Virtual model of the SES solution for extending the vehicles electric propulsion system autonomy

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Abstract. With the support of advanced technical software one can easily and virtually create and study the SES system (Secondary Energy System - presented in a previous paper), in order to determine if its physical realization is appropriate. In the virtual analyzing and testing mode is much easier in terms of time, costs and resources needed to set up the system in practice. In order to carry out the virtual analysis and testing of the SES system, we used the Catia application for the three-dimensional design and the Matlab numerical computing environment for the theoretical-functional analysis of the system.

1. Introduction
In this paper we present the realization of the virtual model of the SES system. The model aims to allow the analysis of possibilities of implementing the adopted solutions.

Modeling of Computer Aided Systems type, was realized through the CATIA V5 design environment. In this case, the program was used as, it offers a number of advantages such as: advanced conception of mechanical parts, interactive realization of assemblies, automatic obtaining of projections of parts or the assembly, the possibility to design in a parameterized way. CATIA V5 also directly allows a three dimensional design of parts and assemblies [1].

2. The virtual model. Methods of realization
Starting with the block diagram described in figure 1, in figure 2 is presented the virtual model of the thermal engine which is a part of the SES system, realized through the CATIA V5 design environment. This model facilitates the optimization of the arrangement of the elements which are part of the system, considering, first of all, the constructive features of the engine [2].

Figure 1. Block diagram.
Figure 2. The virtual model of the thermal engine.

As a reference model for the development of the theoretical study and, in another phase, the experimental one, it was considered a spark ignition engine, characterized by the fundamental dimensions $D = 60.33 \text{ [mm]}$ and $S = 44.45 \text{ [mm]}$. This engine has a compression ratio $\varepsilon = 5.3$.

As it is known, the power of the engine, assimilated to the effective power $P_e$, can be determined in the case of vehicles from the imposed dynamic performance or, in other cases, like this one, based on the calculation of the power of another consumer.

Next, the computational relationships used to determine the parameters of the thermal engine, which characterize its operating cycle, are presented [3].

2.1. The degree of filling, pressure and temperature of the working fluid during the intake process

\[
\eta_f = \frac{p_a}{p_0} \frac{T_0}{T_a} \frac{\varepsilon - 1}{1 - \varphi_{pu} \gamma_r} = \frac{0.84}{1} \frac{298}{355.24} \frac{5,3 - 1}{1 - 0.1 \cdot 0.05} = 0.88 \quad (1)
\]

\[
T_a = \frac{T_0 + T + \tilde{\zeta}_r T}{1 + \gamma_r} = \frac{298 + 30 + 1 \cdot 0.05 \cdot 900}{1 + 0.05} = 355.24 \text{ [K]} \quad (2)
\]

\[
p_a = p_0 - p_0 = 1 - 0.16 = 0.84 \text{ [bar]} \quad (3)
\]

The notations used in the above equations have the following meanings:

- $p_a$ – the pressure in the cylinder at the end of the intake stroke;
- $p_0$ – fresh fluid pressure at engine inlet ($p_0 = 1 \text{ [bar]}$);
- $T_0$ – temperature of the fresh fluid at the engine inlet ($T_0 = 298 \text{ [K]} = 25 \text{ [°C]}$);
- $T_a$ – temperature at the end of the intake stroke;
- $\varepsilon$ – compression ratio;
- $\varphi_{pu}$ – the degree of post-filling ($\varphi_{pu} = 0.08…0.25$);
- $\gamma_r$ – the coefficient of waste gas ($\gamma_r = 0.05$);
- $\Delta T$ – increase of the temperature of the fresh fluid ($\Delta T = 10…40$);
- $\tilde{\zeta}_r = 1$;
- $T_r = 600…900 \text{ [K]}$;
- $\Delta p_a = 0.16 p_0 = 0.16 \text{ [bar]}$. 
2.2. The pressure and temperature of the working fluid at the end of the compression

\[ p_c = p_a e^{n_c} = 0,84 \cdot 5,3^{1,35} = 7,98 \text{ [bar]} \] (4)

\[ T_c = T_a e^{n_c-1} = 355,24 \cdot 5,3^{0,35} = 636,82 \text{ [K]} \] (5)

where:

- \( n_c \) – polytropic exponent dependent on the heat exchange between the motor fluid and the cylinder walls (\( n_c = 1,32 \ldots 1,38 \)).

2.3. The pressure and temperature of the working fluid at the end of the combustion stroke

The temperature at the end of the combustion process is obtained from the following relation:

\[ T_x = 1916,33 \text{ [K]} \] (6)

\[ p_x = \beta \cdot p_c = 17,60 \text{ [bar]} \] (7)

where:

- \( \beta \) – is adopted and has values between 1,70…2,20.

2.4. The pressure and temperature of the working fluid at the end of the relaxation stroke

\[ p_d = \left( \frac{\delta}{\varepsilon} \right)^{m_d} \cdot p_x = \left( \frac{1,41}{5,3} \right)^{125} \cdot 17,60 = 3,37 \text{ [bar]} \] (8)

\[ T_d = \left( \frac{\delta}{\varepsilon} \right)^{m_d-1} \cdot T_x = \left( \frac{1,41}{5,3} \right)^{125-1} \cdot 1916,33 = 1377,15 \text{ [K]} \] (9)

where:

- \( m_d \) – polytopic exponent dependent on speed and load (\( m_d = 1,23 \ldots 1,30 \));
- \( \delta \) – relaxation report.

2.5. The waste gas temperature

\[ T_r = \frac{T_d}{\sqrt[3]{p_d}} = \frac{1377,15}{\sqrt[3]{3,37}} = 989,15 \text{ [K]} \] (10)

\[ \Delta T = \left| \frac{T_r - T_x}{T_r} \right| \cdot 100 = 9,01 \] (11)

The maximum allowable error between the value of the previously adopted waste gas temperature and the one obtained by calculation is 10 %, when calculating the intake process.
3. The simulation of system engine operation

Based on the values obtained in this way, the operating cycle of the engine shown in figure 3 was drawn.

![Figure 3. Pressure-Volume diagram.](image)

In other situations, especially when a reference model is available, estimation of the engine power can also be made by geometrical-mechanical similarity. In this process it is considered that dimensions of the designed engine are changed compared to the reference engine by a certain k ratio, called the similarity ratio. At the same time, it is considered that engines operate after the same cycle and with the same settings.

Keeping an average speed of the piston in order to limit the mechanical demands of the designed engine, the following conditions of definition of the similarity ratio result:

\[
k = \frac{D}{D_0} = \frac{S}{S_0} = \frac{n_0}{n}
\]  

(12)

Expressing the actual powers for the reference engine and the engine designed, we have:

\[
P_{e0} = p_e \cdot \frac{\pi D_0^2}{4} \cdot \frac{S_0 n_0}{300 \tau} \cdot 10^{-5}
\]  

(13)

\[
P_e = p_e \cdot \frac{\pi D^2}{4} \cdot \frac{S n}{300 \tau} \cdot 10^{-5}
\]  

(14)

The notations in the above equations represent:

- \( p_a \) – the pressure in the cylinder at the end of the intake stroke [kW];
- \( P_{e0} \) – the effective power of the standard engine [kW];
- \( P_e \) – the actual power of the designed engine [kW];
- \( D_0 \) – cylinder bore for standard engine [mm];
- \( D \) – cylinder bore for the designed engine [mm];
- \( S_0 \) – piston stroke for standard engine [mm];
- \( S \) – piston stroke for the designed engine [mm];
- \( p_e \) – average effective cycle pressure (same for both engines) [MPa];
- \( n \) – rated standard engine speed [rpm];
- \( n_0 \) – rated designed engine speed [rpm];
- \( \tau \) – number of engine cycle times.
Using this criterion we finally get:

\[ P_e = k^2 P_{e0} \] (15)

The mathematical operations were carried out with the support of the Matlab program. The main advantage of this program consists in the elaboration of subroutines of the algorithm that is done in a short time, which leads to real-time adaptations of the calculation model.

4. The virtual model of the SES system

The determination of the main parameters of the engine within the SES system was imperative, in order to proceed to the next phase, respectively to the virtually system design.

We also mention the fact that the design was carried out taking into account the constraints imposed by the small size of the space available for the proper installation of the system.

Next, the adopted and virtually implemented solution is presented:

**Figure 4.** Virtual model of the location system.

**Figure 5.** Virtual model of the positioning system.
Figure 6. The virtual model of the training system-scheme.

Figure 7. The virtual model of the clamping, tensioning system – scheme.

This way of arranging the components within the SES has proved to be the best in terms of space. The internal combustion engine and the two generators are fixed by a frame using rubber pads that are designed to dampen vibrations. The transmission is realized by belts with grooves, their tension being produced by moving the two generators on the frame.

The entire assembly is placed on the vehicle easily, using the available space for the spare wheel.

5. Conclusion
Based on the carried out study, the optimization of the SES system was realized in order to show that this system is effective and that it can be successfully used on electric-powered road vehicles, improving their autonomy.
In addition to the main role, that of increasing the autonomy of vehicles, also an increase in period of batteries lifetime is obtained due to the reduced charge-discharge cycles, as well as the elimination of the imminent disadvantage of the electric vehicles, the so-called “power outage” phenomenon.

Therefore, after the theoretical studies and the analysis of the virtual model that prove the efficiency of the SES system, we can proceed to the next stage, respectively the one of building the physical model.

6. References
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