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EXPERT SYSTEM FOR SUPPORTING THE PROCESS OF HYDRODYNAMIC TORQUE CONVERTER CONSTRUCTION

SYSTEM EKSPERTOWY WSPOMAGAJĄCY PROCES KONSTRUOWANIA PRZEKŁADNI HYDROKINETYCZNEJ

A b s t r a c t

This paper presents an advisory expert system to assist the process of constructing the hydrodynamic torque converter. The system has been constructed using program Delphi 7 Enterprise in Object Pascal. The system includes three types of means of transport, a car, a rail bus and a working machine.

Keywords: *expert systems*, *computer aided design*, *hydrodynamic torque converter*

S t r e s z c z e n i e

W artykule przedstawiono doradczy system ekspertowy wspomagający proces konstruowania przekładni hydrokinetycznej. System zbudowano z użyciem programu *Delphi 7 Enterprise* w języku *Object Pascal*. W systemie tym uwzględniono trzy rodzaje środków transportu, w którym przekładnia hydrokinetyczna pracuje: samochód osobowy, autobus szynowy i maszynę roboczą.

Słowa kluczowe: *systemy ekspertowe*, *komputerowe wspomaganie konstrukcji*, *przekładnia hydrokinetyczna*

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Symbols

η_{75} – economic range of operation
η^* – maximum efficiency
χ_p – computational durability
$\lambda_{M,i}$ – moment coefficient
α_1, α_2 – damping factor for pump and turbine impellers
S – execution cost
g – metal consumption factor
i_{d0} – dynamic transmission ratio
n_p – idle gear loss coefficient
i_M – coefficient of torque limit
$\lambda_{A,i}$ – coefficient of axial force
i_ω – coefficient of speed reduction
p – permeability
X – coefficient of stiffness performance
β_{11} – blade angle at the entrance of the pump impeller
β_{12} – blade angle at the exit of the pump impeller
β_{21} – blade angle at the entrance of the turbine impeller
β_{22} – blade angle at the exit of the turbine impeller
β_{31} – blade angle at the entrance of the stator impeller
β_{32} – blade angle at the exit of the stator impeller
r_{12} – radius of the average line at the exit to the pump impeller
r_{21} – radius of the average line at the entrance to the turbine impeller
r_{22} – radius of the average line at the exit to the turbine impeller
J_1, J_2 – moments of inertia of the input shaft
c_1, c_2 – stiffness of the input shaft
l_2 – length of the average line

1. Introduction

A hydrodynamic transmission system (HTS) is a part of the propulsion system in the ground transportation using the kinetic energy of the working fluid. No permanent connection between the input shaft and the output shaft causes no shock loads transferred from the working tool to the propulsion system. The main advantage of the HTS is shifting in relation to the applied load. Furthermore, it effectively reduces the dynamic load and damping vibration, thus highly increasing the durability of the propulsion system [1]. One of the major disadvantages of the HTS is low maximum efficiency and narrow range of high efficiency as a function of the speed ratio. The basic element of a HTS consists of an hydrodynamic sub-assembly which includes: torque converters, clutch or brake. The most complicated component in the design is the hydrodynamic torque converter (HTC) which is composed of three impellers: pump, turbine and the stator as it is shown in Figure 1.

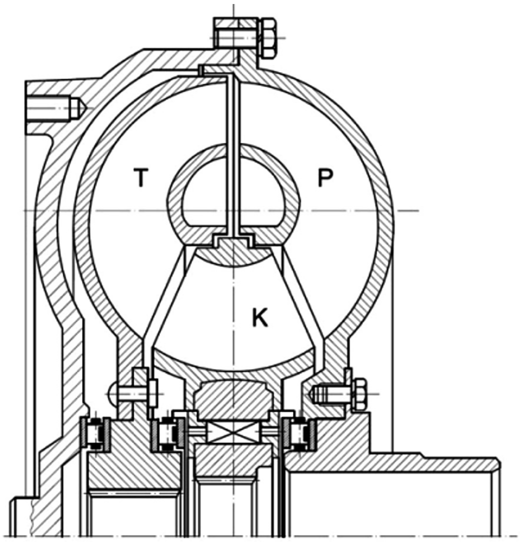

Fig. 1. Construction of the hydrodynamic torque converter [2]: *P* – pump impeller, *T* – turbine impeller, *K* – stator impeller

Rys. 1. Budowa przekładni hydrokinetycznej [2]: *P* – koło łopatkowe pompy, *T* – koło łopatkowe turbiny, *K* – koło łopatkowe kierownicy

The impellers consist of blades that with together the housing create the work area for the working fluid.

The introduction of modern low-speed engines using alternative fuels, the requirement of exhaust emissions reduction and the increase of the efficiency of the propulsion system reducing fuel consumption means that the torque converter design process is very current and important. Too low accuracy of existing mathematical models results in a large discrepancy between the requirements and the resulting characteristics of the HTC. The failure to comply with the prescribed requirements results in the deterioration of the characteristics of the propulsion system and forms of economic losses.

The development of the methodology supporting the process of constructing the HTC by using expert system can resolve the existing problems of the construction. The benefits of using this solution can include not only economic aspects in the form of increasing the efficiency, but also the optimal choice of torque converter for a given mode of transport.

Expert systems are complex computer programs that use knowledge derived from subject matter experts sources. They consist of three main components: the interface, inference engine and a knowledge base. Such systems are increasingly being used in the design and operation of machines and equipment. They can be divided into advisory, diagnostic and decision-making systems. Are widely used in supporting the construction process advisory systems [3], their main task is to solve a problem using the knowledge contained within the database.

This paper presents an advisory system for supporting the process of design the HTC.

2. Advisory expert system to assist in the process of designing a hydrodynamic torque converter

The presented system in the paper the which support the design of a HTC is an advisory expert system software based on the collected data [4]. The system has been developed using *Delphi 7 Enerprise* software with the help of object-oriented programming language – *Object Pascal*. The result of the working system is the choice of the optimum design solution for the design of a HTC. Solving the decision-making problems in the system is done by selecting:
– optimal torque converter evaluation index for the predefined means of transport,
– optimal design parameters having an impact on the rate of the highest evaluation,
– field variation of the optimal design parameters.

The diagram of the system in the form of a decision tree is shown in Figure 2.

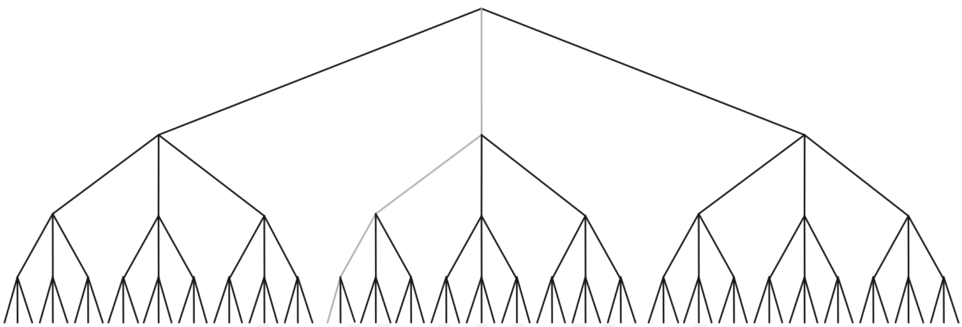

Fig. 2. A decision tree system supporting the process of designing a hydrodynamic torque converter
Rys. 2. Drzewo decyzyjne systemu wspomagającego proces konstruowania przekładni hydrokinetycznej

The selection of the optimal values of the assessment indicators, construction parameters and their ranges of variation have been implemented for a passenger car, a rail bus and a working machine.

A knowledge base of the advisory expert system to support the process of designing the hydrodynamic torque converter has been developed on the basis of domain subject matter experts opinions and professional literature in the field of HTS such as: scholarly articles, books, standards, patents. The knowledge base includes:
– assessment indicator impact on a means of transport,
– the impact of construction parameters on the assessment indicators,
– ranges of the construction parameters variability.

The knowledge base has been divided into various sources of data provenance. The data obtained during the point assessment method as well as the data from books, articles, JCR and standards [5] has been implemented. The data coming from various literature sources has been divided into experimental and theoretical ones. In addition, arbitrary coefficients of confidence have been introduced for all the data. A division of the knowledge base fragment is shown in Figure 3.

```
SYEXP2
{MASZYNA ROBOCZA}
  Procedure Dane1m;{Dane dla etamax - maszyna robocza}
 begin
  ocenaeksperta:= 161; maxpunktow:=180;
  wksiazkach:=3; wartykulachJCR:=7; winnych:=9;
  eksperymentalne:=10; teoretyczne:=9;
  u1:=0.9; u2:=0.9; u3:=0.9;
 end;
  Procedure Dane2m;{Dane dla id0max - maszyna robocza}
 begin
  ocenaeksperta:= 178; maxpunktow:=180;
  wksiazkach:=4; wartykulachJCR:=6; winnych:=2;
  eksperymentalne:= 10; teoretyczne:=2;
  u1:=1; u2:=1; u3:=0.9;
 end;
```

Fig. 3. A division of the knowledge base fragment

Rys. 3. Podział fragmentu bazy wiedzy

The inference engine retrieves data from a knowledge base with some weights. The value of "1" is assigned to the data coming from the books, the value of "0.8" to the articles of the JCR and the value of "0.5" to other literature sources.

3. Indicators assessment and design parameters

Completely different working conditions of ground transportation cause that the propulsion system is subjected to different types of resistance, and hence there are various types of loads. The HTC design requires the determination of the requirements for a given means of transport, including the expected load, or cooperation with the propulsion system. To ensure the optimal design the following requirements kinematic, dynamic, productive, economical and exploitation ones should be taken into account in order to ensure the optimal design. Assessment indicators have been introduced to check if HTC meets the requirements and to assess the impact of design parameters on the design process [2, 5]. When selecting a HTC for a given means of transport which operates in very specific conditions, the assessment indicator is to achieve its optimal value.

Assessment indicators chosen for the HTC which have been subjected to the expert point assessment method [5–7] have been selected they are affected by a large number of construction parameters: η_{75}, η^*, χ_p, $\lambda_{M,i}$, α_1, α_2, S, g, i_{d0}, n_p, i_M, $\lambda_{A,i}$, i_ω, p, X. Next the indicators have been evaluated by subject – matter experts. The level of validity of the assessment indicators for a given means of transport using the point assessment method [5] has been evaluated by experts. The indicators have been assessed on the scale 0 to 180. The results are shown in Table 1.

For each means of transport three assessment indicators with most points have been selected and they have been implemented to the knowledge base of the advisory expert system.

In order to obtain optimum values of the HTC assessment indicators is the structural parameters directly affecting the assessment indicators must be changed. Design parameters with greatest impact on the assessment indicators evaluated by means of the assessed using point assessment expert method [4, 6], have been selected. They are: β_{22}, β_{32}, β_{12}, r_{12}, J_1, r_{21}, r_{22}, J_2, β_{21}, β_{11}, c_1, c_2, β_{31}, l_2.

Table 1

Assessment indicator impact on a selected means of transport

	Passenger car	Rail bus	Working machine
η_{75}	148	176	164
η^*	158	158	174
χ_p	134	98	78
$\lambda_{M,i}$	88	122	112
α_1, α_2	111	95	100
S	82	68	75
g	123	114	102
i_{d0}	172	148	56
n_p	48	68	126
i_M	92	75	93
$\lambda_{A,i}$	116	46	69
i_ω	77	123	112
p	58	88	148
X	66	48	96

The parameters were subjected to subject matter experts evaluation. The experts assessed the impact of various design parameters on the indicators [5] by using the point assessment method. The parameters were assessed on 0 to 180 points scale. The results are shown in Table 2.

Three design parameters with the highest score have been selected and implemented to the knowledge base of the advisory expert system.

The ranges of design indicator variability have been selected on the base of current HTC construction and they have been evaluated by subject matter experts on 0 to 180 scale. The results are shown in Table 3.

Table 2

Design parameters impact on the indicators of the hydrodynamic torque converter

	η_{75}	$\eta*$	i_{d0}	p
β_{22}	168	162	128	118
β_{32}	172	143	166	122
β_{12}	162	140	149	136
r_{12}	112	98	85	75
J_1	88	48	102	98
r_{21}	78	66	59	66
r_{22}	67	104	100	88
J_2	74	62	84	60
β_{21}	166	122	116	162
β_{11}	168	138	141	144
c_1	112	110	66	78
c_2	88	90	110	94
β_{31}	175	144	170	128
l_2	66	50	65	70

Table 3

Ranges of design of parameter variability

	Range I	Range II	Range III		Range I	Range II	Range III
β_{22}	129–139	139–148	148–160	β_{21}	30–45	45–50	50–75
Rating	122	164	125	Rating	149	88	138
β_{32}	20–30	30–40	40–50	β_{11}	90–102	102–114	114–130
Rating	158	98	48	Rating	111	166	102
β_{12}	75–100	100–125	125–150	β_{31}	70–92	92–114	114–140
Rating	74	148	134	Rating	66	165	78

4. The result of the system performance

The optimal design solution suggested by the described expert system for the HTC is following:

- for a passenger car – assessment index p and the construction parameter β_{12} (75º – 100º),
- for rail bus assessment index i_{d0} and the construction parameter β_{12} (125º – 150º),
- for a working machine – evaluation index $\eta*$ and the construction parameter β_{32} (20º – 30º).

5. Conclusions

1. The expert system for each means of transport chooses the assessment indicator which is to achieve the max. The process is carried out by choosing the design parameter and the variability range of this parameter.
2. Inference system is based on the data contained in the knowledge base.
3. The knowledge base is separated from the rest of the program, which allows for continuous modification and the data completion.

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