Increasing of Power Output of Racing Motorcycle Engine using of Exhaust System Optimisation

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BIOGRAPHICAL NOTES

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KEY WORDS

Temperature of Exhaust System, Engine Output Performance

ABSTRACT

An exhaust gas system of a two-stroke piston combustion engine has a significant impact on its maximal power output and speed characteristics. In the first part of this paper there is described an impact of the exhaust gas pipeline system on the output speed characteristics. In the second part is analysed a relation between temperature of exhaust gases and speed characteristics, as well as there is determined an optimal temperature for achievement of the best output characteristics. Results presented in this paper enable to optimise curve of the speed characteristics for application in various kinds of single-track vehicles.

INTRODUCTION AND AIMS

An exhaust system is the important supplement of the all engines. It has got the determining influence on engine outgoing parameters for the engines with two-stroke operating cycle. Gas flow in an exhaust system is controlled by means of the difficult principles of non-stationary convection with very difficult calculation. Although the existing special software reached the certain voluminous results, the main merits of work are still in the verification of calculated values on a testing engine. In practice, in most motorcycle firms which are the leaders for development, there are designed several modifications of exhaust systems according to generally known rules. These modified systems are tested and consequently improved with output brake engine tests. One exhaust system is suitable theoretically only for one value of engine speed. It is rather small speed range in practice. The final modification of exhaust system is accommodated to the most using speed values considering the operation possibility in its other modes.

In a cylinder on a piston top edge there is an impulse created by means of the opening of exhaust port. It causes an overpressure wave which is spreading into an exhaust manifold in existing environment with sound speed. In an exhaust manifold there is the sound speed much higher than in the open air. Exhaust manifold gases are step by step exposed the pressure wave influence. In consequence of this fact the gases begin to move outwards from an engine. But there is a reflection back of pressure wave from the opposite cone (Fig.1) what causes the gas oscillation following a longitudinal axle of an exhaust stroke. The aim of the correct dimensioned exhaust system is to improve exhaust of gases from a cylinder and this way to improve the scavenging process. During scavenging of working space with overflowing streams there is the certain mixing of combustion products and fresh fuel-air mixture. The part of fresh fuel-air mixture leaks out into an exhaust port. A fuel-air mixture and combustion products mixing continues there. Close by an engine the gas mixture contains rather few combustion products [3]. That is why there is the effort dimensionally to dispose the exhaust system so that the back movement occurs in the final phase. This back movement comes into existence by reason of the oscillation and again there is the return of off-take gases into the cylinder working space [2].
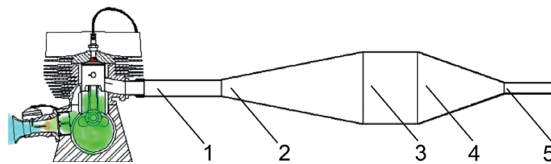

Fig. 1 *Parts of Exhaust System: 1-exhaust pipe, 2- expansion cone, 3-rezonator, 4- opposite cone, 5- fishtail*

The fuel-air mixture, which contains lower percentage of combustion products, can be used at combustion. In the Fig.1 there is the design of exhaust system with two-stroke engine in the section [4].

The aim of this article was established in consequence of the described theoretical knowledge about combustion products oscillation in an exhaust system:

"to increase the output of two-stroke combustion engine by means of exhaust system optimization with keeping its main technical parameters (a diameter of diffuser in carburator, a shape of ignition curve, an origin mould of engine bloc and a compression ratio)"

The following steps are connected to this main aim:

■ *analysis of exhaust system length influence on a maximum engine output and a range of exploitable engine speed,*

■ *analysis of combustion product temperature influence in an exhaust system on a maximum engine output and its position in engine speed range.*

1 Experimental Models and Devices

That is very difficult to develop theoretically the individual components and then to demonstrate the components influence on the output parameters and torque of two-stroke petrol engine. Although there is software for modelling of processes which are operating inside a cylinder and an exhaust system during the combustion, the real results are performed seriously. That is why the experiment was used to achieve the main aim.

It is necessary to choose the experimental model for experimental measurements. The development was realised with this experimental model. Further it is a need to develop the measurement devices (to provide feed back, to give information about a real output proposition for concrete change in an exhaust system).

1.1 Experimental Models

The motorcycle Aprilia RS 125 was used as the first experimental model. This single-track vehicle is equipped with the two-stroke engine ROTAX 122

(Fig.2). In Tab.1 there are the technical parameters of serial version for this engine (specified by producer). Output parameters of our engine ROTAX 122 are higher because we used some racing parts (cylinder, head of cylinder and other parts). But these parts doesn't have an influence on results of this experiment.
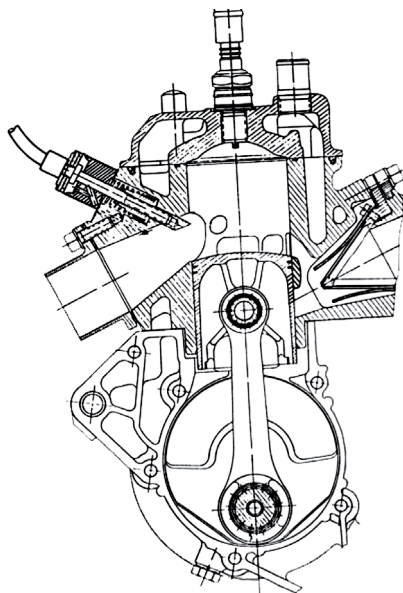

Fig. 2 *Engine ROTAX 122*

Type	a single-cylinder, a two-stroke engine, liquid cooled, membrane filled, an electrical-controlled exhaust power valve
Capacity	124,8 cm^3
Bore x Stroke	54 x 54,5 mm
Compression ration	12,5 ± 0,5:1
Max. output	21,8 kW (29,3 HP) – 11 000 rpm
Max. torque	19,1 Nm (1,95 kpm) – 10 000 rpm
Carburator	Dell'Orto PHBH 28 BD

Tab. 1 *Technical Parameters of Engine ROTAX*

The motorcycle Honda RS 125R was used as the second experimental model. The second single-track vehicle is equipped with the engine Honda 125. The principle of filling and scavenging of this engine is similar as that is for the engine ROTAX 122. The technical parameters of serial version of this motorcycle are also similar. Only the diameter of carburator diffuser (39 mm) in the shape of an ignition curve is different and that is why a maxi-

mum output is higher.

1.2 Experimental Devices

Two testing and measuring devices were developed for a need of experimental measurements.
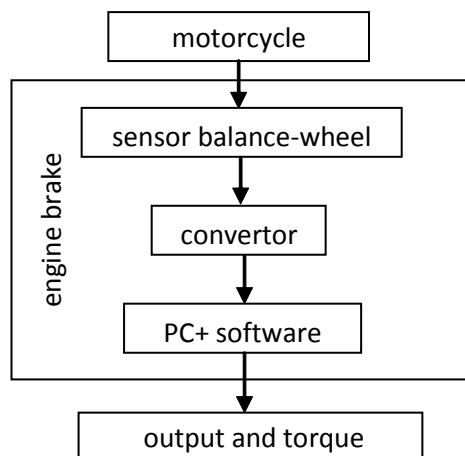

Fig. 3 *Output (Engine) Brake*

Fig. 4 *Block Diagram of Engine Brake*

Output Engine Brake

That is a starting dynamic brake (Fig.3). Its advantage is a possibility to obtain an output–moment characteristic during several seconds. A measurement is performed in place that is why a testing ring is not needed. In Fig. 4 there is the block diagram for data measurement, data operating and data evaluating. The principle consists in an accelerating of constant mass (balance-wheel) which has got a constant moment of inertia. The sensor, which is set on the brake frame, scans every revolution of the balance-wheel and time when the revolution is done. The program determines an average of times from the certain number of revolutions. The time-lag between individual averages is pro-

portional to an output increment. The operating period of one measurement is relative short (circa several seconds). After what the measurement is finished, the software calculates the functional relation among engine output, torque and engine revolutions (Fig. 6).

Engine Watch and Control System – EWaC

That is a data-recording system, i.e. a device which scans and stores information during a motorcycle ride (in real conditions, in real loading). This device makes possible to diagnose parameters of a two-stroke combustion engine: an output, a torque and their behaviours, a temperature of exhaust system and its behaviour, detonating strokes and their number per time unit and other characteristics. A number and a kind of scanned parameters are related to the types and a number of sensors which are installed on the two-stroke. The block diagram for data measurement, operating and evaluation is similar as output engine brake is but there is a difference of its output. The engine activity record in dependence on time is the result of this system.
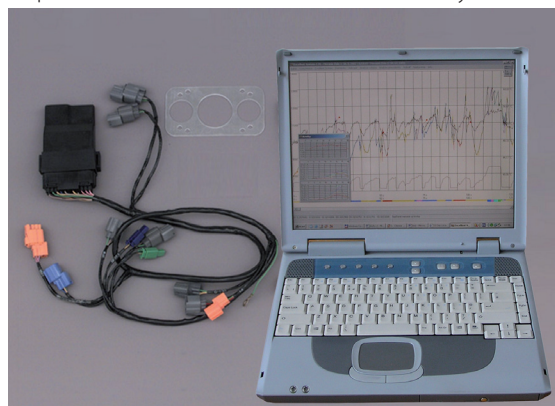

Fig. 5 *Engine Watch and Control System*

The principle of EWaC system is in the measurement of the engine instantaneous speed, an instantaneous temperature of exhaust system and scanning of active speed gear or further parameters. The system does a functional record of engine activity on the base of scanned and entered data (a wheel circumference, gear ratios of individual speed gears, a curve of air resistance and a motorcycle weight). This record is stored in the memory of EWaC system. After finishing of the measurement, it is possible to copy the record by mean of parallel port into PC (Fig. 5). On PC display (Fig.10) there is the record of engine activity in dependence on a time axis graphically presented (by means of the software which is a component of EWaC system). Every point of the record covers an instantaneous speed, detonating strokes, a temperature of exhaust system and an output at a crank shaft end [5, 6].

2 Experimental Results

2.1 Analysis of Exhaust System Length Influence on Output Characteristic

The performed measurements are intent on the analysis of an exhaust system length influence with an output characteristic in consideration of the defined aim. The motorcycle Aprilia RS 125 was used as an experimental model. Aprilia RS 125 is equipped with the engine ROTAX 122 (Fig. 2).

A standard exhaust system, used in the motorcycle Aprilia RS 125, was applied for the first measurement APR1. The second measurement (APR2) was performed with the same exhaust system which had the 5-mm-trimmed exhaust pipe (Fig.1). For the realisation of APR3 measurement there was the exhaust system again shortened. The system had the 10-mm-trimmed exhaust pipe.

The measurement device was used the output engine brake (Fig. 3). In Fig. 6, 7, 8 there are illustrated graphically the measured dependences of an output and a torque on engine speed with using of various exhaust system variants. An upper curve represents the dependence an output on revolutions; a bottom curve represents the behaviour of torque. In Fig. 9 there is the comparison of these measurements.

The range of exploitable speed, i.e. revolutions in which there is constantly kept the high value of instantaneous output (over 22,4 kW, i.e. 30 HP) and the torque (over 19,6 Nm, i.e. 2 kpm.), is the most important parameter in term of the practical application. In Tab.2 there are the measurement results and the individual ranges of exploitable engine speed displayed.

Axis: x - axis revolutions per minute, y - axis (left) output [HP], i.e. x0,7457[kW], z - axis (right) torque [kpm], i.e. x9,81[Nm], This system operates only with HP and kpm.

Upper legend in the graphs: MOTOR - engine, VYFUK - exhaust port, KARB. - carburettor, ZAPAL. - ignition, Q.S.K. - capacity of combustion space, STRB. - distance between the piston and head, TLAK - pressure, TEPL - temperature, VLHK. - humidity, BENZ. -

petrol, **Pmax = 34.2/11318 rpm, Mkmax = 2.22/10723 rpm**

MOTOR: APRILIA RS 125
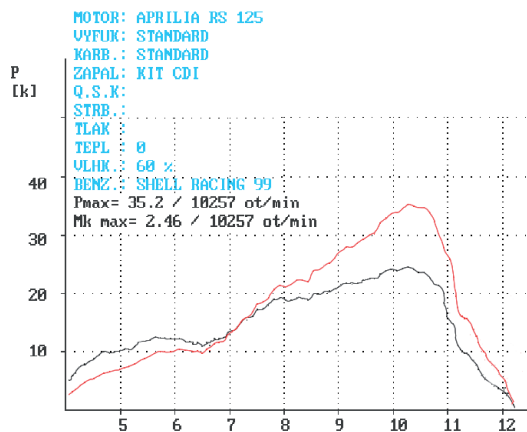VYFUK: STANDARD
KARB.: STANDARD
ZAPAL: KIT CDI
Q.S.K:
STRB.:
TLAK :
TEPL : 0
VLHK.: 60 %
BENZ.: SHELL RACING 99
Pmax= 35.2 / 10257 ot/min
Mk max= 2.46 / 10257 ot/min

Fig. 6 *Output and Torque Behaviour with Using of Standard Exhaust System (APR1)*
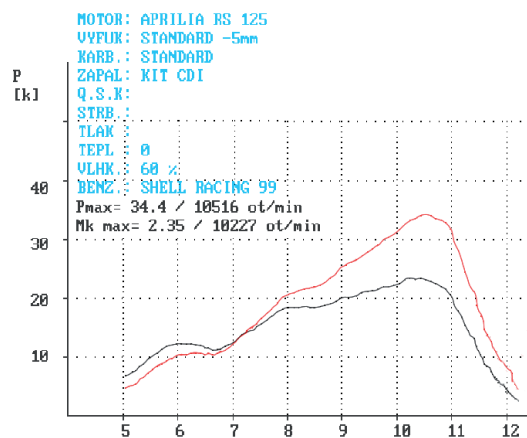
MOTOR: APRILIA RS 125
VYFUK: STANDARD -5mm
KARB.: STANDARD
ZAPAL: KIT CDI
Q.S.K:
STRB.:
TLAK :
TEPL : 0
VLHK.: 60 %
BENZ.: SHELL RACING 99
Pmax= 34.4 / 10516 ot/min
Mk max= 2.35 / 10227 ot/min

Fig. 7 *Output and Torque Behaviour with Using of 5-mm-trimmed Exhaust System (APR2)*

MOTOR: APRILIA RS 125
VYFUK: STANDARD -10mm
KARB.: STANDARD
ZAPAL: KIT CDI
Q.S.K:
STRB.:
TLAK :
TEPL : 0
VLHK.: 60 %
BENZ.: SHELL RACING 99
Pmax= 34.2 / 11318 ot/min
Mk max= 2.22 / 10723 ot/min

Fig. 7 *Output and Torque Behaviour with Using of 5-mm-trimmed Exhaust System (APR2)*

MOTOR: APRILIA RS 125
VYFUK: STANDARD
KARB.: STANDARD
ZAPAL: KIT CDI
Q.S.K:
STRB.:
TLAK :
TEPL : 0
VLHK.: 60 %
BENZ.: SHELL RACING 99
Pmax= 35.2 / 10257 ot/min
Mk max= 2.46 / 10257 ot/min
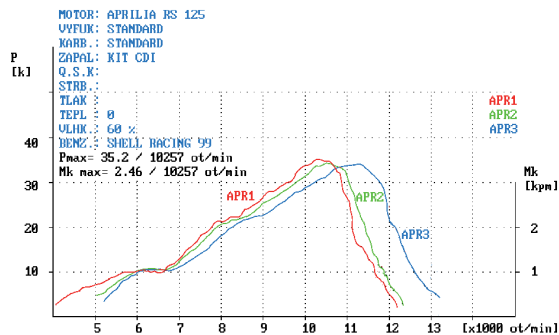
APR1
APR2
APR3
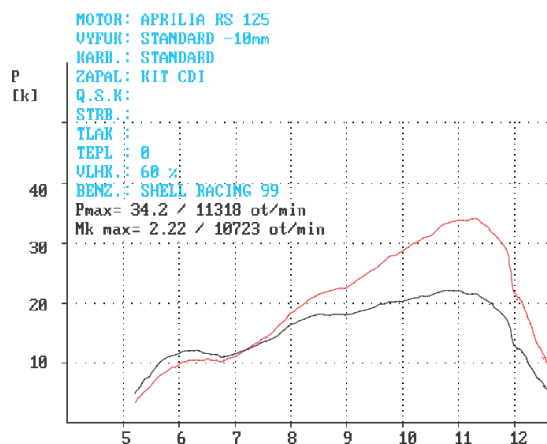
Fig. 9 *Comparison of Output Behaviours with Using of All Three Exhaust Systems*

	Speed range with the output over 22,4 kW (30 HP) n [rpm]	Speed range with the torque over 19,6 Nm (2 kpm) n [rpm]
Standard exhaust system	1200	2000
5-mm-trimmed standard exhaust system	1250	2000
10-mm-trimmed standard exhaust system	1500	2000

Tab. 2 *Measurement Results*

2.2 Analysis of Combustion Products Temperature Influence in Exhaust System for Output Characteristic

When the exhaust system length is shortened the maximum output and the maximum torque are moved into higher operating speed of the two-stroke combustion engine. That is valid at a constant temperature and a constant pressure .

And similarly the sonic wave rate of spread depends on a pressure and a temperature (1) according to the undulatory theory [1,2].

$$C = \sqrt{K \times \frac{R \times T}{M}} \qquad (1)$$

where: C sonic waves rate of spread; K ratio of specific heats; R gas constant; T temperature; M molar mass

A sonic wave rate of spread increases with an accumulative temperature in the exhaust system (1). A maximum and minimum temperature exists theoretically for every exhaust system, defined shape

and dimensions. The output and torque behaviours increase the most effectively in this thermal interval because the scavenging of two-stroke engine cylinder is optimized by means of the exhaust system. With regard to above-mentioned assumption, the experimental measurements were performed on the base of this prediction and these measurements were intent on the explanation of combustion products temperature in an exhaust system for an output characteristic of two-stroke combustion engine. The measuring device was the Engine Watch and Control System (EWaC system) (Fig. 5). The motorcycle Honda RS 125R was used as an experimental model.

The aim of measurements was defined for the optimal operating thermal interval to achieve a maximum output for used exhaust system.

Three thermal states were used for the measurement in the exhaust system:

1. Thermal interval from 440 to 540°C (Fig. 10)
2. Thermal interval from 520 to 620°C (Fig. 11)
3. Thermal interval from 600 to 720°C (Fig. 12)

The temperature values were measured at points where the temperature of exhaust system reaches the maximum, i.e. in the area of exhaust pipe, approximately 150 mm from the upper edge of exhaust port (Fig.1). In the outputs from EWaC system there are displayed the record of engine activity in dependence on time. That is illustrated by means of an upper curve. The concrete section, delimited with both sides, is selected from this curve. In this section there are performed the output analysis (left smaller window) and the temperature analysis of combustion products in an exhaust system (the curve in the middle of the picture). This system operates only with HP and Nm.

Fig. 10 *Activity Record and Output Behaviour of Two-Stroke Engine in 1st Thermal State*
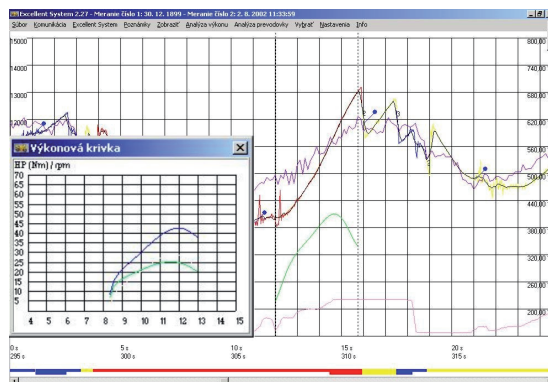

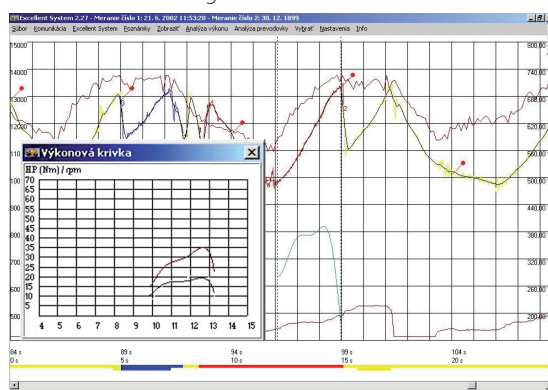Fig. 11 *Activity Record and Output Behaviour of Two-Stroke Engine in 2nd Thermal State*

Fig. 12 *Activity Record and Output Behaviour of Two-Stroke Engine in 3rd Thermal State*

An sonic waves rate of spread increases with accumulative temperature (1). In the exhaust system a back wave returns quicker and so the back scavenging process of a cylinder is accelerated. Theoretically, an exhaust system is shortened.

An exhaust system temperature hast to rise with the increasing revolutions of optimal adjusted engine therefore the exhaust system is theoretically shorter at higher speed and theoretically longer (with lower temperature) at lower engine speed.

The maximum output and the range of exploitable speed, i.e. revolutions with high value of instantaneous output is constantly kept (over 22,4 kW, i.e. 30 HP), are important parameters for the practical use.

In Tab. 3 there are the measurement results, the maximum outputs and the ranges of exploitable speed in the individual thermal intervals.

	Maximum output P [kW (HP)] / n [rpm]	Range of exploitable speed n [rpm]
1. Thermal interval: from 440 to 540°C	31,3 (42) / 13000	2700
2. Thermal interval: from 520 to 620°C	32,1 (43) / 12000	3000
3. Thermal interval: from 600 to 720°C	26,1 (35) / 12500	1100

Tab. 3 *Measurement Results*

3 Conclusions

According to the measurement results analysis in last section the shortening of exhaust system length in the area of exhaust pipe induces the transfer of a maximum output and a maximum torque to the higher operating speed of two-stroke combustion engine. Simultaneously the range of operating speed (i.e. revolutions, in which the engine reaches the constant high output, over 22,4 kW, i.e. 30 HP) is wider. The next contribution is the more fluent increasing of an output and a torque what provides better steering control. This knowledge makes possible the variability of output curve according to the concrete necessity of given single-track vehicle.

According to the measurement results analysis, the <520; 620°C> is the optimal interval of operating temperatures in an exhaust system for this two-stroke combustion engine. The engine reaches the perfect output 32,1kW (43 HP) at 12 000 rpm and the range of exploitable speed is 3000 rpm. However, the conditions are not so optimal in this interval of limited values 520°C and 620°C. The highest output is reached if the temperature converges in an exhaust system to the mean value of interval, i.e. 570°C. The temperature in an exhaust system increased with an output what is characteristic for an optimal adjustment.

In thermal interval <440; 540°C> there was the maximum engine output lower and the range of exploitable speed decreased as well. The exhaust system was overcooled thus theoretically shorter. That is valid predominately for the temperature 440°C. The exhaust manifold is theoretically shortened toward an upper limit of interval and the en-gine characteristics are improved significantly.

In thermal interval <600; 720°C> there was the maximum engine output the lowest and there was the range of exploitable speed practically unavailable. That is valid predominately for the temperature 720°C. In lower limit of interval 600°C there are good output characteristics. The output parameters make significantly worse with the increasing temperature. The system is overheated and theoretically the exhaust manifold is excessively shortened.

In the exhaust manifold the low temperature means that there is an overrich mixture (fuel redundancy) and it follows an imperfect burning.

In the exhaust manifold the high temperature means that there is a weak mixture, it smoulders out in the exhaust manifold, the combustion process takes longer time (fuel lack).

In the exhaust manifold the optimal temperature means that the composition of mixture is optimal and heat is changed into mechanical energy with the high efficiency.

It follows that a temperature in an exhaust system has got a cardinal influence on an engine output characteristic. That is why it is necessary to ensure its optimal interval. It will be important for this thermal interval where the temperature increases proportionately with an operating engine speed and an engine load. It causes theoretically the lengthening (for lower operating engine speed) and theoretically the shortening (for higher operating engine speed) of an exhaust system. This effect provides a higher output in the whole regime of revolutions and decreases a production of emission because there is more perfect combustion here. Now, the highest efficiency of two-stroke combustion engine will be provided.

4 Acknowledgement

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