The Fiat Multiair Technology

A step towards high efficiency SI engines

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Downsizing and turbo charging in combination with UNIAIR electronic valve control and gasoline direct injection are now commonly regarded as key technologies for SI engines to cope with the challenges of fuel economy enhancement and driveability improvement. The Spark Ignition (SI) engine in Europe has been marginalised in the upper passenger car segment due to the increasing competitiveness of modern diesel engines, both in terms of fuel efficiency and comfortable driving. This market evolution was primarily promoted by the recent introduction of electronically controlled injection systems i.e. Common Rail, representing a real breakthrough, allowing significant reduction in exhaust emissions and Noise, Vibration and Harshness (NVH), and opening the way to important performance increase. Direct Injection diesel still has an enormous development potential, primarily oriented to overtake the residual gap in terms of pollutants emissions and NVH; this will have anyway a huge impact on diesel powertrain cost and efficiency, hindering the future market penetration in lower segment vehicles.

SI engines are still maintaining a larger share of the medium-low segments, where their intrinsic features represent real strategic advantages:

- Lower costs due to simpler structural parts and robust and low cost emission control technology (three-way catalyst)
- Higher comfort, thanks to the smoother combustion and lighter moving masses
- Low weight and packaging

In the last decade, a strong innovation effort was put on diesel technologies to improve functional results and market acceptability; SI engines did not receive equivalent significant innovation since the introduction of three-way catalyst and electronic injection systems. Ongoing continuous R&D effort on the base engine, aimed to optimise combustion and mechanical efficiency, will not be sufficient to improve significantly the main issues related to fuel economy and CO_2 emissions.

The strategic path for SI engines to recover market share remains the identification of a technological "breakthrough" allowing substantial savings in fuel consumption, while

- Improving performance and fun-to-drive almost to the same level of modern diesel
- Fully maintaining the potential to fulfill the future emissions standards
- With low additional cost, lower than what is needed for future emissions control in diesel engines
- Maintaining the intrinsic characteristics of comfort
- Leveraging on its potential to burn low carbon fuels

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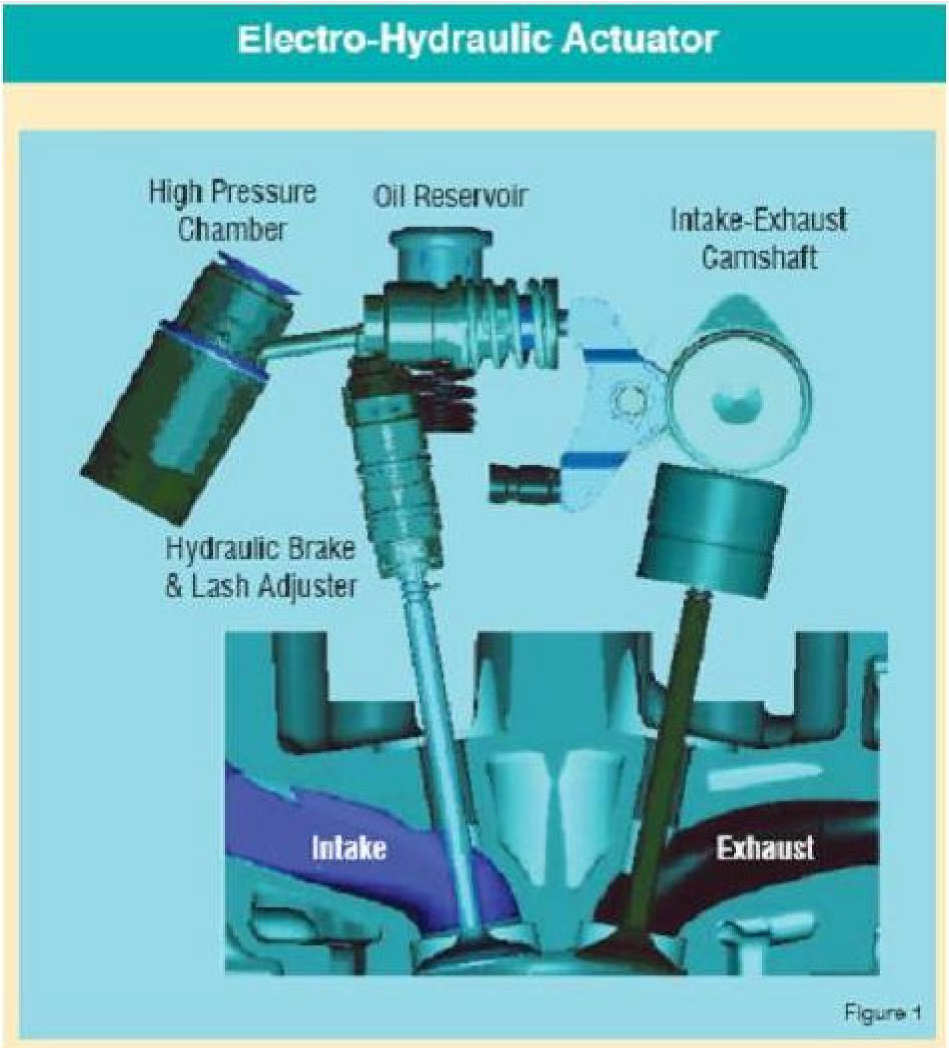
It is well recognised that the main issue of the SI engine concerns the elimination or major reduction of the pumping losses at part load due to the conventional throttle-based load control. Throttleless engine control systems, through variable valve actuation, exhibit the inherent advantage of conventional load control through mixture quantity. The use of stoichiometric air/fuel mixture opens the way to meet worldwide emissions standards with no negative impact on aftertreatment technology i.e. stratified lean GDI; On the contrary, due to the increased system flexibility, a reduction of aftertreatment requirements and costs could be foreseen. Different approaches have been studied and developed from different OEMs, Universities and Research Institutes.

All the mechanical solutions are normally based on the valve lift variation through complex mechanisms, combined with cam phaser to allow control of both valve lift and phase. The major limitation of the mechanical system is linked to the low flexibility level in order to maintain costs and complexity at a reasonable level, all the cylinders of an engine bank are actuated simultaneously and no cylinder selective actions are possible.



On the opposite site, electro-magnetic and electro-hydraulic camless solutions offer the full flexibility in management of intake and exhaust valve lift event. The current technology level is still at embryonic stage, showing interesting potential but suffering from intrinsic problems due to power consumption, safety, NVH control and costs. The electro-hydraulic variable valve actuation technology developed at Fiat (UNIAIR) is based on the “lost motion” principle which was selected for its relative simplicity, low power requirements, intrinsic fail safe nature and low cost potential. A further important point, contrary to other competing systems, was the possibility to use the same technology also for diesel engine applications. The technology is now mature for industrialisation having solved all the key technological issues that could hinder its full exploitation, while maintaining very attractive additional costs. The operating principle of the system, applied to intake valves, is shown in figure 1.

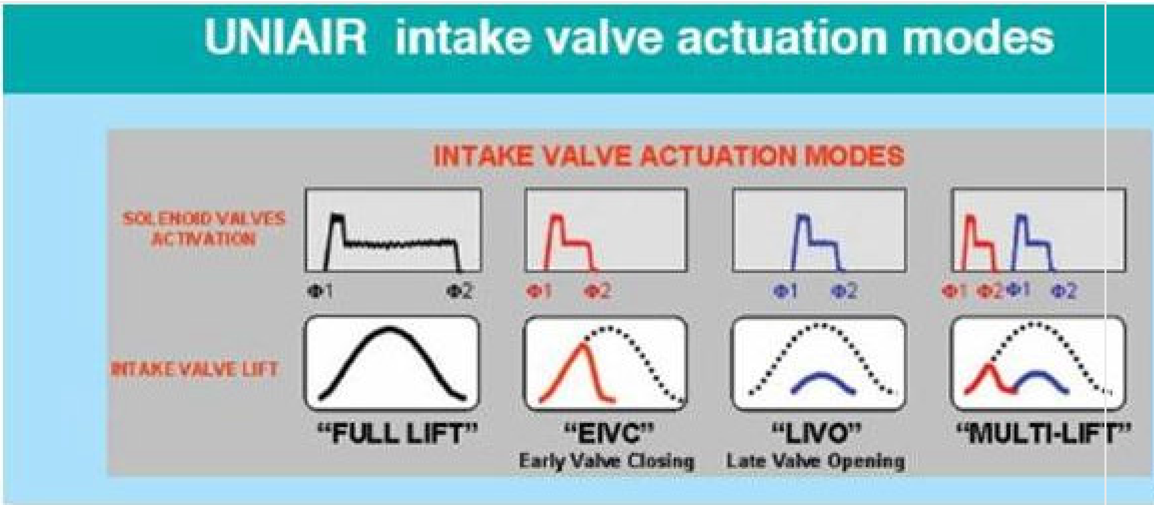


Figure 2

Different actuation modes are possible to allow complete flexibility and compatibility with engine needs in any possible operating condition (Figure 2). In addition to the standard EIVC and LIVO actuation strategies, the "MultiLift" mode has been studied and introduced in the control system. Two different valve lifts can be actuated in the same intake stroke to control, in a continuous and flexible way, both the air quantity and the tumble charge motion in the cylinder. The "Multilift" mode has an important impact system architecture, enabling important simplification of actuator layout and allowing important reduction of system costs through minimisation of the number of expensive components (SV, pump pistons, RFF).

The current industrial solution consists of an integrated module, containing all the "core" hydraulic components, to be manufactured, assembled and tested at the supplier site, with no need for further tuning or adaptation. Since standardisation of components plays a fundamental role to maintain low costs, the core "expensive" components (hydraulic pistons and brake, SV) can be common for all the applications, while the housing has to be designed accordingly with the different engine cylinder head layout.

Electronic control system

A new generation Integrated EMS, called Multiair, has been developed to improve system functionality through the complete integration of engine and valve control functions. The valve control module, including dedicated ASIC's, power stages and specific HW/SW modules is embedded in the ECU board, fully integrated with the standard engine control functions and with the advanced Multiair specific air and combustion control strategies.

Features and benefits

The UNIAIR actuator was designed and developed following specific guidelines to satisfy both functional requirements and industrial constraints with minimal impact on costs; major effort was put on optimisation of packaging, weight, friction, impact on existing cylinder head design and use of conventional engine oil. Through an extensive development and optimisation effort, the system was brought to a performance and maturity level fully compatible with industrial application in mass production. A wide operational range in terms of engine speed (up to >7000 erpm) and oil temperature (from -30°C to 150°C) is allowed, while maintaining a precise cylinder to cylinder and stroke to stroke air control over the full engine life.

The application of the Multiair technology offers the potential to improve almost all the critical areas of SI engines:

- Throttleless load control reduced fuel consumption
- Optimal charge trapping efficiency increased performance
- Fast and direct valve control improved dynamic response and fun to drive
- Advanced combustion control reduced fuel consumption and emissions

The most important aspect is the reduction of fuel consumption, measured at vehicle level on NEDC cycle, in the range of 10 percent both for NA and TC engines. The optimal integration with turbocharging technology enables the feasibility of downsized configurations offering very important potential for fuel economy reduction, from 20 to 25 percent depending on the downsizing rate. Performance and driveability increase potential is significant, thanks to:

- Torque and power increase, due to optimal volumetric efficiency over the whole engine speed range, increasing both torque and power values
- Improved fun to drive due to the faster response to driver pedal request during acceleration

Considering pollutant emissions, the flexibility in combustion control through specific valve lift strategies leads to a significant reduction of both engine out emissions during cold phase and catalyst light-off time. Results at vehicle level indicated possibility to fulfill future emission standards, maintaining today's aftertreatment system.

Integration of Multiair on turbocharged engines

The Turbo GDI, integrating cam phasing control, can be today considered as a state-of-the-art for high performance engines, offering significant torque and power density combined with excellent fun to drive, very low emissions and some potential for fuel economy reduction, almost exclusively due to downsizing possibility. The conventional throttle-based load control presents anyway some additional limitation when adopted on a turbocharged engine, related to system efficiency and dynamic response affecting both fuel consumption and fun to drive.

It is well known that through turbocharging the increase of charge density is obtained by exploiting the pressure and temperature drop through the turbine (enthalpy), to drag the compressor and generate a corresponding boost pressure. Due to the relative efficiencies this is achieved generating additional pumping losses if compared with a traditional NA engine, having a negative impact on fuel economy, especially at part load.

Adopting Multiair control, this limitation is avoided because the air quantity can be controlled directly at the intake valves, without any additional throttling. The Multiair air control integration with turbocharging represents the way to approach a very efficient gasoline powertrain able to achieve

- very low fuel consumption and CO_2 emissions, due to combined and synergic contribution of de-throttling and downsizing
- excellent driveability and fun to drive, due to high dynamics due to fast air and fuel control potential for very low emission
- lower costs with respect to diesel powertrain, considering equivalent emission targets

Conclusions

In addition to the technical consideration and expected improvements, many other aspects related to the integration of advanced SI technologies have to be considered. Due to the expected increase in cost and complexity, a very "product-oriented" integration strategy has to be developed and taken into account to identify the most effective solution for the different engine size and mission.

Considering NA engines, two different technological ways can be foreseen:

- Small / medium engines: the market drivers are represented by cost and fuel economy, while performance can assume a lower importance in customer choice. The UNIAR PFI solution represents the optimal trade-off, able to combine a significant improvement on fuel economy (10%) with a good behaviour in driveability and fun-to-drive.
- Large, 'power-oriented' engines: GDI currently represents a "state-of-the-art" technology, offering a significant potential for high performance, thanks to the synergic integration with cam phasing technologies. On the other side, the limited fuel economy potential can be anyway accepted since it is not a strategic driver for the target customer.

  Moving to turbocharged engines, the intrinsic potential of the two ways will be further reinforced:
- Small / medium engines: The increasing demand for very efficient powertrain with improved fun-to-drive with respect to today's conventional SI engines, will make this segment very appealing for the market. The adoption of the Uniair technology, combining the effects of downsizing and dethrottling, will represent the ideal solution to realise a "fuel economy oriented" downsized turbocharged engine. This configuration makes possible to approach the CO_2 emission and fun-to-drive of diesels with lower costs while maintaining the intrinsic advantages in terms of emissions and comfort.
- Large performance oriented engines: In this segment, where top performance will still represent the major market driver, GDI + CVCP will probably continue to be the leading technology; thanks to the possibility of downsized configurations, advantages in terms of CO_2 can be achieved as well. Even if this cannot represent a real driver for the customer, it will be an appreciable effect for the OEM, to meet the requirements in terms of CO_2 reduction.

A natural evolution could be represented by the integration of GDI in throttle-less air control systems, i.e. Multiair, to realise a fully optimised package for a complete direct control of combustion at cylinder level, offering the possibility to increase performance, and slightly improve fuel economy.

The major issue is anyway represented by costs. Today's costs of GDI technology do not allow this further step in integration; the real application will be possible only if a significant long-term reduction of the cost of GDI technology is achieved.