Analysis of the vibrations of the low power ORC turbines operating under conditions of strongly developed hydrodynamic instability

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Abstract

The paper presents the results of the analysis of the dynamic performance of the rotor being a component of the ORC turbine set with the net electrical output of 100 kW and the nominal speed of 9000 rpm. This device is dedicated for municipal Local Energy Centres (LEC). These Centres reveal a moderately optimistic view of developments in prosumer power engineering and distributed power systems.
The research was conducted using tools capable of performing the necessary simulation of the system operating under highly unstable conditions, i.e. in a strongly nonlinear regime. In this regard, the author of the paper followed the subsequent phases of whirl/whip formation manifested in the fluid film.

Keywords: dynamics of rotors and slide bearings, ORC microturbines, hydrodynamic instability, distributed power engineering

1. Introduction

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The analyses concerning the dynamic performance of the turbine set are particularly important since the rotors mounted in machines of this type are characterised in general by high rotational speeds while being subjected to low static forces. This means that difficulties in maintaining stable system operation may be encountered, particularly if the rotor is supported by slide bearings. The final outcome includes the hydrodynamic instability during which a lubricating medium in the slide bearings quickly passes from whirl to whip which results in very dangerous mechanical vibrations of the entire system. The processes of this type can also be found in traditional high power turbine sets but they are not as rapid or as common as in low power units.
In ORC turbines, if a low boiling fluid is to be used as a working medium in the turbine there is always a temptation to use the same fluid as a lubricant for the slide bearings. Such solution not only greatly simplifies the construction, it also makes it possible for the turbine – bearings system to form a whole and be mounted in a hermetic enclosure. It is a very attractive idea. Unfortunately, the low boiling agents used in ORC systems have extremely poor lubricating properties, and furthermore, a two-phase flow occurs relatively often in the lubricating film of the bearing, which adversely affects its operation.
The paper presents the research concerning the possibility of applying the low boiling fluids for lubricating the slide bearings being part of a hermetically sealed low power ORC turbine. The rapid passes of the working medium to a 'whip' state mean the system operates under conditions of developed hydrodynamic instability. A theoretical analysis of the system operation under such conditions can only be conducted with tools based on nonlinear (and even strongly nonlinear) vibration theory. The identification of phenomena occurring under such conditions was the main objective of the research presented herein. In this context, the fundamental question arises: Can non-conventional lubricating mediums be used in slide bearings to provide stable operation of a hermetically sealed low power ORC turbine?
The answer to this question was an essential objective for the author of this paper and was also a utilitarian aspect of the study. In order to respond in the most efficient manner possible, an analysis must be made consisting of the examination of the performance of slide bearings operating with conventional lubricating mediums (mineral oil) and the examination of the operation of the system equipped with rolling bearings. This approach will allow the author to evaluate the advantages and disadvantages of each solution and to take a final decision on selecting turbine design.

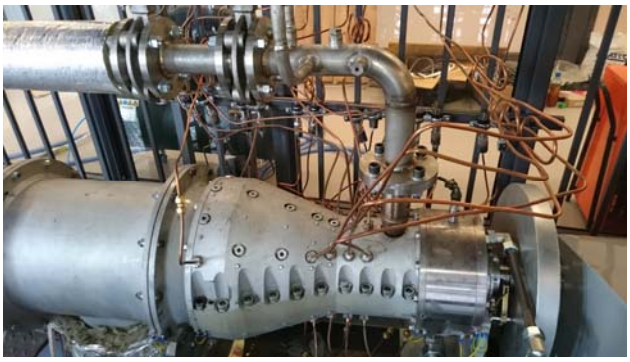

Figure 1: Photo showing the prototype of a 100 kW ORC turbine set. This device is currently undergoing operation tests at a laboratory belonging to the IMP PAN in Gdańsk.

Three constructional solutions within the scope of the bearing were examined with conventional and non-conventional lubricating mediums (mineral oils and low boiling mediums). An approach using rolling bearings was also considered. On the basis of those scientific studies, the decision to build a working prototype of the machine was taken. Such a prototype has already been manufactured, having regard to the outcome of the conducted analyses. The operation tests are currently underway in the Vapour Microturbines Laboratory at the Institute of Fluid-Flow Machinery Polish Academy of Sciences (IMP PAN) in Gdańsk. It is the most modern facility of this type in Poland.

The research presented herein produced interesting results showing that, under the conditions of hydrodynamic instability, the phenomena taking place inside the lubricating gap of the slide bearing are not recurrent for each individual rotor revolution, notwithstanding the fact that the external excitation forces acting on the system are fully repeatable. The research tools were presented that allow a detailed qualitative and quantitative description of such phenomena.

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