Developing high-performance heat exchangers for low-emission power systems

In the quest to lower emissions from engine systems, heat exchangers are a key enabling technology for low-emission power systems. The development of high-performance heat exchangers poses a set of complex engineering challenges that the InDEStruct project is looking to overcome.

Heat exchangers transfer heat from a working system, e.g. an engine, to a working fluid. Attached to an engine, the heat exchanger will help to cool the engine system in order for it to run efficiently. However, heat exchangers present several challenges from different fields of engineering, such as vibration, thermal cycling and material limitations, while they still having to perform the main goal of heat transfer between the circulating fluids. The resulting stress concentrations and cracks can appear. It is precisely these challenges that the researchers of the InDEStruct project are looking to alleviate in their goal of designing a cooler heat exchange system.

InDEStruct project

The InDEStruct project was specifically created to link academic insight and critical thinking to the practical engineering sector in order to develop high-performance heat exchange systems. This collaborative doctoral training programme provides a model for the development of technology leaders, enabling them to apply scientific methods from academia to interdisciplinary industrial design.

Each early-stage researcher (ESR) spends equal time situated in an academic university and in industry, specifically 18 months at University of Southampton in the UK and 18 months at Vestas aircool in Denmark, a market leader in air charge coolers for diesel engines in the marine sector. Vestas aircool has a comprehensive industrial cooling division and are a pioneer in their field, having developed the first ever charge air cooler alongside Burmeister & Wain (Copenhagen).

Vibration

The vibration experienced by heat exchangers cannot be simply prevented, considering they are invariably connected to the engines which transmit the vibration which is intrinsic to their operation. However, the vibration problem can be alleviated by ensuring that the dynamic properties of the heat exchangers are such that they do not match the excitation frequencies coming from the engine, thus avoiding the amplification of the vibrations generated by the engine. Hence, an accurate calculation of the dynamic properties of heat exchangers is crucial to ensure they are not in resonance with the operating excitations.

System modelling challenges

The two stages of computational modelling and testing of heat exchanger structures come with their own challenges. For computational modelling, despite the ever-more powerful computers available today, computational efficiency is critical to calculating these dynamic properties. This arises from the fact that heat exchangers are composed of hundreds of parts in the form of tubes, fins and plates, which together determine the vibration characteristics of these systems. Running a simulation to determine the natural frequencies of heat exchangers considering all those components and without proper consideration for computational efficiency can take significantly longer than if using an appropriate model.

Furthermore, performing tests on heat exchangers to validate the computational model is not a trivial task. The conditions that exist during operation, that is, the flow of the fluids through the components, the high temperature, and the way in which the heat exchanger is attached to the engine, can all influence the natural frequencies of heat exchangers. So, proper testing requires evaluating the effects of those conditions as well.

The typical computational approach used for modelling the dynamic behaviour of heat exchangers is using finite element (FE) analysis. This is a very powerful and general computational modelling technique which relies on discretising complex geometries using small and simple shapes to approximate the...
structure being studied. However, running FE analysis is computationally expensive and requires the use of high-performance computers to speed up the calculations involved. In early design phases, when various design options are being explored, this can be an impediment. This points toward the need for a modelling technique which would provide computationally inexpensive means to estimate the dynamic behaviour of heat exchangers.

"To build such a model, we focused on the lower vibration modes and used some physics-based simplifying assumptions", explains Kevin Jose. "We came up with some simple structures whose vibration characteristics are similar to the heat exchangers in question. These simple structures, which stand in for the heat exchangers, have vibrational properties which can be studied in a computationally efficient manner. This model was encoded as an algorithm which takes material and geometrical design parameters as input and gives estimates about dynamic behaviour as output. This algorithm is then packaged as a stand-alone programme with a user-friendly graphical user interface for use in Vestas aircraft."

The experimental work performed by Milena:

- allowed validation of the model proposed by Kevin, ensuring that the algorithm can be used by Vestas aircraft when designing the dynamic characteristics of heat exchangers in replacement of other models which were computationally expensive;
- added value to Vestas aircraft by exploring and confirming new methods to test their products under operating conditions (some methods are quite common in the academia, so this point also goes in hand with bridging academia and industry, which is important for InDEStruct);
- shed some light on the influence of operating conditions on the dynamic properties of heat exchangers that need to be investigated further (beyond the project) to improve these estimates.

Kevin Jose

PROJECT TITLE
Computational modelling of complex structures and structured materials

PROFILE
Kevin graduated from the Indian Institute of Technology Kanpur (India) with an integrated Master's degree in Mechanical Engineering. He subsequently conducted graduate-level research in the area of smart materials at New York University (USA). In his current role, Kevin is interested in developing numerical and analytical models of periodic structures with a special focus on potential use in industry.

RESEARCH INTERESTS
Dynamics, phononic crystals and acoustic metamaterials and musical acoustics.

Milena W. Bavaresco

PROJECT TITLE
Novel experimental characterisation of elastic and acoustic metamaterial as produced using additive manufacturing technology

PROFILE
Milena graduated in Mechanical Engineering at the Federal University of Parana (Brazil) with a Master’s degree in solid mechanics, with a focus in vibrations and structural dynamics of heat exchangers that need further investigation. The validation of the techniques for testing these components will also be useful for the company with our future research project of developing a digital twin for our heat exchangers".

To find out more about InDEStruct and stay up-to-date on Milena and Kevin’s work, visit www.indestruct.eu.