Finite-element Simulation of Water Jet Machining Process

Ali. Moarrefzadeh

Abstract— **A stern-mounted Water jet installation as used in commercial applications, can be divided into four components: the inlet, the pump, the nozzle and the steering device. In this paper, the Water jet Process is studied and stainless steel temperature field is gained in this process. The thermal effect of Water jet that specially depends on the Water and Nozzle type and temperature field of it in workpiece, is the main key of analysis and optimization of this process, from which the main goal of this paper has been defined. Numerical simulation of machining process in SIMPELC method and by ANSYS software for gaining the temperature field of stainless steel, the effect of parameter variation on temperature field and process optimization are done.**

Keywords– Plasma, Shielding Gas, Temperature Field, Stainless Steel and ANSYS-FSI

I. INTRODUCTION

A stern-mounted Water jet installation as used in commercial applications can be divided into four components: the inlet, the pump, the nozzle and the steering device. Fig. 1 shows a drawing of a typical water jet installation, with the main components labeled.

The main component is the pump, which delivers the head to produce the jet at the nozzle exit. In general the stator bowl and the nozzle are integrated in one part. In the remainder of the paper, the combination of the pump unit and the nozzle is regarded as the water jet pump.

The ducting system upstream of the pump is called the inlet. The water jet in Fig. 2 shows a flush mounted inlet duct. This is used, for example, in fast ferries and high speed motor yachts. Kruppa have given an overview of the basic concepts of water jet inlet ducting systems. Besides the flush mounted inlet, ram and scoop type inlets are mentioned. The latter two have an opening that is situated more or less perpendicular to the flow direction, whereas the flush mounted inlet opening is parallel to the flow. The ram and scoop intake will not be considered in this work.

Downstream of the nozzle there is a steering device, which can deflect the jet in order to create steering and reversing forces. There are also installations for the deflection of the jet possible, with only the reversing option. This can be useful for quick crash-stop man oeuvres. If the water jet has no steering device at all, it is called a booster water jet.

Faculty member of Department of Mechanical Engineering, Mahshahr Branch, Islamic Azad University , Mahshahr , Iran
E-mail: a_moarrefzadeh@yahoo.com, a.moarefzadeh@mahshahriau.ac.ir
Tel: +989123450936

II. RELATION OF WATER JET PROPULSION SYSTEM TO OTHER TURBO MACHINERY

If the very early 17^{th} century developments are neglected, water jet propulsion is relatively new. For further development of the installation it may be useful to look at related engineering applications. Figure 1.2 shows a box with eight different types of apparatus. The three faces which are connected to the water jet share a common property.

The front face is formed by four installations which are designed to produce thrust. This group contains, besides the water jet, the ship propeller and the two main aero-plane propulsion systems. Any thrust production by the installations at the back face (mixed-flow pump, compressor, ventilator and mixer) is an undesirable side effect. If history is reviewed an interesting parallel can be recognized. In aerospace the propeller has been replaced by the jet engine, which was necessary to reach higher speeds. Application of water jets in marine industry shows a similar trend where the water jet propelled vessels reach higher speeds.

Many relations which describe the principles of water jet propulsion are directly derived from propeller theory, with the same nomenclature. This can lead to misunderstandings, if the same water jet is described as a mixed-flow pump, with the accompanying pump nomenclature. For example, often Q is used for torque in propeller theory and for flow rate in pump theory.

The two side planes of the box show the difference in type of flow. The left side is formed by external flow machines and the right side by internal flow machines. Transmission of the forces in an external flow machine can only be done through the shaft. Internal flow machines can also transfer forces through the surrounding structure.

The top plane of the box shows four installations which operate in water, whereas the applications on the bottom plane operate in air. So here the fluid is the distinguishing factor. Cavitation is a typical problem for installations operating in water. Another important fluid property of water is its very low compressibility. Both phenomena can be important in the selection of numerical solution methods.

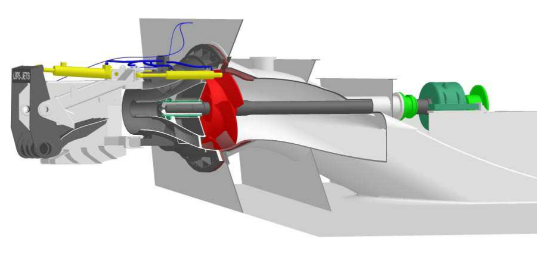


Fig. 1. Three-dimensional view of a water jet installation for receiving to complete solutions

Numerical methods used for the analysis of compressors and other flow machinery often require a certain amount of compressibility, what makes these methods less suitable for the analysis of a water jet propulsion system.

The box model will be used to relate the occurring phenomena in a water jet installation to known ones in other machines, like the ship propeller, the aero plane jet engine and the mixed-flow pump.

A ship propeller seems to be the most logical connection to a water jet for a description of the propulsion system. Typical parameters used in propeller theory are the thrust loading coefficient and the cavitations number. These parameters can be employed to describe the performance of a water jet as well. Moreover the concept of wake fraction, which represents the difference between the free stream advance speed and actual inflow velocity, can be used to account for the effect of the hull boundary layer ingestion.

It is well-known that the inflow velocity distribution to the water jet impeller is strongly non-uniform. This is similar to the wake field of a ship propeller. Due to this wake field the loading of a propeller blade fluctuates during a revolution. This results in fluctuations of the pressure distribution on the blades and in a radial force on the shaft. These phenomena will also be present in a water jet. Therefore the choice of a propeller as a starting point for the analysis of a water jet installation seems to be logical. However, there is a very important difference between a propeller and a water jet installation.

A propeller is an external flow machine whereas the water jet installation is mainly an internal flow system. The thrust of a propeller will always be guided through the shaft into the ship. In a water jet installation the forces can be transferred to the vessel via the shaft and via the ship structure. In fact it is possible to have higher thrust acting on the shaft than the net thrust of the installation. In that case a negative force will work on the transom stern and the inlet ducting.

The working point of the water jet installation is based on the volume flow rate Q through the system. In this system the pump head curve matches the system resistance curve, which is based on the required head to produce the jet velocity and the head to overcome the hydraulic losses. The influence of ship speed on the operating condition is small.

As a consequence, the available set of propeller equations cannot be used for a good description of the water jet propulsion system.

The theory of aero plane jet engines may provide the missing equations to describe the performance of a water jet system. A turbojet engine is a thrust producing internal turbo machine, just like the water jet. The turbojet engine can be divided into five major components: intake, compressor, combustion chamber, turbine and nozzle (see for example. These components include the power generating part of the jet engine, i.e. the compressor is driven by the turbine. In water jet a separate diesel engine or gas turbine is needed to supply the required power to the shaft.

III. AIM OF THE ANALYSIS

In this research work a detailed analysis of a water jet propulsion system is made. Results of Computational Fluid Dynamics (CFD) calculations are used to get an impression of the flow phenomena occurring in such systems and to

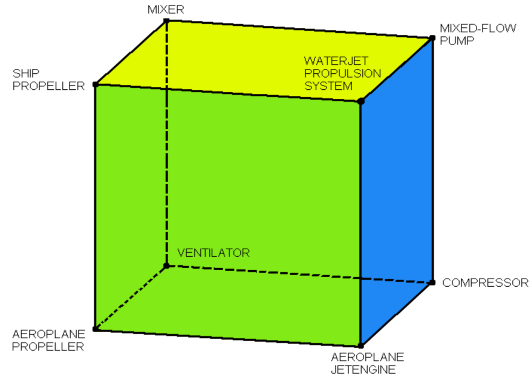


Fig. 2. Box model of connections of water jet to other types of turbo machinery

quantify system parameters, such as flow rate, torque and thrust. With the application of a numerical method some flow features are easier to determine than in a model scale test. Typical complicating factors in the analysis of water jets are the boundary layer ingestion and the non-uniform velocity distribution just upstream of the pump. Unfortunately, both the boundary layer ingestion as well as the non-uniformity of the velocity distribution is inevitable in commercial water jet propulsion systems with a flush type of inlet.

The major problem of the impeller inlet velocity distribution is the large variation of the velocity in circumferential direction. This will give rise to a blade loading, which varies strongly with time. This may lead to a decrease in system performance, like a reduced efficiency, deterioration in capitation behavior and an increase of forces acting on the impeller. These phenomena will increase the noise and vibrations in the installation. The aim of the analysis presented in this paper is (i) to quantify the effects of the non-uniform inflow to the mixed-flow pump and resulting no stationary flow in the pump on the system performance and (ii) to quantify the forces on the complete water jet installation in both axial and vertical direction.

The currently used theory to determine system performance includes some assumptions about the influence of the pressure distribution on the stream tube of the ingested water. These assumptions will be reviewed to check their validity.

IV. CHARACTERISTIC VELOCITIES IN A WATER JET SYSTEM

In the equations for pump performance and thrust, use is made of some specific velocities. Four main velocities are distinguished and will be used throughout this work:

1. ship speed (*vship*)
2. mass averaged ingested velocity at duct inlet (*vin*)
3. averaged axial inflow velocity at the pump entrance (*v pump*)
4. averaged outlet velocity at the nozzle (*vout*)

V. WATER JET SELECTION

Up to this point, the entire analysis has been based on optimal performance at one single design operating condition. In many cases water jet installations have multiple operating points. If the water jets are applied for example in large fast ferries or planning hulls, the resistance line is quite different from the one of a regular displacement vessel. There is an additional resistance at a speed range between about 20 and 30 knots. The speed, at which the local maximum resistance occurs, is denoted as hump speed. The water jet installation has to provide sufficient thrust to exceed the resistance at the hump speed. This requirement may lead to a larger water jet than necessary for the design operating point.

In all shown examples, values for the wake fraction μ, pump efficiency η *pump*, inlet losses, etc., have been considered as constants. In actual installations all these parameters depend on the ship speed and/or the flow rate *Q* through the installation. Implementation of all of these dependencies will result in a complex water jet performance prediction program.

For a realistic comparison of various installations with different sizes over the complete range of ship speeds, such program should be used in order to take the actual values for the loss coefficients and the efficiencies into account.

VI. NUMERICAL SIMULATION

Finite elements simulations are done in 3 steps with the main pieces

1- Modeling by FEMB
2- The thermal study and processing
3-Post-Processing result of analysis by Ansys software for results discussion

Modeling special techniques for finite elements:

1-Finite elements modeling, types and properties for model different parts.
2-The definition of material properties
3- parameter definition
4- Loading
5- Boundary and initial value definition
6- Common interfaces definition
7- Control parameter definition

VI. WATER JET MODELING

It is generally accepted that water jet self propulsion tests be conducted with a pump of convenience (also referred to as "surrogate" or "dummy" pump). There is however less agreement as to what extent the water jet intake should be modeled. This is sometimes an issue when a compact water jet has to be modeled and the geometrically scaled intake is to be matched with the surrogate pump. It is hoped that CFD will provide some guidance in this issue.

For the determination of the overall powering characteristics, the working point of the water jet should be determined. To learn this point of the water jet, the demand by the hull should be quantified.

The demand of the hull is usually quantified by a thrust-speed relation. This relation needs to be converted to a relation between pump required powers, pump rpm and ship speed. Most often, this conversion is made on the basis of a flow rate *Q* through the water jet system.

The relation between flow rate *Q*, thrust and hydraulic power (*QH*) is affected by the non-uniformity of the velocity distribution in the stream tube that models the jet. This is caused by the relation between flow rate, momentum flux and energy flux. Corrections on the momentum and energy flux, when obtained from an average volumetric flow velocity may be as high as some 10% for the momentum flux and some 25% for the energy flux due to the non-uniformity of the velocity distribution (see Scherer et al., 2001).

These corrections apply at the interface of the system considered with its environment.

Relations between the powering characteristics of the distinct elements and the jet system are schematized in Fig. 3.

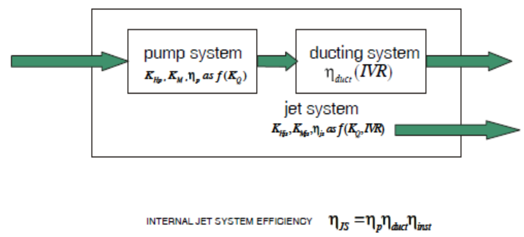


Fig. 3. Scheme of water jet system elements and their characteristics

This implies that momentum and energy flux corrections (for constant flow rate) may be required for the pump system when its environment is changed from a pump loop setup to a pump mounted in a water jet system. That

is that the corresponding quantities (torque and head respectively) will be affected by the non-uniformity of the inflow. Furthermore, additional differences in viscous and rotational losses may be induced by the impeller and stator blades.

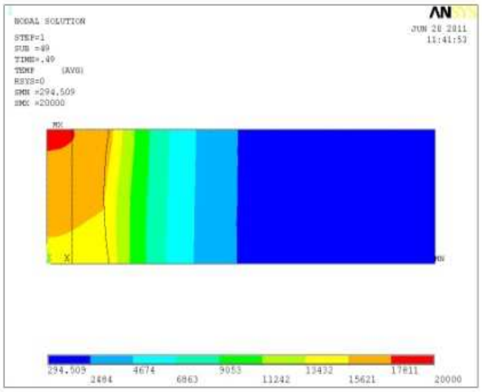
An estimate of the magnitude of these effects on e.g. efficiency is given by Kruppa (1993).

He presents in a written contribution to a workshop on water jets (20th ITTC), results that were obtained with a mixed flow pump that was tested in several distorted inflow conditions.

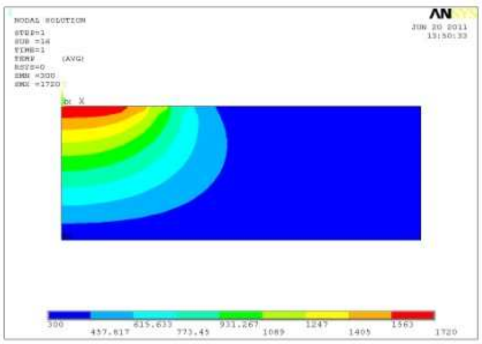
The difference in pump performance between performance in a pump loop and that in distorted conditions can be summarized by installation efficiency. This installation efficiency is reported to be approximately 0.96 for a mixed flow pump, originally designed as a water jet pump, working behind a 90 deg elbow in a pump loop. The effects on head coefficient and torque coefficient may however be greater (some 6.5% reduction in head coefficient at the maximum efficiency operating point). It is furthermore noted by Kruppa that "there is a general tendency for high specific speed devices, such as axial flow pumps, to react more sensitive to inflow disturbances than medium or low specific speed runners".

VII. RESULTS AND DISCUSSION

Conclusions for fluid temperature field, stainless steel temperature field shown in Fig. 4.



(a)



(b)

Fig. 4. Conclusions for temperature field

Determination of Capture Area using CFD. Based on the above literature, it is anticipated at this point that the derived momentum and energy fluxes in the region of Station 1 are insensitive to minor variation in area shape. This greatly simplifies the data reduction procedure used in conjunction with experiments, as well as adds to the confidence of the momentum flux method. It is noted at this point however that there is at least one reference (Roberts and Walker, 1998) claiming that the choice of a rectangular capture area may lead to an under-prediction of gross thrust by some 10% for a typical high speed ferry. Given the growing use of CFD, estimation of the capture area using CFD tools is becoming more feasible and could be advantageous, if found to provide reliable results. The capture area can be estimated by CFD, by tracing back the streamlines ingested into the inlet as shown in Fig.5 for the "Athena" design.

VIII. CONCLUSIONS

Two types of conclusions are drawn. The first category refers to the administrative part of the standardization tests, the second to the technical problems that are addressed by these tests. All ITTC members and a selected number of well-established water jet manufacturers have received an invitation to participate in the standardization tests. These standardization tests are divided into self propulsion tests, pump tests and water jet system tests. In addition to the tests, all addressees received an invitation to participate in a supporting CFD exercise. The positive reactions and the support from the ONR sponsored Gulf Coast Project have

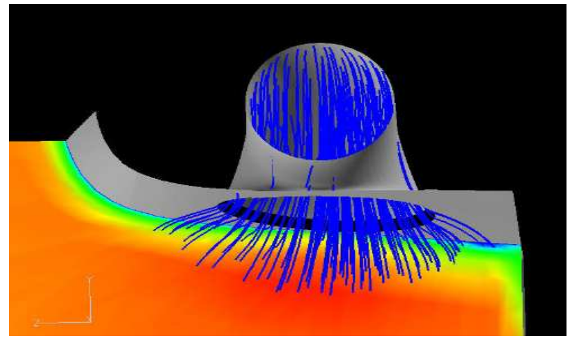


Fig.5. Use of CFD to determine Capture Area

strengthened the belief of the committee that the ambitious objectives set forth by the 22nd Water jet Committee can be met.

REFERENCES

[1] Tashiro,S,Tanaka,M,Murphy,A,Lowke, J "Prediction of energy source properties of free-burning arc", Welding journal , March 2008, P23-29

[2] Gorman.E. "Two-dimensional heat transfer study study on Keyhole plasma arc welding process "Journal of Heat transfer, July 2007, P: 1409 -1421

[3] Brandner, P. & Walker, G.J., 'A water jet test loop for the Tom Fink cavitation tunnel', Proceedings Water jet Propulsion III conference, Gothenburg, 2001

[4] Bulten, N.W.H.,'Influence of boundary layer ingestion on water jet performance parameters at high ship speeds', Proceedings of the 5th international conference on Fast Sea Transportation, pp 883-892, Seattle, 1999

[5] Verbeek, R. & Bulten, N.W.H.,'Recent developments in water jet design', Proceedings RINA Water jet Propulsion II conference, Amsterdam, 1998

[6] Hu, P. & Zangeneh, M.,'CFD calculation of the flow through a water-jet pump', Proceedings Water jet Propulsion III conference, Gothenburg, 2001

[7] Schlichting, H.,'Boundary layer theory', Mc Graw-Hill, New York, 1968

[8] Betz, A, 'Introduction to the theory of flow machines', Pergamon Press, Oxford, 1966

[9] Hu, P., Zangeneh, M., 'Investigations of 3D turbulent flow inside and around a water-jet intake duct under different operating conditions', ASME Journal of Fluids Engineering, Vol. 121, pp. 396-404, 1999

[10] Seil, G.J. 'The effect of the shaft, shaft rotation and scale on the flow in water jet inlets', Proceedings Water jet Propulsion III conference, Gothenburg, 2001

[11] Manen, J.D. van, 'Invloed van de ongelijkmatigheid van het snelheidsveld op het ontwerp van scheepsschroeven', PhD thesis, Wageningen, 1951

[12] Sulzer Brothers Ltd, 'Sulzer centrifugal pump handbook', Elsevier Applied Science, London, 1989

[13] Cooper, P.,'Perspective: the new face of R&D - A case study of the pump industry', ASME Journal of Fluids Engineering, Vol. 118, pp. 654-664, 1996.

Ali Moarrefzadeh

Faculty member of Department of Mechanical Engineering, Mahshahr Branch, Islamic Azad University , Mahshahr , Iran
E-mail: a_moarrefzadeh@yahoo.com
a.moarefzadeh@mahshahriau.ac.ir, Tel: +989123450936