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Structural Analysis and Shape Optimization in Turbocharger Development

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1. Preface

It is essential to incorporate the CAE (Computer Aided Engineering) in the turbocharger development and design process. Structural analysis of the component parts has been made so far mainly on the automotive and marine turbochargers, screw compressors and centrifugal compressors. We have made analysis of the stress caused by external force and pressure, analysis of the thermal stress caused by heat and analysis of vibration caused by natural frequency in the compressor impellers, turbine impellers and rotors as rotary parts, and housings and heat seal plates as stationary parts. And we have started to establish the method for getting the optimum profile using stress value and displacement as limiting condition.
This paper introduces the transitions of the structural analyses of the impeller as the most important component of the turbocharger and some examples of analyses. It is introduced that products can gain the performance and reliability etc. by using CAE and shape optimization, and the future objectives are also described.

2. Achievements of CAE

Fig.1 illustrates the achievements of CAE/CAD in our General Machinery Division.

Structural analysis of turbocharger has been made through the following three phases:

(1) 1st Phase: Introduction of structural analysis

We started application to designing work through introduction of MSC.Nastran in 1979. However, analysis took much time and we could not achieve the speed required by designing. Much time was consumed in the creation of a model and generation of a mesh in particular. To solve this issue, we created our own mesh generating software SANA/MESH, and introduced post-treatment software FEMOS to increase the speed. However, the speed was insufficient.

(2) 2nd Phase: Spread of structural analysis

CADES was introduced in December, 1991. The system was mainly used by development engineers for the development of new products. It was also used by designers. This made it possible to perform creation of a model, generation of a mesh, analysis, post treatment and display with only one software package.

(3) 3rd Phase: Advanced analysis

It was made possible to create models of complicated profiles by introduction of I-DEAS, CATIA and Unigraphics as three dimensional CAD[(1),(2)]. As for CFD, the authors are using STAR-CD from 1997. Further, these introduction made it possible to solve the integration analysis issues using multiple software packages [(3)].

(4) 4th Phase: optimum design analysis

According to the conventional analysis method, profile models was created, and analysis was made to get only the result. However, a new analysis method has already started. This is a method for getting the optimum profile using stress value and displacement as limiting conditions.

3. Role of CAE

Fig.2 compares the conventional method and subsequent method to show how to use the CAE.

According to the conventional method, structural analysis was started after the 2D drawing was created. So several months were required to get the result. It was not possible for the analysis result to come out. To solve this problem, trial manufacture and test were conducted at the same time, and it was made possible to get the result of analysis by the time the product was manufactured. However, if any issue occurred at this time, it was necessary to go back to the designing stage and to repeat the long process.

To solve this problem, 3D designing will be adopted, and design data will be input to the CAE to make an effective use of these data. The result of analysis will be evaluated, and will be fed back to the designing step. If the result of evaluation is satisfactory, go to the step of trial manufacture and test. This procedure will minimize the need to go back to the design step by evaluation of trial manufacture and test.

An ideal method of using the CAE is obtained by incorporating CAE into the design and development process in the first place, and secondly by using the CAE in the earlier stage of design and development.

We understand the role of CAE as discussed above.

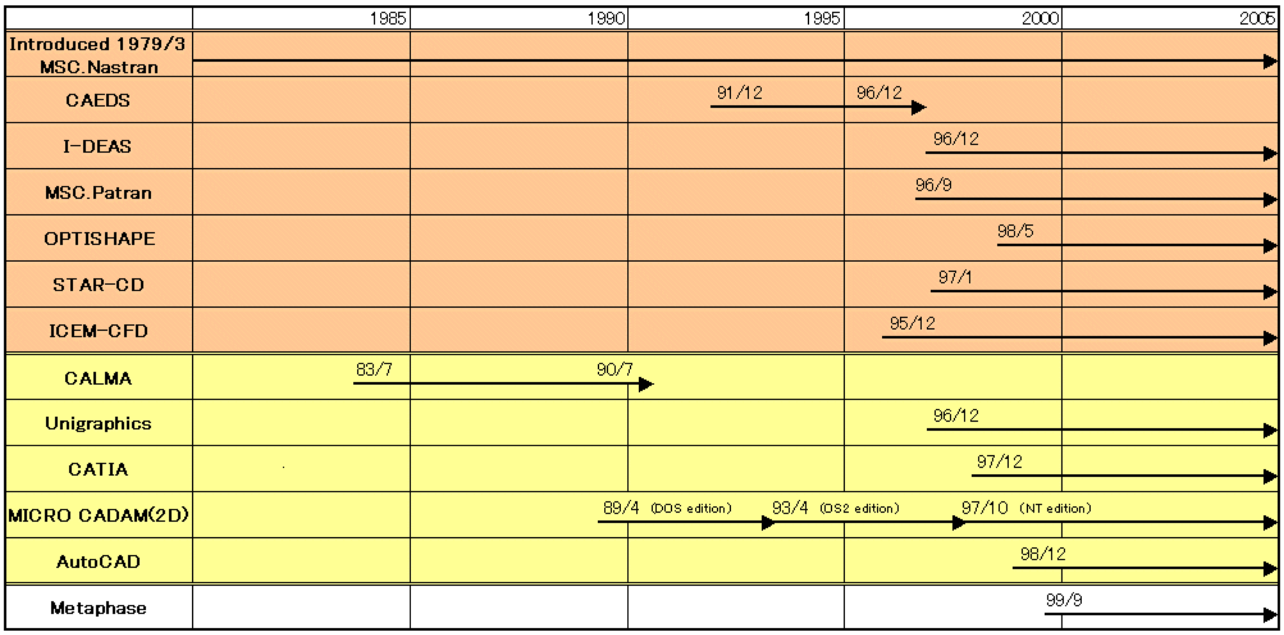
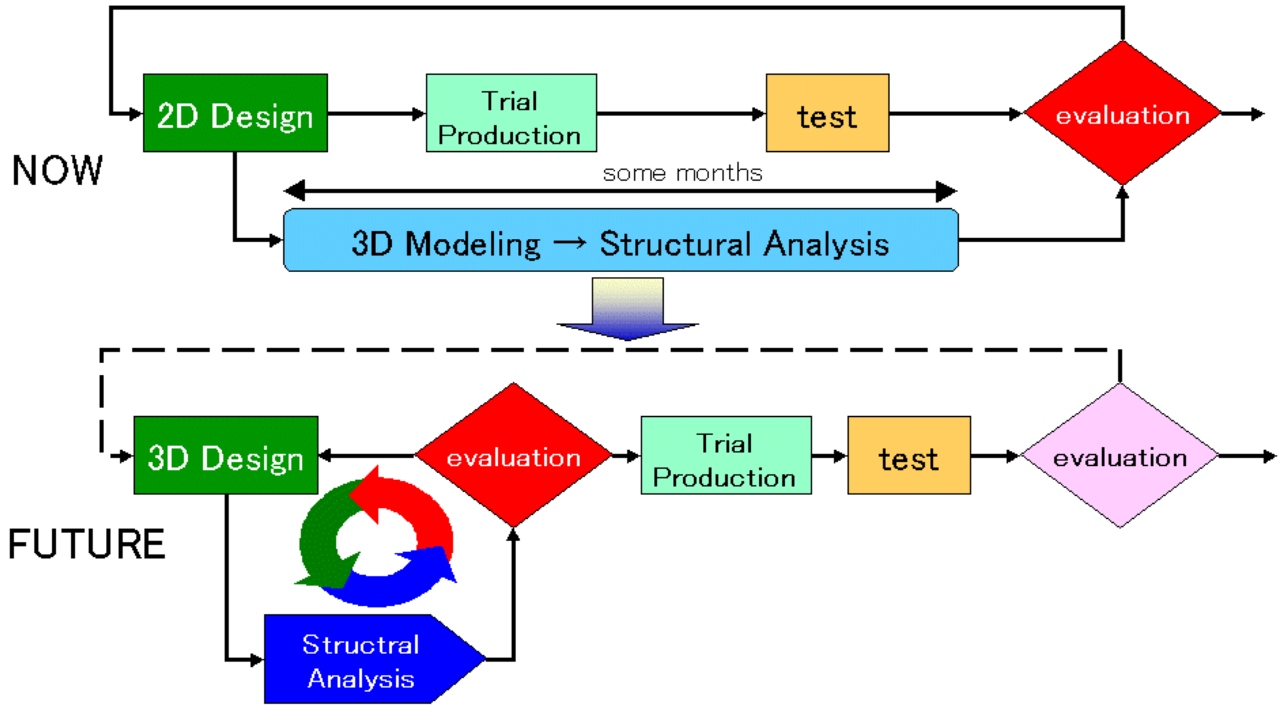


Fig.1 CAE/CAD records



....2 Role of structural analysis in development and design processes

4. Examples of analyzes

The following introduces an example of analysis for turbocharger.
Fig.3 illustrates the cross sectional view of the turbocharger. It shows major analysis items. The parts to be subjected to structural analysis include the compressor impeller, turbine impeller, compressor housing, turbine housing, and bearing housing.

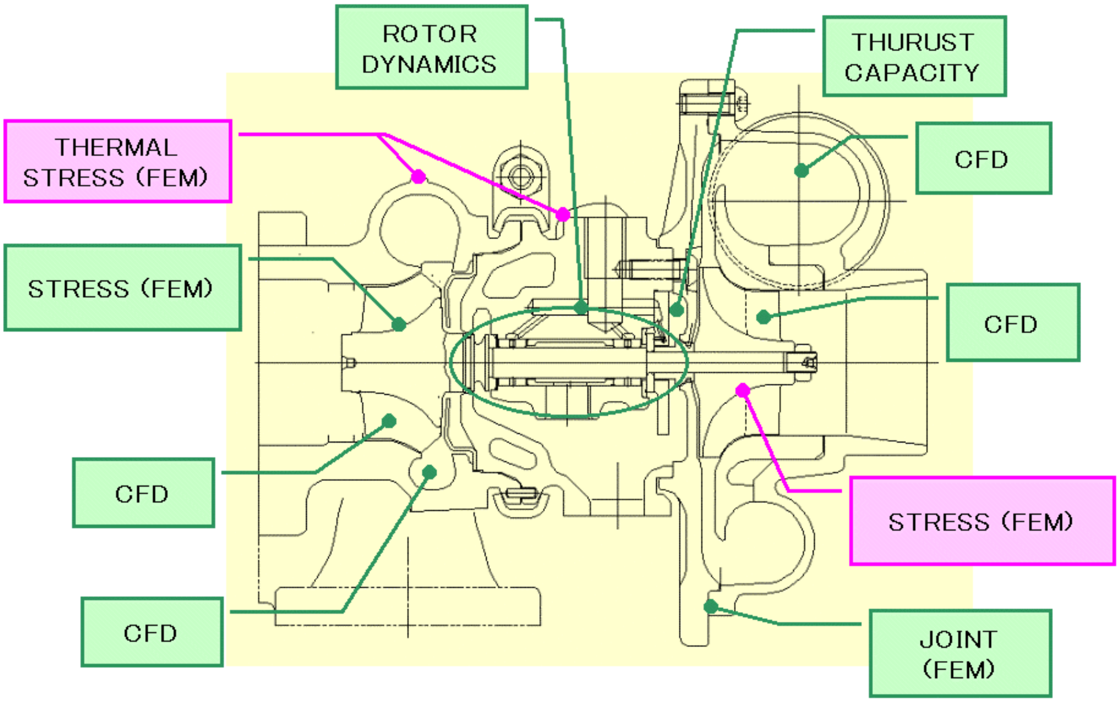
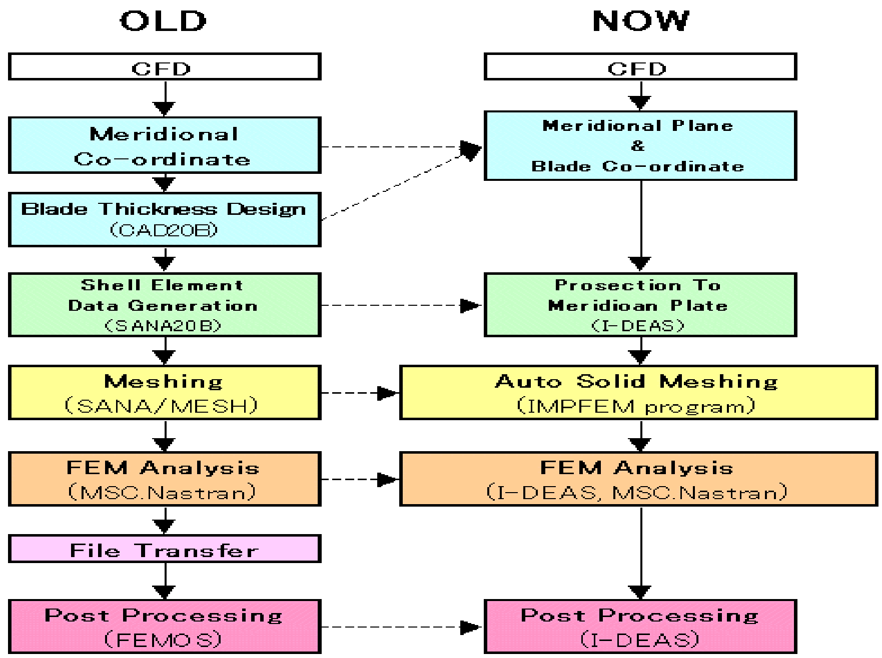


Fig.3 Cross section of turbocharger and analysis parts

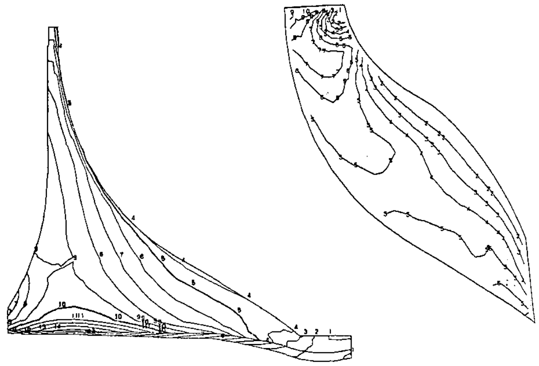
4.1 Compressor impeller

The compressor makes 240,000 revolutions per minute, and is one of the most important components. In the introduction phase of structural analysis, the blade component was used as a shell element to reduce the data size and to facilitate creation of data. Further, the disk was used as solid element to improve the accuracy in analysis. The data size will be excessive if the entire compressor impeller is analyzed. So calculation is made by picking up one pitch of one blade.
Fig.4 illustrates the conventional impeller analysis procedure using the data on meridional plane from CFD analysis.
Fig.5 illustrates an example of the centrifugal stress analysis result of the compressor impeller where the blade is used as a shell element. Fig.6 illustrates the result of centrifugal stress analysis of the compressor impeller where the blade is used as a shell element. I-DEAS was used for post treatment.

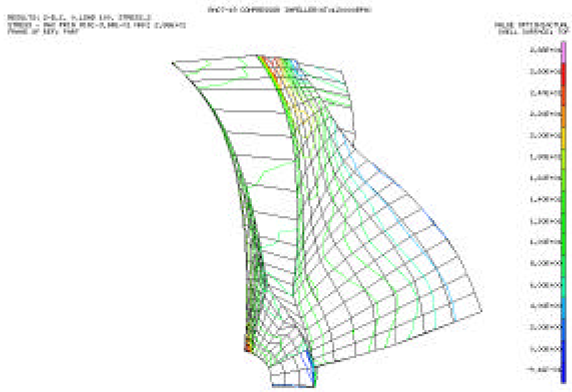
In the introduction phase, attention was given to the strength of the blade. Increasing speed of the compressor impeller made it necessary to pay due attention to disk strength. When the blade was used as the shell element, the blade and disk were connected by the bar element. The result was that bending force occurring to the blade was not transmitted to the disk. This made it necessary to use the solid blade. Since the blade data was manufactured manually, excessive time was needed. Fig.7 illustrates an example of the centrifugal stress analysis where the blade was analyzed by the solid element. MSC.Nastran on the host computer had been used up to this point.



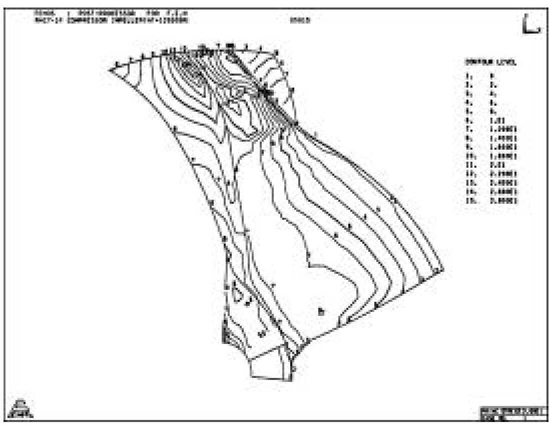
....4 Process of structural analysis for impeller



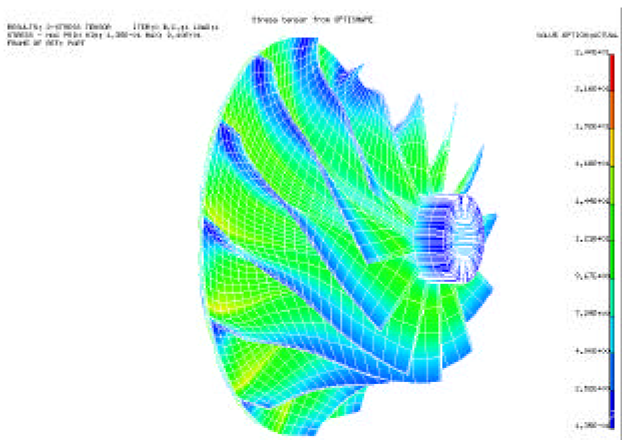
....5 Centrifugal stress analysis result of compressor (blade : shell element, solver code : MSC.Nastran, post treatment : FEMOS)



....6 Centrifugal stress analysis result of compressor (blade : shell element, solver code : MSC.Nastran, post treatment : I-DEAS)



....7 Centrifugal stress analysis result of compressor (blade : shell element, solver code : MSC.Nastran, post treatment : FEMOS)

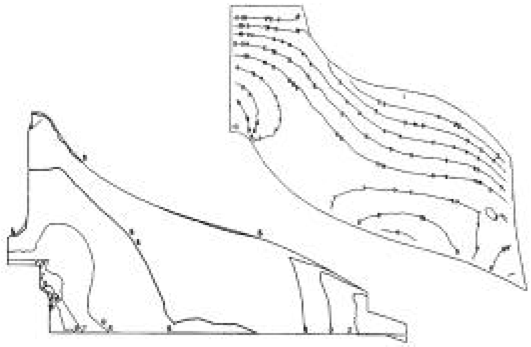


....8 Centrifugal stress analysis result of compressor (blade : solid element, solver code : MSC.Nastran, post treatment : I-DEAS)

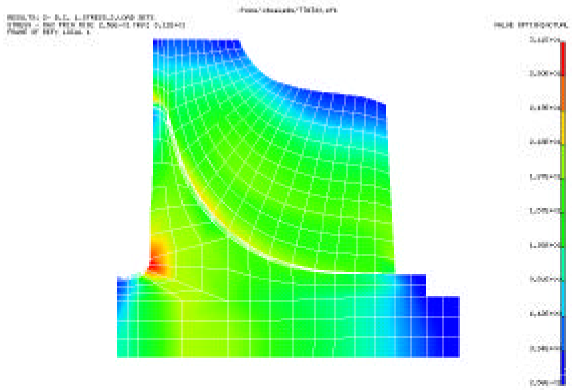
After that, structural solver code I-DEAS was introduced to the EWS, so that the blade and disk models could be created by the I-DEAS. At this time, much time was still needed to create the blade model. So we developed an automatic solid FEM data generation program designed specifically for impeller (IMPFEM).
With introduction of the 3D CAD, it has become easy to make the blade component solid, and the blade and disk can be handled as one integral component. Fig.4 illustrates the current impeller analysis procedure.
This has facilitated analysis of the dot group impeller of 3D free-form surfaces defined by a group of dots. Fig.8 shows an example of centrifugal stress analysis where the entire compressor impeller equipped with all the blades was analyzed by the solid element. This has been made possible by improvement of computer performances.

4.2 Turbine impeller

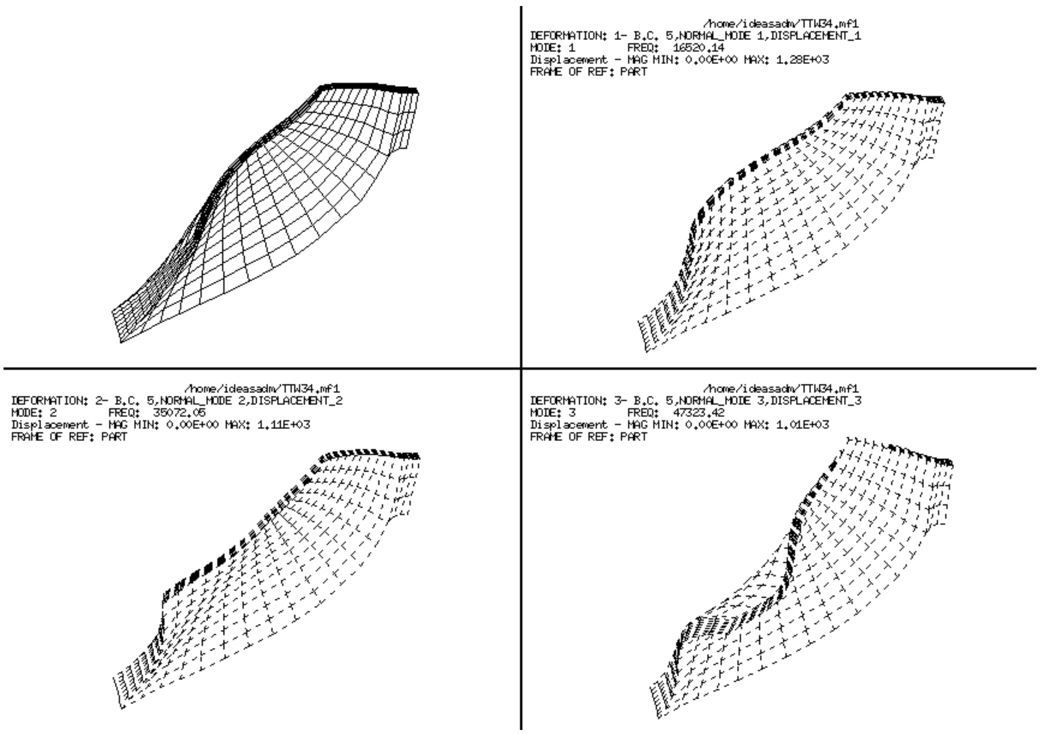
The turbine impeller is exposed to gas having a temperature in excess of 900 when it makes high speed revolution. Fig.9 illustrates the the result of centrifugal stress calculation where the blade is analyzed by the shell element. Fig.10 shows the result of centrifugal stress calculation where the blade is analyzed as a solid element.



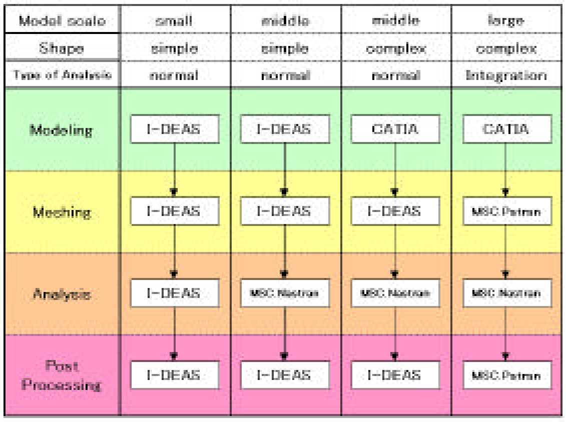
....9 Centrifugal stress analysis result of turbine (blade : shell element, solver code : MSC.Nastran, post treatment : FEMOS)



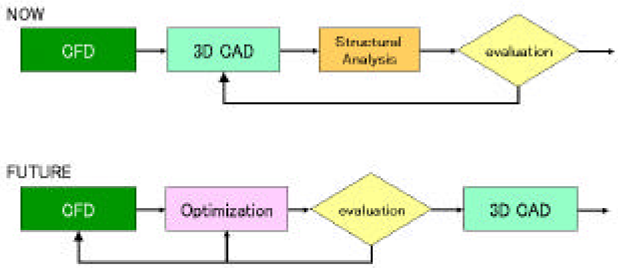
....10 Centrifugal stress analysis result of turbine (blade : solid element, solver code : I-DEAS, post treatment : I-DEAS)



....11 Natural frequency analysis result (blade : shell element, solver code : I-DEAS, post treatment : I-DEAS)



....12 Kind of structural analysis software and usage way



....13 Shape determination process of impeller

Fig.11 shows the primary to tertiary modes in natural frequency analysis of the blade.

5. Software for structural analysis

Fig.12 shows software for structural analysis and classification by use.

6. Problems to be solved

The conventional method of impeller structural analysis has been the repeated work: The profile model is created and analysis is made. The profile is changed according to the evaluation result. Then calculation is made again. In future, however, it is important to adopt the process of getting the optimum profile where stress and displacement are used as limiting conditions. For the impeller, the optimum profiles of the blade and disk can be enumerated as such profiles.
Fig.13 shows the conventional profile determining process and subsequent profile determining process based on optimization.
Further, integration problems between thermal fluid analysis and structural analysis are also to be solved in future.

7. Conclusion

To cope with a big change in flow of product development from the 2D to 3D designing, the role of various types of CAE is very important. It is ideal that CAE be incorporated in the development design process and used in the initial phase of development designing.
To achieve this, we will make more efforts to solve many issues and to make contribution to further development of the subsequent CAE and renovations in the true sense of manufacturing.

8. References

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(3) Mikio OBI, Nobuo TAKEI and Namiko MATSUURA: Integration of CFD and Thermal Stress Analysis in Supercharger, Ishikawajima Gihoh, No.39 Vol. 3, May 1999, PP. 167-171