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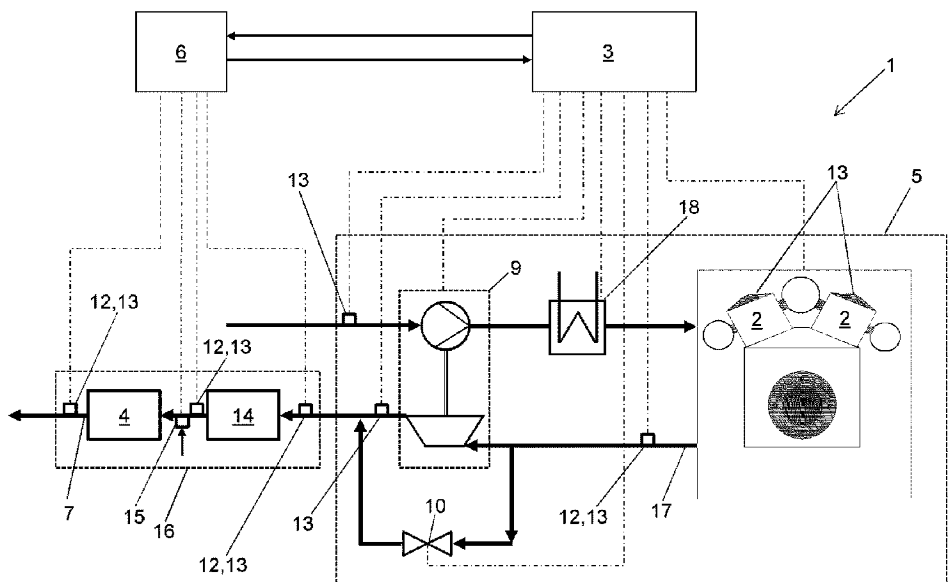

(57) Abrégé/Abstract:
An internal combustion engine (1), with an engine regulating device (3) and an exhaust gas aftertreatment device (16) with an SCR catalytic converter (4) for the reduction of at least one NOx component, and with a catalytic converter regulating device (6), wherein the engine regulating device (3) is prescribed a target value for an NOx mean value of the NOx component of the exhaust gases, which mean value results at an outlet point (7) of the exhaust gas aftertreatment device (16) in relation to a predefinable time period, and the engine regulating device (3) is configured at least in one operating mode to continuously calculate an NOx reference value for the catalytic converter regulating device (6) with consideration of NOx components which have already been emitted and the predefined target value, which reference value is selected in such a way that the predefined target value results at the outlet point of the exhaust gas aftertreatment device (16) at the end of the predefinable time period when the calculated NOx reference value of the catalytic converter regulating device (6) is fed as NOx setpoint value to the regulating means.

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ABSTRACT

An internal combustion engine (1), with an engine regulating device (3) and an exhaust gas aftertreatment device (16) with an SCR catalytic converter (4) for the reduction of at least one NOx component, and with a catalytic converter regulating device (6), wherein the engine regulating device (3) is prescribed a target value for an NOx mean value of the NOx component of the exhaust gases, which mean value results at an outlet point (7) of the exhaust gas aftertreatment device (16) in relation to a predefinable time period, and the engine regulating device (3) is configured at least in one operating mode to continuously calculate an NOx reference value for the catalytic converter regulating device (6) with consideration of NOx components which have already been emitted and the predefined target value, which reference value is selected in such a way that the predefined target value results at the outlet point of the exhaust gas aftertreatment device (16) at the end of the predefinable time period when the calculated NOx reference value of the catalytic converter regulating device (6) is fed as NOx setpoint value to the regulating means.

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INTERNAL COMBUSTION ENGINE WITH EXHAUST GAS AFTERTREATMENT AND CONTROL OF NITROGEN OXIDE EMISSION

The invention relates to an internal combustion engine and a genset having such an internal combustion engine.

In operation of an internal combustion engine of the general kind set forth the combustion processes in the piston-cylinder units result in the production of exhaust gases which have in particular NO_x and hydrocarbon proportions or components. An exhaust gas aftertreatment apparatus is provided to treat those exhaust gases. Observing the emission limit values is made possible in the thermally steady operation of the internal combustion engine in regard to the NO_x proportion or component by the provision of an SCR catalytic converter ("selective catalytic reduction" catalytic converter) in which a reducing agent (generally urea) is converted. An oxidation catalytic converter is additionally often provided, which is disposed upstream or downstream of the SCR catalytic converter in relation to a flow direction of the exhaust gases. Additionally or alternatively the system can have an ammonia slip catalytic converter (ASC) connected upstream and/or downstream of the SCR catalytic converter. There are for example the following options in relation to the arrangement of the various catalytic converters:

- SCR catalytic converter -> ASC
- ASC -> ASC -> oxidation catalytic converter
- Oxidation catalytic converter -> SCR catalytic converter -> ASC
- Oxidation catalytic converter -> SCR catalytic converter -> ASC-> oxidation catalytic converter

The individual catalytic converters can be structurally separate from each other or can be structurally combined.

It has proven to be difficult in the state of the art to meet the emission limit values also in a transient operating mode of the internal combustion engine (this is an operating mode in which the rotary speed of a crankshaft driven

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by the piston-cylinder units and/or the mechanical power output of the internal combustion engine changes, for example the operating mode immediately after the internal combustion engine starts). That applies in particular to the so-called NO_x average value of the NO_x proportion or component in the exhaust gases at the discharge from the SCR catalytic converter, both upon a warm start and also upon a cold start for the internal combustion engine. Here it is difficult to keep that NO_x average value lower than a target value prescribed by statute without prolonging a starting time of the internal combustion engine and/or unnecessarily increasing the HC or CO_2 emissions.

The requirements for a fast start for the internal combustion engine (that is to say the shortest possible starting time) on the one hand and complying with the target value for the NO_x average value on the other hand are in a conflicting area. Dynamic enrichment, that is to say reducing the excess air number of the fuel-air mixture available for combustion (an air excess number $\lambda = 1$ corresponds to a stoichiometric ratio of air to fuel, an air excess number $\lambda > 1$ corresponds to an air-fuel mixture with a proportion or component of air greater than the stoichiometric ratio), of the air-fuel mixture to be burnt in the piston-cylinder units during the increase in the speed and the power output of the internal combustion engine (and thus a reduction in the starting time) leads to an increase in the NO_x proportion or component in the exhaust gases, that is produced in the combustion processes, in an exhaust manifold of the internal combustion engine. As the SCR catalytic converter to which the exhaust gases are fed by way of the exhaust manifold is still cold when the internal combustion engine involves a cold start, the NO_x conversion rate of the catalytic material of the SCR catalytic converter is not sufficient to be able to reduce an increased NO_x proportion or component at the discharge from the SCR catalytic converter.

If the catalytic converter closed-loop control device of the SCR catalytic converter is too sluggish in its reaction to the changing demands in the transient operating mode, wrong amounts of the reducing agent provided at the SCR catalytic converter can occur. That can lead to critical transient effects, in relation to which either the NO_x passing into the SCR catalytic converter is not sufficiently reduced by virtue of a deficiency in provided reducing agent (so that too much NO_x proportion or component occurs at the discharge from the SCR catalytic converter) or – in the situation of overdosing of the reducing agent – NH_3 resulting from the reducing agent can pass into a downstream-disposed oxidation catalytic converter and thus additionally increase the NO_x proportion or component in the exhaust gas. Those critical transient effects can also occur due to sluggish thermal performance on the part of the SCR catalytic converter.

Closed-loop control circuits for controlling the exhaust gas aftertreatment apparatus in accordance with the state of the art have proven not to be reliable enough to meet a desired target value of the NO_x proportion or component in the exhaust gas at the discharge from the SCR catalytic converter, in particular when interference factors occur like a changing moisture content in the ambient air of the internal combustion engine or the proportions or components (in particular the SCR catalytic converter) of the internal combustion engine age.

The object of the invention is to provide a internal combustion engine of the general kind set forth, in which fulfilment of a predetermined or predeterminable target value for the average value of the NO_x proportion or component of the exhaust gases occurring in operation of the internal combustion engine is possible in a transient operating mode of the internal combustion engine, in particular upon a cold start or a warm start of the internal combustion engine, without the acceptance of a delayed increase in the speed and/or mechanical power output of the internal combustion engine (or electrical power of a genset involving mechanical coupling of the internal combustion engine to an electric generator) and a genset with such an internal combustion engine. Preferably with an internal combustion engine according to the invention or a genset according to the invention having such an internal combustion engine the aim of the invention is also to make it possible:

- to keep the average value of the NO_x proportion or component of the exhaust gases occurring in operation of the internal combustion engine equal to a predetermined or predeterminable target value upon the occurrence of interference factors like changing humidity in the ambient air or upon aging of proportions or components of the internal combustion engine (in particular the SCR catalytic converter), and/or

- to take account of secondary conditions which are also predeterminable like consumption of reducing agent or total operating resources outlay, and/or
- not to increase the content of HC emissions.

That object is attained by an internal combustion engine having the features of the invention described herein and a genset having such an internal combustion engine. Advantageous embodiments of the invention are also described herein.

To attain that object it is provided that:

- the engine closed-loop control unit is or can be prescribed a target value for an NO_x average value of the NO_x proportion or component of the exhaust gases, that occurs in relation to a predeterminable or predetermined period of time at a discharge from the exhaust gas aftertreatment apparatus (preferably by the manufacturer of the internal combustion engine but possibly also by an operator of the internal combustion engine),
- the engine closed-loop control unit is configured at least in one operating mode to continuously calculate an NO_x reference value for the catalytic converter closed-loop control device having regard to already emitted NO_x proportions or components and the predeterminable or predetermined target value, which reference value is so selected that at the end of a predeterminable or predetermined period of time the predeterminable or predetermined target value results at the discharge of the exhaust gas aftertreatment apparatus, and
- the calculated NO_x reference value is fed to the catalytic converter closed-loop control device as setpoint value.

The NO_x proportion or component, the NO_x reference value, the target value and the NO_x average value can be specified either in the form of a mass flow or in the form of a concentration.

The discharge from the exhaust gas aftertreatment apparatus is the discharge of the at least one SCR catalytic converter, if downstream thereof there are no further catalytic converter apparatuses, in particular no oxidation catalytic converter and/or ammonia slip catalytic converter; if an oxidation catalytic converter and/or an ammonia slip catalytic converter is disposed downstream of the at least one SCR catalytic converter then the discharge of the oxidation catalytic converter or the ammonia slip catalytic converter is the discharge from the exhaust gas aftertreatment apparatus.

It may suffice if the engine closed-loop control unit activates the operating mode according to the invention only when it is to be expected or if the situation is looming that the predeterminable or predetermined target value cannot be reached without the measure or measures according to the invention.

By virtue of the invention it is possible in particular during a transient operating mode (in particular during a cold or warm start) to temporarily allow higher levels of NO_x proportion or component in the exhaust gas at the discharge from the exhaust gas aftertreatment apparatus, as this ensures that overall after expiry of the predeterminable or predetermined period of time the NO_x average value of the exhaust gas NO_x proportion or component, that occurs in relation to the predetermined or predeterminable period of time at the discharge from the exhaust gas aftertreatment apparatus, is equal to the predeterminable or predetermined target value.

The invention makes it possible to observe a predetermined or predeterminable starting time without the target value for the NO_x average value in relation to the predeterminable or predetermined period of time being exceeded. The starting time is that time which elapses until, from starting the internal combustion engine (for example by actuating a start button) a predetermined or predeterminable target value for the speed and/or the mechanical power output of the internal combustion engine (or for the electrical power output of a genset formed by mechanical coupling of the internal combustion engine to an electric generator) is achieved.

The invention makes it possible to minimize consumption of reducing agent by the exhaust gas aftertreatment apparatus because it is possible to operate over longer periods of time than in the state of the art closer to the predeterminable or predetermined target value for the NO_x average value and thus less reducing agent is required. In those periods of time the internal combustion engine can be operated at a higher level of efficiency than in the state of the art.

In the invention the closed-loop control circuit for controlling exhaust gases from the internal combustion engine therefore has at least two proportions or components which are logically separated from each other (which in hardware terms can be in a common electronic control device or in physically mutually separated electronic control devices), more specifically on the one hand the engine closed-loop control unit and on the other hand the catalytic converter closed-loop control device.

The engine closed-loop control unit has various functions:

- by means of an engine open-loop control apparatus (which can be designed in accordance with the state of the art and therefore does not need to be described in greater detail here) it influences actuators of the engine block for influencing the state thereof (in particular influencing the fuel available for the combustion processes, as an absolute variable and/or in relation to the air in the cylinders of the engine block, controlling further proportions or components of the engine block like the performance of a turbocharger which is possibly present, a wastegate; controlling the position of the ignition time in the piston-cylinder units; shutting down ignition devices for selected piston-cylinder units; and so forth), in particular to provide a desired rotary speed and/or power output performance on the part of the internal combustion engine;

- it receives signals from sensors corresponding to the state of the art, by way of which the engine closed-loop control unit can acquire or determine information about the state of the engine block (in particular in regard to the above-described control tasks) and optionally the state of the exhaust gas aftertreatment apparatus;
- it provides for open-loop control (having regard to the signals made available by the sensors) or closed-loop control for the catalytic converter closed-loop control device by means of control commands, by presetting a desired NO_x setpoint value in the exhaust gas at a discharge from the exhaust gas aftertreatment apparatus (as to how the catalytic converter closed-loop control device has to actuate the exhaust gas aftertreatment apparatus so that that aim is achieved, corresponds to the state of the art) and provides for open-loop control – if required - of the engine block so that the catalytic converter closed-loop control device can achieve the predetermined desired NO_x setpoint value in the exhaust gas at the discharge from the exhaust gas aftertreatment apparatus as close as possible to the target value at the time of the end of the predeterminable or predetermined period of time.

The catalytic converter closed-loop control device:

- receives control commands from the engine closed-loop control unit, in particular the above-discussed predetermined desired NO_x setpoint value in the exhaust gas at the discharge from the exhaust gas aftertreatment apparatus and converts same, in particular by controlling an injection device for the injection of reducing agent (for example urea) into an exhaust manifold before a catalytic zone of the at least one SCR catalytic converter,
- optionally in accordance with the control commands of the engine closed-loop control unit it can influence the state of the at least one SCR catalytic converter by means of optionally provided additional devices (like for example a heating device for heating the catalytic zone).

Apart from the fact that the catalytic converter closed-loop control device receives control commands from the engine closed-loop control unit it can be designed in accordance with the state of the art and therefore does not need to be described in greater detail here.

The time-related NO_x average value $\overline{NO_x}$ of the NO_x proportion or component of the exhaust gases at the discharge of the at least one SCR catalytic converter is defined in relation to a period of time $t_{av} = t_2 - t_1$ by the following equation (NO_x (t) is in that case the time rate of the NO_x proportion or component at the time t, therefore the NO_x mass flow or the NO_x concentration):

$$\bar{N}\bar{O}_x = \frac{1}{t_{av}}\int_{t_1}^{t_2} NO_x\,(t')dt'$$

Preferably the control according to the invention is implemented as follows:

The engine closed-loop control unit is or can be prescribed a target value $\overline{NO_x}_{,Tar}$ which has to be reached after expiry of the predeterminable or predetermined period of time t_{av} (and generally may not be exceeded). The period t_{av} can be for example 30 minutes but alternatively or additionally other periods t_{av} are also conceivable like for example an hours value or a day value and so forth. It is conceivable that the period t_{av} only has to be covered once and then control can be operated in accordance with the state of the art. It is also conceivable that the period t_{av} is to be considered floatingly (and for example always in relation to the last preceding 30 minutes, one hour, one day and so forth). In the state of the art that target value $\overline{NO_x}_{,Tar}$ was reduced to prevent it being exceeded, by a safety margin which was prescribed for the catalytic converter closed-loop control device as a constant NO_x setpoint value.

The period of time t_{av} can:

- begin with starting of the internal combustion engine and/or
- begin at a fixed moment in time after synchronization of the genset with a power supply grid and/or during the power output ramp of the

internal combustion engine and/or while running up the speed of the internal combustion engine, and/or

- begin to run after attainment of the nominal power output of the internal combustion engine when there is a change in load and can preferably last until the change in load subsides.

The engine closed-loop control unit of the internal combustion engine according to the invention calculates continuously or in time steps (hereinafter for brevity: ongoing) having regard to the already emitted NO_x proportions or components, how large an NO_x mass flow has to be, which mass flow in relation to the remaining period of time for the purposes of this calculation is deemed to be constant (but ongoing calculated afresh in each calculation step) so that at the end of the predeterminable or predetermined period of time t_{av} at the discharge from the exhaust gas aftertreatment apparatus the predeterminable or predetermined target value $\overline{NO_x}_{,Tar}$ ensues. That calculated NO_x mass flow is ongoing determined as an NO_x reference value $NO_{x,Ref}(t)$ at the current time t (for $t_1 < t < t_2$) from the following equation and continuously passed to the exhaust gas control device as the NO_x setpoint value:

$$\bar{N}\bar{O}_{x,Tar} = \frac{1}{t_{av}}\left(\int_{t_1}^{t} NO_x(t')dt' + (t_2 - t)NO_{x,Ref}(t)\right)$$

The term on the left-hand side of the equation is known as it is or can be prescribed for the engine closed-loop control unit as the target value. The first term on the right-hand side of this equation takes account of the NO_x proportions or components which were already emitted in the period of time $t_1 < t$ and are therefore known (they can be measured or – depending on the state of the engine block and the exhaust gas aftertreatment apparatus – can be calculated or taken from a look-up table during the period $t_1 < t$), the second term calculates that NO_x proportion or component which may be emitted from the point of view of the time t in the remaining period $t < t_2$ so that this gives the predetermined or predeterminable target value

$\overline{NO_x}$,*Tar* and is to be calculated by means of this equation. Resolving that equation in accordance with the unknown NO_x,*Ref*(*t*) gives:

$$NO_{x,Ref}(t) = \frac{1}{t_2 - t}(t_{av} \cdot \bar{N}\bar{O}_{x,Tar} - \int_{t_1}^{t} NO_x(t')dt')$$

It is conceivable that the engine closed-loop control unit is configured to take account of exhaust gas NO_x proportions or components which have already occurred before the beginning of the period t_{av} in cumulated relationship for calculation of the NO_x reference value NO_x,*Ref*(*t*). Those cumulated NO_x proportions or components *cumul*NO_x can be known from measurements, calculations or estimations. In that case NO_x,*Ref*(*t*) can be calculated from the known $\overline{NO_x}$,*Tar* , the known cumulated NO_x proportions or components *cumul*NO_x and the known previously emitted NO_x proportions or components by resolution in accordance with NO_x,*Ref*(*t*):

$$NO_{x,Ref}(t) = \frac{1}{t_2 - t}(t_{av} \cdot \bar{N}\bar{O}_{x,Tar} - \int_{t_1}^{t} NO_x(t')dt' - cumulNO_x)$$

The more time of the predetermined or predeterminable period t_{av} has elapsed the correspondingly closer the NO_x reference value NO_x,*Ref*(*t*) comes to the predetermined or predeterminable target value $\overline{NO_x}$,*Tar* until finally it reaches it at $t = t_2$.

After expiry of the predeterminable or predetermined period of time the engine closed-loop control unit can be configured to control the engine block and the catalytic converter closed-loop control device in such a way as corresponds to a steady-state operation of the internal combustion engine. That kind of control is known from the state of the art and therefore does not have to be described in greater detail here.

How much of the mass flow of NO_x proportion or component $NO_{x,in}(t)$ that comes from the engine block and passes into the exhaust gas aftertreatment apparatus is reduced in at least one SCR catalytic converter (and in a possibly also provided oxidation catalytic converter) and leaves same as an issuing mass flow $NO_{x,out}(t)$ can be easily expressed by the so-called conversion rate $R_{conv}(t)$ defined by the following equation:

$$R_{conv}(t) = 1 - \frac{NO_{x,out}(t)}{NO_{x,in}(t)}$$

The momentary mass flows $NO_{x,in}(t)$ and $NO_{x,out}(t)$ can be measured by NO_x sensors. Alternatively, values from a look-up table or from a calculation can be used as it is known from theory, what mass flows are to be expected for a given state of the engine block.

The conversion rate $R_{conv}(t)$ at the time t can be monitored by the engine closed-loop control unit as an absolute value or – preferably – relative to an expected target value and used for open-loop or closed-loop control of the catalytic converter closed-loop control device.

If the at least one SCR catalytic converter is not active at a time t (for example because the temperature of the catalytic zone is too low) and there is no oxidation catalytic converter then naturally $NO_{x,out}(t) = NO_{x,in}(t)$ and thus $R_{conv}(t) = 0$.

It is particularly preferably provided that the engine closed-loop control unit is configured during a first part of the predeterminable or predetermined period of time (preferably from starting the internal combustion engine) to predetermine a momentary (time-dependent, in particular ramp shaped) setpoint value for the preferably electrical power output of the internal combustion engine lower than corresponds to the desired setpoint value in a steady-state mode of operation of the internal combustion engine.

In that first part of the predetermined or predeterminable period of time there is a first and optionally a second maximum of the NO_x proportions or components in the exhaust gas.

A first maximum is caused by enrichment of the air-fuel mixture for increasing the engine speed.

A second maximum can occur when at least one turbocharger which is provided is switched on until the turbocharger or turbochargers overcomes or overcome the turbo lag. After the turbo lag is overcome the engine block is in a state in which an actual value for a charging pressure of a charge air (or a mixture) can follow a setpoint value predetermined by the engine closed-loop control unit so that this gives stable values for the exhaust gas NO_x proportion or component (any deviations can be attributed to air humidity, charge air temperature and so forth).

A preferred embodiment provides that the engine closed-loop control unit is configured upon control of the engine block besides a state of the engine block also to take account of a state of the exhaust gas aftertreatment apparatus. That can relate to the above-described first part of the predeterminable or predetermined period of time and/or (independently of the first part of the predetermined or predeterminable period of time) can be indicated to take account of aging of the at least one SCR catalytic converter (which reduces the efficiency of NO_x reduction).

In that first part of the predeterminable or predetermined period of time the temperature of the catalytic zone of the at least one SCR catalytic converter is still below a temperature necessary for reduction of the NO_x so that here the exhaust gas NO_x proportions or components after the piston-cylinder units are of substantially the same size as the exhaust gas NO_x proportions or components at the discharge from the exhaust gas aftertreatment apparatus (therefore $R_{conv}(t) \approx 0$). Taking account of that state of the at least one SCR catalytic converter by the engine closed-loop control unit upon control of the engine block in a preferred embodiment provides that overall during the first part of the predetermined or predeterminable period of time fewer NO_x proportions or components are produced by the engine block.

That can be effected in such a way that the engine closed-loop control unit is configured to move a current first operating point of the engine block which is present after attainment of a nominal power output of the internal combustion engine to a transient operating point with lower NO_x emissions, for example to an operating point with higher temperatures of the exhaust gases immediately after exhaust valves of the piston-cylinder units (preferably in that case the temperature of the hottest piston-cylinder unit is used by the engine closed-loop control unit). That can be effected for example by setting an ignition time of the ignition in the piston-cylinder units to late (whereby the NO_x produced is reduced). It is however also possible – optionally as an alternative – to implement a (preferably simultaneous) reduction in the strength of the fuel-air mixture available for combustion in the piston-cylinder units to reduce the NO_x produced. Those measures are of course effected in such a way that no misfires occur. In a combustion diagram (with the coordinate axes "air excess number" and "ignition time") the operating point thereby moves within the knock limit and the misfire limit in the direction of higher exhaust gas temperatures.

That can optionally be effected in a first step (along a first trajectory in the combustion diagram) by means of a pre-control action to cause a rapid first adjustment of the operating point of the engine block. That can be followed in a second step (along a second trajectory in the combustion diagram) by a closed-loop control action in order to be able to more precisely select the ensuing transient operating point.

If the at least one SCR catalytic converter begins to reduce the NO_x proportion or component in the exhaust gas (because the catalytic zone has reached the required temperature) the engine closed-loop control unit provides for open-loop and/or closed-loop control of the engine block in such a way that the current operating point moves away from the transient operating point back in the direction of the first operating point (preferably on the same trajectory as for the movement of the nominal operating point to the steady-state operating point but in the reverse direction) and reaches same.

For the above-discussed open-loop and/or closed-loop control the engine closed-loop control unit can use the current conversion rate $R_{conv}(t)$. If the current NO_x proportion or component is excessive (that is to say the exhaust gas aftertreatment apparatus is not capable of observing the NO_x reference value $NO_{x,Ref}(t)$ predetermined by the engine closed-loop control unit at the discharge thereof) and the current conversion rate $R_{conv}(t)$ is below a predeterminable or predetermined value (this can be for example near to zero) then the above-described shift in the operating point from the first operating point towards the transient operating point with reduced NO_x emissions takes place. When the current conversion rate $R_{conv}(t)$ reaches or exceeds the predeterminable or predetermined value the above-described return shift of the operating point from the transient operating point towards the first operating point takes place, preferably in (for example proportional) dependency on the current conversion rate $R_{conv}(t)$ until it has reached a target conversion rate at which the first operating point is to be reached.

As soon as the temperature required for reduction of the NO_x in the catalytic zone of the at least one SCR catalytic converter is reached the engine closed-loop control unit therefore recognizes that new state of the at least one SCR catalytic converter and can now control the engine block in such a way that the engine block is operated at the first operating point at optimum efficiency (and in return with higher NO_x proportions or components of the exhaust gas in an exhaust manifold of the engine block).

To sum up: in that way open-loop and/or closed-loop control of the current operating point of the engine block is effected in dependence on the conversion rate $R_{conv}(t)$ of the exhaust gas aftertreatment apparatus (possibly the at least one SCR catalytic converter if there are no further catalytic converters), preferably after the expiry of an internal combustion engine starting time.

To reduce the exhaust gas NO_x proportion or component emitted during the starting time by the internal combustion engine – in combination with the above-described embodiments or in isolation – a preferred embodiment of the invention provides that the engine closed-loop control unit is configured during the starting time of the internal combustion engine to predetermine a power ramp for the engine block in a first time portion, preferably after attainment of the minimum power output, until reaching a predetermined limit valve for the power output with a first lesser gradient and in a second time portion until reaching a nominal power output of the internal combustion engine with a second greater gradient, wherein it is preferably provided that the greater gradient is calculated in dependence on the remaining time until the starting time is reached. The first lesser gradiet prevents excessive enrichment of the air-fuel mixture and thus excessive production of NO_x in the exhaust gas in the first time portion. The second greater gradient ensures that the nominal power output is reached within the desired starting time.

To reduce the exhaust gas NO_x proportion or component emitted during the starting time by the internal combustion engine – in combination with the above-described embodiments or in isolation – a preferred embodiment of the invention provides that the engine closed-loop control unit for reduction of the exhaust gas NO_x proportion or component emitted during a starting time of the internal combustion engine is configured within the starting time of the internal combustion engine to increase an air excess number of the air-fuel mixture available for combustion in the piston-cylinder units from a lower first value to a higher second value. That reduces the NO_x proportions or components in the exhaust gases, that are emitted during the starting time by the internal combustion engine.

In a preferred embodiment of the invention – in combination with the above-described embodiments or in isolation – it is provided that the engine closed-loop control unit is configured to raise a charging pressure of the engine block after reaching a nominal power output of the internal combustion engine for a predeterminable or predetermined period of time. That can provide for a reduction in the strength of the air-fuel mixture available for combustion in the piston-cylinder units and thus a reduction in the exhaust gas NO_x proportion or component issuing from the engine block.

The nominal operating point of the internal combustion engine is the desired operating point in a steady-state operation, therein a leaner fuel-air mixture with an air excess number $\lambda > 1$ is used. Preferably therefore the internal combustion engine is in the form of a lean burn engine, that is to say the internal combustion engine is always operated with an air excess number λ > 1 and even with a possible enrichment an air excess number $\lambda > 1$ is maintained.

Quite generally a strength reduction can be achieved by raising the charging pressure (as described for example in EP 0 259 382 B1) and/or by a direct reduction in the absolute amount of fuel. Correspondingly enrichment can be achieved by a reduction in the charging pressure or by a direct increase in the absolute amount of the fuel.

In an embodiment of the invention – in combination with the above-described embodiments or in isolation – it is provided that the engine closed-loop control unit is configured in the selection of a desired air excess number λ to take account of a synchronization duration (time duration until a synchronous speed is achieved relative to a grid frequency of the power supply grid) of a genset including the internal combustion engine with a power supply grid. In that case for example enrichment limits can be selected in dependence on the synchronization duration. If for example the synchronization duration is short (that is to say the synchronous speed is quickly reached) then enrichment is to be less than when a longer synchronization duration is involved, as there is more time available from the starting time to reach the nominal power output of the internal combustion engine. If in contrast the synchronization duration is long (that is to say the synchronous speed is reached slowly) enrichment has to be greater than in the case of a shorter synchronization duration as less time remains from the starting time to reach the nominal power output of the internal combustion engine. The terms "long" and "short" are naturally to be considered in relation to a predetermined or predeterminable limit value for the synchronization duration.

It is preferably provided that the synchronization time is measured and the decision regarding the further procedure in respect of the air excess number λ is to be made as soon as the length of the synchronization time is established.

Examples of sensors, by way of which the engine closed-loop control unit can acquire or determine information about the state of the engine block (in particular in regard to the above-described control functions) and the state of the exhaust gas aftertreatment apparatus are NO_x sensors and temperature sensors for measuring an exhaust gas temperature.

By way of example at least one NO_x sensor can be provided in an exhaust manifold after a possibly provided low-pressure turbine of a turbocharger before an injection device for reducing agent of the at least one SCR catalytic converter (preferably there is provided at least one such NO_x sensor for each engine bank of the engine block) and/or at least one NO_x sensor at a discharge from the exhaust gas aftertreatment apparatus (for example the at least one SCR catalytic converter and/or an oxidation catalytic converter which may be provided).

For example for each piston-cylinder unit a temperature sensor can be arranged directly after the exhaust valve or valves of the respective piston-cylinder unit. Preferably the temperature of the exhaust gases from all piston-cylinder units is determined and the temperature of the hottest piston-cylinder unit is used for control of the internal combustion engine by the engine closed-loop control unit.

By way of example at least one temperature sensor can be provided at an inlet location of the at least one SCR catalytic converter.

For example there can be provided at least one temperature sensor at a discharge from an oxidation catalyst which is possibly provided.

The internal combustion engine according to the invention is preferably a spark-ignition four-stroke engine and preferably has at least eight and particularly preferably at least twenty piston-cylinder units. The invention can preferably be used in relation to a stationary internal combustion engine. The internal combustion engine preferably serves as part of a genset as mechanical drive, for example in combination with an electric generator which is or can be mechanically coupled, for generating electrical energy.

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The introduction of fuel into the piston-cylinder units can be effected by means of port injection or in the form of a pre-mixed air-fuel mixture.

A preferred reducing agent is urea.

A preferred embodiment of the invention provides that the engine closed-loop control unit is configured not to exceed a predetermined or predeterminable limit value which is in particular dependent on the mode of operation (steady-state or transient) – possibly time-dependent – for a momentary mass flow or for a momentary concentration of the NO_x proportions or components of the exhaust gases in an exhaust manifold.

Embodiments of the invention are discussed with reference to the Figures in which:

Figure 1 shows an internal combustion engine according to the invention,
Figure 2 shows a view of the state of the internal combustion engine in relation to time on the basis of selected parameters,
Figure 3 shows a further view of the state of the internal combustion engine in relation to time on the basis of selected parameters with adaptation of a load ramp,
Figure 4 shows an open-loop and closed-loop control movement of the operating point of the engine block in a combustion diagram,
Figure 5 shows a view of the state of the internal combustion engine in relation to time on the basis of selected parameters when using the open-loop and closed-loop control strategy shown in Figure 4, and
Figure 6 shows a genset according to the invention.

The moments in time identified by the same references in Figures 1, 3 and 5 are identical.

Figure 1 diagrammatically shows an embodiment of an internal combustion engine 1 according to the invention with the following proportions or components:

2 piston-cylinder units
3 engine closed-loop control unit

4 SCR catalytic converter
5 engine block
6 catalytic converter closed-loop control device
7 discharge from the exhaust gas aftertreatment apparatus
8 electric generator of a genset including the internal combustion engine
9 turbocharger (optional)
10 wastegate (optional)
11 ignition device
12 NO_x sensor (optional), in particular NO_x sensors do not have to be provided at all illustrated positions,
13 temperature sensor (optional), in particular temperature sensors do not have to provided at all illustrated positions,
14 oxidation catalytic converter (optional), in particular alternatively or additionally there can be an ammonia slip catalytic converter and/or oxidation catalytic converter upstream of the SCR catalytic converter
15 injection device for reducing agent
16 exhaust gas aftertreatment apparatus
17 exhaust manifold
18 charging air temperature control device (optional)

Figure 6 shows a genset which is or can be electrically connected to a power supply grid 23 and having an internal combustion engine 1 according to the invention which is coupled to an electric generator 8 by means of a mechanical coupling 24.

The term state of the engine block 5 is used to denote in particular (individually or in any combination, naturally not all the following variables have to be taken into account):

- the temperature of the exhaust gases directly after a turbine of a possibly provided turbocharger 9 and/or directly after exhaust valves of the piston-cylinder units 2;
- temperature of operating means (like oil, cooling water, ...) or a material of the engine block 5 itself;
- NO_x proportion or component in the exhaust gases in an exhaust manifold 17 after a possibly provided low-pressure turbine of a

turbocharger 9 before an injection device 15 for reducing agent of the at least one SCR catalytic converter 4 (preferably for each engine bank of the engine block 5);

- NO_x proportion or component in the exhaust gases at a discharge 7 from the at least one SCR catalytic converter;
- ratio of NO proportion or component to NO_2 in the exhaust gas or the NO_2 proportion or component to NO_x or the NO proportion or component to NO_x, that can be converted as desired, as the following applies: $NO_x = NO + NO_2$;
- actual speed of a crankshaft of the internal combustion engine 1, driven by the piston-cylinder units 2 of the engine block 5;
- speed of a turbocharger 9 which is possibly provided;
- exhaust gas pressure ensuing from a degree of opening of a wastegate 10 which is possibly provided;
- selected ignition times for the piston-cylinder units 2;
- on/off state of ignition devices for the piston-cylinder units 2;
- charging pressure (pressure in front of the inlet valves of the piston-cylinder units 2);
- charging temperature (temperature in front of the inlet valves of the piston-cylinder units 2);
- induction air temperature;
- fuel mass flow or mixture mass flow to the piston-cylinder units 2;
- air mass flow;
- currently produced mechanical and/or electrical (in the case of a genset) power; and
- valve control times (in the case of a variable valve drive).

The state of the engine block 5 can be influenced by way of the engine closed-loop control unit 3 by means of actuators known in the state of the art (and therefore not shown). For example:

- the temperature of the exhaust gases can be influenced directly after outlet valves of the piston-cylinder units 2 by the selection of an ignition time and/or the air excess number of the fuel-air mixture and/or exhaust gas recycling, total amount of fuel, temperature of the charging air or the fuel-air mixture in front of inlet valves of the piston-cylinder units 2, skip firing, valve control times and so forth;

- the NO_x proportion or component in the exhaust gases in the exhaust manifold 17 can be influenced by the choice of a combustion temperature and/or combustion speed, in particular by the choice of an ignition time and/or the air excess number λ of the fuel-air mixture and/or exhaust gas recycling, total amount of fuel, temperature of the charging air or the fuel-air mixture in front of inlet valves of the piston-cylinder units 2, valve control times and so forth;
- the exhaust gas backpressure can be influenced by the degree of opening of an optionally provided wastegate 10 or by a variable turbine geometry (VTG); and
- the selected ignition times and/or the on/off state (skip firing) of ignition devices for the piston-cylinder units 2 can be influenced by appropriate actuation of the ignition devices of the piston-cylinder units 2.

The term state of the exhaust gas aftertreatment apparatus 16 is used to mean in particular (individually or in any combination, naturally not all the following variables have to be taken into consideration):

- the exhaust gas mass flow fed to the at least one SCR catalytic converter 4;
- a temperature of a catalytic zone and/or a temperature of the exhaust gas at an inlet location and/or a temperature of the exhaust gas at a discharge location of the at least one SCR catalytic converter 4;
- a mass flow Redux of reducing agent introduced into the at least one SCR catalytic converter 4;
- an amount of reducing agent reacted in the catalytic zone of the at least one SCR catalytic converter 4;
- an NH_3 storage state of the at least one SCR catalytic converter 4;
- the state of a possibly provided heating device for the at least one SCR catalytic converter 4; and
- state of a possibly provided oxidation catalytic converter 14.

The state of the exhaust gas aftertreatment apparatus 16 can be influenced by the catalytic converter closed-loop control device 6 by way of actuators known in the state of the art (and therefore not shown). By way of example the following can be influenced:

- the exhaust gas mass flow fed to the at least one SCR catalytic converter 4, influenced by the selection of a power output or an operating point of the engine block 5;
- the temperature of the catalytic zone of the at least one SCR catalytic converter 4, influenced by a temperature of the supplied exhaust gas and/or a heating device and/or a change in the exhaust gas mass flow;
- the temperature at the inlet to the at least one SCR catalytic converter 4, influenced by a temperature of the supplied exhaust gas and/or a heating device;
- a mass flow Redux of reducing agent introduced into the at least one SCR catalytic converter 4, being influenced by suitable actuation of an injection device 15 for reducing agent;
- the NH_3 storage state in the catalytic zone of the at least one SCR catalytic converter 4, being influenced by the supplied amount of reducing agent, the temperature of the catalytic zone, a change in the exhaust gas mass flow, a change in the NO_x proportion or component and/or the NO_2 proportion or component of the exhaust gas.

The engine closed-loop control unit 3 can be or is prescribed a target value $\overline{NO_x}_{,Tar}$ for an NO_x average value $\overline{NO_x}$ of the NO_x proportion or component of the exhaust gases in relation to a predetermined or predeterminable period of time t_{av} at a discharge 7 from the exhaust gas aftertreatment apparatus 16.

The engine closed-loop control unit 3 at least during the period t_{av} is in an operating mode in which it is configured to continuously calculate an NO_x reference value $NO_{x,Ref}(t)$ for the catalytic converter closed-loop control device 6 having regard to already emitted NO_x proportions or components and the predeterminable or predetermined target value $\overline{NO_x}_{,Tar}$, which reference value is so selected that at the end of the predeterminable or predetermined period of time t_{av} the predeterminable or predetermined target value $\overline{NO_x}_{,Tar}$ results at the discharge of the exhaust gas aftertreatment apparatus 16, and to feed the calculated NO_x reference value $NO_{x,Ref}(t)$ to the catalytic converter closed-loop control device 6 as an NO_x setpoint value.

Figure 2 shows a typical operating situation in relation to the Figure 1 embodiment of an internal combustion engine 1 according to the invention, the starting point here being a start of the internal combustion engine 1 by actuating a start button at the moment in time t_1.

At the moment in time t_3 the internal combustion engine 1 has reached the nominal power output (here in the form of an electrical nominal power output P_{el} of a genset afforded by way of a coupled electric generator – not shown in Figure 1 as it corresponds to the state of the art, but see Figure 6) so that the following applies for the starting time: $t_{Start} = t_3 - t_1$. The starting operation is therefore concluded at the moment in time t_3 (here for example approximately 5 minutes).

Within the starting time t_{Start} in relation to the NO_x proportions or components occurring in the engine block 5 at $NO_{x,in}$ of the exhaust gases (the index "in" is adopted because this involves the NO_x proportions or components flowing into the exhaust gas aftertreatment apparatus 16) it is possible to see two clear peaks, namely a first peak by virtue of the increase in the speed v to a nominal value (synchronous speed in relation to a power supply grid) and – after coupling of the genset to the power supply grid and the load uptake resulting therefrom – a second peak because of the build-up in torque during the turbo lag (which can be seen in the electrical power output as a divergence which remains behind the predetermined ramp). After overcoming the turbo lag (as soon as the turbocharger or turbochargers is or are brought up to speed) the NO_x proportions or components $NO_{x,in}$ in the exhaust gases occuring the engine block 5 fall to a first value which is constant for the rest of the starting time t_{Start}.

The reduction in the NO_x proportions or components $NO_{x,in}$ in the exhaust gases occuring in the engine block 5, that can be seen after the conclusion of the starting operation, is to be attributed to the fact that the engine closed-loop control unit 3 is configured after the attainment of a nominal power output of the internal combustion engine 1, for a predetermined or predeterminable period of time, to increase a charging pressure of the engine block 5 and/or to set an ignition time of the ignition in the piston-cylinder units to late (see also the combustion diagram in Figure 4).

The engine closed-loop control unit 3 monitors a conversion rate $R_{conv}(t)$ of the exhaust gas aftertreatment apparatus as an absolute value or – preferably – relative to an expected target value. The SCR catalytic converter 4 begins to work at the moment in time t_4 as the temperature necessary for reduction of the NO_x in the catalytic zone is reached and reducing agent is injected with a mass flow Redux by the injection device 15 (controlled by the catalytic converter closed-loop control device 6) into the exhaust manifold 17. Therefore the conversion rate $R_{conv}(t)$ begins to rise from the value zero and the NO_x proportions or components $NO_{x,out}$ of the exhaust gases at the discharge from the SCR catalytic converter 4 begin to diverge from the NO_x proportions or components $NO_{x,in}$ (the expected target value of the conversion rate $R_{conv}(t)$ is first reached at the moment in time t_5).

As from the moment in time t_4 the engine closed-loop control unit 3 begins to enrich the air-fuel mixture again and to set the ignition time back to earlier (see also the combustion diagram in Figure 4). Therefore the NO_x proportions or components $NO_{x,in}$ increase again to the value at the moment in time t_3, this however can be accepted as now in fact the SCR catalytic converter 4 is working.

At the moment in time t_2 the predetermined period of time t_{av} (here for example 30 minutes) has expired and the NO_x reference value $NO_{x,Ref}(t)$ for the catalytic converter closed-loop control device 6 has reached the predetermined target value $\overline{NO_x}_{,Tar}$ (see Figure 5).

The illustration as from the moment in time t_6 (here for example 2 hours) to the moment in time t_7 (here for example 24 hours) shows by way of example that here a 24 hours - target value $\overline{NO_x}_{,Tar}$ which is increased in relation to the 30 minutes - target value $\overline{NO_x}_{,Tar}$ – is accepted in order to minimize a consumption of reducing agent.

Figure 3 shows an optional control diagram in which the engine closed-loop control unit 3 of the internal combustion engine 1 in Figure 1, to reduce the NO_x proportion or component in the exhaust gases that is emitted during a starting time by the internal combustion engine 1 is additionally configured during the starting time t_{Start} of the internal combustion engine 1 to predetermine a power output ramp (dotted line which covers over a long period of time with the solid line) for the engine block 5 (here for the electrical power output P_{el}) in a first time portion, preferably after reaching a minimum power output (moment in time t_8) until reaching a predetermined limit value for the power output (moment in time t_{11}) with a first lesser gradient and in a second time portion (from the moment in time t_{11}) until reaching a nominal power output of the internal combustion engine 1 (at the moment in time t_3) with a second greater gradient, wherein it is preferably provided that the greater gradient is calculated in dependence on the remaining time (period $t_3 - t_{11}$) until the starting time t_{Start} is reached.

The solid line represents the actual power output. It can be seen that the engine block 5 can follow the power output ramp only after overcoming the turbo lag, which occupies the greatest part of the period of time $t_9 - t_8$.

A power ramp is shown in dashed-line form without the optional control scheme, and it can be seen that from the outset a steeper power output ramp is adopted, which during the turbo lag leads to increased NO_x emissions which as from the moment in time t_9 would have to be compensated by a drop in the power output ramp in order to be able to reach the predetermined NO_x average value $\overline{NO_x}$ of the NO_x proportion or component of the exhaust gas for the period of time t_{av}.

Figure 4 shows a combustion diagram in which it can be seen that the engine closed-loop control unit 3 of the internal combustion engine 1 in Figure 1 is optionally configured to move a current first operating point 19 of the engine block 5 which occurs after attainment of a nominal power output of the internal combustion engine 1 to a transient operating point 20 with lower NO_x emissions (the NO_x emissions occurring in the engine block 5, for which straight lines involving constant values are shown, decrease upwardly in Figure 4), for example to an operating point at higher temperatures (the temperatures of the piston-cylinder units, for which straight lines involving constant values are shown, increase towards the left in Figure 4), of the exhaust gases immediately after exhaust valves of the piston-cylinder units (preferably in that respect the temperature T of the hottest piston-cylinder unit is used by the engine closed-loop control unit 3). That can be achieved for example by adjusting an ignition time of igition in the piston-cylinder units to late and/or (preferably at the same time leaning of the fuel-air mixture available for combustion in the piston-cylinder units from the first value λ_1 to a second value λ_2 (naturally in such a way that no misfires or knocking occurs). In the combustion diagram (with the coordinate axes "air excess number λ" and ignition time measured at the "crankshaft angle θ") the operating point thereby moves within the knock limit and the misfire limit in the direction of higher exhaust gas temperatures.

That can optionally occur in a first step (along a first trajectory 21 in the combustion diagram) by means of a pre-control in order to cause rapid first adjustment of the operating point of the engine block 5. That can be followed in a second step (along a second trajectory 22 in the combustion diagram) by a control action in order to be able to more accurately select the ensuing transient operating point 20.

When the at least one SCR catalytic converter begins to reduce the NO_x proportion or component in the exhaust gas (because the catalytic zone has reached the required temperature) the engine closed-loop control unit provides for open-loop and/or closed-loop control of the engine block in such a way that the current operating point moves away from the transient operating point back in the direction of the first operating point (preferably on the same trajectory as for the movement from the nominal operating point to the steady-state operating point, but in the reverse direction) and reaches same.

Figure 5 shows once again the most important above-discussed parameters in the course of time t. It can be clearly seen how the time-dependent NO_x reference value $NO_{x,Ref}(t)$ increasingly approaches the predetermined target value $\overline{NO_x}_{,Tar}$ and finally reaches it at the time t_2 (right-hand dark point). By way of example shown for an earlier time (left-hand dark point) in a shape with a gray background are rectangles which correspond to the average NO_x proportions or components in the exhaust gases, that have already been emitted by the internal combustion engine 1 up to that moment in time, and the average NO_x proportions or components in the exhaust gases, that are thus still available to reach the predetermined target value $\overline{NO_x}_{,Tar}$.

With reference to Figure 3 the synchronization duration is measured (here equal: $t_8 - t_1$) and in dependence on the synchronization duration it is decided (immediately after the moment in time t_8) whether the mixture is to be more or less greatly enriched, and therefore a desired air excess number λ is established in dependence on the synchronization duration.

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List of references:

1	internal combustion engine
2	piston-cylinder units
3	engine closed-loop control unit
4	SCR catalytic converter
5	engine block
6	catalytic converter closed-loop control device
7	discharge of the SCR catalyst
8	electric generator
9	turbocharger
10	wastegate
11	ignition device
12	NO_x sensor
13	temperature sensor
14	oxidation catalytic converter
15	injection device for reducing agent
16	exhaust gas aftertreatment apparatus
17	exhaust manifold
18	charging air temperature control device
19	first operating point
20	transient operating point
21	first trajectory in the combustion diagram
22	first trajectory in the combustion diagram
23	power supply grid
24	mechanical coupling between internal combustion engine and electric generator

t_{av}	predetermined or predeterminable period of time
t_1, t_2, t_3, ...	first, second, third ... moment in time
t	current moment in time
t_{Start}	starting time of the internal combustion engine
$NO_x(t)$	rate of the NO_x proportion or component (mass flow or concentration) at the moment in time t

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$\overline{NO_x}$	NO_x average value
$\overline{NO_x}_{,Tar}$	predeterminable or predetermined (constant) target value
$NO_{x,Ref}(t)$	time-dependent NO_x reference value (mass flow) at the moment in time t
$cumulNO_2$	cumulated NO_x proportion or component
$R_{conv}(t)$	conversion rate of the exhaust gas aftertreatment apparatus at the moment in time t
$NO_{x,in}(t)$	mass flow entering the exhaust gas aftertreatment apparatus at the moment in time t
$NO_{x,out}(t)$	mass flow issuing from the exhaust gas aftertreatment apparatus at the moment in time t
Redux(t)	mass flow of reducing agent at the moment in time t
λ	air excess number
λ_1	first value of the air excess number
λ_2	second value of the air excess number
P_m	mechanical power output of the internal combustion engine
P_{el}	electrical power output of the internal combustion engine
V	speed of a crankshaft of the engine block
T	temperature
θ	crankshaft angle

CLAIMS:

1. An internal combustion engine (1) comprising:

- an engine block (5) having a plurality of piston-cylinder units (2) in which in operation of the internal combustion engine (1) an air-fuel mixture is combustable with the production of exhaust gases containing an NO_x proportion or component, wherein there is provided an engine closed-loop control unit (3) for controlling operation of the engine block (5), and

- an exhaust gas aftertreatment apparatus (16) for aftertreatment of the exhaust gas occurring in operation for reduction at least of the NO_x proportion or component, wherein the exhaust gas aftertreatment apparatus (16) has at least one SCR catalytic converter (4) and a catalytic converter closed-loop control device (6) for open-loop or closed-loop control at least of the at least one SCR catalytic converter (4),

characterised in that:

- the engine closed-loop control unit (3) is prescribed a target value ($\overline{NO_x},_{Tar}$) for an NO_x average value ($\overline{NO_x}$) of the NO_x proportion or component of the exhaust gases, that occurs in relation to a predeterminable or predetermined period of time (t_{av}) at a discharge (7) from the exhaust gas aftertreatment apparatus (16),

- the engine closed-loop control unit (3) is configured at least in one operating mode to continuously calculate an NO_x reference value ($NO_x,_{Ref}(t)$) for the catalytic converter closed-loop control device (6) having regard to already emitted NO_x proportions or components and the predeterminable or predetermined target value ($\overline{NO_x},_{Tar}$), which reference value is so selected that at the end of a predeterminable or predetermined period of time (t_{av}) the predeterminable or predetermined target value ($\overline{NO_x},_{Tar}$) results at the discharge of the exhaust gas aftertreatment apparatus (16), and

- the calculated NO_x reference value ($NO_x,_{Ref}(t)$) is fed to the catalytic converter closed-loop control device (6) as an NO_x setpoint value.

2. An internal combustion engine as set forth in claim 1 wherein the engine closed-loop control unit (3) is configured to calculate

the NO_x reference value ($NO_{x,Ref}(t)$) for the catalytic converter closed-loop control device (6) continuously in accordance with the following formula:

$$NO_{x,Ref}(t) = \frac{1}{t_2 - t}\left(t_{av} \cdot \bar{N}\bar{O}_{x,Tar} - \int_{t_1}^{t} NO_x(t')dt'\right)$$

or having regard to NO_x proportions or components in the exhaust gases that have already occurred prior to the beginning of the period of time t_{av} in cumulated form (*cumul*NO_x) in accordance with the following formula:

$$NO_{x,Ref}(t) = \frac{1}{t_2 - t}\left(t_{av} \cdot \bar{N}\bar{O}_{x,Tar} - \int_{t_1}^{t} NO_x(t')dt' - cumulNO_x\right)$$

3. An internal combustion engine as set forth in any one of claims 1 and 2 wherein the engine closed-loop control unit (3) is configured upon control of the engine block (5) besides a state of the engine block (5) also to take account of a state of the exhaust gas aftertreatment apparatus (16).

4. An internal combustion engine as set forth in any one of claims 1 to 3 wherein the engine closed-loop control unit (3) is configured to take account of the state of the exhaust gas aftertreatment apparatus (16) in the form of a current conversion rate ($R_{conv}(t)$).

5. An internal combustion engine as set forth in any one of claims 1 to 4 wherein the engine closed-loop control unit (3) is configured to provide for open-loop and/or closed-loop control of a current operating point of the engine block (5) in dependence on a conversion rate ($R_{conv}(t)$) of the exhaust gas aftertreatment apparatus (16).

6. An internal combustion engine as set forth in any one of claims 1 to 4 wherein the engine closed-loop control unit (3) is configured after the expiry of a starting time of the internal combustion engine (1) to provide for open-loop and/or closed-loop control of a current operating point of the engine block (5) in dependence on a conversion rate ($R_{conv}(t)$) of the exhaust gas aftertreatment apparatus (16).

7. An internal combustion engine as set forth in any one of claims 1 to 6 wherein the engine closed-loop control unit (3) is configured to

move a current operating point of the engine block (5) away from a first operating point (19) to a transient operating point (20) with lower NO_x emissions if the at least one SCR catalytic converter (4) of the exhaust gas aftertreatment apparatus (16) reduces fewer NO_x proportions or components than is required to attain the NO_x reference value ($NO_{x,Ref}(t)$) at the discharge of the exhaust gas aftertreatment apparatus (16).

8. An internal combustion engine as set forth in any one of claims 1 to 7 wherein the engine closed-loop control unit (3) is configured to take account of a mechanical actual power output ($P_{m,ist}$) of the internal combustion engine (1) or an electrical actual power output ($P_{el,ist}$) of an electrical generator (8) coupled to the internal combustion engine (1) in control of the engine block (5) and the catalytic converter closed-loop control device (6).

9. An internal combustion engine as set forth in any one of claims 1 to 8 wherein there is provided an injection device (5) for the injection of reducing agent into an exhaust gas manifold (17) before a catalytic zone of the at least one SCR catalytic converter (4) and the catalytic converter closed-loop control device (6) provides for open-loop or closed-loop control of an amount (Redux) of reducing agent converted in at least one SCR catalytic converter (4).

10. An internal combustion engine as set forth in any one of claims 1 to 9 wherein the engine closed-loop control unit (3) for reduction of the exhaust gas NO_x proportion or component emitted during a starting time of the internal combustion engine (1) is configured during the starting time of the internal combustion engine (1) to predetermine a power ramp for the engine block in a first time portion until reaching a predetermined limit value for the power output with a first lesser gradient and in a second time portion until reaching a nominal power output of the internal combustion engine (1) with a second greater gradient.

11. An internal combustion engine as set forth in any one of claims 1 to 9 wherein the engine closed-loop control unit (3) for reduction

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of the exhaust gas NO_x proportion or component emitted during a starting time of the internal combustion engine (1) is configured during the starting time of the internal combustion engine (1) to predetermine a power ramp for the engine block in a first time portion after attainment of the minimum power output until reaching a predetermined limit value for the power output with a first lesser gradient and in a second time portion until reaching a nominal power output of the internal combustion engine (1) with a second greater gradient, wherein the greater gradient is calculated in dependence on the remaining time until the starting time is reached.

12. An internal combustion engine as set forth in any one of claims 1 to 11 wherein the engine closed-loop control unit (3) for reduction of the exhaust gas NO_x proportion or component emitted during a starting time of the internal combustion engine (1) is configured within the starting time of the internal combustion engine (1) to increase an air excess number (λ) of the air-fuel mixture available for combustion in the piston-cylinder units from a lower first value (λ_1) to a higher second value (λ_2).

13. An internal combustion engine as set forth in any one of claims 1 to 12 wherein the engine closed-loop control unit (3) is configured, after the attainment of a nominal power output of the internal combustion engine (1) for a predeterminable or predetermined period of time:

- to reduce a charging pressure of the engine block (5), and/or
- to set an ignition time of ignition in the piston-cylinder units to late.

14. An internal combustion engine as set forth in any one of claims 1 to 13 wherein the predeterminable or predetermined period of time (t_{av}) begins to run:

- with a start of the internal combustion engine (1), and/or
- at an established moment in time after synchronization of the genset with a power supply grid or during the power output ramp of the internal combustion engine, and/or
- after attainment of the nominal power output of the internal combustion engine (1) when there is a change in load.

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15. An internal combustion engine as set forth in claim 11 wherein the predeterminable or predetermined period of time (t_{av}) begins to run with a start of the internal combustion engine (1), with a duration of 30 minutes.

16. An internal combustion engine as set forth in any one of claims 1 to 15 wherein the engine closed-loop control unit (3) is configured not to exceed a predetermined or predeterminable limit value which is in particular dependent on the mode of operation – possibly time-dependent – for a momentary mass flow or for a momentary concentration of the NO_x proportions or components of the exhaust gases in an exhaust manifold (17).

17. An internal combustion engine as set forth in any one of claims 1 to 16 wherein there are provided sensors, by way of which the engine closed-loop control unit (3) can acquire or determine information about the state of the engine block (5) and the state of the exhaust gas aftertreatment apparatus (16).

18. An internal combustion engine as set forth in claim 17 wherein the sensors comprise at least one NO_x sensor (12) and/or one temperature sensor (13).

19. An internal combustion engine as set forth in any one of claims 1 to 18 wherein the engine closed-loop control unit (3) is configured to effect adaptation of conversions and/or the NO_x proportions or components in the exhaust gas to achieve optimization of the reducing agent and/or a total operating resources consumption.

20. An internal combustion engine as set forth in claim 19 wherein the exhaust gas comprises urea and propellant gas.

21. An internal combustion engine as set forth in any one of claims 1 to 20 wherein the engine closed-loop control unit (3) is configured for controlling the NO_x emissions to control a charging pressure of the engine block (5) so as to give a desired air excess number (λ).

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22. An internal combustion engine as set forth in any one of claims 1 to 21 wherein the engine closed-loop control unit (3) is configured in the selection of a desired air excess number (λ) to take account of a synchronization duration of a genset including the internal combustion engine (1) with a power supply grid.

23. An internal combustion engine as set forth in any one of claims 1 to 22 wherein the exhaust gas aftertreatment apparatus has at least one oxidation catalytic converter (14) which is connected fluidically upstream or downstream of the at least one SCR catalytic converter (4).

24. An internal combustion engine as set forth in any one of claims 1 to 23 wherein the engine closed-loop control unit (3) and the catalytic converter closed-loop control device (6) are provided in a common control apparatus.

25. A genset comprising an internal combustion engine (1) as set forth in any one of claims 1 to 24 and an electric generator (8) which is coupled to the internal combustion engine (1) by means of a mechanical coupling (24).

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Fig. 1

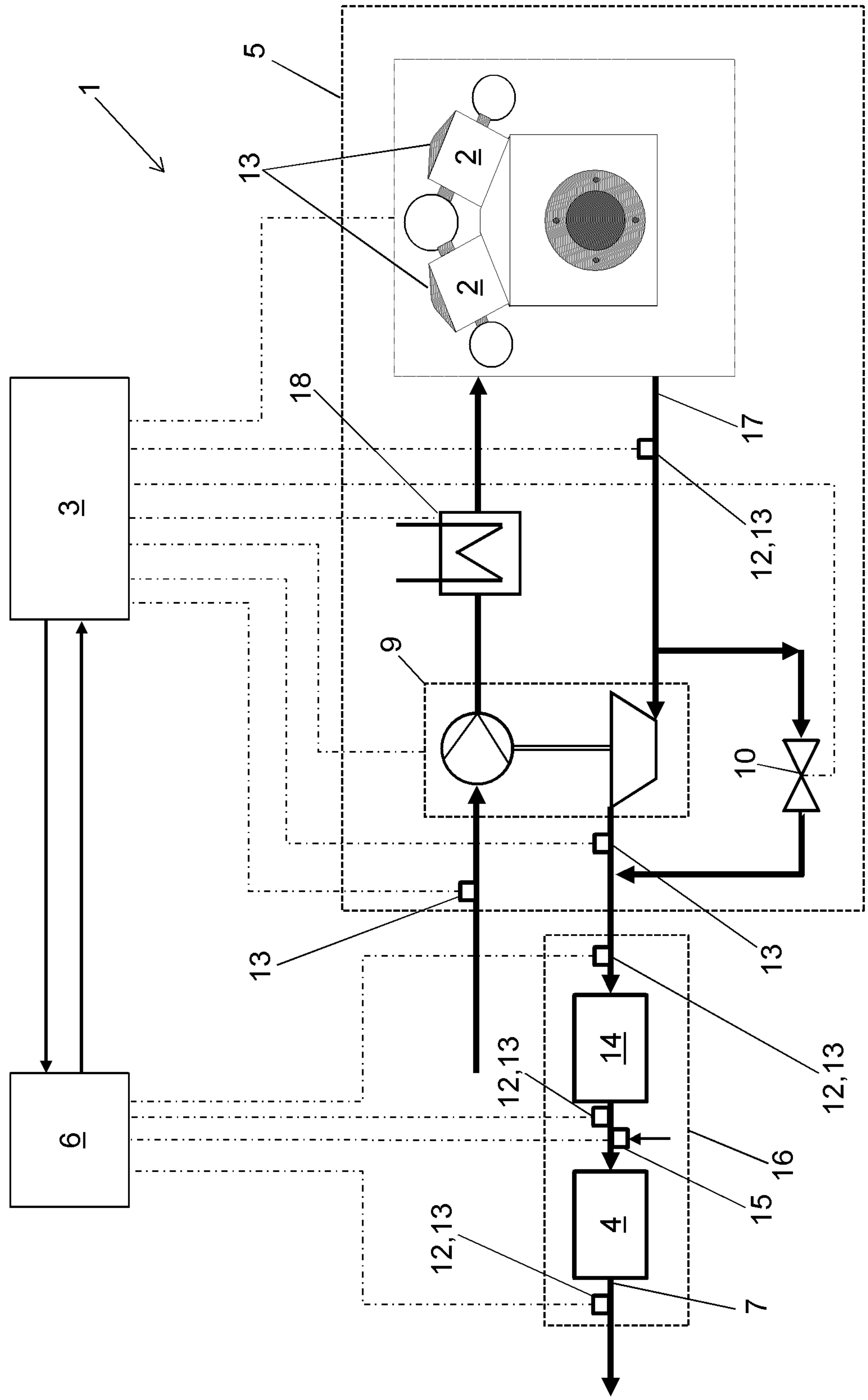

Fig. 2

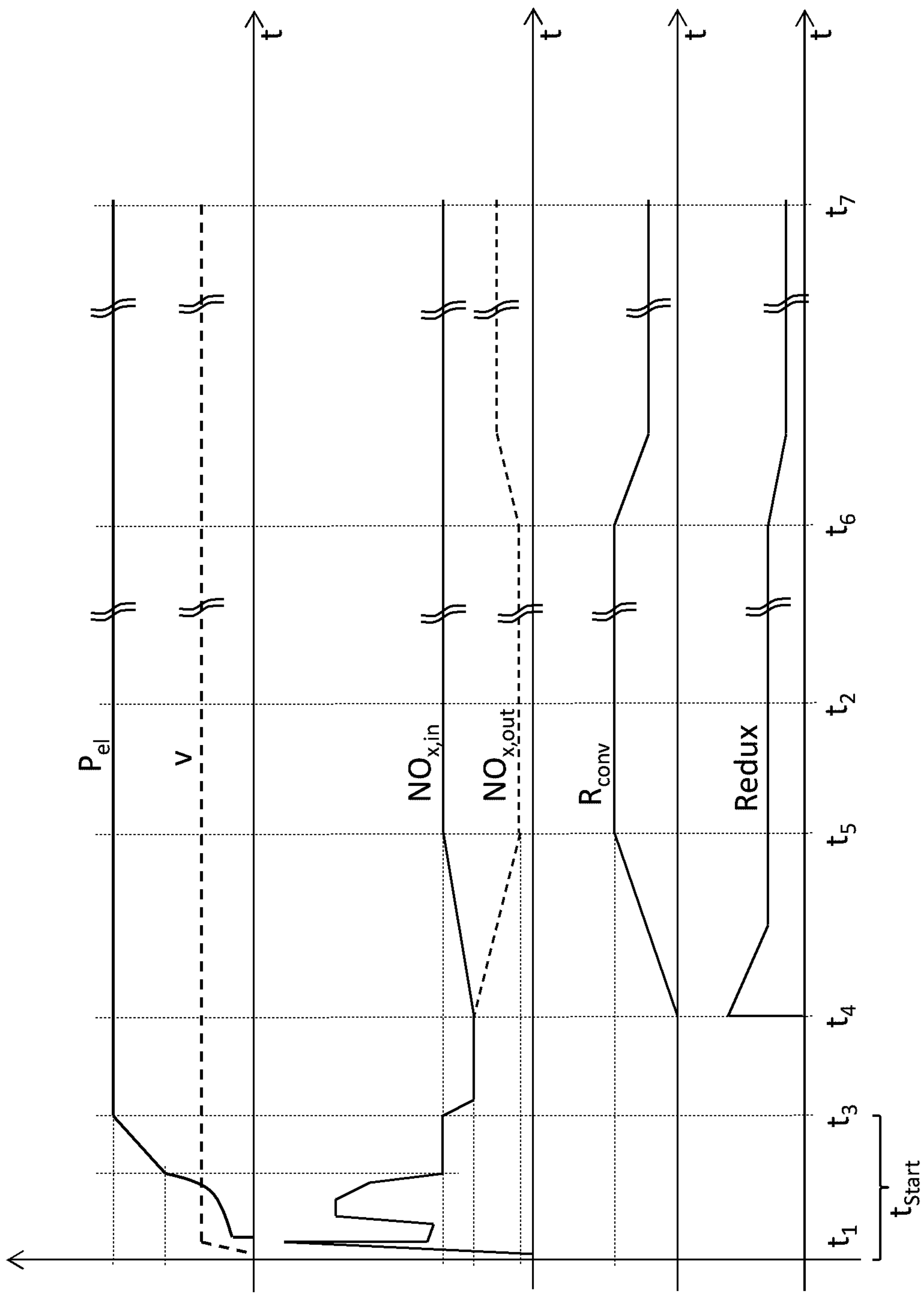

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Fig. 3

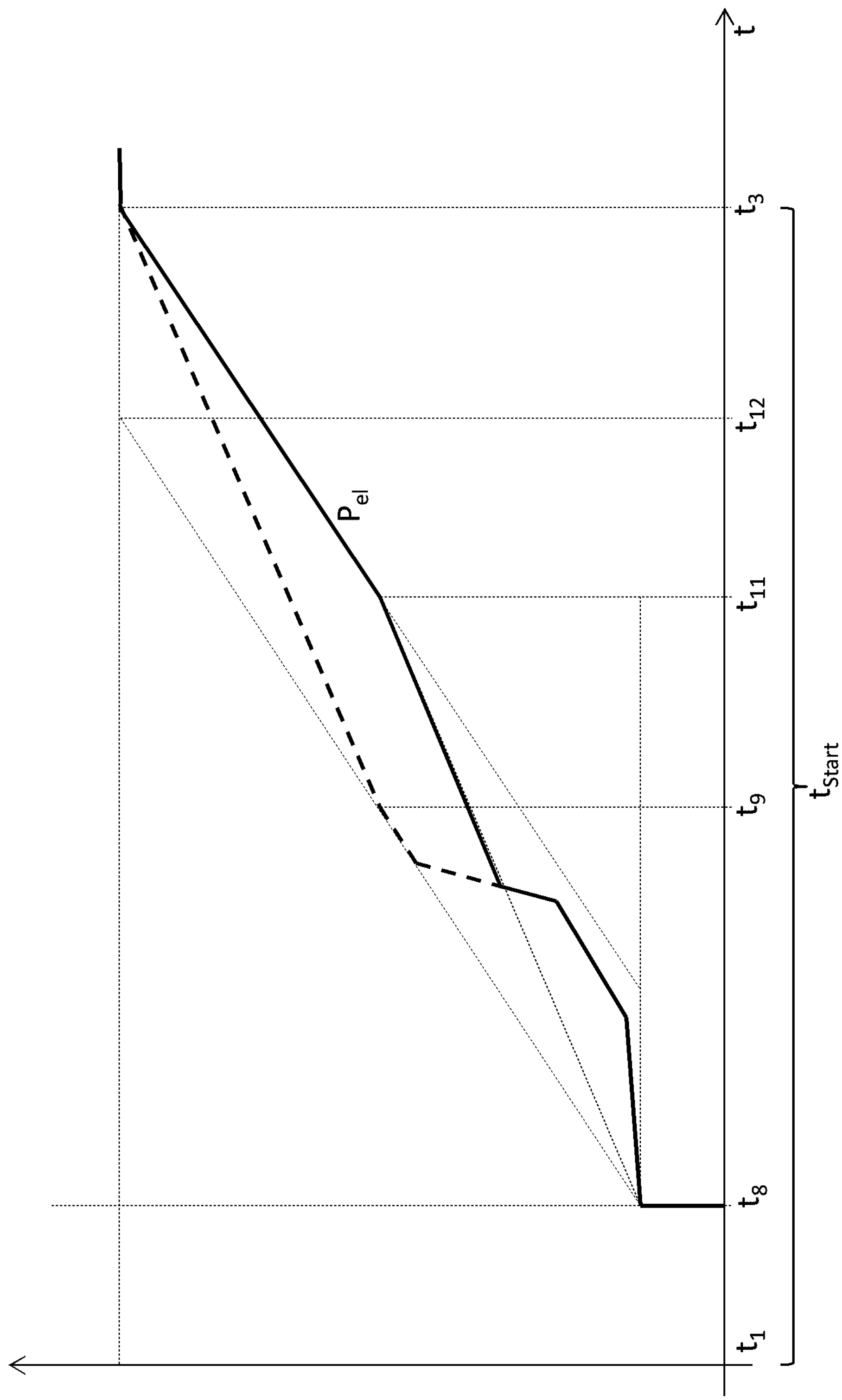

Fig. 4

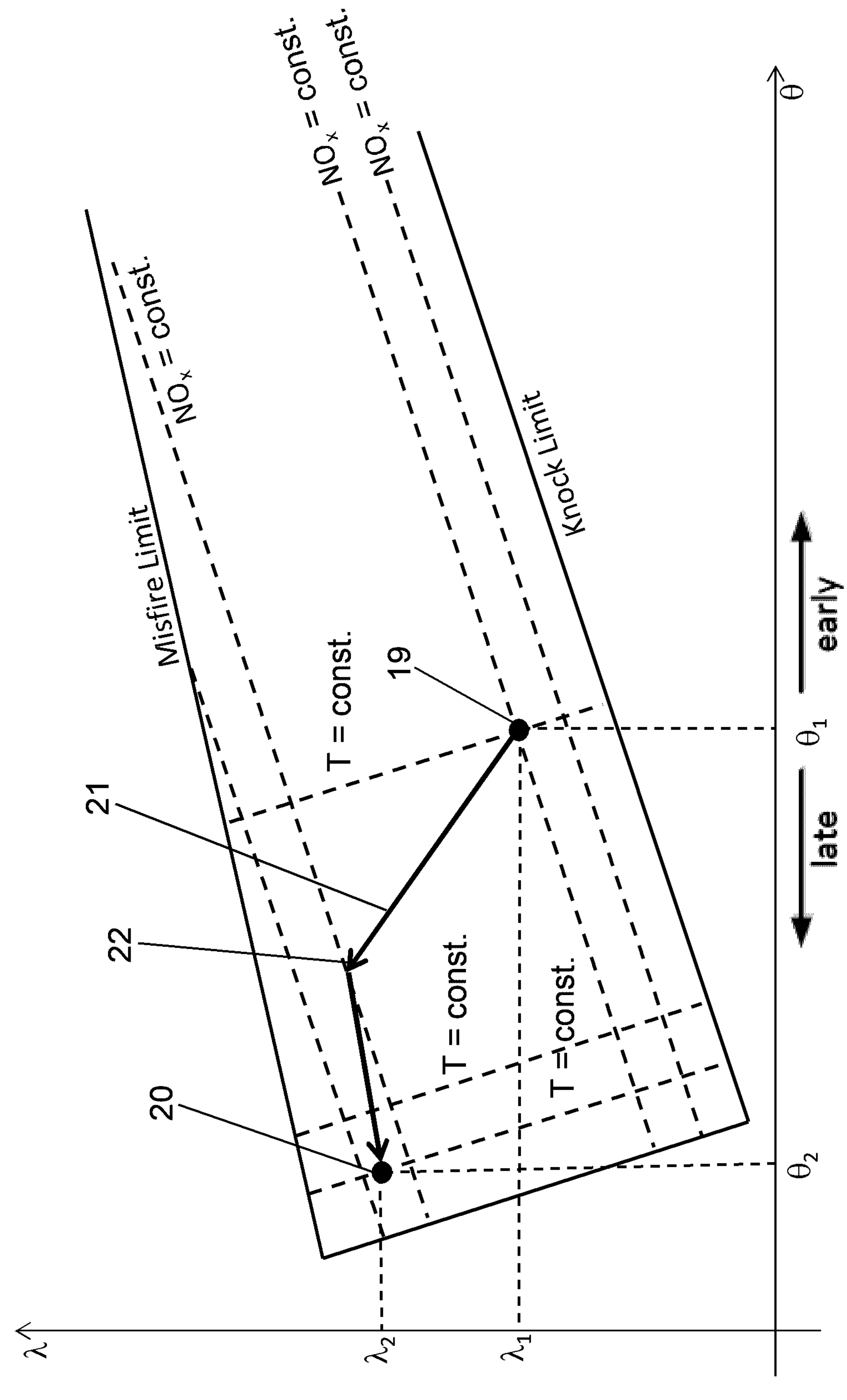
Misfire Limit
NO_x = const.
NO_x = const.
NO_x = const.
Knock Limit
T = const.
T = const.
T = const.
19
20
21
22
late
early
θ
θ_1
θ_2
λ
λ_1
λ_2

Fig. 5

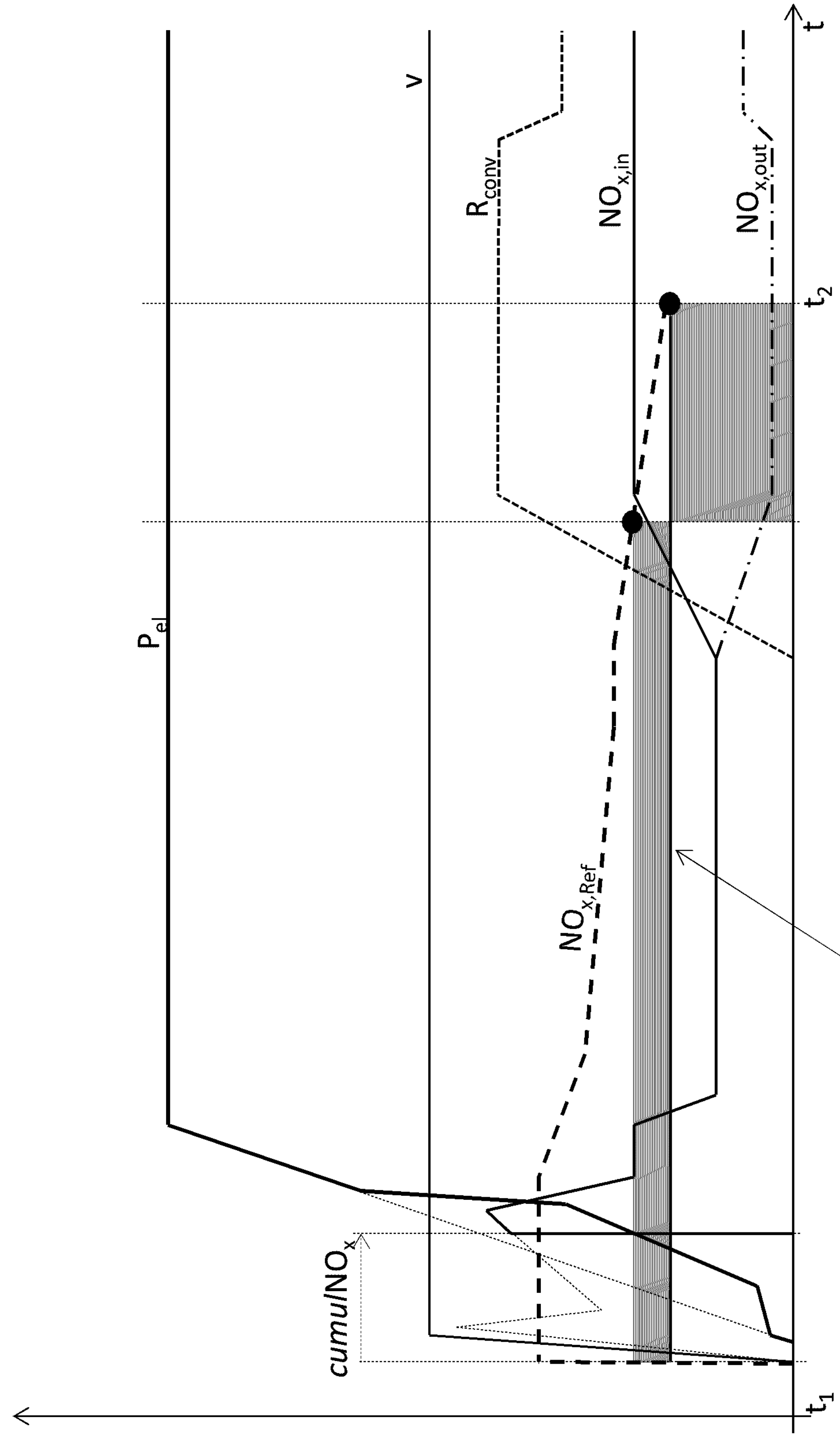

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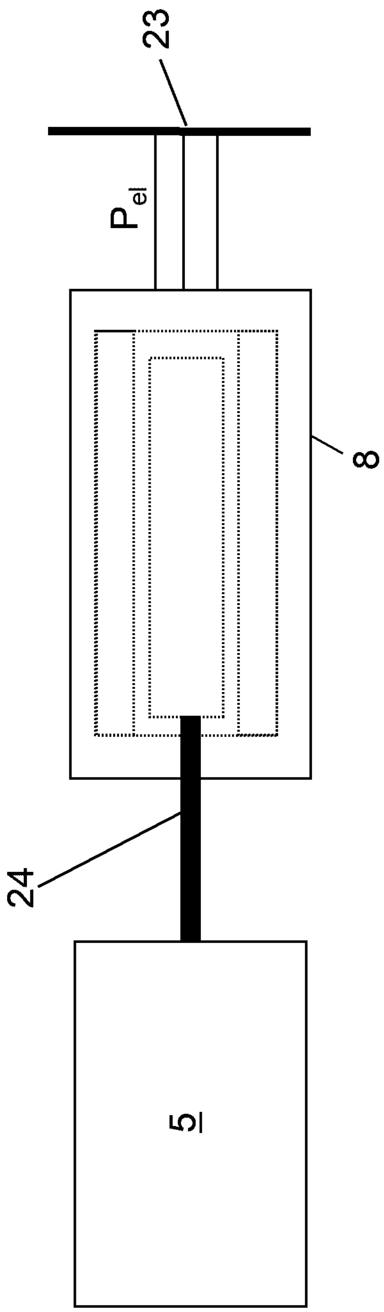
Fig. 6



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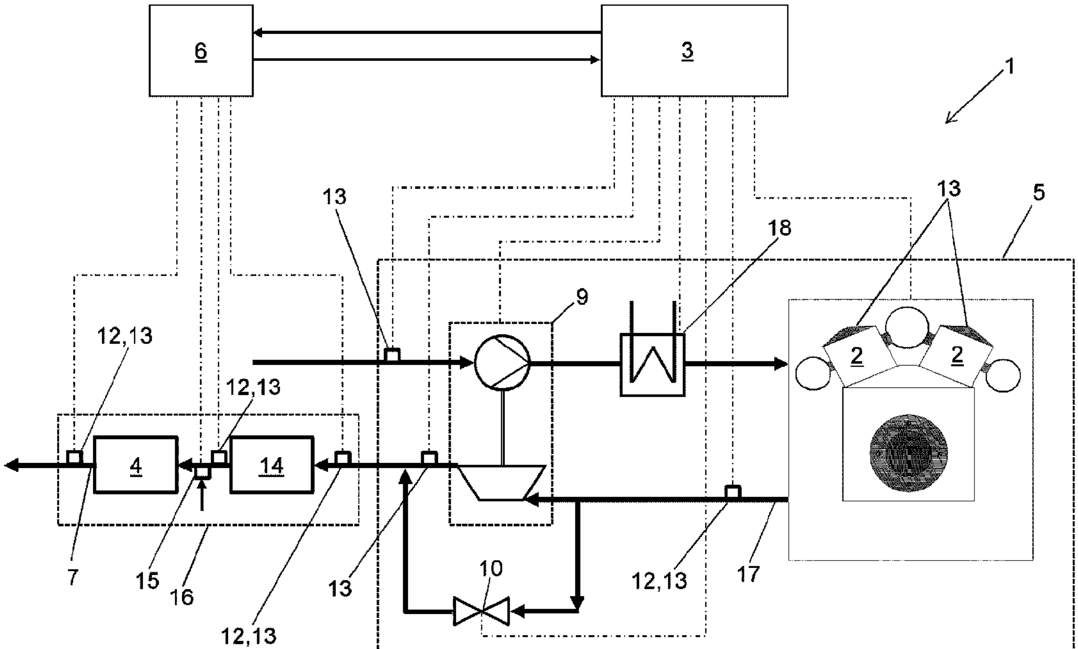
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