ARCHIWUM MOTORYZACJI
3 pp. 83–97 (2001)

Automobile alternators as electric energy sources for heating resistors of catalytic converters

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The concept of improving functioning of automobile catalytic converter during so called cold starts of combustion engine is presented. During these periods, lasting even several minutes, it is possible a supplementary heating of converter by thermal energy from heating resistors that form alternator's load operating under controlled overload. Results of experimental tests of alternator operating under such unconventional conditions are provided. Construction and operation of catalytic converter special heating chamber as well as atmospheric air supplying device, both belonging to test stand representing combustion engine exhaust system, are described. Obtained results showed that alternator can reach overrated power at much higher voltage (60÷70V). This increased electric power (approx. 5 kW) may substantially shorten the length of period during which catalytic converter monolith reaches the temperature for efficient neutralisation of toxic exhaust gas components.

1. Introduction

The pollution of environment is a serious problem occurring in XX century, as a result of civilisation development and growing industrialisation of many countries. Automobile combustion engines are estimated to generate more that 60% of air pollution [1]. The effective automobile emission protection is performed by the application of vehicle ecology devices.

The catalytic converters represent modern effective facilities used to diminish emissions of toxic exhaust components [2] in which carbon oxide (CO), hydrocarbons (HC) and nitric oxides (NO_x) are dominating gases. It can be stated on the base of analysis of catalytic converters functions and their behaviour in different temperatures that in temperature range 273–523 K during so called cold start of combustion engine converters do not show any activity. This is the least efficiency period of neutralising exhaust toxic. The test starting from idle and small acceleration runs show that converter temperature set-up time (for efficient neutralisation) reaches 120 s [3]. The exhausts are not neutralised during that time and over 80% of toxic exhaust compounds are emitted to the atmosphere.

Improvement of catalytic converters early stage operation efficiency needs additional thermal energy to be supplied to them, which may be supplied by available sources of electric energy like alternative current generator (alternator) or electrochemical car battery. The load for both energy sources would be the resistor forming the supplemental energy source. The power necessary to operate resistantive heating elements is estimated at about 5 kW, depending on converter type and engine output [3]. If a 12 V car battery is the only one source of electric energy delivered to heating resistors, the current consumption reaches 400 A. During the converter heating period, such a high current may be destructive for the buttery itself and heating devices as well as switching or control elements. For this reason the application of car alternator seems to be justified. The typical car alternators with average rate power of 0.6–1.5 kW are expected to operate under short controlled overloads reaching the power of several kilowatts. The alternator rotational speed should reach several thousands rpm. Together with changes in construction, combustion engine with so called „fast idle'' could be utilized, for example, that facilitate reaching by alternator a specified rotational speed during cold start phase. However the decision belongs to specialists in automobile construction.

While feeding catalytic converter resistors, the alternator neither charges the battery nor supplies energy to other devices of the vehicle. The alternator is not expected to feed battery and other electric devices during the time of catalytic converter heating resistors' charge. In the case of using alternator for feeding catalytic converter heating resistors, the other electric energy receivers installed in the car would be powered by the car battery.

2. Alternator operation under controlled overload

When utilising car alternator as a source of electrical energy, its operation with much more power than nominal must be taken into account. This deserves quite new approach to generating possibilities of these electric machines. Such unconventional application requires recognition of characteristics of such generators under such operating conditions.

The Figures 1 and 2 contain respectively, current-speed characteristic and electric scheme of the tested alternator.

Independently on alternator rated current values and regulated voltage values its maximum constant rotational speed is equal to 14000 rpm (the speed of 15000 rpm for 15 min operation is acceptable). The rotational speed range of 4000 through 15000 rpm was available at the test stand. Rotational speed was measured by means of electronic tachometer.

Two thermocouples were applied to record temperature of armature and rectifying diode of alternator bridge system. Also values of current and voltage were recorded as well. Car alternator was tested in self-excited (Table 1) and separately excited (Table 2) operation systems, with determining at various rotational speeds (*1*) and various voltages on machine terminals (*2*) the load resistance (*4*) for which alternator reaches maximum power (*3*). Also during (*8*) the 120 s of the experiment armature coil (*5*), rectifying diode

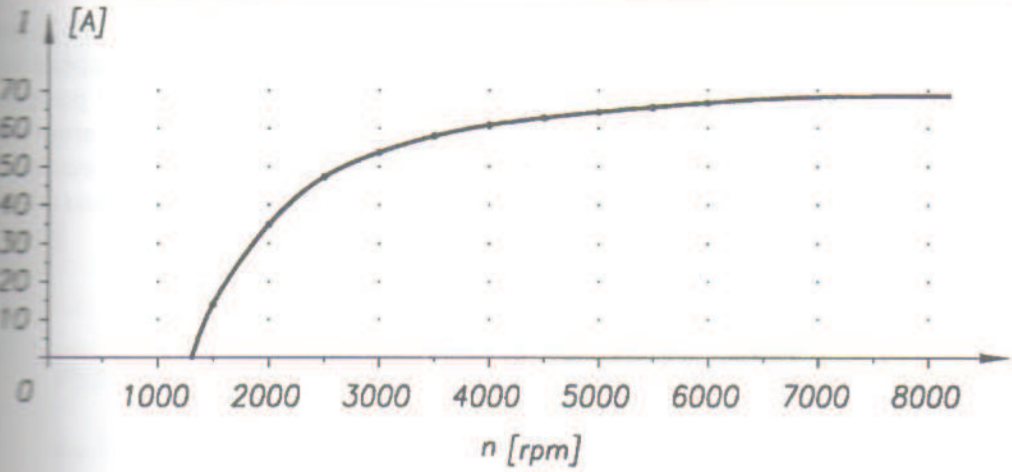

Fig. 1. Current-speed characteristic of the tested alternator ($U_{regulated}$ = 14 V).
Rys. 1. Charakterystyka prądowo-prędkościowa badanego alternatora ($U_{regulowane}$ = 14V).

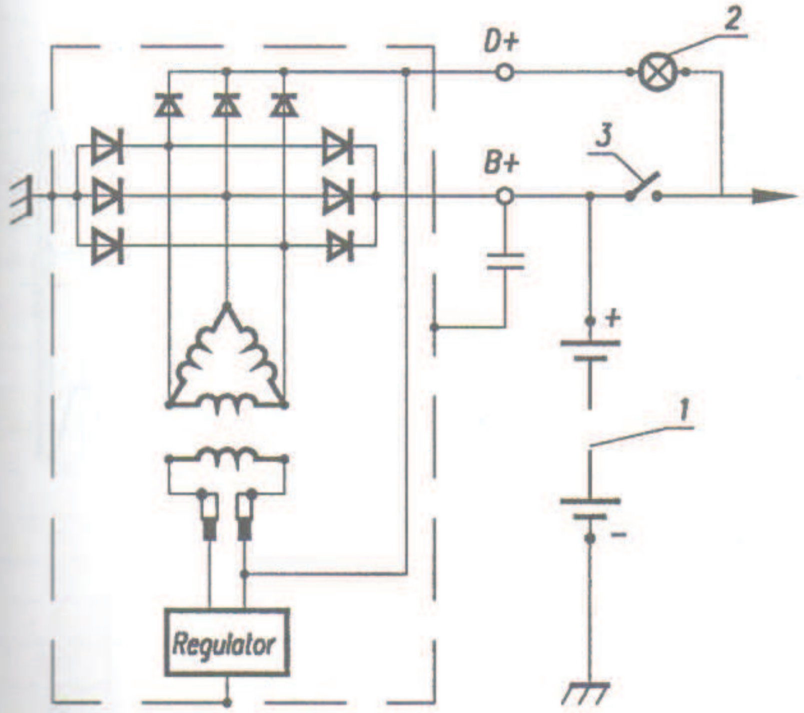

Fig. 2. Electric scheme of the tested alternator (*1* — battery, *2* — control bulb, *3* — load switch, D+, B+ clamps).
Rys. 2. Schemat elektryczny badanego alternatora (*1* – akumulator, *2* — żarówka kontrolna, *3* — wyłącznik obciążenia, D+, B+ zaciski).

(*6*) and rotor coil (*7*) temperatures were checked. Columns (*9*) and (*10*) of Table 2 present alternator's separate excitement voltage and current. Rotor coil temperature was registered by coil resistance measurement after 120 s of operation. Figure 3 presents the cross-section of automobile alternator with indicated measurement point of armature coil temperature. The alternator armature coil temperature profile in frontal direction is shown in Fig. 4. Thermoelement is located at the point where coil reaches the maximum temperature.

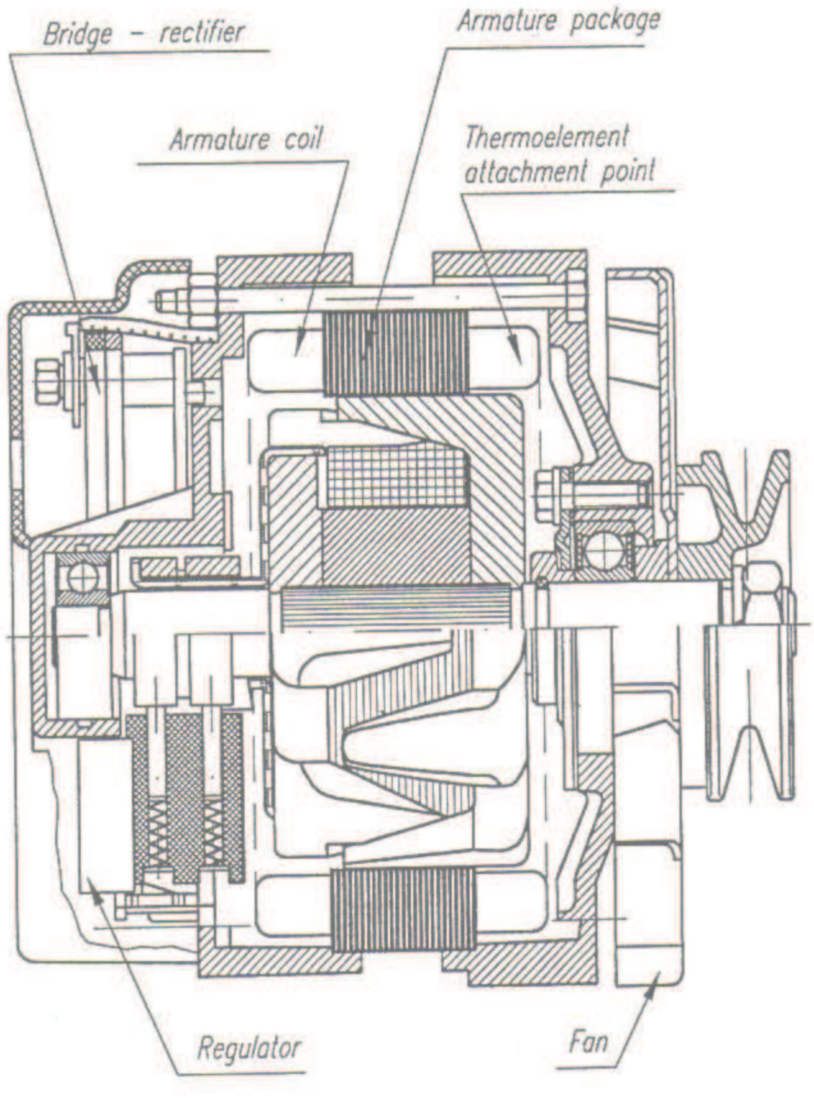

Fig. 3. Tested alternator cross-section with armature coil temperature measurement points.
Rys. 3. Przekrój badanego alternatora z zaznaczeniem miejsca pomiaru temperatury uzwojenia twornika.

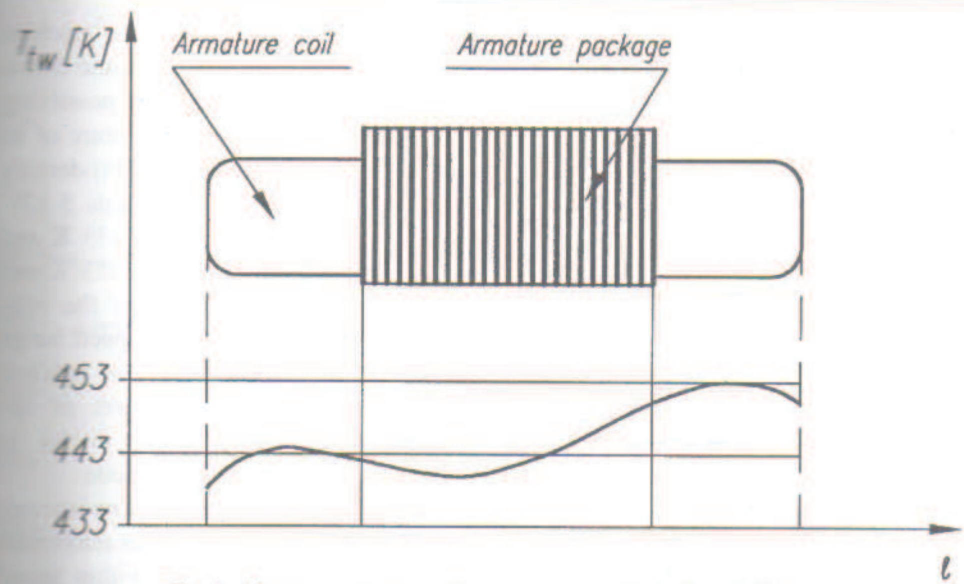

Fig. 4. Alternator armature coil temperature profile in frontal direction.
Rys. 4. Rozkład temperatury uzwojenia twornika badanego alternatora w kierunku osiowym.

Table 1. Results of alternator tests in self-excitement operation mode.
Tabela 1. Wyniki badań alternatora pracy samowzbudnej

n	U	P	R	T_{tw}	T_{diode}	T_{rotor}	t
rpm	V	W	Ω	K	K	K	s
1	2	3	4	5	6	7	8
4000	30	1740	0.51	422	374	429	120
5000	40	2252	0.71	417	366	440	120
6000	45	2812	0.72	424	364	450	120
7000	50	3400	0.73	434	365	459	120
8000	60	3960	0.91	427	356	463	120

Table 2. Results of alternator tests in separate excitement operation mode.
Tabela 2. Wyniki badań alternatora pracy obcowzbudnej.

n	U	P	R	T_{tw}	T_{dioda}	T_{rotor}	t	U_{wzb}	I_{wz}
rpm	V	W	Ω	K	K	K	s	V	A
1	2	3	4	5	6	7	8	9	10
4000	30	2228	0.45	420	375	432	120	35	11.4
5000	40	2884	0.55	423	378	440	120	45	13.2
6000	45	3433	0.59	426	372	451	120	50	14.3
7000	50	3945	0.53	433	378	461	120	55	18.1
8000	60	5258	0.80	432	368	466	120	60	20.0

Conducted tests of a typical alternator showed that it is possible to use the machine under controlled overload. Such non-typical operation requires introducing some constrain, mainly with respect to operation time. The tests confirmed the assumed possibility to overload the machine during 120 s of operation while keeping the temperature of its elements in acceptable limits. Alternator operation with approx. 70 V considerably increases its overall efficiency, so actual power of alternator slightly exceeds 5 kW. According to the manufacturer data, armature coil temperature may reach 453 K and rectifying diodes temperature may reach 428 K. The above values come to 473 K and 448 respectively for 15 minutes of instantaneous running. During the tests the self-excited alternator reached maximum load power of 2.812–3.960 kW at speed range 6000–8000 rpm, while during separate excitement at 8000 rpm alternator reached maximum load power of 5.258 kW. Comparing to alternator rated power of approximately 0.9 kW, above values show the overload rate of 3.1 up to 4.4 in self-excitement operation mode and 5.84 in separate excitement operation mode.

The dependence of alternator load power on rotor speed for such a load resistances that alternator (for both self-excited and separately excited operation) reaches maximum load power is presented in Fig. 5. Maximum armature coil temperatures within tested rotational speed range (for both self-excited and separately excited operation) is presented in Fig. 6. The controlled overload operation (with external regulator voltage equal to 60 V, for example) is anticipated for short periods during normal work breaks

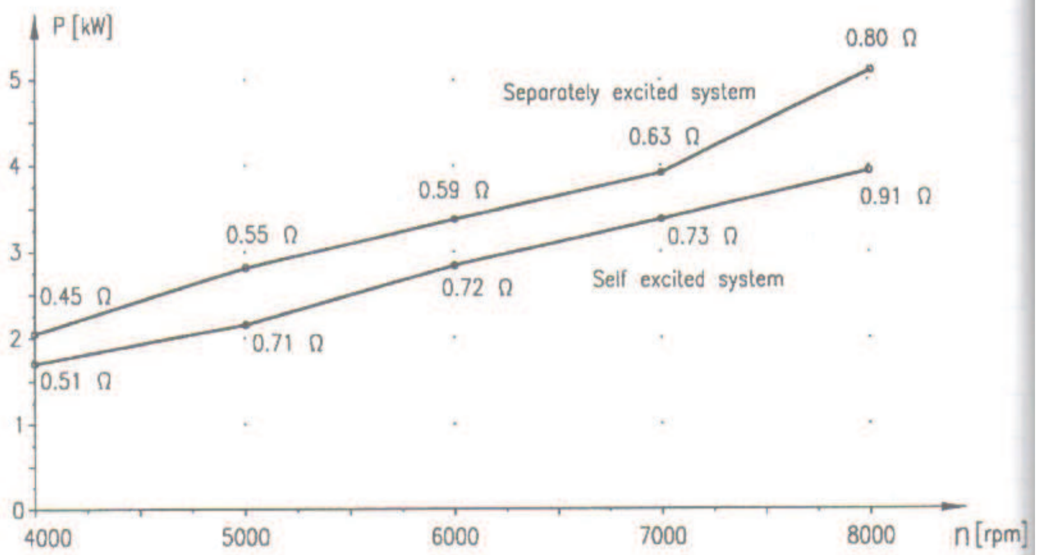

Fig. 5. Alternator load power versus rotational speed of rotor corresponding to load resistance which yield maximum load power of the alternator (during self-excited and separately excited operation).

Rys. 5. Zależność mocy obciążenia alternatora od prędkości obrotowej wirnika dla takich wartości rezystancji obciążenia, dla których alternator (w pracy samowzbudnej i obcowzbudnej) uzyskuje maksymalną moc obciążenia.

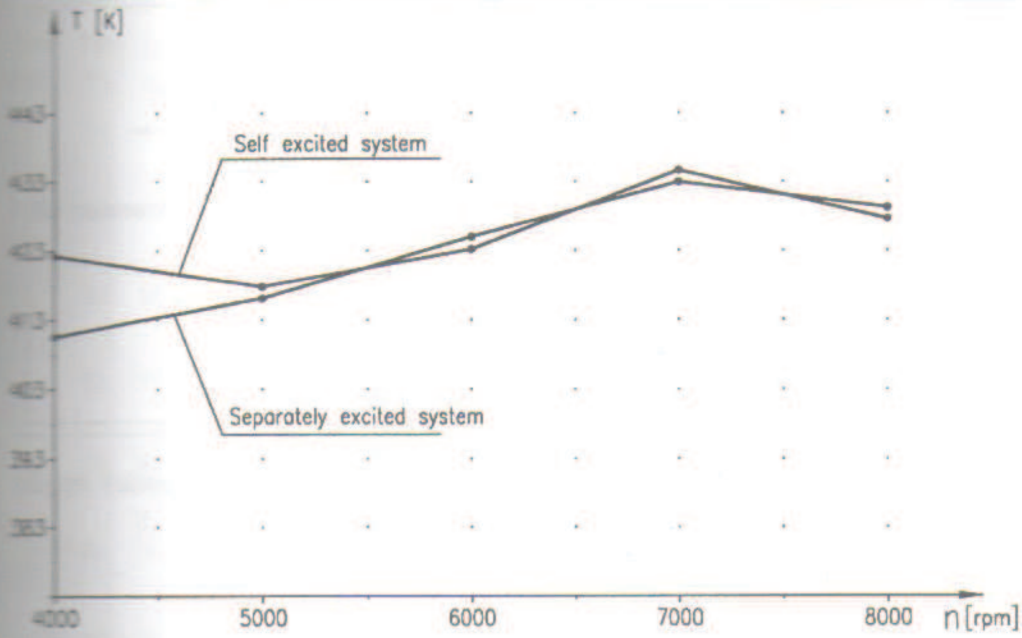

Fig. 6. Alternator armature coil maximum temperatures versus rotational speed within the tested range (during self-excited and separately excited operation).

Rys. 6. Zależność maksymalnych temperatur uzwojenia twornika alternatora w zakresie badanych prędkości obrotowych (praca alternatora w układzie samowzbudnym i obcowzbudnym).

of vehicle alternators. In spite of the length of overload time is 120 s or less, the proper switching system for the regulator to work at different voltage, for example 14 V or 60 V, should be provided. According to the system operation principle, the temperature regulator may be switched on to change over the system when catalytic converter monolith (heating resistor) reaches the temperature of 523 K. In order to obtain a certain overload of the alternator, the voltage regulator able to hold for example 60 V at machine clamps should be constructed [5]. It must be encountered in the regulator design, that while feeding the heating resistors of the catalytic converter, the alternator is connected to the battery not in parallel. That is why the connection system of regulator elements has to be equipped with additional electronic parts in order to avoid possibilities of occurring overvoltages (sudden voltage increases).

Apart from conducted measurements, alternator was tested under controlled overload on special model test stand [6]. Block diagram of the stand is presented in Fig. 8. The test stand equipment included:

— IBM PC equipped with Pentium II 300 MHz processor, WINDOWS 95 PL operating system and laboratory card ADVATECH- PCL818L;

— Inverter VECTOR CONTROL EVF9324-EV LENZE with rated output 3.0 kW, output current 10.5 A and RS 232C based controller;

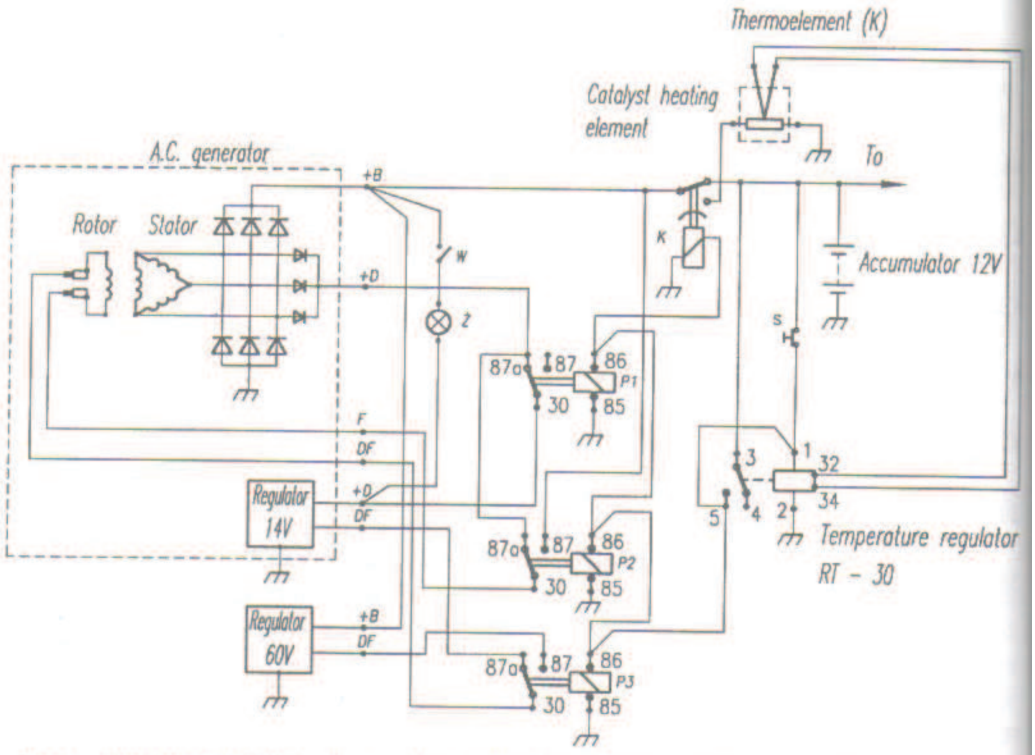

Fig. 7. Alternator with 60 V voltage regulator and heating element controlled by temperature regulator.
Rys. 7. Alternator z regulatorem napięcia 60 V i elementem grzejnym sterowanym regulatorem temperatury.

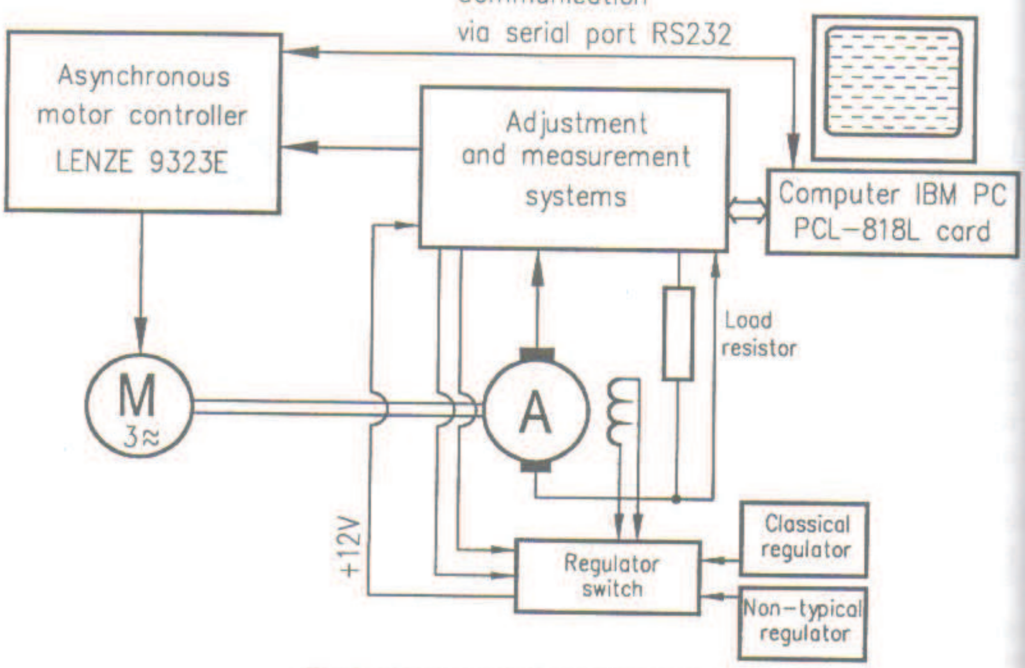

Fig. 8. Block diagram of model test stand.
Rys. 8. Schemat blokowy modelowego stanowiska badawczego.

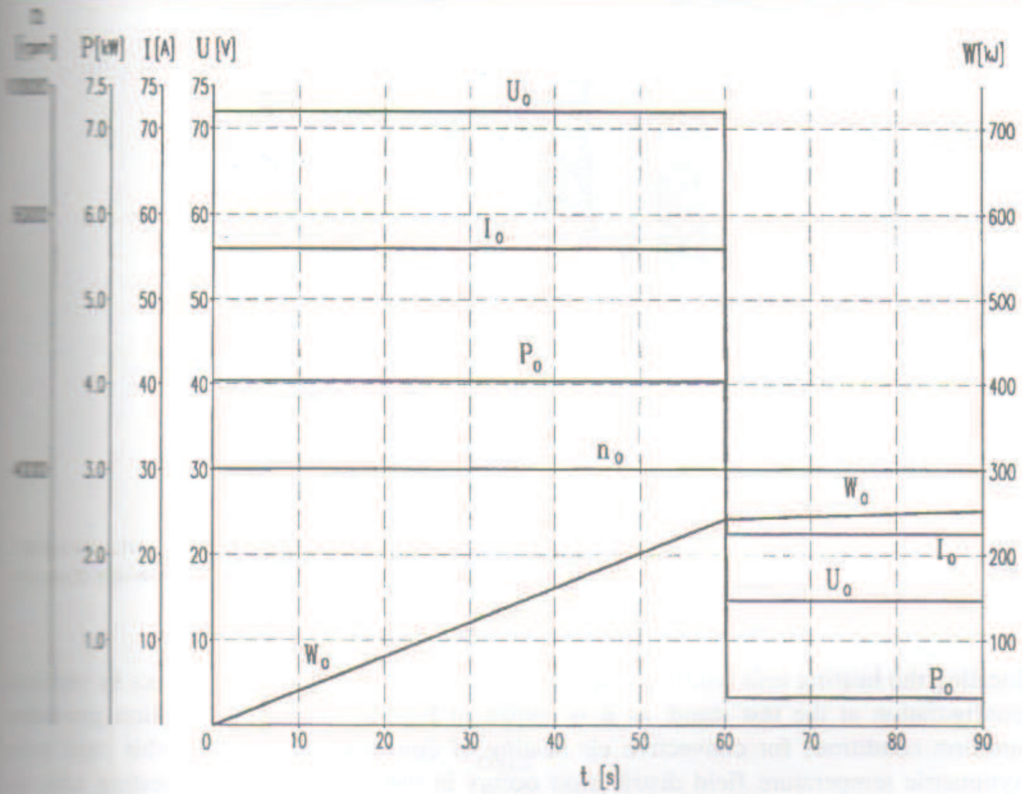

Fig. 9. Current, voltage and energy versus time for alternator tested on model test stand.

Rys. 9. Wartości prądu, napięcia mocy i energii w czasie, alternatora badanego na modelowym stanowisku badawczym.

— Three-phase induction motor (Fsg 100L) with nominal output 3.0 kW, voltage 380/220 V and nominal rotational speed of 2905 rpm;

— Automobile alternator with voltage regulator of approx. 14.7 V and voltage regulator of approx. 70 V.

Graphic presentation of exemplary test results is shown at Fig. 9. During the first 60 s of experiment, alternator with load current $I_0 = 56$ A and voltage on machine's terminal $U_0 = 72$ V reached power $P_0 = 4.0$ kW. Electric energy come into value of $W_0 = 248$ kJ. During the next 30 s of experiment alternator with load current $I_0 = 22.5$ A and voltage on machine's terminal $U_0 = 14.7$ V reached power $P_0 = 0.33$ kW. Electric energy W_0 has increased up to 253 kJ. Load resistance was equal to 1.8 Ω in the first case, and 0.65 Ω in the second one.

3. Construction and operation of the catalytic converter heating chamber

The flow of air warmed in the heating unit is used to increase temperature of catalytic converter at the test stand. The structure of catalytic converter allows for

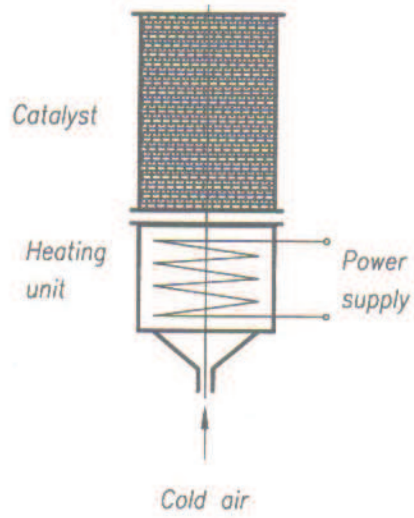

Fig. 10. Block diagram of thermal energetic part of model stand for heating up catalytic converter monolith.
Rys. 10. Schemat blokowy części energetyczno termicznej modelowego stanowiska do nagrzewania monolitu reaktora katalitycznego.

locating the heating unit within the resistantive heating unit [4], which works in vertical configuration at the test stand, as it is shown in Fig. 10. Such configuration provides uniform conditions for convective air heating of converter monolith. In this case axis symmetric temperature field distribution occurs in the monolith and in heating unit as well. This feature does not depend on different intensity of forces air circulation. Under normal conditions this system will be situated horizontally because of the catalytic converter, therefore its efficiency could be lower. The model of resistance heating unit of catalytic converter is supplied with electric energy produced by alternator operating under controlled overload. The electric and thermal parameters of heating resistor should be selected to providing possibility of feeding it by alternator energy at different power and voltage. The heating chamber with resistant warming unit renders estimation of converter energy consumption. This is the energy necessary for quick heating the converter monolith to the effective operating temperature (533 K). The energy as Joule heat emitted by resistor is transmitted to the air (according to Newton convection rule) and taken up by porous monolith of the converter. The heating process goes on in a continuous fashion. Directions of air movement satisfy the consistency condition in two types of convection during its heating process. This uniforms temperature field in air duct intersection of heating chamber. The main section of the heating chamber is the air duct made of thin walled quartz pipe with radiation shield covered by an insulation layer (Fig. 11). Kanthal wire coiled over ceramic alumina element forms the resistor heater fastened to framework made of heat resisting steel. Durability of kanthal resistor is comparable with durability of catalyst (80 000 km). The framework is freely mounted by ceramic elements in external confusor. The quartz pipe is protected with an internal cover made of heat resisting steel which is also used as cylindrical radiation shield and internal element closing inside space of thermo-insulating fabric settlement. The space

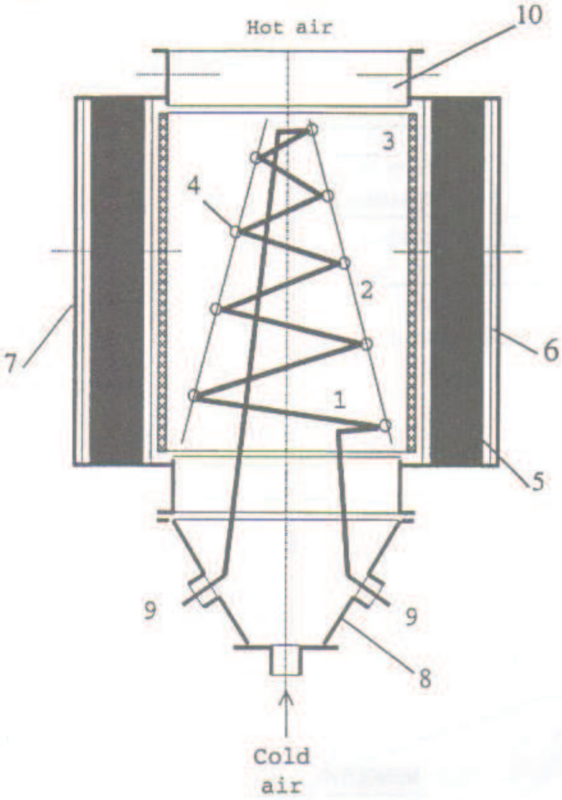

Fig. 11. Electric diagram of heating chamber (*1* — heating wire, *2* — framework, *3* — quartz pipe, *4* — electric ceramics, *5* — fabric cover, *6* — air gap, *7* — chamber housing, *8* — inlet diffuser, *9* — resistor electric throttles, *10* — outlet confusor).

Rys. 11. Schemat elektryczny komory grzewczej (*1* — drut grzejny, *2* — szkielet nośny, *3* — rura kwarcowa, *4* — ceramika elektryczna, *5* — osłona maty, *6* — szczelina powietrzna, *7* — obudowa komory, *8* — dyfuzor wlotowy, *9* — przepusty elektryczne rezystora, *10* — konfuzor wylotowy.

between internal and external covers of the fabric was unsealed to avoid pressure stresses during fabric gassing. Cylindrical air slot formed by inlet airtight external cover of fabric and chamber housing reduces additional heat losses.

Two airtight electric throttles made of special ceramic metal elements were placed in the entry diffuser. Heating chamber was manufactured within the research project [4] by Technika Serwis Sp. z o.o. Radom.

4. Experiments

The experimental tests of warming up converter monolith demand a special method of temperature measurement, a suitable airflow and sensitive data recording.

The atmospheric air supplying unit is a set of several devices that gathered in a block diagram is shown in Fig. 12. Its main task is air supply to outlet system with heating furnace and catalytic converter. The supplying system can feed 100 dm^3/min of free air

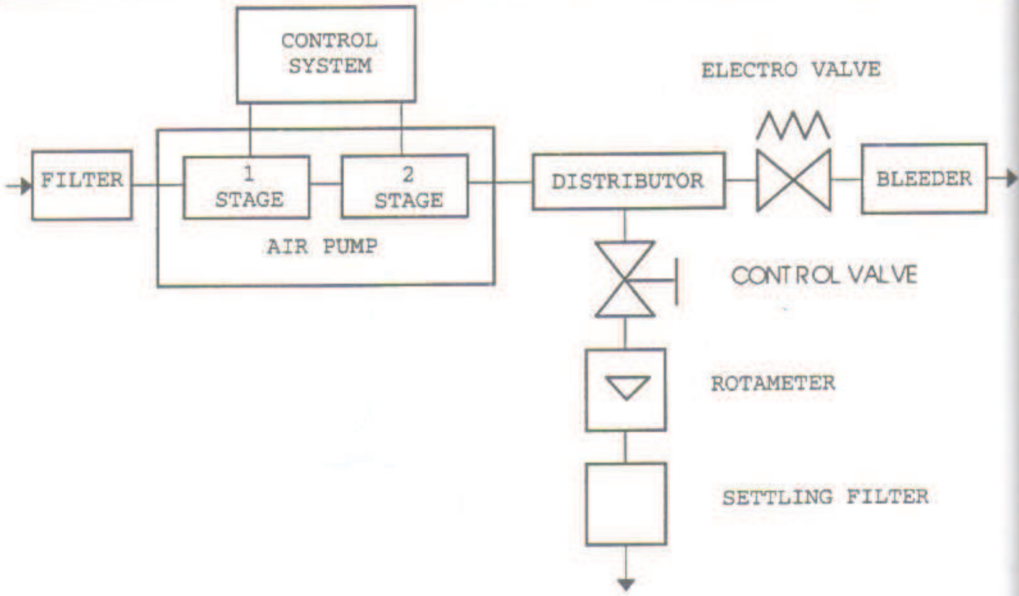

Fig. 12. Block diagram of the air supply system.
Rys. 12. Schemat blokowy układu zasilania w powietrze atmosferyczne.

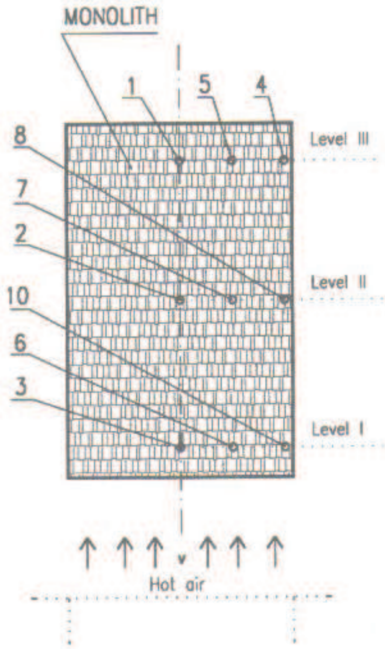

Fig. 13. Diagram of temperature measuring points lay out in converter monolith for 9 thermoelements option.
Rys. 13. Schemat rozmieszczenia punktów pomiaru temperatury w monolicie reaktora katalitycznego w wersji z dziewięcioma termoelementami.

that is used as the oxidiser. The two-stage pump induces the airflow. The air flowing through a distributor is directed to a overflow valve by the electromagnetic valve or to settling filter passing control valve and rotameter.

The test stand enables measuring temperature field distribution in converter monolith. Figure 13 shows the layout of measuring thermoelements in the monolith body. The experiments were carried out using heating chamber equipped with heating resistors for catalytic converter and with support of the atmospheric air supplying system. Data acquisition and recording during the experiment were performed by a computer system. Atmospheric air feeding unit together with temperature measurement and recording system was manufactured within the research project [4] by Technika Serwis Sp. z o.o. Radom.

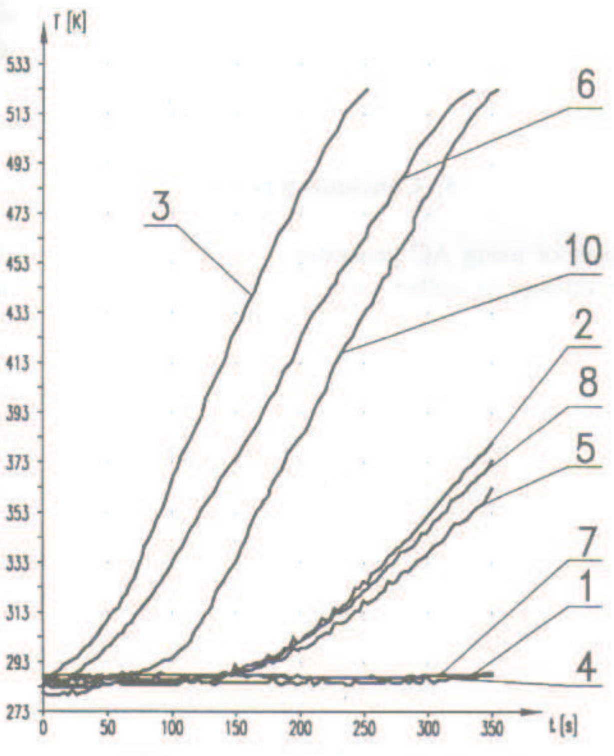

Fig. 14. Temperature variation at selected monolith points versus heating time (heating power 5 kW, air flow 60 dm3/min). Numbers of characteristics refer to temperature measurement points in catalytic converter monolith presented in Fig. 13).

Rys. 14. Charakter zmian temperatury w określonych miejscach monolitu reaktora katalitycznego w zależności od czasu nagrzewania (moc grzania 5 kW, wydatek powietrz 60 dm3/min), numery charakterystyk odpowiadają punktom pomiarowym temperatury w monolicie reaktora katalitycznego przedstawionym na rys. 13.

Graphs of catalytic converter temperature warmed in the model furnace equipped with heating resistors are shown in Fig.14. The alternator at the rate of 5 kW powered heating resistors and the airflow was kept constant, equal to 60 dm^3/min. The graph shows chamber of temperature variations measured by each thermocouple placed according to the scheme shown in Fig. 13. The temperature of the monolith was registered by 9 thermocouples located on the three levels:

Level I — thermocouples 3, 6, 10.
Level II — thermocouples 2, 7, 8.
Level III — thermocouples 1, 5, 4.

During the experiments (Fig. 14), the catalytic converter monolith reached the temperature of 523 K after 226 s. The supplied energy was 1130 kJ. According to [3], the same amount of energy is supplied within 120 s to the catalytic converter by exhaust gases. So it could be assumed, that these two sources of energy would reduce to 80 s the time of catalytic converter warming up to 523 K. The other methods of fast warming up of catalytic converter are applied. Highly promising technologies are Exhaust Gas Ignition (EGI) systems for exhausts gases after-burning, Pierburg system with starting converter or methods used by PSA (Peugeot-Citroen). These methods do not utilize electric energy.

5. Concluding remarks

Presented concept of using AC generator (alternator) as a mechanical into electric nergy transformer during so called cold start of a combustion engine proved the following:

- A vehicle alternator can operate at certain time under controlled overload to supply energy to heating resistors at the level several time higher then specified power rate;
- Special heating furnace (with load heating resistors) built into vehicle exhaust system and supplied by alternator sufficiently shortens the monolith warming up time to reach the temperature of efficient operation (523 K);
- The experiments carried out on the model stands confirmed the possibility of alternator operation under controlled overload and supplying power at the rate that provides for effective work of catalytic converter on the early stage of vehicle operation.

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Alternatory samochodowe jako źródła energii elektrycznej rezystorów grzejnych reaktorów katalitycznych

S t r e s z c z e n i e

W publikacji przedstawiono koncepcję usprawnienia pracy samochodowego reaktora katalitycznego w okresach tzw. zimnego rozruchu silnika spalinowego. W okresach tych, trwających nawet kilka minut, jest możliwe dodatkowe nagrzewanie reaktora energią cieplną pochodzącą z rezystorów grzejnych, stanowiących obciążenie alternatora pracującego w warunkach kontrolowanego przeciążenia. Podano wyniki badań doświadczalnych alternatora pracującego w tych niekonwencjonalnych warunkach. Opisano budowę i działanie specjalnej komory grzewczej reaktora katalitycznego oraz zespołu do zasilania układu powietrzem atmosferycznym stanowiących wyposażenie stanowiska badawczego odwzorowującego układ wylotowy silnika spalinowego. Uzyskane wyniki badań wykazały, że alternator przy znacznie wyższym napięciu (60÷70 V) może uzyskiwać moc wyższą od znamionowej. Ta zwiększona moc elektryczna (ok. 5 kW) może znacznie skrócić czas dojścia monolitu reaktora katalitycznego do temperatury skutecznej neutralizacji toksycznych gazowych składników spalin.