ISSN: 1231-4005
e-ISSN: 2354-0133
ICID: 1133157
DOI: 10.5604/12314005.1133157

EFFECT TO THE FUEL SYSTEM TYPE ON ENERGY, ECONOMIC AND ENVIRONMENTAL INDICATORS OF THE SPARK-IGNITION ENGINE WORK

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Abstract

The paper presents selected results of tests on the Fiat Panda I car powered by 1.2 dm3 spark ignition engine. The engine had production installed fuel system with the single-point petrol injection. To improve its in-service performance, the engine was fitted with the multi-point injection fuel system. The assessment of the indicators of the work of the engine, fitted with single-point, or alternatively, multi-point injection fuel system, was conducted on the basis of the tests performed on the MAHA chassis dynamometer. First, tests were run for single-point injection fuel system. Next, the same tests were performed when the engine was fitted with the multi-point injection fuel system. In the tests, engine power, torque, fuel consumption and the concentrations of the exhaust gas components were measured. The latter included carbon monoxide CO, carbon dioxide CO2, hydrocarbons HC, nitrogen oxides NOx, and oxygen O2. AVL Digas 4000 exhaust gas analyser was used to take measurements of the concentrations of the basic components of the exhaust gas and of the excess air ratio %u03BB. The investigations were conducted by performing the inertia test and by using the dynamometer to determine the basic indicators of the engine operation. In the investigations, the crankshaft rotational speed ranged from 1500 to 6500 rpm with 500 rpm step. The experimental results made it possible to evaluate how the manner and site of fuel delivery affect the engine work indicators.

***Keywords**: vehicles, combustion engines, fuel supply system, emission of exhaust gases*

1. Introduction

The basic purpose of the feed system is to supply the necessary amount of air-fuel mixture of appropriate composition, depending on the engine operation conditions. The aim of the engine control is to ensure the highest possible engine efficiency in different operation conditions [1, 3]. The main factor stimulating the development of internal combustion engines is seeking to increase their reliability and durability and to minimize their adverse impact on the natural environment. The ever-stricter standards prescribing permissible limits on the emissions of harmful exhaust gas components, low fuel consumption as well as other high requirements related to the engine operation period; including engine recycling, force further improvement in the design of engines [9]. In view of environmental protection, the emissions of harmful gaseous exhaust gas components, including carbon dioxide and NO_x, as well as particulates, which make a barrier to the development of both self-ignition and spark-ignition engines, continue to be a high hazard [2]. The greatest challenge to engine manufacturers is to meet the Euro 6 emission standard that has been in force since 2014, and whose limits are several times lower that those applicable in the previous years. These requirements have resulted in a significant development of feed systems for self-ignition and spark-ignition engines and systems for the neutralization of harmful exhaust gas components, as well as the use of technologically advanced engine control systems [3, 10]. The development of those systems has brought self-ignition engines and spark-ignition engines closer to each one another in terms of design, which has resulted in the utilization of the advantages of both of them and the elimination of their drawbacks [4, 9].

Over the years, the spark-ignition engine feed systems have changed considerably. Until the 90s of the 20th century, the most often used system had been the carburettor. However, the introduction of strict EURO standards and an increase in fuel prices forced the manufacturers to develop engines with petrol injection systems and to implement them in production. These systems allowed a reduction in fuel consumption and in the atmospheric emissions of harmful chemical compounds.

In terms of the method of supplying fuel to the air, forced-ignition engine's feed systems can be divided into two basic groups: the carburettor system and the injection system. The drawbacks of the carburettor feed system diverted designers' attention to an injection feed system. The system of injection feeding spark-ignition engines has been in use for a fairly long time. For some time, its common use in the automotive industry was prevented by high costs of injection equipment. The increasingly stringent demands on the purity of exhaust gas emitted by automotive vehicles had resulted in such a complexity of carburettors and intake systems that the manufacturing cost of carburettors became comparable with that of injection devices. The existing solutions of spark-ignition engine injection feed systems can be categorized as follows: SPI – central single-point low-pressure fuel injection to the inlet manifold; MPI – multi-point low-pressure fuel injection to the inlet connection pipes; and GDI – high-pressure direct fuel injection to the combustion chamber [5, 8, 11].

Figure 1 illustrates the division of spark-ignition engine feed systems.

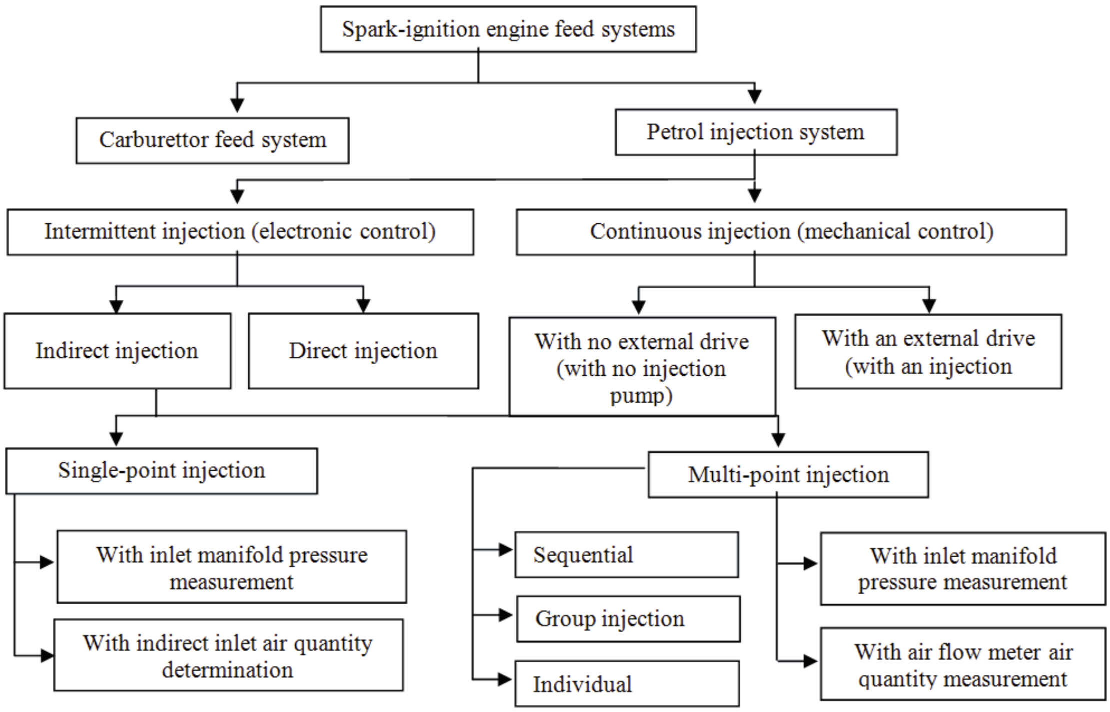

Fig. 1. Division of spark-ignition engine feed systems

Internal combustion engines will long remain the basic source of drive for vehicles. Harmful compound emission restriction standards compel the designers to seek technologies that will mitigate the harmful environmental impact of engines.

At the turn of the 70 s and 80 s, an injection feed system and trifunctional exhaust gas catalysts were introduced to spark-ignition engines. This resulted in a certain stagnation in their development, which extended into the mid-90 s. In that time, the performance of self-ignition engines got close to that of spark-ignition engines, with the fuel consumption of the former being much lower [4]. This decreased the competitiveness of spark-ignition engines as against self-ignition engines Only in recent years can an intensive development of spark-ignition engines be observed, which is due to growing demands on their performance and environmental protection standards. The intensive development of spark-ignition engines observed in recent years is associated with the implementation of features and systems in them, such as:

- reduced sizes of the main engines, including their cubic capacity, i.e. so called downsizing,
- supercharging systems with supercharging air cooling, including turbocharging, and mechanical supercharging and pulse pressure charging,
- electronically controlled exhaust gas recirculation systems with exhaust gas cooling,
- state-of-the-art feed systems, including direct injection systems with an advanced injection control system and a system enabling a high injection pressure of up to 200 bar,
- multi-valve timing systems with variable valve phase and lift systems, and intake systems influencing the swirl and turbulence of the working medium in the cylinder,
- improved catalytic exhaust gas purification systems, and
- on-board diagnostic systems.

In addition to improving the design itself, the development of spark-ignition engines involves the development of the engine fuel feed system. The latter has caused the carburettor, being in use for over a hundred years, to be replaced first with a single-point and then multi-point intake duct injection system, which is currently prevailing.

The contemporary multi-point fuel injection systems in spark-ignition engines are characterized by the following properties:

- ensuring the air-fuel mixture of a composition corresponding strictly to the engine operation conditions and assuring the minimum toxicity of the exhaust gas,
- accurately metering the quantity of injected fuel, as appropriate to the quantity of air aspirated by the engine within a strictly defined time,
- pumping the fuel to a dispenser that is connected with all the injectors,
- the injectors feeding the fuel sequentially to the intake lines upstream the intake valves,
- due to the action of the trifunctional exhaust gas catalyst, in order to achieve a minimum level of exhaust gas toxicity, the injection system has to deliver the mixture of the stoichiometric composition (λ = l),
- for the accurate production of the mixture, the measurement of the quantity of air taking part in combustion is necessary,
- a basic element of the injection system is the electronic control unit.

The requirements imposed on new internal combustion engine designs spurred a further development of fuel feed systems, including the use of direct fuel injection to the combustion chamber in spark-ignition engines.

The idea of using injection systems in spark-ignition engines arose as early as in the 80s of the 19th century. Those system had, however, many drawbacks and flaws. The fast development of the design of carburettors resulted in a drop in the interest in injection engine fuel feed systems. The further development of petrol feed systems was associated with the work of the Robert Bosch, DVL and Bendix companies. The work by DVL resulted in the implementation of direct petrol injection to the combustion chamber during the intake stroke in Daimler-Benz and Junkers engines in 1937. A year later, Bendix introduced an injection carburettor that corresponds to today's feed system with a single-point fuel injection. Work on direct petrol injection systems conducted by Daimler-Benz resulted in the introduction by this company in 1954 of the first large-scale produced car, namely the Mercedes-Benz 300SL, fed by the direct mechanical injection of petrol to the cylinder. A contribution to the development of contemporary petrol engine injection feed systems was made by the work of the Bendix and Caproni companies, whereby the latter constructed the first electromagnetically controlled injection device which was implemented for the first time in the Alfa Romeo 2.5L car in 1938. The solutions developed by Bendix concerning the control of electromagnetic injectors, including the fuel dose depending on the engine operation conditions, were purchased by Bosch, which provided a basis for introducing the D-Jetronic injection system in 1966.

New spark-ignition engine designs, in addition to advanced injection systems, use so called downsizing, which involves the reduction of the engine's overall dimensions, including its cubic - capacity. This allows the improvement of the engine operation indices, as related to the engine's unit cubic capacity. The implementation of downsizing by designers enables also a reduction of fuel consumption and harmful exhaust gas component emissions. Moreover, apart from the reduction of the overall engine dimensions, electronically controlled high-pressure supercharging systems are used, while for building engines, constructional materials are used, which are able to carry higher mechanical and thermal loads. The constructional changes described above reduce the heat losses of the engine and its mass, while increasing its efficiency and reducing fuel consumption.

2. The object of investigation

The object of investigation was a Fiat Panda 1000 FIRE automotive vehicle featuring a 1242cm^3 capacity engine. The engine is factory equipped with the multipoint IAW fuel injection system manufactured by Magnetti Marrelli. This system controls the injectors in the fullgroup system, which allows a single-point injection system to be installed. Tab. 1 lists the basic technical specifications of the Fiat 1242 cm^3 engine, while Fig. 2 shows a photograph of the engine chamber of the vehicle under investigation.

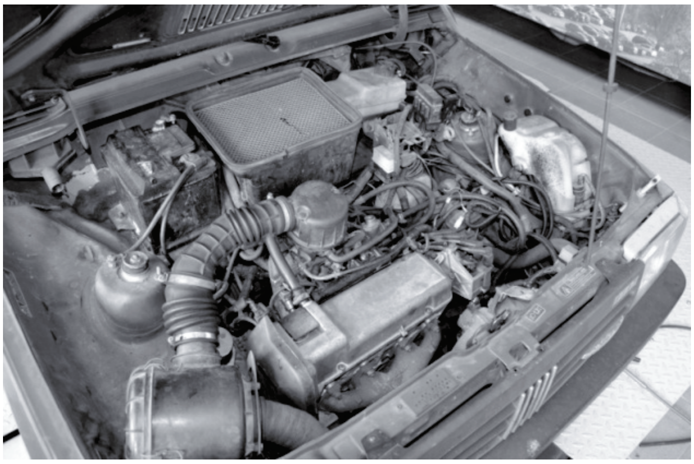

Fig. 2. The engine chamber of the investigated vehicle

Table 1 provides the basic technical specifications of the Fiat 1242 cm^3 engine.

Tab. 1. Basic technical data of the Fiat 1242 cm3 engine

Parameter	unit	value
Cylinder arrangement	-	row
Number of cylinders, c	-	4
Number of valves	-	8
Type of injection	-	single-point injection SPI
Compression ratio, ε	-	9.8
Cylinder bore, D	m	$70.8 \cdot 10^{-3}$
Piston travel, S	m	$78.9 \cdot 10^{-3}$
Engine cubic capacity, V_{ss}	m^3	$1.242 \cdot 10^{-3}$
Maximum engine power, N_e	kW	54
Maximum power rotational speed, n_N	rpm	6000
Maximum torque, M_e	Nm	106
Maximum torque rotational speed, n_M	rpm	4000

3. Scope of experimental tests

The purpose of the tests was to determine the effect of single-and multi-point fuel injection on the basic indices of engine operation. The assessment of the performance indices of the engine fed, alternately, with the single-and multi-point fuel injection system was done based on the results of tests on the V-tech VT-4/B4 chassis dynamometer. The first stage of the tests was completed with feeding the engine using a single-point fuel injection system, and then the same tests were carried out after installing a multi-point fuel injection feed system on the engine. During testing, the engine's power, torque, fuel consumption and many other operation parameters were measured. The tests carried out included an inertia test performed for crankshaft rotational speeds in the range from n=1500 to 6500 rpm with a step of 500 rpm. The obtained test results allowed the assessment of the effect of the mode and location of fuel feed on the engine performance indices.

4. The test stand and control and measuring apparatus

The power and torque tests were carried out on the V-tech VT-4/B4 chassis dynamometer. The chassis dynamometer parameters are given in Tab. 3.

Tab. 3. Parameters of the V-tech VT-4/B4 chassis dynamometer

Type	Load, synchronized
Dimensions (D x S) [mm]	5500 x 3800 (2)
Max./min. axle base [mm]	3300/2300
Max./min. wheel track [mm]	2200/900
Minimum tyre diameter [mm]	400
Single axle load [kg]	3000
Number of axles	2
Eddy current brakes	4xTelma
V_{max} [km/h]	300
Measuring modes	inertia, load, traffic, constant rotation
P_{max} [HP] – inertia mode	450
P_{max} [HP] – dynamic mode and traffic test	2000
P_{max} [HP] – constant rotation mode (power on wheels)	1000
Measurement accuracy, inertia mode [%]	0.1
Measurement accuracy, load modes [%]	1
Supply (without cooling and exhaust fans)	min. AC 400V / 40A
Required pressurize air	min. 6 bar
Assembly versions	duct-built / stand-alone
Additional accessories	supercharging pressure sensor, AFR sensor, cooling fan, exhaust fan, exhaust gas discharge lines

The fuel consumption measurement was done using a universal on-board computer by Reveltronics. The computer indicates the fuel consumption determined based on signals from the fuel injector and the vehicle speed sensor. The key parameters of this device are given in Tab. 4.

Tab. 4. Technical specification of the Reveltronics on-board computer

Power supply:	+12V DC (safe range: +9...+16V DC)
current input during operation:	max 160 mA for the LCD version, max 80 mA for the OLED version
current input in the sleep model:	max 30 mA (type 25 mA)
device operation temperature:	-40°C...+85°C
LCD display operation temperature:	-20°C...+70°C (recommended +10°C...+40°C)
OLED display operation temperature:	-40 C...+85C
temperature sensor measuring range:	-40°C...+120°C
temperature measurement accuracy:	0.5°C (a resolution of 0.1°C)
speed reading accuracy:	+/-1 km/h (possible calibration)
acceleration measurement accuracy:	+/-0.1s
fuel consumption measurement accuracy:	1% for petrol engines, 2% for petrol
engines with a sequential gas system:	1-3% for diesel engines (possible calibration)
momentary combustion measurement time: averaged of 1s, 2s, 3s (possible selection)	
analog sensor signal sampling rate:	25Hz
analog sensor measurement accuracy:	+/-0.1 [V], graphic representation (oscilloscope) with resol. Of 1/32 range [V]
analog sensor signal sampling rate:	25Hz
analog sensor measurement accuracy:	+/-0.1 [V], graphic representation (oscilloscope) with resol. Of 1/32 range [V]
analog sensor measurement accuracy:	+/-0.1 [V], graphic representation (oscilloscope) with resol. Of 1/32 range [V]
battery voltage measurement accuracy:	+/-2% (possible calibration)
communication with the PC via USB 2.0 transmission	

Figure 3 shows the chassis dynamometer with the Fiat Panda I test vehicle.

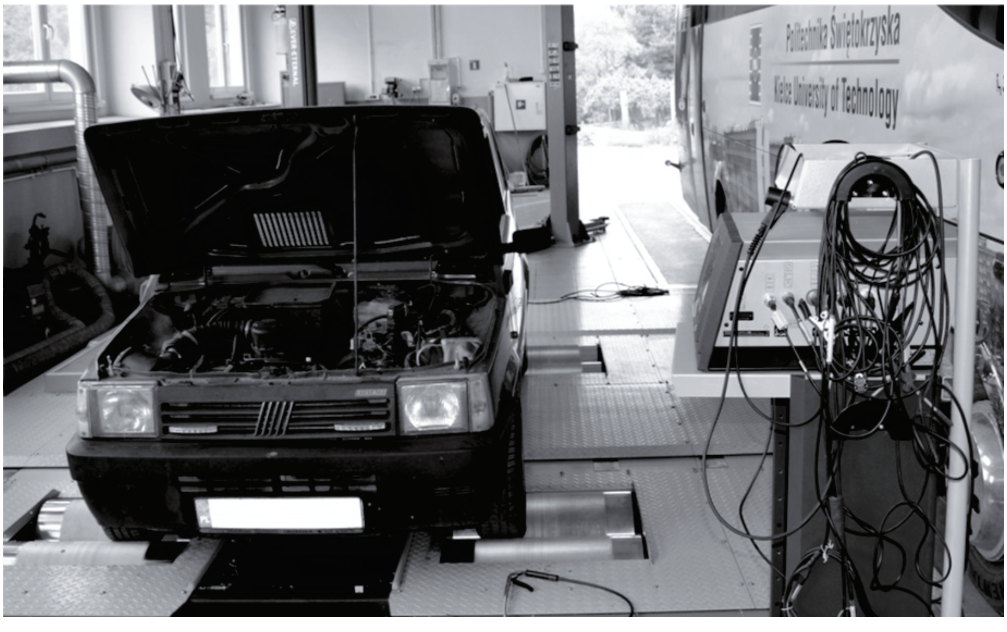

Fig. 3. The V-tech VT-4/B4 chassis dynamometer together with the Fiat Panda I vehicle

7. Experimental testing results

Shown below are the diagrams of the variations of the power and torque of the engine with a single-and multi-point fuel injection system, as determined on the chassis dynamometer during an inertia test.

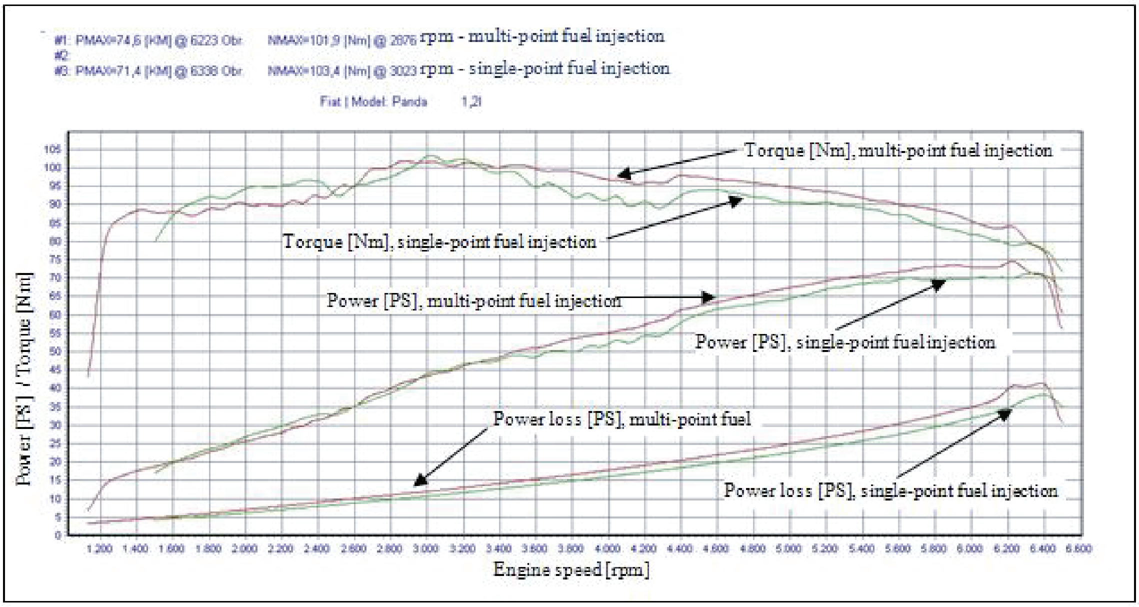

Fig. 4. Variations in the power and torque of the engine with single-point fuel injection

Power consumption was measured in l/100 km in a test performed on the 4th gear in the engine rotation range from n=1500 to 6500 rpm with a step of 500 rpm. The comparative measurement results are presented in Tab. 5 and in diagram 5.

Tab. 5. Fuel consumption by the engine running with single-and multi-point fuel injection, respectively

Engine speed [rpm]	Fuel consumption [l/100km]	
	single-point fuel injection	multi-point fuel injection
1500	6.8	6.8
2000	6.8	6.7
2500	6.9	6.9
3000	6.9	6.8
3500	7.0	6.6
4000	7.1	6.8
4500	7.2	6.9
5000	7.2	7.0
5500	7.3	7.1
6000	7.4	7.1
6500	7.5	7.0

8.Conclusions

The tests carried out have shown that the engine attains slightly better performance parameters when fed with single-point fuel injection. However, this is at the cost of an increased fuel consumption. The engine fed with multi-point injection has a more linear power and torque characteristic. The torque for multi-point feed has a flat characteristic in a wider rotation range, which translates into a better engine response. The single-point injection causes an increase in fuel consumption, which also an adverse influence on the concentration of harmful exhaust gas components emitted to the environment.

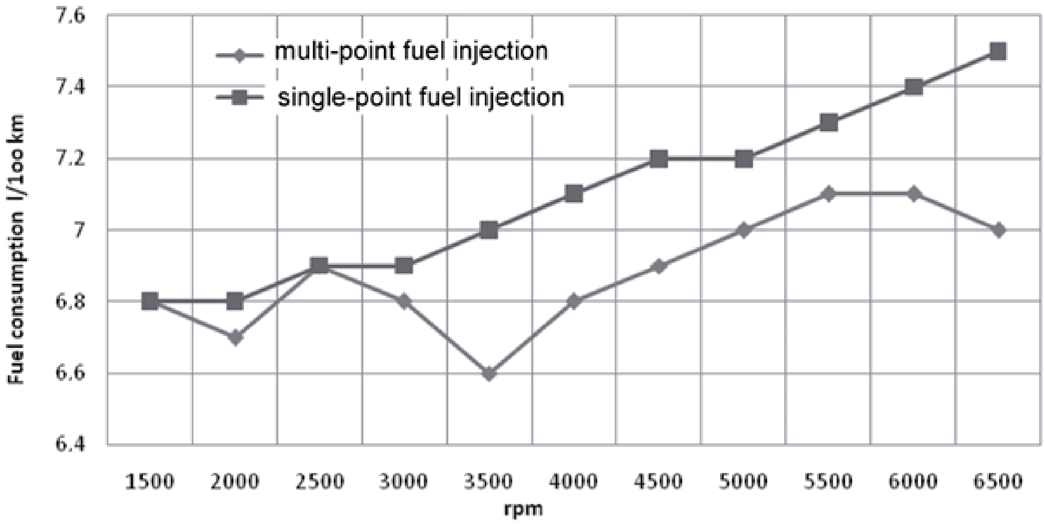

Fig. 5. Variation in the fuel consumption by the test engine running with single-and multi-point fuel injection, respectively

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