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Flow simulation in hydrodynamic torque converter

Symulacja przepływu w przekładni hydrokinetycznej

Abstract

The paper compares the theoretical non–dimensional steady–state characteristics of a hydrodynamic torque converter with the experimental ones. The theoretical characteristics were calculated numerically based on two flow models: a one–dimensional model created by the authors and a three–dimensional model prepared by means of the ANSYS CFX software. The experimental characteristics were obtained on the basis of test rig investigations.

Keywords: hydrodynamic torque converter; numerical calculations; flow models

Streszczenie

W artykule porównano teoretyczne bezwymiarowe charakterystyki przekładni hydrokinetycznej w stanie ustalonym z danymi eksperymentalnymi. Charakterystyki teoretyczne obliczono numerycznie na podstawie modeli przepływu: model jednowymiarowy utworzony przez autorów i trójwymiarowy model przygotowany za pomocą oprogramowania ANSYS CFX. Charakterystyki eksperymentalne zostały uzyskane na podstawie badań na stanowisku badawczym.

Słowa kluczowe: przekładnia hydrokinetyczna, obliczenia numeryczne

1. Introduction

A hydrodynamic torque converter is a component of a driveline system which transfers the engine power to wheels of a vehicle. This torque converter increases the torque produced by the engine, but it can also work as a clutch. Due to the flexible transmission of torque and its high vibration damping capacity, which significantly increases the durability of the driveline system, the hydrodynamic torque converter is widely used in cars, agricultural machines, road–making plants, etc.

The non–dimensional steady–state characteristics of a hydrodynamic torque converter are used to calculate the overall ratio between the engine and the driven wheels and consequently, the motive force required to overcome the traction resistance of vehicles. They consist of curves presenting the torque ratio i_d, the efficiency η and torque coefficient λ versus the velocity ratio i_k.

Currently, design calculations of both geometric parameters of a hydrodynamic torque converter and non–dimensional steady–state characteristics are based on the commonly used one–dimensional model of fluid flow in the working space of the converter [1–3]. The advantage of such a model is its simplicity, but its disadvantage is low calculation accuracy.

Efforts are also made to calculate the non–dimensional steady–state characteristics of a hydrodynamic torque converter by means of a three–dimensional model of fluid flow based on Computational Fluid Dynamics (CFD) methods. The Computational Fluid Dynamics is a new branch of mechanics which uses computer tools to analyze pressure distribution, velocity distribution and heat transfer in the flowing fluid. The results of numerical calculations are verified by laser anemometry measurements of the fluid flow in hydraulic device channels [4]. These attempts, however, are still at the model creating and improving stage [5].

The use of commercial CFD computer programs, developed for the calculation of three–dimensional flows in various channels could improve the accuracy of the non–dimensional steady–state characteristics of a hydrodynamic torque converter.

The paper presents the results of a calculation obtained on the basis of a one–dimensional model of the non–dimensional steady–state characteristics of the PH 305 hydrodynamic torque converter [6]. These calculation results were compared with the ones obtained with the ANSYS CFX software [7] and verified by means of experimental investigations [8].

2. PH 305 Hydrodynamic Torque Converter

The object of this study was a three–element one–phase hydrodynamic torque converter named PH 305 with an active diameter of D = 0,305 m. The hydrodynamic torque converter had a pump with alternately long and short blades in order to reduce the flow losses. The basic data of the PH 305 impellers is given in Table 1.

Table 1. Basic data of PH 305

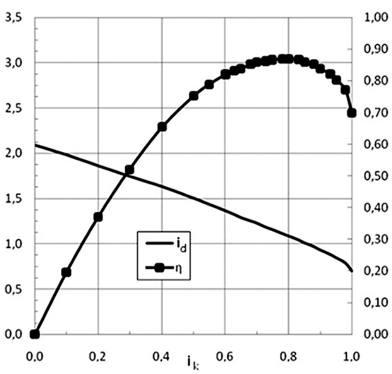
Rotor	Number of blades	Angle of blade β [°]	
Pump	26	Input 90	output 90
Turbin	26	Input 31.7	output 155.2
Stator	13	Input 70	output 24

The HL 46 mineral oil was used as the working fluid in the PH 305 hydrodynamic torque converter.

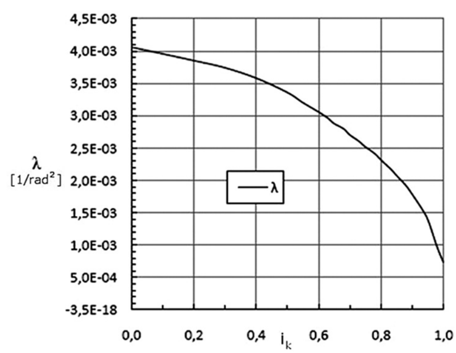
The experimental non–dimensional steady–state characteristics of the hydrodynamic torque converter PH 305 were performed on a specialized test rig. During the test, the input shaft angular velocity ω_1 was kept constant. The output shaft angular velocity ω_2 was changed, so as to obtain the target values of the velocity ratio $(0 \leq i_k < 1)$. For each recorded point the values of torques were measured on the input (T_1) and the output (T_2) shafts. During the test, the working fluid temperature was maintained constant. On the basis of the measured values of ω_1 and ω_2 angular velocities and T_1 and T_2 torques, the points coordinates of the non–dimensional steady–state characteristics of the PH 305 hydrodynamic torque converter were calculated by means of the following formulas:

$$i_k = \frac{\omega_2}{\omega_1} \qquad \eta = i_k \cdot i_d \qquad \lambda = \frac{T_1}{\omega_1^2 D^5} \tag{1}$$

and presented in Fig. 1.



a)



b)

Fig. 1. Test based non–dimensional steady–state characteristics of the PH 305 hydrodynamic torque converter: a – the efficiency η and the torque ratio i_d versus the velocity ratio i_k, b – the torque coefficient λ versus the velocity ratio i_k

3. Calculation models of Hydrodynamic Torque Converter

3.1. One–dimensional model (1D)

The model, which is commonly used in the calculation of the hydrodynamic torque converter, is called "the average stream model". The model assumes that the flow in the working space of the hydrodynamic torque converter is replaced with a single stream flow on the mean flow path. The parameters of the single stream are treated as the average parameters of all streams. This replacement allows to deriver calculation formulas on the basis of a limited number of parameters, without taking into consideration all dimensions of the hydrodynamic torque converter working space. For this purpose, the introduction of further assumptions is as follows [1, 2]:

- the fluid flow is constant;
- the inlet and outlet angles of the fluid flowing in the channels are the same as the blades angles;
- the friction flow losses in the channels depend on the relative velocity of the fluid flow;
- the impact flow losses linearly depend on the impact angles;
- the inertia of the fluid flowing in channels is added to the inertia of the pump and the turbine, respectively;
- the vortex flow occurs in gaps between the pump, the turbine and the stator;
- there are no volume losses of the fluid;
- physical properties of the fluid do not depend on the pressure but depend on the temperature;

In order to obtain equations for the calculation of T_1 and T_2 torques on the basis of ω_1 and ω_2 angular velocities, the absolute flow velocity c of the average stream is projected on two planes:

- the first one passes through the axis of shaft rotation as the meridional speed c_m,
- the other one is perpendicular to the axis of shaft rotation as the peripheral velocity c_u.

Three equations are formulated in the following way: two moment–of–momentum equations and the power balance for the hydrodynamic torque converter. The power balance follows from the principle that the net power supplied by the input shaft of the hydrodynamic torque converter is equal to the dissipated power [1]. The dissipated power includes the disc impellers friction, the bearings and the seal friction. The angular velocities of the pump ω_1 and turbine and the volumetric flow rate Q are the independent variables in this equations. The values of T_1 and T_2 torques obtained from the equations solving, together with the values of ω_1 and ω_2 angular velocities are used for the calculations of point coordinates of the non–dimensional steady–state characteristics by means of formula (1). The low accuracy of the average stream model results mainly from simplifying assumptions. On the other hand, the simplicity of the model equations is particularly useful when the calculations are repeated a number of times, for example during optimization. In addition, this model is helpful when the working space geometry of the hydrodynamic torque converter is not fully determined.

3.2. Three –dimensional model (3D)

In order to enhance the calculations accuracy of the non–dimensional steady–state characteristics of the PH 305 hydrodynamic torque converter, a three–dimensional model of the fluid flow was used. This model was based on the Navier–Stokes equations describing three–dimensional fluid flow [9, 10]. The commercial ANSYS CFX program was applied for the numerical calculation of the model. The program allowed to create additional equations for the turbulent flow in the hydrodynamic torque converter working space based on the Navier–Stokes equations. The turbulence should be taken into account when internal forces acting on the fluid molecule are significant in comparison to viscous forces [10]. Before numerical calculations of the non–dimensional steady–state characteristics of the PH 305 hydrodynamic torque converter, the ANSYS CFX option called "k–ε" was selected. The first parameter k described the turbulent kinetic energy and the second one ε described the turbulent dispersion. The Reynolds Number, defined as the ratio of inertia forces to viscous forces within the fluid, which determines turbulent flow was chosen as $4 \cdot 10^3$.

4. Numerical Calculations

4.1. The average stream model calculations

Before the application of the model, the parameters describing the mean path of the PH 305 hydrodynamic torque converter were established by using the estimation methods in order to enhance the accuracy of the calculations. The parameter estimation was made on the basis of the non–dimensional steady–state characteristics of the PH 305 hydrodynamic torque converter obtained from the tests and presented in Fig. 1. Computational programs solving equations of the average stream model were written in the Turbo Pascal language. The results of the calculations according to the model are shown in Fig. 10.

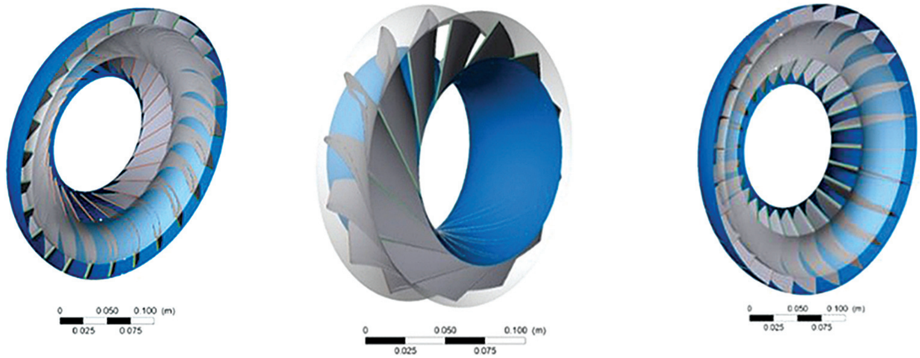
4.2. The CFD methods calculations

The first stage of the CFD method application was to define the working space geometry of the PH 305 hydrodynamic torque converter. It was done by creating the impellers solid models.

Due to the limited power of the computer used for the calculations by means of the ANSYS CFX program, the following simplifications were introduced:

- the short blades in the pump were replaced by long ones,
- the meridional cross–section was used as the basis for the solid model creation.

On the basis of the PH 305 specification it was established that the working surface of each impellers blade was described by a set of 398 points (199 internal and 199 external). The CATIA v5 software was used in order to define a data file including the coordinates of these points. The impellers solid models were created on the basis of the data file by using the ANSYS Turbogrid Module (ANSYS CFX). The solid models are shown in Fig. 2.



a) b) c)

Fig. 2. The PH 305 impellers solid models created by means of the ANSYS Turbogrid Module: a – pump, b – stator, c – turbine

In order to obtain the continuous fluid flows in the working space of the PH 305 hydrodynamic torque converter, the relationships between the input and the output flow surfaces of the impellers were determined by means of the ANSYS CFX Module, Fig. 3.

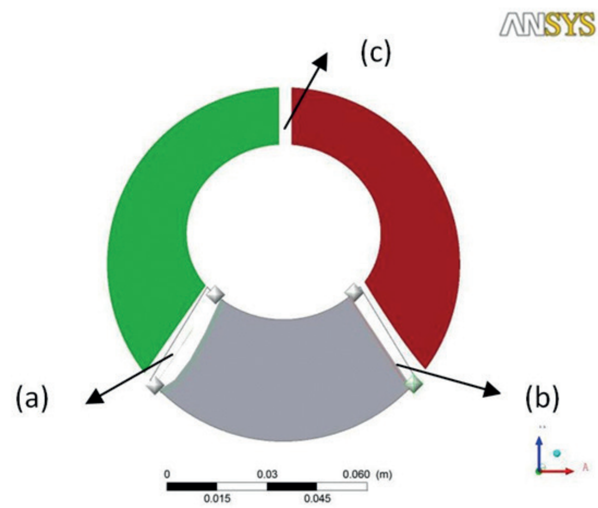


Fig. 3. Relationship between the input and the output flow surfaces of the impellers: a – stator – pump, b – turbine – stator, c – pump – turbine

The ANSYS CFX Pre Module was used in order to create the PH 305 working space by joining the impeller grid structures. However, due to the low processing power of the computer which was applied for the numerical calculations the model was not useful. The problem was solved by dividing the PH 305 working space solid model into the blade–to–blade segments by means of the "Periodicity" option. The results of the option application are illustrated in Fig. 4.

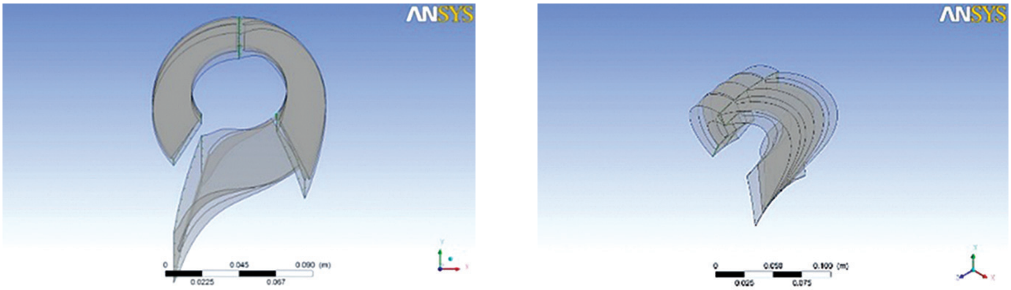


Fig. 4. Application of the "Periodicity" option for the blade–to–blade segment of the PH 305 working space

The boundary conditions and the data for the calculations of the PH 305 hydrodynamic torque converter according to the CFD model were established as shown in Table 2.

Table 2. The data and the boundary conditions for the calculations of the PH 305 hydrodynamic torque converter

Rotor	Fluid flow conditions		Turbulence
Pump	Speed, pressure, rotation axis	40 m/s 0.1 MPa X	none
Turbine	Speed, pressure, rotation axis	40 m/s 0.1 MPa X	k–ε model
Stator	Speed, pressure, rotation axis	40 m/s 0.1 MPa X	none

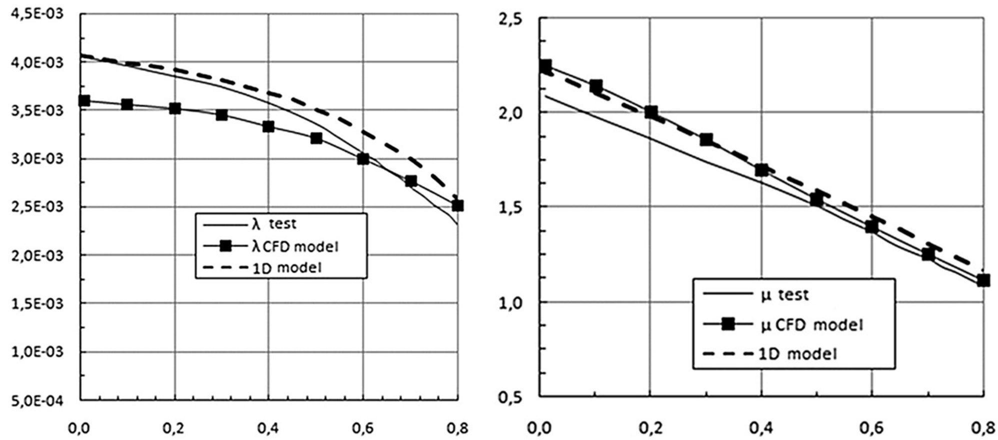
Due to the computer processing power limitation, the turbulent flow model "k–ε" was applied for the calculations of the fluid flow in the turbine. The turbine was selected because of its most complicated shape and a wide range of angular velocity [11].

The calculations were performed by means of the Stationary Model, which was a part of the ANSYS CFX–Pre module for the steady–state working condition of the PH 305 hydrodynamic torque converter. In the model the time was not an independent value. In addition, the "General Connection" option was selected from the menu list of the module in order to determine the working conditions of each impeller. As a reference pressure of the 0,1 MPa value was chosen.

The main aim of the calculations was to obtain the non–dimensional steady–state characteristics of the PH 305 hydrodynamic torque converter on the basis of:

- one-dimensional average stream model,
- three–dimensional ANSYS CFX model.

The results of the non–dimensional steady–state characteristics calculations for both models are compared in Fig. 5.



a) b)

Fig. 5. The non–dimensional steady–state characteristics of the PH 305 hydrodynamic torque converter calculated on the basis of 1D and 3D models: a – torque coefficient λ versus i_k, b – the torque ratio i_d versus i_k

It follows from Figure 6 that both 1D and 3D models can be successfully used for calculations of the non–dimensional steady–state characteristics of the PH 305 hydrodynamic torque converter, because the accuracy of both models is similar.

5. Conclusions

The accuracies of one–dimensional mathematical models and three–dimensional mathematical models used in the design process of the hydrodynamic torque converter for calculation of its non–dimensional steady–state characteristics were similar. This conclusion confirms the results obtained by other researchers.

The difficulties associated with the calculation of the hydrodynamic torque converter characteristics resulted from both:

- the complex fluid flow phenomena occurring in the short, strongly curved, and rotating impellers channels;
- insufficient processing power of the computer used for the calculations.

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