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 vibrations reduce the lifetime of the components within the heat exchanger, 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 aircoil in Denmark, a market leader in air charge coolers for diesel engines in the marine sector. Vestas aircoil 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.

Accurately estimating these dynamic properties involves having a robust model of the system that can be used to calculate its natural frequencies—the critical frequencies where the system/heat exchanger presents amplified levels of vibrations—which, in turn, require experiments that verify this model.

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

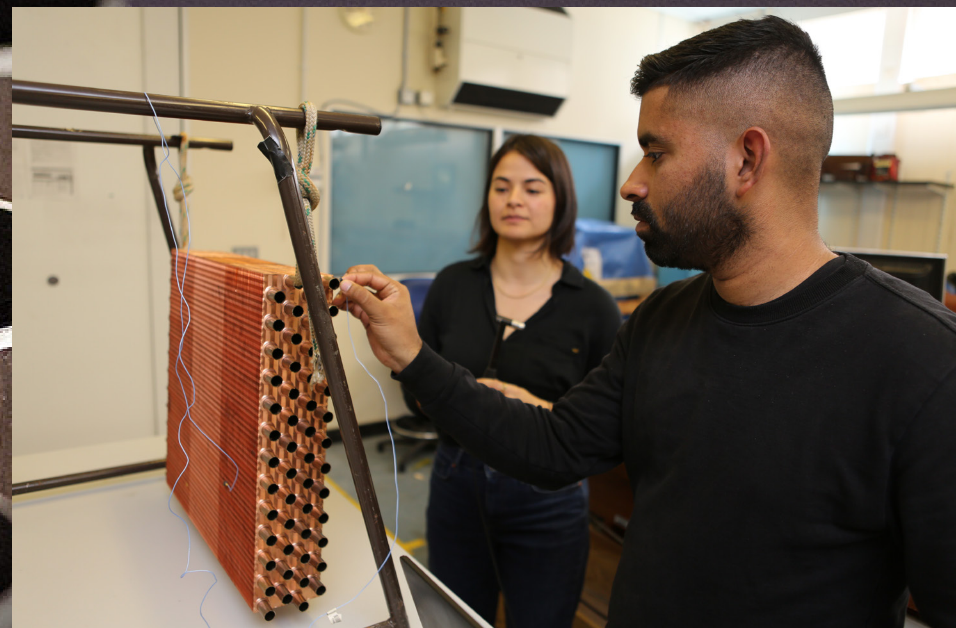


Image: Kevin and Milena setting up an experiment to test a heat exchanger for its dynamic properties in the laboratory at the University of Southampton.

Image: Talha, Kevin and Milena, PhD students in the project.

Image: Supervisors Dr Neil Ferguson and Prof. Atul Bhaskar.

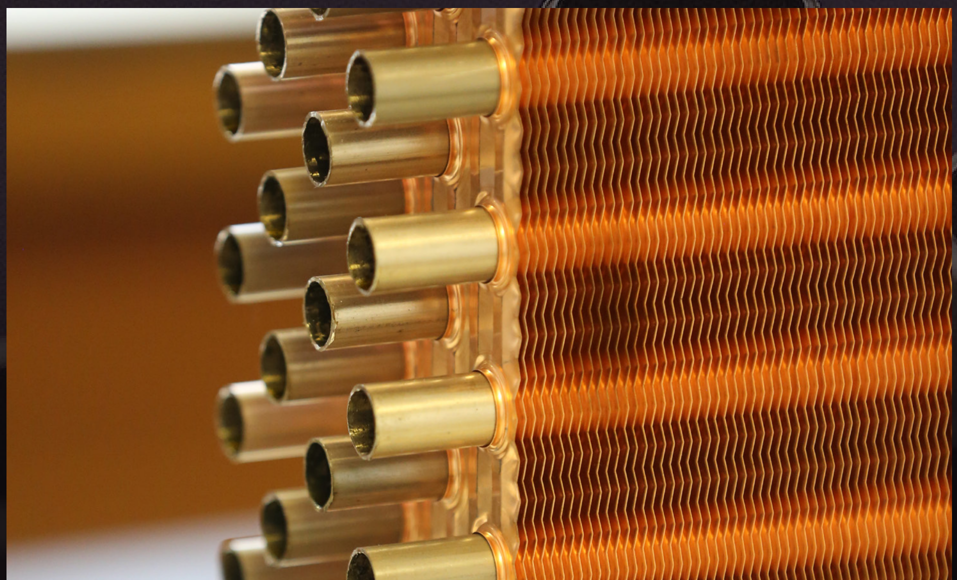
structure being studied. However, running FE analysis is computationally expensive and requires the use of high-performance computers to speed up the calculations involved. In early design phases, when various design options are being explored, this can be an impediment. This points toward the need for a modelling technique which would provide computationally inexpensive ways 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 aircoil."

"For the challenge of testing heat exchangers under operational conditions, the expertise necessary to perform these tests was brought to InDEStruct by our partner Prof. Anders Brandt, who at the time was at the University of Southern Denmark (SDU) in Odense", says Milena Bavaresco. It was a one-month secondment plus continuous support that allowed Milena to learn about and apply these methods to the heat exchangers at Vestas aircoil.

The experimental work performed by Milena:

- allowed validation of the model proposed by Kevin, ensuring that the algorithm can be used by Vestas aircoil when designing the dynamic characteristics of heat exchangers in replacement of other models which were computationally expensive
- added value to Vestas aircoil 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.

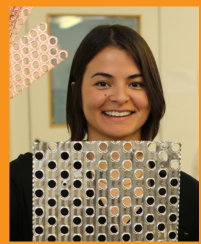


Direct benefit to industry

"The algorithm with a user-friendly graphical user interface developed by Kevin is already available to be used by Vestas aircoil, which enables the determination of dynamic properties of heat exchangers at the initial phases of design, ensuring a smooth design process.", says industrial coordinator Dr Claus H Ibsen.

He adds that "the operational tests of heat exchangers performed by Milena have generated knowledge for Vestas aircoil and created awareness about the 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**.



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 from the universities Technical University Ingolstadt (Germany) and the Federal University of Parana. She has been specialising in the topic of vibrations since her undergraduate studies through scientific research to internships and academic research projects motivated by and in collaboration with the industry.

RESEARCH INTERESTS

Experimental and operational modal analysis, periodic structures, metamaterial, modal and wave approach techniques for dynamic characterisation, vibration control.

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.

InDEStruct

PROJECT SUMMARY

The InDEStruct project is a collaborative engineering design doctoral training programme that provides a model for developing technology leaders, enabling them to apply scientific methods from academia to interdisciplinary industrial design.

InDEStruct is driven by the need to develop more efficient and lower emission engine systems, with air charge cooling identified as the key enabling technology. To meet the challenge, InDEStruct brought together a consortium of industrial and academic partners in a novel and bespoke doctoral training programme, with four doctorates covering diverse aspects of mechanical engineering: structural vibration, stress and thermal analysis, additive manufacturing, multifunctional metamaterials, fatigue and materials development.

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Vestas aircoil

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