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(54) A method and a control system for controlling the operation of a last field of an electrostatic precipitator

(57) An electrostatic precipitator (1) has a last field (14) being provided with discharge electrodes (16), collecting electrodes (18) and a rapping device (22), which is adapted for cleaning the collecting electrodes (18) by means of rapping them. A control system (30) for controlling the dust particle emission from the electrostatic precipitator (1) comprises a control device (38), which is operative for adjusting, based on a relation between a magnitude (H) of a selected dust particle emission peak caused by a selected rapping and the time (t) between said selected rapping and its immediately preceding rapping, at least one parameter chosen from the group of: the time (t) to elapse until a rapping is to be executed in the last field (14), and the type of rapping to be executed in the last field (14).

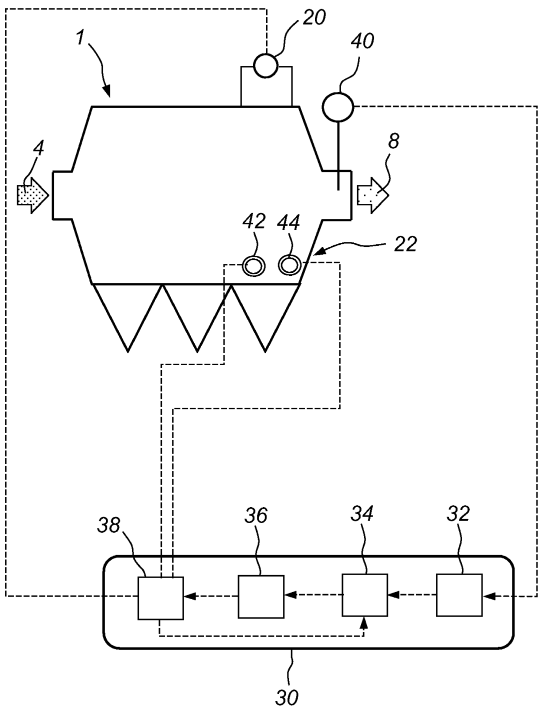

Fig. 2

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Description

Field of the invention

[0001] The present invention relates to a method of controlling the dust particle emission from an electrostatic precipitator having a last field, the last field being provided with discharge electrodes, collecting electrodes, and a rapping device, which is adapted for cleaning the collecting electrodes by means of rapping them.

[0002] The present invention also relates to a method of predicting the emission of dust particles during the rapping of at least one collecting electrode of a last field of an electrostatic precipitator.

[0003] The present invention also relates to a control system for controlling the dust particle emission from an electrostatic precipitator of the type described above.

[0004] The present invention also relates to a control system for predicting the dust particle emission from an electrostatic precipitator of the type described above.

Background of the invention

[0005] Combustion of coal, oil, industrial waste, domestic waste, peat, biomass, etc., produces flue gases that contain dust particles, often referred to as fly ash. The emission of dust particles to ambient air must be kept at a low level, and, therefore, a filter of the type electrostatic precipitator (ESP) is often used for collecting dust particles from the flue gas, before the flue gas is emitted to the ambient air. ESP's, which are known from, among other documents, US 4,502,872, are provided with discharge electrodes and collecting electrode plates. The discharge electrodes charge dust particles, which are then collected at the collecting electrode plates. When the collecting electrode plates are loaded with dust particles, the collecting electrode plates are rapped in order to make the collected dust particles release from the collecting electrode plates and fall down into a hopper, from which the dust particles may be transported further. The cleaned gas is emitted to ambient air via a stack.

[0006] Often an ESP is provided with several independent units, also called fields, coupled in series. An example of this can be found in WO 91/08837 describing three individual fields coupled in series. The first field collects the largest amount of dust particles and therefore requires much more frequent rapping than the subsequent fields. The last field collects only about 0-3% of the total amount of dust particles entering the ESP. When a field is rapped, which is made on a pre-set regular basis, the amount of dust particles, which leave the ESP, and is emitted to the ambient air, increases for a short period to quite high levels, which may even be visually observed as dust particles in the flue gas being emitted via the stack.

Summary of the invention

[0007] An object of the present invention is to provide a method, which makes it possible to control the temporarily large dust particle emission peaks caused by rapping of a last field in an electrostatic precipitator.

[0008] This object is achieved by a method of controlling the dust particle emission from an electrostatic precipitator having a last field, the last field being provided with discharge electrodes, collecting electrodes, and a rapping device, which is adapted for cleaning the collecting electrodes by means of rapping them, the method being characterised in the steps of

i) utilizing a relation between a magnitude of a selected dust particle emission peak caused by a selected rapping and a time between said selected rapping and its immediately preceding rapping, and
ii) adjusting, based on said relation, at least one parameter chosen from the group of: the time to elapse until a rapping is to be executed in the last field, and the type of rapping to be executed in the last field.

[0009] An advantage of this method is that the rapping can be accurately controlled in such a manner, that dust particle emission limits are not exceeded. Thus, it may be possible, by means of the present invention, to employ fewer fields, or smaller fields, in the electrostatic precipitator, than what was necessary when operating according to a prior art method. This is due to the fact that safety margins in the mechanical design of the electrostatic precipitator can be reduced when the electrostatic precipitator is operated according to the method of an embodiment of the present invention. The control of the rapping could relate to the time to elapse until a rapping is to be executed, or could relate to the type of rapping to be executed, or could relate to both the time to elapse and to the type of rapping.

[0010] According to one embodiment said step ii) further comprises
calculating rolling average values, each corresponding to the average dust particle emission during a preset period, and adjusting, based on said relation, the rapping of the collecting electrodes of the last field with respect to a preset rolling average limit value. This embodiment provides, advantageously, for controlling the rapping in such a manner, that a

limit for dust particle emission, which limit is a rolling average value, is not exceeded by accidentally rapping at the wrong time, or by accidentally performing the wrong type of rapping.

[0011] According to a preferred embodiment, the type of rapping to be employed is, in said step i), identified, and a rapping type specific model is selected for being utilized in step i), such selected rapping type specific model being a model of the relation between a magnitude of a selected dust particle emission peak caused by a selected rapping and the time between said selected rapping of that specific type of rapping, which has been identified, and its immediately preceding rapping. The amount of dust released during rapping depends on the type of rapping that is executed. By utilizing models that are rapping type specific a more accurate control is possible.

[0012] Preferably, in said step i), the type of rapping executed prior to said selected rapping is identified and accounted for when utilizing said relation between a magnitude of a selected dust particle emission peak caused by a selected rapping and a time between said selected rapping and its immediately preceding rapping, the type of which has been identified. The amount of dust released during rapping depends on the type of rapping that was executed prior to the rapping in question. By accounting for the type of rapping that was performed before the rapping in question a more accurate control is possible.

[0013] Preferably said relation between a magnitude of a selected dust particle emission peak caused by a selected rapping and the time between said selected rapping and its immediately preceding rapping is represented by:

magnitude $\propto$ function(time),

wherein said function is chosen among: logarithmic functions, and approximations of logarithmic functions, preferably said function is a natural logarithmic function. The longer the time elapsed since the immediately preceding rapping, the more dust is released during rapping. However, the dust is also agglomerated on the collecting electrode plates, and thus the relation between magnitude of a selected dust particle emission peak and elapsed time since its immediately preceding rapping is not linear, but best described by a logarithmic function.

[0014] According to a preferred embodiment a mathematical model of a relation between a magnitude of a selected dust particle emission peak caused by a selected rapping and the time between said selected rapping and its immediately preceding rapping can be obtained by measuring magnitudes of dust particle emission peaks and coupling them with the respective times elapsed since the respective immediately preceding rapping. The data records thus obtained can be utilized for preparing the mathematical model.

[0015] Preferably a mathematical model of a relation between a magnitude of a selected dust particle emission peak caused by a selected rapping and the time between said selected rapping and its immediately preceding rapping is updated by the steps of

D) measuring the dust particle emission after the last field for identifying a dust particle emission peak relating to a rapping of at least one collecting electrode of the last field,

E) coupling the measured magnitude of said dust particle emission peak with the corresponding time elapsed since the immediately preceding rapping of said at least one collecting electrode of the last field in order to form a data record, such data record comprising the magnitude of the dust particle emission peak and the corresponding time elapsed since the immediately preceding rapping, and

F) updating, based on said data record, said mathematical model of a relation between a magnitude of a selected dust particle emission peak caused by a selected rapping and the time between said selected rapping and its immediately preceding rapping. An advantage of this embodiment is that the model is updated, such that the model can be adapted to changing conditions of the operation of the electrostatic precipitator. Such changing conditions could relate to a change in the type of fuel, a time-dependent change in the surface properties of the collecting electrode plates, etc. The updating of the model is preferably, but not necessarily, done after each new rapping. As alternative the updating could also be made every second, every third, etc. rapping. Still more preferably, a data filter is utilized during step F) while updating the mathematical model. An advantage of this embodiment is that the model is updated in a more accurate way, and may also be adapted quicker to changing conditions in the electrostatic precipitator.

[0016] According to another preferred embodiment said step of adjusting, based on said relation, at least one parameter chosen from the group of: the time to elapse until a rapping is to be executed in the last field, and the type of rapping to be executed in the last field, is performed by means of:

measuring the magnitude of a dust particle emission peak which is caused by rapping of at least one of said collecting electrodes of the last field,

sending information about the measured magnitude of the dust particle emission peak to a calculating device,

said calculating device comparing said measured magnitude of the dust particle emission peak to a dust particle emission peak magnitude target value, and

automatically adjusting, by means of said calculating device, at least one parameter chosen from the group of: the time to elapse until a subsequent rapping is to be executed in the last field, and the type of subsequent rapping to be executed in the last field, for the purpose of minimizing the difference between said dust particle emission peak magnitude target value and the measured magnitude of a subsequent dust particle emission peak caused by the subsequent rapping of at least one of said collecting electrodes of the last field. An advantage of this embodiment is that a rather simple calculating device, such as PID-controller, a PI-controller or a model-free adaptive controller, can be utilized. Since there is no need for a model, there is no need for any extensive work with obtaining such a model. Furthermore, the control of the rapping will adapt rather quickly to changing conditions in the electrostatic precipitator, since measured data on the magnitude of the dust particle emission peaks are continuously sent to the calculating device.

[0017] Another object of the present invention is to provide a reliable method of predicting the emission of dust particles during the rapping of at least one collecting electrode of a last field of an electrostatic precipitator.

[0018] This object is achieved by means of a method of predicting the emission of dust particles during the rapping of at least one collecting electrode of a last field of an electrostatic precipitator, the last field being provided with discharge electrodes, collecting electrodes, and a rapping device, which is adapted for cleaning the collecting electrodes by means of rapping them, the method being characterised by the steps of
utilizing a relation between a magnitude of a selected dust particle emission peak caused by a selected rapping and the time between said selected rapping and its immediately preceding rapping, and
predicting, based on said relation between a magnitude of a selected dust particle emission peak caused by a selected rapping and the time between said selected rapping and its immediately preceding rapping, a parameter which is chosen among:

1) the magnitude of the dust particle emission peak caused by a selected rapping, based on a time to elapse between said selected rapping and its immediately preceding rapping, and
2) the time to elapse between a selected rapping and its immediately preceding rapping, based on the magnitude of a dust particle emission peak caused by said selected rapping.

[0019] An advantage of this method is that it becomes possible to predict, with a high accuracy, the dust particle emission caused by rapping of at least one collecting electrode of the last field. Thereby, it is possible to predict which dust particle emission that would result from a certain frequency of rapping, or to predict which frequency of rapping would be required to stay below a certain dust particle emission, e.g., a certain maximum rolling average of dust particle emission. This information can be utilized in the design of electrostatic precipitators, and in tuning the operation of electrostatic precipitators during the commissioning phase.

[0020] Another object of the present invention is to provide a control system, which makes is possible to eliminate, or at least to reduce, the problem of temporarily large dust particle emissions occurring during the rapping of a last field of an electrostatic precipitator.

[0021] This object is achieved by a control system for controlling the dust particle emission from an electrostatic precipitator having a last field being provided with discharge electrodes, collecting electrodes and a rapping device, which is adapted for cleaning the collecting electrodes by means of rapping them, the control system being characterised in that it comprises
a control device, which is operative for adjusting, based on a relation between a magnitude of a selected dust particle emission peak caused by a selected rapping and the time between said selected rapping and its immediately preceding rapping, at least one parameter chosen from the group of: the time to elapse until a rapping is to be executed in the last field, and the type of rapping to be executed in the last field.

[0022] An advantage of this control system is that it provides for efficient control of the rapping, such that the dust particle emission from an electrostatic precipitator can be minimised.

[0023] According to a preferred embodiment the control system further comprises
a data receiver, which is operative for receiving measurement data relating to the dust particle emission after the last field and for identifying, in said measurement data, a dust particle emission peak relating to rapping of said at least one collecting electrode of the last field,
a data processor, which is operative for coupling the measured magnitude of said dust particle emission peak with the corresponding time elapsed since the immediately preceding rapping of said at least one collecting electrode of the last field in order to form a data record, such data record comprising the magnitude of the peak and the corresponding time elapsed since the immediately preceding rapping, and
a calculating device, which is operative for updating, based on said data record, said mathematical model, which is an approximation of said relation between a magnitude of a selected dust particle emission peak caused by a selected rapping and the time between said selected rapping and its immediately preceding rapping. An advantage of this embodiment is that by updating the mathematical model, e.g., by updating the mathematical model as such, or by updating

a bias factor, the control function of the control system will adapt itself automatically to changing conditions in the electrostatic precipitator, making the control more accurate, and requiring less manual calibration over time.

[0024] According to another preferred embodiment a calculating device is operative for receiving measurement data relating to the measured magnitude of a dust particle emission peak which is caused by rapping of at least one of said collecting electrodes of the last field, said calculating device further being adapted for comparing said measured magnitude of the dust particle emission peak to a dust particle emission peak magnitude target value, and for automatically inducing adjustment, by means of said control device, of at least one parameter chosen from the group of: the time to elapse until a subsequent rapping is to be executed in the last field, and the type of subsequent rapping to be executed in the last field, for the purpose of minimizing the difference between said dust particle emission peak magnitude target value and the measured magnitude of a subsequent dust particle emission peak caused by the subsequent rapping of said at least one of said collecting electrodes of the last field. An advantage of this embodiment is that it provides for simple, yet effective, control of the rapping. The calculating device could be a PID-controller (a controller operating with proportional, integral, and derivative parameters), a PI-controller (a controller operating with proportional and integral parameters), or a model-free adaptive controller, i.e., a controller which, based on, e.g., a neural network, strives to decrease the difference between an observed value and a target value, without utilizing an actual model of the physical behaviour.

[0025] A further object of the present invention is to provide a control system which enables the accurate prediction of dust particle emission caused by rapping of at least one collecting electrode of the last field of an electrostatic precipitator.

[0026] This object is achieved by means of a control system for predicting the dust particle emission from an electrostatic precipitator having a last field being provided with discharge electrodes, collecting electrodes, and a rapping device, which is adapted for cleaning the collecting electrodes by means of rapping them, characterised in that the control system comprises

a data processor, which is operative for utilizing a relation between a magnitude of a selected dust particle emission peak caused by a selected rapping and the time between said selected rapping and its immediately preceding rapping, the data processor further being operative for predicting, based on said relation between a magnitude of a dust particle emission peak caused by a selected rapping and the time between said selected rapping and its immediately preceding rapping, a parameter which is chosen among

1) the magnitude of the dust particle emission peak caused by a selected rapping, based on a time to elapse between said selected rapping and its immediately preceding rapping, and

2) the time to elapse between a selected rapping and its immediately preceding rapping, based on a magnitude of a dust particle emission peak caused by said selected rapping. An advantage of this control system is that it provides for easy tuning of the rapping of an electrostatic precipitator.

[0027] Further objects and features of the present invention will be apparent from the description and the claims.

Brief description of the drawings

[0028] The invention will now be described in more detail with reference to the appended drawings, in which:

Fig. 1 is a cross-sectional view, and illustrates an electrostatic precipitator.
Fig. 2 is a side view, and illustrates the electrostatic precipitator and a control system.
Fig. 3 illustrates a diagram of measured dust particle emission peaks.
Fig. 4 illustrates a schematic diagram of dust particle emission peaks.
Fig. 5 illustrates an example of a model, which describes dust particle emission peak height caused by a selected rapping, versus the time elapsed since the immediately preceding rapping.
Fig. 6a is an illustration of how a height of a future dust particle emission peak is determined.
Fig. 6b is an illustration of the determination of a time to elapse until a future rapping is executed.
Fig. 7 illustrates a flow diagram of the method of controlling the rapping of the last field.
Fig. 8 is a schematic diagram, and illustrates dust particle emission peaks obtained by different types of rapping.
Fig. 9 is a side view, and illustrates an electrostatic precipitator and a control system according to an alternative embodiment.

Description of preferred embodiments

[0029] The expression "model" refers, in the present description, to a representation of a phenomenon, such as a physical phenomenon, a chemical process or the like. Furthermore, the expression "mathematical model" refers, in the present description, to a mathematical representation of a phenomenon.

[0030] Fig. 1 illustrates, schematically, an electrostatic precipitator (ESP) 1. The electrostatic precipitator 1 has an inlet 2 for flue gas 4, that contains dust particles, and an outlet 6 for flue gas 8, from which most of the dust particles have been removed. The precipitator 1 has a casing 9, in which a first field 10, a second field 12, and a last field 14, are provided. Each field 10, 12, 14 is provided with discharge electrodes and collecting electrodes, in the form of collecting electrode plates, as is per se known in the art, for instance from US patent No 4,502,872, which is hereby incorporated by this reference. The last field 14 is provided with discharge electrodes, of which only one discharge electrode 16 is depicted in Fig. 1, and collecting electrode plates, of which only one collecting electrode plate 18 is depicted in Fig. 1. A power source 20 applies a current between the discharge electrode 16 and the collecting electrode plate 18. When the flue gas 4 passes the discharge electrode 16, the dust particles will become electrically charged. The charged dust particles will travel towards the collecting electrode plate 18, where the dust particles will be collected. The electrostatic precipitator 1 is provided with a rapping device 22, which is adapted for removing the collected dust particles from the collecting electrode plates 18. The rapping device 22 comprises a first set of hammers, which are adapted for rapping the upstream end of the collecting electrode plates. A first hammer 24 is comprised in this first set of hammers, and is adapted for rapping the upstream end of the collecting electrode plate 18. The rapping device 22 also comprises a second set of hammers adapted for rapping the downstream end of the collecting electrode plates. A second hammer 26 is comprised in the second set of hammers, and is adapted for rapping the downstream end of the collecting electrode plate 18.

[0031] The cleaning of the collecting electrode plates 18 can be made in different ways. One parameter that can be varied is the current situation, i.e., whether the power source 20 does or does not apply a current between the electrodes 16, 18 during the rapping. It is also possible to decrease the current during the rapping, to, e.g., 5 % of the normal current, without reducing the current all the way down to zero. According to further alternative manners of performing the rapping, the current could be increased or decreased, compared to the current employed during normal operation, during the rapping. If the collecting electrode plates 18 are subjected to rapping while the current is applied, the ability of the particles to stick to the collecting electrode plates 18 will be higher than if the current is not applied during the rapping. Another parameter that can be varied, is whether the rapping is made with both the first hammer 24 and the second hammer 26 at the same occasion, or if the rapping is performed with only one of the hammers 24, 26. Further, the number of occasions that the hammers 24, 26 are made to rap the collecting electrode plate 18 will influence how much of the collected dust particles that are removed from the collecting electrode plate 18. Thus, there are several different ways of rapping the collecting electrode plates 18. Each way of rapping the collecting electrode plates 18 will have a specific behaviour as regards the amount of dust particles that are removed from the collecting electrode plates 18, and also as regards, which will be described hereinafter, the amount of dust particles that are dispersed in the flue gas and leaves the electrostatic precipitator 1 together with the cleaned flue gas 8.

[0032] The dust particles, that are removed from the collecting electrode plates 18 by means of the rapping, are collected in a hopper 28 and transported away.

[0033] Fig. 2 illustrates a control system 30 which comprises a data receiver 32, a data processor 34, a calculating device 36, and a rapping control device 38. A dust particle concentration analyser 40, which is, e.g., an opacity meter, analyses, on a continuous or periodic basis, the concentration of dust particles in the cleaned flue gas 8, that has passed the last field 14. The data receiver 32 receives information on the dust particle emission from the analyser 40. In the data, which the data receiver 32 has received from the analyser 40, the data receiver 32 identifies dust particle emission peaks, that are related to a rapping event. Information on the magnitude, and the point in time when the dust particle emission peak occurred, for each dust particle emission peak, is forwarded to the data processor 34. The data processor 34 also receives information from the rapping control device 38. The information from the rapping control device 38 concerns the point in time when the respective rapping was performed. Based on this information, the data processor 34 couples the magnitude of a dust particle emission peak, which is caused by a rapping, with a corresponding time, that has elapsed since an immediately preceding rapping was performed. The data processor 34 then forms, for each such peak, a data record, as will be described hereinafter. The information contained in said data record is forwarded from the data processor 34 to the calculating device 36. The calculating device 36 prepares and/or updates a mathematical model. The mathematical model is adapted for predicting a magnitude of a selected dust particle emission peak caused by a selected rapping, e.g., a future dust particle emission peak caused by a future rapping, based on the time that is to elapse between said selected rapping and its immediately preceding rapping. The mathematical model is forwarded to the control device 38. Based on the mathematical model, the control device 38 determines a suitable time for the future rapping, and a suitable type of rapping to be performed. The control device 38 then sends, automatically and at a desired point in time, signals to the rapping device 22, and, if a change in the current, which is applied between the discharge electrodes 16 and the collecting electrode plates 18, is to be performed, also to the power source 20, in order to execute a desired type of rapping. The signals that are sent by the control device 38 can, thus, include information concerning which current should be applied by the power source 20 during the rapping, and concerning if and how a first motor 42, which operates the first set of hammers 24, should be operated, and if and how a second motor 44, which operates the second set of hammers 26, should be operated. Each time a new data record is obtained, with a following dust particle emission peak, the mathematical model can be updated. Thus, the control system 30 provides for an automatic control of when, and how rapping should be executed in the last field 14 in order to obtain a desired, low dust particle emission peak.

[0034] Fig. 3 depicts an example of measurement data, which are provided by the analyser 40. The opacity signal E (% of max reading on the opacity meter), is depicted on the Y-axis, and the time, T (minutes), is depicted on the X-axis. Dust particulate emission peaks, which are depicted in the form of dust particle emission peaks P1 and P2 in Fig. 3, have been found to correspond to the rapping of the collecting electrode plates 18 of the last field 14. Thus, as soon as a rapping has been performed in the last field 14, the dust particle emission increases to form the dust particle emission peak P1, P2, which lasts for typically about 3-5 minutes. The rapping of the first field 10 and the rapping of the second field 12 usually have a lower impact on the dust particle emission. The reason for this fact is, that a rapping in the first field 10, or a rapping in the second field 12, causes an increased dust particle emission from that particular field 10, 12. However, the dust particles that are emitted during the rapping of the first field 10, or of the second field 12, are efficiently collected by the collecting electrode plates 18 of the last field 14. Thus, the effects of rapping the first field 10, or rapping the second field 12, will often be absorbed by the last field 14, which is located downstream of the first field 10 and the second field 12. When a rapping is performed in the last field 14, however, there is no downstream field, which can collect the dust particles that are released during rapping.

[0035] The amount of dust particles, which are emitted during the dust particle emission peaks P1, P2, has a large effect on the rolling average of dust particle emission from the electrostatic precipitator 1. Thus, the amount of dust particles, that are released from the collecting electrode plates 18 of the last field 14 during rapping, is relevant as regards the dust particle emission rolling average limit value set by authorities. Depending on the country, in which the electrostatic precipitator 1 is installed, the limit value could be, e.g., a 6 minute rolling average value or a 1 day rolling average value. That part of the dust particle emission which is caused by the dust particle emission peaks P1, P2, which are depicted in Fig. 3, has a significant impact on the dust particle emission from the electrostatic precipitator 1, in particular as regards short term rolling averages of dust particle emissions, such as rolling averages referring to 30 minutes and shorter time periods. For example, a 6 minute rolling average value, which is taken around the dust particle emission peak P1, would pose a risk that emission limit values of the authorities cannot be met.

[0036] It has been found, that the magnitude M of a dust particle emission peak P1, P2 is strongly dependent on the time that has elapsed since that rapping which immediately precedes the rapping which caused the dust particle emission peak P1, P2 in question. The magnitude M of the dust particle emission peak P2, which is depicted in Fig. 3, thus depends on the time t that has elapsed since the rapping R' which caused the dust particle emission peak P1. Thus, the magnitude M of the dust particle emission peak P2, which is caused by a rapping R" , depends on the time t, that has elapsed since the rapping R', which immediately precedes the rapping R". By "magnitude" is to be understood a measure defining the size of the dust particle emission peak P1, P2. In theory, the magnitude M of the dust particle emission peak P2 is that area which is covered by the peak P2. Each type of rapping has its own dust particle emission peak "fingerprint" as regards the way in which the dust particle emission rises and falls during the rapping. The "fingerprint" is determined by the mechanical behaviour of the rapping device 22, whether the current is applied or not during rapping, etc. In practice, it is often sufficiently accurate to approximate the magnitude M of a dust particle emission peak P2 by that height H which the dust particle emission peak P2 extends above a baseline dust particle emission B. The baseline dust particle emission B is that dust particle emission which is at hand between the peaks P1, P2, i.e., when there is no rapping in the last field 14.

[0037] Fig. 4 depicts, schematically, the relation between the magnitude H1, H2 of a dust particle emission peak P1, P2, P3, P4 and P5 caused by a rapping, and the corresponding time t1, t2 that has elapsed since the immediately preceding rapping. At first, rapping events are performed such that a time t1 elapses between each rapping event R1, R2, R3. The rapping events R1, R2, R3 causes dust particle emission peaks P1, P2, P3, respectively, each of which dust particle emission peaks P1, P2, P3 having a magnitude corresponding to a height H1. After a while, the time to elapse between each rapping event is increased to a time t2. Thus, the rapping event R4 and the rapping event R5 is each performed after a time t2 has elapsed since the immediately preceding rapping event. The rapping events R4 and R5 result in a dust particle emission peak P4, and a dust particle emission peak P5, respectively. The dust particle emission peaks P4 and P5 each has a height H2, which is much higher than the height H1 of the dust particle emission peaks P1-P3. Thus, it has been found that the magnitude, expressed as a height H1, H2, of a dust particle emission peak P1-P5, depends on the time t1, t2 that has elapsed since the rapping event immediately preceding that rapping event which causes the dust particle emission peak in question. Thus, the height H2 of the dust particle emission peak P4, which is caused by the rapping event R4, depends on the time t2 that has elapsed since the immediately preceding rapping event R3.

[0038] Fig. 5 depicts an example of a mathematical model, which is based on measurements of dust particle emission peak height H, and the corresponding time t, which has elapsed since the rapping event immediately preceding that rapping event which caused the dust particle emission peak in question. Three measurements have been done, which is depicted in Fig. 5. Each measurement has resulted in a data record including the height H of the dust particle emission peak, and the time t elapsed since the immediately preceding rapping event. Additionally, a fictional data record 0, which is located close to the zero point (in practice 1 % peak at 1 min), has been added. The fictional data record 0 is motivated by the fact that with a continuous rapping of the collecting electrode plates 18 no peaks would occur because there would be no collection of dust particles at such conditions.

Table 1: Data records of time elapsed since immediately preceding rapping and the corresponding peak.

Data record No.	Time elapsed since immediat. preceding rapping	Height of peak
	t (min)	H (%)
0	1	1
I	330	30
II	4300	37
III	11540	85

[0039] It has been found that the magnitude of a selected dust particle emission peak caused by a selected rapping is proportional to the logarithm, in particular the natural logarithm, of the time that has elapsed since the rapping immediately preceding the selected rapping causing the selected dust particle emission peak. Consequently, a curve fit was made between the values of Table 1 of Height of peak (H) and the natural logarithm of the time (t). The equation obtained was:

$$H(t) = 7.2 * \ln(t[min]) - 5.6 \quad [\%] \quad (eq.\ 1.1)$$

[0040] The equation 1.1 serves as the mathematical model, which describes the height H of a selected dust particle emission peak, e.g., a future dust particle emission peak, which will be caused by a selected rapping, e.g., a future rapping, that can be expected based on the time t, that will elapse between said selected rapping and the rapping immediately preceding said selected rapping.

[0041] Based on this mathematical model, and suitable conditions, such as a maximum allowed dust particle emission peak height, the control device 38 can determine when it is time to execute a rapping. If, for instance, the environmental regulations are such, that a dust particle emission peak must not exceed a height H of 50%, because then the limit for 6 minute rolling average value is at risk of being exceeded, the equation 1.1 can be solved for t:

$$t = e^{(H[\%] + 5.6)/7.2} \quad [min] \qquad (eq.\ 2.1)$$

[0042] By importing H = 50% into the equation 2.1 the following time t can be calculated:

$$t = e^{(50[\%] + 5.6)/7.2} \quad [min] = 2350 \ [min] \quad (eq.\ 2.2)$$

[0043] The control device 38 can instruct the rapping device 22 to execute a rapping when a time t of 2350 min, which has been determined by means of the mathematical model, has elapsed since the immediately preceding rapping.

[0044] The fact that a natural logarithm function is suitable for modelling said relation between a magnitude H of a selected dust particle emission peak caused by a selected rapping and the time t between said selected rapping and its immediately preceding rapping by means of an expression having the form of:

magnitude H proportional to ln(time t)

[0045] is motivated by the following physical background: The longer the time t since the immediately preceding rapping the more dust particles are accumulated on the collecting electrode plates 18. The more dust particles that are accumulated on the collecting electrode plates 18, the more dust particles will be released during the rapping. However, with increasing time since the immediately preceding rapping the dust particles will undergo increased agglomeration while on the collecting electrode plates 18. The agglomeration counteracts, to some extent, the increase in magnitude of the dust particle emission peak. The total effect is that a longer time t elapsed since the immediately preceding rapping will result in an increase in the magnitude of the dust particle emission peak, but the increase will be less than what would be described by a linear function due to the agglomeration of the dust particles on the collecting electrode plates. As alternatives to the natural logarithm function it is also possible, although sometimes less preferable, to utilize other logarithmic functions, and approximations of logarithmic functions. By approximations of logarithmic functions is meant, e.g., mathematical functions resembling logarithmic functions, trig-functions, piece-wise linear curve fits, etc.

[0046] Fig. 6a illustrates an example of how a height HF of a future dust particle emission peak PF, which is caused by a future rapping event RF, can be predicted from equation 1.1 based on a given time t that has elapsed since the immediately preceding rapping event R1.

[0047] Fig. 6b illustrates an example of how a time tF, that is to elapse from a rapping event R1 until a future rapping event RF is to be executed, can be predicted from equation 2.1 based on a given height H of a future dust particle emission peak PF.

[0048] The mathematical model according to equation 1.1 is based on only three data records, plus one fictional data record. It would also be possible to obtain a mathematical model from only one or two data records, plus the fictional data record. The mathematical model based on these few data records could be considered to be a "starting model". However, conditions change in the electrostatic precipitator 1, and, thus, the mathematical model may become unfit for the control of the rapping, if the mathematical model is not updated. In order to account for changing conditions, such as varying type of fuel combusted etc, and also for the purpose of improving the accuracy of the mathematical model when operating conditions are stable, the mathematical model is preferably updated with new data records as they are measured.

[0049] Fig. 7 is a flow diagram, which depicts the method according to which the control system 30 works. In a step A, the dust particle emission is measured after the last field 14. A peak P_N, which is related to a rapping event R_N of the last field 14, is identified. Any "peaks" that relate to calibration of the dust analyser, etc., are disregarded.

[0050] In a step B, the height H_N of the peak P_N is coupled to the time t_N, that has elapsed since the immediately preceding rapping event, i.e., the rapping event R_{N-1}, of the last field 14. The time t_N describes how long time, after the rapping event R_{N-1}, that the collecting electrode plates 18 of the last field 14 had been operating to collect dust particles, when the rapping event R_N was executed. The time t_N and the corresponding height H_N form a data record.

[0051] In a step C, a mathematical model is fitted to the data records. If step C is performed for the first time, a mathematical model is fitted to one, two or more data records that have been obtained since the start-up of the operation of the electrostatic precipitator 1. If, on the other hand, there is already a mathematical model available, that mathematical model is updated with the new data record comprising t_N and H_N.

[0052] In a step D, a time t_{N+1}, which is to elapse until a next rapping event R_{N+1} is to be executed, is controlled based on the mathematical model. Normally, some kind of condition is used for the control. An example of such a condition is, that the height H of a dust particle emission peak must not exceed a certain value Hmax. The height H_{N+1} is set to Hmax, and is imported into the mathematical model. Then, the time t_{N+1} is calculated, as has been described hereinbefore with reference to Fig. 5 and equation 2.1.

[0053] The sequence A, B, C, and D has a loop, such that when step D ends, N is set be N+1, and step A is started, which is depicted in Fig. 7. In this manner, each time a rapping event has been executed, a new data record, comprising the measured height H_N of the most recent dust particle emission peak, and the corresponding time t_N, is obtained. The new data record can be employed for to update the mathematical model, in order to make the mathematical model even better at predicting the dust particle emission peak height H as a function of the time t. Due to the loop, the mathematical model may, thus, be continuously updated, such that the mathematical model becomes better at predicting the dust particle emission peak height.

[0054] It will be appreciated that the conditions, under which the electrostatic precipitator 1 operates, may be the subject to changes during operation. Such changes include: changes in the properties of the dust particles that are collected on the collecting electrode plates 18, changes in the properties of the flue gas 4, physical changes inside the electrostatic precipitator 1, etc. In view of these possible changes, it is suitable to use a data filter when updating the mathematical model in step C. The data filter may, e.g., be set in such a manner, that the new data record is given a higher weight, when updating the mathematical model, than the old data records. A very simple way of obtaining a data filter function, is to include the new data record twice when performing the curve fit, that forms the basis of the mathematical model. The oldest data record could be discarded before performing said curve fit. Table 2 illustrates an example of how a new data record IV is included twice, as IV' and IV", while the oldest data record, data record I, is discarded, compared to the situation depicted in Table 1. The curve fit is then performed on the values of table 2.

Table 2: Data records after a new data record IV, taken twice as IV' and IV", has been included.

Data record No.	Time elapsed since immediat. preceding rapping	Height of peak
	T (min)	H (%)
0	1	1
II	4300	37
III	11540	85
IV'	2350	48
IV"	2350	48

[0055] Based on the values of Table 2, a new curve fit can be performed, and the following, updated, mathematical model can be obtained:

$$H(t) = 6.9*\ln(t) - 2.2 \quad \text{(eq. 1.2)}$$

[0056] When another data record V is available, that data record is taken twice as V' and V", while the data record IV is only taken once, and the data record II is discarded, before performing the curve fit, etc. While Table 2 illustrates a very simple way of filtering the data records, such that a new data record is given a larger influence on the updated mathematical model than an old data record, it will be appreciated that many different types of per se known data filters can be used. The skilled person can, by routine experimentation, find the setting for the data filter that for a certain electrostatic precipitator 1 provides a suitably quick updating to new operating conditions. It will be appreciated that many alternative data filters could be utilized. Preferably, a quality assessment is made such that reliable data records are given a higher influence on the updating of the mathematical model than less reliable data. The quality assessment could, for instance, give data records that have been obtained during detected process disturbances a lower weight.

[0057] Above it has been described how a mathematical model is updated each time a new data record becomes available. According to an alternative embodiment a bias term, or terms, is added to the mathematical model to allow for automatic adjustment, during continuous operation, of the utilized relation between a magnitude of a selected dust particle emission peak caused by a selected rapping and a time between said selected rapping and its immediately preceding rapping. Based on each new data record the bias term, rather than the core of the mathematical model as such, is updated. Thus, the mathematical model is updated via the bias term, and is thereby adjusted to the actual operating conditions without changing the fundamental relationship. The bias term shifts the mathematical model between a family of curves, but does not redefine the shape of the curves as such. The control could be implemented by utilizing an equation of the form:

$$H_{predicted}(t) = \ln(t) + bias_N \qquad \text{(eq. 3.1)}$$

[0058] The bias term is updated by an adjustment term which is calculated as the difference between the measured and the predicted magnitude of a dust particle emission peak:

$$bias_{adjust} = H_{measured}(t) - H_{predicted}(t) \qquad \text{(eq. 3.2)}$$

the bias term can now be updated by means of:

$$\text{bias}_{N+1} = \text{bias}_N + \text{bias}_{adjust} \qquad \text{(eq. 3.3)}$$

[0059] In practical operation the control of the rapping device 22 by means of utilizing a bias term, as described hereinbefore, could be implemented in a control block, which employs the derivative of the above mentioned mathematical model. In the control block, the slope of the fitted curve is used as starting bias. From equation 1.1 a slope of 7.2 can be derived, and can be used as a starting bias. The control block would perform the following operations:

[0060] Firstly, differences, Δ, are calculated for dust particle emission peak height, H, and time elapsed, t, based on the selected peak and the immediately preceding peak:

$$\Delta H = H_N - H_{N-1} \qquad \text{(eq. 3.4)}$$

$$\Delta t = t_N - t_{N-1} \qquad \text{(eq. 3.5)}$$

[0061] Then the required change in peak height, in order to reach the desired peak height $H_{desired}$, is calculated:

$$\Delta H_{required} = H_{desired} - H_N \qquad \text{(eq. 3.6)}$$

[0062] Then, if Δt is not zero, a bias_{new} is calculated:

$$\text{bias}_{new} = \Delta H / \Delta t \qquad \text{(eq. 3.7)}$$

[0063] Now the bias can be updated:

$$\text{bias}_{N+1} = \text{bias}_N * \text{biasfilter} + \text{bias}_{new} * (1-\text{biasfilter}) \qquad \text{(eq. 3.8)}$$

[0064] The required change in elapsed time can then be calculated:

$$\Delta t_{required} = \Delta H_{required} / \text{bias}_{N+1} \qquad \text{(eq. 3.9)}$$

[0065] The point in time t_{N+1} for the next scheduled rapping event may then be calculated from the mathematical model as:

$$t_{N+1} = t_N + e^{(\Delta t_{required})} \qquad \text{(eq. 3.10)}$$

[0066] Finally, N = N+1, and the procedure is started again with a new data record.

[0067] The biasfilter is a factor, that is set to, typically, a value in the range of 0.2-0.8, depending on how quick adaption to changing conditions that is preferable. The biasfilter factor accounts for measurement errors, unexpected upsets in the measured values etc.

[0068] Fig. 8 illustrates the effects of different types of rapping. It has been described hereinbefore, that the rapping could be performed in different manners. For instance, rapping could be performed by means of operating the first hammer 24 and the second hammer 26 simultaneously, or by means of operating only one of the hammers 24, 26. In Fig. 8, RA denotes rapping with only the first hammer 24. Each rapping RA results in a dust particle emission peak P1, P2 and P3, which has a height H1. However, rapping with only hammer 24 may result in that the collecting electrode plates 18 are not sufficiently cleaned. Therefore a rapping RB, in which both hammers 24, 26 are operated, is performed with certain intervals. When the first rapping of the RB type is performed, that rapping RB results in a very high dust particle emission peak P4, which has a height H4, due to the fact that some dust particles, that have become accumulated on the collecting electrode plates 18 during the RA type rapping, are released. When a second rapping of the RB type is performed, that rapping is performed on collecting electrode plates 18 on which there is no accumulated dust, and therefore the height H5 of the dust particle emission peak P5 is lower than the height H4 of the dust particle emission peak P4. It is obvious from Fig. 8 that the time elapsed between each rapping is constant, at a time t1. The peaks P1, P2, P3, that are obtained by rapping by means of the RA rapping type, are different from the peaks P4, P5, that are obtained by rapping by means of the RB rapping type. Further, the dust particle emission peak P4, which is obtained when a rapping of the RB rapping type is performed directly after a rapping of the RA rapping type, is higher than the dust particle emission peak P5, which is obtained when a rapping of the RB rapping type is performed directly after another rapping of the RB rapping type. In order to account for this behaviour, it is preferable to employ a specific mathematical model for each type of rapping, such that the dust particle emission peak height can be accurately predicted for each type of rapping. By the example depicted in Fig. 8 it would, thus, be preferable to employ one mathematical model for each rapping of the RA type of rapping, and another mathematical model for each rapping of the RB type of rapping. If an electrostatic precipitator 1 is designed for employing rapping of more than one type, e.g., rapping from both sides of the collecting electrode plates 18 and rapping from only one side of the collecting electrode plates 18, then it is preferable that the method and the control system 30 are adapted for selecting the proper mathematical model, with respect to the type of rapping that is to be executed, and for applying that mathematical model when calculating the time to elapse until a next rapping of that specific type is performed. Each data record, which comprises information on dust particle emission peak height H, and elapsed time t, could, additionally, be provided with a first label R, which indicates what type of rapping that was performed. This first label R is employed in order to ensure, that the relevant mathematical model is updated, i.e., the mathematical model corresponding to that particular type of rapping. Thus, a data record describing the dust particle emission peak P4 preferably comprises the height H4, the time t1, and, as the first label, the rapping type RB. This data record is utilized for to update that mathematical model which corresponds to the RB type of rapping.

[0069] Furthermore, each mathematical model is, preferably, also adjusted to account for the rapping history, i.e., the type of rapping that has preceded the rapping in question. Such an adjustment is, preferably, made in such a manner that the mathematical model accounts for the fact that the first rapping of the RB type of rapping, which results in the dust particle emission peak P4, is preceded by a rapping of the RA type of rapping, while the second rapping of the RB type of rapping, which results in the dust particle emission peak P5, is preceded by a rapping of the RB type of rapping. In order to make it possible to account for historical information, each data record is, preferably, provided with a second label. The second label indicates what type of rapping was performed at the immediately preceding rapping event, or, optionally, at several preceding rapping events. There are different manners in which the historical information on the type of rapping can be accounted for. One way is to employ a specific mathematical model for each combination of a type of rapping that is to be performed and a type of rapping that has been executed before the rapping that is to be performed. In such a case, referring to Fig. 8, one mathematical model would be utilized for a rapping of the RB type of rapping when preceded by a rapping of the RA type of rapping, and another mathematical model would be utilized for a rapping of the RB type of rapping when preceded by another rapping of the RB type of rapping.

[0070] It is also possible to use some kind of compensation factor, which accounts for the type of rapping that was performed in the preceding rapping. For example, the dust particle emission peak height, which is calculated by means of the mathematical model corresponding to an RB type of rapping, can be increased by, e.g., 5% in the case the preceding rapping event was a rapping of the RA type of rapping, and could be decreased by, e.g., 5% in the case the preceding rapping was a rapping of the RB type of rapping. Thus, a data record describing the dust particle emission peak P4 would, preferably, comprise the dust particle emission height H4, the elapsed time t1, the rapping of the RB type of rapping, as the first label, and, as the second label, the fact that a rapping of the RA type of rapping preceded that rapping which caused the peak P4. This data record is employed to update that mathematical model which corresponds to a rapping of the RB type of rapping, and to compensate for the fact that a rapping of the RA type of rapping preceded the rapping of the RB type of rapping.

[0071] The conditions, under which the control device 38 controls the rapping, can be set in accordance with the emission standards that are in use in the country in question. The emission limit for dust particles after the last field 14 could, for example, be 10 mg/Nm^3 dry gas as a 6 minute rolling average, or as a one day rolling average. Thus, there is normally a preset rolling average limit value with respect to which the rapping needs to be controlled. For instance, the actual rolling average value, when employing an opacity meter, could be calculated as:

$$rolling\_average = \sum_{i=1}^{n} \frac{opacity_i}{n} \qquad \text{(eq. 4.1)}$$

where n is the number of sampling points during the rolling average period, e.g., during 6 minutes, or during a day. Based on knowledge of the measured baseline dust particle emission, i.e., the dust particle emission between two rapping events, it is possible to simulate which rolling average would result if a dust particle emission peak, which is caused by a rapping, would occur during a 6 minute, or a one day, period. Based on this simulation, the maximum allowed dust particle emission peak magnitude, e.g., the maximum dust particle emission peak height, could be determined. Such maximum dust particle emission peak height is entered as an input to the control device 38, such that the control device 38 can control the rapping of the last field 14 of the electrostatic precipitator 1, based on the mathematical model, in such a manner that a dust particle emission peak, which exceeds the maximum dust particle emission peak height, is avoided. Thus, what is meant is that the control device 38 controls the rapping by controlling the time to elapse between a rapping and a future rapping, and/or the type of rapping that should be performed.

[0072] Fig. 9 illustrates an electrostatic precipitator 101 in accordance with an alternative embodiment. The design of the electrostatic precipitator 101 is similar to that of the electrostatic precipitator 1 which has been described hereinbefore. A control system 130 comprises a calculating device 136, and a rapping control device 138, which is operative for initiating rapping in a last field 114 of the electrostatic precipitator 101. The rapping control device 138 controls the current situation, i.e., whether a power source 120 does or does not apply a current between the electrodes, not shown in Fig. 9, of the last field 114 during the rapping. Furthermore, the rapping control device 138 also controls a rapping device 122 and thus controls if and how a first motor 142, which operates a first set of hammers, not shown in Fig. 9, should be operated, and if and how a second motor 144, which operates a second set of hammers, not shown in Fig. 9, should be operated.

[0073] The calculating device has the form of a PID-controller 136 and is operative for determining when the rapping control device 138 should initiate a rapping in the last field 114. The PID-controller 136 receives information from a dust particle concentration analyser 140. The dust particle analyser 140, which could, e.g., be an opacity meter, analyses, on a continuous or periodic basis, the concentration of dust particles in the cleaned flue gas 8, that has passed the last field 114. Information concerning the measured opacity, i.e., the measured magnitude of a dust particle emission peak caused by a rapping in the last field 114, is sent from the dust particle analyser 140 to the PID-controller 136, which compares said measured magnitude to a dust particle emission peak magnitude target value. The PID-controller 136 accordingly adjusts, if necessary, the time that is to elapse until the rapping control device 138 is instructed to execute another rapping of the collecting electrode plates of the last field 114. The PID-controller 136 thus utilizes the fact that there is a relation between a magnitude of a selected dust particle emission peak caused by a selected rapping and a time between said selected rapping and its immediately preceding rapping for the purpose of automatically chasing that elapsed time t that will result in a magnitude of a dust particle emission peak that is as close as possible to the dust particle emission peak magnitude target value. Thus, the PID-controller 136 provides for an automatic control of when rapping should be executed in order to obtain a desired magnitude of the dust particle emission peak. It will be appreciated that the PID-controller 136 utilizes the fact that there is a relation between the magnitude of a selected dust particle emission peak caused by a selected rapping and a time (t) between said selected rapping and its immediately preceding rapping, without utilizing an actual mathematical model that represents the relation. Thus, the PID-controller can be said to operate according to a model-free algorithm. Alternative controller types, including the PI-controller, and the model-free adaptive controller, can also be utilized for controlling the rapping of the last field, and also operate according to a model-free algorithm. More advanced controllers could have the further function of controlling which type of rapping that should be executed by the rapping control device 138, either in combination with controlling the time until a rapping is executed, or instead of controlling the time until a rapping is executed.

[0074] It will be appreciated that numerous variants of the above described embodiments are possible within the scope of the appended claims.

[0075] For instance, it has been described above that the control system 30 could utilize the mathematical model for the determination of the peak height which is to be expected after a certain time has elapsed since the immediately preceding rapping, or for the determination of the time that is to elapse in order to obtain a dust particle emission peak of a certain height. It will be appreciated that other control strategies can also be employed. For example, it is possible to adapt the control device 38 to make iterative calculations for to obtain a sequence of times to elapse and types of rapping to be employed, which sequence provides for low dust particle emissions. The sequence may, as example, be similar to the sequence which is depicted in Fig. 8.

[0076] It has been described hereinbefore, that the rapping is executed by means of hammers 24, 26. It is also possible to execute the rapping with other types of rappers, for instance with so called magnetic impulse gravity impact rappers, also known as MIGI-rappers. A further possibility is to employ only one set of hammers, for example only the hammers 24, thereby rapping only one side of the collecting electrode plates 18.

[0077] Hereinbefore it has been described, that the mathematical model employs a relation in which the height of a dust particle emission peak is proportional to the logarithm, in particular the natural logarithm, of the time elapsed since the immediately preceding rapping. It will be appreciated that other types of mathematical models can be employed. For instance, it may in some cases be accurate enough to fit a linear model, or an exponential model, to the data records, in particular if the data records and the relevant operating range refer to a rather narrow range as regards the time elapsed since the immediately preceding rapping.

[0078] Hereinbefore it has been described that the height H of a dust particle emission peak is often a good approximation of the magnitude of the dust particle emission peak. As alternative to peak height H, the magnitude of a dust particle emission peak may also be represented by other quantities, such as the area of the dust particle emission peak, etc.

[0079] It has been described hereinbefore, that a separate mathematical model is preferably employed for predicting the peak heights of each type of rapping. It will be appreciated that some types of rapping could use the same mathematical model, if it is found that the peak height is similar for those types. For instance, if it is found that rapping with only the first set of hammers 24 provides a similar peak height as rapping with only the second set of hammers 26, then these two types of rapping could utilize the same mathematical model.

[0080] As described hereinbefore, it is often preferable to control the time to elapse until a rapping is to be executed in the last field 14. It is also possible, however, to operate with fixed times for executing a rapping, for instance to execute rapping once or twice per day at fixed hours. In such a case, the control system 30 can, based on mathematical models for different types of rapping, control which type of rapping that is to be executed in order to avoid large dust particle emission peaks, and to still manage to avoid having dust accumulating on the collecting electrode plates 18 over time. As described hereinbefore, it is often preferable to have the control system 30 control both the time to elapse until a rapping is to be executed, and the type of rapping to be executed.

[0081] While it has been described hereinbefore that the control system 30 and the method are utilized for controlling when and/or how a rapping is to be executed, it is also possible to utilize the control system 30 and/or the method for predicting the magnitude of a dust particle emission peak at a certain elapsed time, or for predicting the time until a dust particle emission peak of a certain magnitude is obtained. Such information can be utilized in the development and design of electrostatic precipitators, and in the commissioning of electrostatic precipitators.

[0082] It has been described hereinbefore that one option of updating the mathematical model is to update the model with new measured data records, and to give more recent data records a larger weight than older data records. It will be appreciated that there are other ways of updating the model. One possibility is to collect data records in one or more "buckets". From such a "bucket" data records are picked up for updating the mathematical model. It would, e.g., be possible to utilize one "bucket" for full-load conditions, one "bucket" for half-load conditions, and one "bucket" for low load conditions. If, for instance, the model is to be updated to fit with half load conditions, then data records relating to half load conditions, or close to half load conditions, can be collected from the "bucket" containing such data and be used for updating the mathematical model, such that it will provide a relevant basis for controlling the rapping at half load conditions. Thus, the "bucket" comprises a source, or "bank" of data records, such that suitable data records can be picked up for preparing or updating a relevant mathematical model with respect to the present operating conditions. New data records are placed in the relevant "bucket", and may replace old data records of that same "bucket". The use of "buckets", that may of course relate to other operating conditions than just load, increases the accuracy of the model, since the model is updated using the data records from the relevant "bucket", the model thus not being biased by a large number of data records relating to another type of operating conditions.

[0083] It has been described hereinbefore that the control system 30 can be utilized for controlling the rapping of the last field 14 of an electrostatic precipitator 1, and/or for predicting the dust particle emission from an electrostatic precipitator 1. Such a control system 30 could be a separate control system, or could be integrated in the overall process computer controlling the operation of the entire combustion plant. A further option, which may be very attractive, in particular when predicting the emission of dust particles, is to use a pocket calculator, a laptop computer, or a Personal Digital Assistant (PDA) as the control system. In such a case the mathematical model is simply programmed into the device in question, thus using the micro processor of that device as the data processor 34, which device can then be used as a hand-held tool for making predictions of dust particle emissions from the electrostatic precipitator.

Claims

1. A method of controlling the dust particle emission from an electrostatic precipitator (1) having a last field (14), the last field (14) being provided with discharge electrodes (16), collecting electrodes (18), and a rapping device (22), which is adapted for cleaning the collecting electrodes (18) by means of rapping them,
characterised in the steps of

i) utilizing a relation between a magnitude (H) of a selected dust particle emission peak caused by a selected rapping and a time (t) between said selected rapping and its immediately preceding rapping, and
ii) adjusting, based on said relation, at least one parameter chosen from the group of: the time (t) to elapse until a rapping is to be executed in the last field (14), and the type of rapping to be executed in the last field (14).

2. A method according to claim 1, said step ii) further comprising
calculating rolling average values, each corresponding to the average dust particle emission during a preset period, and
adjusting, based on said relation, the rapping of the collecting electrodes (18) of the last field (14) with respect to a preset rolling average limit value.

3. A method according to any one of claims 1-2, wherein, in said step i), the type of rapping to be employed is identified, and a rapping type specific model is selected for being utilized in step i), such selected rapping type specific model being a model of the relation between a magnitude (H) of a selected dust particle emission peak caused by a selected rapping and the time (t) between said selected rapping of that specific type of rapping, which has been identified, and its immediately preceding rapping.

4. A method according to any one of claims 1-3, wherein, in said step i), the type of rapping executed prior to said selected rapping is identified and accounted for when utilizing said relation between a magnitude (H) of a selected dust particle emission peak caused by a selected rapping and a time (t) between said selected rapping and its immediately preceding rapping, the type of which has been identified.

5. A method according to any one of claims 1-4, wherein said relation between a magnitude (H) of a selected dust particle emission peak caused by a selected rapping and the time (t) between said selected rapping and its immediately preceding rapping is represented by:

magnitude (H) $\propto$ function(time (t)),

wherein said function is chosen among:

logarithmic functions, and
approximations of logarithmic functions,
preferably said function is a natural logarithmic function.

6. A method according to any one of claims 1-5, wherein a mathematical model of a relation between a magnitude (H) of a selected dust particle emission peak caused by a selected rapping and the time (t) between said selected rapping and its immediately preceding rapping is obtained by the steps of

A) measuring the dust particle emission after the last field (14) for identifying dust particle emission peaks (P2; P4) relating to rapping (R2; R4) of at least one collecting electrode (18) of the last field (14),
B) coupling the measured magnitude (H1; H2) of each of said dust particle emission peaks (P2; P4) with the corresponding time (t1; t2) elapsed since the immediately preceding rapping (R1; R3) of said at least one collecting electrode (18) of the last field (14) in order to form data records, each such data record comprising the magnitude (H1; H2) of the dust particle emission peak (P2; P4) and the corresponding time (t1; t2) elapsed

since said immediately preceding rapping (R1; R3), and
C) preparing, based on said data records, said model of a relation between a magnitude (H) of a selected dust particle emission peak caused by a selected rapping and the time (t) between said selected rapping and its immediately preceding rapping.

7. A method according to claim 6, said step B) further comprising including in each data record a first label indicating the type of rapping employed when obtaining the dust particle emission peak (P4) in question, said step C) further comprising preparing a rapping type specific model for each type of rapping in accordance with said first label.

8. A method according to claim 7, said step B) further comprising including in each data record a second label comprising historical information on the specific type of rapping executed before the rapping to which the magnitude, time and first label of the data record relate, said step C) further comprising accounting for said historical information in each said rapping type specific model.

9. A method according to any one of claims 1-8, wherein a mathematical model of a relation between a magnitude (H) of a selected dust particle emission peak caused by a selected rapping and the time (t) between said selected rapping and its immediately preceding rapping is updated by the steps of

D) measuring the dust particle emission after the last field (14) for identifying a dust particle emission peak (P5) relating to a rapping (R5) of at least one collecting electrode (18) of the last field (14),
E) coupling the measured magnitude (H2) of said dust particle emission peak (P5) with the corresponding time (t2) elapsed since the immediately preceding rapping (R4) of said at least one collecting electrode (18) of the last field (14) in order to form a data record, such data record comprising the magnitude (H2) of the dust particle emission peak (P5) and the corresponding time (t2) elapsed since the immediately preceding rapping (R4), and
F) updating, based on said data record, said mathematical model of a relation between a magnitude (H) of a selected dust particle emission peak caused by a selected rapping and the time (t) between said selected rapping and its immediately preceding rapping.

10. A method according to claim 9, said step E) further comprising including in each data record a first label indicating the type of rapping employed when obtaining the dust particle emission peak in question, said step F) further comprising updating a rapping type specific mathematical model corresponding to the type of rapping represented by said first label.

11. A method according to claim 10, said step E) further comprising including in each data record a second label comprising historical information on the specific type of rapping executed before the rapping to which the magnitude, time and first label of the data record relate, said step F) further comprising accounting for said historical information when updating said mathematical model of a relation between a magnitude (H) of a selected dust particle emission peak caused by a selected rapping and the time (t) between said selected rapping and its immediately preceding rapping.

12. A method according to any one of claims 9-11, wherein during step F) a data filter is used while updating the mathematical model.

13. A method according to claim 1, wherein said step of adjusting, based on said relation, at least one parameter chosen from the group of: the time (t) to elapse until a rapping is to be executed in the last field (14), and the type of rapping to be executed in the last field (14), is performed by means of:

measuring the magnitude of a dust particle emission peak which is caused by rapping of at least one of said collecting electrodes (18) of the last field (14),
sending information about the measured magnitude of the dust particle emission peak to a calculating device (136),
said calculating device (136) comparing said measured magnitude of the dust particle emission peak to a dust particle emission peak magnitude target value, and
automatically adjusting, by means of said calculating device (136), at least one parameter chosen from the group of: the time (t) to elapse until a subsequent rapping is to be executed in the last field (14), and the type of subsequent rapping to be executed in the last field (14), for the purpose of minimizing the difference between said dust particle emission peak magnitude target value and the measured magnitude of a subsequent dust particle emission peak caused by the subsequent rapping of at least one of said collecting electrodes (18) of

the last field (14).

14. A method according to claim 13, wherein said calculating device (136) comprises a controller which operates according to a model-free algorithm, such as a PI-controller, a PID-controller, or a model-free adaptive controller.

15. A method of predicting the emission of dust particles during the rapping of at least one collecting electrode (18) of a last field (14) of an electrostatic precipitator (1), the last field (14) being provided with discharge electrodes (16), collecting electrodes (18), and a rapping device (22), which is adapted for cleaning the collecting electrodes (18) by means of rapping them, **characterised by** the steps of
utilizing a relation between a magnitude (H) of a selected dust particle emission peak caused by a selected rapping and the time (t) between said selected rapping and its immediately preceding rapping, and
predicting, based on said relation between a magnitude (H) of a selected dust particle emission peak caused by a selected rapping and the time (t) between said selected rapping and its immediately preceding rapping, a parameter which is chosen among:

1) the magnitude (HF) of the dust particle emission peak (PF) caused by a selected rapping, based on a time (t) to elapse between said selected rapping and its immediately preceding rapping, and
2) the time (tF) to elapse between a selected rapping and its immediately preceding rapping, based on the magnitude (H) of a dust particle emission peak (PF) caused by said selected rapping.

16. A method according to claim 15, wherein said relation between a magnitude (H) of a selected dust particle emission peak caused by a selected rapping and the time (t) between said selected rapping and its immediately preceding rapping is represented by:

magnitude (H) $\propto$ function(time (t)),

wherein said function is chosen among:

logarithmic functions, and
approximations of logarithmic functions,
preferably said function is a natural logarithmic function.

17. A method according to claim 15 or 16, wherein a mathematical model, which is an approximation of said relation between a magnitude (H) of a selected dust particle emission peak caused by a selected rapping and the time (t) between said selected rapping and its immediately preceding rapping, is utilized in predicting said parameter.

18. A method according to any one of claims 15-17, wherein a mathematical model is obtained by the steps of

A) measuring the dust particle emission after the last field (14) for identifying dust particle emission peaks (P2; P4) relating to rapping (R2; R4) of said at least one collecting electrode (18) of the last field (14),
B) coupling the measured magnitude (H1; H2) of each of said dust particle emission peaks (P2; P4) with the corresponding time (t1; t2) elapsed since the immediately preceding rapping (R1; R3) of said at least one collecting electrode (18) of the last field (14) in order to form data records, each such data record comprising the magnitude (H1; H2) of the peak (P2; P4) and the corresponding time (t1; t2) elapsed since the immediately preceding rapping (R1; R3), and
C) preparing, based on said data records, said mathematical model of a relation between a magnitude (H) of a selected dust particle emission peak caused by a selected rapping and the time (t) between said selected rapping and its immediately preceding rapping.

19. A method according to any one of claims 15-18, wherein a mathematical model of said relation between a magnitude (H) of a selected dust particle emission peak caused by a selected rapping and the time (t) between said selected rapping and its immediately preceding rapping is updated by the steps of

D) measuring the dust particle emission after the last field (14) for identifying a dust particle emission peak (P5) relating to a rapping (R5) of the collecting electrodes (18) of the last field (14),
E) coupling the measured magnitude (H2) of said dust particle emission peak (P5) with the corresponding time (t2) elapsed since the immediately preceding rapping (R4) of said at least one collecting electrode (18) of the last field (14) in order to form a data record, such data record comprising the magnitude (H2) of the peak (P5)

and the corresponding time (t2) elapsed since the immediately preceding rapping (R4), and
F) updating, based on said data record, said mathematical model of a relation between a magnitude (H) of a selected dust particle emission peak caused by a selected rapping and the time (t) between said selected rapping and its immediately preceding rapping.

20. A control system for controlling the dust particle emission from an electrostatic precipitator (1) having a last field (14) being provided with discharge electrodes (16), collecting electrodes (18) and a rapping device (22), which is adapted for cleaning the collecting electrodes (18) by means of rapping them,
characterised in that the control system (30) comprises
a control device (38; 138), which is operative for adjusting, based on a relation between a magnitude (H) of a selected dust particle emission peak caused by a selected rapping and the time (t) between said selected rapping and its immediately preceding rapping, at least one parameter chosen from the group of: the time (t) to elapse until a rapping is to be executed in the last field (14), and the type of rapping to be executed in the last field (14).

21. A control system according to claim 20, wherein the control device (38) is operative for utilizing a mathematical model, which is an approximation of said relation between a magnitude (H) of a selected dust particle emission peak caused by a selected rapping and the time (t) between the immediately preceding rapping and said selected rapping, when controlling said parameter.

22. A control system according to claim 21, wherein the control system (30) further comprises
a data receiver (32), which is operative for receiving measurement data relating to the dust particle emission after the last field (14) and for identifying, in said measurement data, a dust particle emission peak (P5) relating to rapping (R5) of said at least one collecting electrode (18) of the last field (14),
a data processor (34), which is operative for coupling the measured magnitude (H2) of said dust particle emission peak (P5) with the corresponding time (t2) elapsed since the immediately preceding rapping (R4) of said at least one collecting electrode (18) of the last field (14) in order to form a data record, such data record comprising the magnitude (H2) of the peak (P5) and the corresponding time (t2) elapsed since the immediately preceding rapping (R4), and
a calculating device (36), which is operative for updating, based on said data record, said mathematical model, which is an approximation of said relation between a magnitude (H) of a selected dust particle emission peak caused by a selected rapping and the time (t) between said selected rapping and its immediately preceding rapping.

23. A control system according to any one of claims 20 to 22, wherein said relation between a magnitude (H) of a selected dust particle emission peak caused by a selected rapping and the time (t) between said selected rapping and its immediately preceding rapping is represented by:

magnitude (H) $\propto$ function(time (t)),

wherein said function is chosen among:

logarithmic functions, and
approximations of logarithmic functions,
preferably said function is a natural logarithmic function.

24. A control system according to any one of claims 20 to 23, wherein the control device (38) is operative for the purpose of adjusting both the type of rapping to be executed and the time to elapse until a rapping is to be executed.

25. A control system according to claim 20, wherein a calculating device (136) is operative for receiving measurement data relating to the measured magnitude of a dust particle emission peak which is caused by rapping of at least one of said collecting electrodes (18) of the last field (14), said calculating device (136) further being adapted for comparing said measured magnitude of the dust particle emission peak to a dust particle emission peak magnitude target value, and for automatically inducing adjustment, by means of said control device (138), of at least one parameter chosen from the group of: the time (t) to elapse until a subsequent rapping is to be executed in the last field (14), and the type of subsequent rapping to be executed in the last field (14), for the purpose of minimizing the difference between said dust particle emission peak magnitude target value and the measured magnitude of a subsequent dust particle emission peak caused by the subsequent rapping of said at least one of said collecting electrodes (18) of the last field (14).

26. A control system for predicting the dust particle emission from an electrostatic precipitator (1) having a last field (14) being provided with discharge electrodes (16), collecting electrodes (18), and a rapping device (22), which is adapted for cleaning the collecting electrodes (18) by means of rapping them,
characterised in that the control system (30) comprises
a data processor (34), which is operative for utilizing a relation between a magnitude (H) of a selected dust particle emission peak caused by a selected rapping and the time (t) between said selected rapping and its immediately preceding rapping, the data processor (34) further being operative for predicting, based on said relation between a magnitude (H) of a dust particle emission peak caused by a selected rapping and the time (t) between said selected rapping and its immediately preceding rapping, a parameter which is chosen among

1) the magnitude (HF) of the dust particle emission peak (PF) caused by a selected rapping, based on a time (t) to elapse between said selected rapping and its immediately preceding rapping, and
2) the time (tF) to elapse between a selected rapping and its immediately preceding rapping, based on the magnitude (H) of a dust particle emission peak (PF) caused by said selected rapping.

27. A control system according to claim 26, wherein the control device (38) is operative for utilizing a mathematical model, which is an approximation of said relation between a magnitude (H) of a selected dust particle emission peak caused by a selected rapping and the time (t) between said selected rapping and its immediately preceding rapping, when predicting said parameter.

28. A control system according to claim 27, wherein said control system further comprises
a data receiver (32), which is operative for identifying dust particle emission peaks (P5) relating to rapping (R5) of at least one of said collecting electrodes (18) of the last field (14) and for coupling the measured magnitude (H2) of each of said dust particle emission peaks (P5) with the corresponding time (t2) elapsed since the immediately preceding rapping (R4) of said at least one of said collecting electrodes (18) of the last field (14) in order to form a data record, each such data record comprising the magnitude (H2) of the peak (P5) and the corresponding time (t2) elapsed since the immediately preceding rapping (R4),
said data processor (34) further being operative for updating, based on said data record, said mathematical model.

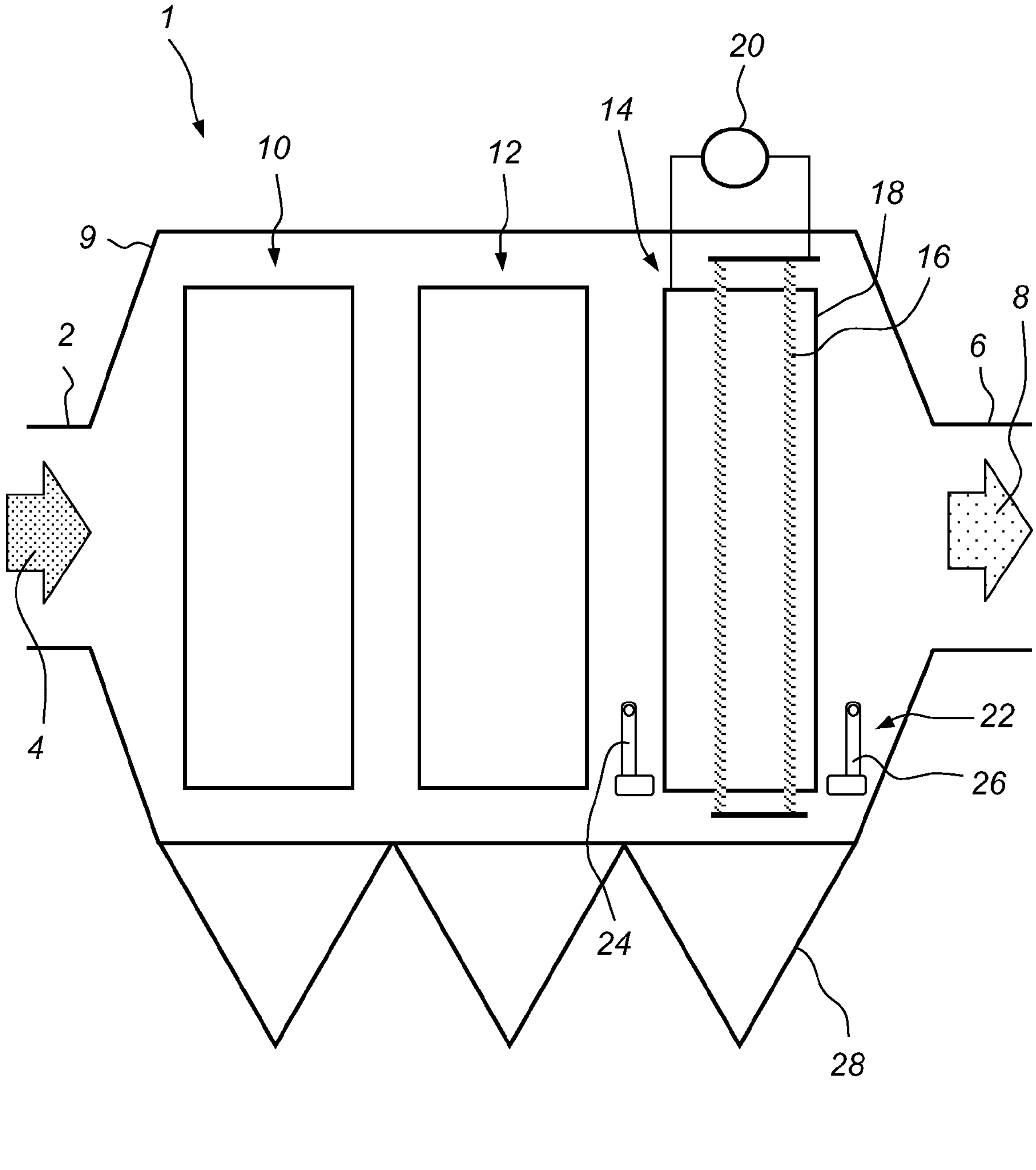

Fig. 1

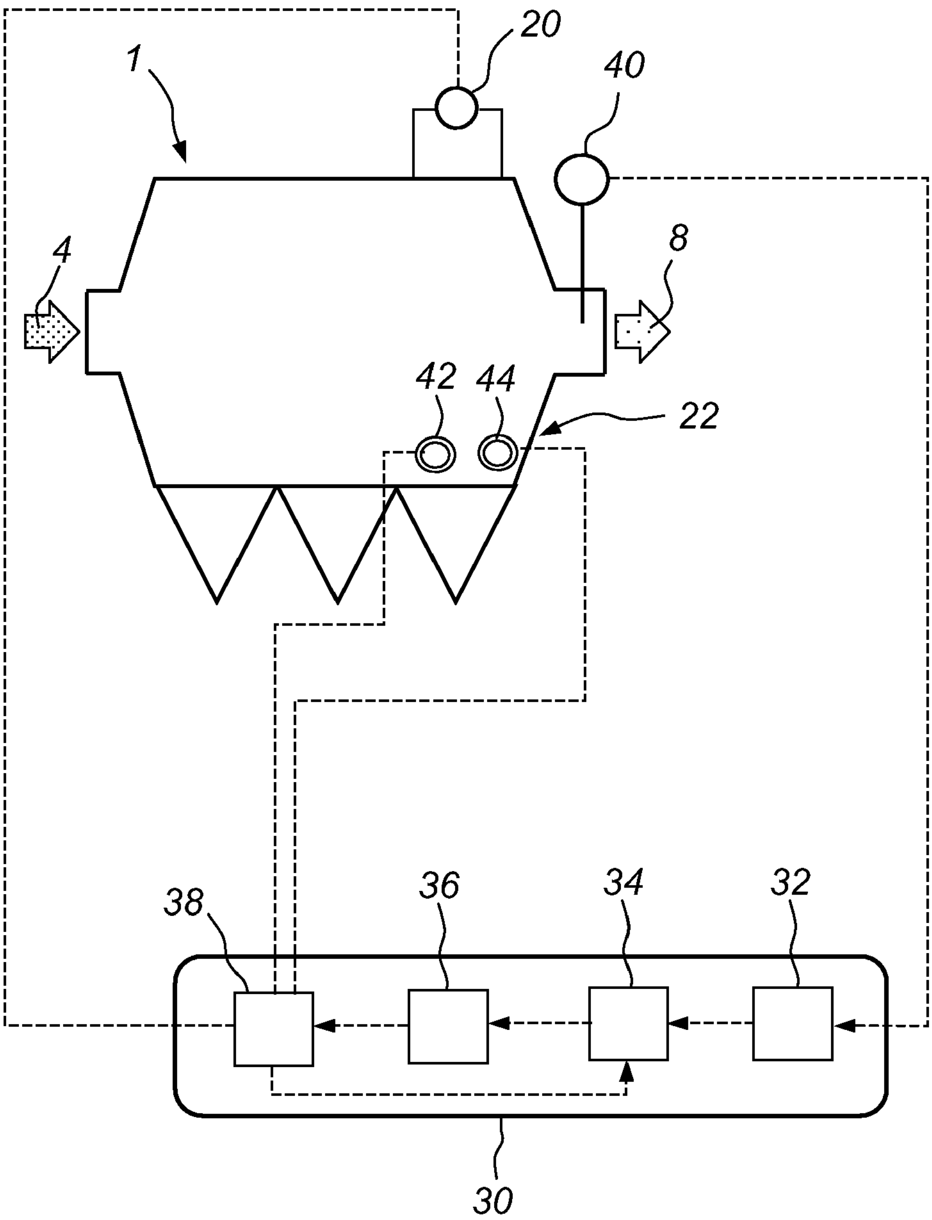

Fig. 2

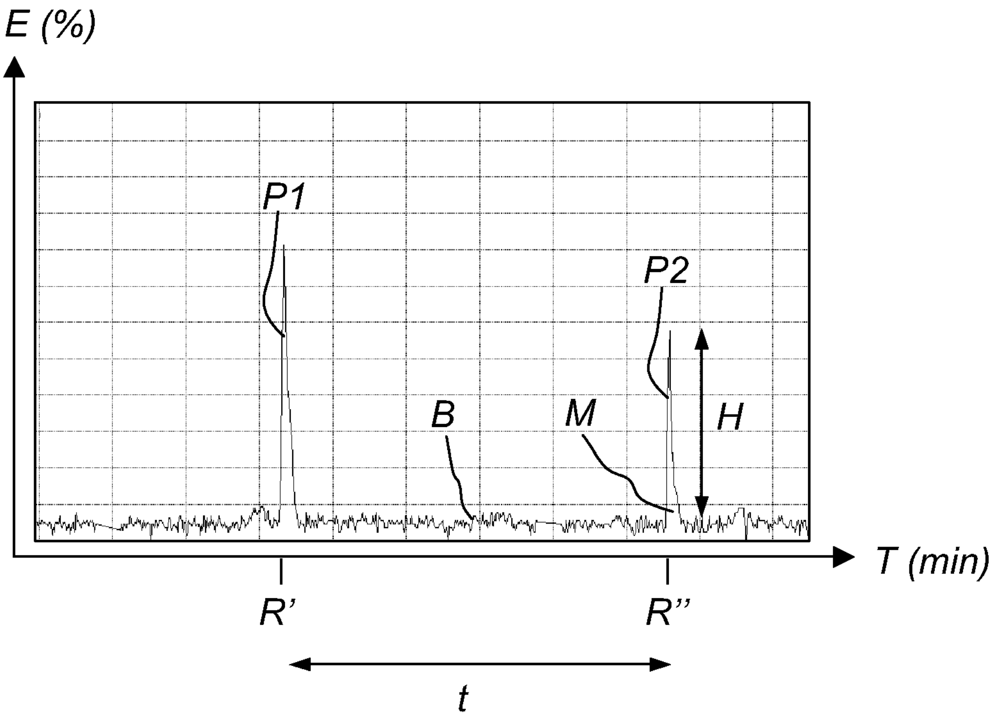
E (%)
P1
P2
B
M
H
T (min)
R'
R''
t

Fig. 3

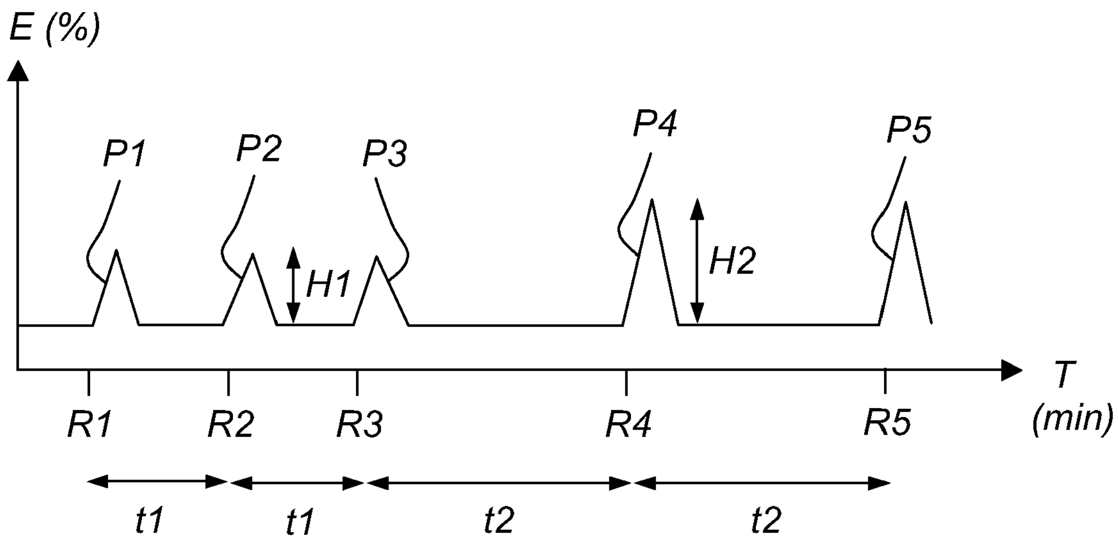
E (%)
P1
P2
P3
P4
P5
H1
H2
T (min)
R1
R2
R3
R4
R5
t1
t1
t2
t2

Fig. 4

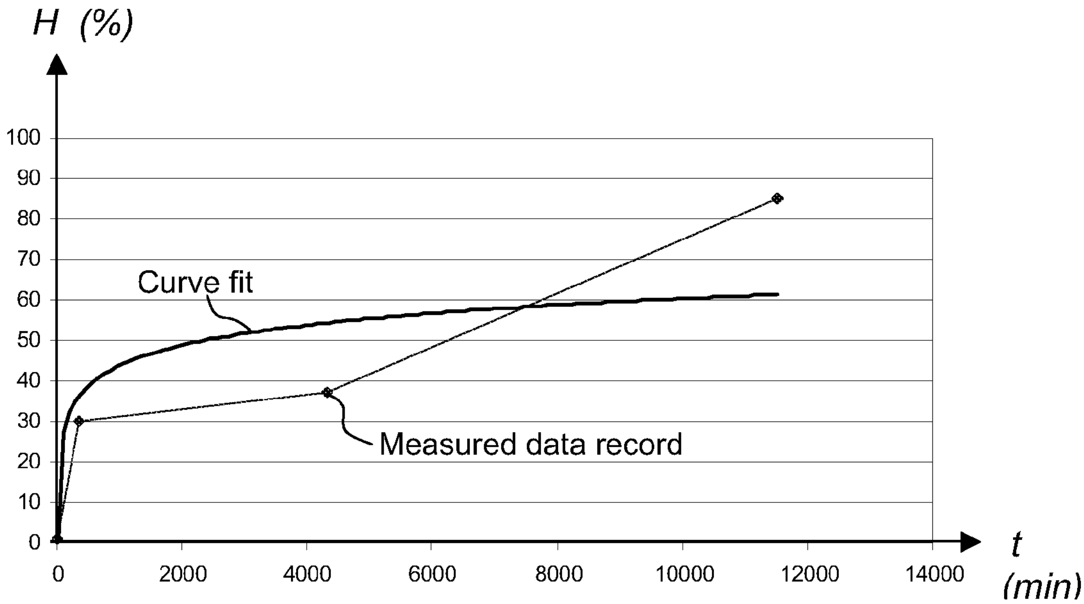

Fig. 5

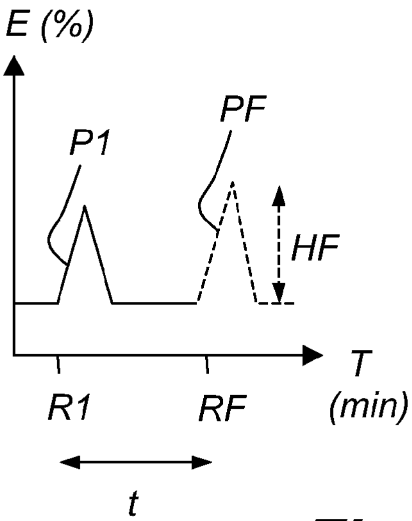

Fig. 6a

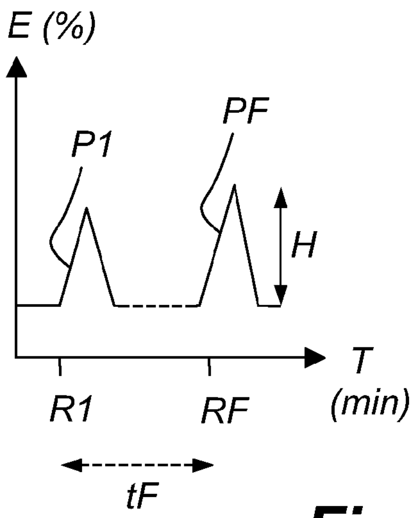

Fig. 6b

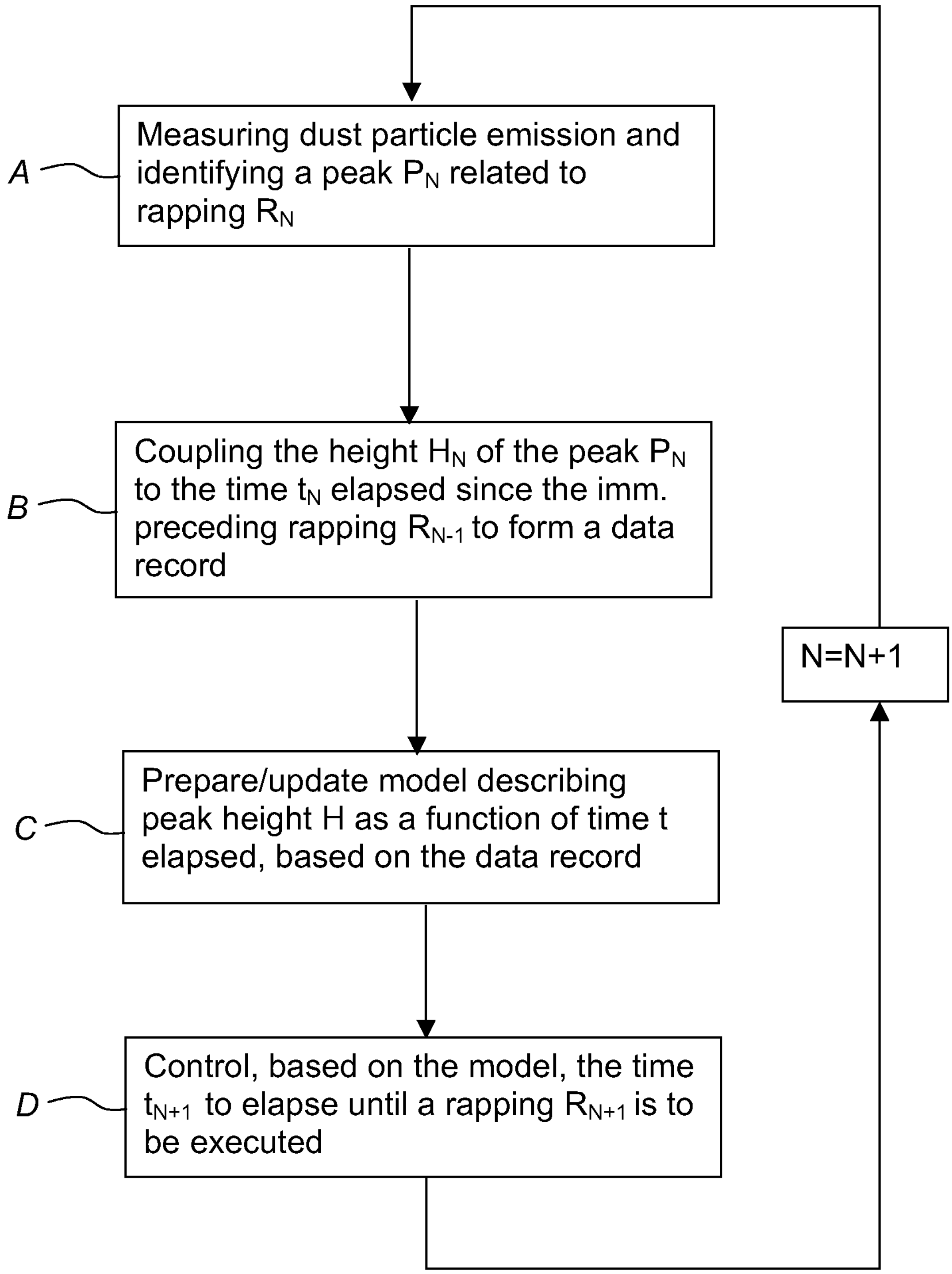
A
Measuring dust particle emission and identifying a peak P_N related to rapping R_N
B
Coupling the height H_N of the peak P_N to the time t_N elapsed since the imm. preceding rapping R_{N-1} to form a data record
C
Prepare/update model describing peak height H as a function of time t elapsed, based on the data record
D
Control, based on the model, the time t_{N+1} to elapse until a rapping R_{N+1} is to be executed
N=N+1

Fig. 7

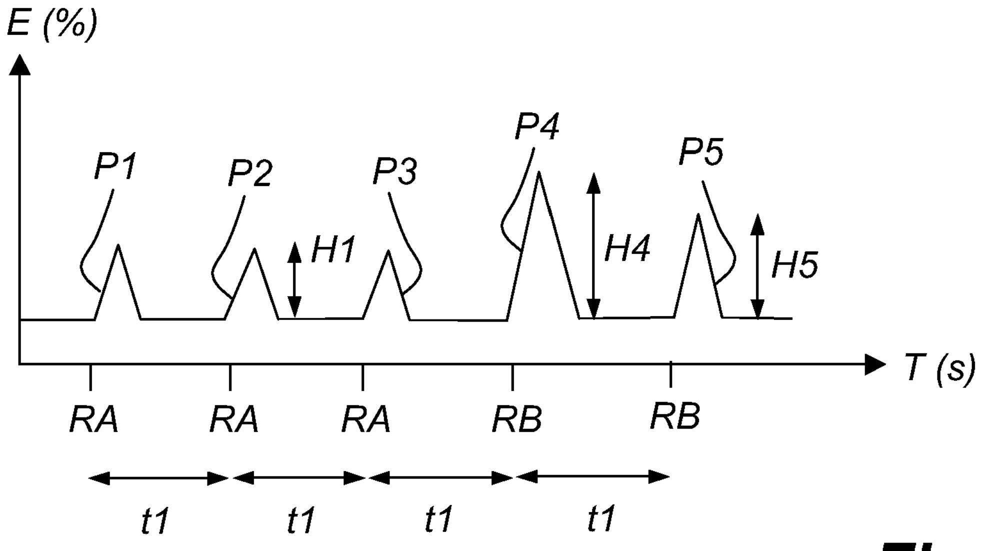
E (%)
P1
P2
P3
P4
P5
H1
H4
H5
T (s)
RA
RA
RA
RB
RB
t1
t1
t1
t1

Fig. 8

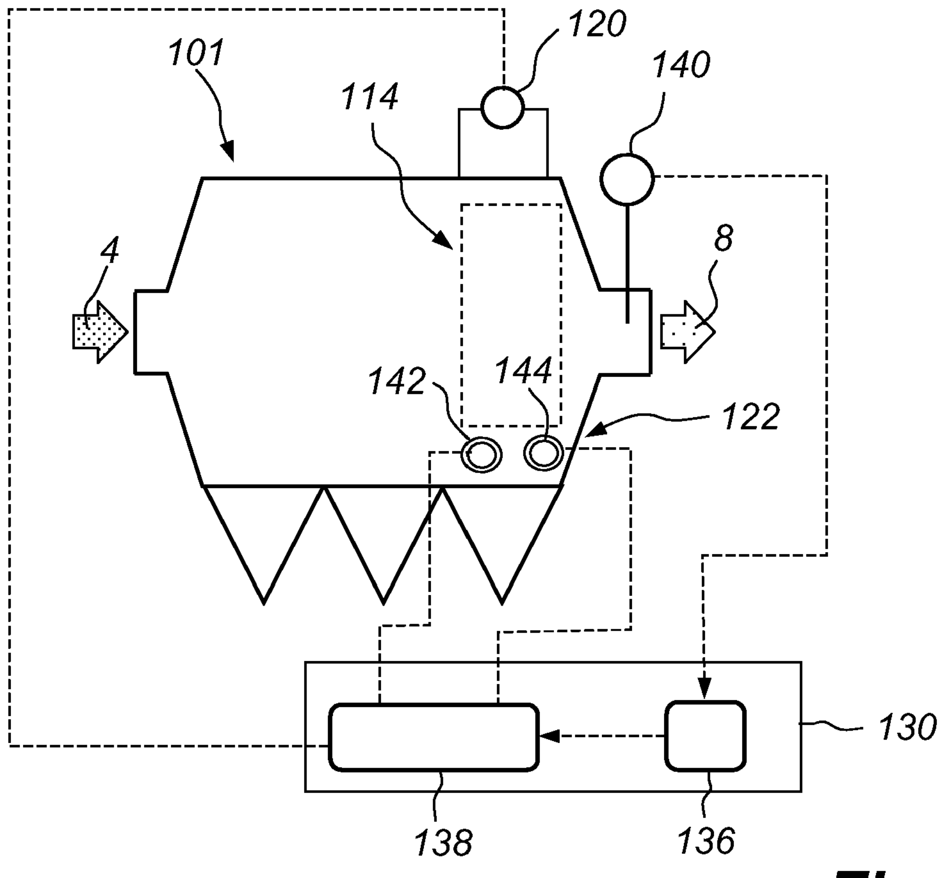
120
101
140
114
4
8
142
144
122
130
138
136

Fig. 9

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 07 10 3491

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B03C

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
The Hague	8 August 2007	Demol, Stefan

CATEGORY OF CITED DOCUMENTS

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& : member of the same patent family, corresponding document

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08-08-2007

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For more details about this annex : see Official Journal of the European Patent Office, No. 12/82

REFERENCES CITED IN THE DESCRIPTION

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