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Application of numerical calculations in the design process of hydrodynamic torque converter

Zastosowanie obliczeń numerycznych w procesie konstruowania przekładni hydrokinetycznej

Abstract

The use of numerical calculations to assess the impact of construction parameters on properties of a hydrodynamic torque converter has been presented in the article. The calculations have been based on a verified mathematical model of the transmission system including a hydrodynamic torque converter.

Keywords: numerical methods, mathematical model, hydrodynamic torque converter

Streszczenie

W artykule przedstawiono zastosowanie obliczeń numerycznych do oceny wpływu parametrów konstrukcyjnych na właściwości przekładni hydrokinetycznej. Obliczenia przeprowadzono w oparciu o zweryfikowany model matematyczny układu napędowego z przekładnią hydrokinetyczną.

Słowa kluczowe: metody numeryczne, model matematyczny, przekładnia hydrokinetyczna

1. Introduction

In the design process of technical systems, mathematical models are applied for the construction analysis which allows for defining the impact of construction parameters on the equipment performance. It is very costly and time consuming to analyze a real object. Mathematical models are widely applied for testing technical dynamic systems including mechanical systems. It is caused by the increase of system speed and loads as well as greater demands concerning durability, reliability and quality control. At the current stage of design development, due to the common usage of computers, complex mathematical models are created and their equations can be solved only by means of numerical methods. Solving the equation of a model is connected with writing a computer program, its testing and doing numerical calculations. The way of carrying out these tasks is connected with defining a method for solving a given problem, accuracy of results and selection of a programming language. To establish a method for solving a model equation, a verification of results of numerical calculations should be done depending on checking of the compatibility of the obtained results with the performance of a real system.

The wide application of the hydrodynamic torque converter in the design of machine drive systems and devices resulted in the development of research connected with the improvement of sub-assembly characteristics. According to many theoretical considerations concerning the hydrodynamic torque converter design, the shape of a working space of blade wheels has a great impact on the performance of this sub-assembly [1, 2]. In the process of hydrodynamic torque converter design, the selection of optimal construction parameter values plays a significant role [3–5].

In the article, numerical calculations have been introduced for the assessment of the impact of blade wheel construction parameters on the properties of a hydrodynamic torque converter. The calculations have been carried out on the basis of a mathematical model of a drive system with a hydrodynamic torque converter which has been introduced in the paper [6]. In order to verify the obtained results of calculations, a comparison has been done of steady-state characteristics received on the basis of experimental research. A hydrodynamic PH1 280 1 type torque converter has been the object of the research.

2. Assessment indicators and construction parameters of a hydrodynamic torque converter

The construction of a hydrodynamic torque converter working in a drive system of a selected means of transport should meet kinematic, dynamic, operational and economic requirements, as well as those connected with a motor drive [7]. Steady-state characteristics are the main source of information on the basis of which construction assumptions can be assessed:

$$i_d = M_2 / M_1 \qquad (1)$$

where: M_1, M_2 – torque of the input and output shaft;

$$\eta = i_d \, i_k \tag{2}$$

with $i_k = \omega_2 / \omega_1$
where: ω_1, ω_2 – angular velocity of the input and output shaft;

$$\lambda_{M,1} = \rho \omega_1^{\,2} D^5 \tag{3}$$

where: ρ – working fluid density,
D – active diameter of hydrodynamic torque converter.

On the basis of steady-state characteristics, the following assessment indicators have been determined:

- maximum efficiency η_{max} $[-]$,
- maximum dynamic transmission ratio i_{d0} $[-]$,
- maximum moment coefficient $\lambda_{M,\,1max}$ $[1/rad^2]$,
- permeability p, defined by the formula:

$$p = \lambda_{M,1max} / \lambda'_{M,1} \; [-] \tag{4}$$

economic range of operation or $d_{\eta p}$, defined by the formula:

$$d_{\eta p} = i_{k,\,\eta_p,\,max} / i_{k,\,\eta_p,\,min} \; [-] \tag{5}$$

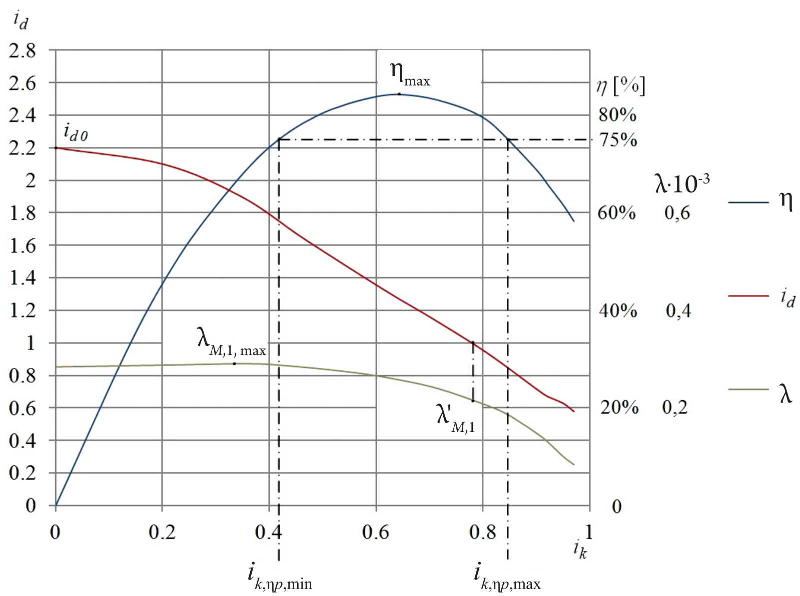

Fig. 1. Indicators: η_{max}, i_{d0}, $\lambda_{M,\,1max}$ and $d_{\eta p}$ determined on the basis of steady state characteristics

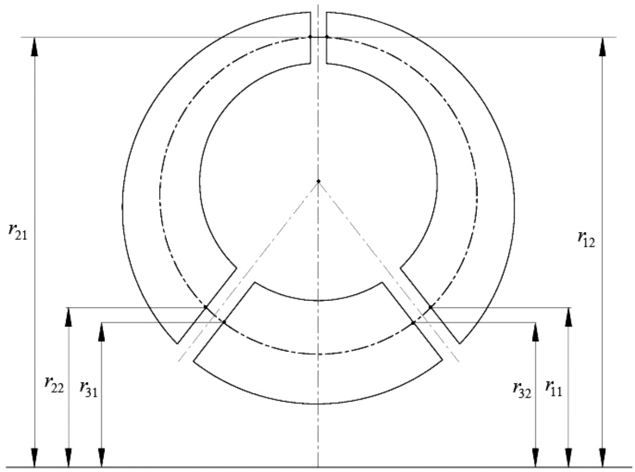

Fig. 2. Blade wheel radiuses of a hydrodynamic torque converter

They enabled the assessment of hydrodynamic torque converter properties. The indicators: η_{max}, i_{d0}, $\lambda_{M,\,1max}$ and $d_{\eta p}$ have been defined in Fig. 1.

It is usually assumed that hydrodynamic torque converter parameters are radiuses and angles at the input and output of blade wheels defined on the average line of channels [8]. Radiuses of blade wheels, that is, r_{11}, r_{12}, r_{21}, r_{22}, r_{31}, r_{32} for a three-stage hydrodynamic torque converter (pump, turbine, stator) have been defined in Fig. 2. Blade angles β_{11}, β_{12}, β_{21}, β_{22}, β_{31}, β_{32} correspond to the radiuses.

3. Mathematical model used to assess the impact of construction parameters on the assessment indicator of a hydrodynamic torque converter

In order to assess the impact of construction parameters of blade wheels on the assessment indicators of the hydrodynamic torque converter, mathematical model equations of the hydrodynamic transmission system have been used, written in the following form [7]:

$$M_s = \rho k_{12/32} Q^2 + \rho r_{12}^2 \omega_1 Q$$

$$M_r = \rho k_{12/22} Q^2 + \rho r_{12}^2 \omega_1 Q - \rho r_{22}^2 \omega_2 Q$$

$$a_{1st}\omega_1^2 + a_{2st}\omega_2^2 + a_{3st}Q^2 + a_{4st}\omega_1 Q + a_{5st}\omega_2 Q = 0 \tag{6}$$

where:

M_s – engine torque reduced on the shaft of the pump blade wheel,
M_r – torque resistance movement reduced on the shaft of the turbine blade wheel,
k, a – constant coefficients, depend on radiuses r and angles β blade wheels,
Q – volumetric flow rate.

A detailed description of the mathematical model of a hydrodynamic torque converter as well as the way of solving equations of the model have been shown in the paper [7].

4. Verification of mathematical model

The mathematical model of a hydrodynamic torque converter used for calculations has been verified by means of comparing steady-state characteristics calculated on the basis of the mathematical model with steady-state characteristics obtained on the basis of experimental research. To improve the accuracy of linear relationship between coefficients of friction losses ϕ_1, ϕ_2, ϕ_3 and angles shock losses α_u:

$$\phi = f(\alpha_u) \tag{7}$$

Coefficients of the function described with formula (7) have been selected as a result of the estimation according to the procedure presented in the paper [7].

The verification has been made for a hydrodynamic PH1 280 1 type torque converter with the active diameter of D = 280 mm, used in forklifts. The values of construction parameters of the hydrodynamic torque converter included in the technical specification are shown in Table 1.

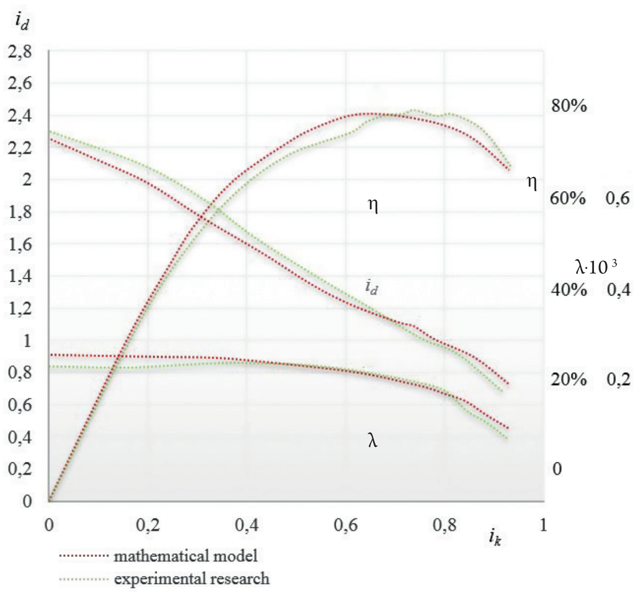

Fig. 3. Steady-state characteristics of type PH1 280 1 hydrodynamic torque converter obtained for the following parameters: ω_1 = 200 rad/s, T = 96°–104°C

Table 1. Basic construction parameters of a PH1 280 1 hydrodynamic torque converter

Radiuses	r_{11}	r_{12}	r_{21}	r_{22}	r_{31}	r_{32}
Value [mm]	0,085	0,13	0,13	0,085	0,075	0,075
Blade angles	β_{11}	β_{12}	β_{21}	β_{22}	β_{31}	β_{32}
Value [°]	119	111	44	143	105	27

Steady-state characteristics have been made for angular the velocity $\omega_1 = 200$ rad/s and working fluid temperature $T = 96° \div 104°C$. Steady-state characteristics of a hydrodynamic PH1 280 1 torque converter obtained on the basis of numerical calculations and experimental research have been shown in Fig. 3.

On the basis of the comparison of the steady-state characteristic obtained on the basis of experimental research, one can claim that the standard error of verification for all the curves shown in Fig. 3 does not exceed 8%, which is acceptable during the design process of a hydrodynamic transmission system.

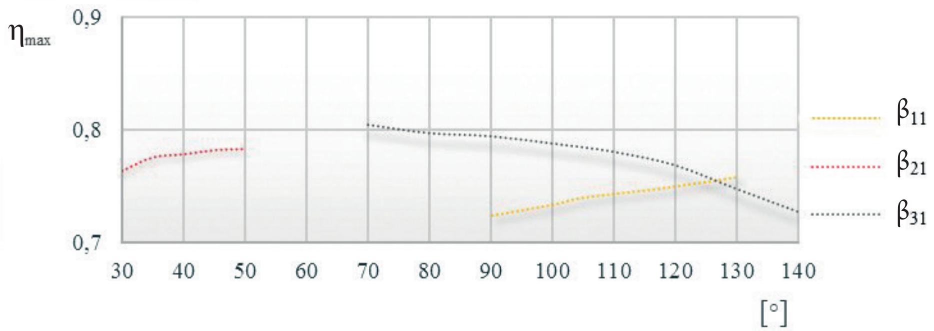

Fig. 4. Impact of β_{11}, β_{21}, β_{31} on η_{max} for PH1 280 1 type hydrodynamic torque converter

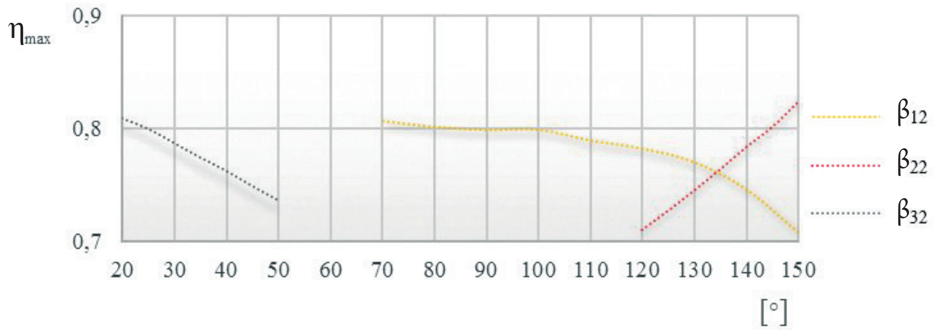

Fig. 5. Impact of β_{12}, β_{22}, β_{32} on η_{ma} for PH1 280 1 type hydrodynamic torque converter

5. Assessment of construction parameters on hydrodynamic torque converter assessment indicators

On the basis of the mathematical model of the transmission system including a hydrodynamic torque converter (6), (7) and computational written programs in Delphi 7 Enterprise, tests of the impact of construction parameters of blade wheels on hydrodynamic torque converter assessment indicators have been made.

For example, in Figs. 4 and 5, the results of calculations concerning the impact of the angles β_{11}, β_{12}, β_{21}, β_{22}, β_{31}, β_{32} on the indicator η_{max} have been illustrated. The calculations have been made for subsequent values of the selected angle within the accepted range. Ranges of angle values have been determined on the basis of real constructions of hydrodynamic torque converters.

As it is shown in Figures 4 and 5, the increase of angle values β_{11} and β_{22} results in the increase of maximum efficiency η_{max}, whereas the increase of angle values β_{12}, β_{31} and β_{32} causes a decrease. The increase of β_{21} practically does not change the maximum efficiency value. If it is significant for the transmission system design to obtain the greatest values of maximum efficiency η_{max}, it is reasonable to select such angle values β_{11}, β_{12}, β_{21}, β_{22}, β_{31}, β_{32} that will fit in strictly determined value ranges. The angle values ranges for which the maximum efficiency has the greatest values have been shown in Table 2.

Table 2. Angles value ranges for which maximum efficiency takes the greatest values

Description	β_{11}	β_{12}	β_{21}	β_{22}	β_{31}	β_{32}
Value ranges [°]	120¸130	70÷80	40÷50	140¸150	70÷80	20¸30

The deviation between the angle value ranges given in Table 2 and the values given in Table 1 for the hydrodynamic PH1 280 1 type torque converter occur since during the design of this hydrodynamic torque converter, the remaining assessment indicators have been considered.

6. Conclusions

On the basis of the considerations presented in the paper that deals with a hydrodynamic PH1 280 1 torque converter, the following conclusions have been formulated:

1. Numerical calculations carried out on the basis of a mathematical model of the transmission system allow for analyzing the assessment of the impact of construction parameters on hydrodynamic torque converter assessment indicators.
2. As it follows from the verifications, mathematical models applied for calculations as well as computational programs used to solve equations of this model allow for modelling steady-state characteristics of a hydrodynamic torque converter with the accuracy which is sufficient for engineering aims.
3. Applications of the numerical calculations can be used during the design of a hydrodynamic torque converter as a supplement of experimental research.

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