110 Years of Turbocharging

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The adoption of turbochargers in internal combustion engines allows for more useful energy to be extracted from the exhaust gases and simultaneously increase the power of engines . The higher density of the air at the intake leads to a rise in torque and power due to more fuel being injected. In this way, the specific power of each cylinder is increased together with the overall efficiency of the engine. Moreover, for constant engine power, a turbocharged engine can reduce the number of cylinders by decreasing friction and moving masses. A patent published by the Swiss engineer Alfred Büchi in 1905 described a turbocharger as a turbine and a compressor coupled by a common shaft [1]. The unit was meant to be installed in a way that the exhaust gases could expand and make the turbine rotating. Consequently, the spinning motion would be passed to the compressor which could pressurize the air delivered to the engine [1]. Successively in 1924, Brown Boveri (BBC) developed and installed the first turbocharger on a large Diesel engine [2]. Since then, the technology has been subjected to continuously improvements in the industrial sector supported also by new simulative and experimental tools [3, 4].

Turbochargers have found applications in two-stroke and four-stroke diesel and gas engines with the aim to increase power and reduce specific fuel consumptions and presence of emissions in the exhaust. In the mid-1990s, variable turbine geometry was included in ABB TPS line in order to improve emissions and operations of the engine under part-load and transient conditions [2]. The requirements for further enhancement of brake mean effective pressure (BMEF) drove the development of two-stage turbocharging technologies in series configuration as single turbochargers were not able to provide elevated boost pressures [5, 6]. The turbocharging efficiency can be kept as high as 75% with the inclusion of an intercooler between the compression stages [7]. This turbocharging solution could cause elevated in-cylinder pressures and, of consequence, an increase in emission and generated smoke. Therefore, an extreme Miller cycle could be a solution to reduce in-cylinder temperature and pressure [8].

It is clear that two-stage turbocharging with variable valve timing might have the potentiality to satisfy the stringent limits on nitrous oxides and sulphur dictated by the International Maritime Organisation (IMO) III legislation [9]. Additionally, this will restrict the emissions of shipping vessels in Emission Control Areas (ECAs) even further. In this scenario, the turbocharging system has to integrate with after-treatment systems for reducing harmful nitrous oxides. In two-stroke engines, ammonia is injected before the turbine entry when selective catalytic reduction (SCR) is employed with single stage turbochargers [9]. SCR is placed between the expansion stages of a two-stage turbocharged four-stroke engine and it is important to notice the change in status of the exhaust flow between high pressure (HP) and low pressure (LP) stages. Moreover, turbochargers might be adopted for favouring exhaust gas recirculation (EGR) to the engine. Therefore, EGR compressors might require to be fouling resistant and cleaning operations could be necessary [10]. In this way, it would be possible to reduce fuel consumptions and satisfy the IMO III emission requirements for shipping vessel.

A main example of fuel reduction can be represented by the new turbocharged two-stroke diesel engine on the MSC Oscar which has obtained a reduction of 35% in fuel usage compared to its predecessor [11]. In fact, if a pair of sneaker has to be shipped from Houston to London for 7798Km with MSC Oscar predecessor, assumed to have the same size as the MSC Oscar, about 3.6 million litres of fuel are required. This results in 53.5% increase of fuel required for pair of sneaker to travel assuming that MSC Oscar is able to ship 117 million pairs of sneaker at once. Meanwhile, the new turbocharged engine installed in the MSC Oscar is capable of using only 0.0187 litres of fuel per pair of sneaker against 0.0287 litres of its predecessor. This could be resulting in a saving of around 1.18 million litres of fuel in a sole journey from Houston to London for less CO_2. In this scenario, the economical benefits of turbocharged solutions could also be supported by more environmental friendless of maritime shipping.

The spreading of turbocharged engines in the industrial sector would seem a reliable and immediate solution in terms of improved running costs and emissions. The increase of BMEP in both four-stroke [12] and two-stroke [13] engines showed potential fuel saving improvements that could reach 50%. However, single stage turbochargers would not be able to deliver the required pressure ratios and two-stage turbocharging solutions will become more of a necessity also for 2-stroke natural gas engines [14] where single stage turbochargers could limit the engine at 22bar of BMEP. The present findings suggest that turbochargers would become more widely adopted in large industrial engines. More precisely, the adoption of two-stage turbochargers with variable valve timing could reduce engine emissions in order to comply with restrictive emission regulation. Conclusively, turbo-compounding [7] and hybrid turbocharging solutions [15] could be able to extract more useful energy from the exhaust gases and improve overall engine efficiency in both stationary and shipping applications.

References

[1] Zinner, K., 1978. *Supercharging of internal combustion engines: fundamentals, calculations, examples*. Berlin: Springer

[2] ABB, 2014. *Turbocharging in Switzerland – A history* [Online] Article (2014-02-27). Available from ABB Download Center

[3] ABB, 2014. *Turbo boost* [Online] Report (2014-03-28). Available from ABB Download Center

[4] Copeland, C. D., Martinez-Botas, R. and Seiler, M., 2012. Unsteady performance of a double entry turbocharger turbine with a comparison to steady flow conditions. *Journal of Turbomachinery: Transactions of the ASME*, 134 (2), 021022

[5] Codan, E., Mathey, C. and Rettig, A., 2010. 2-Stage Turbocharging – Flexibility for Engine Optimisation. *26th CIMAC World Congress in 2010, Bergen*. Paper No. 293

[6] Fitzky, G. et al., 2010, Testing and qualification of two-stage turbocharging systems. *9th International Conference on Turbochargers and Turbocharging, IMechE, London.* pp. 79-94

[7] Codan, E. and Huber, T., 2012. Potential of 2-stage Turbocharging. *17th Supercharging Conference, Dresden*

[8] Wik, C. et al., 2009. 2-stage turbo charging on medium speed engines – future supercharging on the new LERF – test facility. *14th Supercharging Conference, Dresden*

[9] Codan, E., Bernasconi, S. and Born, H., 2010. IMO III Emission Regulation: Impact on the Turbocharging System. *26th CIMAC World Congress in 2010, Bergen.* Paper No. 139

[10] Codan, E. and Wuethrich, J., 2013. *Turbocharging solutions for EGR on large diesel engines* [Online] Article (2013-11-27). Available from ABB Download Center

[11] ABB, 2015. Maritime cargo vessels - Is bigger better? [Online] Available from: http://new.abb.com/turbocharging/maritime-cargo-vessels---is-bigger-better [Accessed 22 July 2015]

[12] Behr, T. et al., 2013. Second generation of two-stage turbocharging Power2 systems for medium speed gas and diesel engines. *27th CIMAC World Congress in 2013, Shanghai.* Paper No. 134

[13] Schuermann, P. et al., 2014. *Turbocharging solutions for improving fuel efficiency in two-stroke low-speed engines* [Online] Article (2014-05-22). Available from ABB Download Center

[14] Codan, E. and Christen, C., 2014. Turbocharging solutions for gas engines. *19th Supercharging Conference, Dresden*

[15] Ono, Y., Shiraishi, K. and Yamashita, Y., 2012. Application of a Large Hybrid Turbocharger for Marine Electric-power Generation. *Mitsubishi Heavy Industries Technical Review*, Vol. 49 (1), March 2012