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ASSESSMENT OF THE ENGINE BOOST MODERNIZED ACCORDING TO THE RULES OF DOWNSIZING

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Abstract

Downsizing is one of the development trends of internal combustion engine due to its direct impact on fuel economy and indirectly in reducing the emission of carbon dioxide into the atmosphere. Changing the displacement associated with the same engine performance needs support by additional systems, which primarily include the boost. This paper describes downsizing idea, a review of recharging methods and thermodynamic analysis of the combustion process for the chosen engine before and after downsizing taking into account the different variants of boost. The core objective of this study is to downsize a naturally aspirated 1.6L BMW PSA engine by 25% of its initial swept volume and then boosting downsized engine with higher-pressure ratio using the turbocharger set. The study focuses on the analysis of four turbochargers from Garrett turbos. The study winds up with the analysis of engine performance based on the values of compression ratio, air-fuel ratio, polytropic exponents of compression and decompression with keeping the same chemical composition of the fuel. At the end, study was resulted with turbocharger Garrett GT1548 as a the best solution form considered ones, because of: wide range of pressure rate, reasonably sufficient for the engine of this size, enough room (60%) for extracting better performance, lower compression ratio value, which counts the rise of brake mean effective pressure, although to a very little extent and leaner mixture at 1,20 value of the air/fuel ratio with maximum power and reduction of fuel consumption, what was satisfied for downsizing techniques.

***Keywords**: combustion engine, downsizing, boosting*

1. Introduction

Downsizing in relation to the internal combustion engine is a reduction in displacement while keeping or even increasing engine power as well as reducing fuel consumption. Indirectly it influences carbon dioxide concentration in the exhaust to decrease Greenhouse Effect [1, 4].

To maintain the performance of engine subjected by downsizing process it requires to use support systems, among which in the first place is located boost as an induction system that increases engine's efficiency and power by forcing more air into the combustion chamber. The most popular boost system is turbocharging with two wheels of high-speed compressor and turbine assembly on one axle. Turbocharger is driven by exhaust gases, so it is more efficient than other solutions, but there is a design limitation known as turbo lag. The increased engine power is not instantly available due to the fact that it takes time to build up pressure and to spin up the turbo, before the turbo starts to do any useful air compression. The increased intake volume causes increased exhaust input to the turbine wheel and spins it faster, and so forth until a steady high power operation is reached. Another difficulty is that the higher exhaust pressure causes the exhaust gas to transfer more of its heat to the engine components. Turbochargers are employed to increase the power output of an internal combustion engine, reduce the CO_2 emission and improve their fuel efficiency. Their total design, as in the other turbo machines, involves different types of analyses such as mechanical, thermal and acoustical. Engineers are still searching pathways to improve turbocharger design while balancing other factors [2, 3, 6, 7].

Turbo play an important role in increasing power density, defined as the ratio between power output and engine size. This characteristic makes turbocharging a key advantage of engine downsizing. The smaller size makes the engines more efficient, also brings additional advantages such as a quicker engine warm-up (reducing cold-start emissions), and lower weight (which further helps fuel economy). All the major manufacturers are currently planning to expand their line-up of downsized engines. Consequently, the impact of turbo over the next 10 years will include a reduction of average engine displacement in two ranges from 3.6 dm^3 to 3.0 dm^3 and 1.7 dm^3 to 1.5 dm^3 or smaller [5].

2. The engine and turbochargers in study

The aim of this project is to analyse a turbocharger systems for a downsized gasoline engine with focus on the thermodynamics. The theme for this paper to analyse four turbochargers from Garrett viz. Garrett GT1241, Garrett GT1548, Garrett GT2554R and Garrett GT2860RS on a naturally aspirated 1.6L BMW PSA "prince" engine. "Prince" is used, since 2009 as a drive in many vehicles jointly by BMW and PSA. It includes lots modern features including gasoline direct injection and variable valve timing. It has an 85.8 mm stroke and a 77.0 mm bore for a total of 1.598 dm^3 of displacement, which was transferred to 1.191 dm^3 by 82 mm stroke and 68 mm of cylinder diameter. It was achieved downsizing factor by 0.25.

The study fundamentally involves the analysis of chosen turbochargers and boosting the engine with their respective pressure ratios obtained. Before, the analyses takes off, the engine is down-sized. To keep power output at the same level after downsizing thermodynamic process was a bit changed by changing coefficient of exponents of thermodynamic cycle, by changing the valve timings, by compression ratio and by the air combustion factor. The addition of a turbocharger will lead to the rise in the temperature of the air-fuel mixture, it is well to be noted that the interference of the intercooler to cool the air from the turbocharger outlet to air-fuel mixture is not practically considered. The properties of the fuel considered are as that of the standard fuel and, hence, keeping room for the improving the engine performance by using premium fuels and achieving better results for a practical use. After founding preliminary operating factors, it could be selected turbochargers, following their characteristics maps and design parameters:

- GARRETT GT 1241,
- GARRETT GT 1548,
- GARRETT GT 2554R,
- GARRETT GT 2860RS.

For each of them compressor map, turbine flow and technical specifications were analysed regarding thermodynamics process within engine by showing typical parameters and operating indicators.

The Garrett GT1241 is a small turbocharger ideally suited for turbocharging small engines producing at least 50 HP. The GT12 features a maximum compressor efficiency of 75% and internally gated turbine housing with wastegate actuator. Recommended displacement from Garrett for this turbo is at a minimum 0.400 dm^3 and at most 1.200 dm^3. This turbocharger has a flow capacity of 3.15 kg/min to 4.56 kg/min at a pressure ratio varying from 2.0 to 2.6 [8].

The Garrett GT1548 turbocharger is well suited for 1.0 to 1.6 dm^3 displacement applications. The turbocharger comes complete with internal wastegate and an actuator [8]. The recommended horsepower for this turbocharger is from 100 to 200. The turbine housing here is the T25 that means it could use a T25/T28 turbo inlet flange with this GT1548 turbo. From the compressor map, this compressor has a wide pressure ratio (PR) range to operate at different efficiencies. This turbocharger has a too big compressor as to achieve the pressure ratio of 2.50 at 3.6 kg/min with an efficiency of 60%.

The Garrett GT2554R is a compact full ball bearing turbocharger ideally suited for single turbo projects where space is at a premium. Turbine housing is internally gated, and it includes a wastegate actuator calibrated at 0.07 MPa. The dual ball bearing GT25 give a very quick spool, even on a very small engine. This turbocharger works well for the engines between 1.4 dm^3 to 2.0 dm^3, giving a 270 HP in the engine. Flows for it is a maximum of 6.7 kg of air per minute with an operating PR range from 2.20 to 3.00 at 68 % efficiency.

The Garrett GT2860RS is an upgrade turbocharger for the GT2554R. This turbo has a flow capacity of about 250-360 HP and works well for engines between 1.8-3.0 dm^3. It has the fastest spool among the turbochargers in its category. It also has an internally wastegated style T25 turbo housing with actuator bracket and actuator fitted from the factory. This turbocharger operates with a maximum airflow of 9.5 kg/min and has a wide range of PR from 1.50 to 2.25 at maximum efficiency of 77%. Technical specifications are shown in Tab. 1.

Figure 1 shows an example of compressor flow map and turbine flow.

Tab. 1. Selected Garrett turbochargers specifications

		GT 1241	GT 1548	GT 2554R	GT 2860RS
	bearing type	journal	journal	ball	dual ball
	cooling	oil and water	oil and water	oil and water	oil and water
compressor	inducer diameter, mm	29	37.2	42.1	47.2
	exducer diameter, mm	41	48	54.3	30.1
	area/radius	0.3	0.48	0.8	0.6
	trim	50	60	60	62
turbine	wheel diameter, mm	35.5	41.2	53	53.9
	area/radius	0.4	0.35	0.64	0.86
	trim	72	72	62	76
	engine recommendation, cc	400-1200	1000-1600	1400-2200	1800-3000

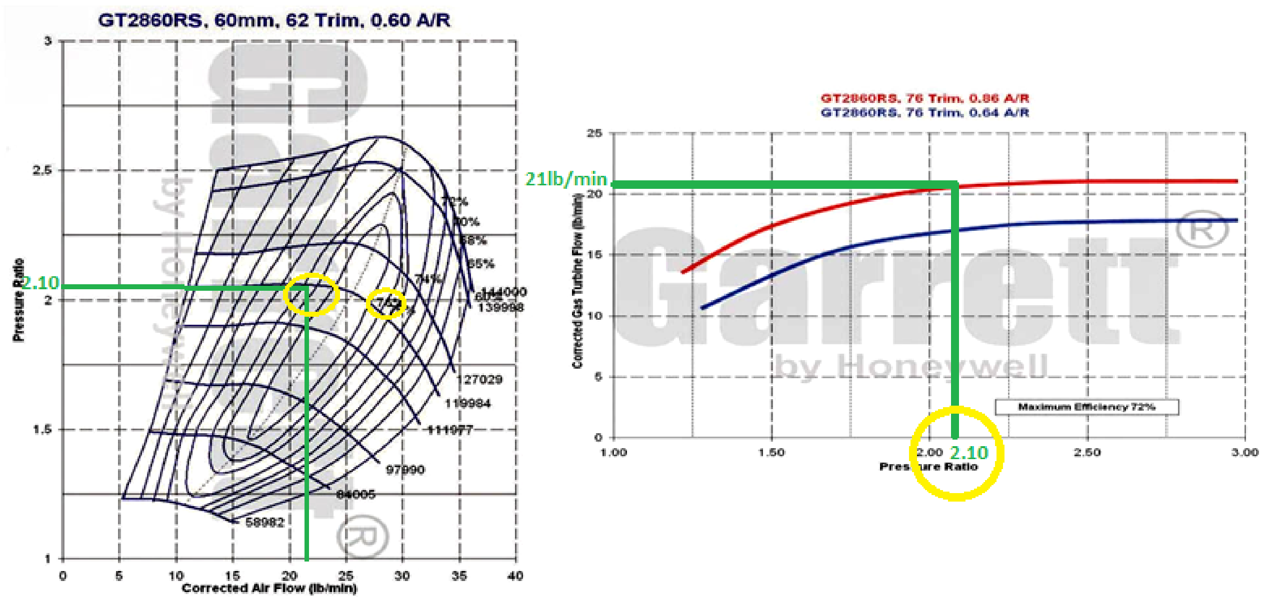

Fig. 1. Compressor flow and turbine flow analysis for Garrett GT 2860RS TC [9, 10]

3. Results

To fulfil goal of this project first the base engine was evaluated, then downsizing process was implemented and after that, turbos were studied.

Following the engine, there were considered different combinations of values: degree of compression, polytropic exponents for compression and expansion, lambda factor, the level of heat transfer from the combustion chamber walls etc. On the side of the turbocharger takes into account their characteristics, scopes of changes in pressure ratio and flow maps such as structural indicators. The system response was obtain inter alia in the form of brake mean effective pressure, useful efficiency, specific fuel consumption as well as the degree of change of power in a single cylinder. The results were counting also as relative values referring to base engine after downsizing and showing in parenthesis – Tab. 2.

Tab. 2. Effect of turbochargers on some engine performance parameters, where: PR – pressure ratio of turbo, ε – compression ratio, λ – air/fuel factor

Engine parameter	Garrett Turbochargers											
	GT1241			GT1548			GT2554R			GT2860RS		
	PR	ε	λ	PR	ε	λ	PR	ε	λ	PR	ε	λ
	2.00 (+33)	8.10 (–2.4)	1.00 (0.0)	2.20 (+47)	8.30 (0,0)	1.20 (+20)	2.20 (+47)	8.00 (–3,6)	1.20 (+20)	2.10 (+40)	8.00 (–3,6)	1.10 (+10)
Mean effective pressure, MPa	2.26 (+40%)			2.18 (+3.5%)			2.16 (+34%)			2.20 (+37%)		
Mechanical efficiency	0.93 (+4.5%)			0.93 (+4.5%)			0.93 (+4.5%)			0.93 (+4.5%)		
Total efficiency	0.33 (+3.1%)			0.35 (+9.4%)			0.34 (+6.3%)			0.34 (+6.3%)		
Specific fuel consumption, g/(kW·h)	252 (–4.5%)			241 (–8.7%)			244 (–7.6%)			248 (–6.1%)		
Power output per cylinder, W	30276 (–5.6%)			29219 (–8.9%)			28906 (–9.8%)			29472 (–9.2%)		

The results on several operating indicators of engine point to the possibility of downsizing with the participation of all analysed turbochargers, although the effects are different. In order to preserve the power for adopted parameters preferably presents the use of turbo GT1241 (approx. 6% power loss – which is acceptable to the user), but in general effective work best solution proved to be a second option with a Garrett turbo GT1548. This is so for following reasons:

– GT1548 has a wide range of pressure ratio from 1.40 at 2.25 kg/min through 2.25 at 3.60 kg/min of airflow, reasonably sufficient for the engine of this size,
– the analysis made for this turbocharger is at a pressure ratio of 2.2 at 3.6 kg/min of air flow, where for these values the efficiency of the turbocharger is only 60%, thus it is able to have enough room for extracting better performance from this turbocharger,
– for the analysis, the compression ratio was assumed at 8.30 as that for the natural aspirated engine so as to achieve a reasonable desired power outcome. While, the value for the compression ratio will tend to decline, and thus justifying the selection of this turbocharger, as a lower compression ratio value will counter the rise of BMEP, although to a very little extent,
– considered a leaner mixture at 1.20 value of the air/fuel combustion factor, the power loss is nominal as that compared to the maximum power that is achieved after boosting. In addition, leaner mixture has reduced the fuel consumption considerably; this can be taken as a win-win solution. This is because; the aim is to lose a nominal power from the downsized engine, while achieving a better fuel mileage,
– in addition, cost of GT1548 turbocharger is reasonable to power loss for a fuel-efficient engine.

4. Summary

As the study followed, the target of the project was to achieve a desirable outcome from the engine after downsizing and air boosting. First, downsized engine by 25% of its initial displacement lost the power output. Thus boosted the same downsized engine with air and analysed how can maximize the benefits of downsizing at the minimum cost of losing the power output and the efficiencies.

From the tabulated information the effect of compression ratio, the air combustion factor and the polytropic exponents of the thermodynamic cycle on the engine performance parameters gave a few conclusions or recommendations for the designing stage. This analysis showed that the higher-pressure ratio (PR) of turbo is the key factor for increased power output in the downsized engines. This leads to a drastically higher brake mean effective pressure (BMEP), making the engine incapable of bearing, such high-pressure and is dangerous. Thus, the higher PR should also accompany in a better compression ratio to counter this rise to some extent. The value of the compression is solely based on the engine dimensions, thus dependent on the bore and the stroke of the engine and the clearance volume of the engine. Thus, the compression ratio can be varied by varying the clearance volume of the cylinder when engine is downsized.

With more air forced into the engine to make the air fuel mixture higher than for the stoichiometric value of 1.00. Thus, a leaner mixture will efficiently burn the fuel, thus increasing the specific fuel consumption of the engine. At the same time, with more air into the engine, it is also add more fuel into the engine for higher power output need and so as also to not to let the air fuel mixture part away too much from the stoichiometric value. The air combustion factor is a crucial factor in deciding the specific fuel consumption of the engine. It also plays a crucial role to counter the rise in BMEP of the engine. Perhaps, at the cost of a considerable power loss from the engine.

From the tabulated data for the effect of polytropic exponent of compression, the results show that higher value for the exponent of compression is very crucial for a better specific fuel consumption and reasonable power output. Although, by boosting the engine, it was tended to reduce the value of the exponent of compression, it is desirable to manipulate its value to a higher degree by whatever means, changing the valve timings, by their positions, or by using a pre-defined fuel. The date for the effect of polytropic exponent of expansion shows that it was drastically lose both, the power and fuel efficiency. Thus, it is highly recommended to have the values for the exponent of compression and expansion the same as that for the natural aspirated engine.

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