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# THE EFFECT OF INLET VALVE OPENING AND CLOSING ANGLES ON ENGINE PERFORMANCE

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**Summary.** The paper presents the problems connected with modelling of the course of engine filling on the basis of Brandstetter's method based on using non-dimensional criteria of similarity and adapted for multi-cylinder engines. After the analysis of criterial numbers we decided to determine the effect of criteria referring to inlet valve opening and closing on the engine filling and to find that effect by an examination on the engine test stand. Modelling reliability degree was determined as compared to the real situation.

**Key words:** Diesel engine, filling, inlet valve

## INTRODUCTION

The indicator characterising combustion engine filling process is the filling ratio $\eta_v$. It is the ratio of the mass of fresh charge which truly reached the cylinder during the filling stroke to the mass of fresh charge which could have filled the piston-swept volume cylinder capacity at ambient temperature and pressure. In the classical formulation, the filling ratio is described by air parameters at inlet and engine compression ratio:

$$\eta_v = T_{\square} (\varepsilon \, p_{\square}/T_{\square} - p_{l}/T_{l}) \; / \; p_{\square}(\varepsilon - 1), \tag{1}$$

where: $T_{\square}$ – ambient temperature,
$p_{\square}$ - ambient pressure,
$\varepsilon$ – compression ratio,
$p_{\square}$ – terminal filling pressure,
$T_{\square}$ – terminal filling temperature,
$p_{l}$ – exhaust gas pressure,
$T_{l}$ – exhaust gas temperature.

On the other hand, terminal filling temperature depends on ambient temperature in accordance to the following expression:

$$T_{\square} = (T_{\square} + \Delta T + \gamma T_{l}) \; / \; (1 + \gamma), \tag{2}$$

where: $\Delta T$ – air temperature increment resulting from conduit wall warming,
$\gamma$ – residual gas coefficient.

Reciprocal influence of different factors being of use in determination of the filling ratio compels caution with respect to their value. Formal approach to that problem may lead to erroneous generalisations. It might be thought that the filling ratio $\eta_v$ would decrease proportionately to element $1/\varepsilon - 1$ together with an increase in the compression ratio. As a matter of fact, that relationship is much more complex because $\gamma$ i $T_r$ decrease with the increase of $\varepsilon$ and the same the value $\eta_v$ does not practically depend on $\varepsilon$ [2].

Theoretical considerations allow stating that analytical determination of the filling ratio is very complex and in this situation the theory of similarity proved to be useful, which was used by Brandstetter [1]. The theory of similarity makes generalisation of results into phenomena similar to each other possible. In the flow problems, the condition of geometric similarity must be satisfied in the first place, according to which the ratio of appropriate linear dimensions for flux limitations comparable to each other must be the same [6]. On the basis of the theory of similarity, Brandstetter isolated ten criterial quantities $K_1$ to $K_{10}$ for cylinder filling process and filling value determination [1]. These assumptions were correct for single-cylinder test engine. The author modified this method for application with multi-cylinder engines proving that the effect of symmetric inlet conduit bifurcation is small if the flow number on inlet into the conduit $\alpha_w$ is larger than 0,6; however, Brandstetter adopts a value of 0,63 as a lower limit securing dynamic supercharging. In his considerations, Brandstetter omitted the effect of inlet conduit roughness on the filling, which was taken into account in the form of introduced loss coefficient $\lambda$ decreasing the filling to more real values presented in the Siguranz's computer programme [5].

Long-time engine test bed and simulation studies of multi-cylinder engines (SW 680, 4C90, Star 359) and single-cylinder engine SB 3.1 constructed on the basis of the SW 680 engine at WSW DELTA Mielec (Diesel Engine Factory) allowed for the determination of the effect of Brandstetter's coefficients on engine filling ratio. This effect can be divided into three groups [4]:

1. Criteria practically not affecting the value of filling coefficient:
   - compression ratio $\varepsilon$,
   - adiabate exponent $\kappa$,
   - connecting rod length coefficient $\lambda$.
2. Criteria greatly affecting the value of filling coefficient:
   - relative flow ratio $\alpha_d$, affecting this value within 10-12% at average and large crankshaft rotational speeds,
   - inlet valve opening angle $\varphi_{do}$, affecting this value within 5-8% within the whole range of useful rotational speeds,
   - pressure ration $p_c/p_s$, affecting this value up to 10% within the whole range of useful rotational speeds,
   - suction manifold inlet discharge coefficient $\alpha_w$, affecting this value within 10-12% at average and large crankshaft rotational speeds.
3. Criteria very considerably affecting the value of filling coefficient:
   - inlet valve closing angle $\varphi_{dz}$ after TDC affecting this value within 25-30% at small and average rotational speeds and within 20% at large rotational speeds.

The aforesaid criteria determined the selection of further tests which focused on the effect of inlet valve opening and closing angles on four-stroke engine filling.

## TESTS

Examinations were carried out for the SW 680 engine with inlet valve opening angle of 4°±4° before TDC and inlet valve closing angle of 57°±4° after BDC. For both these situations, the curve of Brandstetter's coefficient is presented in Figs 1 and 2 for inlet conduit length $L_D$ = 936 mm which, according to initial calculations, should have guaranteed the obtainment of dynamic supercharging effect according to the following formula:

$$L_D = (6 \cdot a_o/n) \pm 0{,}075 \text{ m}, \tag{3}$$

where: $a_o$ – speed of sound under normal conditions of 343.13 m/s
n – engine rotational speed, at which we wish to obtain the effect of dynamic supercharging.

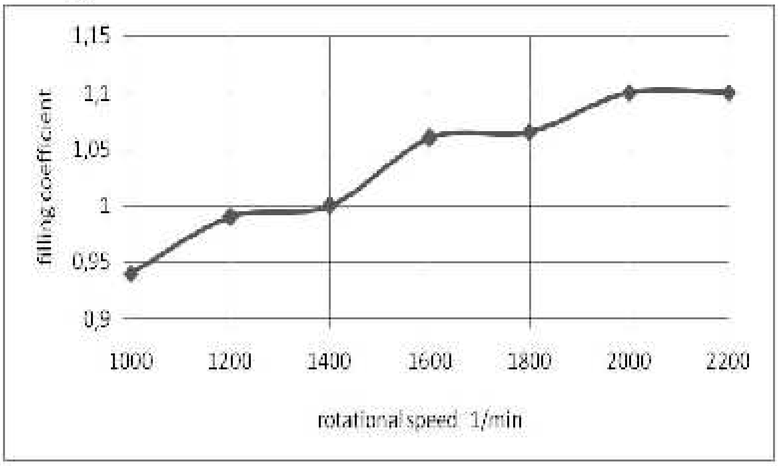


Fig. 1. Filling ratio variation in the function of inlet valve opening angle for the SW 680 engine at inlet conduit length of 936 mm

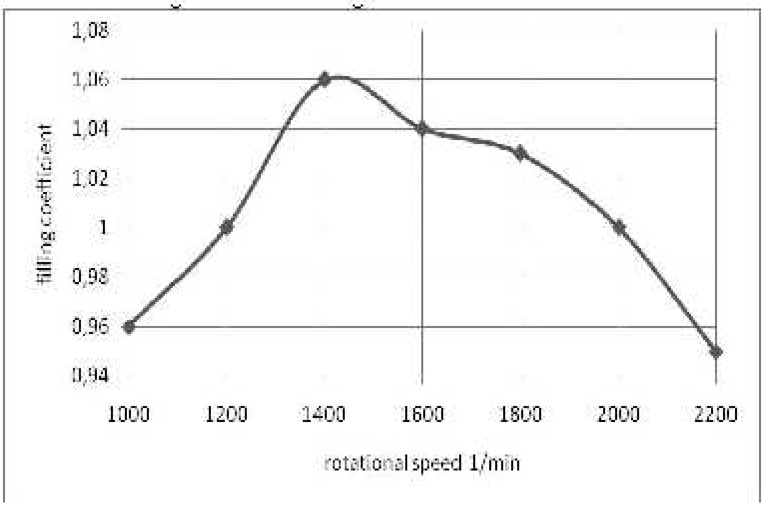


Fig. 2. Filling ratio variation in the function of inlet valve closing angle for the SW 680 engine at inlet conduit length of 936 mm

The filling ratio curves, in conjunction with the degree of effect of respective criterial numbers given earlier, clearly indicate a favourable effect of inlet valve closing angle on the filling of the examined engine within its maximum torque.
Parameters of the engine described in Fig. 3 are as follows:
$L_D$ = 936 mm, D = 127 mm, s = 146 mm, $\varepsilon$ = 15.8; $\lambda$ = 0.258; $\alpha_d$ = 0.68; $\varphi_{do}$ = 10°; $\varphi_{dz}$ = 60°; $\kappa$ = 1.41; $p_c/p_s$ = 1.1; $\alpha_w$ = 0.63.

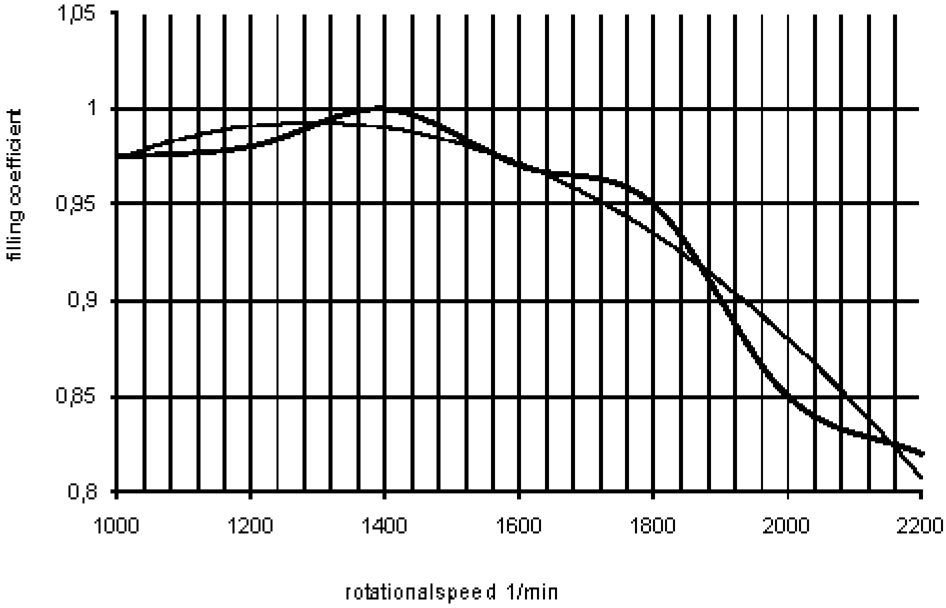


Fig. 3. Filling ratio curve for the SW 680 engine dynamically supercharged for inlet conduit length of 936 mm and diameter of 50.4 mm; thin solid line is used to present a polynominal trend

Based on the trend line, a coefficient of divergence between the trend line and the data obtained during examination [3] was calculated; these calculations were made in Tabular form and are presented in Table 1.
The variance of trait y is $s^2$ = 0.004615, a $\varphi^2 = \Delta^2/n \cdot s^2$,
where: n – number of measurements,

hence: $\varphi^2$ = 0.001375 / 7 · 0.004615 = 0.0425, i.e. 4.25%.

This means that real and theoretical values are inconsistent in 4.25% only. Therefore, they are consistent in 95.75%, which is an acceptable result.

Table 1. Calculation of the coefficient of divergence $\varphi^2$ for engine filling ratio

| Item | Real value<br>$y$ | Theoretical value<br>$y_t$ | Difference<br>$y-y_t = \Delta$ | $\Delta^2$ |
|---|---|---|---|---|
| 1. | 0.98 | 0.98 | 0 | 0 |
| 2. | 0.985 | 0.99 | -0.005 | 0.000025 |
| 3. | 1.0 | 0.99 | 0.01 | 0.0001 |
| 4. | 0.98 | 0.975 | 0.005 | 0.000025 |
| 5. | 0.96 | 0.93 | 0.03 | 0.0009 |
| 6. | 0.86 | 0.875 | 0.015 | 0.00025 |
| 7. | 0.83 | 0.82 | 0.01 | 0.0001 |
| Σ | 6.595 | 6.56 | 0.065 | 0.001375 |

On the SB 3.1 test engine, examination of the effect of angles $\varphi_{do}$ and $\varphi_{dz}$ on the filling ratio of Diesel four-stroke direct-injection engine was carried out and its results are presented in Fig. 4.

Examination of the effect of inlet valve opening and closing angles for the engine, for which the course of filling is presented in Fig. 3, showed correctness of the values of these angles adopted in simulation calculations. It is clearly visible that for angle values adopted in Fig. 3 the engine at rotational speed of 1400 l/min obtains the maximum filling and that within the whole range of useful rotational speeds 1500-2200 1/min the filling is larger by 2% from the next version of the examined valve adjustment. In comparison to theoretical adjustment, i.e. for valve opening and closing in piston dead centres, the engine filling is larger by 4% outside the range of rotational speed 1000-1200 1/min.

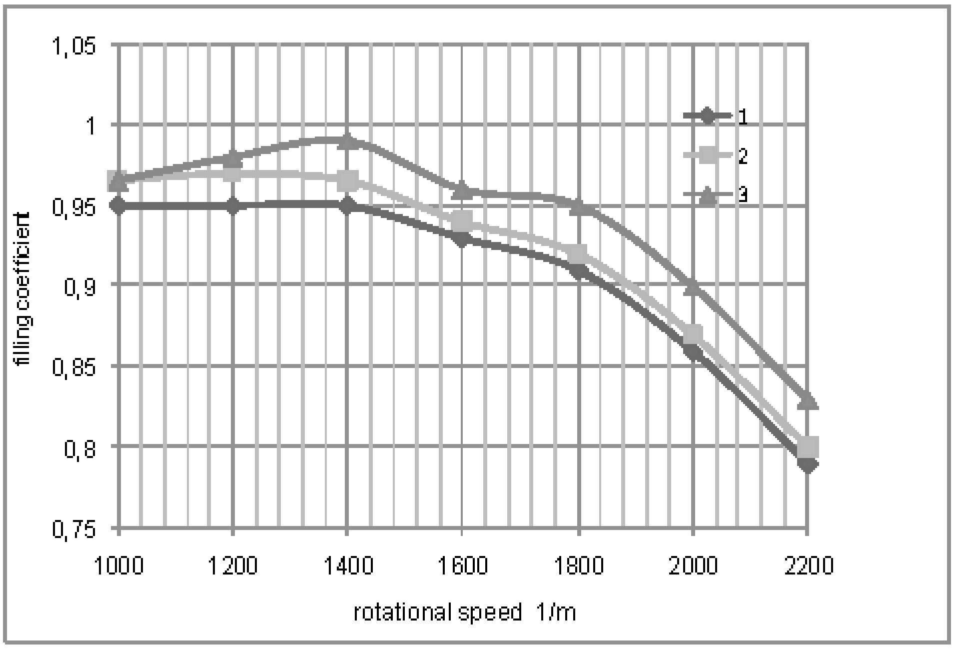


Fig. 4. The effect of angles φdo and φdz on the filling ratio of SW 680 engine 1. $\varphi_{do} = 0°$, $\varphi_{dz} = 0°$; 2. $\varphi_{do} = 25°$, $\varphi_{dz} = 30°$; 3. $\varphi_{do} = 10°$, $\varphi_{dz} = 60°$

## CONCLUSIONS

The briefly presented results of the examination of one of the parameters affecting engine filling ratio showed that the developed simulation test programme is reliable and the findings are encouraging. The coefficient values adopted in the simulation programme, further elaborated in numerous simulation and engine test bed studies, properly express the nature of phenomena taking place during four-stroke engine filling and the absolute values of the filling coefficient are real.

## REERENCES

Brandstetter W.: Ähnlichkeitsgesetzte das Viertaktmotors. MTZ 9/1967.
Chaczijan A. S.: Dvigateli vnutrennegosgoranija. Moskva 1978
Hozer J., Talaga L., Korol J., Korol M., Witek M.: Statystyka – Opis statystyczny. Uniwersytet Szczeciński. Szczecin 1998.
Mysłowski J.: Vlijanie niekotorych konstrukcjonnych faktorov na napolnienije DVS. VII-th International Symposium a Suppoprt of EAEC. Strbske Pleso 1990.
Mysłowski J.: Doładowanie bezsprężarkowe silników z zapłonem samoczynnym. WNT Warszawa 1995.
Ochęduszko S.: Termodynamika stosowana. WNT Warszawa 1964.

## WPŁYW KĄTÓW OTWARĆ I ZAMKNIĘĆ ZAWORÓW DOLOTOWYCH NA OSIĄGI SILNIKA

**Streszczenie.** W pracy przedstawiono problemy związane z modelowaniem przebiegu napełnienia silnika w oparciu o metodę Barandsttera opartą o wykorzystanie bezwymiarowych kryteriów podobieństwa , przystosowaną do silników wielocylindrowych. Po analizie liczb kryterialnych zdecydowano na określenie wpływu kryteriów odnoszących się do otwarć i zamknięć zaworów dolotowych na napełnienie silnika i stwierdzenie tego wpływu na drodze badań stanowiskowych silnika. Określono stopień wiarygodności modelowania w konfrontacji z rzeczywistością.

**Słowa kluczowe:** silnik wysokoprężny, napełnienie, zawór dolotowy