SOME ASPECTS OF CONTROL CHARGE QUALITY IN A DUAL FUEL DIESEL ENGINE FUELLED WITH CNG AND DIESEL OIL

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Abstract

In the paper some results connected with pro-ecological charge control of the dual fuel Diesel engine have been shown. Control conception of charge quality that is a mixture of air, natural gas and Diesel oil was formed as a result previous model analysis and carried out experiments. Basing those results the control system of charge parameters and composition in suitable λ range has been presented. The control system includes active changes of Diesel oil pilot dose, injection timing and air quantity, corresponding with an engine load down. Such operational system allows maintaining correct composition gas-air mixture and restricts disadvantageous phenomena connected with combustion excessive lean gas mixtures. In the paper single cylinder direct injection research Diesel engine adapted to the technical accomplishment of charge control has been presented. The research engine was equipped with air-flow mass control, electronic throttle control, sequentional indirect gas injection and Diesel oil, separately propelled common rail system.

1. Introduction

The maintenance of qualitative and quantitative fuel mixture composition is a difficult task in the dual fuel traction engine because of rapid torques changes and thus changes of fuel quantity, both Diesel oil and natural gas. Mechanical Diesel engine control system with classical injection equipment and gas carburetor has not given satisfactory results. Changes of gas quantity and its inertia do not follow up with engine torque changes that cause changeability as well mean excess air ratio and excess air ratio beyond Diesel oil jet at gas-air mixture. It is one of the reasons engine efficiency reductions and exhaust emission increase and also effectively limits traction application of dual fuel Diesel engine. Contrary to the mechanical systems the electronic ones allows to precise control oil and gas injection and can guarantee suitable charge composition. The advantages of dual fuel Diesel engine can take opportunity for medium sized engines for urban and sub-urban transport.

In a dual fuel Diesel engine combustion process initiate from a small oil pilot dose and for good fuel jet atomization, combustion commences in big quantities of ignition centers. Combustion process becomes very rapid lasts merely only few degrees of crank revolution and takes a part of oxygen, which is contained in engine charge. As the result, combustion runs at homogenous gas mixture with less excess air ratio than excess air ratio of inlet gas mixture. These factors significantly have an effect on combustion rate and run of the process in time. The choice of a dual fuel system has to take care above aspects and that mean an engine operational system prefers implementation of electronic injection of natural gas and electronic injection of initial fuel dose.

2. The parameters describes of charge quality in a dual fuel engine

Charge properties in a dual fuel Diesel engine are determined by followings excess air ratio:

λ_o – excess air ratio for inlet gas-air mixture;

λ - average excess air ratio of the charge (air, gas, Diesel oil);

λ_{DO} – excess air ratio for Diesel oil only, with assumption that Diesel oil burns first;

λ_g – excess air ratio for gas only, with assumption that gas burn after complete burned of the pilot dose.

Two coefficients of them λ and λ_o are control parameters. Remaining coefficients are hypothetical parameters and they are useful to evaluate combustion process.
Relations with excess air ratios are following:

$$\lambda_o = \frac{\dot{m}_a}{\dot{m}_g \cdot L_g} \tag{1}$$

$$\lambda = \frac{\dot{m}_p}{\dot{m}_{DO} \cdot L_{DO} + \dot{m}_g \cdot L_g} \tag{2}$$

where: $\dot{m}_a$ - mass air-flow rate;

$\dot{m}_g$ - mass gas flow rate;

$\dot{m}_{DO}$ - Diesel oil jet;

L_g, L_{DO} – theoretical air fuel ratio for gas and Diesel oil.

Total energy led to the combustion chamber consists of heat delivered with both fuels. Heat participation in total energy can be describes as:

$$U_g = \frac{\dot{m}_g \cdot H_g}{\dot{m}_{DO} \cdot H_{DO} + \dot{m}_g \cdot H_g} \tag{3}$$

$$U_{DO} = \frac{\dot{m}_{DO} \cdot H_{DO}}{\dot{m}_{DO} \cdot H_{DO} + \dot{m}_g \cdot H_g} \tag{4}$$

Where: H_g, H_{DO} – heating values for gas and Diesel oil.

Ignition and gas fuel combustion are depending on quantity of initial oil dose. Two parameters describe quantity of the initial oil dose: the pilot dose quantity q [mm^3/cycle] and the ignition dose X [kgDO/nm^{3}gas]. The pilot oil dose q is determined for a one engine cycle and characterizes possibilities and conditions for real injection equipment. Value of the pilot dose can be constant or variable according to engine torque changes.

Ignition dose X, describes energetic ignition level for both fuels and mostly rises according to decreasing of engine load. Parameters connected with unit doses can be calculated from following formulas:

$$X = \frac{\dot{m}_{DO} \cdot \rho_g}{\dot{m}_g} \tag{5}$$

Where: ρ_g – gas density.

$$U_{DO} = \frac{X \cdot H_{DO}}{X \cdot H_{DO} + H_g} \tag{6}$$

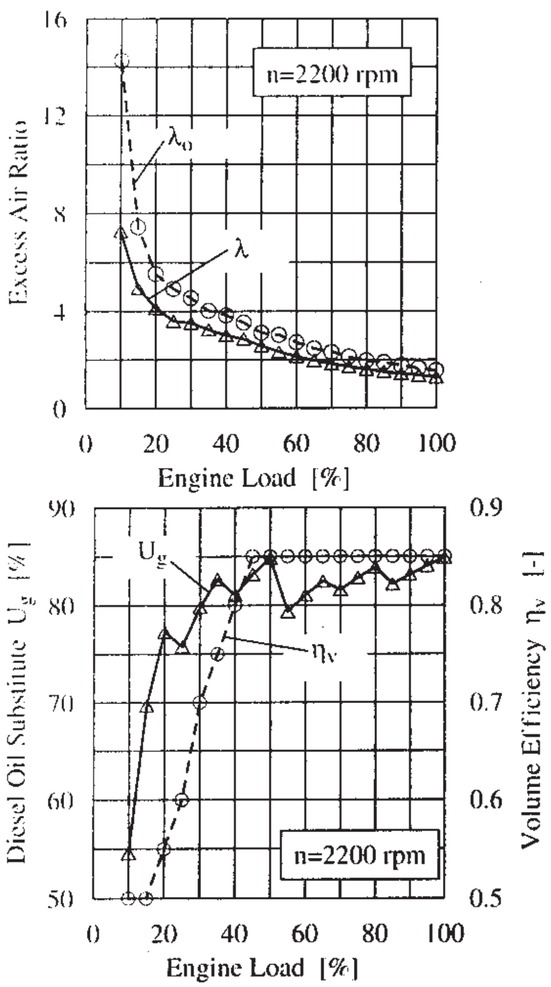
$$X = \frac{U_{DO}}{1 - U_{DO}} \cdot \frac{H_g}{H_{DO}} \tag{7}$$

Using expression 1÷2 and 5÷7 final equation can be written:

$$\lambda = \frac{\lambda_o}{1 + \frac{L_{DO}}{L_g} \cdot X} \tag{8}$$

$$\lambda_o = \lambda \cdot \left(1 + \frac{L_{DO}}{L_g} \cdot X\right) = \lambda \cdot \left(1 + \frac{L_{DO}}{L_g} \cdot \frac{H_g}{H_{DO}} \cdot \frac{U_{DO}}{1 - U_{DO}}\right) \tag{9}$$

Course of the operational parameters for the research engine SB3.1 has been presented in Fig.1. Analyzed parameters have been calculated for average qualities of natural gas and Diesel oil. During engine load changes quantity of initial injection dose increases from 6-20 mm^3/cycle and it is 4.5-15, 2% part of the nominal dose.



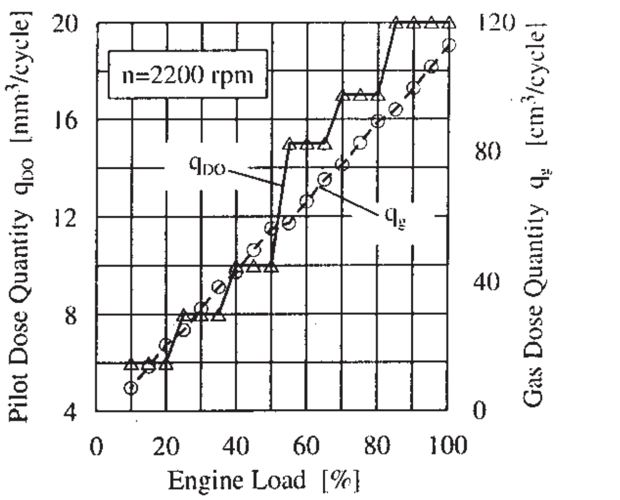


Fig. 1. Course of controls parameters in function of engine load: test engine type SB3.1; Displacement Volume 1849 ccm

Moreover for engine loads lesser than 50% of the rated load, inlet air has been throttled. Applied activities allow to keep gas-air mixture composition in the range λ_o <4.0 for the engine load of 30% nominal load. Further engine load decreasing is connected with coefficient λ_o increasing and can lead to efficiency losses and increase CO and HC. It can be noticed that active charge control for naturally aspirated Diesel engines does not guarantee correct composition of the gas-air mixture and excess leaning the mixture can be observed. For the multicylinders supercharged engines improvement of gas-air mixture composition can be achieved by supercharging rate change or skip-fire effect.

Application of charge control system enables the use of natural gas as a substitute of Diesel oil in the range 70-85% for engine load changes in the range 20-100%.

3. The system of electronically controling of a dual fuel engine

The test stand has been built as a control & measurement system. The research object is a single cylinder naturally aspirated Diesel engine with displacement volume 1849 ccm. Diesel oil is delivered with common rail system. Natural gas is delivered by gas injection. Test stand of control system is shown in Fig.2.

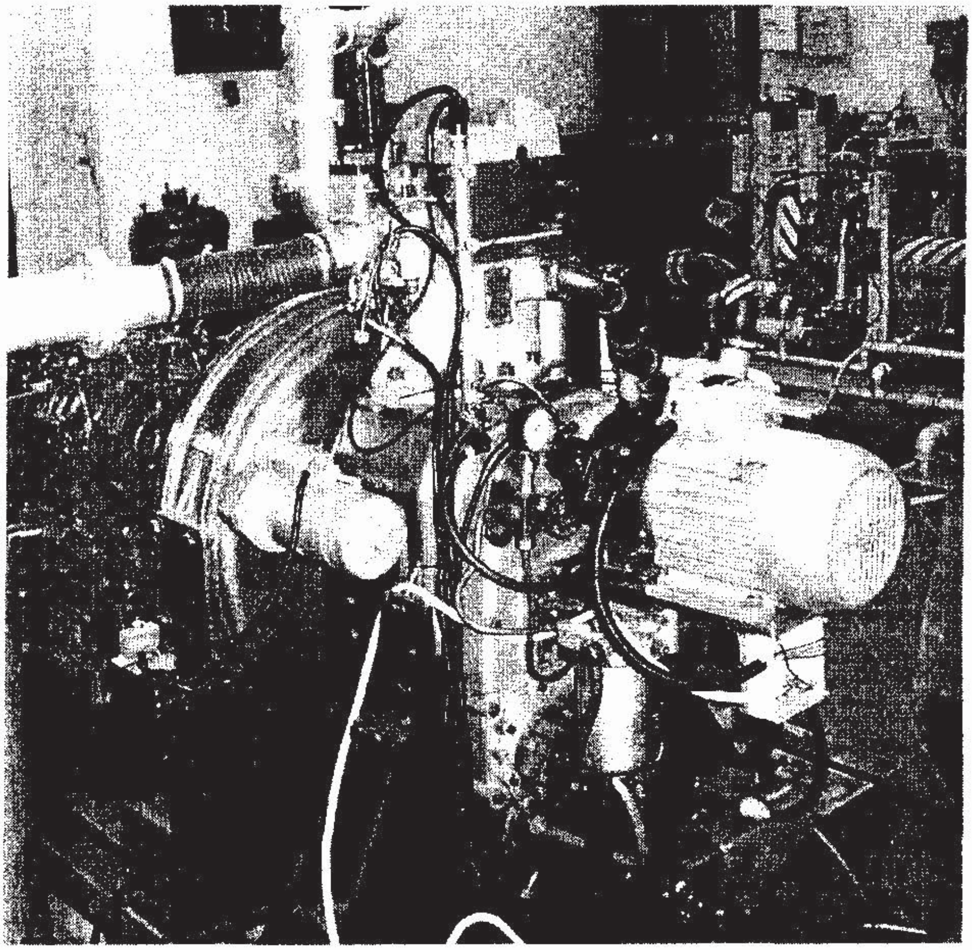


Fig. 2. The view of the test engine type SB3.1

Structure of the dual fuel engine electronic control system is shown in Fig. 3. The control system enables active operating of charge quality. Following parameters have been operated:

- Quantity of initial Diesel oil dose according to engine load;
- Quantity of natural gas according to air quantity and engine load (active control of excess air ratio λ_o);
- Quantity of aspirated air;
- Injection timing active correction of initial dose dependent on air gas mixture composition, engine revolution and knock sensor signal;
- Correction of gas-air mixture composition basing on knock sensor signal.

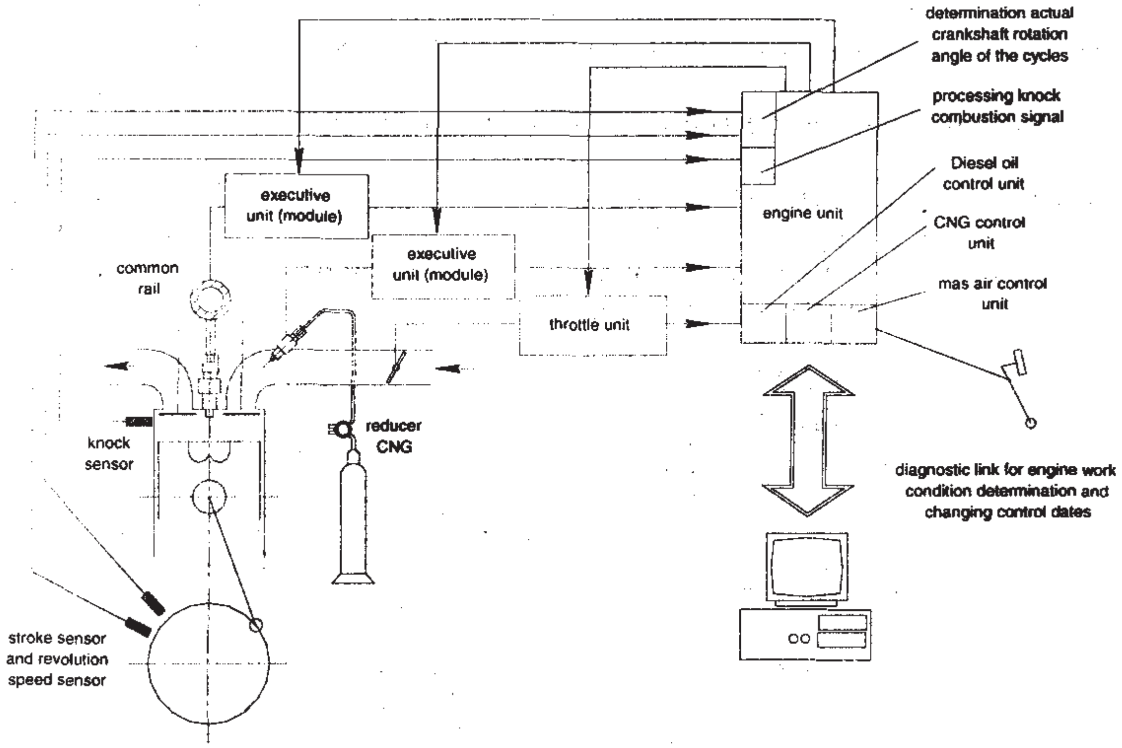


Fig. 3. The scheme of electronically controlling of a dual fuel engine

Initial dose injection is realized by common rail system came from serial number 611, DB engine. Common rail system ensures high quality injection of small dose Diesel oil. High pressure common rail pump, because of power absorbing is separately propelled by an electric engine. (P=3kW, n=1440 rpm). Prototype controller carries out character and quantity of Diesel oil dose and injection timing. The prototype controller of common rail has been built in Technical University of Bielsko-Biala. Structure of the controller is shown in Fig.4. The most important elements of controller structure are following modules:

- Injection timing module;
- Control module of quantity and character injection dose;
- Common rail pressure controller.

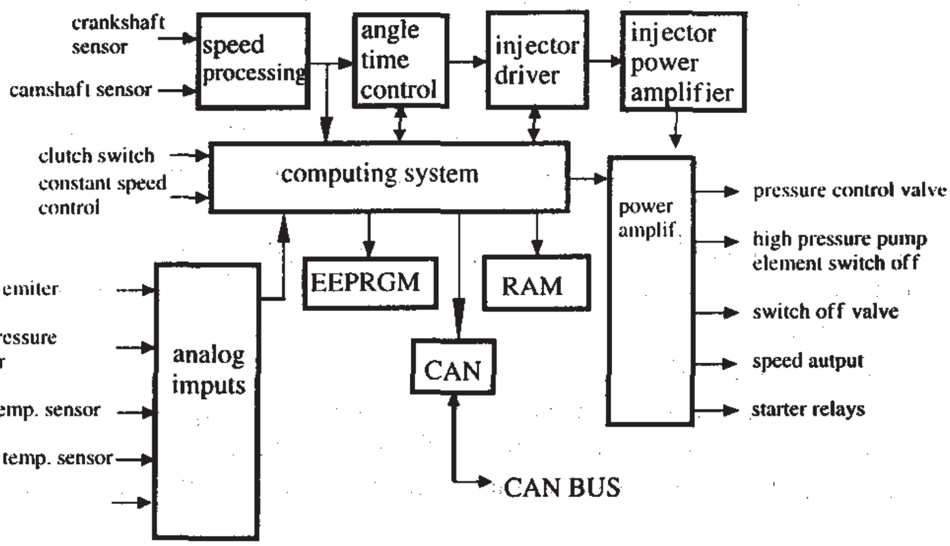


Fig. 4. Block diagram common rail control unit

Synchronization module cooperates with magnetic angular rate sensor to identify crankshaft position and with Hall sensor to identify engine cycle. Control module of quantity and character injection dose enables to create different profile of injection dose. The following injection doses have been realized:

- single dose;
- double dose with pilot injection dose;
- multi jet dose.

The choice adequate earlier prepared profile is *on-line*. Example of injection dose profile is presented in Fig.5.

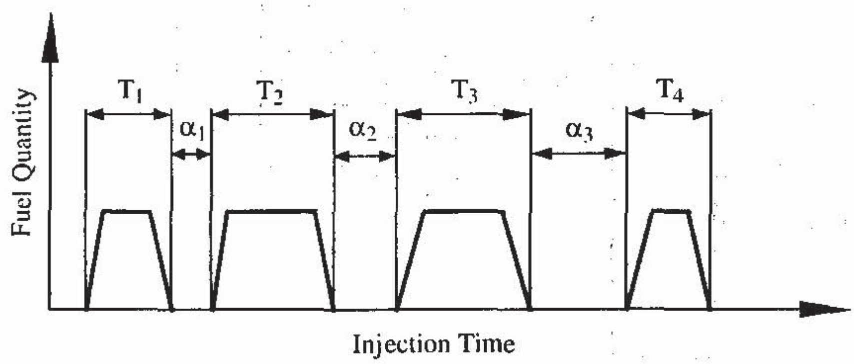


Fig. 5. Example profiles of the pilot dose injection with application the common rail system and control unit shown on the fig. 4; T_1, T_2, T_3, T_4 – injection duration (150-3000µs); α_1, α_2, α_3 – injection interval (2°-180°CA)

Common rail pressure module controls pressure level and release valve. Distinct impact of the oil pressure on quantity of injection dose what is shown in Fig. 6.

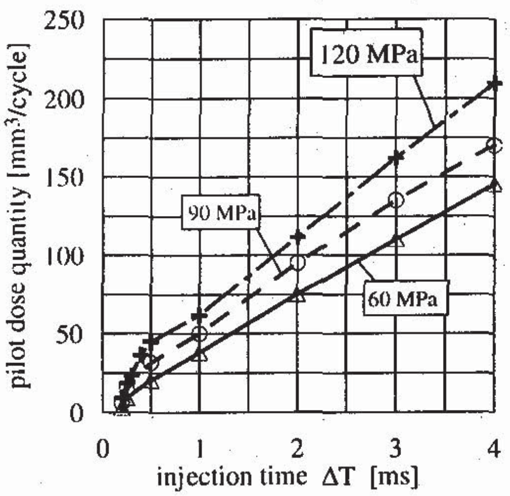


Fig. 6. Run of the pilot dose quantity in function of the opening time of the injector Bosch CDI 611 070 OS 87 for various rail pressure

To meet requirement natural gas precise injection, CNG controller has been built and two electromagnetic injectors have been used. Gas doses at proper time are injected from gas rail to the inlet collector, close inlet valve with a pressure 0.5-1.0 MPa. Typical automotive CNG injectors are applied. Gas rail is fed from gas cylinders set through remote controlled pressure reducing valve. Structure of the gas injection controller is show in Fig. 7.

The research engine is equipped with air-flow mass control (hot-wire MAF sensor) and electronic throttle control. The research engine is equipped with knock sensor and real time knock analyzer. All operational parameters and input signals are controlled by engine management system, which controls the object in real time.

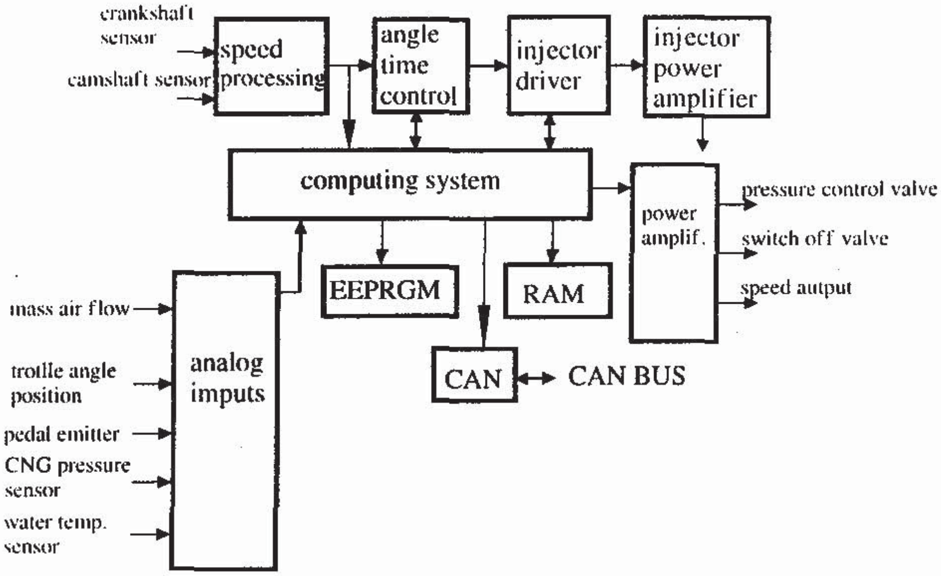


Fig. 7. Block diagram CNG injection control unit

4. Conclusions

Results of the analyses of air excess ratio show that through change of the initial dosage one can maintain the composition of gas-air mixture in range of λ_o<4.0 at engine load changing within interval of 20-100% of the nominal load. In naturally aspirated engines at a load below 50% of the nominal load, however, usage of throttling of sucked air is needed. In naturally aspirated engines the loads below 20% are difficult to be reached even in case of usage of minimal dosages needful for robust ignition of gaseous mixture and maintaining its composition of λ_o<4.0. In those engines, at minimal dose securing robust ignition, air excess ratio rapidly grows during reduction of the load below 20%, what enables to make assumption that there could occur difficulties with its ignition or complete combustion. It seems that maintaining a correct composition of gaseous mixture in naturally aspirated engine can be reached via implementation of skip-fire or shift to the traditional feeding.

Tests of controllers and injectors performed on a test bench have shown the runs of injected dosages similar to the ones presented in literature. The tests show, however, that very small dosages below 10 mm^3/cycle, in case of used injectors, are reached at very short injection times (it concerns the time of so called hold current). It makes more difficult to change actively the pilot dosage below 10 mm^3/cycle. An improvement in such case can be obtained through implementation of smaller injectors, anyhow, in this case one should maintain a possibility of change over to the traditional feeding, what presently can constitute significant advantage of dual fuel engines used in public transport.

Performed initial tests of the controllers and complete control system show that this system is suitable for usage in traction engines. Developed control system should enable energetic interchangeability of the Diesel oil in range of 70-85% during change of engine load in range of 20-100%. Response times of the controllers are significantly smaller comparing with real engine's processes what should ensure proper composition of the charge even at very rapid changes of engine load.

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