expert's commentary

Trends in R&D of Sustainable Vehicle Propulsion

Today's world is beset on one side by the challenges of global warming, on the other by the need to secure energy supplies in the face of diminishing resources. The ongoing increase in global energy demand only aggravates this situation. Vehicles burning fossil fuels in internal combustion engines emit carbon dioxide (CO_2) and consume valuable energy resources. Together with the existing trend toward megacities, this is a key factor that needs to be kept in mind when considering the future of individual mobility. However, there is also a clear trend toward the substitution of fossil energy with renewable energy, something that has the potential to provide a long-term solution.

The many sources of renewable energy include solar energy, wind energy, and biogas produced from biomass or even from microorganisms. Unfortunately, none of these technologies are yet a viable alternative to fossil energy. This needs to be taken into account when looking at trends in the research and development (R&D) of vehicle propulsion systems.

Assuming sufficient electric energy is available from renewable sources, electric mobility (e-mobility) is an attractive option for individual mobility in the future. Unfortunately, the amount of renewable electric power capacity remains small, and even if it were used for electric vehicles (EVs), there would still be a need to generate electricity from fossil sources for industrial and domestic use. Mobile storage of electric energy is another major challenge that has yet to be solved. This means that EVs do not have the potential to become a predominant or widely used propulsion system in the short term. Nevertheless, short-term countermeasures are still needed for the problems of global warming and increasing energy demand. Presently, the most effective short-term measure is to improve existing vehicle propulsion technology. Such opportunities for improving efficiency and emissions continue to exist.

One possibility is a propulsion system that combines an electric motor and internal combustion engine. Vehicles with these hybrid systems are becoming more and more common. The advantages include the capture of regenerative energy during braking and the potential use of the electric motor on its own to propel the vehicle. This results in a zero-emission propulsion system within the context of the vehicle itself, a factor of particular importance in locations where exhaust emissions are a concern. Nevertheless, scope for improvement remains. Further developments are needed in the characteristics of the internal combustion engine and electric motor, and energy storage remains a major challenge.

Another possibility with hybrids is the use of hydraulic energy storage and propulsion. While the durability and efficiency of these systems is good, they only make sense as a means of providing a power boost. The system required for a vehicle powered by hydraulic energy alone would be too big and heavy to be practical. Meanwhile, in addition to propulsion system enhancements, efficiency can also be improved through changes in the mode of operation. If the topology of the intended route is known, for example, the engine control unit (ECU) can predict energy demand and determine the optimal combination of regeneration and electrical or combustion propulsion, thereby achieving the full potential of the hybrid configuration.

More than a century on from the invention of the internal combustion engine, scope for improvement remains. Areas offering potential savings include the fuel, enhancements to the combustion process, and the reduction of parasitic losses. Waste heat recovery is another possibility being intensively studied. Alternative fuels include natural gas, which contains around 20% less carbon than gasoline and therefore emits an equivalently lower quantity of CO_2. A problem with natural gas, however, is that it consists primarily of methane, a much more potent greenhouse

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gas than CO_2. This means that either measures to prevent methane slip (incomplete combustion) or effective exhaust aftertreatment is required. A big advantage of gas propulsion, whether it be compressed natural gas (CNG), liquefied petroleum gas (LPG), or liquefied natural gas (LNG), is the wide availability of the gas. Reserves are geographically more widespread than oil, and it can also be produced from renewable biomass. Hydrogen is another potential fuel for internal combustion engines. While the combustion process of hydrogen in an engine is well-understood, production, distribution, and in-vehicle storage remain enormous challenges. Yet another approach is to improve the combustion process for conventional liquid fuels. Recent investigations have shown, for example, that optimizing the content of oxygen in the fuel itself can significantly reduce the generation of particles. This offers another way forward for combustion process development.

While the combustion process is already well developed, there are still details that can be improved. One example is the Otto direct injection (DI) engine with central injection. This leads to better mixture formation and thus to better combustion with higher efficiency and lower emissions. Modern calculation methods and highly sophisticated experimental techniques, such as the use of lasers for visualizing combustion progress, generate a lot of knowledge that can be used for improvements. The use of very flexible combustion process management is another key factor in successful development. A fully flexible gas exchange valve control system developed recently can be used to deliver the optimal amount of air into the cylinder at every operating point. Combined with multiple direct injection, this opens up the potential for new and innovative combustion processes, such as Otto homogeneous charge compression ignition (HCCI). While much research is still needed, these innovations demonstrate that considerable scope remains for reducing emissions.

When seeking to achieve 100% conversion of the chemical energy in the fuel into heat, and finally to torque, we also need to consider friction losses. This is a field that has experienced considerable activity in recent years. One well-known approach is to increase specific power output by downsizing. This takes advantage of the effect whereby a higher mean effective pressure increases the ratio between the mean effective pressure and friction losses. The limiting factor with this approach, however, is the increased load it places on engine materials. Thus it is also worthwhile to look at friction losses directly. Besides the ancillary components, the main sources of friction are the bearings, gas exchange valves, and the piston/liner system. Low-friction oils can help, as can optimizing geometries and choice of materials to minimize friction. There is particular scope of improvement in the tribological system formed by of the piston and liner. Continuous improvements are being made in the running surfaces of piston rings, contact pressures, and the shape of the piston skirt. Friction losses are not the only consideration in this work, however, with wear and blow-by also needing to be taken into consideration.

In conclusion, one can state that, in the long term, we need new approaches to ensure individual mobility. EVs are a possible solution but will take time, something that is not available. Therefore it is important to improve existing propulsion systems, namely the different types of internal combustion engine. In the interim, the intelligent combination of electric motors and internal combustion engines is a step in the right direction. The internal combustion engine itself also has further potential for increased efficiency, although it is unlikely that any one measure will bring a major improvement. Rather, what is needed is ongoing work on incremental improvements in various different areas that will sum up to a significant boost in efficiency.