibration Simulation

- Development of Design Process with 3D CAD/CAE -

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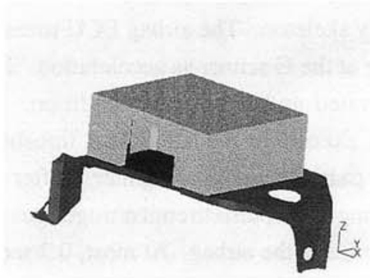
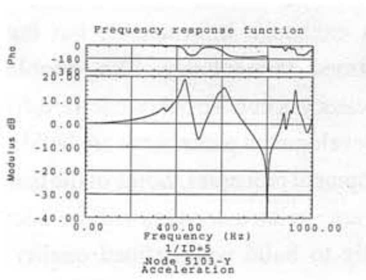
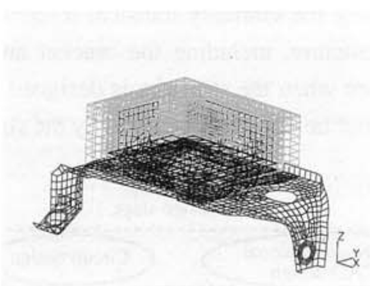
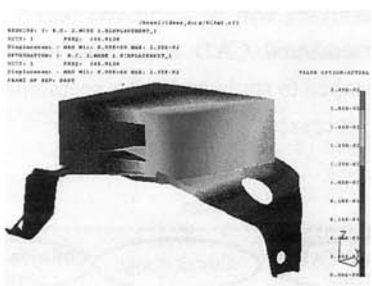








To meet the recent crunch in automobile production due to shortened periods of development, we are making efforts to use computers in product performance testing. In particular, we are using simulations to evaluate airbag ECU performance. This paper focuses on three-dimensional CAD/CAE design processing and the vibration prediction method, which was developed to improve the quality and production efficiency of airbag ECUs.

1. Introduction

Recently, automobile industries are challenged to reduce costs, improve development process efficiency, and shorten development periods. To assist in meeting these challenges, extensive efforts among related sections and personnel[1), 2), 3)] are being made to use three-dimensional CAD/CAM technologies to build design and development processes under simultaneous cooperation.

The basis of our product development is the two-dimensional CAD structure design (Figure 1-a). The development process usually involves design, prototyping, and experimental evaluation steps. The steps of these processes were developed from hands-on experience. Related sections exchange information, but tasks are generally performed sequentially. So, problems in development efficiency occur. To overcome the difficulties involved in this development process, we are building new design and development processes. Some of the features of the new process are: related sections will be allowed to work concurrently to build well-defined quality in the initial design stage; related sections will be allowed to share three-dimensional CAD data to make collaboration possible; FEM analyses will be improved based on the shared three-dimensional CAD data; and preemptive measures will be taken to study and solve problems likely to occur in later processes.

This paper focuses on the following subjects:

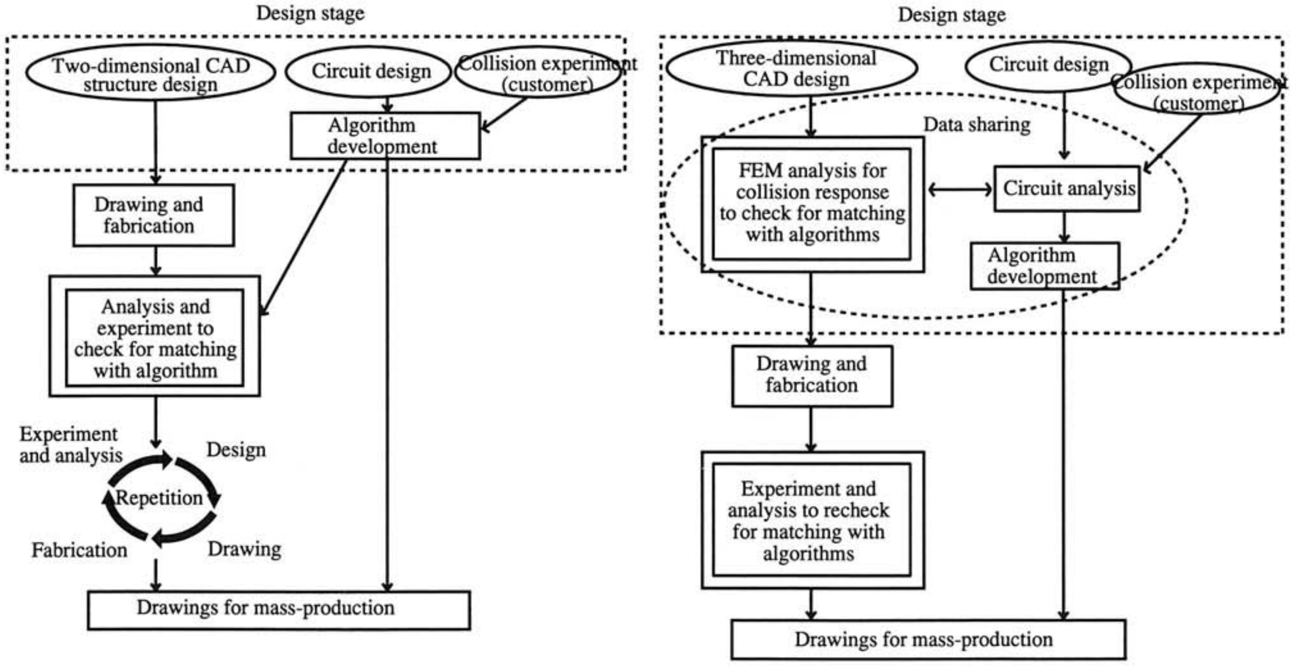
① The concept of design and development processes for airbag ECUs, which require the concurrent development of vibration analysis and collision judgment algorithms

② The vibration prediction method as a design support tool, which helps implement the above design and development processes

2. Outline of development processes

2.1 How an airbag works[4)]

Figure 2 shows the processes in which an airbag works. The collision impact is transmitted to a sensor via the body skeleton. The airbag ECU measures the impact arriving at the G sensor as acceleration. The acceleration is integrated under a certain condition. If the resulting integral exceeds a predetermined threshold, an igniting current passes through an igniter. After ignition, a gas-generating agent burns to emit nitrogen gas from an inflator, which inflates the airbag. At most, 0.2 second is required for the airbag to inflate after a collision is detected. Usually, an airbag ECU is bolted to the body by a bracket (Figure 3). Evaluating the vibratory transient response of the airbag ECU structure, including the bracket and bolt joint, is important when the structure is designed. The G sensor should not be adversely affected by the structure. Airbag



(a) Two-dimensional CAD design and development flow

(b) Three-dimensional CAD design and development flow

Figure 1. Design and development flow

ECU development is complete; the results of the above evaluation are used to create circuit and collision analysis algorithms.

2.2 Outline of development processes and principal engineering component

Figure 1-(a) shows the current standard development process. The process begins with conducting the design and prototyping steps, and collision experiments at a customer's test facility. The results of these experiments are used to develop circuit design and collision judgment algorithms. Consequently, structure design, circuit design, prototyping and performance examination steps must be completed before developed algorithms can be matched. Thus, problems arise, such as prolonged development periods, numerous prototyping attempts, and increased development costs.

To solve these problems, changing the current serial task flow is necessary. We recommend that this change be done by developing a concurrent development framework based on the shared data among related sections. By having such a framework, building well-defined, quality products in the initial development stage, which consist of planning and design steps (front loading: Figure 4[5]), is possible. Figure 1-(b) shows development processes, which illustrate the above flow. The principal engineering component, which can realize these development processes, are design support tools. These support tools include those for three-dimensional CAD design, FEM modeling based on CAD data, and FEM vibration prediction. These design support tools are detailed below as the required main aspects of the engineering component.

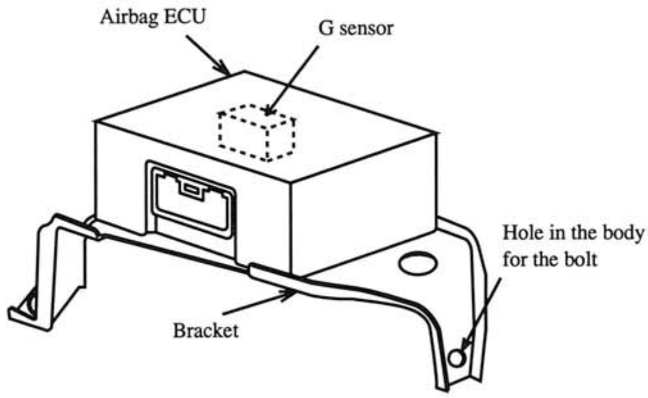


Figure 3. Airbag ECU structure

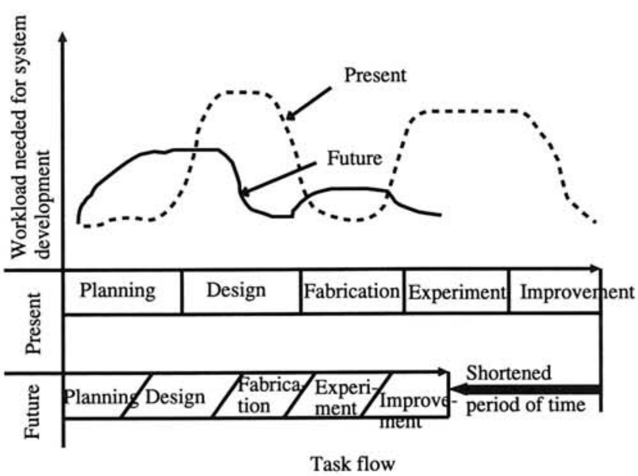


Figure 4. Lead time of current and furture development

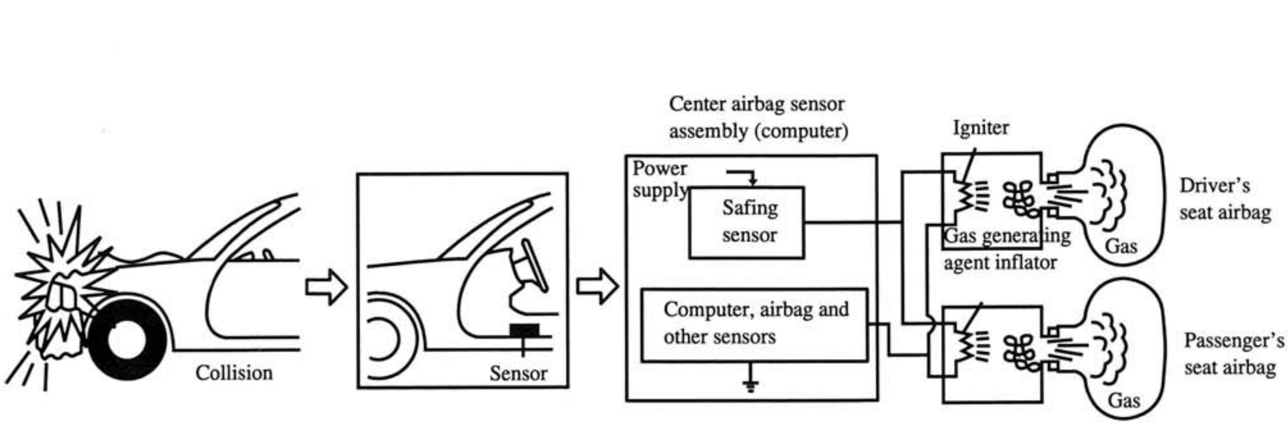


Figure 2. Process of airbag function

3. Design support tool development

The newly developed process can calculate the frequency response function of the structure from three-dimensional design data in the drawing creation step. In addition, this process can check whether the structure specifications are satisfied. Therefore, incorporating the necessary reinforcement and other support factors in the structure when creating first draft drawings is possible. Also, calculating how the vibratory acceleration causes a collision to be transmitted to the G sensor is possible. The results of this calculation can be used for the development of the collision judgment algorithm.

3.1 Three-dimensional CAD design and FEM modeling

It is difficult for designers to complete FEM analysis within a limited period of time if they have to rely on CAD systems, which create three-dimensional models for FEM after conventional two-dimensional models are designed (Figure 5-a). Although designers are given lenient deadlines, designers are heavily burdened if they have to create three-dimensional models. To assist designers, we have standardized the tasks of selecting a type of three-dimensional CAD system, registering standard libraries, and creating FEM models. Designers can now use the three-dimensional CAD system with ease (Figure 5-b). The standardized steps are listed below:

① System selection allowing installed data from different customers to be shared

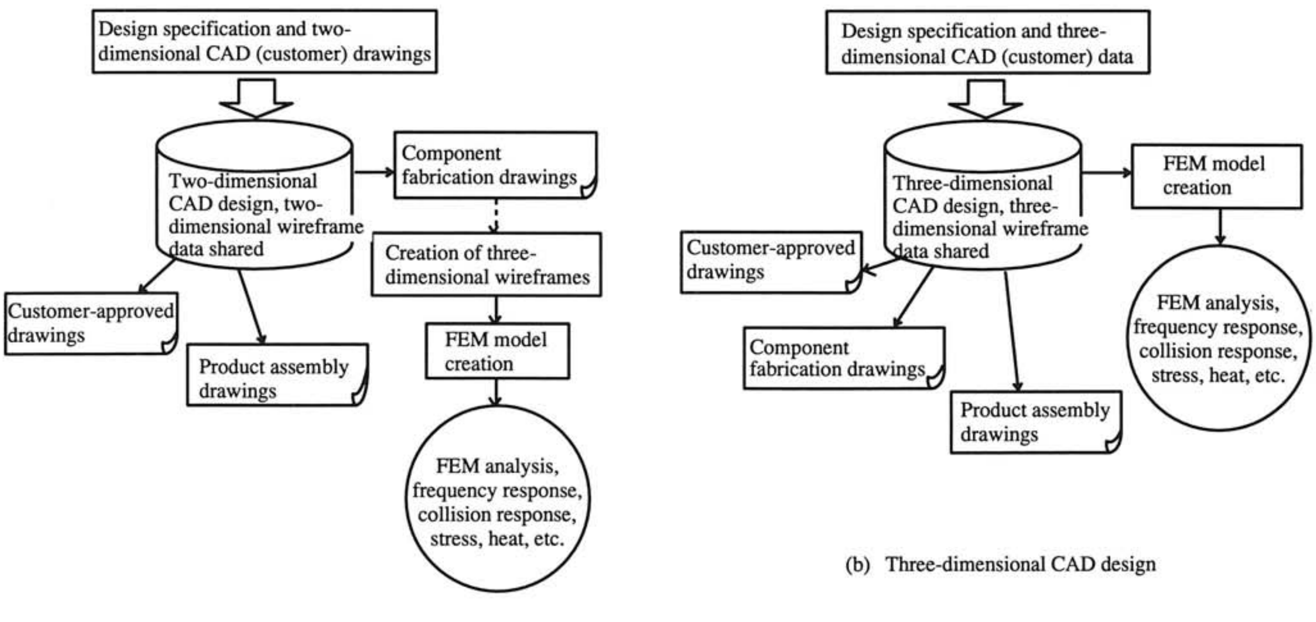
② System selection, compatible with existing FEM analysis systems in terms of three-dimensional CAD wireframe surface data

③ Standard library creation, in which drawing frames, annotations, and common components are registered. Two-dimensional drafting is performed more efficiently

④ Software creation, three-dimensional CAD data is converted to IGES formats semi-automatically and the results are transferred to FEM analysis workstations

⑤ FEM model standardization, representing joints between components

This standardization has made the following possible: data compatibility among different systems within the company is assured and supplied by customers located in the beginning of the design flow. Such customer-supplied data includes basic design data for installation on vehicles. Designers can complete their designs by incorporating the necessary reinforcement structures and combination with the ECU case on the body. Once three-dimensional data is completed, the geometry can be automatically laid out in the two-dimensional drawings. The drawings are completed when detailed dimensions and other information are added. Thus, the most time-consuming tasks in the present design processes can be more easily accomplished with the aid of



(a) Two-dimensional CAD design

(b) Three-dimensional CAD design

Figure 5. Computer aided design system

customer-supplied data. This allows designers to spend more time for FEM model creation.

3.2 Development of the FEM vibration prediction method

Standardizing the modeling process is necessary for designers. Standardization assures that the highest FEM analysis accuracy is obtained. The verification method of this standardization and its results are detailed below.

3.2.1 Outline of FEM dynamic models

FEM analysis software can assure the accuracy of the analysis of vibrations of single components made of isotropic material, regardless of how the components are shaped. However, the accuracy of the calculation depends greatly on the suitability of the modeling used when products combined of multiple components are analyzed. We focused attention on the modeling of spot welds jointing sheet-metal components. Initially, welds and sheet-metal components were modeled with solid and shell elements, respectively (physical properties were assumed to be iron). These components are shown in Figure 6(a). When the results of this FEM analysis were compared with the results of experiments on actual equipment, the frequency of vibration in degree-1 mode was found to be low. In addition, the relationship between the degree and mode shape was reversed in higher-degree mode. The experiment results indicate that the mode shape corresponding to the bending deformation was in effect. The reason seems to be that the model was built to prevent rotational displacements from being transmitted through the welds. Then, we adopted a model representing welds by beam elements and peripheral sheet-metal parts by rigid elements (Figure 6-b). The characteristics of this model are as follows: a total of six degrees of freedom keep the continuity of displacements; and the rigidity of the welds can be considered in all respects, including rigidity against axial, shear, bending, and torsion deformation. The rigidity of the rigid elements cannot be considered.

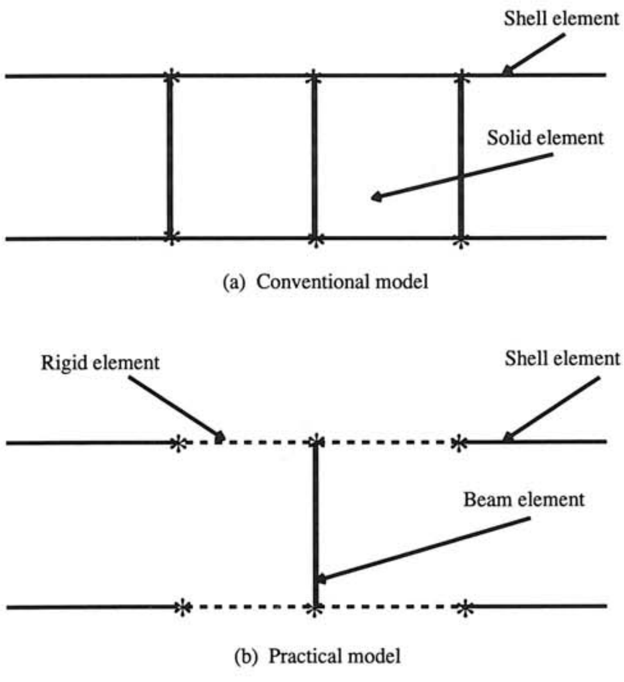
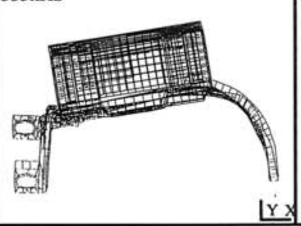
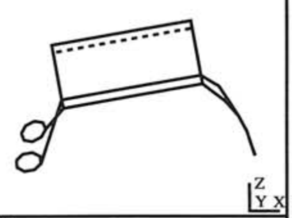
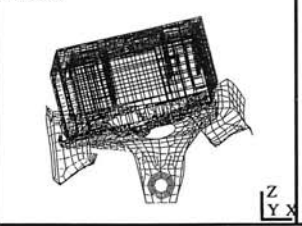
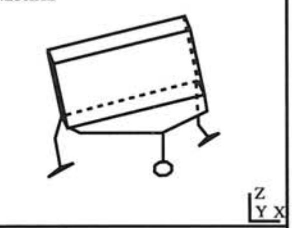
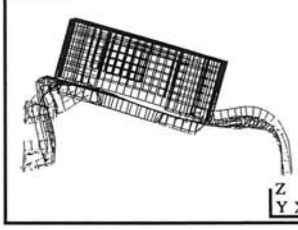
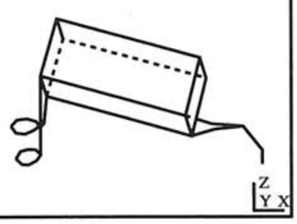


Figure 6. Spot welding FEM model

3.2.2 FEM calculation

Next, the completed FEM model was used to determine the vibration mode and calculate the frequency response function of the G sensor mount. The results are shown in Table 1 and Figure 11. Table 1 shows the mode shapes and resonant frequencies of degree-1 to -3 modes of vibration obtained through FEM and experimental mode analyses. Figure 11 is a board diagram that shows the results of FEM and experimental response analyses. The horizontal axis represents frequencies from 0 to 1 kHz. The vertical axis represents the acceleration response gains and phases.

Table 1 Mode shapes of airbag ECU

FEM	Experimental modal
Mode 1	
335kHz 	350kHz 
Mode 2	
422kHz 	425kHz 
Mode 3	
574kHz 	585kHz 

3.2.3 Roles of experimental verification

Experimental verification is an important process to understand the dynamics of factual events. In our context, it is used to verify the FEM modeling technology based on experimental analysis data. The results of the verification were fed back to subsequent FEM modeling attempts. The adopted experimental verification method is detailed below.

a) Experimental analysis using impulse excitation
Figure 7 shows the configuration used in our excitation experiment. The ECU was mounted on a fixture, which was installed on the vehicle to simulate an actually installed ECU. An impulse hammer was used to excite the ECU case at a single point. By measuring the force given by the impulse hammer and the response acceleration at the excitation point, obtaining the frequency response function at the measuring point was possible. The resonant frequency and mode shape of the ECU were determined by using the method based on modal parameters. Figure 8 gives an example of a frequency response function. The peak and phase of this function indicate that this ECU has eight resonant vibration modes. Detailed information about the resonant frequencies and mode shapes are given in Table 1 above. (Degree-4 and higher modes of vibration are omitted because their accurate representations cannot be obtained at the used measuring points because vibrations within the case existed.)

b) Experiment using sine sweep excitation
Figure 9 shows the configuration used in our excitation experiment. Similar to the impulse excitation experiment, the ECU was mounted on a fixture, which was fixed on an excitation table. A sine wave was applied as the input to give sweep excitation at frequencies from 10 to 1 kHz. By measuring the response accelerations at the acceleration sensor attached to the fixture and at a measuring point, obtaining the frequency response functions at these locations was possible. Figure 10 shows the frequency response function at the G sensor mount, which receives excitation from the fixture. The attenuation factor, which checks the gain at each resonant frequency, was obtained through curve fitting applied to this frequency response function.

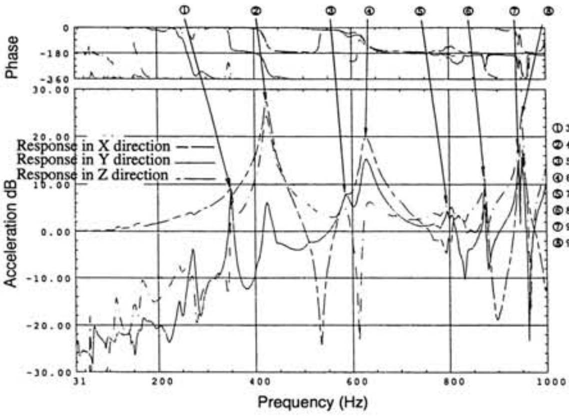


Figure 8. Measured frequency response function

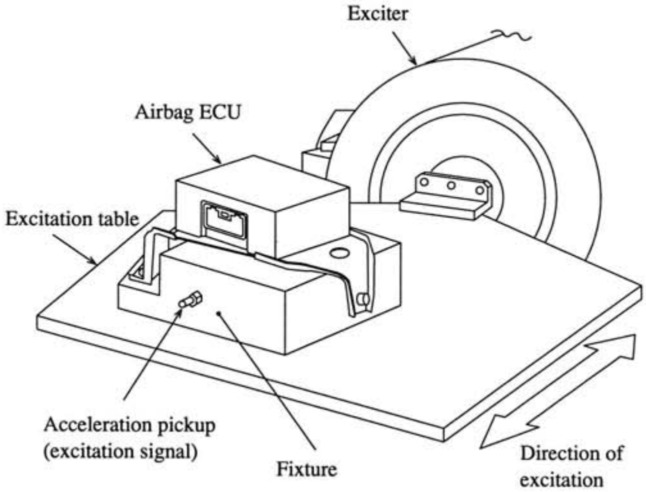


Figure 9. Configuration of the sine sweep excitation test

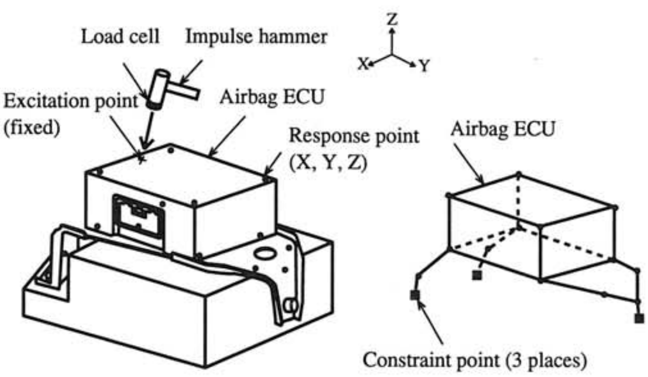


Figure 7. Configuration of the inpulse excitation test

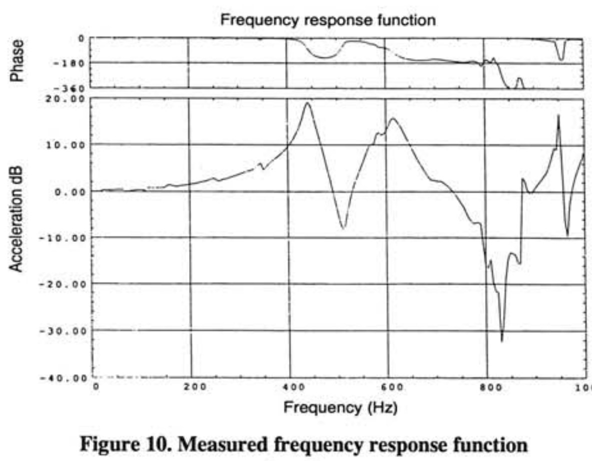


Figure 10. Measured frequency response function at acceleration sensor

3.2.4 Verification of the FEM analyzing power

The mode shapes, resonant frequencies, and frequency response functions obtained through the FEM and experimental analyses were compared to verify the completeness of the model. The following FEM analytical values give the performance of the model.

a) Comparison of mode shapes and resonant frequencies
The mode shapes and resonant frequencies obtained through the FEM and experimental analyses are shown in Table 1 above. We conclude that FEM analysis is highly reliable in predicting ECU vibrations by comparing these results.

b) Comparison of frequency response functions
The frequency response functions obtained through the FEM and experimental analyses are shown in Figure 11 above. This figure clearly shows that FEM analysis can accurately provide information about the acceleration gain at each resonant frequency. Even the acceleration gains at antiresonant parts are accurately reflected.

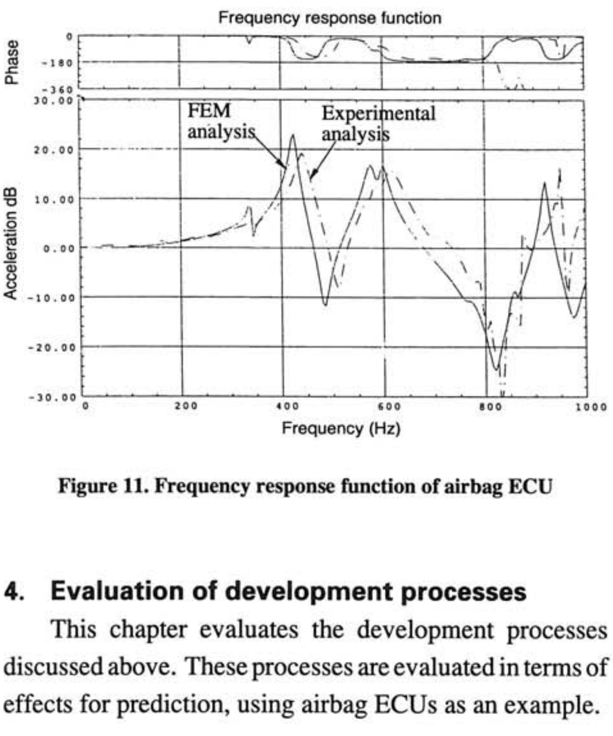


Figure 11. Frequency response function of airbag ECU

4. Evaluation of development processes

This chapter evaluates the development processes discussed above. These processes are evaluated in terms of effects for prediction, using airbag ECUs as an example.

4.1 Early stabilization of quality (shortened development period) and reduction in development costs

Using three-dimensional models for development in the prototyping stage has two main benefits. First, the theoretically best shape can be obtained through simulations. Second, drawing, prototyping, and prototype testing can all be completed simultaneously. These benefits lead to about an 80% reduction in the repeated tasks of a day. These repeated tasks were discussed earlier and are indicated in Figure 1-(a). Also, cutting about 50% of the simple mold costs and mold processing expenses required to fabricate a prototype is possible.

4.2 Prospects

The above design and development processes proved to be beneficial. These processes should now be utilized for conducting timely performance evaluations and in assisting in the design of mass-production structures.

4.2.1 Introduction to mass-production designs (side airbag ECU)

Since the rules for accepting customer data have been established, we have begun to apply the above design and development processes to the development of side airbag ECUs, which has already started. These developed processes will actually be used for mass-production designs. Further efforts will be made to improve the maneuverability of processes.

4.2.2 Continued efforts to advance technology

The FEM analysis technology developed this time has proved to be accurate enough to satisfy structure specifications from customers. We plan to apply this technology to new ECUs to check reliability. To directly apply collision response waveforms to the development of algorithms, it was discovered that the analysis accuracy had to be kept up to higher degrees of vibration modes than that with the present analysis method. More specifically, the modes associated with printed wiring board vibrations must be calculated accurately. For this purpose, studying one of the two techniques seems necessary: ① response calculation in which experimental modal data is integrated with FEM analysis; or ② modeling of composite materials. The first technique was discovered to be able to achieve this by making use of an existing system. We plan to check whether this technique can help improve analysis accuracy.

5. Conclusion

All the functions of this airbag simulator we developed have met target performance levels. The development results are summarized below:

- The frequency response function of a structure can be predicted in the creation of drawings step

- Collision response waveforms were applied to the development of algorithms
- Environment around three-dimensional CAD systems was improved and cooperation between three-dimensional CAD and FEM analysis systems

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