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IAAPS
ADVANCING PROPULSION

Moving the world towards **zero emissions**

Our state-of-the-art £70m research & innovation centre at the Bristol & Bath Science Park delivers a wide range of expertise to drive multi-disciplinary collaboration across all propulsion types and transport sectors, accelerating the pace of innovation in future mobility.

Our areas of expertise include:

- Advanced combustion, future fuels and energy conversion
- Propulsion systems efficiency and thermal management
- Fuel cells and H2 technologies
- E-machines, drives and power electronics
- Energy storages, batteries and energy management
- Integrated control, calibration and optimisation
- Digital systems, simulation and modelling
- Test systems, HiL, Pil and ViL

We're keen to connect with potential partners, learn about their challenges and explore how we can collaborate to find solutions. For more information, email iaaps@iaaps.co.uk

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Zero disturbance

IAAPS are collaborating with Zeroshift and motorcycle brand **BSA** on an **Innovate UK** funded Project, **Paradigm Shift**, to develop a two-speed electric motorcycle

Electric powertrains are an increasingly popular choice for passenger vehicles, but battery power has yet to ignite the passions of motorcycle riders, where a connection to the engine is much more important. UK-based powertrain pioneers IAAPS, a leading advanced propulsion R&I centre, aims to change this. Its team of engineers and experts is collaborating with gearbox innovators Zeroshift and historic motorcycle brand BSA on an Innovate UK funded Project, Paradigm Shift, to develop a two-speed electric motorcycle that's all the fun of an ICE bike without the emissions.

Before we tackle the torque, what is IAAPS? "IAAPS is a true collaboration, bringing together partners from research, academia and industry to co-create solutions and develop insight across a full range of technologies according to their needs," said Managing Director Professor Rob Oliver. A wholly owned subsidiary of the University of Bath, IAAPS is building on nearly 60 years at the forefront of propulsion systems research and innovation, which enables a broader experimental approach than conventional test facilities.

Today, it's a world-leading centre of excellence for research and innovation in clean, efficient and affordable zero-carbon propulsion technologies. Based at the Bristol & Bath Science Park, IAAPS works on a range of clean propulsion systems for various transport uses, including automotive, aerospace and maritime. As well as electric vehicles, IAAPS is also at the forefront of hydrogen technologies, including for hard to electrify sectors such as heavy-duty and off-highway applications.

Oliver is currently the managing director at IAAPS, but he's also a seasoned engineer with over 30 years' of industry experience and project lead on Paradigm Shift. The Innovate UK-funded project is developing a novel two-speed electric motorcycle with seamless gear shifting. The final demonstrator machine will deliver market-leading performance in the A2 (35kW) category – at an affordable price. "The project is exciting because it's innovative, but also because we're taking a new technology to demonstration level," said Oliver. Specifically, the motorbike is built around Zeroshift's advanced gearbox that delivers smooth transitions without any interruption to torque. It's a rapid process, said Oliver. "The partners – including IAAPS – are developing a new technology, doing the design, development, system modelling and evaluation, and then taking it through to a running prototype with a motorcycle OEM. All within two years."

L: IAAPS Lead Engineer Rob Cherry

R: Professor Rob Oliver

One of the joys of motorcycling is the dull thud as you kick the bike into gear, pull the throttle and set off. Electric bikes deliver almost instant torque, with no gear changes. It's something that can reduce rider feel, control and pleasure. "The two-speed transmission provides low-end performance that you might see with a bigger electric motor, but also delivers high speeds," said IAAPS Lead Engineer Rob Cherry. "It's a cost-effective way to deliver a clear performance benefit."

As anyone who has ridden a motorbike knows, changing gears while cornering is a bad idea as the fraction of a second it takes to shift up or down disrupts the torque to the rear wheel, which can cause an imbalance and ultimately lead to crashes. The Zeroshift gearbox delivers what it calls a "seamless shift". Essentially, the system removes the deceleration that typically occurs while changing gear, ensuring a continual delivery of torque to the rear wheel – even while driving round corners. The benefits are increased stability and safety – something every rider would appreciate.

The transition from ICE to electric isn't a given in motorcycling, with concerns about control, feel and speed. "One of the key requirements of the project is that we don't degrade the performance of the existing benchmark ICE motorcycle," said Oliver. In fact, the solution delivers an improvement, said Cherry. "With an electric motor, you've got constant power throughout the majority of the operating range. Where an internal combustion engine has a sweet spot, with an electric motor the sweet spot happens to be most of the range, so you can actually get more performance from a motor." Performance is one benefit, but the new approach can reduce price too, said Oliver. "The idea is that with a two-speed gearbox, you can downsize physically the motor and inverter. They will be less expensive – that price includes the price of the transmission."

IAAPS is applying its expertise in simulation, control techniques and advanced testing methodologies to accelerate the development of the prototype transmission. "We have been involved at two levels of simulation," said Cherry. "The first level involved system-level simulation. We evaluated the motorcycle's performance, comparing the two-speed electric bike to the existing internal combustion variant that's available on the market today and a single-speed electric bike." Using the simulation programme Simulink in combination with IAAPS developed physics-based models, IAAPS was able to model and simulate the shifting mechanisms, enabling efficient prediction and comparison of performance and providing a platform to develop the control strategies. This simulation work is vital in refining the system's behaviour prior to physical testing. This helped to establish the potential for the technology and determine some of the performance parameters.

Cherry and the team also conducted component level simulations, creating a plant model that incorporated the novel shift components designed by Zeroshift.

"The main purpose of this phase was to streamline both the mechanical design and the refinement of the controller in parallel." This approach allowed IAAPS to bypass the need for an early physical prototype to guide control optimisation. Consequently, insights could be fed back early into the mechanical design process, speeding up progress.

The process pushed all partners, with IAAPS testing and simulation taking place at the same time as Zeroshift was refining its technology. "Some of our modelling influenced the design in terms of the forces that are applied to the shift mechanism and some of the angles of engagement of the shift mechanism," said Cherry. All partners had to be adaptable and flexible, working in a truly iterative – or agile – way. "It very much was a parallel process with us slightly behind Zeroshift. They would produce the mechanical design and update it. We would then change the model and feed back the results to them, identifying ways they could optimise the design. They would put this into practice and feed back to us so we could run the model again."

The team has made rapid progress, with the project nearing completion in just 18 months, Cherry said. "We are currently in the test phase of the project and that's largely to undertake the development and refinement of the control system. We're in the final refinement and validation stage." They have developed a physical prototype which has been integrated within a simulated virtual environment on a test rig. "The transmission, the control system, the electric machine and the power electronics are all physically on the rig and we are running it in a virtual environment," explained Oliver. "The transmission effectively 'believes' that it's on a bike being driven on the road. It's actually calculating the road load, the inertia of the bike, the wind resistance and all of the other elements that the physical bike would experience on the track. We simulate that on the rig by running a model of the actual motorcycle."

Modelling and simulation can only take you so far. The future will see a demonstrator built and tested by historic motorbike brand BSA. Oliver is confident the two-speed transmission will work as well in the real world as it does in the virtual one. "We've done 95% of the testing required on the rig, and the track is a final validation rather than a complete development exercise," he said. Cherry agrees, pointing out how the process followed has massively shortened development time and costs.

"We anticipate that the hardware will be right first time. It's working on the rig perfectly," said Cherry. Of course, there will be a need for collaboration and tweaks as the bike is adapted to the specific conditions of the road and the rider, but the majority of the work has been done.

Oliver acknowledged that there is often a long process to transfer concept vehicles (and components) to the roads, but IAAPS is there for the long term. "We want to continue working with Zeroshift, who have ambitions to move this technology to a broader range of vehicles, including three-wheeled vehicles and even small four-wheeled vehicles," said Oliver. "Obviously, BSA could take this technology forward in their motorcycles, which could include production in its facilities in India or the UK."

Paradigm Shift is a perfect project that showcases IAAPS' capabilities. The organisation can support projects ranging from building a 35kW motorcycle to a one-megawatt, ground-based, electrified propulsion demonstrator for aircraft. The organisation can provide everything from short-term test programmes to long-term research collaborations. "The IAAPS team specialises in industry-focused R&I," said Oliver. "We work inclusively and flexibly with all partners to co-create solutions and develop insight across a full range of technologies. It's all done according to their needs."

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