THE INTERPLAY BETWEEN FLUID FLOW AND IC ENGINE COMBUSTION CHAMBER GEOMETRY LAYOUT

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Abstract: *In this paper some results concerning the comparison of 3D fluid flow patterns in combustion chambers with entirely different bowl-in-piston shapes such as "omega" and "cylinder" were presented. Both combustion chambers were with flat head, vertical valves and identical elevation of intake and exhaust ports. All results were obtained by dint of multidimensional modeling of nonreactive fluid flow in arbitrary geometry with moving objects and boundaries. The fluid flow pattern during induction and compression in both cases was extremely complicated and entirely three-dimensional. Some differences due to geometry of the bowl were observed only in the vicinity of TDC. In the case of "omega" bowl all three types of organized macro flows were observed while in the case of "cylinder" bowl no circumferential velocity was registered at all. In the case of "cylinder" bowl the reverse tumble center of rotation shifting from exhaust valve zone to intake valve zone during induction stroke and vice-verse from intake valve zone to exhaust valve zone during compression were observed while in the case of "omega" bowl no such a displacement was legible.*

Key words*: 3D MODELING, FLUID FLOW PATTERN, COMBUSTION CHAMBER*

1. Introduction

The mutual interaction between combustion chamber layout and macro flows that incur in automotive engines is quest intricate for a while. Some results related to the isolated and synergic effect of squish and swirl for no-valve cases are published elsewhere [1, 2] as well as results related to isolated or combined effect of the tumble in the case with 2 or 4 valves [3, 4, 5, 6].

In the case with valves the idealized fluid flow pattern in the combustion chamber is the well-formed high intensity tumble motion in the vicinity of BDC. The destruction of such well-formed tumble vortex during compression in the vicinity of BDC generates the increase of turbulence intensity and larger length scale of turbulence in the vicinity of TDC yielding, for the reduction of flame kernel formation period and higher flame propagation velocity thereafter. It is entirely consistent with the general principle of turbulence theory which presumes that vortex filament subjected to compression reduces its length and promotes rotational velocity around its axis i.e. the movement is on the larger scale ("spin-up" effect).

The principal goal of this paper was qualitative and quantitative characterization of fluid flow and its analysis from the point of ideal fluid flow derogation.

2. Modelling of nonreactive fluid flow

The multidimensional numerical modeling of nonreactive fluid flow in arbitrary geometry was applied due to fact that it encompasses the valve/port geometry in an explicit manner. In lieu of the fact that multidimensional models formally require initial and boundary conditions only, their application is fairly complicated and highly dependent on a set of various assumptions. Namely, 3D conservation integral form of equations governing non-stationary turbulent flow of nonreactive compressible fluid is solved on a fine computational grid by dint of CGS numerical method [7];

3. Results

The calculation of 3D fluid flow was carried out for combustion chambers and valve/port geometry layouts shown in fig.1-4. Two basic combustion chamber shapes were selected and analyzed. The first one contains so called "omega" bowl in piston crown (fig.1 and 3) while the other contains "cylindrical" bowl (fig.2 and 4) in piston crown. Results for variations of both basic shapes are not presented due to economy of the paper. In the case of cylindrical bowl the basic block data sheet encompasses bore/stroke ratio S/D=9.55 cm/9.843 cm, diameter of the bowl and its depth Dc=5.6 cm and Hc=1.155cm respectively, diameter of the valve Dv=3.38 cm, squish gap SG=0.2 cm and engine speed N= 2000 min^{-1}.

In the case of "omega" bowl the identical basic block data sheet was applied except for the profile of the bowl that was generated in a fairly arbitrary fashion. It should be stated that maximum valve lift for all cases was 0.82 cm (at 90 deg. ATDC) and the commencement of the intake valve lift was set at 15 deg. BTDC and its closure at 195 deg. ATDC. The opening of exhaust valve was set at 525 deg. ATDC and its closure at 15 deg. ATDC.

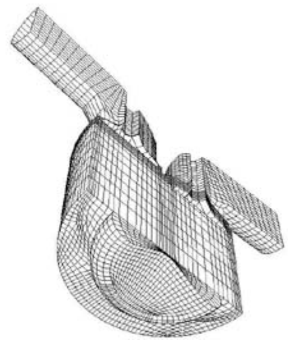

Figure 1. *Perspective plot of the combustion chamber and valve/port geometry ("omega" bowl)*

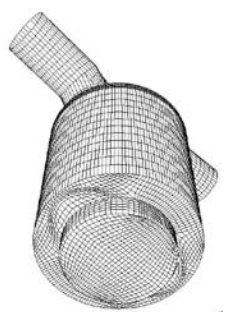

Figure 2. *Perspective plot of the combustion chamber (squish area = 54%, "cylinder" bowl)*

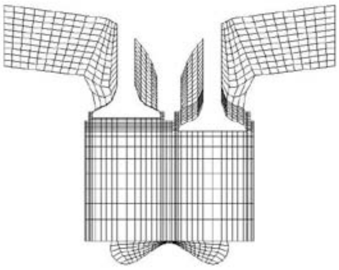

Figure 3. *Combustion chamber geometry layout in x-z plane („omega“ bowl)*

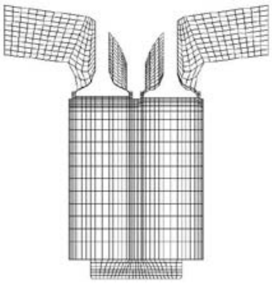

Figure 4. *Combustion chamber geometry layout in x-z plane (squish area = 54%, cyl. bowl)*

The evolution of fluid flow pattern, represented as vectors, during intake is shown in fig. 5 and 7 for omega bowl and fig. 6 and 8 for cylindrical bowl.

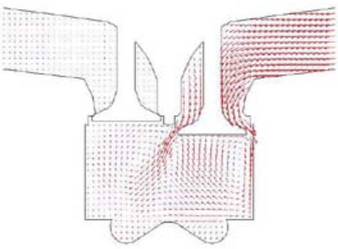

Figure 5. *Fluid flow pattern in x-z plane at 75 deg. ATDC („omega“ bowl)*

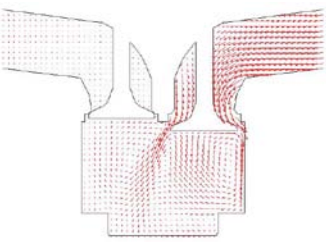

Figure 6. *Fluid flow pattern in x-z plane at 75 deg. ATDC (SA=54%, "cylindrical" bowl)*

It can be seen in fig. 5 and 6 that intake flow hits the piston crown, curls and commences slightly to form the vortex flow around y-axis in a clockwise direction. At the same time the intake flow strikes upon the cylinder wall, rebounds and commences to form the vortex flow around y=const. axis in the same direction i.e. non-symmetric fluid flow pattern is encountered. The further piston displacement downward (75 deg. ATDC), the increase of the valve lift (Hv=0.77cm) and subsequent increase of intake flow elevation generate in both cases ("omega" bowl and "cylindrical" bowl) the formation of reverse tumble with its center of rotation in the zone beneath the exhaust valve (fig. 5 and 6).

At the same time the intensity of the vortex flow in a zone between wall and valve face is increased yielding more expressive fluid flow separation, change of the fluid flow direction towards reverse tumble and intensity increase of reverse tumble thereafter.

The general increase of the zone with high intensity of turbulence is pursued with well- formed vortex flow around x=const. axis. Fluid flow at the beginning of change of direction of valve displacement (120 deg. ATDC and Hv=0.74cm) is characterized with conflict action of reverse tumble with its axis of rotation located beneath exhaust valve and low intensity vortex flow with axis located beneath intake valve. The net result is shifting of the small vortex to cylinder wall, the increase of the intensity of the reverse tumble and the displacement of its center of rotation to the central part of the chamber. The same trend is clearly legible up to 180 deg. ATDC (fig.7, 8).

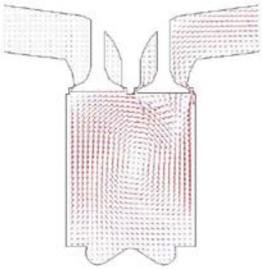

Figure 7. *Fluid flow pattern in x-z plane, y=0, at 180 deg. ATDC („omega“ bowl)*

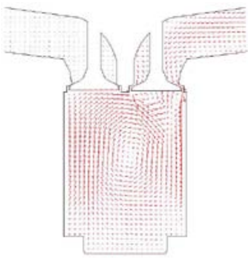

Figure 8. *Fluid flow pattern in x-z plane, y=0, at 180 deg. ATDC (SA=54%, "cyl." bowl)*

Namely, the reverse tumble increases its intensity and engulfs the central part of the combustion chamber. The axis of its rotation is shifted to the zone beneath the intake valve generating large zone with high turbulence intensity. The effect of small vortex beneath intake valve is constrained onto a small zone in the close proximity of intake valve face. The reverse tumble promotes the detention of flank vortex flows therefore only low intensity vortex flows in a cut plane passing through intake valve are encountered. The corresponding spatial distributions of kinetic energy of turbulence (tke) in x-z plane, y=0 and x-y plane, z=9.65 cm for "omega" and "cylindrical" bowl are shown in fig. 9, 10,11 and 12.

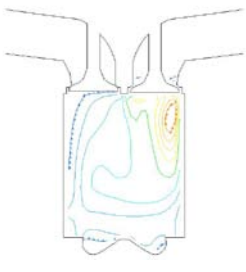

Figure 9. *Spatial distribution of tke in x-z plane, y=0, at 180 deg. ATDC („omega“ bowl)*

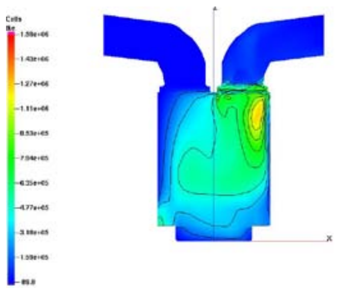

Figure 10. *Spatial distribution of tke in x-z plane, y=0, at 180 deg. ATDC (SA=54%, "cyl" bowl)*

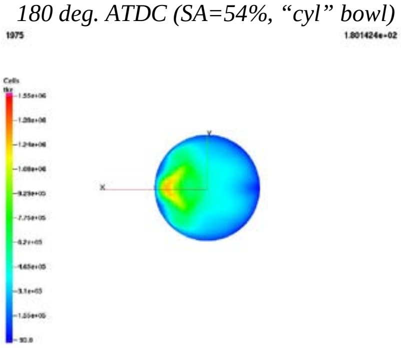

Figure 11. *Spatial distribution of tke in x-y plane, z=9.65cm, at 180 deg. ATDC („omega" bowl)*

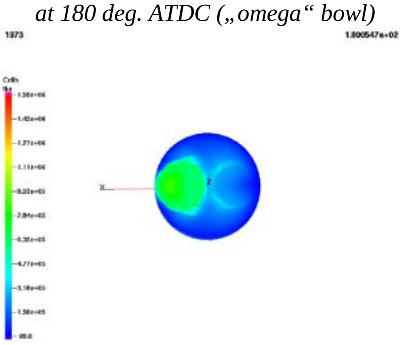

Figure 12. *Spatial distribution of tke in x-y plane, z=9.7cm, at 180 deg. ATDC ("cyl" bowl)*

It can be seen in fig 7 that well-formed high intensity reverse tumble engulfs the entire combustion chamber at BDC and dominates the fluid flow pattern. The gradual shifting of reverse tumble center of rotation to the intake valve zone and the increase of its intensity affects the deflection of flank vortices and their redirection to the cylinder wall. Vortex flow in the zone beneath intake valve, to the left of its axis, is subjected to compression by dint of reverse tumble and therefore increases the velocity of its rotation. Namely, in the zone beneath the intake valve the vortex flow around all three axis is encountered but reverse tumble flow prevails. This explanation is verified through spatial distribution of kinetic energy of turbulence (tke) in x-z plane, y=0, shown in fig. 9 and in x-y plane, z=const=9.65 cm, shown in fig. 11. Obviously, the largest zone is the zone of reverse tumble effect. The zone with maximum turbulence intensity is yellow painted.

Obviously, regarding fluid flow pattern and spatial distribution of kinetic energy of turbulence, during intake stroke, there is no any difference in the case of "cylindrical" and "omega" bowl.

During compression the fluid flow preserves its pattern for both cases until approximately 300 deg. ATDC. At approximately 300 deg. ATDC, pursuant to "spin-up" theory, the commencement of stretching of the reverse tumble is observed yielding the engulfment of the zone beneath the exhaust valve thereafter. In the case of cylindrical bowl the reverse tumble is subjected to compression by piston movement and is slowly squeezed out from the intake valve zone. In that way the axis of its rotation is shifted to the exhaust valve. Namely, in the upper part of the chamber two vortices are rotating in opposite direction (impact flow) yielding the generation of the increased coinciding flow in the zone beneath the intake valve (fig.13).

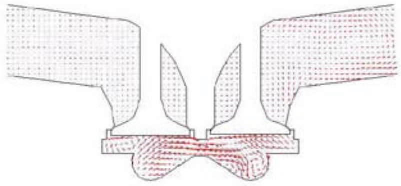

Figure 13. *Fluid flow pattern in x-z plane, y=0, at 360 deg. ATDC (SA=54%, "cyl." bowl)*

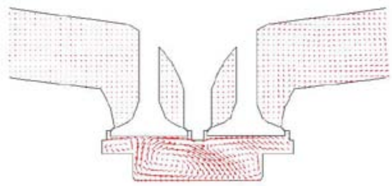

Figure 14. *Fluid flow pattern in x-z plane, y=0, at 360 deg. ATDC („omega" bowl)*

On the contrary the geometry of the "omega" bowl prevents such a movement (from intake to exhaust valve) therefore the entirely different motion is encountered. Namely, the reverse tumble is nearly broken up by central reef of the bowl yielding extremely complicated fluid flow composed of three clearly legible vortices in the zone beneath intake valve and two distinct vortices in the zone beneath exhaust valve (fig 14).

In the case of "omega" bowl the reef in the central part of the bowl is responsible for the complete restructuring of the fluid flow. The slope of the central part of the bowl mitigates completely 3D structure of the fluid flow in the zone beneath the intake valve converting it into well defined rotational structure shown in fig 15. This type of macro flows was not encountered in the case with cylindrical bowl .

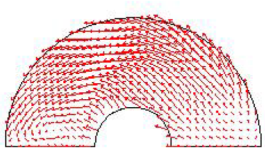

Figure 15. *Fluid flow pattern in x-y plane, z=9.65cm, at 360 deg. ATDC („omega" bowl)*

The complicated fluid flow patterns are pursued by corresponding spatial distributions of kinetic energy of turbulence, shown in fig. 16, 17, 18 and 19.

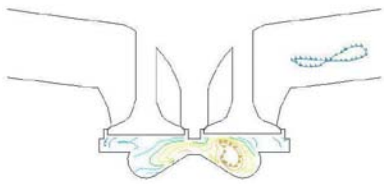

Figure 16. *Spatial distribution of tke in x-z plane, y=0, at 360 deg. ATDC („omega" bowl)*

It can be seen that the maximum kinetic energy of turbulence for the case with "omega" bowl, in TDC (360 deg. ATDC) is located in the part beneath but a little bit astray from intake valve (figs. 16 and 18) while in the case of cylindrical bowl the maximum kinetic energy of turbulence is located in the central part of the chamber (fig 17 and 19).

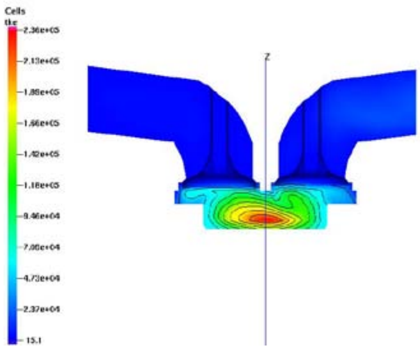

Figure 17. *Spatial distribution of tke in x-z plane, y=0, at 360 deg. ATDC ("cyl" bowl)*

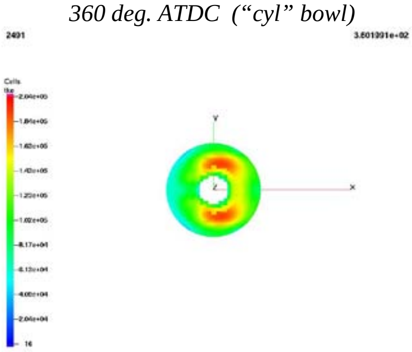

Figure 18. *Spatial distribution of tke in x-y plane, z=9.65 cm, at 360 deg. ATDC („omega bowl")*

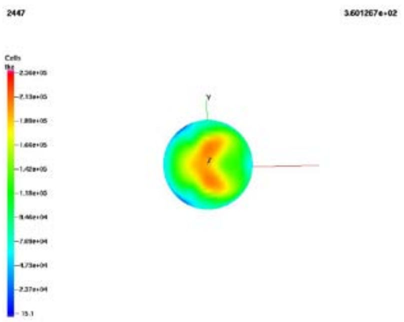

Figure 19. *Spatial distribution of tke in x-y plane, z=9.70 cm, at 360 deg. ATDC, ("cyl" bowl)*

During expansion rapid decay of both vortex motions is encountered. Namely laminar fluid flow is observed in both chambers (figs. 20 and 21).

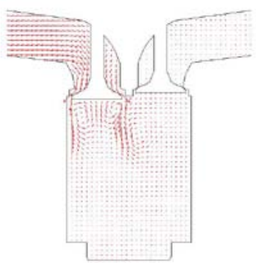

Figure 20. *Fluid flow pattern in x-z plane, y=0, at 540 deg. ATDC („omega")*

Figure 21. *Fluid flow pattern in x-z plane, y=0, at 540 deg. ATDC ("cyl" bowl)*

Obviously no effect of the bowl shape onto fluid flow pattern and therefore onto spatial distribution of kinetic energy of turbulence were encountered.

4. Conclusions

During intake and large part of compression (up to 300 deg ATDC) fluid flow patterns and spatial distributions of kinetic energy of turbulence (tke) for both cases ("omega" and "cylindrical" bowl) are entirely identical. The clear difference is observed in the vicinity of TDC.

In the case of cylindrical bowl, in the upper part of the combustion chamber, two vortices are rotating in opposite directions (impact flow) yielding the generation of the coinciding flow in the zone beneath intake valve. The maximum kinetic energy of turbulence is located in the central part of the chamber.

In the case of "omega" bowl the extremely complicated 3D fluid flow, composed of three vortices in the zone beneath intake valve and two vortices in the zone beneath exhaust valve, is observed.The maximum kinetic energy of turbulence is located in the zone beneath and aside from intake valve.

REFERENCES

[1] Z. Jovanovic, The role of tensor calculus in numerical modeling of combustion in IC Engines, ISBN 0-89116-392-1, Hemisphere Publishers, 1989, pp. 457-541

[2] Z. Jovanovic, The new fluid flow criterion for the characterization of flame front shape and its displacement, *VII Intern. Scientific Conference, Simulation Research in Automotive Engineering*, pp. 1-7, Lublin (Poland), 1999

[3] Z. Jovanovic, S. Petrovic, The effect of intake flow modeling on flame front shape and its displacement in cylindrical combustion chamber, *Society of Automotive Engineers, Multidimensional engine modeling*, pp. 1-6, Detroit, 2001

[4] B. Basara, Z. Jovanović, The current capabilities of turbulence modeling in automotive flows, *YUMV 010021, International Automotive Conference SCIENCE & MOTOR VEHICLES* pp. 93-96, Belgrade, 2001

[5] Z. Jovanovic, B. Basara, The controversy concerning turbulence modeling in automotive application, paper M13, *4th PCO Global Conference*, Kuching, Sarawak, Borneo, Malaysia, December, 2-4, 2010, ISBN 978-983-44483-32

[6] Z.J ovanović, S. Petrović, M. Tomić, The effect of combustion chamber geometry layout on combustion and emission, *Thermal Science*, vol 12 (2008), No.1, pp. 7-24.

[7] A. A. Amsden, KIVA3V, Rel.2-Improvements to KIVA3V, LA-UR-99-915, 1999