# The Development of New Evaluation Criteria for Supercharged Engines Based on Elasticity and Adaptability at Traction

**Ivan Florian, Mihai Stelian Niculae and Dragoş Constantin Neacşu**

**Abstract** This paper aims to outline supercharged engines from the perspective of elasticity and adaptability, starting with the curves of power and torque. As is already known, the diagram of supercharged engine is not similar with the one of natural aspirated engine. As a result, classic coefficients are not suitable for this type of engines, because they can't define in a proper way how the engine is running. Beginning with the particularities of the supercharged engine, in the paper are defined new coefficients which allows to appreciate in a correct way the engine behavior on the vehicle. As a result, are defined the following coefficients: the coefficient of torque diagram flattening, the coefficient of power diagram flattening, the coefficient of stability, the coefficient of instability, the coefficient that define the field of use, the coefficient of adaptability, the coefficient of elasticity, the coefficient of torque reserve, the coefficient of power reserve. Using these coefficients, the authors defined an equation of optimization, termed equation of efficiency, which allows to evaluate in a global way a wide variety of supercharged engines.

**Keywords** Engine diagram · Elasticity · Adaptability · Equation of efficiency · The field of use

## Study Motivation

Over time, internal combustion engines for vehicles have progressed more and more from the perspective of dynamic economic and ecologic performances.

I. Florian · M.S. Niculae (✉) · D.C. Neacşu
University of Piteşti, Piteşti, Romania
e-mail: mihainiculae92@yahoo.com

I. Florian
e-mail: florianivan2002@yahoo.com

D.C. Neacşu
e-mail: neacsudragos54@yahoo.com

 
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The behavior of an engine is evaluated usually by using elasticity and adaptability coefficients

## *Natural Aspirated Engine*

For the natural aspirated engine, as is already known the stability operating area is defined by the maximum torque engine speed and maximum power engine speed (Fig. 1).

Corresponding to this area are defined the classic coefficients of adaptability $k_a$ and elasticity $k_e$.

$$k_e^{na} = \frac{n_M}{n_P} \tag{1.1}$$

$$k_a^{na} = \frac{Me_{max}}{M_P} \tag{1.2}$$

$M_{emax}$—maximum torque; $M_P$—maximum torque at maximum power; $n_M$—maximum torque engine speed; $n_P$—maximum power engine speed; na—stands for natural aspirated

Manufacturers aims to achieve the lower value possible for the coefficient of elasticity and a value equal to 1 for the coefficient of adaptability.

The authors of this paper consider that the classic coefficients are not entirely suitable for a proper analysis of the potential of an internal combustion engine.

Therefore are proposed two new coefficients:

(a) The coefficient of torque reserve:

$$r_M^{na} = \frac{M_{rez}}{M_{emax}} = \frac{M_{emax} - M_p}{M_{emax}} = 1 - \frac{1}{k_a^a} \tag{1.3}$$

$M_{rez}$—Torque reserve

(b) The coefficient of power reserve:

$$r_P^{na} = \frac{P_{rez}}{P_{emax}} = \frac{P_{emax} - P_M}{P_{emax}} = 1 - \frac{P_M}{P_{emax}} = 1 - \frac{M_{emax} \cdot \frac{\pi \cdot n_M}{30}}{M_p \cdot \frac{\pi \cdot n_p}{30}} = 1 - \frac{M_{emax}}{M_p} \cdot \frac{n_M}{n_P} = 1 - k_a^a \cdot k_e^a \tag{1.4}$$

$P_M$—Maximum power at maximum torque; $P_{rez}$—Power reserve; $P_{emax}$—Maximum power

Obvious for these coefficients are desired lower values possible.

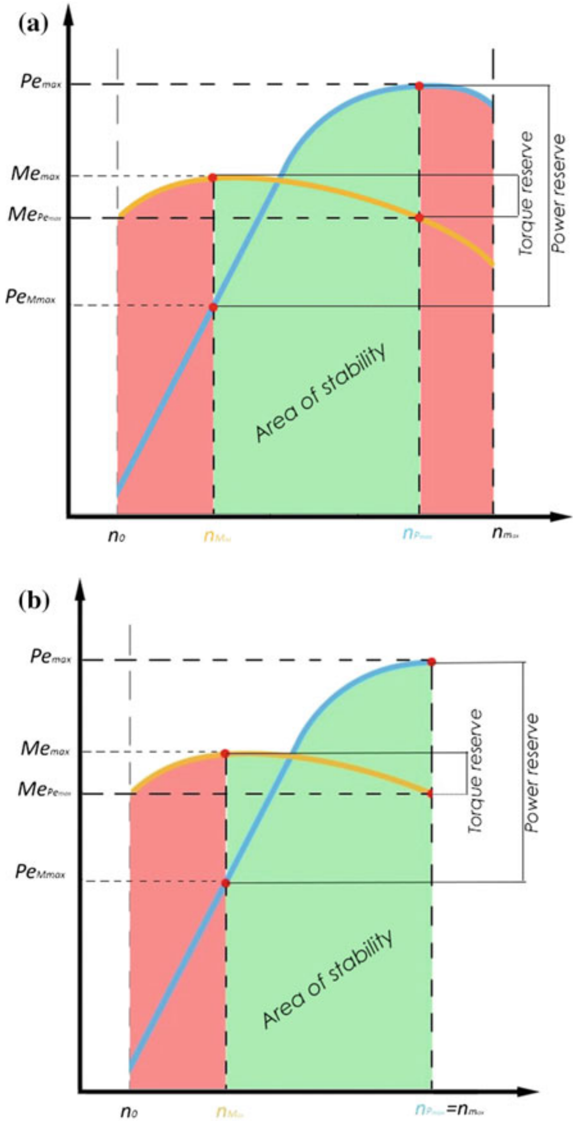


**Fig. 1** Engine diagram of a natural aspirated engine (Ivan 2014). **a** M.A.S. **b** M.A.C

## *Supercharged Engine*

Experience has shown that in case of the supercharged engine the power and torque diagrams are not similar with the diagrams of the natural aspirated engines.

In technical literature are not known coefficients that can define the particularities of a supercharged engine diagram.

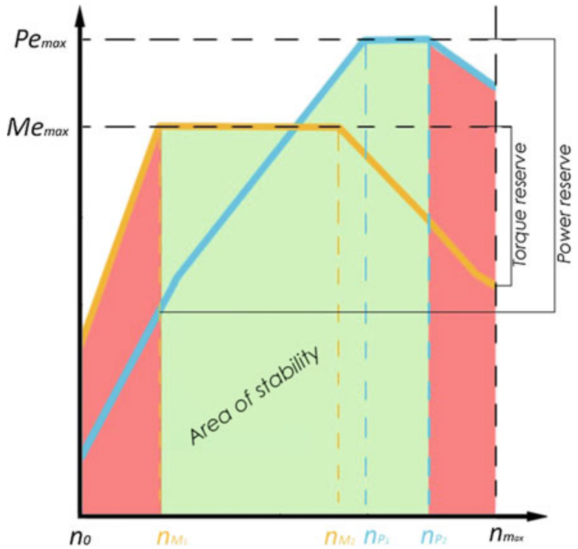


**Fig. 2** Engine diagram of a supercharged engine (Ivan 2014)

Therefore the authors of this paper redefined the coefficients from above for the supercharged engine case (Fig. 2).

The coefficients are:

(a) The coefficient of elasticity:

$$k_e^s = \frac{n_{M1}}{n_{P2}} \tag{1.5}$$

$n_{M1}$—minimum engine speed where the maximum torque is achieved; $n_{p2}$—maximum engine speed where maximum power is achieved; s—stands for supercharged

(b) The coefficient of adaptability:

$$k_a^s = \frac{M_{emax}}{M_{P2}} \tag{1.6}$$

$M_{P2}$—torque obtained at maximum power engine speed;
The coefficient of torque reserve:

$$r_M^s = \frac{M_{rez}}{M_{emax}} = \frac{M_{emax} - M_{p2}}{M_{emax}} = 1 - \frac{1}{k_a^s} \tag{1.7}$$

(c) The coefficient of power reserve:

$$r_P^s = \frac{P_{rez}}{P_{emax}} = \frac{P_{emax} - P_M}{P_{emax}} = 1 - \frac{P_M}{P_{emax}} = 1 - \frac{M_{emax} \cdot \frac{\pi \cdot n_M}{30}}{M_p \cdot \frac{\pi \cdot n_p}{30}} = 1 - \frac{M_{emax}}{M_p} \cdot \frac{n_M}{n_P} = 1 - k_a^s \cdot k_e^s \quad (1.8)$$

$P_{M1}$—maximum power obtained at maximum engine speed

Therefore because the engine torque and power diagrams are flattened, are defined two new coefficients for the supercharged engine.

The flattened area highlights a better behavior of the engine from the perspective of elasticity and adaptability.

(d) The coefficient of torque diagram flattening:

$$a_M = \frac{n_{M2} - n_{M1}}{\frac{n_{M2} + n_{M1}}{2}} = \frac{2(n_{M2} - n_{M1})}{n_{M2} + n_{M1}} \quad (1.9)$$

It is desired that this coefficient to have high values. This coefficient give us information about the capability of the vehicle to climb a ramp in a superior gear without changing gears.

It can be observed that the denominator highlights the area where the curve is flattened.

For example if a vehicle is designed to be a taxi, the flattened area should be preferable in the low engine speed range.

(e) The coefficient of power diagram flattening

$$a_P = \frac{n_{P2} - n_{P1}}{\frac{n_{P2} + n_{P1}}{2}} = \frac{2(n_{P2} - n_{P1})}{n_{P2} + n_{P1}} \quad (1.10)$$

It is also desired to have high values, because it give us information about engine capacity to accelerate in a specific gear.

It can be observed that the denominator highlights the area where the curve is flattened.

Researching the diagrams of a variety of cars it can be observed that the power curve is narrowed than torque curve. (4 times arrowed than the torque curve)

In some cases engines don't have a flattened power curve. Even more, the flattening power curve is situated in the maximum engine speed area.

As a result this area it has no essential significance in terms of dynamic performance. (the differences between a flattened power curve and a classic power curve are not significant)

The authors suggest that this parameter called "the coefficient of power diagram flattening" to not be integrated in the equation of an objective function which allows to appreciate the influence of the supercharged engine diagram over the dynamic performance of a car.

## The Function of Efficiency

The dispersion of the values obtained for these coefficients require defining an objective function which allows an overall assessment over the performances developed by an engine.

This function should be capable to allow to compare a wide range of engines from the perspective of elasticity and adaptability.

The equation that was developed by the authors is named function of engine efficiency—FEE.

- natural aspirated engine:

$$FEE^{na} = \frac{1}{k_e^{na} \cdot k_a^{na} \cdot r_M^{na} \cdot r_P^{na}} \tag{2.1}$$

- supercharged engine:

$$FEE^{s} = \frac{a_M}{k_e^{s} \cdot k_a^{s} \cdot r_M^{s} \cdot r_P^{s}} \tag{2.2}$$

The comparison between engines that equip Unimog trucks:(Figs. 3 and 4; Tables 1 and 2)

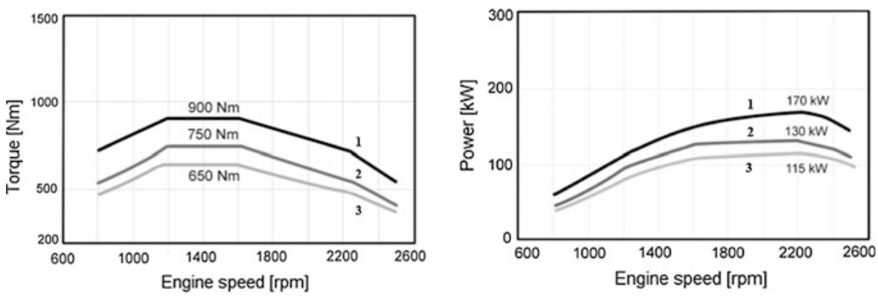


**Fig. 3** Engine diagrams of 4 cylinder version (Technical Manual for Unimog implement carrier BlueTec 6)

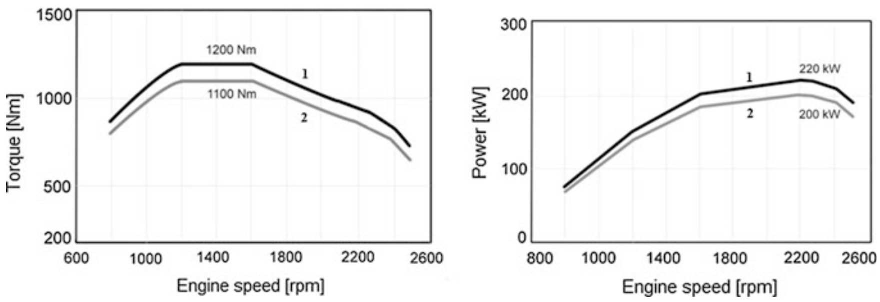


**Fig. 4** Engine diagrams of 4 cylinder version (Technical manual for Unimog implement carrier BlueTec 6)

**Table 1** Engine characteristics

| Engine | OM 934 LA | OM 934 LA | OM 934 LA | OM 936 LA | OM 936 LA |
|---|---|---|---|---|---|
| Version | 934.971 | 934.971 | 934.972 | 936.971 | 936.971 |
| Number of cylinders and alignment | L4 | L4 | L4 | L6 | L6 |
| Maximum power (kW) | 115 | 130 | 170 | 200 | 220 |
| Maximum torque (Nm) | 650 | 750 | 900 | 1100 | 1200 |
| Engine speed at maximum power (rpm) | 2200 | 2200 | 2200 | 2200 | 2200 |
| Idle speed (rpm) | 720 | 720 | 720 | 720 | 720 |
| Total displacement ($cm^3$) | 5132 | 5132 | 5132 | 7698 | 7698 |
| Displacement unit ($cm^3$) | 1283 | 1283 | 1283 | 1283 | 1283 |
| Compression ratio | 17.6 | 17.6 | 17.6 | 17.6 | 17.6 |
| Minimum engine speed where the maximum torque is achieved (rpm) | 1200 | 1200 | 1200 | 1200 | 1200 |
| Maximum engine speed where maximum power is achieved (rpm) | 1600 | 1600 | 1600 | 1600 | 1600 |
| Maximum torque at maximum power (Nm) | 500 | 650 | 750 | 800 | 980 |
| Maximum engine speed (rpm) | 2500 | 2500 | 2500 | 2500 | 2500 |

Technical Manual for Unimog Implement Carrier BlueTec 6

**Table 2** Obtained values

| Engine | OM 934 LA | OM 934 LA | OM 934 LA | OM 936 LA | OM 936 LA |
|---|---|---|---|---|---|
| Version | 934.971 | 934.971 | 934.972 | 936.971 | 936.971 |
| $k_e^s$ | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 |
| $k_a^s$ | 1.30 | 1.15 | 1.20 | 1.38 | 1.22 |
| $r_M^s$ | 0.23 | 0.13 | 0.17 | 0.27 | 0.18 |
| $r_P^s$ | 0.29 | 0.37 | 0.35 | 0.25 | 0.33 |
| $a_M^s$ | 0.29 | 0.29 | 0.29 | 0.29 | 0.29 |
| FEE | 6.00 | **9.19** | 7.58 | 5.59 | *7.03* |

## Conclusions

The optimal version between all engines is OM934-LA (4L), which has a medium supercharge ratio and between the 6 cylinders versions, the optimal engine is OM936 LA which also has a medium supercharge ratio.

As can be seen, engines have the same constructive characteristics, but different types of supercharge ratio.

The proposed method can be applied to any type of supercharged engine and allows selection of the optimal variant from the perspective of dynamic, economic and ecologic performances.

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