Hybrid building machinery

A diesel-electric hybrid drive and optimised auxiliary units save more than 40 % fuel

Hybrid drives make construction machinery not only more economical and quieter – the power from the two engines also provides power reserves for special loads. The advantages of combining a combustion engine with an electric drive have been demonstrated by the DEUTZ engine manufacturing company from Cologne using an excavator. In order to realise the full savings potential, the engineers have also closely examined the auxiliary units as part of the Green Industrial Diesel (GRID) project.

The excavator slowly lifts its boom and its upper superstructure, the house, rotates 180 degrees to the rear. The gripper lowers the 1,000-kilogram test weight and then raises it again immediately before rotating back to the starting position. “We are conducting here one of three precisely defined test cycles,” explains Marco Brun, technical project leader for the GRID project at DEUTZ AG. “This enables us to compare the hybrid drive under practical conditions with a conventional system.”

Unusual operating noises give the game away: an electric motor is rotating the house. This swing drive is also used to brake the rotational movement, whereby it works as a motor generator and converts part of the kinetic energy back into electrical energy. A supercapacitor pack acting as an electrical energy storage unit enables the energy-saving, two-way feeding and generation of electricity. The excavator’s diesel engine only has to compensate for the energy not recovered and the efficiency losses from the electrical components.

The supercapacitor pack is recharged by the motor generator, which is flange-mounted to the excavator’s 160-kW diesel engine. The generator also plays the decisive role for the excavator’s hybrid drive. When considerable force is needed, the motor generator reverses its function and supports the diesel drive as an electric motor, whereby it uses the energy previously stored in the supercap pack. This power...
boost decisively improves the system dynamics with peak loads. For instance, the torque is provided particularly quickly by the electric motor when there are abrupt load increases in the operating mode. A start-stop function automatically switches off the combustion engine when the excavator is idle. It is then restarted automatically by using the motor generator. The engineers are testing the new hybrid drive on a TEREX FUCHS MHL350. The 35-tonne machine can reach up to 16 metres with its boom. The recuperative system shows its advantages particularly well when carrying out movements typical of material handlers. If, for example, scrap metal is being loaded, the house rotates back and forth. With conventional models, each braking movement converts kinetic energy into useless heat. The rotational movement is therefore responsible for more than half of the diesel consumption. The savings potential is particularly great here.

The development engineers view the electric swing drive, however, as just one example of the different loads possible using their hybrid system. “It should be possible to transfer the technology to other construction machinery, forklift trucks, aircraft tractors and agricultural vehicles,” says Brun.

The diesel-electric hybrid
The developers are using a DEUTZ diesel engine as the combustion engine, whose auxiliary units and components have been further optimised to achieve economical operation. An electrical generator from Robert Bosch GmbH is connected to the joint drive shaft via a flexible coupling. The hydraulic pump that moves the material handler boom is located on its stator housing. The drive is designed to be compact so that it can be integrated into the excavator’s standard upper superstructure.

Supercap: High performance, small capacity
The excavator’s types of usage require an energy storage unit that reaches a high a number of cycles and features very high charge and discharge capacities. In addition, it must be very robust in practical use and be able to withstand the vibrations that occur in such construction equipment. However, a large capacity as is required for electric vehicles is not necessary. The power from the energy storage unit only needs to be available for a maximum of 5 to 20 seconds in order to cover short-term peak loads. Supercapacitors are better suited to meeting all these requirements than the standard lithium-ion batteries used in conventional hybrid vehicles. The engineers therefore developed a DC/DC converter with control electronics and measurement technology around a supercapacitor pack with a capacity of about 300 Wh.

Experiences with the test excavator
The complex interaction between the diesel engine, generator motor, energy storage unit and the superstructure drive functions very reliably, as was hoped. The electrical components that were initially deemed to be critical such as the supercap pack and the DC/DC converter have also proved to be robust. The fuel savings exceed the expectations of the developers. In the practically based test operation, the excavator’s consumption was reduced by an average of 7.6 litres of diesel per operating hour. The decisive factor here is primarily the energy recovered from the movement of the house. Electrify-
ing the swing drive has enabled 20 % of the fuel to be saved in the observed duty cycle. This represents a fuel saving of about 4.3 l/h relative to the reference machine. If the dynamic speed reduction is also used, this enables the consumption values to be even improved by more than 40 % or 9.7 l/h.

For about one third of the time during a excavator’s typical deployment, the diesel engine is only running at idling speed. During this time, the diesel engine for the hybrid model can be switched off using the automatic start-stop function. The developers have calculated fuel savings of 48 % under these conditions.

Practical applicability

Construction machinery is subject to much greater loads than hybrid-driven motor vehicles. Environmental influences such as severe shocks, dirt and the cleaning of the machinery with high pressure cleaners also need to be taken into consideration when designing the system. Minor repairs and maintenance work are also often carried out by the operator, who is not specially trained for this purpose. Since the operator is usually not the owner, it cannot always be assumed that the equipment is carefully looked after. The engineers are convinced, however, that they have achieved their goals of achieving good operability and easy maintenance.

Optimisation of the auxiliary units

In another sub-project, the developers investigated the savings with excavators and construction machinery that result from optimising the auxiliary units. These assemblies differ considerably from those in cars or lorries. For example, fans have to be much more powerfully dimensioned because there is no air flow contributing to the cooling. However, because they are designed for maximum loads, the fans are oversized for most of the machines’ operation. Similar “worst-case” configurations can also be found with water pumps, oil pumps, thermostats and alternators. A control system in accordance with needs, which is standard with vehicles, would therefore provide significant efficiency benefits here.

With a moderate amount of engineering work, the technicians succeeded in equipping fully developed standard units with a control system adapted to needs. The engineers checked the reduction in consumption in various test cycles that varied in terms of the dynamics and the average power. Compared with the consumption of standard engines, a savings potential of up to 9 % was identified depending on the cycle and type of measure. The measurements showed that the fan offers the greatest potential for savings, whereby two effects come together: firstly, the developers managed to reduce the drive power, and secondly they raised the temperature of the water. This also warms up the lubricating oil and the lower viscosity reduces friction losses in the engine.

The engineers want to use the findings of the investigations to improve the general development of diesel engines.
Optimising mobile machinery

Hybrid drives are not equally suitable for all construction machinery. The movement sequences are too different, as are the possibilities for recovering energy. For example, whereas the excavator house constantly swings back and forth, excavators or wheel loaders carry out a variety of complex movements on construction sites. Although several German, American and Asian manufacturers are working on the hybridisation of industrial utility vehicles, hybrid drives are still unusual among construction machinery. It is also difficult to transfer the diverse range of experience from the automotive sector, as the requirements and methods of operation are fundamentally different. For the manufacturers of drive technology, the challenge is therefore to develop standardised hybrid technology that can be adapted with scalable energy storage units to a variety of machines such as excavators, forklifts or wheel loaders. The Green Industrial Diesel project has shown that electric hybrid drives for construction machinery are technically feasible and offer substantial savings.

The cost-effectiveness and design of the hybrid system and the electrical components used, such as the motor generator, inverter and supercap pack, still require further optimisation. Further research work should help to reduce the system costs. Hybrid machinery will be able to achieve market success if the payback periods are as short as possible.

The results of the second part of the project are already flowing into the development of the next generation of diesel engines. In the concepts for a future-proof engine, for example, the oil and water circuits have been optimised in order to be as energy efficient as possible in combination with demand-controlled auxiliary units. With the demand-controlled auxiliary units, the developers have managed to precisely determine which fuel savings can be achieved with which load profiles in the construction and agricultural machinery fields. In addition, they have gained experience regarding the regulation of the components and their suitability for use in industrial environments. Further developments are also required here in order to always find the best combination of auxiliary units for the specific application.

Project participants

- **Project management:** DEUTZ AG, Köln, Marco Brun
- **Validation of the supercap cells:** RWTH Aachen University, Institute for Power Electronics and Electrical Drives (ISEA)
- **Investigation of interference emissions:** EMC Test NRW GmbH, Dortmund
- **Manufacturer of the supercap pack:** WIMA Spezialvertrieb elektronischer Bauelemente GmbH & Co. KG, Mannheim
- **Support for the risk analysis:** TÜV Rheinland AG, Cologne
- **Installation and testing of the hybrid drive in the excavator:** Terex Deutschland GmbH (Fuchs), Bad Schönborn
- **Manufacturer of the electric motor and the inverter for the hybrid drive:** Robert Bosch GmbH, Stuttgart (Feuerbach)

Links and literature (in German)

- Deutz AG, Cologne (Hrsg.): Green Industrial Diesel (GRID). Schlussbericht. Förderkennzeichen 03ET068A. 2015, 84 S.

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