

Original Research Paper

# Something about the V Engines Design

<sup>1</sup>Raffaella Aversa, <sup>2</sup>Rely Victoria Petrescu, <sup>1</sup>Antonio Apicella,  
<sup>2</sup>Florian Ion Tiberiu Petrescu, <sup>3</sup>John Kaiser Calautit,  
<sup>4</sup>Ronald B. Bucinell and <sup>5</sup>Bilal Akash

<sup>1</sup>Advanced Materials Lab, Second University of Naples, Naples, Italy

<sup>2</sup>IFTToMM, ARoTMM, Bucharest Polytechnic University, Bucharest, Romania

<sup>3</sup>Department of Mechanical Engineering, University of Sheffield, Sheffield, United Kingdom

<sup>4</sup>Union College, United States

<sup>5</sup>Dean of School of Graduate Studies and Research, American University of Ras Al Khaimah, United Arab Emirates

## Article history

Received: 24-04-2016

Revised: 20-11-2016

Accepted: 30-12-2016

## Corresponding Author:

Florian Ion Tiberiu Petrescu  
 Bucharest Polytechnic  
 University/IFTToMM-  
 ARoTMM;  
 Vice President of IFTToMM,  
 ARoTMM Bucharest branch;

Staff of Board of the Robotics  
 Society of Romania, Bucharest  
 branch;

Director of Master MSSMM,  
 Mobile Mechanical Systems  
 Modeling and Simulation, TMR  
 Department, Bucharest,  
 Romania, Europe;

Staff of Board of SP Group, SP  
 Ethics Committee member,  
 AJEAS EIC.

Member of SIAR, FISITA,  
 AGIR, SRR.  
 Email: scipub02@gmail.com

**Abstract:** First time the corresponding author has studied these problems of motors in V, in the framework of some contracts made with the research collective of UPB and “Autobuzul” plant, in years 1980-1986. In the first phase, have been studied the vibrations and noises of an engine in V, their transmissibility from the engine to the chassis and the cab driver and the possibility of reducing vibration (of the engine or the submitted) by their insulation. Reducing the vibration transmitted, has taken place in various ways, but their level at the driver’s seat and the passengers was still too large, much more than the allowed limits international. The vibrations were still more than the allowed limits, while in a similar engine Otto or diesel in a straight line, they were in line with the normal limits, until at last it was decided to change the type of the engine. The idea of the paper’s authors was: “It can be synthesized one motor in V only by changing the alpha angle value (the constructive angle of a V engine)”. By this method it is possible to change the kinematics of this motor and in the same time its dynamic work. Generally the constructive angle of an engine in V was calculated in function of the number of cylinders and by the engineering condition to achieve an ignition distributed uniformly to all cylinders. This paper try to solve the principal problem of any motor in V (noise and vibration) having in view that one motor in V is more dynamic, more powerful and has a higher yield than any other heat engine. The solution was found and it is very simple to be implemented. It needs only an angle value change. It’s about the constructive angle, alpha. Calculations to demonstrate this fact and all the theory are very difficult and heavy. But the final result is very simple.

**Keywords:** V Engines, Constructive Angle, Dynamic Synthesis, Forces, Velocities, Powers, Efficiency, Dynamic Coefficient

## Introduction

Internal combustion engines works seamlessly 150 years.

Both types of heat engines, the proposed by Otto and the invented by Diesel, both types being in the four-stroke, they have imposed, as being the best, more robust and more reliable, more economic, more silent, more compact, most dynamic, more adaptable and diversifiable.

Heat engines have constituted the starting point of the modern technologies. In the first years after their appearance, the attraction for automobiles was made public and more. Slowly, slowly, has developed a cult of automobile king. Cars have come in a short time on the first plan from all points of view.

Even today after 150 years, the automotive industry is still on the first place in the world. Billions of jobs in direct industries or related.

Auto industry means and an unprecedented growth of all industries and technologies, to solve as well as the various requirements imposed by the construction and diversification of the types of motor vehicles.

The motors driven by the crank recently replaced from those with external combustion have now been superseded almost completely by those with internal combustion.

Now was started another world and another one age.

Applications for personal cars have increased so much that the park the world in current use has exceeded the already a billion.

Even if today they are used massively electric motors, however most of the engines being in use are all those with internal combustion (in particular those of type diesel injection or Otto).

As long as we produce electrical current and by the burning of fuels fossil, we can't replace too fast all internal combustion engines with electric motors, since pollution and consumption would still be much higher.

For this reason we have yet the obligation to continue to develop the thermal engines internal combustion to constantly improve, in order to reduce as much fuel consumption and noise level produced by them.

People do not want to give up on their own car, even under the conditions of fuel price very much.

Internal combustion engines in V are the most dynamic, working with high mechanical efficiency. Their main problem is functioning with high vibration and noise. This is mainly due to the fact that the spindle crankpin receives impulses from two pistons simultaneously. In general the two pistons through connecting rods besides transmit the desired movement and additional forces targeted differently. To adjust these forces to work properly in terms of dynamic authors of the paper conducted a comprehensive study on the functioning engines in V.

V engines have always been rated as the most dynamic. For this reason they were desired by the Formula 1 pilots, but also and by many drivers willing to drive a car dynamically (nervous) (Christensen *et al.*, 1999; Dahl *et al.*, 2013; Dahl and Denbratt, 2012; Dempsey *et al.*, 2013; Dernotte *et al.*, 2014; Erjavec, 2009; Kavuri *et al.*, 2016; Kitamura *et al.*, 2002; Kokjohn *et al.*, 2011; Li *et al.*, 2007; Ludvigsen, 2005; Manente *et al.*, 2011; Ozasa *et al.*, 2016; Pan *et al.*, 2016; Petrescu and Petrescu, 2011; 2012; Reed *et al.*, 2016; Rezaei *et al.*, 2016; Schmitt and Boulouchos, 2016; Sellnau *et al.*, 2015; Shahlari *et al.*, 2013; Sjöberg *et al.*, 2002; Warnatz *et al.*, 2006; Wong *et al.*, 2016).

All the experiments carried out in the years 1980-1986, have shown values too high for Vibrations and noises produced by the engine in V. Have tried very many types of rubber shock absorbers (for to reduce vibrations transmitted from the engine to the chassis and by the driver's cab). Only three models gave better results. A model for the shock absorber pad Dunlop, a model of the shock absorber from vehicles of ARO four-

wheel drive and a French model, adjusted by our team of research. At the end of the research, it was decided unanimously, the replacement of the engines in V with the axle in line, or with the axle in line (as a pseudo V engine). Practically in those moments was signed "death certificate" of the engines in V. The contract for the international research, attended, UK, USA, Canada, Germany, Italy, France, Romania, etc. After this moment almost all of the engines in V used on motor vehicles, have been replaced with engines in line with the yield of the lowest, but also with a vibration level little attenuated. It has been lost from the efficiency of the engine, but the level of noise and vibrations was falling within the limits prescribed by the standards in force.

The engines in V so loved by the public have started to disappear after years 90 and more may be found from time to time, only on tractors, at some trucks or locomotives and on some vessels high tonnage.

## History and Overview

The engine in V belongs to the category of internal combustion, which group together on a single crankpin axis a pair of pistons, who works in the cylinders having regard the shafts of the guide, positioned in such a way as to form a fixed angle  $\alpha$  (located around the  $90^\circ$ ). Thus, the two axles it is essential to pass through the main axis of the crankshaft (the axis of the trunnion bearing). The fundamental idea in the construction of a real engine (Classic) in V is that a single crankpin axis to be operated, practically simultaneously by two pistons, what can be seen in Fig. 1.

In the case of the engines in line in two-stroke engines (here as it is about heat engines with internal combustion type Lenoir, Otto or diesel), the best balance shall be carried out on the engine with three cylinders, while the engines in line in the four-stroke, optimum balance appears at the six cylinders. Corresponding to the solutions in V we have a good balance for engines with six cylinders (V6), but the optimal solutions are carried out by the construction of engines with 12 and 16 cylinders in V (12 V and V 16). Models V4 and V14 are very rare, while the V 8 and V 10 are frequently encountered, even if they not representing the optimal solution.

First motor in V, was carried out in 1903, being an engine V2, as can be seen in Fig. 2.

The idea of paper's authors was: "It can be synthesized one motor in V only by changing the alpha angle value (the constructive angle of a V engine)". By this method it is possible to change the kinematics of this motor and in the same time its dynamic work. Generally the constructive angle of an engine in V (Fig. 3) was calculated in function of the number of cylinders and by the engineering condition to achieve an ignition distributed uniformly to all cylinders.

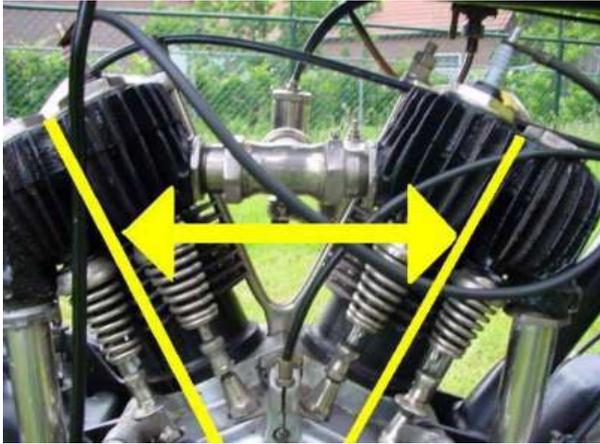


Fig. 1. A motor in V

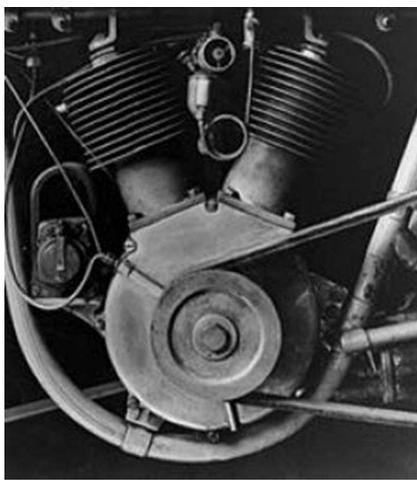


Fig. 2. The first motor in V

This paper try to solve the principal problem of any motor in V (noise and vibration) having in view that one motor in V is more dynamic, more powerful and has a higher yield than any other heat engine.

The solution was found and it is very simple to be implemented. It needs only an angle value change. It's about the constructive angle, alpha. Calculations to demonstrate this fact and all the theory are very difficult and heavy.

First time the corresponding author has studied these problems of motors in V, in the framework of some contracts made with the research collective of UPB and "Autobuzul" plant, in years 1980-1986.

In the first phase, have been studied the vibrations and noises of an engine in V, their transmissibility from the engine to the chassis and the cab driver and the possibility of reducing vibration (of the engine or the submitted) by their insulation.

Reducing the vibration transmitted, has taken place in various ways, but their level at the driver's seat and the

passengers was still too large, much more than the allowed limits international. The noises have been diminished the very much in the driver cab, on the basis of the insulation used. But for the vibrations were still more than the allowed limits, while in a similar engine Otto or diesel in a straight line, they were in line with the normal limits, until at last it was decided to change the type of the engine. After many years working in the field of mechanisms, corresponding author, to understand why the V engine vibration and noise is so great.

The main cause is the binding mode and drive of two different pistons on a single crankpin axis.

### The Basic Idea

To the line engines the forces and velocities are transmitted normally from the driver shaft to the pistons (in the crank times) and vice versa (in the engine times).

The engine in V transmission forces and velocities between elements is forced and unequal regardless of the meaning of transmission (from crank to pistons or from pistons to crank). The main cause that motors in V have higher vibration and noise, is the binding mode and drive of two different pistons on a single crankpin axis.

The two pistons act differently on the same axle (motor). Each of the two pistons connected together has a movement actual (dynamic) difference.

Dynamics imposed to the main piston is one and the required dynamics of the secondary piston is another one, dynamic forces and speeds differ between the two coupled pistons, every one piston operating the motor axis in a different mode. In dynamic operation the differences between the two couplet acting pistons are higher, but to any engine in V (to any heat engine) the time in that the motor works dynamic is majority. In these moments the forces, velocities, powers and moments, are higher.

The only possible solution is to optimize the dynamic of each pair of pistons in movement. This optimization proposed by authors is based on balancing the dynamic coefficients of the two couplet pistons.

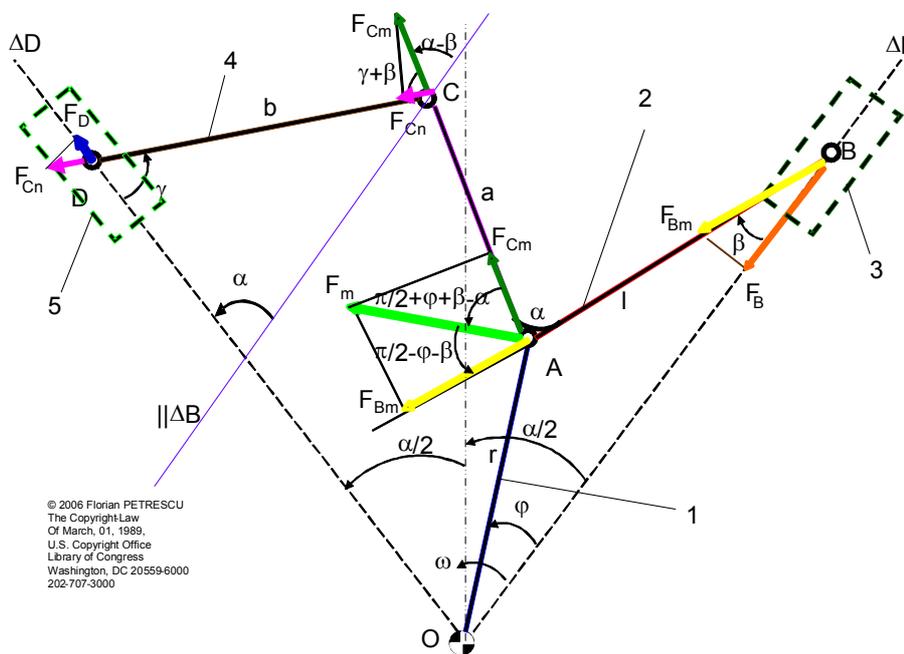
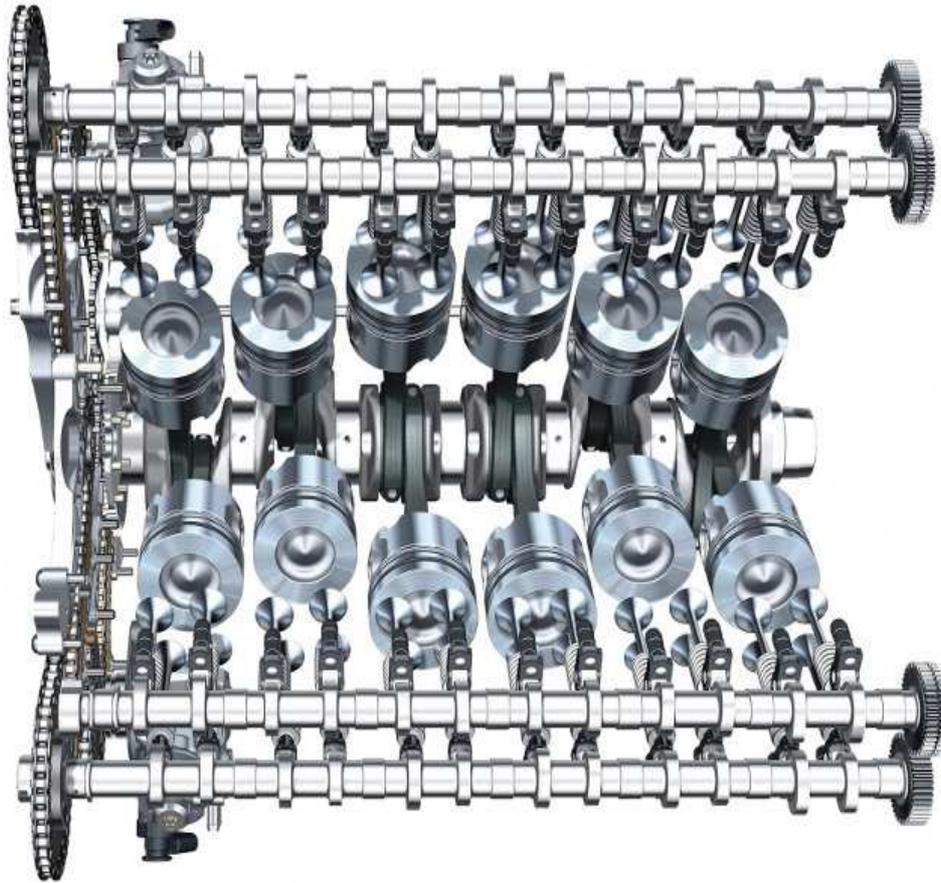
Dynamic coefficient of each (coupled) piston was introduced by this work.

The dynamic variation between the two coupled pistons is due to more factors such as: Kinematics and dynamic, being finally a function of the motor constructive parameters, especially one (the alpha angle).

Usually a mechanism has only one dynamic factor (coefficient; see the engines in line).

To the engine in V occur two dynamic coefficients imposed to the same crank by two coupled pistons (the secondary piston rod link to the main piston rod; see the Fig. 3). These two different dynamic coefficients change themselves the values permanently for any angle position of the motor crank.





V Motors' Kinematics and Dynamics Synthesis by the Constructive Angle Value ( $\alpha$ ); Forces Distribution, Angles, Elements and Couples (Joints) Positions;  $a+b=l$

Fig. 3. Forces and kinematics of a V motor

Both coupled piston (primary and secondary) want to impose its dynamic to the main shaft and the result is a struggle operation of the shaft.

The unique possible solution is matching the dynamic factors of the two coupled pistons.

The authors came with an original set of relations able to make the optimization parameters of an engine in V, based particularly on the constructive angle alpha, which occurs to times in a kinematic scheme of an engine in V: First it is the angle formed by the two axes of the two coupled pistons (the angle formed by the axis of the main piston guide with the secondary piston guide axis); and the second is the constructive angle which occur on the element 2 (the rod of the main piston) between the two arms of the element 2 (AB and AC).

## Presentation

Figure 3 shows the cinematic schema of a motor in V. The motor shaft (in Figure a crank, 1) acts a rotation trigonometric ( $\omega$ ) acting the connecting-rod 2, which put in movement the piston 3 (along the slide bar  $\Delta B$ ) and drives the second connecting-rod 4, which makes the motion of the second piston 5 (along the slide bar  $\Delta D$ ). Here occurs an angle constructive  $\alpha$  (between the two axes  $\Delta B$  and  $\Delta D$ ).

The second angle ( $\alpha$ ) occurs between the two arms of the connecting-rod 2, where the first arm is having the length  $l$  and the second (who transmits a motion to the second connecting-rod 4) of length  $a$  (it is an old rule to any motor in V: Length  $a$ , add to length  $b$ , equals length  $l$ , of the first connecting-rod).

Motor force of the shaft  $F_m$  perpendicular on the length  $r$  of the shaft crank in A, is divided on two components:  $F_{Cm}$  and  $F_{Bm}$ .

The component  $F_{Bm}$  transmits to the first arm of the connecting-rod 2 (along 1) to the first piston 3. Second component  $F_{Cm}$  transmits to the second piston 5, along the second arm of the first connecting-rod 2 (a); see expressions 1 and 2:

$$F_{Bm} = x \cdot F_m \cdot \cos\left[\frac{\pi}{2} - (\phi + \beta)\right] = x \cdot F_m \cdot \sin(\phi + \beta) \quad (1)$$

$$F_{Cm} = y \cdot F_m \cdot \cos\left[\frac{\pi}{2} + \phi + \beta - \alpha\right] = y \cdot F_m \cdot \sin(\alpha - \phi - \beta) \quad (2)$$

## Velocities and Forces

Only one percent  $x$  (of the driving force  $F_m$ ) may be transmitted to the first piston (element 3) and another percent  $y$  is allowed to be transmitted towards the second piston (element 5); sum  $x$  and  $y$  give always 1 (100%).

Dynamic, all the acting forces are imposing their direction vectors to the similar velocities of motor in V:

$$v_{Bm} = x \cdot v_m \cdot \cos\left[\frac{\pi}{2} - (\phi + \beta)\right] = x \cdot v_m \cdot \sin(\phi + \beta) \quad (3)$$

$$v_{Cm} = y \cdot v_m \cdot \cos\left[\frac{\pi}{2} + \phi + \beta - \alpha\right] = y \cdot v_m \cdot \sin(\alpha - \phi - \beta) \quad (4)$$

Starting from element 2 (first arm) and going to the first piston (element 3) they shall be transmitted the force  $F_B$  (5) and the velocity  $v_{BD}$  (a dynamic speed) (6):

$$F_B = F_{Bm} \cdot \cos \beta = x \cdot F_m \cdot \sin(\phi + \beta) \cdot \cos \beta \quad (5)$$

$$v_{BD} = v_{Bm} \cdot \cos \beta = x \cdot v_m \cdot \sin(\phi + \beta) \cdot \cos \beta \quad (6)$$

The expression (7) shows the classic kinematic (known) velocity (which is imposed by the linkage):

$$v_B = v_m \cdot \sin(\phi + \beta) \cdot \frac{1}{\cos \beta} \quad (7)$$

The authors have introduced a dynamic coefficient  $D_B$  (8), which must force the first piston velocity to equalise the dynamic speed value:

$$D_B = x \cdot \cos^2 \beta \quad (8)$$

With:

$$v_{BD} = D_B \cdot v_B \quad (9)$$

$$v_m = r \cdot \omega \quad (10)$$

The expressions (11-12) may solve now the second V motor's outline. In point C, force  $F_{Cm}$  and velocity  $v_{Cm}$  are projected in force  $F_{Cn}$  and speed  $v_{Cn}$  respectively.

$$F_{Cn} = F_{Cm} \cdot \cos(\gamma + \beta) = y \cdot F_m \cdot \sin(\alpha - \phi - \beta) \cdot \cos(\gamma + \beta) \quad (11)$$

$$v_{Cn} = v_{Cm} \cdot \cos(\gamma + \beta) = y \cdot v_m \cdot \sin(\alpha - \phi - \beta) \cdot \cos(\gamma + \beta) \quad (12)$$

Along of the second connecting-rod, the transmitted force ( $F_{Cn}$ ) is projected in  $D$  (on the  $\Delta D$  axe; relation 13) in force  $F_D$ :

$$F_D = F_{Cn} \cdot \cos \gamma = y \cdot F_m \cdot \sin(\alpha - \phi - \beta) \cdot \cos(\gamma + \beta) \cdot \cos \gamma \quad (13)$$

The dynamic speed in point D may now be written with Equation 14:

$$v_D = v_{Cn} \cdot \cos \gamma = y \cdot v_m \cdot \sin(\alpha - \phi - \beta) \cdot \cos(\gamma + \beta) \cdot \cos \gamma \quad (14)$$

The speed of point D (which is imposed by the joint) may be expressed by form (15):

$$\dot{s}_D = v_D = \frac{v_m}{\cos \gamma \cdot l \cdot \cos \beta} \cdot [l \cdot \cos \beta \cdot \sin(\gamma + \alpha - \phi) - a \cdot \cos \phi \cdot \sin(\gamma + \beta)] \quad (15)$$

### Dynamic Coefficients

The dynamic coefficient D (imposed to all gears) influences the crank rotation speed (the crank shaft rotation velocity). For a good dynamic work, any mechanism must take practically only one dynamic factor, D. At the motors in V the real dynamic coefficient is the result of a random momentary compromise between the two different dynamic coefficients imposed by the two pistons in the same time. The right solution is to bringing the two dynamic coefficients around or possibly even to equal values. To this end were the two dynamic factors matched, to see what solutions exist to solve the obtained equation in  $\alpha$ . Obtained complex expression has many variables (the various builder parameters of the engine in V). It sought an analytical synthesis using a complex computer program, by finding of the system alpha general solutions, regardless of the values of others constructive parameters, so that dynamic factors present equal values and the engine so constructed to operate high efficiency without shocks and vibrations, without noise and with reduced noxious emissions, achieved with high power and lower fuel consumption. The cinematic chain composed of crankshaft, two pistons and two rods should function normally. The dynamic coefficient in D is (16):

$$\left\{ \begin{array}{l} D_D = \frac{N}{n} \\ N = (1-x) \cdot l \cdot \sin(\alpha - \phi - \beta) \cdot \cos(\gamma + \beta) \cdot \cos^2 \gamma \cdot \cos \beta \\ n = l \cdot \cos \beta \cdot \sin(\gamma + \alpha - \phi) - a \cdot \cos \phi \cdot \sin(\gamma + \beta) \end{array} \right. \quad (16)$$

It put the condition to have a single dynamic coefficient of the mechanism, D:

$$\left\{ \begin{array}{l} D = D_D = D_B \Rightarrow x = \frac{N_x}{n_x} \\ N_x = l \cdot \sin(\alpha - \phi - \beta) \cdot \cos(\gamma + \beta) \cdot \cos^2 \gamma \\ n_x = l \cdot \cos^2 \beta \cdot \sin(\gamma + \alpha - \phi) - a \cdot \cos \beta \cdot \cos \phi \cdot \sin(\gamma + \beta) + l \cdot \sin(\alpha - \phi - \beta) \cdot \cos(\gamma + \beta) \cdot \cos^2 \gamma \\ D = D_B = x \cdot \cos^2 \beta \end{array} \right. \quad (17)$$

The value of x was determined from the imposed condition to have a single dynamic coefficient for the mechanism.

### Results (Dynamic analysis)

Analysis of dynamic system revealed a range of values for angle alpha that the theory exposed are likely to lead to the synthesis of V-optimal engine (Table 1).

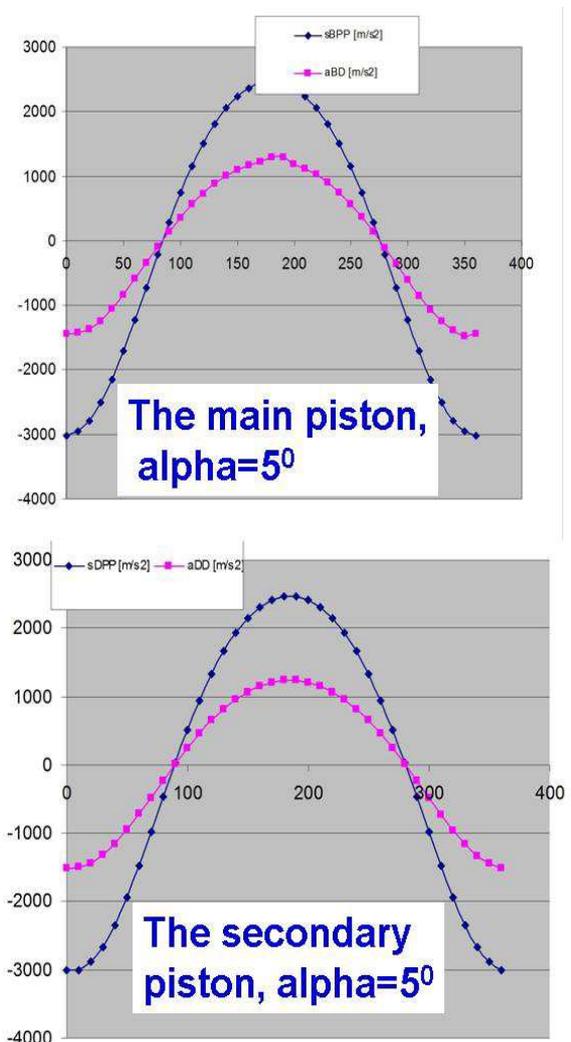


Fig. 4. Special accelerations

For some constructive parameters randomly taken ( $r = 0.01$  [m],  $l = 0.1$  [m],  $a = 0.03$  [m],  $b = 0.07$  [m]) and for a chosen speed of motor shaft ( $n = 5000$  [r/m]), it obtains three different diagrams for the displacement and acceleration of the pistons, corresponding to three alpha angles chosen randomly (50, 750 and 950), (Fig. 2-4). In Fig. 4 the both pistons have an alpha angle of 5 [deg]. On the Fig. 5 the pistons have an alpha angle of 75 [deg]. In the Fig. 6 were taken for the both pistons an alpha angle value of 95 [deg]. The presented diagrams show only the two acceleration, (normal, cinematic acceleration, with blue) and (special dynamic acceleration with pulses, with red), everyone for the main and second pistons.

Value of five degrees are at the beach of values indicated as appropriate, so that acceleration peaks hardly exceed the value of 1000 [m/s<sup>2</sup>] to both pistons (Fig. 4).

Diagrams in Fig. 5 and 6 are somewhat similar (but not identical) and present relevant cases also, even if the acceleration peaks have increased at about 3500 [m/s<sup>2</sup>] for the secondary piston and approximately 30,000 [m/s<sup>2</sup>] for the main piston.

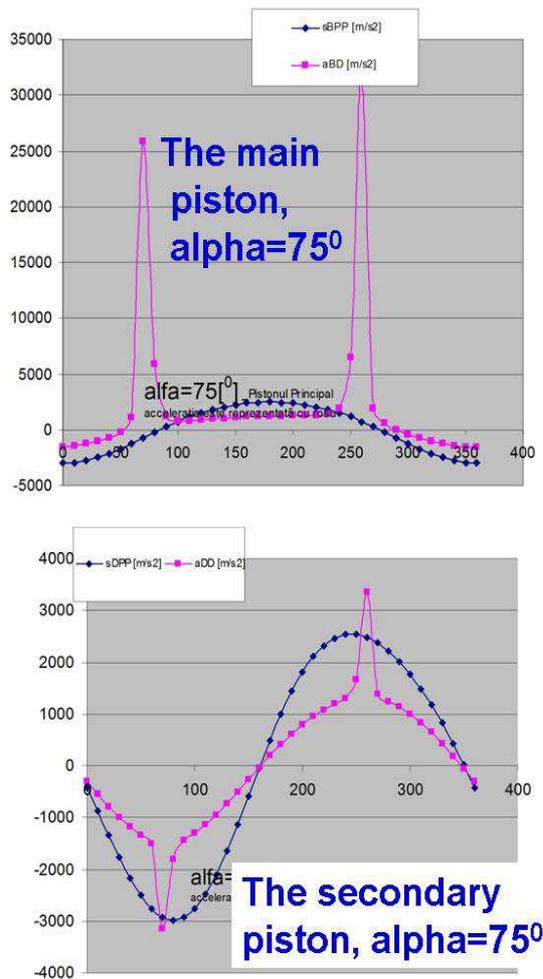


Fig. 5. Special accelerations

The angles of 75 and 95° can also be used (at least for the indicated constructive parameters), to take into account and ignition requirements uniformly distributed.

A V-engine which reaching local at the primary piston a peak of acceleration of 30000 [m/s<sup>2</sup>] to a motor shaft speed of 5000 [r/m] (it comes only a local impact) will work similar to engines in line but the power and efficiency higher.

However the use for alpha of constructive values shown in the Table 1 may lead to the construction of a V engine quieter than the one in line.

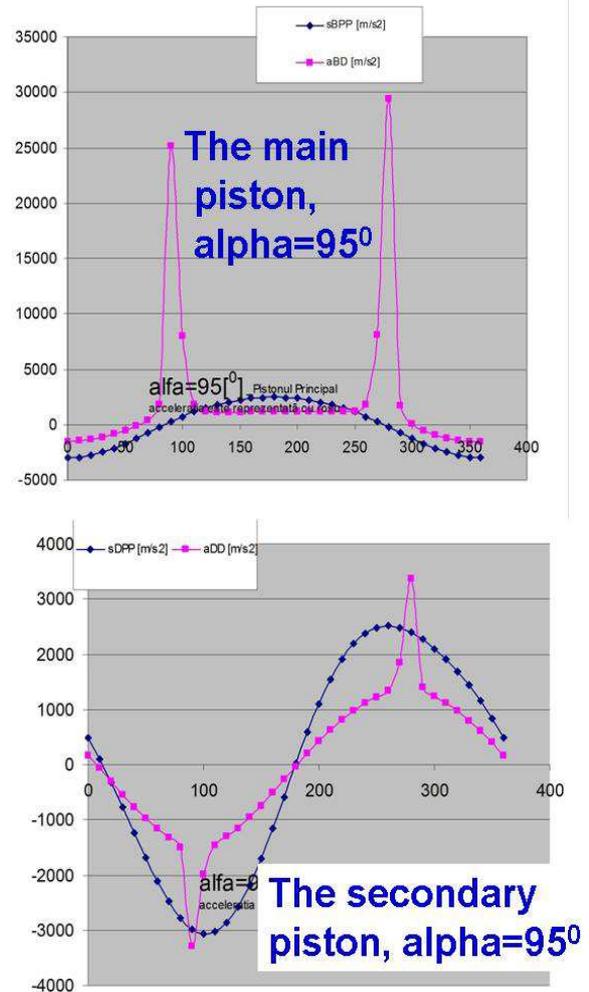


Fig. 6. Special accelerations

Table 1. Alfa angle values in grad

$\alpha$ [grad]
0 – 8
12 – 17
23 – 25
155 – 156
164 – 167
173 – 179

The dynamic analysis made with the presented systems indicates some good values for the constructive angle ( $\alpha$ ), which allow the motor in V works normally without vibrations, noises and shocks (Table 1).

### Experiments of V Engines and Presentation

All the experiments carried out in the years 1980-1986, have shown values too high for Vibrations and noises produced by the engine in V.

Have tried very many types of rubber shock absorbers (for to reduce vibrations transmitted from the engine to the chassis and by the driver's cab).

Only three models gave better results. A model for the shock absorber pad Dunlop, a model of the shock absorber from vehicles of ARO four-wheel drive and a French model, adjusted by our team of research.

At the end of the research, it was decided unanimously, the replacement of the engines in V with the axle in line, or with the axle in line (as a pseudo V engine). Practically in those moments was signed "death certificate" of the engines in V.

The contract for the international research, attended, UK, USA, Canada, Germany, Italy, France, Romania, etc. After this moment almost all of the engines in V used on motor vehicles, have been replaced with engines in line with the yield of the lowest, but also with a vibration level little attenuated.

It has been lost from the efficiency of the engine, but the level of noise and vibrations was falling within the limits prescribed by the standards in force.

The engines in V so loved by the public have started to disappear after years 90 and more may be found from time to time, only on tractors, at some lorries or locomotives and on some vessels high tonnage (Fig. 7).

Even so (with reduced number and importance) engines in V were still in a continuous development and this is due to the characteristics of the engine in V: Power, robustness, flexibility, reliability, consistencies, efficiency, high load, low power consumption etc.

The properties of which they belong to this model of the engine, particular, made possible its entrance in the "world of racing", by equipping the best cars racing.

A solution used by the most eminent physicians builders (Volkswagen, Lancia, Ford, Nissan, Alfa Romeo, Yamaha), is the one shown in Fig. 8, where it is possible to see (axonometric) an engine quickly V6, 24 valves, i.e., a six-cylinder in V (three and three), four-valve on the cylinder (variable distribution performed with four of the camshaft position directly in the cylinder head in order to eliminate the rod and the rocker arm).

In the following Fig. 9, may be observed in several models of construction of the engine V6 quickly, that engine for passenger cars racing.



Fig. 7. Special engines in V on a vessels high tonnage

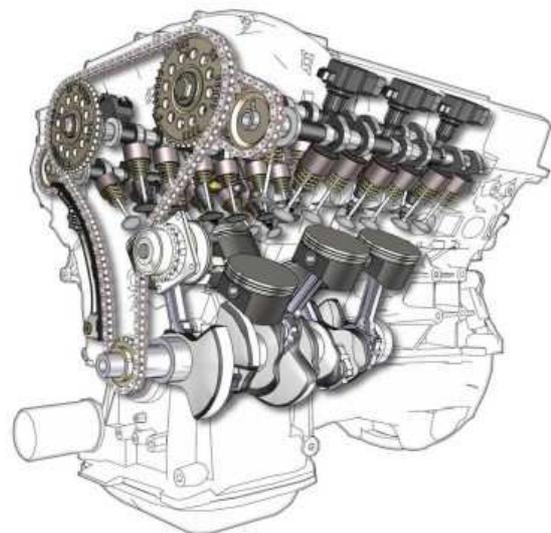


Fig. 8. Axonometric view of a special engine in V



Fig. 9. Several models of construction of the engine V6

The V 12 due to the fact that are much more powerful, more dynamic and provides a balancing much better remain preferably several great builders auto. In Fig. 10 can be noticed a constructive solution to the Type V 12 on which has chosen to adopt the company Ferrari.

In Fig. 11 is presented a V12 achieved by Jaguar.



Fig. 10. A constructive solution to the Type V 12 on which has chosen to adopt the company Ferrari



Fig. 11. A V12 achieved by Jaguar



Fig. 12. A V12 achieved by Lamborghini

In Fig. 12 is presented a V12 achieved by Lamborghini.

In Fig. 13 is presented a V12 achieved by Honda.

The engine TDI 6.0 liters (with 12 cylinders in V), developed by Audi, is the highest diesel engine which is fitted to a car. It is characterized by a torque of the phenomenal 1000 Nm starting at 1750 rpm and a maximum power of 500hp at 3750 rpm (Fig. 14), (\*\*e-automobile).

The V12 TDI fitted to the Audi Q7 (Fig. 15). Equipped with this engine SUV is capable of dynamic performance similar to those of the sports cars-starting 0-100 km/h in just 5.5 s and a maximum speed (electronically limited) 250 km/h). All of this in the conditions in which its mass is 2605 kg and declared consumption is 14.8/9.3/11.3 liters/100 km (urban/extra-urban/combined).



Fig. 13. A V12 achieved by Honda



Fig. 14. A TDI 6.0 liters (with 12 cylinders in V), developed by Audi



Fig. 15. The V12 TDI fitted to the Audi Q7



Fig. 16. The V12 TDI, six liters

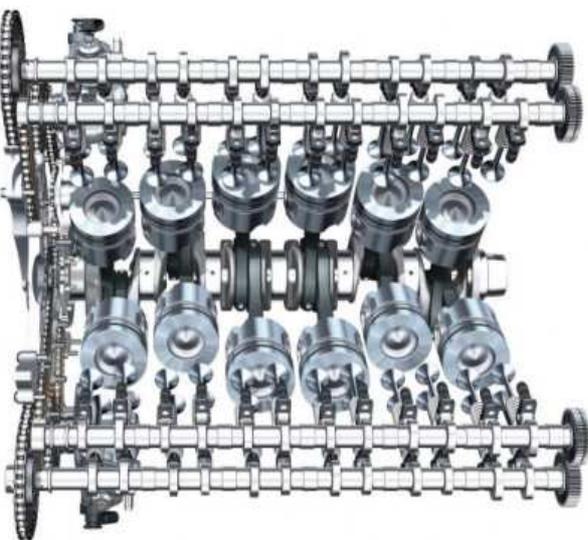


Fig. 17. The V12 TDI is fitted with a B.S. injection system with common rail pressure of the injection computer up to 2000 bar, very similar to that used on Audi R10

The engine has 12 cylinders willing in V at an angle of  $60^\circ$  and contains a large part of the technologies used on engines TDI V6 and V8 Audi car. Together with the petrol engines, 5.0 liters V10 TFSI and 6.0 liters W12, the V12 TDI fitted to the top of the range Audi car. Having regard to Council and the theory of this work, designed in 2006 and made available to the big companies global car in the spring of 2010, the company Audi has attempted to modify the angle of the Alpha traditional  $90^\circ$  to about  $60^\circ$ , in order to achieve a dynamic best of the engine (Fig. 15-16).

A large part of the technologies used on the V12 TDI have as the source of the V10 TDI, which is fitted to the car sport R10, with which the Audi a stroke won 24 h of Le Mans race.

The V12 TDI is fitted with a B.S. injection system with common rail pressure of the injection computer up to 2000 bar, very similar to that used on Audi R10 (Fig. 17).

The V12 TDI is characterized by a series of technological Special notes (see and the chart with torque and motor power in Fig. 18):

- Performance Excellent dynamic
- Low power consumption of fuel
- Noise and vibration
- Low earth
- Synergy with the engine family in v
- In accordance with the pollution standards Euro 5a
- Engine Architecture V12, at an angle of  $60^\circ$
- Electrically [cm<sup>3</sup>] 5934
- Bore Stroke X [mm] 83×91.4
- Report of compression 16:1
- B.S. injection system with common rail, maximum pressure 2000 bar, piezoelectric injectors
- Air Circuit Turbocharging Turbocharger intercooler
- Maximum power 500 [CP] speed [rpm] 3750
- Maximum torque 1000 [Nm] speed [rpm] 1750-3250
- Emission control standards Euro 5

The crankshaft of the engine is wrought alloy steel high resistance. To reduce torsion vibrations the crankshaft has provided for a shock absorber viscous. For increasing resistance to fatigue has opted for the solution with the crankpin journal tariff. So two pistons, opposing are connected via the con rod on the same trunnion crankpin (Fig. 19).

The construction of the engine block was based on the experience gained with the V6 engines and V8 TDI. In order to have increased rigidity, engine block is poured cast lamellar graphite. The oil sump is made of aluminum to reduce the total mass of the engine (Fig. 20).

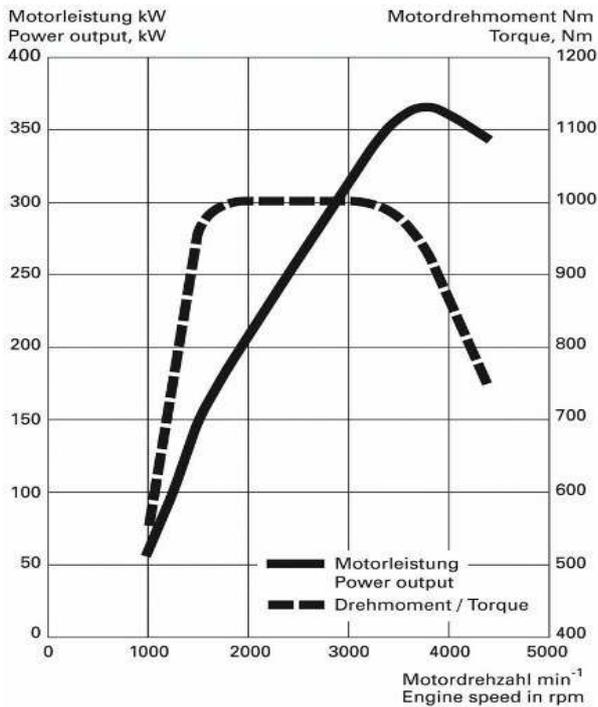


Fig. 18. The charts torque and engine power



Fig. 19. The 6.0-liter TDI V12 500 hp-crankshaft and piston group

The distribution system, the oil pump and the pumps of the high pressure injection are driven with the chain. The crankshaft (by means of some worm gear sprockets) causes an intermediate wheel. This (by means of two chains) causing the shafts of the exhaust camshaft. In their turn the shafts of the exhaust camshaft, by means of a gear train, located on the opposite side of the engine, causes the inlet camshafts (Fig. 21).

The cylinder head contains the camshafts, valves (4 valve/cylinder), the injectors, the glow plugs and a part of the pier of the inlet manifold. The camshafts are tubular trouser which gave them high rigidity and low.



Fig. 20. The 6.0-liter TDI V12 500 hp - the engine block

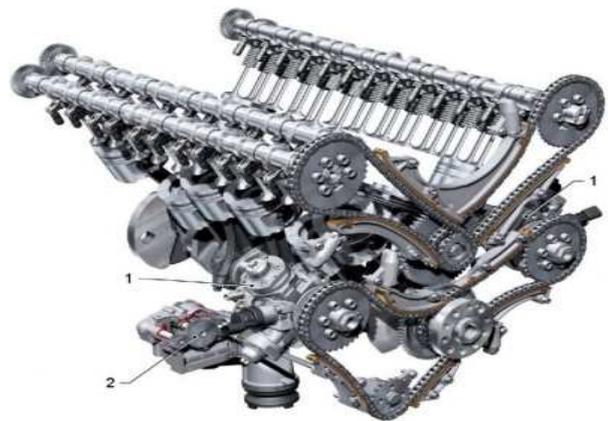


Fig. 21. The 6.0-liter TDI V12 500 hp - the distribution system, the oil pump and the pumps of the high pressure injection  
 1. Pumps of the high pressure injection  
 2. The oil pump

The cylinder head contains and clamping system depressing “swirl”. They are designed to create the crescent of air in the cylinders in order to obtain a mixture the air and the fuel more homogenous and a complete. Also in the cylinder head is fitted and the filtration system gas from the housing (Fig. 22).

The injection system with the Bosch Common Rail works with pressure of the injection computer up to 2000 bar. It contains two ramps of fuel and two injection pump, one for each row of 6 cylinders. Practically, the injection system is divided into two circuits independent, each controlled individually (Fig. 23).

The air inlet is also made up of two independent circuits. They contain an air filter, earth sensor of air and a cooling radiator of compressed air. Both circuits join the throttle before the blanking plugs. The burned gases of the EGR system are being reintroduced into the engine immediately after the throttle blanking covers (Fig. 24).



Fig. 22. The 6.0-liter TDI V12 500 hp-the cylinder head  
 1. the filtration system of the gas cylinder  
 2. cylinder head cover  
 3. lifeliving swirl"  
 4. gear train



Fig. 23. The 6.0-liter TDI V12 500 hp-the injection system with the Bosch Common Rail

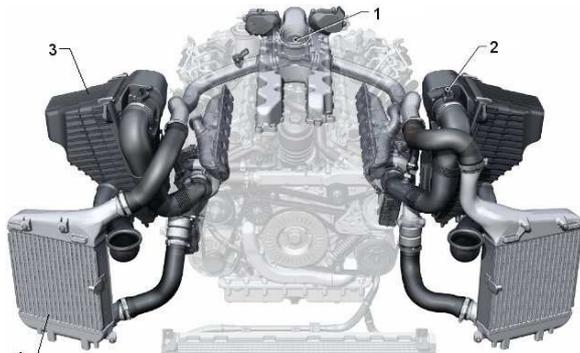


Fig. 24. The 6.0-liter TDI V12 500 hp-the air inlet  
 1. The throttle blanking plugs  
 2. Earth sensor (air flowmeter)  
 3. Air filter  
 4. Radiator compressed air (intercooler)

The exhaust gas recirculation system burned, EGR, play a decisive role in order to ensure the pollution standards Euro 5 as regards the emissions of nitrogen oxide (NOx). The system contains two EGR valve electrically actuated, one for each row of 6 cylinders (Fig. 25).

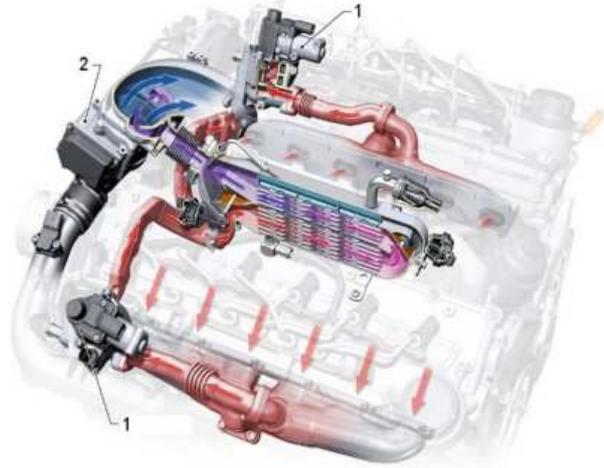


Fig. 25. The 6.0-liter TDI V12 500 hp-the exhaust burned gas recirculation system  
 1. The EGR valve  
 2. Throttle blanking covers

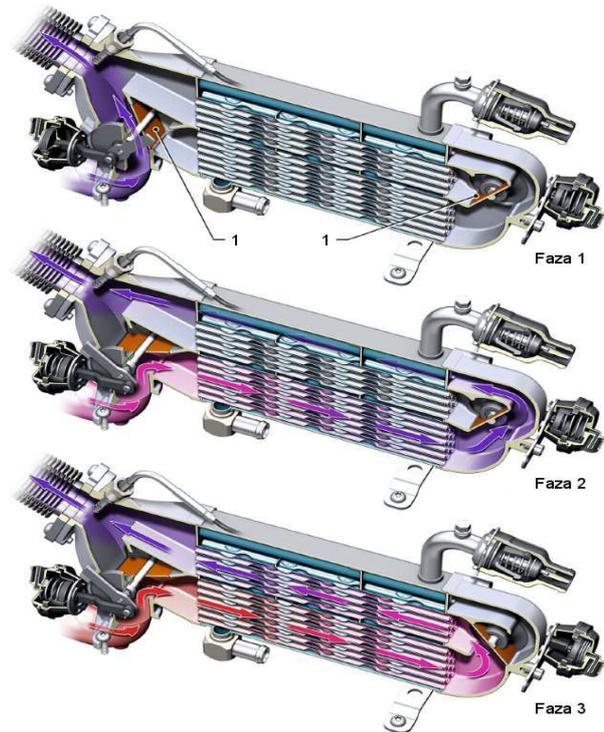


Fig. 26. The 6.0-liter TDI V12 500 hp-the heat exchanger of the EGR system  
 1. The valves of the lock-up solenoid valve

The burned gases are mixed with the fresh air immediately after the throttle blanking covers. In order to obtain an efficiency as high as in the reduction of nitrogen oxides (NOx) the burned gases, before being reintroduced into the engine, are cooled by means of a heat exchanger, equipped with a separate circuit from the coolant bottle (Fig. 26).

A feature of this system is the cooling in three phases of the burned gases.

Thus, according to the operation of the engine, by the command of the two valves by-pass, the burned gases may be cooled at all (Phase 1), partially (Phase 2) or total (Phase 3).

Engine turbocharging is done by means of two Turbochargers with variable geometry of provenance Honeywell Garrett.



Fig. 27. The 6.0-liter TDI V12 500 hp-the engine turbocharging system

1. Silencer
2. Electric actuator
3. Exhaust manifold insulated with layer of air

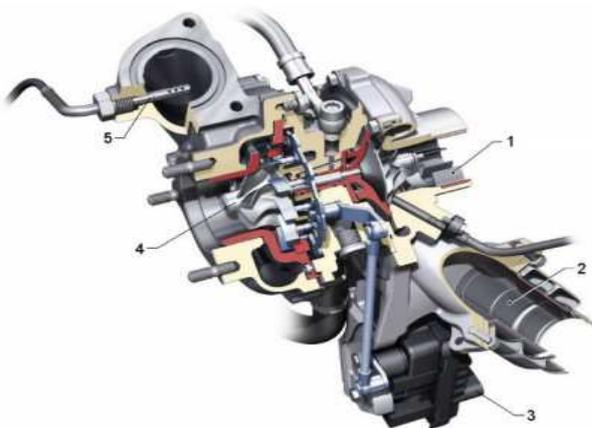


Fig. 28. The 6.0-liter TDI V12 500 hp - the turbocharger

1. The trimmer flow
2. Silencer
3. Electric actuator
4. The turbine with variable geometry turbocharger
5. Temperature Sensor

Each row of 6-cylinder engine uses a turbocharger. The wind turbines are cooled with water and their geometry is adjusted with an electric actuator (Fig. 27).

In order to minimize the heat loss, exhaust manifolds are composed of two layers of the isolated metal between them with the air. To decrease the flow of the turbulence of the air at the compressor inlet, it is equipped with a trimmer of flow. Also to reduce noise occurs due to air flow after the compressor is fitted a shock absorber noise (Fig. 28).

The gases from the housing are filtered and reintroduced back into the intake manifold. The oil vapors are passed through a separator which has the role of filter and separates the liquid oil to oil vapors. Depending on the engine temperature, oil vapor before to be reintroduced in the engine is heat using an electrical resistors (Fig. 29).

Figure 30 the 6.0-liter TDI V12 500 hp-Piston with the injector.

The electronic control system of the engine uses two injection computers connected to each other in a master-slave. This concept allows independent control of the injection on each row of 6 cylinders (Fig. 30).

The injectors are provided with 8 holes of flow to improve the pulverization of the fuel in the combustion chamber. The injection is divided, the injections are made according to the operating mode of the engine. For a greater efficiency of the piston, it is provided with radial channels which circulate the engine oil.

The system of the post-treatment of the exhaust gas is also divided into two circuits. Thus, the gallery for the evacuation of each row of the 6 cylinder contains an oxidation catalytic converter and a particle filter.

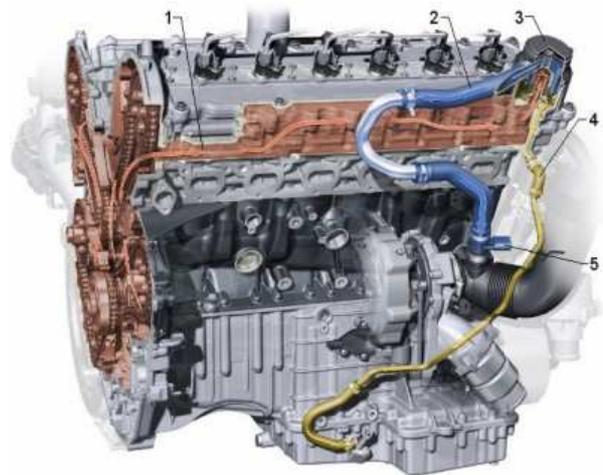


Fig. 29. The 6.0-liter TDI V12 500 hp - the cooling system of the gas cylinder

1. The gas cylinder
2. Gas filtered carter
3. Separator/gas filter cylinder
4. Oil return
5. Electrical resistance heating



Fig. 30. The 6.0-liter TDI V12 500 hp-Piston with the injector

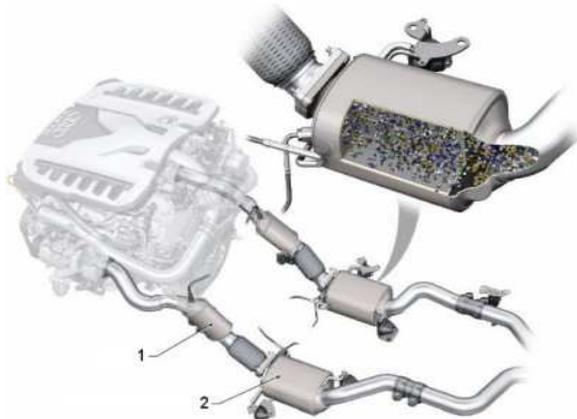


Fig. 31. The 6.0-liter TDI V12 500 hp-a post-treatment system the exhaust gas

The engine has a post-treatment system the exhaust gas (Fig. 31).

In the Fig. 32 may be found a Subaru motorcycle with an engine in V, having an alpha constructive angle about  $25^\circ$  (as the authors of presented paper recommended in the Table 1).

The Detroit Diesel 24V-71 is an example of a modern, two-stroke V24 Diesel engine. It is capable of producing 1,800 horsepower from a 27.9 liter displacement (Fig. 33). A V24 engine is a V engine with 24 cylinders, suitable only for very large trucks, locomotives, or aircraft engine as well.



Fig. 32. A Subaru motorcycle with an engine in V, having an alpha constructive angle about  $25^\circ$



Fig. 33. A two-stroke V24 Diesel aircraft engine

## Discussion

Internal combustion engines works seamlessly 150 years.

Both types of heat engines, the proposed by Otto and the invented by Diesel, both types being in the four-stroke, they have imposed, as being the best, more robust and more reliable, more economic, more silent, more compact, most dynamic, more adaptable and diversifiable.

Heat engines have constituted the starting point of the modern technologies.

In the first years after their appearance, the attraction for automobiles was made public and more.

Slowly, slowly, has developed a cult of automobile king. Cars have come in a short time on the first plan from all points of view.

Even today after 150 years, the automotive industry is still on the first place in the world. Billions of jobs in direct industries or related.

Auto industry means and an unprecedented growth of all industries and technologies, to solve as well as the various requirements imposed by the construction and diversification of the types of motor vehicles.

The motors driven by the crank recently replaced from those with external combustion have now been superseded almost completely by those with internal combustion.

Now was started another world and another one age.

Applications for personal cars have increased so much that the park the world in current use has exceeded the already a billion.

Even if today they are used massively electric motors, however most of the engines being in use are all those with internal combustion (in particular those of type diesel injection or Otto).

As long as we produce electrical current and by the burning of fuels fossil, we can't replace too fast all internal combustion engines with electric motors, since pollution and consumption would still be much higher.

For this reason we have yet the obligation to continue to develop the thermal engines internal combustion to constantly improve, in order to reduce as much fuel consumption and noise level produced by them.

People do not want to give up on their own car, even under the conditions of fuel price very much.

Internal combustion engines in V are the most dynamic, working with high mechanical efficiency. Their main problem is functioning with high vibration and noise. This is mainly due to the fact that the spindle crankpin receives impulses from two pistons simultaneously. In general the two pistons through connecting rods besides transmit the desired movement and additional forces targeted differently. To adjust these forces to work properly in terms of dynamic authors of the paper conducted a comprehensive study on the functioning engines in V.

All the experiments carried out in the years 1980-1986, have shown values too high for Vibrations and noises produced by the engine in V.

Have tried very many types of rubber shock absorbers (for to reduce vibrations transmitted from the engine to the chassis and by the driver's cab).

Only three models gave better results. A model for the shock absorber pad Dunlop, a model of the shock absorber from vehicles of ARO four-wheel drive and a French model, adjusted by our team of research.

At the end of the research, it was decided unanimously, the replacement of the engines in V with

the axle in line, or with the axle in line (as a pseudo V engine). Practically in those moments was signed "death certificate" of the engines in V.

The contract for the international research, attended, UK, USA, Canada, Germany, Italy, France, Romania, etc. After this moment almost all of the engines in V used on motor vehicles, have been replaced with engines in line with the yield of the lowest, but also with a vibration level little attenuated.

It has been lost from the efficiency of the engine, but the level of noise and vibrations was falling within the limits prescribed by the standards in force.

## Conclusion

First time the corresponding author has studied these problems of motors in V, in the framework of some contracts made with the research collective of UPB and "Autobuzul" plant, in years 1980-1986. In the first phase, have been studied the vibrations and noises of an engine in V, their transmissibility from the engine to the chassis and the cab driver and the possibility of reducing vibration (of the engine or the submitted) by their insulation. Reducing the vibration transmitted, has taken place in various ways, but their level at the driver's seat and the passengers was still too large, much more than the allowed limits international. The vibrations were still more than the allowed limits, while in a similar engine Otto or diesel in a straight line, they were in line with the normal limits, until at last it was decided to change the type of the engine. The idea of the paper's authors was: "It can be synthesized one motor in V only by changing the alpha angle value (the constructive angle of a V engine)". By this method it is possible to change the kinematics of this motor and in the same time its dynamic work. Generally the constructive angle of an engine in V was calculated in function of the number of cylinders and by the engineering condition to achieve an ignition distributed uniformly to all cylinders. This paper try to solve the principal problem of any motor in V (noise and vibration) having in view that one motor in V is more dynamic, more powerful and has a higher yield than any other heat engine. The solution was found and it is very simple to be implemented. It needs only an angle value change. It's about the constructive angle, alpha. Calculations to demonstrate this fact and all the theory are very difficult and heavy. But the final result is very simple.

## Indications

These "new V Engines" need to have an angle alpha value taken from the Table 1. One possible constructive example will have a constructive angle  $\alpha = 156$  [deg] (Fig. 34);  $a+b = l$ ; usually  $a = 0$  and  $b = l$ .

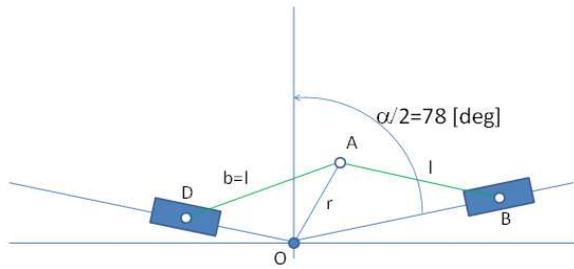


Fig. 34. Kinematic scheme of an engine in V with  $\alpha = 156$  [deg]

## Acknowledgement

This text was acknowledged and appreciated by Dr. Veturia CHIROIU Honorific member of Technical Sciences Academy of Romania (ASTR) PhD supervisor in Mechanical Engineering and by the collectives of mechanisms of TMR departments from Bucharest, Brasov, Cluj-Napoca, Craiova, Iasi, from Romania and by Prof. Gheorghe FRĂȚILĂ, Past Head Department of Automotive Engineering from Bucharest Polytechnic University, Prof. BERTHOLD GRUNWALD, Past Director Mercedes Benz Daimler AG, Germany and Past Head Department of Automotive Engineering from Bucharest Polytechnic University, whom we thank and in this way. Wish to take this opportunity to thank my professor, Paun Antonescu (Professor Dr. Eng. Consul-Emeritus, former president ARoTMM), from which I learned the way of the first steps in the theory of the mechanisms from the year 1977. Wish to take this opportunity to thank my professor, [N.I. Manolescu] (Corresponding member of the Romanian Academy, The founder of the IFToMM and former president ARoTMM), from which I learned the way of the first steps in the theory of the mechanisms from the year 1977. The corresponding author wish to take this opportunity to thank my professor, [Christian Pelecudi] (The former Vice President of the IFToMM, The founder and father of robotics in Romania), from which I learned the way of the first steps in the theory of the mechanisms and robotics from the year 1984, but also the first analytical methods, being his Professor Assistant. Wish to take this opportunity to thank my colleague from Italy Professor Dr. Eng. Emeritus Marco Ceccarelli (The former President of the IFToMM, The founder and father of mechanisms and robotics in Italy), from which I learned the first steps in the history of the mechanisms. Wish to take this opportunity to thank my former colleague Professor [Radu Bogdan] (The founder of mechanisms and robotics in Romania together with N.I. Manolescu and Christian Pelecudi and over 20 years the Romanian Ambassador in Japan). Wish to take this opportunity to thank my former colleague and teacher Professor Dr. Doc. Eng. Berthold GRUNWALD Past

Head Department of Automotive Engineering from Bucharest Polytechnic University. Professor Grunwald (as Head of Department) gathered all my colleagues series and all our teachers then at the Faculty of Transport (1982), during a ceremony of awarding diplomas mechanical engineer, and when he reached me, he said in front of everyone, "he has never had nor believed will have once a student so valuable, whose work diploma, exceeded all expectations, even if the work was not driven by him as he wanted, but by his colleague Professor Gheorghe FRATILA". My work then, it was just the basis of the presented article.

## Funding Information

**Research contract:** Contract number 36-5-4D/1986 from 24IV1985, beneficiary CNST RO (Romanian National Center for Science and Technology) Improving dynamic mechanisms internal combustion engines.

**Preliminary Contract** from 2010-03-13 with:

### BMW Group Germany

Virtuelle Innovations-Agentur (VIA)  
Knorrstraße 147  
D-80788 München  
<http://www.bmwgroup.com/>

-----  
Bayerische Motoren Werke Aktiengesellschaft  
Vorstand: Norbert Reithofer, Vorsitzender,  
Frank-Peter Arndt, Herbert Diess, Klaus Draeger,  
Friedrich Eichiner, Harald Krüger, Ian Robertson  
Vorsitzender des Aufsichtsrats: Joachim Milberg  
Sitz und Registergericht: München HRB 42243  
-----

**Preliminary Contract** from 2010-03-13 with:

### Mercedes Benz Daimler AG, Germany

All these matters are copyrighted. **Copyrights:** 398-tDGpbsxgrD, from 18-02-2010 01:16:36 and 394-qodGnhhtej, from 17-02-2010 13:42:18.

## Author's Contributions

All the authors contributed equally to prepare, develop and carry out this manuscript.

## Ethics

Authors declare that are not ethical issues that may arise after the publication of this manuscript. This article is original and contains unpublished material.

## References

- Christensen, M., A. Hultqvist and B. Johansson, 1999. Demonstrating the multi fuel capability of a homogeneous charge compression ignition engine with variable compression ratio. SAE Technical Paper. DOI: 10.4271/1999-01-3679

- Dahl, D. M. Andersson and I. Denbratt, 2013. The role of charge stratification for reducing ringing in gasoline engine homogeneous charge compression ignition combustion investigated by optical imaging. *Int. J. Engine Res.*, 14: 525-536. DOI: 10.1177/1468087412473464
- Dahl, D. and I. Denbratt, 2012. Valve profile adaptation, stratification, boosting and 2-stroke strategies for raising loads of gasoline HCCI engines. *SAE Int. J. Eng.*, 5: 1033-1045. DOI: 10.4271/2012-01-1108
- Dempsey, A.B., N.R. Walker, E. Gingrich and R.D. Reitz, 2013. Comparison of low temperature combustion strategies for advanced compression ignition engines with a focus on controllability. *Combust Sci. Technol.*, 186: 210-241. DOI: 10.1080/00102202.2013.858137
- Dernotte, J., J.E. Dec and C. Ji, 2014. Investigation of the sources of combustion noise in HCCI engines. *SAE Int. J. Eng.*, 7: 730-761. DOI: 10.4271/2014-01-1272
- Erjavec, J., 2009. *Automotive Technology: A Systems Approach*. 5th Edn., Cengage Learning, Clifton Park, ISBN-10: 1428311491, pp: 1472.
- Kavuri, C., S.L. Kokjohn, D.T. Klos and D. Hou, 2016. Blending the benefits of reactivity controlled compression ignition and gasoline compression ignition combustion using an adaptive fuel injection system. *Int. J. Engine Res.*, 17: 811-824. DOI: 10.1177/1468087415615255
- Kitamura, T., T. Ito, J. Senda and H. Fujimoto, 2002. Mechanism of smokeless diesel combustion with oxygenated fuels based on the dependence of the equivalence ration and temperature on soot particle formation. *Int. J. Engine Res.*, 3: 223-248. DOI: 10.1243/146808702762230923
- Kokjohn, S.L., R.M. Hanson, D.A. Splitter and R.D. Reitz, 2011. Fuel Reactivity Controlled Compression Ignition (RCCI): A pathway to controlled high-efficiency clean combustion. *Int. J. Engine Res.*, 12: 209-226. DOI: 10.1177/1468087411401548
- Li, T., H. Izumi, T. Shudo, H. Ogawa and Y. Okabe, 2007. Characterization of low temperature diesel combustion with various dilution gases. *SAE Technical Paper*. DOI: 10.4271/2007-01-0126
- Ludvigsen, K., 2005. *The V12 Engine: The Untold Story of Technology, Evolution, Performance and Impact of All*. 1st Edn., Haynes Publishing UK, Sparkford, ISBN-10: 1844250040, pp: 432.
- Manente, V., B. Johansson and W. Cannella, 2011. Gasoline partially premixed combustion, the future of internal combustion engines? *Int. J. Engine Res.*, 12: 194-208. DOI: 10.1177/1468087411402441
- Ozasa, T., K. Maitani, Y. Fujimoto and K. Yorizane, 2016. Simplified estimation method of bearing friction for engines. *Int. J. Engine Res.*, 17: 886-896. DOI: 10.1177/1468087415622885
- Pan, J., P. Zhao, C.K. Law and H. Wei, 2016. A predictive Livengood–Wu correlation for two-stage ignition. *Int. J. Engine Res.*, 17: 825-835. DOI: 10.1177/1468087415619516
- Petrescu, F.I. and R.V. Petrescu, 2012. *Motoare Termice Color: Usa 2012*. 1st Edn., CreateSpace Independent Publishing Platform, ISBN-10: 1480204889, pp: 164.
- Petrescu, F.I. and R.V. Petrescu, 2011. *Mechanical Engineering Design*, 1st Edn., CreateSpace Independent Publishing Platform, ISBN-10: 1467913774, pp: 184.
- Reed, M., R.M. Hanson and R.D. Reitz, 2016. Effects of biofuel blends on transient reactivity-controlled compression ignition engine combustion. *Int. J. Engine Res.*, 17: 857-865. DOI: 10.1177/1468087415622340
- Rezaei, R., F. Dinkelacker, B. Tilch, T. Delebinski and M. Brauer, 2016. Phenomenological modeling of combustion and NOx emissions using detailed tabulated chemistry methods in diesel engines. *Int. J. Engine Res.*, 17: 846-856. DOI: 10.1177/1468087415619302
- Schmitt, M. and K. Boulouchos, 2016. Role of the intake generated thermal stratification on the temperature distribution at top dead center of the compression stroke. *Int. J. Engine Res.*, 17: 836-845. DOI: 10.1177/1468087415619289
- Sellnau, M., W. Moore, J. Sinnamon, K. Hoyer and M. Foster *et al.*, 2015. GDCI multi-cylinder engine for high fuel efficiency and low emissions. *SAE Int. J. Eng.*, 7: 775-790. DOI: 10.4271/2015-01-0834
- Shahlari, A.J., C. Hocking, E. Kurtz and J. Ghandhi, 2013. Comparison of compression ignition engine noise metrics in low-temperature combustion regimes. *SAE Int. J. Eng.*, 6: 541-552. DOI: 10.4271/2013-01-1659
- Sjöberg, M., L. Edling, T. Eliassen, L. Magnusson and H.E. Angström, 2002. GDI HCCI: effects of injection timing and air swirl on fuel stratification, combustion and emissions formation. *SAE Technical Paper*. DOI: 10.4271/2002-01-0106
- Warnatz, J., U. Maas and R.W. Dibble, 2006. *Combustion: Physical and chemical fundamentals, modeling and simulation, experiments, pollutant formation*. 4th Edn., Springer Science & Business Media, Berlin, ISBN-10: 3540259929, pp: 378.
- Wong, P.K., H.C. Wong, C.M. Vong and K.I. Wong, 2016. Online wavelet least-squares support vector machine fuzzy predictive control for engine lambda regulation. *Int. J. Engine Res.*, 17: 866-885. DOI: 10.1177/1468087415623909
- \*\*\*e-automobile, Motorul diesel V12 6.0 TDI de 500 CP de la Audi, retrieved from: <http://www.e-automobile.ro/categorie-automobile/23-diesel/102-v12-tdi.html>

## Nomenclature

$F_m$  = the crank motor force is perpendicular at the crank length  $r$ , in  $A$ .

$F_{Bm}$  = a part of  $F_m$  is transmitted to the first arm of connecting-rod 2 (along 1) towards the first piston 3.

$F_{Cm}$  = another part of the motor force ( $F_m$ ) is transmitted towards the second piston 5, by (along) the second arm of first connecting-rod 2 (a).

The dynamic velocities have the same direction like forces:

$v_m$  = the crank motor velocity

$v_{Bm}$  = a part of  $v_m$  is transmitted to the first arm of the connecting-rod 2 towards the first piston 3.

$v_{Cm}$  = another part of  $v_m$  is transmitted towards the second piston 5, by along the second arm of the first connecting-rod 2.

From the element 2 (first arm) to the first piston (element 3) one transmits the force  $F_B$  and the dynamic velocity  $v_{BD}$ .

$v_B$  = the kinematics (known) velocity (imposed by the linkage) is given by the relation 7.

To force the first piston velocity equalises the dynamic value, it introduces a dynamic coefficient  $D_B$ .

$v_{BD}$  = the dynamic velocity

The second Motor' outline can be solved now. In  $C$ ,  $F_{Cm}$  and  $v_{Cm}$  are projected in  $F_{Cn}$  and  $v_{Cn}$ :

The transmitted force along of the second connecting-rod ( $F_{Cn}$ ) is projected in  $D$  on the  $\Delta D$  axe in  $F_D$ .

$v_D$  = the dynamic velocity in  $D$ .

$\dot{s}_D = v_D$  = the velocity of  $D$  imposed by the joint.

$D_B$  = the dynamic coefficient imposed by the piston 3.

$D_D$  = the dynamic coefficient imposed by the piston 5.

$D$  = the final (one) dynamic coefficient of the system.