Exergyn Ltd - Development and Trialling of the *ExergynDrive*™ for Low-Grade Waste Heat Recovery

Summary

Exergyn has world leading expertise in industrial scale application of solid-state SMA (Shape Memory Alloy) technology for use in clean energy applications.

Exergyn has developed a solid-state core technology which can be used in a range of power generation or heat pump products. The technology is ideal for recovery of low-grade heat for the generation of clean, controllable electricity. With low capital cost and very low operating cost, the *Exergyn Drive*™ is designed to be the first commercially attractive solution for transforming low-grade heat to power.

At the start of the project, Exergyn built a prototype waste heat recovery unit which generated clean electricity from low-grade waste heat at 90°C.

As a consequence of the IEEA programme, we identified areas for optimisation and have both doubled the efficiency and halved the total cost of ownership. We have also developed the core for heat pump applications. Multiple products will accelerate cost reduction of the core.

The Industrial Energy Efficiency Accelerator (IEEA)

The IEEA programme supports the development of innovative technologies that will help industry reduce energy consumption and cut carbon emissions. It focuses on innovations with large potential cross-sector energy and carbon reduction impact - either new technologies or established technologies applied to new sectors. Over £15 million in public and private funding has been committed to develop solutions through partnerships between technology developers and industrial companies willing to test technologies on-site. The programme is funded by the UK government (BEIS) and managed by the Carbon Trust, with support from Jacobs.

Introduction

Exergyn has world leading expertise in industrial scale application of solid-state SMA (Shape Memory Alloy) technology, particularly for use in clean energy applications.

Exergyn has developed a solid-state core technology which can be used in a range of power generation or heat pump cycles. The technology is ideal for recovery of low-grade heat for the generation of clean controllable electricity.

At the start of the project Exergyn built a prototype WHR unit which generated electricity from low-grade waste heat at 90°C.

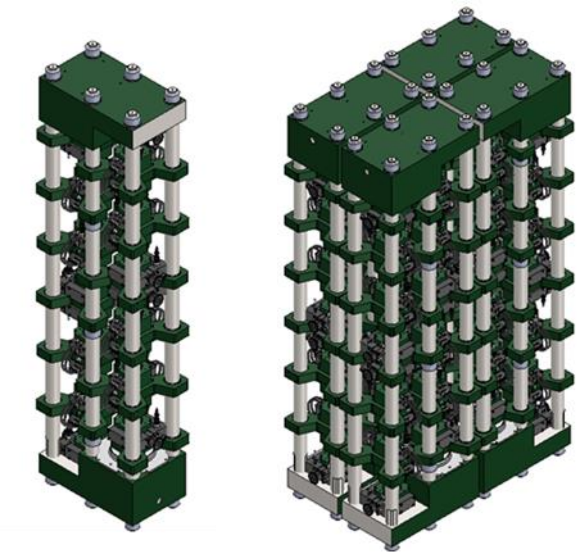
As a consequence of the IEEA programme we identified areas for optimisation and have both doubled the efficiency and halved the total cost of ownership. We have also developed the core for heat pump applications. A single core design will be used in multiple products and this will significantly accelerate cost reduction which will enhance commercialisation

About the innovation

Exergyn has developed a solid-state core technology which can be used in a range of power generation or heat pump cycles. Our expertise is in the industrial scale application of shape memory alloys or SMAs. The technology was originally designed for recovery of low-grade heat for the generation of clean, controllable electricity. During the project we also identified opportunities for energy storage and for the use of the core in thermal applications such as heat pumps, air conditioning and refrigeration. All products can use the same core design, which helps to reduce costs. The only difference is the choice of SMA blend which regulates factors such as the temperature range for operation.

Each core is made up of multiple identical sub-cores making the technology highly scalable. The *Exergyn Drive*™ can easily be scaled from $10kW_e$ to over $1MW_e$.

Single Exergyn sub-core



Scalable sub-core assembly

The demonstration

The original plan was to test the prototype on an industrial manufacturing site with a low-grade waste heat resource which is available 24/7. The initial testing phase of the project delivered a major technical advancement which halved the total cost of ownership and doubled the efficiency. All major components have been tested and validated, and an upgraded core design has been tested in a dedicated laboratory test area. Data from tests have been used to increase accuracy of computer models.

Industrial low-grade waste heat

The system is designed to convert low-grade waste heat (LGWH) in the form of hot water, into clean electricity on demand. Ideally waste heat streams should be between 90°C and 125°C. Waste heat in this range is suitable for heating applications if a synchronous local heat load is available, but the heat goes to waste where there is no suitable heat load. Although there are technologies which can convert heat at this temperature into power, they tend to work better with higher temperature waste heat streams and they are high cost, so they do not give an attractive financial return without financial incentives.

Exergyn Drive™ prototype

Exergyn Core prototype

A prototype was built with all key components and 4 full scale cores. The final design would use 6 cores. This prototype enabled us to test the concept at reduced cost.

Initial Exergyn Drive™ Prototype

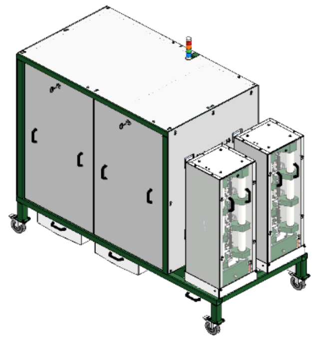
The initial prototype was tested at 6kWe. This demonstrated all key components of the design, including:

- SMA core
- Transmission
- Power generation
- Power conditioning
- Controls

Test indicated all components worked effectively in a full system. This work highlighted that the key area for optimisation was the SMA core where there was an opportunity to increase power density and efficiency and to increase core life which would reduce maintenance requirements.

Optimised sub-core unit

During the testing programme, the opportunity arose to optimise the SMA core which would double the system efficiency and halve the total cost of ownership. Also, the company strategy was updated to focus on the development of the core and work in partnership with companies who could build, sell and support the final product. A pair of redesigned cores was built and tested. Two cores are required in the new design to stabilise fluid flows and to optimise energy efficiency. Data from the tests were used to enhance computer models to increase accuracy.



Core testing rig

The core performance enhancements opened new markets outside of behind-the-meter waste heat.

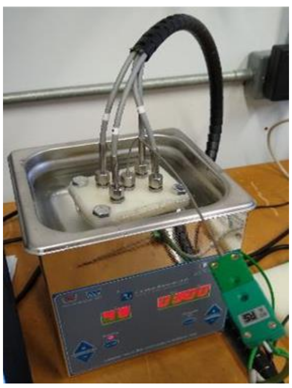
Monitoring

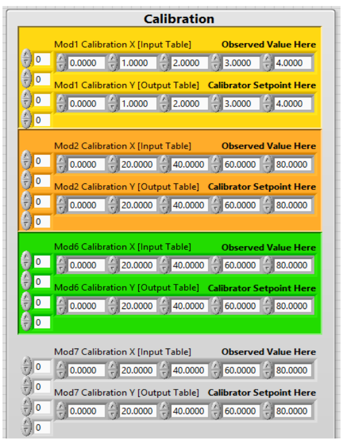
The Exergyn sub-core was monitored in test conditions to establish performance and durability. Data from testing were used in computer models to predict the performance of the core for heat recovery / power generation. As part of the monitoring and validation, all sensors were calibrated prior to testing to ensure all data were of the highest quality.

Measurement summary

Type of measurement	Number of monitoring points
Temperature	35
Pressure	21
Flow rate	2
Displacement / movement	10
Other (timers, safety etc.)	11
Total	**79**

During the project investment was made in calibration facilities. All measurements were made using calibrated sensor to improve the quality of the data. Although time consuming, the calibration process identified several sensors which were operating outside of expected specification and could have potentially impacted on model accuracy or time spent troubleshooting the test rig.





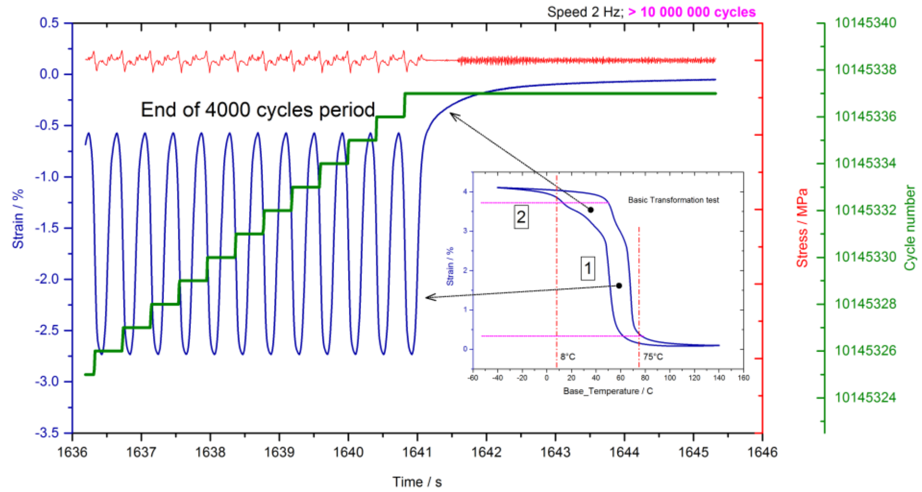
Calibration & testing equipment

Results

The initial Exergyn Drive™ prototype was tested at full power of $6kW_e$ and at the target efficiency. These tests proved that the system worked as a unit and most components operated in line with computer model predictions. Testing also highlighted some areas to enhance the SMA core which could increase life and efficiency.

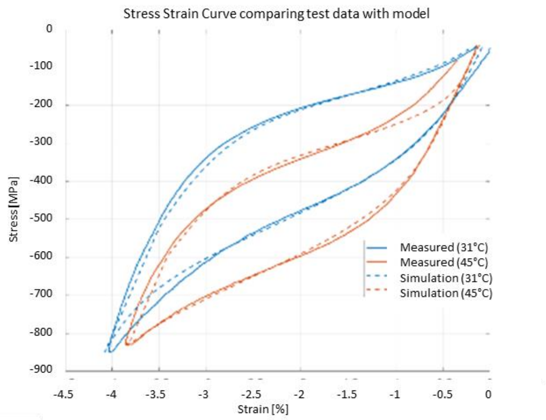
As most components were proven in the initial testing, the SMA core was optimised and tested separately. A design which was shown to be effective and robust was then tested. Test results showed that a 2-core unit would deliver the full $10kW_e$ output with an efficiency of almost 6%. Addition of further cores would add $5kW_e$ if larger output is required.

One of the key challenges often cited is the fatigue life of SMA. A minimum of 5million cycles is expected to be required in a commercial product. Exergyn developed an accelerated test rig and tested SMA samples under representative conditions for over 10million cycles. There was little degradation in performance over the 10million cycles and at the end of the test, analysis indicated that there was no degradation in the material.



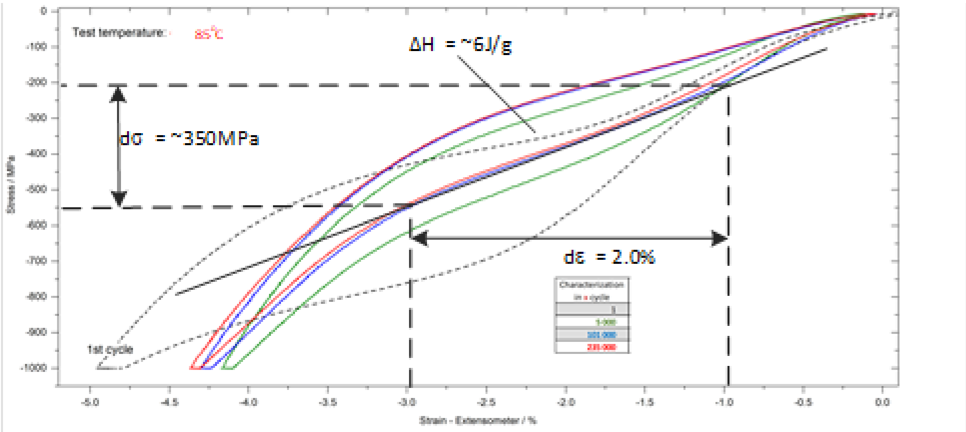
Accelerated endurance test performance

All test data were used to validate Exergyn's unique suite of computer models. The causes of any deviations between measured and simulated performance were analysed and, where necessary, the model was revised. Below are comparisons of modelled and measured performance at 2 temperature points, indicating that a higher level of accuracy has now been achieved.



Comparison of measured performance and simulated output

The test data enabled us to identify an operational window and the modelling indicated that the efficiency would be 6% at this point. Below is an example of stress / strain curves after 1, 5,000, 101,000 and 235,000 cycles indicating that performance is stable after 100,000 cycles. Testing also confirmed that the engine would deliver stable output over its lifetime, with little degradation.



Performance curves showing operational window

In summary, testing has demonstrated that the new optimised core design can deliver 10kWe with 6% efficiency and with core life expected to be at least 20years. This is a significant improvement over the initial expectations at the start of the project.

Future impact

The primary objective is to deliver a technology which is, first and foremost, financially attractive and where significant environmental benefits do not come with a green premium. Testing identified opportunities to reduce operating costs and these enhance financial returns. Many sites can achieve payback in around 3years time, with some sites achieving this in 1 year, purely on the value of the power.

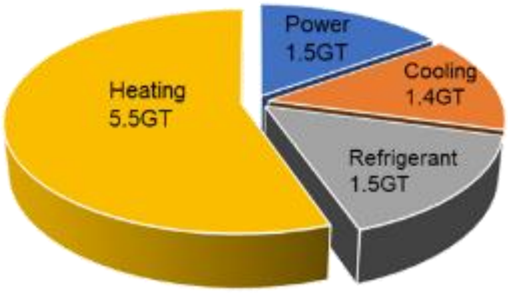
		Annual operational hours			
		4,000	5,500	7,500	8,500
Value of Power per kWh	£0.10	6.0	4.4	**3.3**	**2.9**
	£0.14	4.3	**3.2**	**2.3**	**2.1**
	£0.18	**3.3**	**2.5**	**1.8**	**1.6**
	£0.29	**2.1**	**1.5**	**1.1**	**1.0**

Payback Period (Years) Sensitivity Tables

The Exergyn Core technology has a wide range of potential applications in both power generation, energy storage and thermal products. Key target applications which are expected to be suitable are listed below. There are additional applications which could be developed subject to further technology development.

- Power generation / waste heat recovery
    - Industrial waste heat / renewable heat / energy storage
- Heat pump
    - Space heating / process heating / air conditioning / refrigeration

The potential environmental impact is immense if the core technology is used in all applications.



Potential emissions reductions

The potential for carbon reduction is 10GT CO_2e reduction if used in all markets. 150MT CO_2e could be achieved by 2032 with 1.5% market penetration.

Innovation lessons

The key learning is the revised design of the technology, which has enabled us to enhance the component's life and to double the efficiency, which is ahead of our initial target.

The original target was to replace the SMA 2 or 3 times over a period of 20years. We now expect that the life of the SMA will be the same as the life of the product and the SMA core is no longer a maintenance item. This dramatically reduces the maintenance requirements, which reduces the cost of electricity (LCOE). The target LCOE has fallen from over 4p/kWh at the start of the project to less than 2p/kWh. It also reduces the quantity of raw materials consumed.

As waste heat resources tend to be fixed, doubling efficiency enables double the power output. This enhances the returns for any potential users.

The key innovation lesson was the addition of new products using the same core. The standard heat-to-power unit can be adapted to be used in energy storage applications where power can be utilized during price peaks, or it can be used in solar installations to generate power after dark. The addition of thermal products such as heat pumps, air conditioning and refrigeration will enable us to make an even greater impact and accelerate the cost reduction.

Contact information

Who to contact for more information

+44 (0) 7454 717 588

Industrial Energy Efficiency Accelerator delivered and supported by:

Department for Business, Energy & Industrial Strategy

CARBON TRUST

Jacobs

Disclaimer

The information in this document does not purport to be comprehensive and has been completed using the information provided by Exergyn and has not been independently verified. No responsibility or liability is or will be accepted by Exergyn or any of their respective officers, employees or agents in relation to any inaccuracy or incompleteness of this document and any liability is hereby expressly disclaimed. In particular, but without prejudice to the generality of the foregoing, no representation, warranty or assurance is given as to the achievement or reasonableness of any future projections, management projections, management estimates or prospects contained in this document.

BEIS, the Carbon Trust, and Jacobs give no warranty and make no representation as to the accuracy of this report, and accept no liability for any errors or omissions.

February-2022