

Innovation Trends in the Field of Internal Combustion Engines

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ABSTRACT

One reliable way to measure the research activity in the field of engine technology is through the number of patent applications that are submitted to different patent offices in the world.

This paper offers a thorough statistical analysis of the innovation trends related to downsizing in Europe, USA, Japan, China and Korea in the field of internal combustion engines during the last 10 years, as seen by the European Patent Office. It demonstrates which technical fields (e.g. super- and turbocharging, direct fuel injection systems, hybrid technology, variable valve actuation, exhaust gas recirculation, etc.) are the most active, who are the most important players and which country attracts the highest number of applications. Subfields of certain technical fields are also analyzed. The technical fields discussed are chosen according to the International Patent Classification (IPC) scheme.

INTRODUCTION

Oil is the major source of world-wide energy supply and as a consequence the primary source of fossil based carbon dioxide. Transport in general produces about 20% of overall man-made carbon dioxide. In response to the Kyoto protocol, the EU (European Union) had negotiated an agreement with the vehicle manufacturers that supply to the European market to reduce fleet average CO₂ emission to 140 g/km by 2008 based on the New European Drive Cycle (NEDC). Following the recent fuel price variation, in combination with the public perception of the effects of the global warming, more strict regulations on CO₂ legislation have been discussed world-wide. As an example, on 17 December

2008 the European Parliament voted to adopt a Regulation on CO₂ from cars, key elements of the adopted text being as follows [1]:

- **Limit value curve:** the fleet average to be achieved by all cars registered in the EU is 130 grams per kilometer (g/km). A so-called limit value curve implies that heavier cars are allowed higher emissions than lighter cars while preserving the overall fleet average.
- **Phasing-in of requirements:** in 2012, 65% of each manufacturer's newly registered cars must comply on average with the limit value curve set by the legislation. This will rise to 75% in 2013, 80% in 2014, and 100% from 2015 onwards.
- **Lower penalty payments for small excess emissions until 2018:** If the average CO₂ emissions of a manufacturer's fleet exceed its limit value in any year from 2012, the manufacturer has to pay an excess emissions premium for each car registered. This premium amounts to €5 for the first g/km of exceedance, €15 for the second g/km, €25 for the third g/km, and €95 for each subsequent g/km. From 2019, already the first g/km of exceedance will cost €95.
- **Long-term target:** a target of 95g/km is specified for the year 2020. The modalities for reaching this target and the aspects of its implementation including the excess emissions premium will have to be defined in a review to be completed no later than the beginning of 2013.
- **Eco-innovations:** because the test procedure used for vehicle type approval is outdated, certain innovative technologies cannot demonstrate their CO₂-reducing effects under the type approval test. As an interim procedure until the test procedure is

reviewed by 2014, manufacturers can be granted a maximum of 7g/km of emission credits on average for their fleet if they equip vehicles with innovative technologies, based on independently verified data.

Therefore, engine technology is currently entering a new phase of intense development and technology deployment based on three major drivers: First of all the further intensified pressure for fuel economy improvement which has got another acceleration by recent fuel price increases leaving the customer in an unprecedented uncertainty in terms of energy supply resulting in much more cautious purchase decisions regarding vehicle size and powertrain technology. Secondly, driveability refinement and torque characteristics are powertrain attributes which are highly customer relevant and should by no means degrade. Last not least, future engine technology will continue to become more complex to fulfill more stringent emission legislation.

It is meanwhile widely accepted that engine “downsizing” in combination with pressure charging is the most appropriate technology bundle to address the future key challenges [2]. Fuel economy improvement enabled by downsizing is nowadays a key element for each OEM to be considered in fleet CO₂ reduction strategies. However, while the first stages may still be achievable for a wide range of vehicles with moderate technology efforts or just a downsizing approach alone, the next levels of 120 g/km CO₂ or even lower for many vehicles requires a CO₂ reduction by more than 50% relative to current status.

Therefore, if these extended requirements, see e.g. the adopted EU regulations, are considered, “downsizing” can only be one element in a chain of technologies to be applied. In view of stepwise more stringent limits, it has to be extended by additional technology elements in order to further augment the fuel economy improvement potential beyond the initial achievements. A list of those elements is as follows:

Downsizing is especially efficient when specific power is increased by torque increase. This can be done by improving cylinder filling and BMEP. The two main aspects that contribute to this are:

- Turbocharging / supercharging
- Variable valve / camshaft timing (VVT or VCT) on intake and/or exhaust camshafts.

The most important limit for downsizing engines is the increasing knock sensitivity that comes with boosted engines. Knocking can however be prevented by applying certain technologies, such as:

- Direct Injection (DI) which increases the charge cooling due to the fuel vaporization inside the combustion chamber.

- Variable Compression Ratio (VCR) that allows to change the compression ratio according to the load of the engine and therefore permits to avoid knocking whatever the charging pressure. This offers an opportunity to further enhance the downsizing potential.
- (cooled) Exhaust Gas Recirculation (EGR) which in addition to reducing pumping losses, can also be used to reduce the fuel enrichment in order to cool the combustion process and avoid detonation.

To have an efficient torque response, the in-cylinder trapped mass, adjusted by the throttle and the waste gate, must be controlled with accuracy according to performance and drivability requirements. Depending on admission and exhaust pressures, variable valve timing will allow to control the rate of in-cylinder burned gases to reduce fuel consumption and pollutant emissions, and air scavenging to improve transient speed response. All this requires more complex forms of engine control and new injection strategies.

A downsized engine will have reduced friction losses due to smaller moving parts, but will at the same time demonstrate an increase of the average load on many engine parts. This means that ways have to be found to increase the mechanical resistance limits of these parts.

All the before mentioned aspects of downsizing will also likely be combined with mild hybrid systems or alternative fuels for even more improvement. Downsizing is also not limited to spark ignition engines, because recent developments have shown that also Diesel engines are set to shrink as well.

The aim of this paper is to get an idea of how innovative trends (both for Diesel and spark ignited engines) relating to downsizing has developed in the last 10 years, what specific innovative aspects of downsizing technology are predominant, and who are the key players (patent applicants) in this particular field of engine development. To get this overview, a thorough statistical analysis has been carried out on patent applications related to the main topics related to downsizing received from 1998 until 2007, received in Europe by the European Patent Office (EPO), the USA by the US Patent and Trademark Office (USPTO), Japan by the Japanese Patent Office (JPO), China by the Chinese Patent Office (SIPO) and Korea by the Korean Patent Office (KIPO). These five major patent offices are also called IP5.

The main aspects related to downsizing have been commented on in this introduction above and can be seen grouped in Table 1, with their corresponding IPC codes defined by the International Patent Classification (IPC). For more details on the definitions of EC and IPC and the corresponding classes analyzed, see [3].

Technical Field	IPC Classification
Super- and Turbocharging	F02B27, F02B29, F02B33, F02B37, F02B39, F02D23, F02D41/00(<i>D4*</i>)
Direct Injection	F02B23/06, F02B23/10, F02D41/38**, F02M47, F02M51/06, F02M55, F02M57, F02M59, F02M63/02(<i>C*</i>)
Variable Valve Actuation	F02D13/02, F01L1/34, F01L1/35, F01L9/02, F01L9/04, F01L13/02, F01L13/00(<i>B,D*</i>),
Variable Compression Ratio	F02D13/02(<i>M*</i>), F02D15
Injection Strategy	F02D41/38**, F02M45, F02M69/04(<i>C4*</i>)
Alternative Fuels, Gaseous Fuels, Bi-Fuel	F02D19, F02M21/02, F02M37/00(<i>L4*</i>), F02M43, F02D41/00(<i>F,F2*</i>)
Friction Loss, Heat Management, Mechanical resistance	F02F1/20, F02F1/24(<i>C*</i>), F02F1/26, F02F3/10, F02F3/16, F02F7/00(<i>E2*</i>)
Hybrids***	B60K6/20, B60K6/24, F02D29/02, F02D29/06
EGR	F02D21/08, F02M25/07, F02D41/00(<i>F6*</i>)

Table 1: IPC classes

**) European Classification (EC) scheme*

*** F02D41/38 deals with Direct Injection control*

**** Only those hybrid classes related also to the internal combustion engine in combination with the electrical motor were chosen. The IPC class B60W, dealing with the control of the hybrid vehicle without relation to the internal combustion engine, was not taken into account.*

MAIN SECTION

GLOBAL PATENT FIRST FILINGS PER TECHNICAL FIELD AND PER APPLICANT

As discussed above, patent filing activities related to downsizing concepts concentrate on nine main technical fields. The following figures Fig. 1 to Fig. 4 provide insights of the relative proportion of these nine technical fields, as well as correlations between the technical fields, the most important patent applicants and the

countries from which these patent filings originate. The basis for the data presented in Fig. 1 to Fig. 4 are all first patent filings according to IPC listed in Table 1 in recent years (2004-2008). The data was extracted from the databases using the priority number, which identifies the country in which the patent application was first filed.

The inner circle in Fig. 1 shows the relative proportions of the technical fields. Direct injection, hybridisation and charging are the main areas of development. The outer circle in Fig. 1 lists for each technical domain the five applicants that have filed the most patent applications.

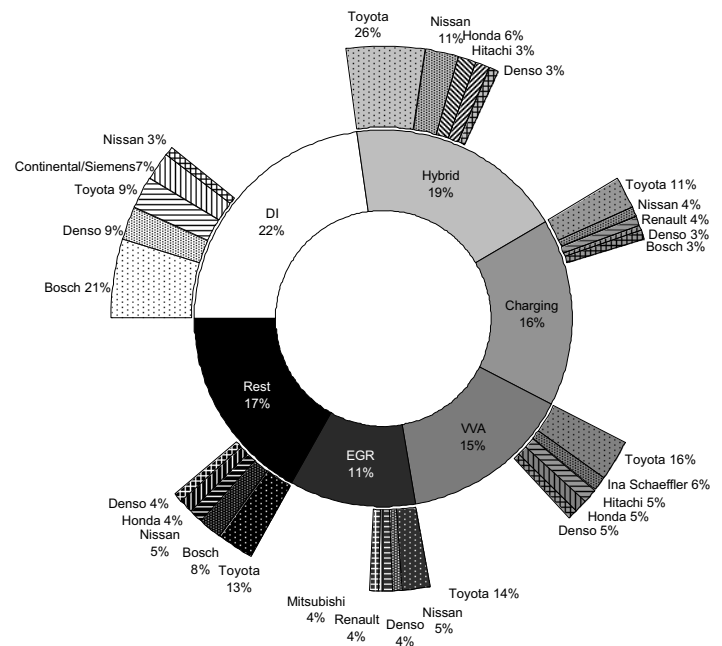


Fig. 1: Share of main technical fields related to downsizing and applicants filing most patent applications in these technical fields with the IP5 offices ("Rest" denotes injection strategy, VCR, alternative fuels and friction losses)

Fig. 2 presents the same data from another perspective. The inner circle shows the relative proportion of the countries from which the patent filings originate. It shows that almost half of all applications come from Japan (JP), followed by Europe (EP+) and the United States (US). Although China (CN) and Korea (KR) nowadays play an important role in the intellectual property world, the number of patents related to internal combustion engine technology originating from these two countries is still small in comparison with Japan, Europe and the United States.

The outer circle in Fig. 2 provides information on which technical fields are predominant in the five regions respectively. As one would expect, Japanese applicants focus on hybridisation, whereas European applicants are most active in direct injection and supercharging technologies. Although, according to recent press releases, the key technology to reduce fuel consumption in the United States is hybridisation, US applicants focused in the last five years mainly on conventional engine technologies.