COMBUSTION ENGINE INTAKE PORT DESIGN ANALYSIS

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Abstract: *Engine "breath" air through the intake ports. It is important part of every engine which has influence to the final characteristic. In this article is shown from where the design of intake port result. Article shows books theory with compare to 1D CFD analysis.*

KEYWORDS: COMBUSTION ENGINE, ENGINE HEAD, ENGINE PORT, FLOWS, ENGINE MODIFICATIONS.

1. Introduction

Important factor, especially in racing engines is power and torque. Torque is taken from the engine dynamometers measurements or could be calculated from brake mean effective pressure (BMEP). Power is a value which results from torque and rotational speed of the engine.

Another important factor is delivery ratio (DR). It is talking about how many air is taken by the engine. It is different than volumetric efficiency because it takes into account the air density which for example various with altitude. Increase of DR gives increase of BMEP, torque and power.

$$DR = \frac{M_{cycle}^{air}}{\rho_{ref} V_e} = \frac{\frac{60}{N}}{360} \frac{\int_{tdc}^{bdc} C_d \rho C A_t d\theta}{\rho_{ref} V_e} \sim \frac{\int_{tdc}^{bdc} A_{stp} d\theta}{6NV_e} \quad (1)$$

where:
ρ_{ref} – air density
C_d – discharge coefficient
C – particle velocity
A_t – flow area
A_{sta} – specific time area
Dθ – crank angle

It have to be explained that A_t is a side area of cone in geometry meaning (fig. 1). It is characterized by valve lift, valve diameter, valve and valve seating shape. Flow area vary with crank angle.

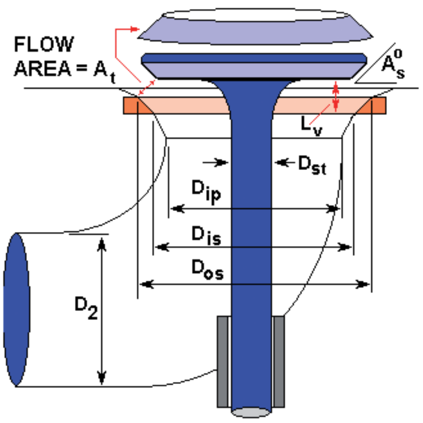

Fig. 1 *Valve and port geometry [1].*

Engine "breath air" through the intake ports. They should:

- maintain the lowest possible air flow resistance,
- be designed with accordance to the wave and dynamic theory,
- be smoothly connected with intake manifold and design
- should take into consideration valves (valve profile, valve seat and valve guide).

Area of the duct cannot be too high or too low. Lower area provide higher flow resistance but gives better dynamic boost and it is better on lower revolution velocity. Fig. 2 shows how change volumetric efficiency with different parameters of K_1 and K_2 (Brandstetter critic numbers), where:

$$K_1 = \frac{L_D}{120} \frac{n}{a} \quad (2)$$

$$K_2 = \frac{L_D}{s} \left(\frac{d_d}{D}\right)^2 \quad (3)$$

where:
L_D - intake duct length
n - RPM
a -local sound velocity
s- engine stroke
d_d - port diameter
D - cylinder diameter [3]

Many scientists assumed that duct area should give velocity of air between 40 and 70m/s [2][4][3].

However document [1] says that the best is velocity near to 0,5 mach.

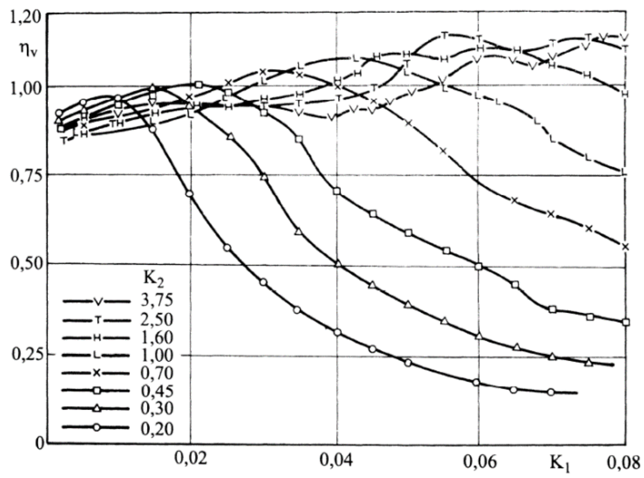

Fig. 2 *Volumetric Efficiency versus critic numbers K_1 and K_2 [3].*

Optimal ratio of manifold area to port area is described in [1] by K_m coefficient.

$$K_m = \frac{A_{manifold}}{A_{port}} = \frac{D_2^2}{n_v \, x \, (D_{ip}^2 - D_{st}^2)} \quad (4)$$

Km in case of exhaust should be in range 1.2 to 1.4
Km in case of intake should be in range 0.9 to 1.0
Diameters are described on fig. 1.

As it was mentioned previously, because of dynamic charging length of duct is strongly connected with engine volumetric efficiency (fig. 3).

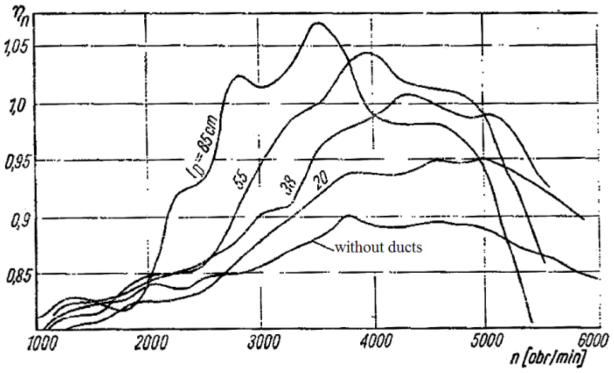

Fig. 3 *Volumetric efficiency versus intake length [2].*

Most popular formulas to calculation of intake length values are Chrysler formula:

$$L_D = \frac{6a}{n} \pm 0{,}075\ [m] \quad (5)$$

and French brands formula:

$$L_D = \frac{2574}{n}\ [m] \quad (6)$$

where:

L_D-intake duct length,
n- RPM in which works dynamic charging,
a-local sound velocity [4].

2. Investigated Engine

Engine under investigation is GM 500. That is 500 ccm, one cylinder engine which was built in 1983 and is still one of the best engine in speedway competition. Engine is also commonly used in karts. Can be also used in Formula Student competition. It has 4 valve engine head with two camshaft inside. It produce brake power about 50 kW in 10000 rpm. Those engines has many configuration and many tuners are trying to improve them.

Engine has been simulated as a 1 dimensional CFD model, which takes into consideration wave, dynamic engine flow phenomena and flow resistances. It allows to choose the best intake, combustion and exhaust system configuration without expensive real measurements.

External characteristic of the engine model correlate with real parameters. Fig. 5 and fig. 6 shows computed power and torque characteristic.

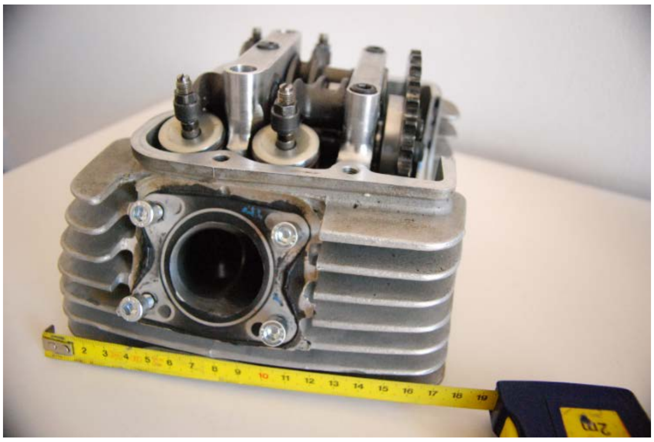

Fig. 4 *Investigated engine head inlet port.*

Table. 1 *GM 500 Engine parameters.*

No. Of cylinders	1
Strokes per cycle	4
Engine Type	Spark Ignition
Power	52 kW/10000 rpm
Torque	55 Nm/8200 rpm
Bore	90 mm
Stroke	78,5 mm
Displacement	496 ccm
Connecting rod lenght	166,5 mm
Compression Ratio	17
Engine head	OHC / 4 valves

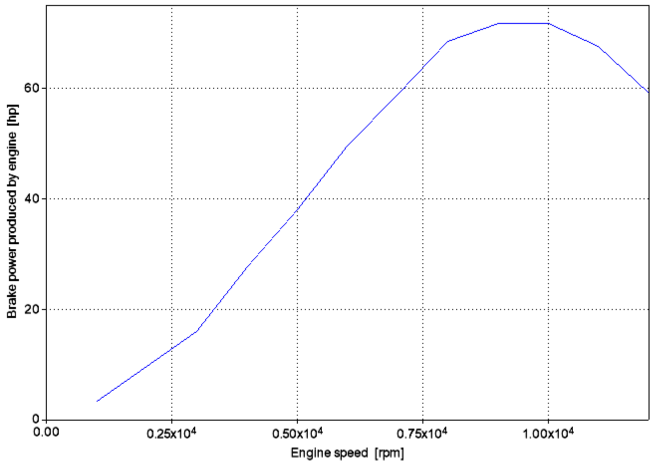

Fig. 5 *Computed characteristic of power.*

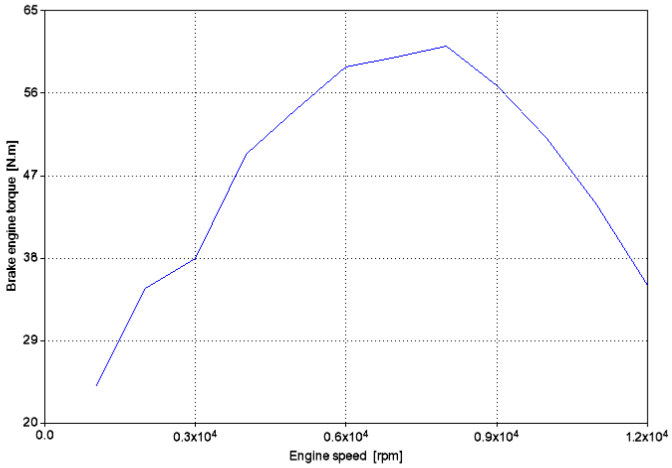

Fig. 6 *Computed characteristic of torque.*

Engine ports has been scanned in 3D. The result was cloud of points. Fig. 7 shows model which was prepared based on scan. On the left side is exhaust port, on the right side is intake port.

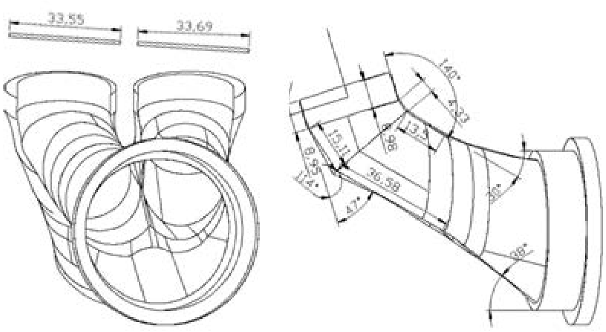

Fig. 7 *Inlet port model.*

3. Analysis of the problem

Fig. 8 shows the schema of the ports. Eliptical cross section in CFD model was adopted to rounded cross section, where the diameter is the average value of both elliptical axes. Intake port is going narrow in the center part. Main idea was to make this area wider together with individual ports for each valve

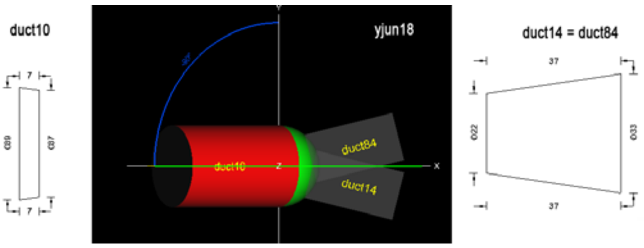

Fig. 8 Inlet port schema.

Investigated variants were:

a) Standard design (yjun18 Ø38) (fig. 8),

b) duct10 Ø39 mm to Ø42 mm; yjun18 Ø42 mm and duct14/84 Ø25 mm to Ø33 mm,

c) duct10 Ø39 mm to Ø44 mm; yjun18 Ø44 mm and duct14/84 Ø26 mm to Ø33 mm.

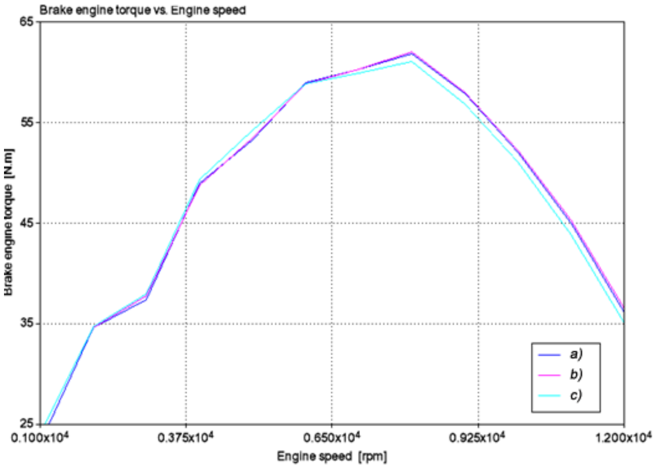

Fig. 9 *Computed torque characteristic before and after modification of inlet port.*

Standard port design gives better torque (and power) about 5000 rpm. Based on that it can be sad that increase in port area makes increase in engine parameters. Increasing of port area destroy characteristic of the engine. Options b) and c) gives higher power output but worst torque about 5000 rpm (fig. 9).

Lowering exhaust ports give smaller torque in high engine speed and higher in low engine speed. However low engine speed is assumed as less important in motorsport engine.

4. Summary

Summarizing modelling of engine was successful. Final results presented by the model and from dynamometer are related enough. Phenomena effect of geometry changing in theory and in simulated engine are similar. Shortening and increasing area of ducts makes high torque on high engine speed.

Final improvement gives higher power, up to 1,5 hp and about 1 Nm higher torque in wide range of engine speed. The maximum power could be higher but then engine torque would be worst.

5. Bibliography

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