Soft sensors for heat pump icing

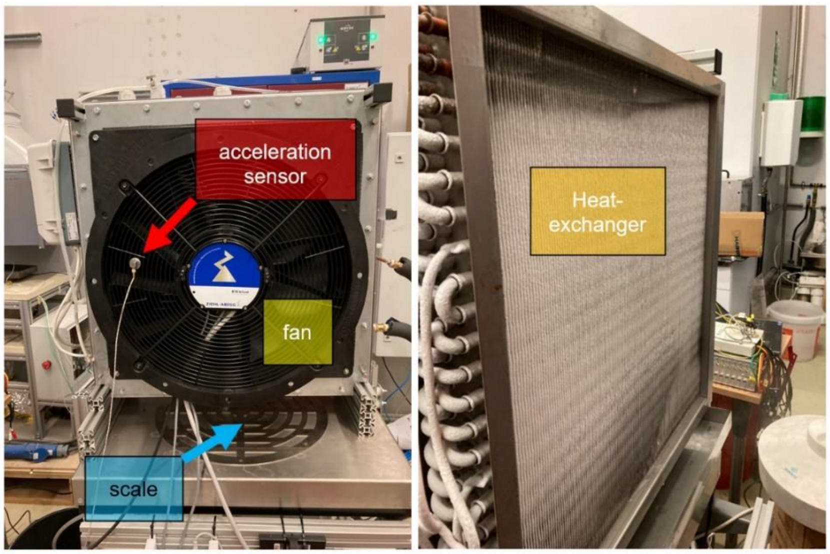

Figure 1: Modified SilentAirHP setup for soil operation: (left) fan – heat exchanger assembly on scale with mounted acceleration sensor; (right) opposite side of assembly showing the heat exchanger with ice coverage

Summary of project

Digitalisation concerns all parts of the energy system and extends to the component level. More and more heat pump components such as compressors or valves, etc. are equipped with sensors and offer advanced connectivity to provide and exchange information. An example of such a connected component is a fan of an air-source heat pump equipped with vibration sensors. The primary use of monitoring vibrations is fault detection for the fan itself. In addition, it can be used to draw conclusions on the operation state of the heat pump, such as the occurrence of icing on the evaporator. A soft sensor can be created, which provides information that cannot be measured directly, but can be calculated based on the conversion of data from various measurements using software-based models. These soft sensors can be used to optimize heat pump operation, e.g. to lower operation costs and to increase comfort.

For the creation of the soft sensor, the icing behaviour of the heat pump was studied during operation under several simulated climatic conditions in a climate chamber at AIT's laboratories. The experiments provided thermodynamic measurement data as well as continuously recorded vibration signals, and ice mass and ice layer thickness data acquired using a scale and image capturing techniques. First tests with the IoT-enabled fan as a part of the air source heat pump did not result in conclusive correlations of vibration and pressure loss data. Most likely, changes in the spectra of the vibration data because of ice accretion on the evaporator were superimposed by vibrations from the compressor. Therefore, the test setup was modified by removing the refrigerant circuit (compressor,

expansion valve, condenser) to operate the evaporator and the fan only (see Figure 1). The refrigerant was replaced by brine, which is passed through the heat exchanger by means of a pump. The brine temperature is directly controlled using the AIT laboratory chiller and is cooled to temperatures well below freezing. In this way, investigation of the icing of the heat exchanger is possible without using the heat pump compressor, which means that the inference from rotating equipment in the heat pump cycle can be completely avoided. An external 3-axis vibration measurement system was integrated in the new experimental setup, which works with a high sampling rate and a high bit depth. The sensor can be mounted at different positions on the fan. The data streams are recorded and analysed simultaneously with the scale signal, the fan internal data and the image data from the cameras. High resolution vibration data was then successfully correlated with the icing status of the heat exchanger. Vibration was measured on the heat exchanger and fan case for various artificial ice coverage situations as shown in Figure 2.

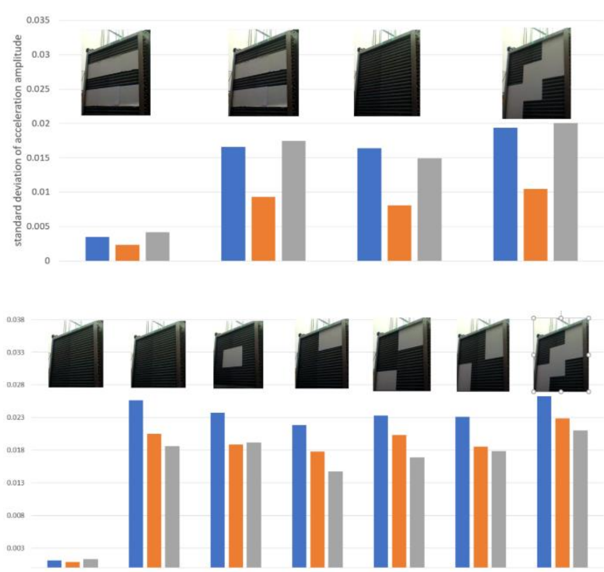

Figure 2: Acceleration measurements visualized as vertical bar charts for artificial ice coverage as shown in the images. The first bar in both images show the level of vibration with the fan not operational.

Vibrations increase depending on the blockage and its symmetry-breaking of the heat exchanger area.

Learnings

Soft sensor development relies on the identification and development of correlation models that map cheap sensor data to key process variables which are usually too expensive or too complex to monitor directly. The experimental work outlined above illustrates the high experimental efforts and the complexity in the experiment design and analysis necessary to generate meaningful quantitative reference data, and the high requirements in terms of an extensive good data base covering all relevant operating ranges and scenarios. However, a cost-benefit analysis is likely to be very positive considering the potential value of detailed online information on the operation state of the heat pump components. This information facilitates operation optimization, and it may provide additional insights for maintenance measures and product design improvements.

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FACTS ABOUT THE PROJECT

IoT Category: performance optimization
Goal: replace complex or expensive measurements with data driven models
Beneficiary: heat pump and component manufacturer
Data required: sensor data, data on the property to be modelled with the softsensor
Analysis method: experiment, data analysis
Modelling requirements: Correlation analysis
Quality-of-Service: real time
Project participants: AIT Austrian Institute of Technology GmbH
Time schedule: 2020-2022
Technology availability: 4