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Proven Mechanical Strengths and New Electric Prospects: Load-Dependent Automatic Shifting Transmissions as Enablers of Cost-Effective Electromobility

How a team at TU Graz's Institute of Thermodynamics and Sustainable Propulsion Systems is turning to the principles of classical mechanical engineering to boost affordable, efficient electromobility – proving that sometimes, the most disruptive ideas are rooted in simplicity.

"Simplicity is the ultimate sophistication." For over two decades, this principle has guided our research group. We have dedicated ourselves to designing powertrains for internal combustion engine-powered two-wheelers, staying at the cutting edge through global collaborations with industry partners. Our focus has always been on optimizing engines in terms of emissions and efficiency. However, in two-wheelers, the engine and transmission are intrinsically linked. Improving real-world efficiency requires a holistic approach to the entire system.

In many regions, two-wheelers are the primary means of transportation, facing far greater cost pressures than passenger cars. These constraints have pushed us to develop simple, affordable, and reliable solutions. While the automotive industry often relies on complex electronics, we have thrived in classical mechanical engineering by finding ingenious mechanical solutions to problems that are typically addressed electronically in cars.

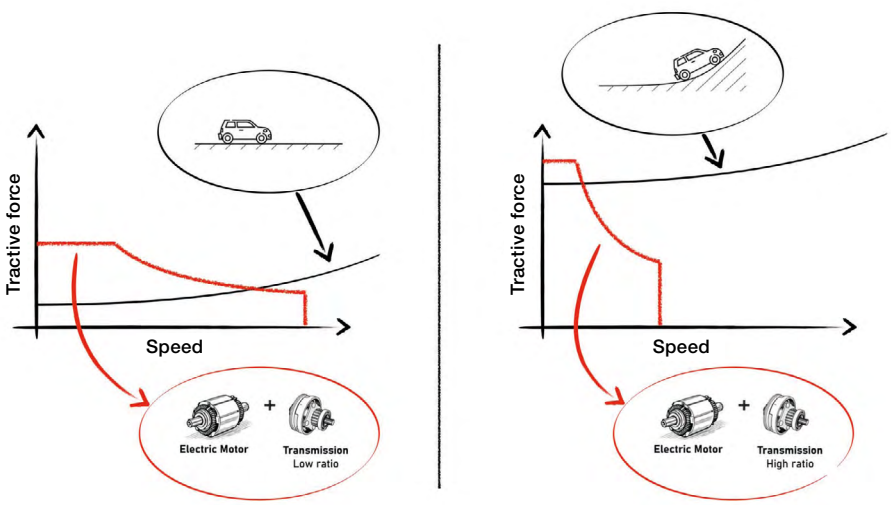
But the landscape shifted. As the automotive industry transitioned to electromobility, our group faced a pivotal question: Where could our expertise make a difference in this new era?

CHALLENGE BEGETS OPPORTUNITY

Our answer lay in the broad experience we had gained over the years. We understood the critical role of transmissions in efficiency and had developed a strong ability to design straightforward, affordable solutions. It soon became clear that scaling battery-electric powertrains for vehicles presents significant challenges. High battery costs, combined with motors that are frequently oversized and therefore expensive, make the technology inaccessible for many use cases.

Figure 1: Tractive force chart. Trade-off between top speed on level road and tractive force requirement to drive on inclinations – as an example the low transmission ratio for best possible top speed is shown on the left side and the high transmission ratio needed for good gradeability is shown on the right side.

Source: Institute of Thermodynamics and Sustainable Propulsion Systems



The issue at hand: A fixed gear ratio must cover both maximum traction (such as for hill climbing or acceleration) and top speed (see Figure 1). This results in operating points where motor efficiency drops, increasing energy demand and battery size. While automated two-speed transmissions exist, they are often complex, electrically actuated and expensive. Such solutions may work for high-end passenger cars, but they are impractical for low-cost electric mobility.

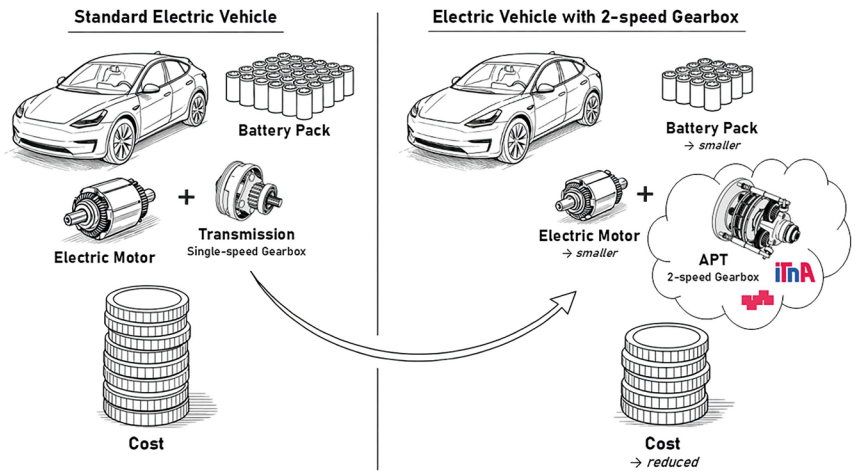
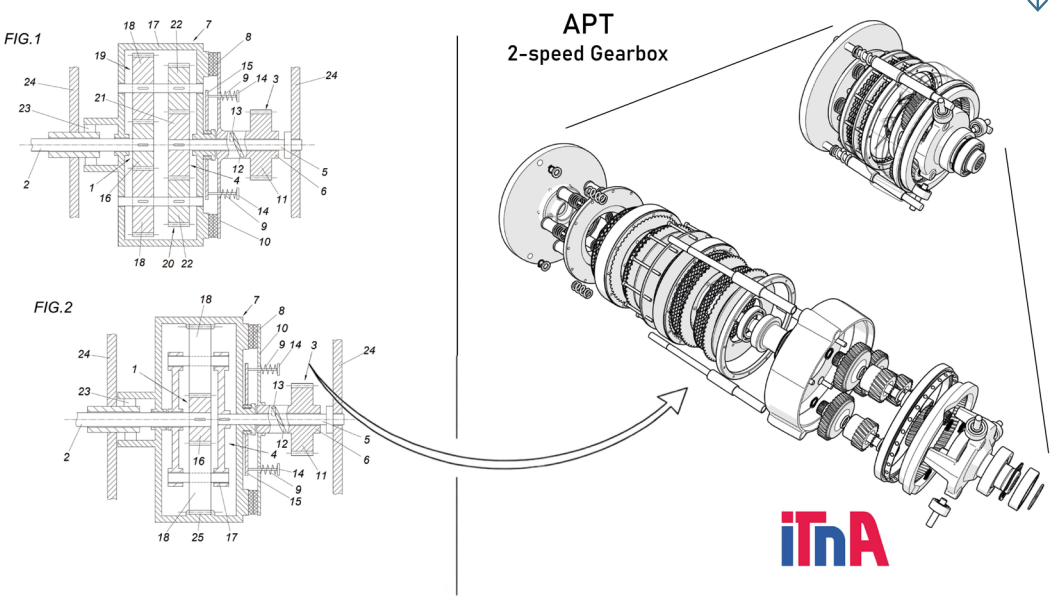


Figure 2: How introducing the innovative APT (Automatic Powershift Transmission) can help to bring down the cost of an electric vehicle by reducing motor and battery size.
Source: Institute of Thermodynamics and Sustainable Propulsion Systems

INNOVATION THROUGH SIMPLICITY

This challenge sparked our creativity. As a team, we envisioned a fully mechanical, automatic transmission that shifts purely based on load, with no electronics or external actuators required. Electric vehicles eliminate the need for a launch clutch and can smoothly pull away in a higher gear under normal conditions. Thus, a transmission should only shift to a lower gear (higher ratio) when high traction is demanded – for example, during strong acceleration, steep inclines or when the vehicle is heavily loaded. The innovation of the solution which has been patented by TU Graz lies in a purely mechanical torque-sensing device at the output. It continuously reacts to the delivered torque and converts it into a proportional force. This force works against pre-tensioned springs to engage or disengage clutches, automatically selecting the ideal gear ratio (see Figure 3).

From idea to reality: the very first patent sketches vs. the latest generation APT design.
Source: Institute of Thermodynamics and Sustainable Propulsion Systems



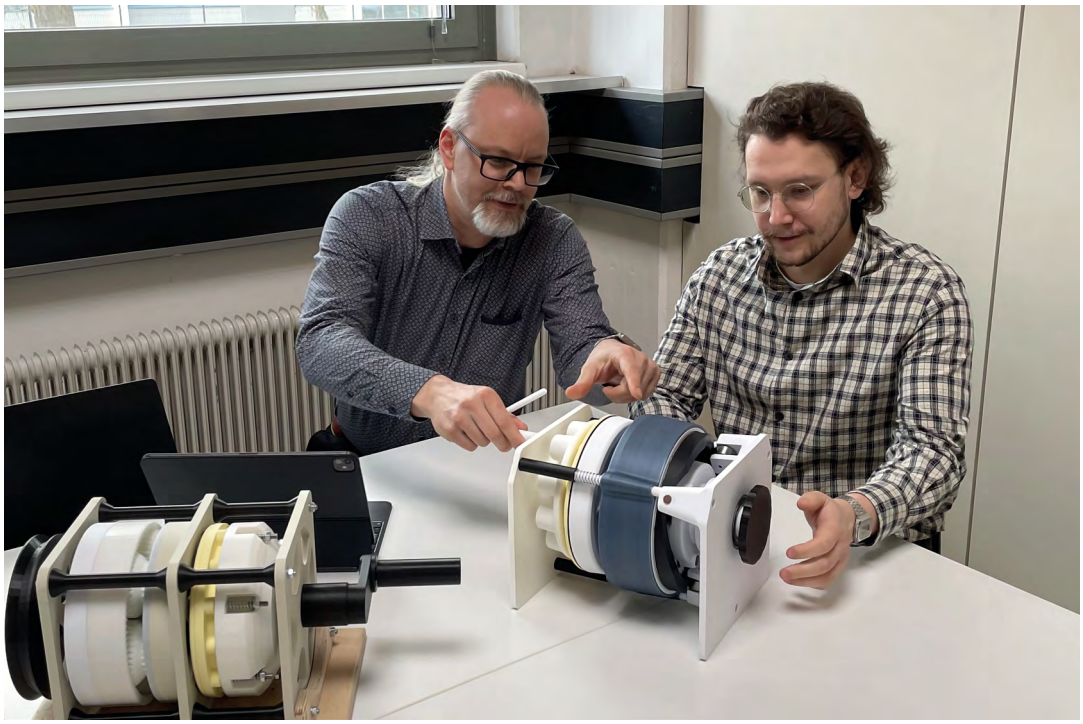


Figure 4: Jürgen Tromayer and Christoph Napetschnig enjoy the most rewarding moments of engineering – the validation of designs first-hand after they have been transformed into tangible 3D-printed prototypes. Source: Institute of Thermodynamics and Sustainable Propulsion Systems

The concept called Automatic Powershift Transmission (APT) is both elegant and straightforward, and this simplicity is its greatest strength. However, bringing it to life demanded unwavering commitment: repeated cycles of ideation, extensive calculations, numerous iterations in 3D design, and hands-on prototype fabrication.

Supported by a series of bachelor's and master's thesis projects, plus our dedicated in-house research programme, we thoroughly validated the concept. We carried out extensive component-level testing on test bench and evaluated complete transmission prototypes using hardware-in-the-loop (HIL) simulation to replicate real-world vehicle operation conditions and assess performance and efficiency gains.

FROM LAB TO ROAD: ENGAGING THE GEARS OF PROGRESS

Negotiations with industry partners are currently underway to integrate our transmission into a vehicle demonstrator, marking a critical step toward real-world application. In parallel, we have built (and continue to build) demonstration units to showcase the principle at fairs and conferences, engaging the public and stakeholders.

The ultimate goal is to put this technology on the road. Here, science, innovation, engineering and serial production must mesh like the gears of a transmission: each component essential, each movement purposeful. By aligning these elements, we aim to demonstrate how sustainable, cost-effective electric mobility can be achieved and delivered to the public. Because progress isn't just about moving forward – it's about moving forward together.

Source: ITnA - TU Graz

Jürgen Tromayer is a senior scientist in the Design Department at the Institute of Thermodynamics and Sustainable Propulsion Systems. His work centres on improving the efficiency of internal combustion engines (ICEs) and optimizing drivetrain systems for both conventional ICEs and electric vehicles.