SIMULATION OF THE FUEL STREAM INJECTION IN WALL GUIDED IN SPARK IGNITION ENGINE

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Abstract

Wall guided direct injection system is one of the most frequently met in modern car gasoline direct injection engines. In technical solutions where gravitational fuel charge movement occurs, concave piston head needs to be extended with specially shaped ascent. This additional surface guide's injected fuel stream in area of spark plug and forms centrally stratified fuel charge. Injector to cylinder axis inclination angle in wall guided direct injection engines is one of critical parameters which decide of combustion process flow. It determines density of injected fuel stream and air-fuel ratio which has to be less than 1 in spark plug area. 3D Studio MAX offers advanced module – Particle System – Super Spray which enables to simulate behaviour of injected fuel spray. These simulation runs resulted in finding optimal range of injector to cylinder axis inclination angle for the modelled direct injection engine. Results obtained from the simulation confirmed importance of injector to cylinder axis inclination angle as a construction parameter. However injection pressure doesn't impact fuel stream movement direction, it impacts time after which injected fuel stream reaches spark plug's electrodes. Undesired effect of increasing pressure value is higher fuel stream dissipation what dominates advantageous effect of shortening the time. This can be achieved by decreasing distance between injector and spark plug like in spray guided direct injection engines.

Keywords: *transport, road transport, simulation, combustion engines, direct injection*

1. Simulation description

The simulation of direct fuel injection process in wall guided gasoline engine is performed in 3D Studio MAX. The purpose of it is to determine how injection pressure and injector to cylinder axis inclination angle influence fuel particles movement. The model is simplified and results of the simulation can be only taken as basis for further scientific work. The combustion chamber used in the simulation is designed in AutoCAD 2000 and ProEngineer and afterwards imported into 3D Studio MAX. Fuel stream model is prepared using Particle System – Super Spray module [2-10]. Piston head reflects fuel particles due to Deflector function usage. The simulation takes into account reciprocal interactions between particles and interactions between fuel particles and piston head. Following effects are simplified in the model:

- combustion chamber temperature influence,
- air flow,
- fuel drops vaporization,
- fuel film formation.

Following assumptions are made about the model:

- Fuel particles are modeled as spherical molecules,
- Following parameters can be set up:
  - injector mounting angle (γ),
  - injection advance angle (α),
  - initial velocity of fuel stream (U_0),
  - fuel stream apex angle (θ),

  - injector opening angle (a_h, a_u),
  - piston movement as a function of crank angle,
- Reciprocal interactions between particles are stochastic and consist in joining and reflecting,
- Interaction between fuel stream and spherical part of piston head is possible due to Deflector function, where reflection coefficient and friction factor between fuel stream and piston head are taken into consideration,
- Model is designed to define approximate shape of fuel stream and location of fuel stream's core when reaching spark plug's electrodes.

Engine model and charge creation process are defined by the following parameters:

- crank radius R_w = 0.0445 [m],
- cylinder diameter D_c = 0.081 [m],
- compression ratio ε = 12,
- swept volume V_{ss} = 0.001834 [m^3],
- connecting-rod slenderness ratio λ_s = 1/3.5,
- injector mounting angle γ = 45°,
- injector nozzle diameter d_o = 0.0002 [m],
- injector speed coefficient C_D = 0.46,
- injection pressure p = 3.5-25.0 [MPa],
- pressure at the beginning of compression stroke p_{ps} = 0.09 [MPa],
- pressure at the end of compression stroke p_{ks} = 1.8 [MPa],
- revolution speed n = 3000 [rpm],
- stoichiometric constant for gasoline combustion L_t = 14.7,
- air density ρ_g = 1.27 [kg/m^3],
- fuel density ρ_p = 775 [kg/m^3],
- cylinder overall volume V_c = 0.000500 [m^3],
- filling degree η_V = 0.79-0.90,
- air-fuel ratio of the stratified charge leanest layer λ_t = 3.3,
- equivalent air-fuel ratio coefficient λ_t = 2.2,
- simulation runs are performed for different combinations of three following parameters:
  - injection advance angle (in a range from 30° BTDC to 60° BTDC),
  - injector mounting angle (in a range from γ = 20° to γ = 60°),
  - injection pressure (in a range from p = 3.5 MPa to p = 25 MPa).

2. Simulation results

All pictures gained from simulation in 3D Studio MAX are taken for engine revolution speed of n = 3000 rpm for which ignition angle is defined to be 30° BTDC. The parameters applied to the simulation runs are:

- injection pressure p = 3.5 MPa
- injection advance angle α = 50° BTDC
- injector to cylinder axis inclination angle γ from 20° to 60°

Figures 1 to 5 present results of computer simulation in phase when injected fuel stream reaches spark plug electrodes. The amount of fuel particles is representing density of injected fuel stream and indirectly air-fuel ratio.

It is clearly visible that changes of injector to cylinder axis inclination angle γ impact fuel stream's movement direction after reflecting from the piston head and fuel stream's dissipation. The appropriate γ angle value is between 30° and 40°. The time after which fuel stream reaches spark plug electrodes decreases with injector to cylinder axis inclination angle increase. Fig. 6 shows injected fuel stream's behavior when γ = 40°, injection advance angle α = 50° BTDC and injection pressure changes in a range from p = 3.5 MPa to p = 23 MPa. Changes of injection pressure don't

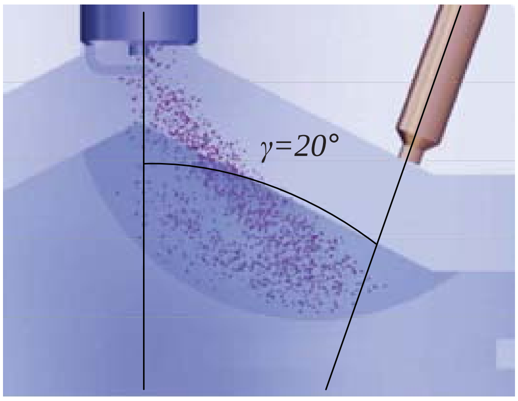

Fig. 1. Pictures of fuel stream reaching spark plug's electrodes (32° BTDC, γ = 20°)

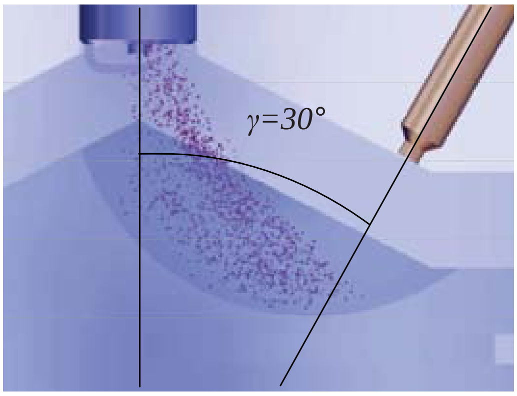

Fig. 2. Pictures of fuel stream reaching spark plug's electrodes (32° BTDC, γ = 30°)

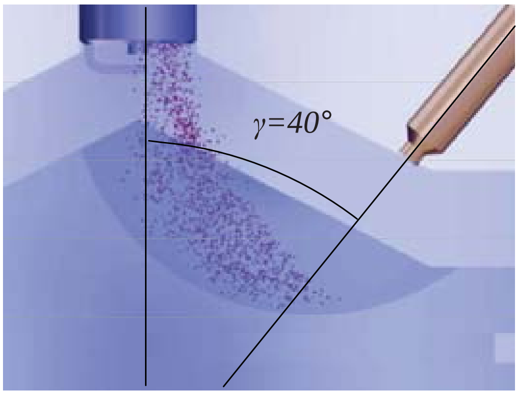

Fig. 3. Pictures of fuel stream reaching spark plug's electrodes (32° BTDC, γ = 40°)

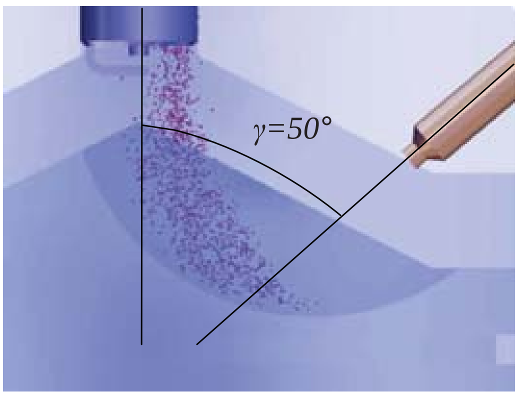

Fig. 4. Pictures of fuel stream reaching spark plug's electrodes (32° BTDC, γ = 50°)

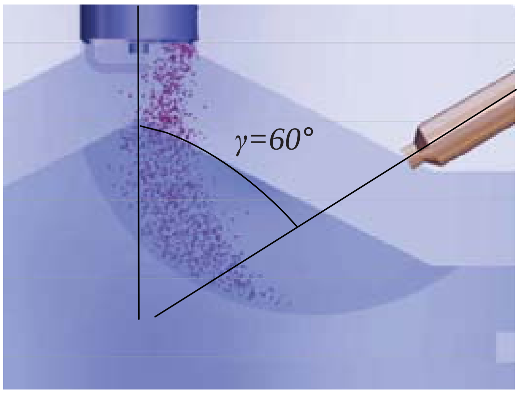

Fig. 5. Pictures of fuel stream reaching spark plug's electrodes (32° BTDC, γ = 60°)

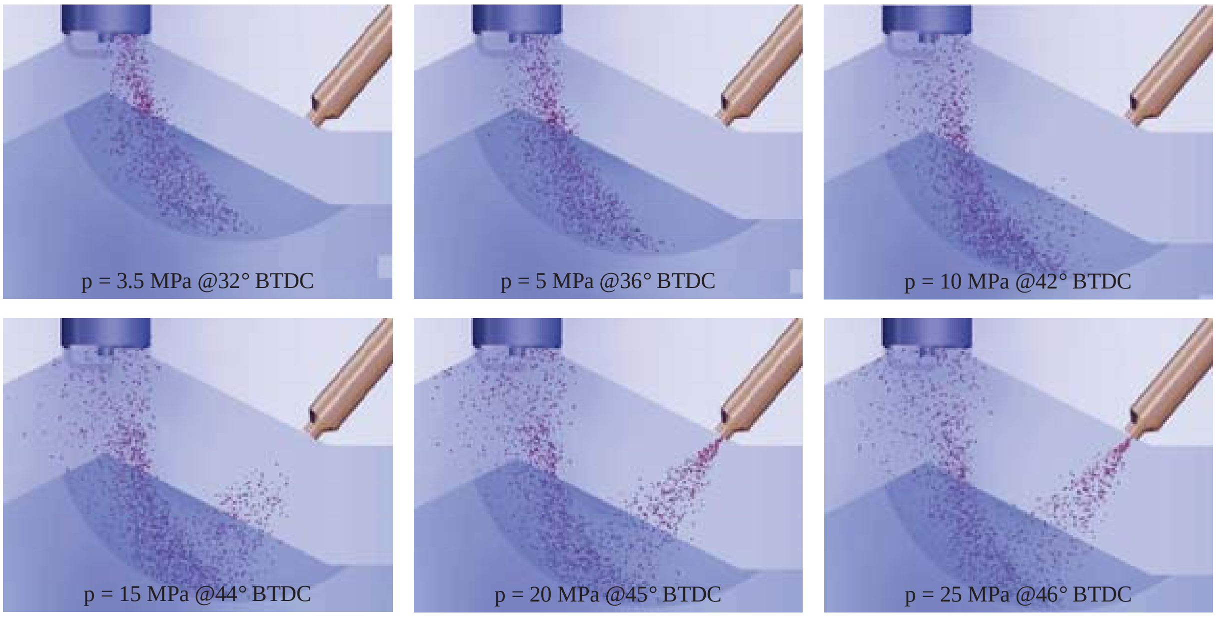

Fig. 6. Pictures of fuel stream reaching spark plug's electrodes (α = 50° BTDC, γ = 40°)

impact fuel stream's movement direction after reflecting from the piston head [11]. Time after which fuel stream reaches spark plug's electrodes decreases with injection pressure (p) increase. Increased injection pressure (p) causes that fuel stream which reflects from piston head is more dissipated.

3. Conclusions

- Injector to cylinder axis inclination angle is a critical engine construction parameter which optimal value in the modelled engine is between γ = 30° and γ = 40°.
- Increased injection pressure doesn't impact fuel stream's movement direction after reflecting from the piston head but increases dissipation of fuel stream.
- Shortening of time after which fuel stream reaches spark plug's electrodes shall not be achieved by increased fuel pressure because of increased dissipation.

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