Integration of CFD and Thermal Stress Analysis for Turbochargers

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1. Foreword

In the manufacturing industries, there is a trend lately to employ a new manufacturing method using 3D-CADs in the manufacturing process. The purpose of employing the new method is to cut the lead time of a new product and achieve the timely introduction of the product into the market when it meets customers' needs by solving manufacturing problems with 3D-CADs in the design phase. [1],[2] The real effects of introducing 3D-CADs can be realized by not only examining designs in three dimensions in the design phase, but also by converting entire development processes to be based on digital data by reflecting design model data in such production data as those for various analyses and mold production. We also have been changing development processes from drawing-based conventional processes to those based on digital data.[3]
Our company develops such rotating machinery as turbochargers and turbo-compressors. Because they are fluid machinery with complex geometry consisting of many free form surfaces, many good results can be expected by employing 3D-based development. Further, because we produce products by partially altering the design of our standard specification products for general-purpose applications according to the customer's requirements, we can expect to improve design speed by establishing the new development processes mentioned above and by re-using existing data effectively. Generally, rotating machinery consists of many machine elements and some of them are put into such severe conditions as high-speed rotation under high temperature. Therefore, analysis is very important in the developing processes and it is fundamental to implement analysis procedures smoothly in the development processes. We analyzed the thermal stress of a turbine housing of turbocharger by transferring the results of temperature distribution analysis, which is based on the results of thermofluids analysis, to structural analysis. By comparing the flow of the analysis with the conventional analysis procedures, we will describe the effects and problems of the new procedures, which we encounter when applying them to design procedures.

2. Records and plans of CAD/CAE

Figure 1 shows CAD/CAE records and plans of our division. As for 3D-CADs, we have used CALMA and CAEDS and are now mainly using I-DEAS, Unigraphics and CATIA. Because we are a parts supplier and required to use several CAD systems to provide data in the format of our customers' systems, and because we often use different systems for different types of data, it is unavoidable to convert data between different systems. For structural analysis, we use MSC/NASTRAN and for pre/post-processing, MSC/PATRAN, I-DEAS. We are also considering the use of PDM system to seamlessly integrate the CAD model and CAE and to re-use design data.

3. Problems of conventional analyses

Figure 2 shows the conventional procedures obtaining temperature distribution from the results of the thermofluids analysis to analyze heat transfer and thermal stress of the solid objects. Because development proceeded based on 2D drawings with the conventional procedures, analyses were separately conducted. In the figure, time-consuming processes are indicated by bold line and the problems of such processes are described below.

(1) Creation of 3D model

Because the conventional development procedures are based on 2D drawings, a 3D model for analysis was created after creating the 2D drawings. Further, in order to create a model of parts that the 2D drawings could not represent, the person creating the model had to thoroughly discuss the design with the person who created the drawings, which took a lot of time. On top of this, because a turbocharger consists of many free form surfaces, there were some parts for which modeling software could not create data.

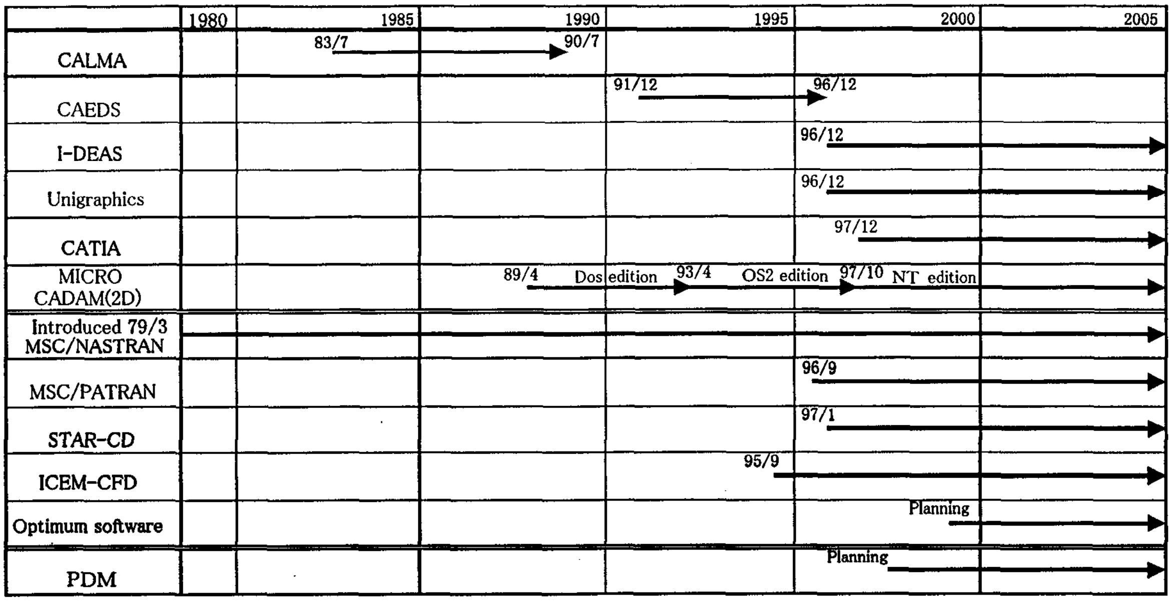


Fig.1 Records and plans of CAD/CAE

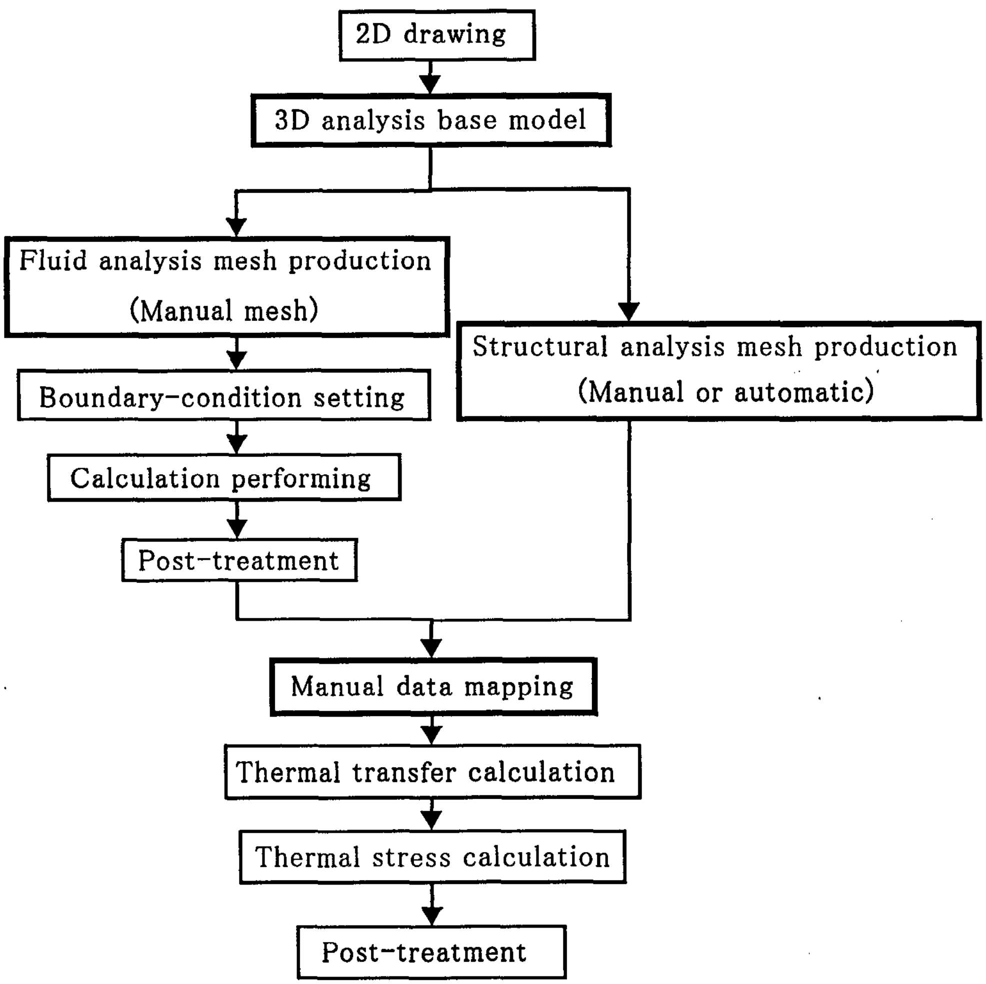


Fig.2 Conventional process of integrated analysis

(2) Creation of meshes

Because the meshes for fluid analysis are finer than those for structural analysis and are generally hexahedral, they were manually created. On top of this, due to the complex fluid flow, it took a significantly long time to create the meshes. It can be said that most time of the procedures was taken for this process.[4]

(3) Temperature data mapping

With the conventional analysis flow, thermofluids analysis and heat transfer analysis were separated. Therefore, computations had to be performed based on the assumption of thermal insulation or using an assumed value between solid objects and fluids. Further, although the thermal conductivity and wall temperatures obtained from the thermofluids analysis results are mapped to the meshes for structural analysis, it was impossible to map accurately by hand because the number of meshes of the two analyses were different each other and were significantly large. Therefore, the similar values were roughly grouped and were represented by a typical value, which was mapped to the meshes for structural analysis. This method had severe disadvantages both in the time taken for analyses and the calculation accuracy. Analyses under such conditions as lack of sufficient capability of both software and hardware and of interface tools between the procedures sometimes took several months.

4. New analysis procedure

Figure 3 shows new analysis procedures. Although the analysis flow is basically the same as the conventional procedures, the 3D model data has a central role in the developing processes. Development proceeds, assuming that a 3D design model has already been created. Interface tools involved in between different processes contribute to automation of the process. Comparison with the conventional analysis procedures is provided below.

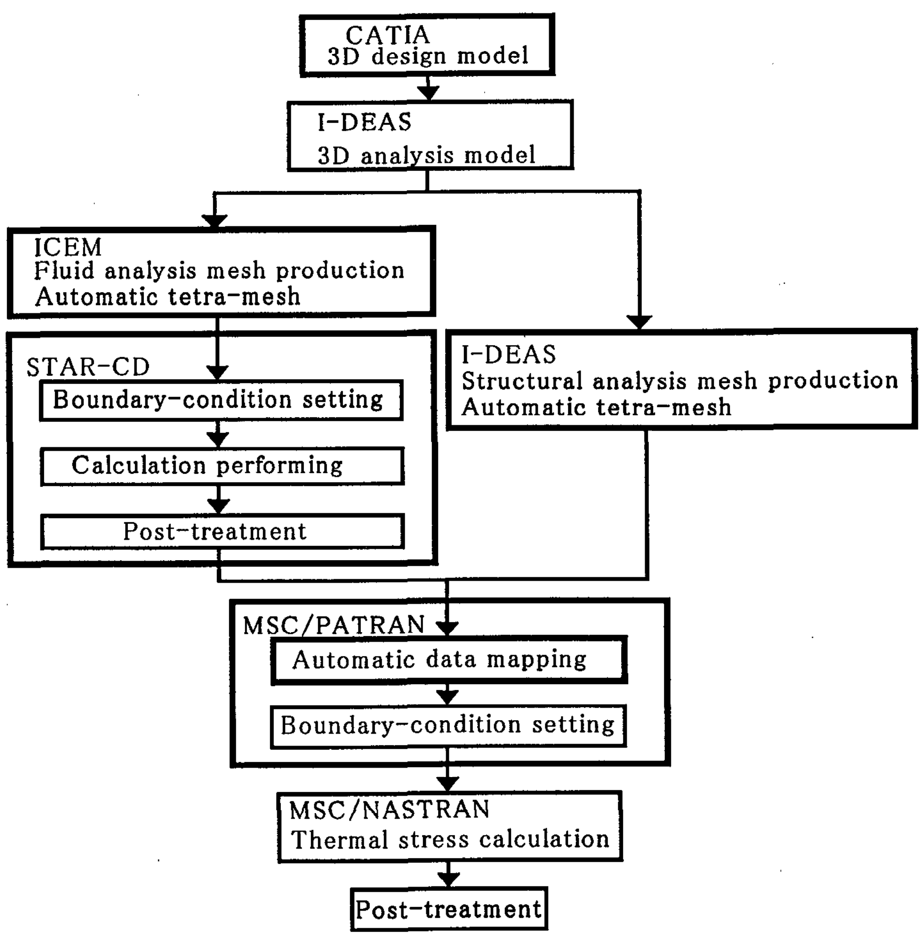


Fig.3 New process of Integrated analysis

(1) Creation of 3D model

In the development process based on the 3D model data, a designer creates 3D models in the design phase. Among 3D models, there is a variety of models from a digital mock-up used for checking interference between surroundings and for ease of assembly to a detailed model, which accurately represents the geometry of the product. Often, it is not necessary for detailed geometry of a product to be expressed for the analysis model. Therefore, such geometry as obstructing to create meshes is sometimes omitted intentionally. Therefore, it cannot always be said that analysis meshes can be created from the 3D model. However, with the new method, it is possible to greatly speed up the process of creating analysis meshes compared to creating a model from scratch from the 2D drawings. It is also possible to avoid a mismatch of the model, which is caused by misunderstanding between the designer and the analysis person. Figure 4 shows a model example on which analysis is carried out.

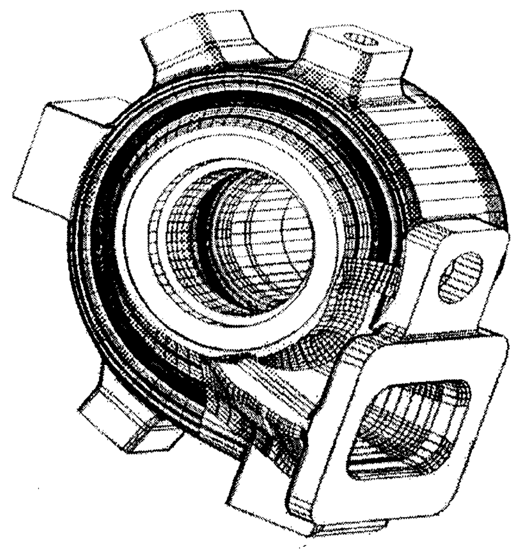
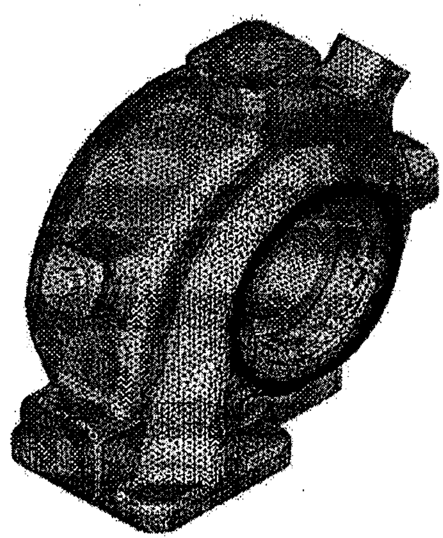


Fig.4 Solid model of turbine housing

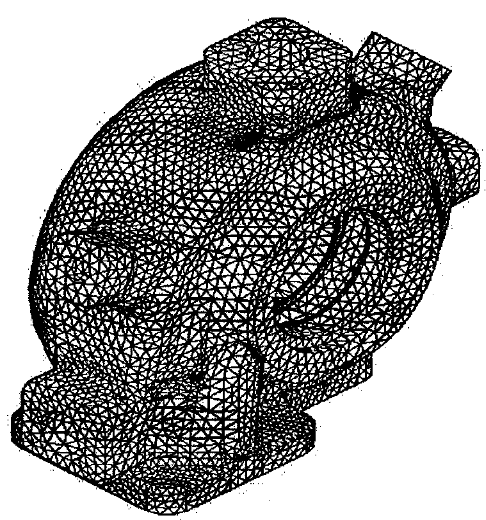
(2) Creation of meshes

With the new method, the time required for mesh creation for both fluid analysis and structural analysis was dramatically reduced by using automatic tetra-mesh technology. Hexahedral mesh generally provides higher analysis accuracy than automatic tetra-mesh for fluid analysis. However, analyses in the new method are not independent procedures like those seen in the conventional procedures but a tool completely integrated in the entire development flow, which is evaluated from a macroscopic viewpoint. In order to make the tool adequate for the entire process, and because the emphasis is on that making the generation of meshes much easier, automatic tetra-mesh is employed. Figures 5 and 6 show fluid analysis mesh and structural analysis mesh, respectively.[4]



Total mesh number : Approx. 690,000

Fig.5 Mesh for CFD



Total mesh number : Approx. 82,000

Fig.6 Mesh for FEM Structure

(3) Temperature data mapping

Figure 7 shows the temperature data of a solid object as a result of thermofluids analysis. In this example, there is a path of cooling water around the path of high-temperature gas and heat is transferred through the solid object. Then, thermofluids analysis was performed through computations including the heat transfer of the solid object. The results were automatically mapped from fluid analysis meshes to structural analysis meshes with a pre-processor for structural analysis. Figure 8 shows temperature data of fluid analysis meshes before mapping and those of structural analysis meshes after mapping. Sufficient accuracy was obtained because data was transferred and interpolated between a different number of meshes. In this case, it took about seven hours to complete mapping. Compared to the conventional manual mapping, this method is expected to provide great advantages in both mapping time and accuracy. Figure 9 shows an example of final results of the thermal stress analysis.

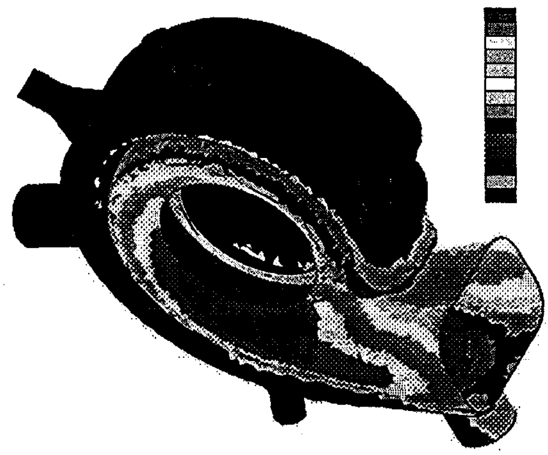
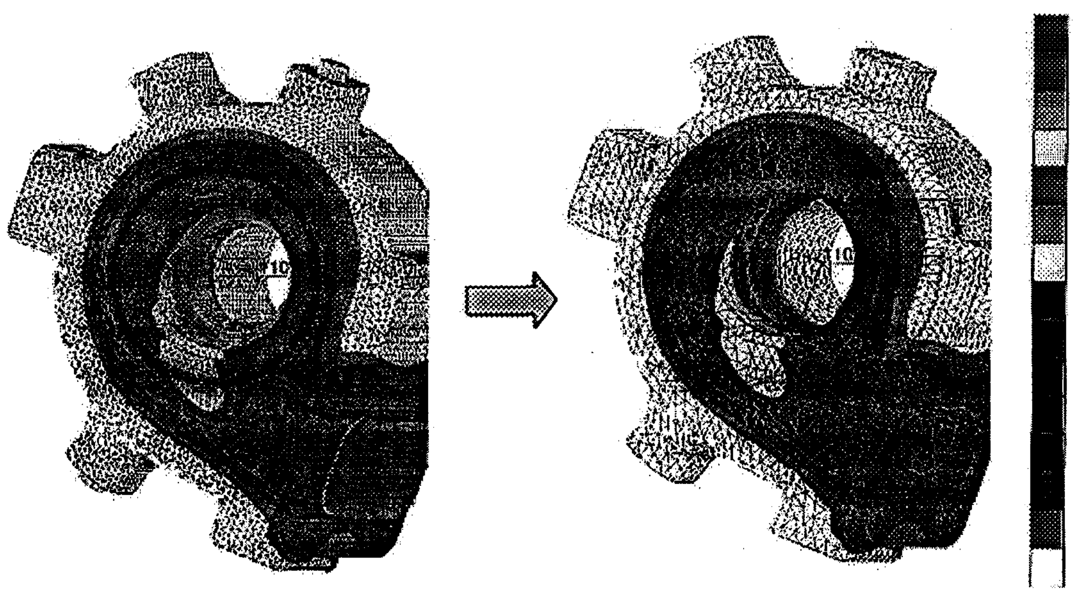


Fig.7 Calculation result of temperature



Solid section : Approx. 420,000 meshes

(a) Mesh for CFD

Solid section : Approx. 82,000 meshes

(b) Mesh for FEM Structure

Fig.8 Temperature data mapping from CFD to FEM Structure

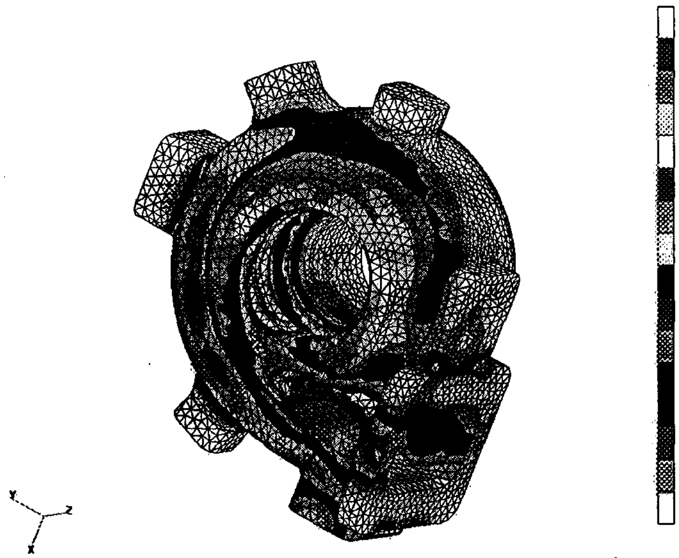


Fig.9 Calculation result of thermal stress

5. Subjects to be improved

As explained so far, analyzing time can be greatly reduced compared to the conventional method. However, there are technical points to be improved so that the new method can become a frequently-used tool integrated in the development flow. They are:

(1) Accumulation and re-use of models

Because the new method assumes that development processes are based on three-dimensional data, it is essential that developed 3D models are accumulated and ready to be re-used as design data to establish the new development flow.

(2) Standardization of analysis methods

In order to employ such analysis procedures into the daily design work, it is necessary to standardize typical analysis so that any designer can do the same analysis by operating only the necessary functions following specific procedures.

(3) Evaluation of analysis accuracy

In order to standardize analysis procedures, it is necessary to accumulate knowledge about the proper assignment of boundary conditions, which are given through comparison with the experiment results. It is important to set analysis conditions aiming at macroscopic design evaluation.

(4) Usability of tools

Although many tools employ GUI and in turn they become easy to use, such tools as 3D-CADs require a lot of training to become accustomed to. Especially in an environment such as that of our example, where many tools are integrated with a result or reduced analysis time, it seems that a limited number of highly skilled persons can intervene in the analysis processes. In order to make these tools become tools designers use in their daily work, extra tools and systems, which can organize necessary functions into easy procedures, are necessary. Usability should be further improved.

6. Conclusion

In a trend to change product development procedures from two-dimensional design to three-dimensional design, analysis occupies a prominent position. When the analysis level improves and when designers gradually get used to what only experts could previously handle, a significant change will occur in manufacturing methods. We would like to make an effort to contribute to the further development of CAE.

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