SIMULATION STUDY TO EVALUATE THE CHARGING EFFICIENCY WHEN IMPROVING THE CHARGING INTAKE MANIFOLD FOR A SINGLE CYLINDER DIESEL ENGINE MANUFACTURED IN VIETNAM

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ABSTRACT

Single-cylinder diesel engines used in agriculture produced in Vietnam using outdated technology from 20 to 30 years ago can hardly meet fuel economy and emission standards. Therefore, in this study, the author focuses on improving the intake structure of the RV165 single cylinder diesel engine manufactured by VEAM to improve the intake coefficient and the mixing between air and fuel. The study was conducted on Ansys-ICE software, with simulation conditions from 1000 (rpm) to 2200 (rpm). The improvement scheme focuses on changing the intake path, with three cases: changing the curvature, the profile and a combination of both for the intake path. The results showed that compared to the original, the intake coefficient in the improved cases was larger, in which the case of combined change of both intake curve and intake throat profile was the largest, corresponding to an increase of 2.18% compared to the unimproved case.

Keywords: *Intake coefficient, intake manifold, turbulent model, CFD, agricultural engine.*

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1. INTRODUCTION

According to the Department of Economic Cooperation and Rural Development (Ministry of Agriculture and Rural Development), in the period from 2011 to 2022, the number of tractors of all kinds increased by 60%, rice transplanters increased by 10 times; water pumps increased by 60%; combine harvesters increased by 80%; agricultural dryers increased by 30%; animal feed processing machines increased by 91%; aquatic feed processing machines increased by 2.2 times and pesticide sprayers increased by 3.5 times. For rice production, the current mechanization rate in plowing and agricultural land preparation reached 94%; sowing and planting reached 42%, rice care reached 77% and rice harvesting reached 65% [1].

Table 1 shows that the demand for agricultural machinery grew very rapidly from 2010 to 2015.

Table 1. Statistics on the demand for agricultural machinery (units)

Type	Year 2010	Year 2015
Tractor	795.700	900.000
Reaper	13.500	33.000
Rice thresher	975.000	1.070.000
Milling machine	550.000	670.000
Rural Truck	181.400	272.000

Along with the growth of agricultural production, agricultural mechanization is developing rapidly in both quantity and quality, meeting the requirements of solving heavy labor stages, increasing urgent seasonality, thereby contributing to improving labor productivity, quality, value and competitiveness of agricultural products. Therefore, in the process of industrialization, urbanization and international economic integration, mechanical products serving agriculture in Vietnam have received more attention, with a variety of product types, in which equipment using internal combustion engines with a capacity range of up to 30 horsepower are widely used such as tillage machines (4- and 2-wheel plows), harvesting machines (combine harvesters, row harvesters, threshers), water pumps, pesticide sprayers, preservation and processing machines (rice mills, dryers).

The current performance of these engines has been evaluated through research by Khong Vu Quang and colleagues [2]. The research evaluated engines with a power range of 8 to 19 (kW) showing that fuel consumption is quite high while toxic emissions have not met Tier1 and Tier2 standards. When comparing emissions with equivalent engines (RT155 engine manufactured by Kubota) [3], it shows that the CO emissions of the SV165 engine are 47.7% higher but meet Tier2 standards, while PM emissions are 69.6% higher and do not meet Tier1.

Vo Thanh Vang et al. [4] collaborated with SVEAM Corporation to study the improvement of the RV125 engine intake with 2 options of improving the intake manifold and improving the intake manifold profile. CFD simulation results show that the new intake manifold is designed with a spherical geometric structure, which helps the pressure increase process in the intake manifold area to occur less than the cylindrical geometric structure. The improved manifold pressure only increases the pressure concentrated around the intake valve, while the old manifold pressure is concentrated at the valve and before the valve. This large area pressure increase increases the resistance to the gas flow moving from outside to inside the cylinder, leading to a decrease in molecular density inside the cylinder, uneven distribution, thereby making the combustion process incomplete, and many areas with excess fuel appear; With the new throat design, air moves easily on the intake pipe, so the molecular density inside the cylinder increases. In addition, the vortex speed of the intake air flow increases and is maintained at a high value during both the intake and compression processes, thereby improving the mixing process between fuel and air, helping the fuel burn thoroughly, increasing capacity, and reducing harmful emissions. At the same time, the increased air flow rate during the intake and compression processes also increases the heat exchange process between the medium in the cylinder and the combustion chamber wall, thereby reducing the temperature of the parts surrounding the combustion chamber, making the parts more durable. Although the study shows a good improvement solution in increasing the intake coefficient, thereby helping to improve the technical and economic features and emissions of the engine, there are also some limitations such as manufacturing is more difficult with a spherical profile than with the old cylindrical profile (also depending on internal structures such as valves, rocker arms, etc.); On the other hand, due to the exhausted fuel, CO, HC, and SOOT emissions are reduced, but the high combustion temperature increases NO_x emissions.

The above analysis shows that improving the intake manifold plays a very important role in the engine's intake efficiency. In this study, the author will proceed according to the following cases: changing the intake curve; changing the intake profile and combining both options to evaluate the effectiveness of each specific option, thereby providing the optimal option for practical application.

2. MODEL SETUP

2.1. Theoretical basis of simulation in Ansys-ICE

Ansys ICE is a software capable of modeling compressible and incompressible flows, laminar flows, and turbulent flows. In this study, the flow simulation model is performed based on the following assumptions [4]:

(1) The medium is a viscous liquid (viscosity depends on temperature and pressure);

(2) The flow is a steady flow;

(3) The influence of gravity is considered;

(4) The medium at the inlet and outlet is a homogeneous liquid;

(5) The standard k-ε turbulence model is used.

The calculation process is based on the system of equations:

Mass conservation equation:

$$\frac{\partial U_i}{\partial x_i} = 0 \tag{1}$$

Momentum equation:

$$\rho U_i \frac{\partial U_j}{\partial x_j} = -\frac{\partial P}{\partial x_j} + \frac{\partial}{\partial x_i}\left[\mu\left(\frac{\partial U_i}{\partial x_j} + \frac{\partial U_j}{\partial x_i}\right) - \rho\overline{u_i' u_j'}\right] \tag{2}$$

Energy equation:

$$\partial c_p U_i \frac{\partial T}{\partial t} = \frac{\partial}{\partial x_i}\left[\lambda \frac{\partial T}{\partial x_i} - \rho c_p \overline{u_i' T'}\right] \tag{3}$$

Trong đó:

U_j and T is the average velocity and temperature of the medium;

u_i', u_j' và T' are the corresponding oscillating components;

$\rho\overline{u_i'u_j'}$ and $\rho c_p\overline{u_i'T'}$ are Reynolds stress and thermal stress.

The k-ε turbulence equation:

$$\rho\frac{\partial k}{\partial t}+\rho U_i\frac{\partial k}{\partial x_i}=\frac{\partial}{\partial x_i}\left[\left(\mu+\frac{\mu_t}{\sigma_k}\right)\frac{\partial}{\partial x_i}\right]+\mu_t\left(\frac{\partial U_i}{\partial x_j}+\frac{\partial U_j}{\partial x_i}\right)\frac{\partial U_j}{\partial x_i}-\rho\varepsilon \quad (4)$$

$$\rho\frac{\partial \varepsilon}{\partial t}+\rho U_i\frac{\partial \varepsilon}{\partial x_i}=\frac{\partial}{\partial x_i}\left[\left(\mu+\frac{\mu_t}{\sigma_\varepsilon}\right)\frac{\partial}{\partial x_i}\right]+C_1\mu_t\frac{\varepsilon}{k}\left(\frac{\partial U_i}{\partial x_j}+\frac{\partial U_j}{\partial x_i}\right)\frac{\partial U_j}{\partial x_i}-\rho C_2\frac{\varepsilon^2}{k} \quad (5)$$

The empirical constants used in the standard k-ε model have the following values:

$C_\mu = 0.09$; $\sigma_k = 1.00$; $\sigma_\varepsilon = 1.30$; $C_1 = 1.44$; $C_2 = 1.92$ and $\sigma_t = 0.85$.

2.2. Simulation object

The research object is the RV165 diesel engine manufactured by VEAM for agricultural use. The basic parameters are shown in Table 2.

Table 2. Specifications of RV165 engine

Nº	Parameter	Value
1	Engine type	Diesel, 4 stroke
2	Cylinder diameter	105mm
3	Piston stroke	97mm
4	Cylinder volume	839cm^3
5	Compression ratio	20:1
6	Rate power/speed	12.1/2200kW/rpm
7	Maximum moment/speed	48/1800Nm/rpm
8	Dry weight	132kg
9	Fuel consumption	239g/kWh

The main dimensions of the intake manifold and intake manifold of the original engine are shown in Fig. 1.

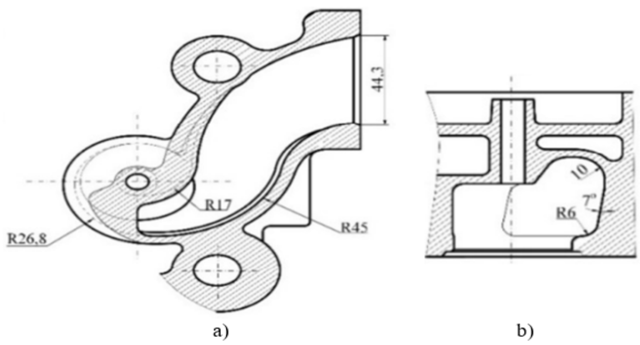

Fig. 1. Original intake structure: a) Intake profile; b) Intake structure

When the engine is running, air is sucked into the engine through the intake manifold, the most important parameter affecting the quality of the intake process is the intake coefficient ηv. When the intake coefficient increases, the efficiency of the combustion process will increase, helping the fuel burn well, burn completely, not only generating high power but also improving the emission quality. Based on the actual structure of the engine intake line shown in Fig.1, the author proposes 3 options to improve the RV165 engine intake line (Fig. 2):

+ Change the curvature of the intake line (case 1);

+ Change the intake profile (case 2);

+ Combine the change of the curvature of the intake line as well as the intake profile (case 3).

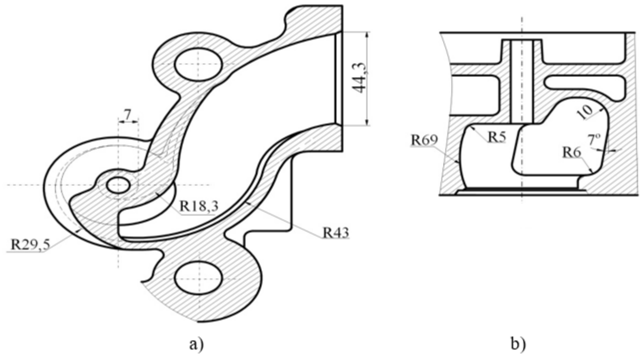

Fig. 2. RV165 engine intake structure improvement options

a) Change the intake profile; b) Change the intake throat profile

2.3. Model Building

From the dimensions of the RV165 engine as well as the dimensions on the intake manifold (Fig. 2) and the engine parameters in Table 1, the research team will build a 3D model on Soild work and transfer to Ansys-ICE to mesh and run the simulation (Fig. 3). In addition, during the meshing process, Ansys-ICE will discretize the model according to the translational displacement condition of the piston from top dead center (TDC) to bottom dead center (BDC). The tetrahedral mesh is used (Tetra) when meshing, in which the interface surfaces between the medium and the wall (cylinder, cylinder head, valve) are divided in a hexagonal pattern (Hexa) to satisfy the log-law [5].

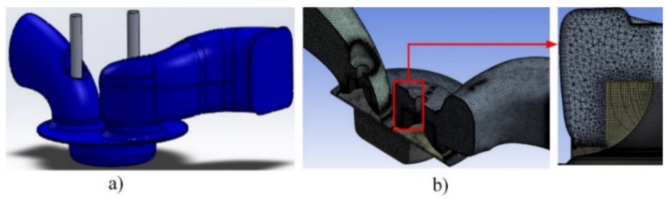

Fig. 3. 3D model (a) and meshing of RV165 engine (b)

The simulation is performed with the intake valve opening early (20^0 before TDC) and ends with the intake valve closing late (45^0 after TDC), the calculation step is used for each 0.5^0 crankshaft angle (CA). The boundary conditions in the simulation are shown in Table 3.

Table 3. Boundary condition values in the simulation model [6, 7]

Nº	Boundary conditions	Value
1	Air intake	300K
2	Intake pipe	330K
3	Piston	450K
4	Intake-exhaust valve	330K
5	Cylinder	450K
6	Engine cover	450K

In addition, before the intake valve opens, the remaining gas in the cylinder has a pressure of 1.1bar and a temperature of 820K [8].

3. SIMULATION RESULTS AND DISCUSSION

3.1. Velocity distribution during engine charging

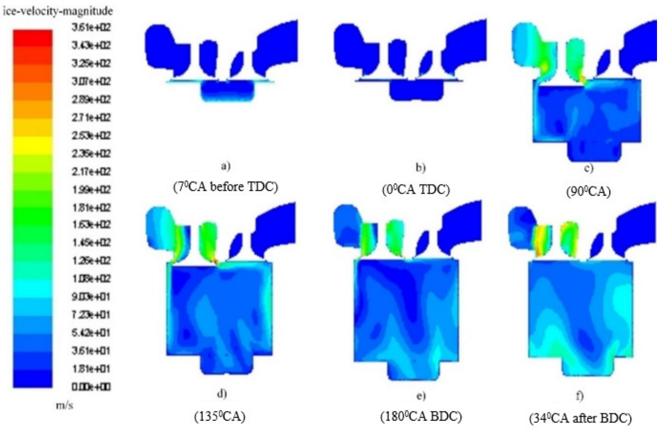

Fig. 4. Cylinder intake velocity distribution

Fig. 4 shows the velocity of the gas flow entering and within the cylinder during the engine intake process. The velocity of the gas flow does not change significantly when the intake valve lift is small (the piston is near the TDC point). Then, the intake gas flow enters the engine cylinder with increasing velocity following the downward movement of the piston, the average velocity of the intake gas flow reaches its maximum when the piston has traveled about half of the intake stroke.

Through the flow velocity field, it can be seen that the gas flow rate during the intake process is not uniform in time (crankshaft rotation angle) and space (combustion chamber volume). From Fig. 5, it can be seen that when the intake air passes through the gap between the valve, the gas flow velocity will have the largest value (due to the small gap between the valve and the valve seat). Figs. 5c and 5d show the formation of turbulence during the movement of the fluid flow in the cylinder, which will increase the mixing process between air and fuel. In addition, Fig. 5 shows a visual image of the intake process in the engine. In fact, the intake process continues when the piston passes the BDC in Fig. 5f, thereby increasing the intake coefficient of the engine.

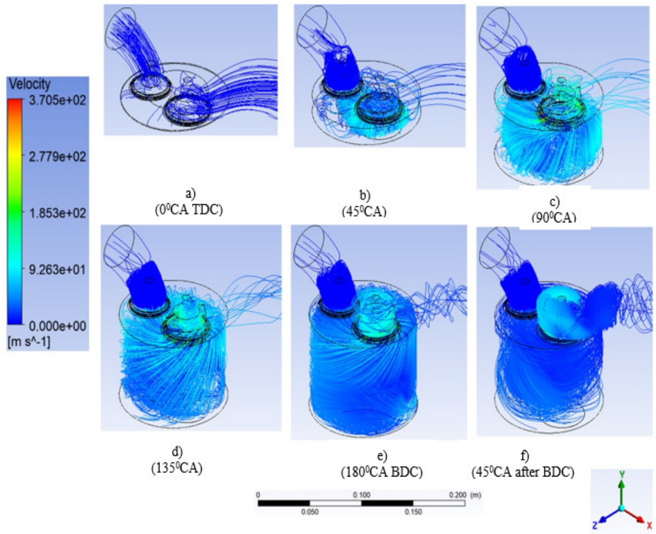

Fig. 5. Cylinder intake velocity distribution

3.2. Pressure distribution during engine intake

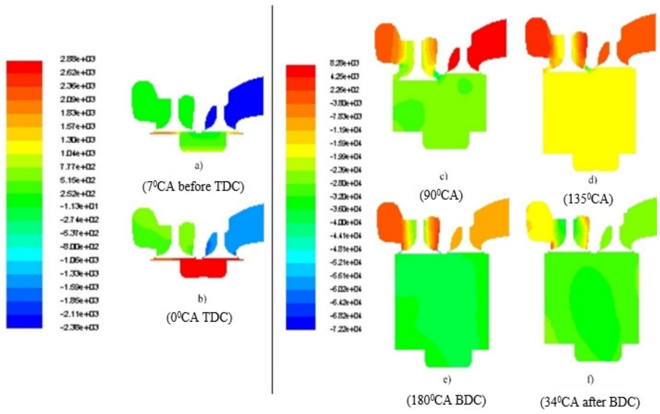

Fig. 6. Pressure distribution during cylinder intake

The pressure distribution in the cylinder is shown according to the crankshaft rotation angles in Fig. 6. From Fig. 6a and Fig. 6b, it can be seen that the pressure inside the cylinder is greater than the pressure on the intake manifold (the piston moves up to TDC). When the piston moves from TDC to BDC, due to the increase in volume in the combustion chamber, the pressure in the cylinder is less than the pressure on the intake manifold (Figs. 6c, d). When the piston is at TDC (Fig. 6e) until the intake valve closes (Fig. 6f), the pressure difference in the cylinder and the intake port gradually decreases due to the gradual closing of the intake valve.

3.3. Intake coefficient

Fig. 7 shows the engine's intake coefficient in 4 different cases when the engine operates at 2200 rpm and 100% load. The results show that with the intake profile according to Case 3, the engine's load factor has a higher value than the remaining cases. Specifically, the intake coefficient corresponding to Case 3 has a value of η_v = 0.798, which is larger than the original case η_v = 0.781; a corresponding increase of 2.18%.

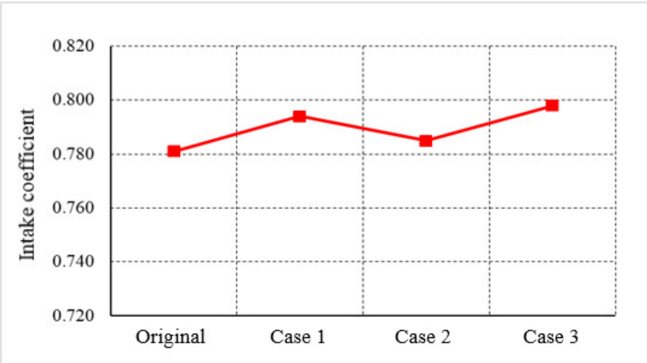

Fig. 7. Engine intake coefficient corresponding to 4 intake profile cases

Fig. 8 shows the results of η_v according to the external characteristics, it can be seen that η_v is inversely proportional to the engine speed. The intake coefficient in the improved case is larger than the original intake line of the engine, in addition, η_v has the largest value when the engine works at a low speed of 1200rpm and has the smallest value when the engine works at 2200rpm.

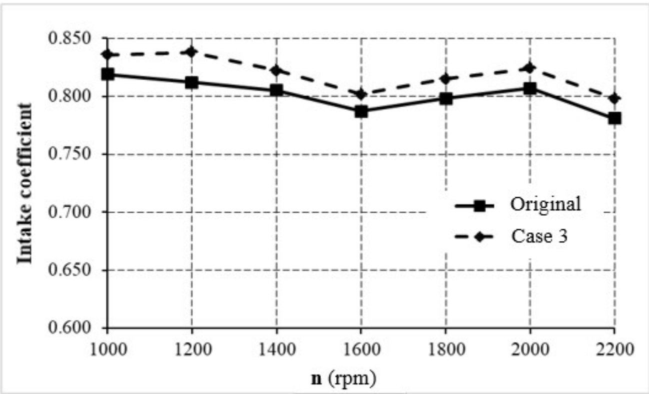

Fig. 8. Intake coefficient according to engine speed characteristics

Fig. 9 shows the simulation results of the intake coefficient (η_v) corresponding to the two cases of the original intake line and the Case 3 case of the engine running according to the ISO 8178-4C1 test cycle. The results show that the intake coefficient in the improved case is higher than the original case in all Modes of the test cycle. Specifically, η_v increases the highest by 2.41% at 2200rpm and increases on average by 2.18% over the entire measurement range.

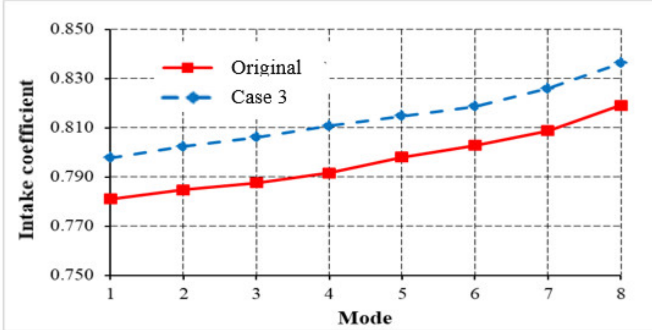

Fig. 9. Intake coefficient of the engine according to the ISO 8178-4C1 cycle

Increasing the intake coefficient can help improve the quality of the combustion process, thereby increasing power, reducing fuel consumption and toxic emissions of the engine.

4. CONCLUSION

The study presented the simulation results to evaluate the impact of the improved intake manifold structure on the technical and economic characteristics and emissions of the RV165 engine based on the combination of Ansys ICE software. The research results showed that by changing the curvature and dimensions of the intake manifold cross-sections along with changing the intake manifold profile, it is possible to improve the mixing process between fuel and air as well as increase the engine's intake coefficient. Specifically, the combination of changing the curvature and intake profile gives the best results with an average intake coefficient increase of 2.18% over the entire speed range. These are the premises that can help improve the quality of the combustion process, thereby increasing power, reducing fuel consumption and toxic emissions of the engine.

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