

A distributed architecture - rethinking traditional hydraulics to accelerate excavator electrification

With the support of the national transport agency Transport Scotland and public body Scottish Enterprise, Orion Research carried out a study to address barriers in the adoption of electrified construction machinery. The study focussed on a 5 ton excavator and confirmed that the system efficiency is only around 20%. 80% of energy delivered by the battery is wasted, predominantly in the hydraulic system. Extensive testing was carried out initially to build a simulation model of the excavator, and then to provide datasets that could be used with this model to evaluate improvements. A key insight is that a modular, decentralised architecture enables significant efficiency gains to be realised. A concept was developed that almost doubles system efficiency to 37%, allowing 8 hours of operation with 46% less battery capacity. The cost of this new system is estimated to be >10% less than the baseline.

Background

The team behind Orion Research have significant prior experience in the design and development of innovative mechanical, electrical and hydraulic systems; from award winning wind turbine transmissions to fruit picking robots and many things in between. Orion Research's current focus is on the improvement of system efficiency to accelerate the clean energy transition in the challenging areas of construction and agricultural machinery.

A small but growing minority of the 15,000 small excavators sold in the UK each year are electric. Most manufacturers quote 4 to 5hrs runtime, although actual operating hours are reported to be lower. For many operators used to the flexibility of simply refilling the diesel tank, this is a real barrier to the adoption of electrified machines. A larger battery would enable a full day (8 hours) of operation, however the associated cost increase would be more than 50% of the base machine cost. This significantly increases the Total Cost of Ownership (TCO). With this in mind, Orion Research proposed that improving the system efficiency would enable a reduced battery capacity, increased runtime and reduction in the TCO.

Testing and analysis

To understand the potential for improvement, a simulation model was developed and validated. This was based on data from a 5 ton excavator that had been instrumented and tested (Figure 1). The results confirmed low system efficiency of 20%, and highlighted that the highest energy loss in the system is caused by the single pressure supply (the load-sensing pump) supplying multiple functions at different pressures; pressure drop between the pump and the functions is required to maintain the desired speed of the functions. A large dataset was generated by combining typical operations into a composite duty cycle representative of a day of operation.

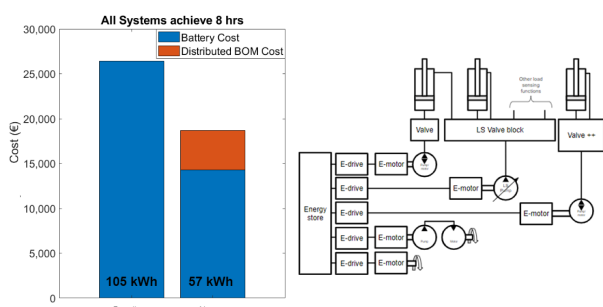


Figure 2. Project outcome: A distributed system enables a 46% reduction in battery capacity and net reduction in BOM cost



Figure 1. Testing the instrumented 5 ton excavator

Simulation

A number of concepts were evaluated, all based on the use of decentralised electro-hydraulic systems in combination with direct electric drive and the original load-sensing system. This system reduces the energy loss during multi-function operation. The effect of increasing the number of independent electro-hydraulic or direct electric functions was analysed based on the reduction in required battery capacity and any change in Bill of Materials (BOM) cost.

The results of this analysis are summarised in Figure 2, which compares the battery capacity and BOM cost for both the baseline and modified system respectively. The results demonstrate that the battery capacity and therefore cost has been reduced by 46%, with an overall BOM cost saving of >10% despite the additional components required. The charging time is also reduced, making it possible to charge the battery overnight from a typical supply (32A single phase).

Further Development

Orion Research is continuing to develop this concept by building a single axis demonstrator, which will be applied to the excavator to develop the control system and validate the findings of this simulation study.

The study also highlighted that the battery capacity and total installed hydraulic power is highly sensitive to the duty cycle; in particular the proportion of time spent tracking and operating high power attachments. Orion Research is therefore developing prototype electric attachments with higher efficiency than conventional hydraulic attachments and the ability to run directly from the battery.

In addition, Orion Research intends to apply the same analysis methodology to evaluate other construction and agricultural machines, in collaboration with OEMs and aftermarket electrification companies.