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ABSTRACT

The present study describes a computer-integrated design modification strategy for a torque converter using virtual modeling and flow analysis. As a preliminary analysis tool, the present study adopted one-dimensional performance analysis with a forced vortex method and a corrected blade angle with flow angle based on three-dimensional flow analysis. From the results of the performance analysis, first-stage optimized blade angles were determined with satisfying design requirements. A CAD program was developed for the virtual modeling of blade geometry with newly chosen blade angles and design path radii. As an accurate inspection tool, a computational fluid dynamics program adopting the mixing plane model was developed with flow and performance analyses for a virtually modeled torque converter, which involves a full three-dimensional flow calculation of a torque converter. This computer-integrated design strategy can significantly reduce the time and cost for the design of an optimized torque converter.

INTRODUCTION

Over the past few decades, the hydrodynamic torque converter has been discussed in a number of papers that have outlined theories, equations, and experimental measurements on various details of its function. However, since a number of variables are involved in the design of a converter, it is very difficult to achieve an optimal design. Until now, the hydrodynamic design of this complex product has been based on technology which utilizes one-dimensional performance analysis and overall performance data of previously built torque converters. [1] This approach may satisfy design requirements in terms of converter diameter, axial length, and torque capacity. However, in spite of being a time-consuming and costly procedure, it is unable to produce an optimized design for a given application. By and Mahoney[2] also pointed out that current design tools need to be developed and upgraded in order to enhance the design technology of torque converters.

Accordingly, the objective of the present study is to develop a new design procedure that can efficiently produce an optimized design using new performance analysis tools and a design tool. The proposed design procedure can significantly reduce the time and cost involved in designing an optimized torque converter.

TECHNOLOGICAL DEVELOPMENTS OF PERFORMAMCE ANALYSIS IN A TORQUE CONVERTER

The objective of the conventional design procedure is to calculate the basic geometric parameters of a torque converter for specified operating conditions, which include the outer diameter, the size and position of the core, and the blade angles for each element of the torque converter. Jandasek [1] investigated the effect of the impeller exit angle, stator exit angle, circuit flow area, hydrofoil blade shape, and fluid density on converter performance and then summarized the most conventional design procedure for a torque converter. These results were extracted from numerous experiments and one-dimensional performance analyses.

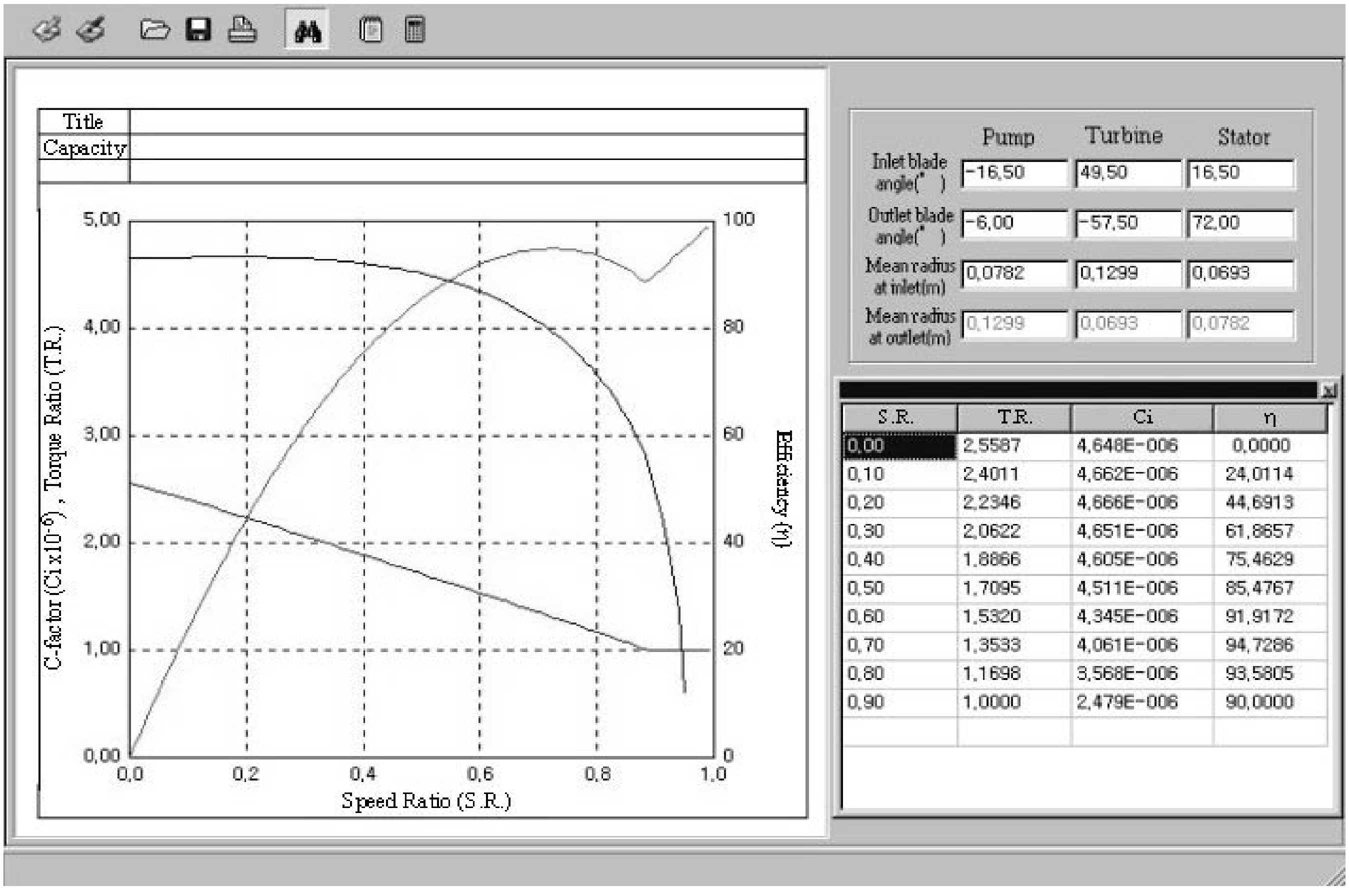

Figure 1. One-dimensional performance analysis

The design of torque converters has been recently advanced through the systematic development of performance analysis. The most widely used performance analysis model for torque converters is based on the simple concept of a one-dimensional single mean stream analysis with a constant circulating flow rate. However, the flow in a torque converter is highly three-dimensional throughout its range of operation. Furthermore, it is insufficient for an accurate detailed performance prediction and thus a more thorough analysis is needed.

Analytical investigations have been initiated to improve the performance prediction of torque converters. Whitfield et al.[3] developed a modified one-dimensional performance model for the torque converter. The circulating motion was assumed to be similar to a forced vortex where the flow velocity is zero at the center and increasing linearly to the outer wall of the torus. A detailed integration method was used in the model to integrate the losses and changes in momentum from core to shell. The effect of varying blade angles from core to shell was also included in the mathematical model. The results indicated a better agreement with the experimental data than that produced by the one-dimensional, single mean stream model. Although the one-dimensional performance model is not sufficient to accurately represent the flow in a torque converter, the one-dimensional performance analysis is very useful to predict the characteristics of torque converters to within a second. Therefore, the present study adopts the one-dimensional performance model as a preliminary analysis tool for torque converters.

In the present study, a program for one-dimensional performance analysis was developed in a Windows-95 environment as shown in Fig. 1. Using direct entering the blade angles and design path radii at each blade, characteristic curves of the torque ratio, efficiency, and input capacity factor versus speed ratio were plotted to within a second. In the analysis, it is assumed that the flow direction coincides with the blade angle. In reality, however, the flow direction deviates 5~15 degrees from the blade angle. In order to enhance the accuracy of the performance analysis, it is necessary to consider the flow angle in the blade angle. Accordingly, in the present study, the flow angle was extracted from results of the three-dimensional flow calculation.

By varying design parameters such as blade angles and radii, we could investigate their effect on the performance characteristics. Through a systematic investigation while varying design parameters, we were able to produce a preliminary optimized value for a given design specification.

VIRTUAL MODELING OF BLADE PROFILES IN A TORQUE CONVERTER

The performance analysis mentioned in the previous section is just an introduction to the conventional analysis method and the new improved one. Based on the optimal design parameters obtained by the performance analysis, including blade angles and design path radii, the design work for generating a new shape is then required. In this study, we developed a program that generates the new shape with the required design parameters. The details of this virtual modeling are explained below and illustrated in the Fig. 2.

1. The CAD program generates the current blade geometry with input data points of each element and shows the blade shape. If input data points do not exist, the blade shape and flow passage area of a torque converter are obtained by a series of calculations
2. The CAD program calculates design path points with blade geometry, that is, the geometry of the shell and the core of a blade. Next, the program interpolates the design path points using a NURB curve and determines the main performance variables of a torque converter including the flow passage area, blades angles, and design path radii. These performance variables are all used in the one-dimensional performance analysis program.
3. After the performance analysis, the CAD program generates a new design path using the optimal blade angles and design path radii.
4. Applying the new design path, a new blade is virtually created by the CAD program. Thus, the virtual modeling of the blade is completed.

Hence, we could generate a new torque converter blade using the proposed CAD program. Having established the outlining dimensions of the blades, a model for three-dimensional flow analysis is then required.

THREE DIMENSIONAL FLOW COMPUTATIONAL ANALYSIS OF A TORQUE CONVERTER

The flow through a torque converter is the most difficult to analyze. Torque converters consist of three elements rotating at different speeds, which causes a highly unsteady three-dimensional and turbulent flow with closed-loop multi-stage geometry. Accordingly, to analyze the flow of a torque converter, a powerful computer program is required which is able to handle a transient, three-dimensional, viscous and turbulent flow.

Recently, numerical techniques have significantly advanced in the turbo-machinery area. Among the notable advances, the mixing plane model transfers multi-stage turbo-machinery problems to full three-dimensional computational flow analyses.

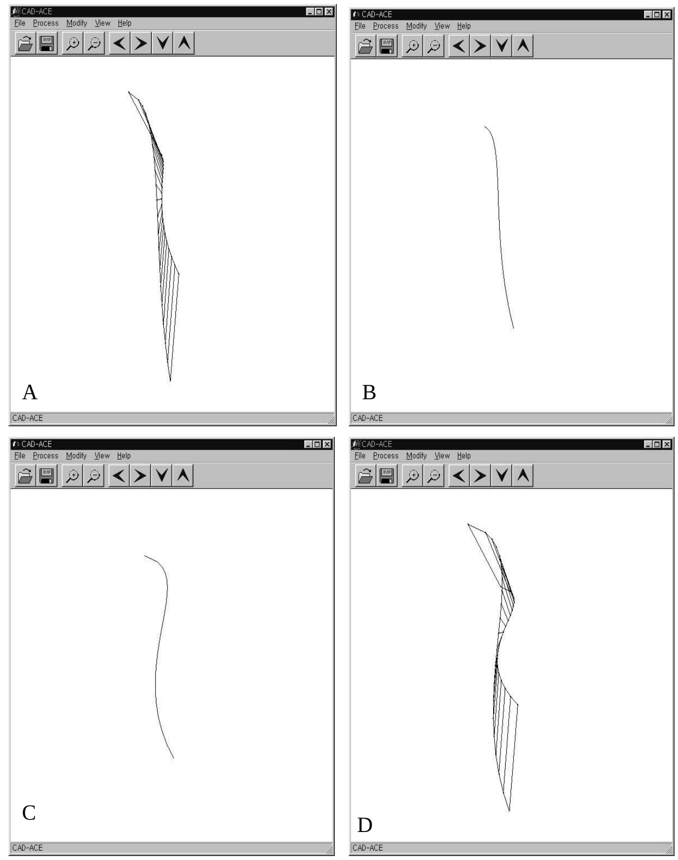

Figure 2. The process of virtual modeling a blade
A. Blade of an impeller
B. Design path of an impeller
C. Modified design path of an impeller
D. Modified blade of an impeller

MIXING PLANE – The mixing plane model was developed by Denton[4] for multi-stage turbomachinery computation. Generally, a mixing plane is used for multistage rotating machines with differential stage speeds. The actual problem is time-dependent with sliding interfaces between the various stages. This is rendered to a quasi-steady problem by replacing the sliding interfaces with mixing planes. The data transfer across such mixing planes is done through circumferentially averaged variables. Since the time-dependency is mainly in the rotating direction as a result of different stage speeds, circumferential averaging removes the time-dependency at the expense of solution accuracy. This approach only accounts for the first order effects of the interaction, however it is sufficiently accurate to provide a practical way of treating multi-stage rotating problems.

Different formulations for averaging and exchanging information across a mixing plane have been proposed and used. The proposed formulation is based on the direct exchange of averaged primitive variables (velocity, pressure), and was found to be suitable for incompressible fluids. A typical mixing plane is shown in Fig. 3. It has two rotating elements at different speeds. It is also necessary to define an upstream and downstream boundary according to the flow direction.

The data averaging and exchange is as follows:

1. The upstream of the mixing plane is an exit boundary for stage 1 with specified static pressures. The down stream is an inlet boundary for stage 2 with specified velocity distributions. Variations in radial directions are allowed and variables are constant in a circumferential direction.
2. Velocities at the upstream of the mixing plane (stage 1 exit boundary velocities) are area-averaged in a circumferential direction at each radial grid station. The tangential velocities are averaged using mass-weighting to conserve the angular momentum going across the boundary.
3. Static pressures at the downstream of the mixing plane (stage 2 inlet boundary pressures) are also area-averaged in a circumferential direction.
4. Averaged (stage 1) velocities from the upstream are passed to stage 2 and imposed at the stage 2 inlet boundary. Similarly, the averaged (stage 2) static pressures are passed to stage 1 and are imposed at the stage 1 exit boundary.

The individual stages are solved in separate reference frames that rotate with the stages at the various stage speeds. This is needed to render the individual stage problems quasi-steady. The differences in the stage speeds affect the tangential momentum in and out of the stages and appropriate corrections to the tangential velocities are made at the mixing planes in step 2 and step 4.

COMPUTATIONAL FLOW ANALYSIS FOR A TORQUE CONVERTER

The above-mentioned mixing plane model was inserted into a computational fluid dynamics program CFD-ACE[5], where the solution procedure uses a pressure-velocity coupling method in a SIMPLE-C algorithm. The proposed numerical analysis adopts the standard κ-ε model for turbulence and upwind scheme for diffusion terms. Non-uniform grids (24x24x52) were generated on each element as shown in Fig. 4. For the convenience of post-processing, all the torque on the blade surfaces was integrated so that the net torque on each element could be obtained. The computing time for one-run was approximately 6 hours for an engineering workstation (SGI's INDIGO2), which is quite reasonable.

A complete three-dimensional flow analysis for the proposed blades produced the performance characteristics which were compared with the previous data as shown in Fig. 5. The one-dimensional performance analysis data was also compared with experimental data. In Fig. 5, the results of the three-dimensional analysis indicated a better agreement with the experimental results than those of the one-dimensional analysis in terms of the torque ratio, efficiency, and input capacity factor.

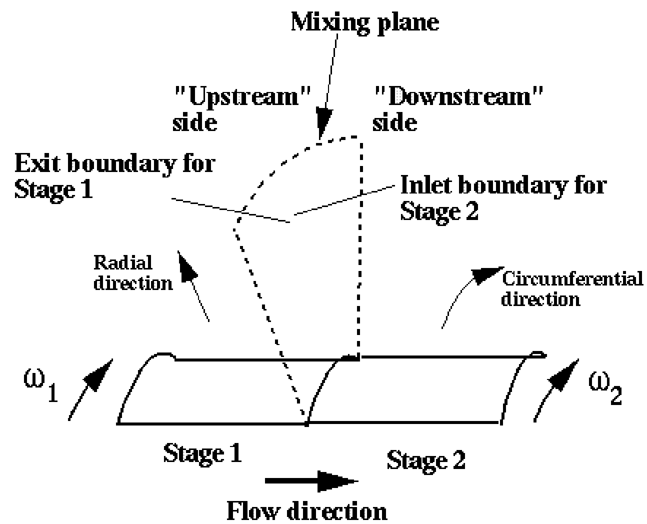

Figure 3. Treatment of Fluxes at the Mixing Plane

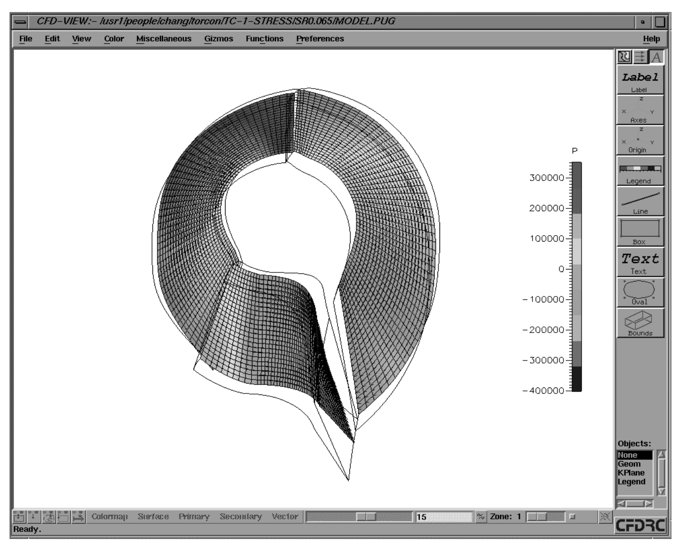

Figure 4. Three-dimensional Flow Analysis Model

From a review of the technological developments in torque converter analysis, we conclude that one-dimensional performance analyses and three-dimensional flow calculations have their own individual advantages and disadvantages as analysis tools of torque converters. Accordingly both should be used with their own advantages for rapid design optimization.

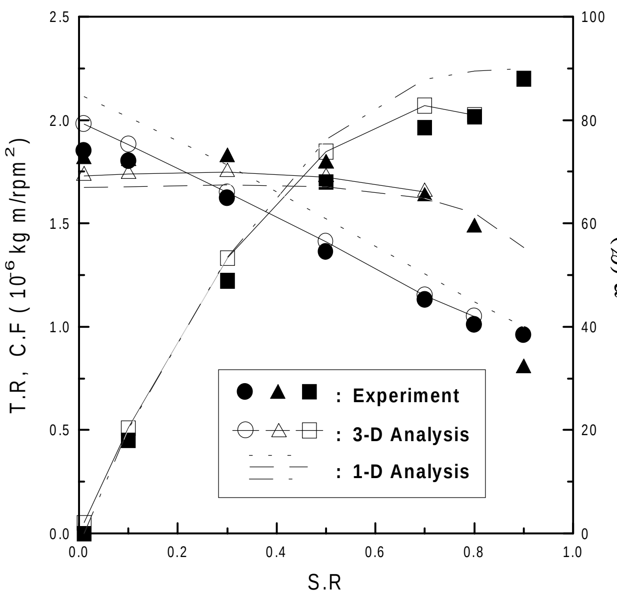

Figure 5. Comparison of a three-dimensional flow analysis with a one-dimensional analysis and experimental results

COMPUTER-INTEGRATED DESIGN STRATEGY OF A TORQUE CONVERTER

If the performance characteristics meet the design requirements and also show a high efficiency, then the proposed blades will be selected for a new converter. Of course, there should be a finishing process including minor modifications of scroll and bias angles. However, if the results can not satisfy the designer's needs, the proposed blades will undergo a modification process with a CAD program and one-dimensional analysis. The present serial design procedure for converter blades is summarized in Fig. 6.

CONCLUSION

The present study develops a design strategy for torque converters using combining flow analysis and virtual modeling. The proposed strategy is able to both reduce the lead-time to market for a new torque converter and optimize the design with a low cost. In the development of the proposed design strategy, each of the essential techniques was investigated and then integrated as progressive steps in a single design procedure. There are three major elements to the techniques including performance analysis, virtual blading or modeling, and three-dimensional flow analysis. These three components are simultaneously interacted with each other and are fundamental to the design process. Currently, this design system has been integrated on a PC system and eventually it will be operated in CATIA. The proposed design strategy and design system are being tested at a torque converter manufacturer and the results look very promising.

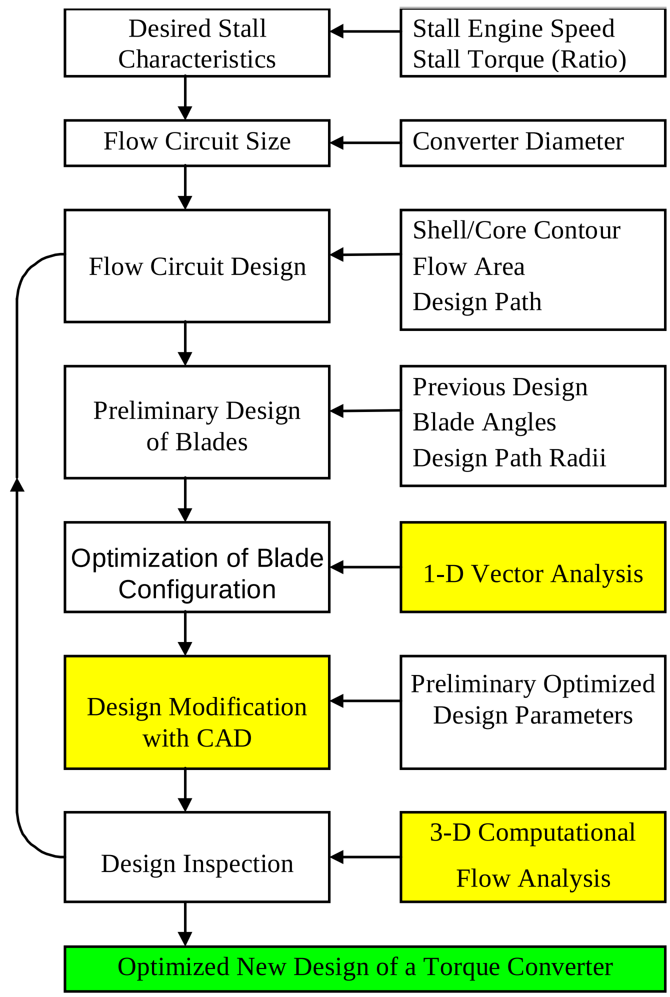

Figure 6. Design Procedure of a Torque Converter

ACKNOWLEDGMENTS

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