# Reverse Engineering Design of a Hydraulic Turbine Runner

Alper Kaplan, Huseyin Cetinturk, Kutay Celebioglu, Selin Aradag

***Abstract*— Reverse engineering is an important method utilized in manufacturing and design process. When there is no technical data of a product or it is unusable, the CAD model is obtained with this method. After obtaining the data of the existing product, rehabilitation studies are carried out for improvement in the design. In this rehabilitation process, numerical methods can be used to optimize the current product. This study presents a reverse engineering process of detecting the reasons for lack of performance of an actual hydraulic turbine runner. Reverse engineering methodology is applied for Kahta H.E.P.P. in Turkey, Adıyaman which has two identical horizontal Francis type turbines. The head and discharge are 125 m and 3.25 m$^3$/s per turbine, the power plant capacity is 3.66 MW and overall turbine efficiency is 92%. According to the results of this study, it is determined that the turbine runner blade trailing edge theta angle causes a large recirculation region which drops the performance of the turbine.**

***Index Terms*—Reverse Engineering, Hydraulic Turbine**

## I. INTRODUCTION

In reverse engineering, existing parts are converted to engineering designs whereas traditional engineering converts engineering designs to products. There are many different application areas of reverse engineering. It can be applied in engineering areas such as aerospace and automotive where there may be some difficulties to develop a CAD model of a current part. A great variety of products can be manufactured and improved through the utilization of this method. Reverse engineering may be required for several situations. This design method is commonly essential if there are not any available engineering drawings. In addition to this, it can be used for actual parts when analysis or modifications are needed to develop products. It is also possible to have a digital product archive of complex geometries for which it was difficult to create the CAD models at first [1,2].

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Reverse engineering operation can generally be classified into four steps as digitization of the product, surface approximation for geometrical modelling, development of CAD model to provide technical documentation and NC programming and CNC machining [2, 5]. The entire transaction of this design method should be computer aided. Reverse engineering process can constitutively be described by the block diagram in Fig. 1.

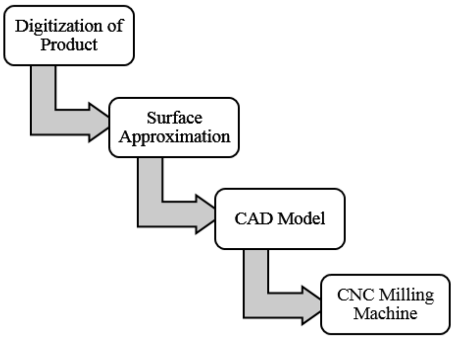


*Fig. 1. The basic stages of reverse engineering [Adapted from 1]*

Vital section of reverse engineering is digitization of the product. Some devices and phenomenon are used in digitization methods for interaction with the surface or volume of the object of interest. Scanning methods of three dimensional geometries are separated into two groups such as contact and non-contact methods. Different data acquisition methods are shown in Fig. 2 [1]. Light, sound and magnetic fields are used in non-contact scanning method. Contact type data acquisition methods touch the surface by using a mechanical probe. When these two methods are compared, contact probing measurement tools are more accurate but slower in data acquisition. Contact type scanning devices might damage the product surface. Contactless acquisition methods cause no surface damage, but laser technology is one type of non-contact scanning that can be applicable in some areas due to high energy limits. Selection of data acquisition system should be made carefully to capture the desired shape. Various practical problems can be faced with acquiring data, the major ones being calibration, accuracy, accessibility, occlusion, fixturing, multiple views, noise and incomplete data, statistical distributions of parts and surface finish [1,3,4].

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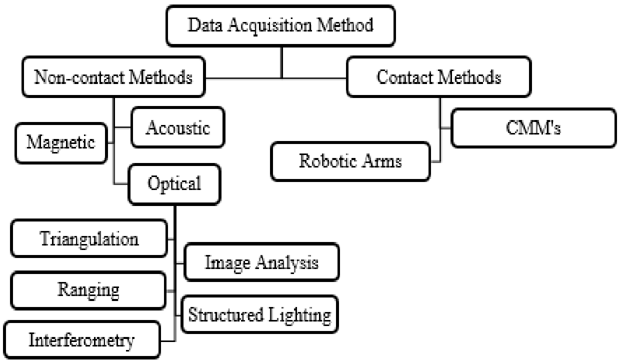


*Fig. 2. Classification of data acquisition methods [Adapted from 1]*

The CAD model can be formed by any CAD program, after processing of measurement data and correcting the data format. CAD model from measurement data can be created with two different ways. Curve mode is the one that firstly generates construction curves from the data and then the surface can be produced via the construction curve by mesh generation. Another way to generate surface is called surface mode, creates the surface directly from measurement data by using point cloud [2].

The purpose of this paper is to acquire three dimensional profile of a hydraulic turbine runner which cannot operate with full performance by using reverse engineering methodology. Non-contact data acquisition technique is used to form CAD model of turbine runner. A blade of the runner is selected in order to form point cloud. Two dimensional point cloud of meridional contour, blade thickness and blade angles are obtained from digitized CAD model blade and the profile of the runner blade is developed by using these three constituents. Computational Fluid dynamics analyses are carried out in different operating ranges through the three dimensional profile. The reason of the lack of performance in the turbine is investigated in accordance with CFD results.

## II. DESIGN METHODOLOGY

Design methodology is developed with respect to basic steps of reverse engineering for a hydraulic turbine runner. In addition to basic steps, a blade of the turbine is developed from the CAD model to perform CFD analysis. Developed design methodology is shown in Fig. 3.

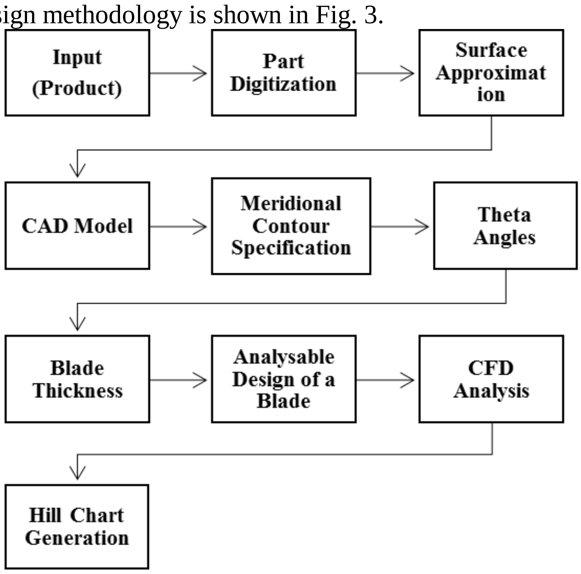


*Fig. 3. Design methodology*

The methodology starts with part digitization. Digitized point cloud is formed by surface approximation. CAD model of the runner is formed with the help of obtained data. One of the blades is assigned as reference blade and meridional contour is specified from this reference. Theta angles are determined from each span and blade thickness is detected on midsection of the reference blade. This angle is the position angle in the cylindrical coordinate system as it is shown in Fig.4. CFD analyses of the blade geometry are performed.

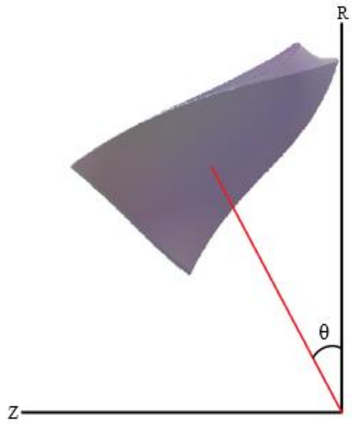


*Fig. 4. Theta position angle*

This methodology is applied to Kahta H.E.P.P. in Turkey, Adıyaman which has two identical horizontal Francis type turbines. The head and discharge are 125 m and 3.25 $m^3/s$ per turbine. The power plant capacity is 3.66 MW and overall turbine efficiency is 92%.

First phase of the methodology is part digitization as it is in the traditional reverse engineering. Part digitization is performed by a portable coordinate measuring machine which has laser probe. Portable measuring system is selected because of working on an actual power plant. Whole body of the turbine runner is scanned by laser probe. Scanned point cloud is converted to intersection curves to form the CAD model of runner by using curve mode.

ANSYS v.15 BladeGen [6] and SolidWorks [7] are used for the design of the new blade. Primarily, boundaries of the leading edge and trailing edge are measured in order to determine the outline of the blade from SolidWorks. Defined outline point cloud is inserted to BladeGen initial meridional configuration. To determine the outline, point clouds are organized from hub, shroud, leading edge, trailing edge, inlet and outlet of the model blade as it is seen in Fig. 5.

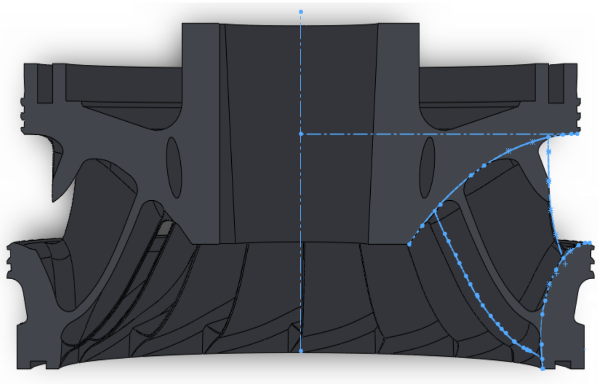

*Fig. 5. Determination of meridional contour*

Generated point clouds are settled to BladeGen module for meridional geometry and five span curves, including hub and shroud curves that are shown in Fig.6, which identify theta angle. Theta angles are explored by sectioning span curves as it is seen in Fig.7. Each section's angle data are transformed into point cloud and set in angle definition add-on of BladeGen. Blade thickness is detected only from midsection and thickness determination is shown in Fig.8.

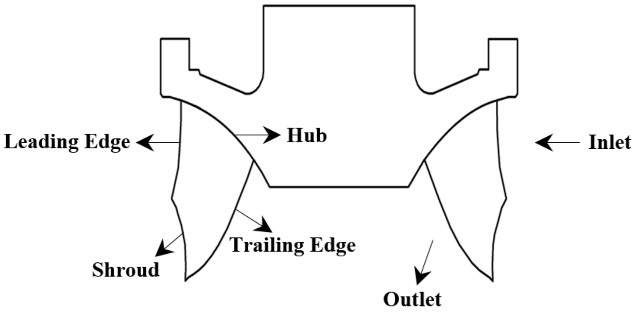


*Fig. 6. Definitions of meridional contour*

After the whole process takes place, volumetric comparison is implemented between CAD model and analyzable design. A new runner geometry is created which is identical to the model runner. The CAD model blade has 598 $cm^3$ of volume and created blade volume is 593 $cm^3$. Volumetric inaccuracy is 0.84%. Thus CFD analysis is performed on the obtained geometry, assuming it is identical to the real one.

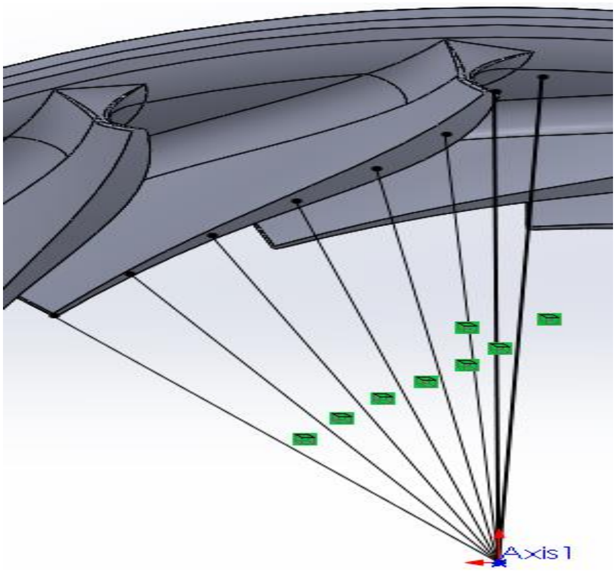


*Fig. 7. Determination of theta angle*

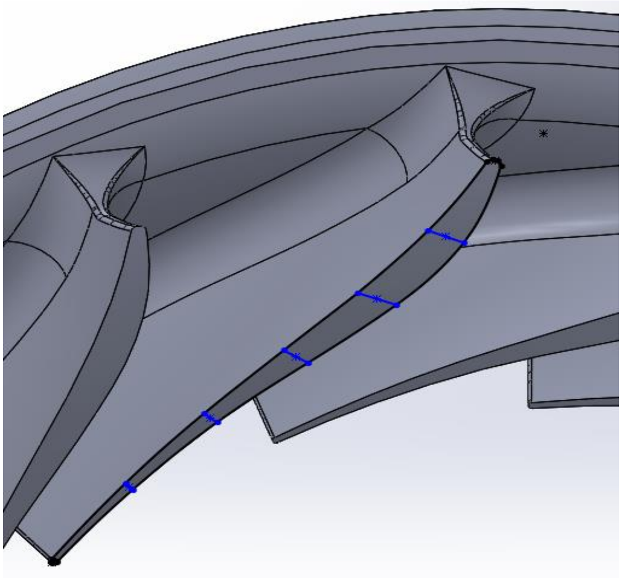

*Fig. 8. Determination of blade thickness*

ANSYS v.15 CFX Solver [6] is used for the CFD analysis. Modeled blade geometry is meshed with H/J/C/L Grid using TurboGrid [6] module. Firstly, total pressure inlet and mass flow outlet boundary conditions are given for the component in CFX module, to verify that designed geometry provides hydraulic parameters of the actual runner. After the verification process, mass flow inlet and static pressure outlet boundary conditions are given for hill chart generation. Hill chart can be generated in several ways with respect to four independent variables of the hydraulic turbines which are turbine diameter, rotational speed, head and discharge. Two of these parameters, turbine diameter and rotational speed, are constant for hill chart generation because of being design criteria. This diagram provides information about turbine operating range for different head and discharge values.

## III. RESULTS

Hydraulic parameters of the runner are verified using CFD. The inlet flow angle is 15.1 degrees for verification analysis. However, the blade is at cavitation region because of the incorrect leading edge flow angle. Although the stagnation point is at the center of the leading edge, flow separation is detected hence misleading inlet flow angle as it is seen in Fig. 9. Cavitation starts from inlet of the blade due to being a back loaded blade as it is shown in Fig. 10. Therefore, further analyses are performed for different inlet flow angle and discharge values.

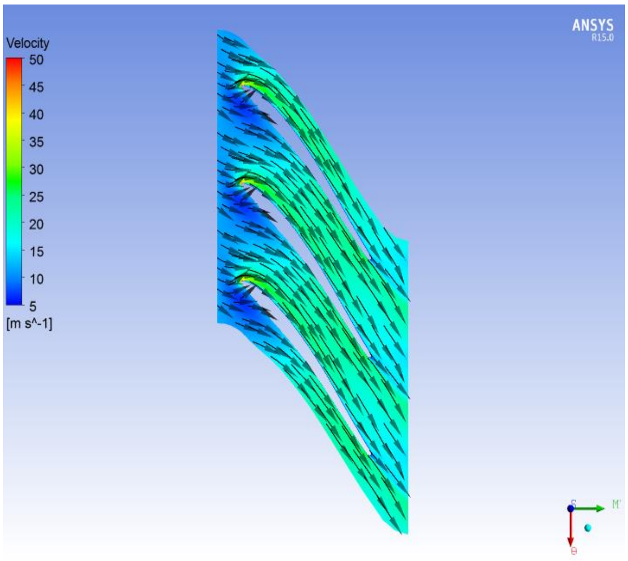


*Fig. 9. Velocity vectors at 50% span*

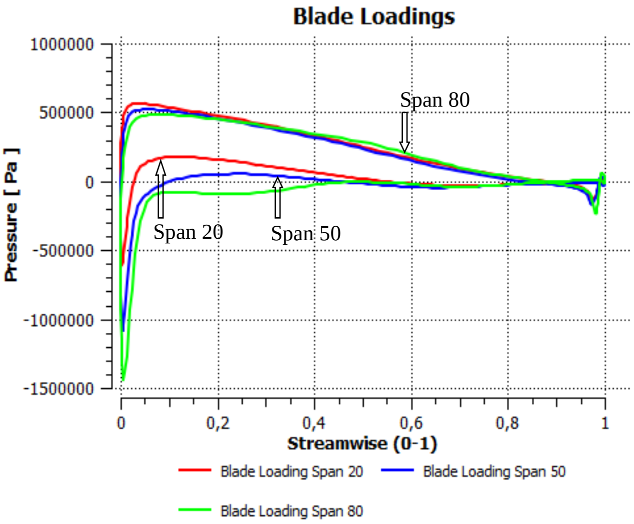


*Fig. 10. Blade loadings of verification analysis*

According to hill chart results, proper inlet angle is 21 degrees, yet runner cannot produce desired power at this angle. Water cannot drop all of its energy because of incorrectly designed trailing edge flow angle. Outlet flow angle is about 40 degree for all inlet conditions. Desired capacity is never reached because of this reason.

## IV. CONCLUSION

The developed design methodology is applied for an actual hydraulic turbine runner which has no technical drawings. CAD model of the runner is obtained by laser scanning of the blade geometry and the new blade geometry is obtained by generating point clouds from the scanned CAD model. Point clouds are formed for three constituents of blade as meridional contour, theta angle and blade thickness. CFD analyses of the new blade geometry are carried out. According to the results, the reason for not providing the required capacity is incorrect outlet design. The design is corrected and the required capacity is reached with the help of reverse engineering and computational fluid dynamics.

## ACKNOWLEDGMENT

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