



(51) International Patent Classification:

G01F 23/00 (2006.01) G01F 23/288 (2006.01)

(21) International Application Number:

PCT/GB2017/051378

(22) International Filing Date:

17 May 2017 (17.05.2017)

(25) Filing Language:

English

(26) Publication Language:

English

(30) Priority Data:

1608887.4 20 May 2016 (20.05.2016) GB

(71) Applicant: **JOHNSON MATTHEY PUBLIC LIMITED COMPANY** [GB/GB]; 5th Floor, 25 Farringdon Street, London EC4A 4AB (GB).

(72) Inventors: **METCALFE, Benjamin**; Measurement Technology Centre, The Moat, Belasis Hall Technology Park,

Billingham Cleveland TS23 4ED (GB). **ROE, Stephen John**; PO Box 1, Belasis Avenue, Billingham Cleveland TS23 1LB (GB). **STOREY, Paul Bryan**; Measurement Technology Centre, The Moat, Belasis Hall Technology Park, Billingham Cleveland TS23 4ED (GB).

(74) Agent: **BOWN, Mark**; Johnson Matthey PLC, Group Intellectual Property Dept, PO Box 1, Belasis Avenue, Billingham Cleveland TS23 1LB (GB).

(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC,

(54) Title: RADIATION INTENSITY MEASUREMENT APPARATUS FOR NUCLEONIC LEVEL OR DENSITY GAUGE

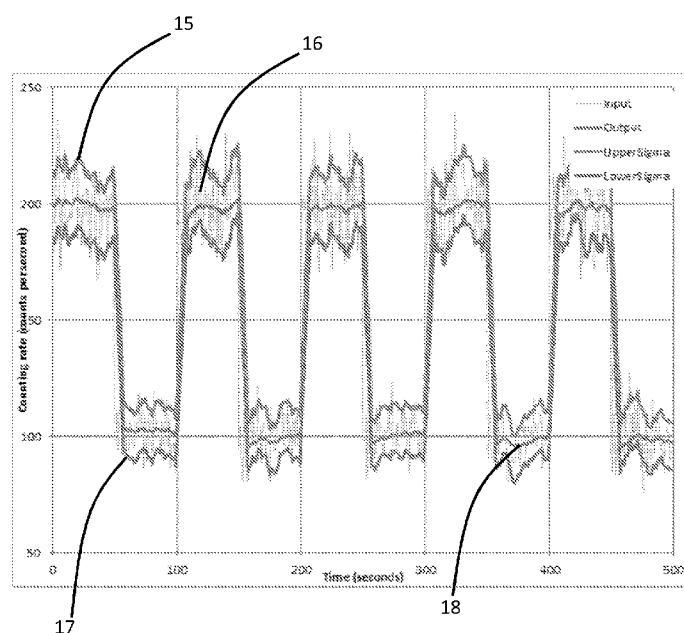


Fig. 7

(57) Abstract: A radiation measurement apparatus for use in a nucleonic level or density gauge is disclosed. The measurement apparatus comprises a radiation detector and a control unit configured to receive radiation measurements from the radiation detector. The control unit is configured to calculate an exponential moving average over time with a first time constant and a linear moving average over time with a second time constant. The second time constant is smaller than the first time constant. The control unit is configured to select either the exponential moving average or the linear moving average to use in determining a level or density based on the criterion that if the linear moving average differs from the exponential moving average by more than a pre-determined threshold the linear moving average is used and, if not, the exponential moving average is used.

SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR,
TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States (*unless otherwise indicated, for every kind of regional protection available*): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:

- *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*
- *of inventorship (Rule 4.17(iv))*

Published:

- *with international search report (Art. 21(3))*

RADIATION INTENSITY MEASUREMENT APPARATUS FOR NUCLEONIC LEVEL OR DENSITY GAUGE

Field of the Invention

- 5 The present invention relates to radiation measurement apparatus, in particular radiation intensity measurement apparatus for use in nucleonic level or density gauges. The invention also relates to nucleonic level or density gauges and to methods of measuring fluid level or density.

Background

- 10 It is well known to use radiation to measure the level or density of fluids. For example arrays of radiation sources may be arranged opposite arrays of radiation detectors so that the radiation passes from the sources to the detectors through the fluid to be measured. Since the attenuation of the radiation during its passage from the sources to the detectors is determined by the density of the fluid between the sources and the detectors, the measured intensity arriving at the detectors
- 15 can be used to calculate the density of the fluid. The density thus calculated can either be used directly or can be used to determine fluid levels by comparing the densities determined at different heights. An apparatus that uses such an approach is disclosed for example in US6633625. Many other density and level gauge arrangements are also known in the art.
- 20 Regardless of the arrangement and number of sources and detectors, all such nucleonic instruments must cope with the statistical variations that are inherently present in radiation-based measurements. Those variations arise from the random nature of the radioactive decay of the sources, and the random nature of the interactions of the radiation with the fluid through which it passes. Nucleonic instruments are typically used on industrial plant for monitoring and control
- 25 purposes and the statistical variations can result in noisy measurements, which are not useful for such purposes. As a result it is usual to operate some form of smoothing of the recorded intensities so as to produce a more stable measurement. When a process is at steady state, the intensities can simply be averaged over time to produce a stable value. An exponential moving average is typically used to provide a computationally efficient average. The time constant of the average (i.e.
- 30 a value representative of the time over which the average is taken) can be selected to be sufficiently long that a required precision is reached for the measurement. However, in a dynamic process the situation is more complex. A long time constant will produce measurements with a high degree of precision during times of relative stability of the process, but will be slow to react to changes in the process. That may be unacceptable since changes in the process will often require
- 35 control responses without undue delay. For example, a typical requirement might be that the measurement system should react quickly enough to a step change in the process that the measured value has achieved 90% of the change in the process value within 10s of the change occurring (this would be referred to as the measurement system having a T_{90} of 10s). An

alternative would be to have a short time constant. In those circumstances, the response to change will be rapid, but the measurement will be susceptible to the statistical variations and thus will not give a sufficiently precise value at times of process stability.

5 In order to provide a reasonable dynamic response along with a reasonable precision, it is known to use two exponential moving averages with different time constants. At times of stability the average with the longer time constant is used, while during dynamic situations the average with the shorter time constant is used. The selection of which average to use is based upon the difference between the two averages. A relatively small deviation between the two is assumed to be the result
10 of the susceptibility of the shorter average to statistical variations that do not reflect any underlying change in the process conditions (e.g. a change in the fluid level), while a larger deviation is taken as indicating that the process conditions have changed and that the shorter average has reacted to that change while the longer average has not yet reacted. Thus in the first case the longer average is used and in the second the shorter average is used.

15

The prior art systems can produce a reasonable balance between response and precision in many processes. However, they may not reliably produce a target T_{90} response time, particularly in very noisy systems such as heavy oil processes where the count rate is low.

20 Another important criterion may be the number of false excursions of the measured value. A false excursion occurs when the apparatus selects the shorter time constant moving average (thus assuming that the process variable has changed significantly) when in fact the process variable has not changed significantly and the shorter time constant moving average differs from the longer time constant moving average due to the sensitivity of the shorter time constant moving average to
25 the statistical noise in the measurement. Prior art systems may be unable to improve the T_{90} response without also producing an unacceptably large number of false excursions.

Preferred embodiments of the present invention seek to overcome one or more of the above disadvantages of the prior art. In particular, preferred embodiments of the present invention seek to
30 provide an improved system for radiation intensity measurement in nucleonic level or density gauges.

Summary of Invention

According to a first aspect of the invention, there is provided a radiation measurement apparatus
35 for use in a nucleonic level or density gauge, the measurement apparatus comprising a radiation detector and a control unit configured to receive radiation measurements from the radiation detector, wherein the control unit is configured to use the radiation measurements to calculate an exponential moving average over time with a first time constant and a linear moving average over time with a second time constant, the second time constant being smaller than the first time

constant, and to select either the exponential moving average or the linear moving average to use in determining a level or density based on the criterion that if the linear moving average differs from the exponential moving average by more than a pre-determined threshold the linear moving average is used and, if not, the exponential moving average is used.

5

The invention thus differs from the prior art systems in that the shorter average is a linear moving average filter. We have found that the combination of a short time constant linear moving average with a long time constant exponential moving average and decision logic to select one or the other based on the difference between them results in a particularly advantageous system for nucleonic level and density gauges. The linear moving average has a quicker rise time compared to an exponential moving average with the equivalent smoothing capacity and thus using a linear moving average during dynamic changes will advantageously deliver the measured value to its new final value in a quicker time. Meanwhile, maintaining the exponential moving average with the longer time constant at times of relative stability results in a precise measurement at those times and maintains the advantage of computational efficiency. In particular, the combination of the different types of average results in an improvement to the important T_{90} response of the apparatus, without compromising measurement stability. While the response of a short time constant exponential moving average may be similar to a comparable linear moving average for less-stringent criteria such as T_{50} (the time taken for the measured value to respond to 50% of a change in the process value), the linear moving average provides superior performance on the T_{90} criterion. For modern control processes, the T_{90} response may be the more important criterion and the radiation measurement apparatus of the present invention may therefore be superior to prior art measurement apparatus.

10

15

20

25

30

35

Preferably the measurement apparatus is a radiation intensity measurement apparatus. Preferably the control unit is configured to receive radiation intensity measurements from the radiation detector. Preferably the smoothing occurs before the intensity measurements are used to calculate the level or density. In that way the measurement apparatus outputs a smoothed radiation intensity measurement, which can then be used in any desired calculation. Thus the control unit is preferably configured to calculate an exponential moving average intensity over time with a first time constant and a linear moving average intensity over time with the second time constant, the second time constant being smaller than the first time constant, and to select either the exponential moving average intensity or the linear moving average intensity to use in a level or density calculation based on the criterion that if the linear moving average intensity differs from the exponential moving average intensity by more than a pre-determined threshold the linear moving average intensity is used and, if not, the exponential moving average intensity is used.

Preferably the criterion is that if the linear moving average differs from the exponential moving average by more than the pre-determined threshold for more than a pre-determined length of time

the linear moving average is used and, if not, the exponential moving average is used. By requiring the linear moving average to differ from the exponential moving average by more than the pre-determined threshold for more than a predetermined time the possibility of false excursions is reduced. Such a system may be particularly advantageous in the control of heavy oil systems such as desalters, where the signal to noise ratio may be low. In such systems, the possibility of false excursions due to the noise is increased. The possibility of false excursions could be reduced by increasing the time constant of the linear moving average. However, there is a limit to how long the time constant of the linear moving average can be if a specified T_{90} response is to be achieved. The apparatus of the invention provides advantages over the prior art in that respect because the linear moving average may have a longer time constant and still achieve a desired T_{90} than the prior art exponential moving average filter. However, further improvements can be made by requiring the linear moving average to differ from the exponential moving average by more than the pre-determined threshold for more than a predetermined time. The predetermined time should be less than the target T_{90} and therefore may be less than the second time constant. For example the predetermined time may be not more than half of the second time constant. The predetermined time may be at least 0.05 times the second time constant or at least 0.1 times the second time constant. Preferably, the predetermined time is expressed as a number of consecutive measurements. Preferably the predetermined time is from 2 to 10 consecutive measurements, more preferably from 3 to 5 consecutive measurements, most preferably from 3 to 4 consecutive measurements. In some embodiments, the predetermined time may be at least two consecutive measurements, preferably at least three consecutive measurements, and not more than half of the second time constant. The predetermined time is small enough that a genuine change in the underlying process state (for example, a fall in the fluid level) will be reliably detected within the target T_{90} time, but long enough that an excursion due to noise is unlikely to result in a false measurement due to the statistical likelihood that an excursion due to noise will be reversed by another statistical fluctuation in the opposite direction.

Preferably the predetermined threshold is based on the standard deviation of the linear moving average. For example the pre-determined threshold may be a value between 2 and 4 times the standard deviation of the linear moving average. In that way the absolute value of the threshold is increased when the uncertainty in the linear moving average value is increased.

Preferably the first time constant is not less than 20 seconds. More preferably the first time constant is not less than 60 seconds or not less than 100 seconds. The first time constant is preferably chosen on the basis of a required precision for the measurement. It is an advantage of the present invention that the improved dynamic response of the linear moving average allows the first time constant to be increased, thus improving the precision of the measurement during periods of steady operation. Preferably the second time constant is not more than 15 seconds. More

preferably the second time constant is not more than 10 seconds. The second time constant is preferably chosen based on the desired T_{90} response of the apparatus.

According to a second aspect of the invention there is provided a nucleonic level or density gauge comprising a radiation measurement apparatus according to the first aspect. The nucleonic level or density gauge may be a gauge for use in a heavy oil process. Preferably the level or density gauge is for use in a desalter. Preferably the level or density gauge comprises a source of radiation and a radiation measurement apparatus according to the first aspect. The gauge may comprise a plurality of radiation detectors. The control unit may be the same for all of the radiation detectors. There may be a control unit for each of the radiation detectors. The gauge may comprise a plurality of sources of radiation arranged in an array and a plurality of detectors held in a second array, the sources of radiation being associated with collimators so that a beam of radiation extends from each source to a corresponding detector. The source array and the detector array may be contained in dip pipes for insertion into a vessel. The source array and the detector array may be held in a fixed relationship to one another. The gauge may comprise more radiation detectors than sources. In that case, the source or sources may be collimated so that radiation from a source passes to more than one detector.

According to a third aspect of the invention there is provided a method of measuring fluid level or density comprising measuring a level of radiation passing through the fluid, using the measured radiation level to calculate an exponential moving average over time with a first time constant and a linear moving average over time with a second time constant, the second time constant being smaller than the first time constant, and using either the exponential moving average or the linear moving average to determine the level or density wherein if the linear moving average differs from the exponential moving average by more than a pre-determined threshold the linear moving average is used and, if not, the exponential moving average is used.

Preferably the intensity of radiation passing through the fluid is smoothed and the smoothed intensity used to calculate the level or density. The method thus preferably comprises measuring radiation intensity of radiation passing through the fluid, calculating an exponential moving average intensity over time with a first time constant and a linear moving average intensity over time with a second time constant, the second time constant being smaller than the first time constant, and using either the exponential moving average intensity or the linear moving average intensity to calculate the level or density wherein if the linear moving average intensity differs from the exponential moving average intensity by more than a pre-determined threshold the linear moving average intensity is used and, if not, the exponential moving average intensity is used.

Preferably the radiation intensity is measured as a number of counts received over a time window, with a series of radiation intensity measurements being generated one after the other over a period

of time. The time between measurements, which also corresponds to the time over which counts are recorded for an individual measurement, may be referred to as the sampling period, s .

Preferably the exponential moving average, I_F , at any given time is calculated according to the formula:

$$I_F = I_p + \left(\frac{I_c - I_p}{F} \right)$$

Where I_p is the previous exponential moving average, I_c is the current intensity measurement and F is a filter factor which is related to the time constant T_c by the relationship $F = \frac{T_c}{s} + 0.5$. The linear moving average, I_F , may be calculated according to the formula:

$$I_F = \frac{\sum_{i=0}^{n-1} I_{c-i}}{n}$$

- 10 In other words, the linear moving average is the average of the last n values. The time constant of the linear moving average is thus given by $T_c = ns$. Preferably the linear moving average is computed recursively, for example using the formula:

$$I_F = I_p - I_{c-n} + I_c$$

- Thus the current linear moving average is the previous linear moving average, I_p , minus the oldest measurement in that previous linear moving average, I_{c-n} , plus the current measurement, I_c . It may be that the apparatus comprises a programmable controller having a moving average function available as a standard function. In that case the built-in function may be used.

- 20 Preferably the fluid level is the level of an oil-water interface in a desalter. Desalters may be characterised by thick walls and heavy oils, which combine to reduce the signal received by radiation detectors. The method of the invention may be particularly suited to capturing dynamic changes in desalters whilst also providing reliable measurement of steady state levels.

- It will be appreciated that features described in relation to one aspect of the invention may be equally applicable in another aspect of the invention. For example, features described in relation to the apparatus of the invention, may be equally applicable to the method of the invention, and *vice versa*. Some features may not be applicable to, and may be excluded from, particular aspects of the invention.

30 Description of the Drawings

Embodiments of the present invention will now be described, by way of example, and not in any limitative sense, with reference to the accompanying drawings, of which:

- Figure 1 is a histogram of the smoothed count rate response times to 49,999 step inputs containing random noise to a prior art system;

Figure 2 is a histogram of the smoothed count rate response times to 49,999 step inputs containing random noise to a system embodying the present invention;

Figure 3 is a histogram of the smoothed count rate response times to 49,999 step inputs containing random noise to a system not embodying the present invention;

Figure 4 is a histogram of the smoothed count rate response times to 49,999 step inputs containing random noise to a system embodying the present invention;

5 Figure 5 is a histogram of the smoothed count rate response times to 49,999 step inputs containing random noise to a system embodying the present invention;

Figure 6 is a plot of count rate against time for a series of step changes in input count rate containing random noise to a prior art system;

10 Figure 7 is a plot of count rate against time for a series of step changes in input count rate containing random noise to a system embodying the present invention;

Figure 8 is a plot of count rate against time for a series of step changes in input count rate containing random noise to a prior art system;

Figure 9 is a plot of count rate against time for a series of step changes in input count rate containing random noise to a system embodying the present invention;

15 Figure 10 is a plot of count rate against time for a series of step changes in input count rate containing random noise to a prior art system;

Figure 11 is a plot of count rate against time for a series of step changes in input count rate containing random noise to a system embodying the present invention; and

20 Figure 12 is a plot of count rate against time for a series of step changes in input count rate containing random noise to a system embodying the present invention.

Detailed Description

For comparison to the present invention, 49,999 step inputs containing random noise were passed through a prior art control system to observe the response. The control system calculated two
 25 exponential moving averages. The first had a time constant of 20s and the second had a time constant of 4s. That configuration was intended to deliver a t_{90} response of less than 10s. The control system used the first exponential moving average (the “long” average) as the output unless the second exponential moving average (the “short” average) differed from the first exponential moving average by more than 2 standard deviations based on the short average. The time taken
 30 for the output to react to the change in the step input was recorded based on the time taken for the output to achieve 90% of the step change (the t_{90} response) and the time taken for the output to achieve 95% of the step change (the t_{95} response). In figure 1, the response time is on the x-axis and the frequency of achieving the response time is on the y-axis. The t_{90} (1) and t_{95} (2) responses are plotted. The average t_{90} was 12.22s, with a minimum of 4s and a maximum of 45s. The t_{90}
 35 response was below 10s in 25,544 out of 49,999, or 51% of cases. The average t_{95} was 17.52s, with a minimum of 4s and a maximum of 78s. The t_{95} response was below 10s in 14,829 out of 49,999, or 30% of cases.

The same test was run using a control system according to the present invention, which calculated an exponential moving average having a time constant of 20s and a linear moving average having a time constant of 7s. The linear moving average having a time seconds of 7s gives equivalent smoothing performance to the 4s exponential filter. The control system used the exponential moving average as the output unless the linear moving average differed from the exponential moving average by more than 2 standard deviations based on the linear moving average. In figure 2, the response time is on the x-axis and the frequency of achieving the response time is on the y-axis. The t_{90} (3) and t_{95} (4) responses are plotted. The average t_{90} was 8.35s, with a minimum of 5s and a maximum of 41s. The t_{90} response was below 10s in 41,234 out of 49,999, or 82% of cases. The average t_{95} was 11.80s, with a minimum of 5s and a maximum of 75s. The t_{95} response was below 10s in 34,571 out of 49,999, or 69% of cases.

Comparing the two outcomes, it can be seen that the control system according to the present invention had a superior performance to the prior art system. In the control systems compared, the response may be judged against a target of $t_{90} < 10s$. Such a target may, for example, be important for the stable control of levels in a vessel. It can be seen that the system of the invention achieved this target in 82% of cases compared to 51% of cases for the prior art system.

An advantage of the present invention is that it may permit the use of more advanced logic by the control system in choosing between the short and long averages. For example, the control system of the invention may use the long, exponential moving average unless the short linear average has differed from it by at least a predetermined amount for at least a predetermined length of time. For example, when the intensity data is received as a series of readings, the logic may require the control system to use the exponential moving average unless the linear moving average has differed from the exponential moving average by more than a set number of standard deviations over a number of consecutive readings. That may permit optimisations of the control system performance that were not possible with prior art systems. To demonstrate this, a system not embodying the invention uses two exponential moving averages, as in the prior art systems, one having a time constant of 20s and one having a time constant of 4s. The control system uses the first exponential moving average unless the second differs from it by more than 3 standard deviations for at least 4 measurements. The t_{90} (5) and t_{95} (6) response are plotted in figure 3 in the same way as in figures 1 and 2. The average t_{90} was 14.53s, with a minimum of 5s and a maximum of 48s. The t_{90} response was below 10s in 13,888 out of 49,999, or 28% of cases. The average t_{95} was 27.25s, with a minimum of 5s and a maximum of 75s. The t_{95} response was below 10s in 1583 out of 49,999, or 3% of cases. Thus it can be seen that modifying the prior art to include a so-called 'switch delay', whereby the short average is only used if it has differed from the long average for a pre-determined length of time, results in worse performance in terms of average response and achieving the $t_{90} < 10s$ target. By contrast, a control system according to the invention is shown in figure 4. As with the system of figure 2, the exponential moving average has a time constant of 20s

and the linear moving average has a time constant of 7s. However, in figure 4 the control system uses the exponential moving average unless the linear moving average has differed from the exponential moving average by 3 standard deviations for 4 measurements. The t_{90} (7) and t_{95} (8) response are plotted in figure 4 in the same way as in figures 1, 2 and 3. The average t_{90} was 6.64s, with a minimum of 5s and a maximum of 29s. The t_{90} response was below 10s in 49668 out of 49,999, or 99% of cases. The average t_{95} was 7.57s, with a minimum of 5s and a maximum of 61s. The t_{95} response was below 10s in 45,934 out of 49,999, or 92% of cases. In contrast to the prior art systems therefore, including a switch delay in the control system of the present invention results in a significant improvement in the response.

A further advantage of the control systems of the present invention is illustrated in figure 5. In this case the control system is as in figure 4, but the time constant of the exponential moving average filter has been increased to 120s. The t_{90} (9) and t_{95} (10) response are plotted in figure 5 in the same way as in figures 1, 2, 3 and 4. The average t_{90} was 12.21s, with a minimum of 5s and a maximum of 123s. The t_{90} response was below 10s in 39,206 out of 49,999, or 78% of cases. The average t_{95} was 30.16s, with a minimum of 5s and a maximum of 199s. The t_{95} response was below 10s in 31,515 out of 49,999, or 63% of cases. The advantage of a long time constant on the exponential moving average is that it provides a more stable reading during steady state conditions. Comparing with figures 1 and 2, the control system of the present invention enables the length of the long exponential moving average to be increased in this way without significantly impacting on the $t_{90} < 10s$ target and while still providing improved performance with respect to that target as compared to the prior art systems.

In figure 6 a prior art control system is shown responding to a series of step changes in an input 12. The output 14 is selected from a first exponential moving average having a time constant of 20s and a second exponential moving average having a time constant of 4s. This is the same control system as in figure 1. In figure 6 the boundaries of two standard deviations above the second exponential moving average (the upper boundary 11) and two standard deviations below the second exponential moving average (the lower boundary 13) are also shown. It can be seen that the control system acts by returning an output 14 corresponding to the first exponential moving average, until that output crosses either of the boundaries 11 and 13. That typically occurs during the step changes in the input 12. When that occurs the output switches to the shorter exponential moving average, resulting in a correction of the output 14 back towards the centre of the 'carriageway' formed between the upper 11 and lower 13 boundaries. Such a correction can be seen for example at 14'.

Referring now to figure 7, a control system according to the invention is used. In this case an input 16 again includes random noise and a series of step changes. The control system now selects between an exponential moving average having a time constant of 20s and a linear moving

average having a time constant of 4s. The switch between the two is made when the linear moving average differs by more than two standard deviations from the exponential moving average. This is shown in figure 7 by the upper boundary 15 and the lower boundary 17. The output 18 lies within the boundaries 15 and 17 until a step change occurs. However, by comparison with figure 6, the
5 carriageway between the upper 15 and lower 17 boundaries tracks the step change more closely across the full range of the step change. Thus where the carriageway has a curved transition out of the step change in the prior art systems, in the system of the invention, the transition is a sharp change. That has the advantage that the output 18, which was able to pass around the edges of the curved transition in some instances under the prior art system, is forced to respond more
10 completely to the step change in order to stay within the carriageway of the present invention. As a result, the t_{90} response of the present invention is improved.

In figures 8 and 9 the prior art control system of figure 6 and the inventive control system of figure 7 are used again, but now with the time constant of the second exponential moving average of the
15 prior art control system and the linear moving average of the inventive control system being increased to 10s. In figure 8 it is clear that the upper boundary 19 and the lower boundary 21 allow significant curving of the carriageway in which the output 22 is confined in the prior art system. Thus when the input 20 undergoes a step change, while the initial reaction is quick, the time for the output to correctly arrive at the new level is poor. This reduces the percentage of cases that
20 achieve the $t_{90} < 10s$ target. By contrast, the system of the present invention has sharp changes in both the start and the finish of the step changes in the upper 23 and lower 25 boundaries and thus the output 26 is constrained to follow the step change in the input 24 more closely. That results in a much-improved t_{90} response.

25 The control system is used in nucleonic level or density gauges. In such instruments changes in the intensity of the radiation are related to changes in level or density of the material in a vessel in which the gauge is operating. Typically the level or density will be an important variable for process control and thus it is important to track changes in that variable. The challenge in many such instruments is that there may be significant noise in the input signal. That is not least because
30 nucleonic instruments detect radiation emitted by a radioactive source. That emission occurs as random events and thus the count rate is inherently noisy because the number of emission events in a given time window is itself uncertain. Because the aim of such instruments is to provide control on the order of seconds, it is not possible to simply collect data over a long period of time in order to even out the random nature of the radioactive emission from the source. Further noise is also
35 present from the detectors, electronics and the process variables themselves such as temperature and pressure. Moreover, the measured intensity is determined by the level of attenuation of the material through which the radiation has passed. However, that attenuation is the result of further random processes such as scattering and thus contributes a further source of noise to the measurements. Thus nucleonic measurements are typically trying to detect significant underlying

changes in noisy measurements. The present invention has particular utility in such circumstances because it combines the advantages of averaging the noise out of the measurements when it is appropriate to do so, with reliable tracking of genuine changes.

5 The challenges are particularly significant when tracking heavy oil levels in processes such as desalters. Such processes may experience rapid changes due, for example to the arrival of slugs in the apparatus and are also characterised by particularly low count rates due to the high density of the heavy oils. Thus there are rapid changes which need to be robustly tracked, but the noise is high due to the lack of counts to smooth out the random nature of the source emissions and
10 scattering events. The system of the present invention has been shown to be particularly advantageous in such processes. Looking at figures 10 and 11, in a prior art system (long exponential average with 60s time constant, short exponential average with 10s time constant, switch if short differs from long by more than two standard deviations) the carriageway between the upper 27 and lower 29 boundaries follows a curving path and barely settles to the new level in the
15 input 28 before the next step occurs. Thus the output 30 is slow to fully react to each of the step changes. By contrast a system according to the invention (exponential moving average with 60s time constant, linear moving average with 10s time constant, switch if linear differs from exponential by more than 2 standard deviations) produces an output 34 which tracks more reliably the step changes in the input 32, without compromising the stability of the measurements in the
20 steady phases between the steps. The carriageway between the upper boundary 31 and the lower boundary 33 (i.e. the +/- two standard deviations region, the boundaries 31 and 33 of which trigger the switch to the linear moving average) tracks the step changes in the input 32 more sharply than the prior art boundaries 27 and 29 thus improving the response time. In such systems it would be typical to target a t_{80} response of 10s. That is achieved with the present invention but not with the
25 prior art.

The present invention also advantageously reduces the number of so-called 'false excursions'. False excursions occur when the control system erroneously treats a random variation resulting from the noise in the measurement as a change resulting from a change in the process (for
30 example, the level or density) being measured. It will be appreciated that a system could be designed to respond very quickly to changes in the process, for example by carrying out no smoothing, but that such a system would give very poor stability in periods in which the process is unchanged. The advantage of the control system of the invention is that it combines satisfactory response to changes in the underlying process with good measurement stability at all other times.
35 In figure 12, the system of figure 11 is shown controlling a process over a longer length of time. The upper boundary 35, lower boundary 37, input 36 and output 38 are shown. Occasionally the output demonstrates a false excursion 39 where the output incorrectly switches to the linear moving average to track a change that is actually simply an artefact of the random noise. The presence of such false excursions 39 can be reduced or even eliminated by altering the logic of the

decision by which the control systems selects that average to output. For example, the control system may be configured to only switch to the linear moving average if the linear moving average has differed from the exponential moving average by the predetermined threshold (in this example, two standard deviations) for a predetermined length of time. For example, the false excursions 39
5 could be eliminated by only switching to the linear moving average if the linear moving average is outside the carriageway between the upper boundary 35 and the lower boundary 37 for three consecutive measurements or 4 consecutive measurements. The advantage of the system of the present invention is that, because the carriageway tracks more closely the changes in the process, logic that requires the measurement to leave the carriageway for more than one measurement
10 before switching to the linear moving average can be implemented without increasing the response time beyond acceptable levels.

It will be appreciated by persons skilled in the art that the above embodiments have been described by way of example only, and not in any limitative sense, and that various alterations and
15 modifications are possible without departure from the scope of the invention as defined by the appended claims.

Claims

1. A radiation measurement apparatus for use in a nucleonic level or density gauge, the measurement apparatus comprising a radiation detector and a control unit configured to receive measurements from the radiation detector, wherein the control unit is configured to
5 use the measurements to calculate an exponential moving average over time with a first time constant and a linear moving average over time with a second time constant, the second time constant being smaller than the first time constant, and to select either the exponential moving average or the linear moving average to use in determining a level or density based on the criterion that if the linear moving average differs from the exponential moving average by more
10 than a pre-determined threshold the linear moving average is used and, if not, the exponential moving average is used.
2. A radiation measurement apparatus according to claim 1, wherein the criterion is that if the linear moving average differs from the exponential moving average by more than the pre-determined threshold for more than a pre-determined length of time the linear moving average
15 is used and, if not, the exponential moving average is used.
3. A radiation measurement apparatus according to any preceding claim wherein the predetermined threshold is based on the standard deviation of the linear moving average.
4. A radiation measurement apparatus according to claim 3, wherein the pre-determined threshold is a value between 2 and 4 times the standard deviation of the linear moving
20 average.
5. A radiation measurement apparatus according to any preceding claim wherein the first time constant is not less than 20 seconds.
6. A radiation measurement apparatus according to any preceding claim wherein the second time constant is not more than 15 seconds.
- 25 7. A nucleonic level or density gauge comprising a radiation measurement apparatus according to any preceding claim.
8. A method of measuring fluid level or density comprising measuring radiation intensity of radiation passing through the fluid, using the measured radiation intensity to calculate an exponential moving average over time with a first time constant and a linear moving average
30 over time with a second time constant, the second time constant being smaller than the first time constant, and using either the exponential moving average or the linear moving average to determine the level or density based on the criterion that if the linear moving average differs from the exponential moving average by more than a pre-determined threshold the linear moving average is used and, if not, the exponential moving average is used.
- 35 9. A radiation measurement apparatus substantially as herein described with reference to the accompanying figures.
10. A method substantially as herein described with reference to the accompanying figures.

1/8

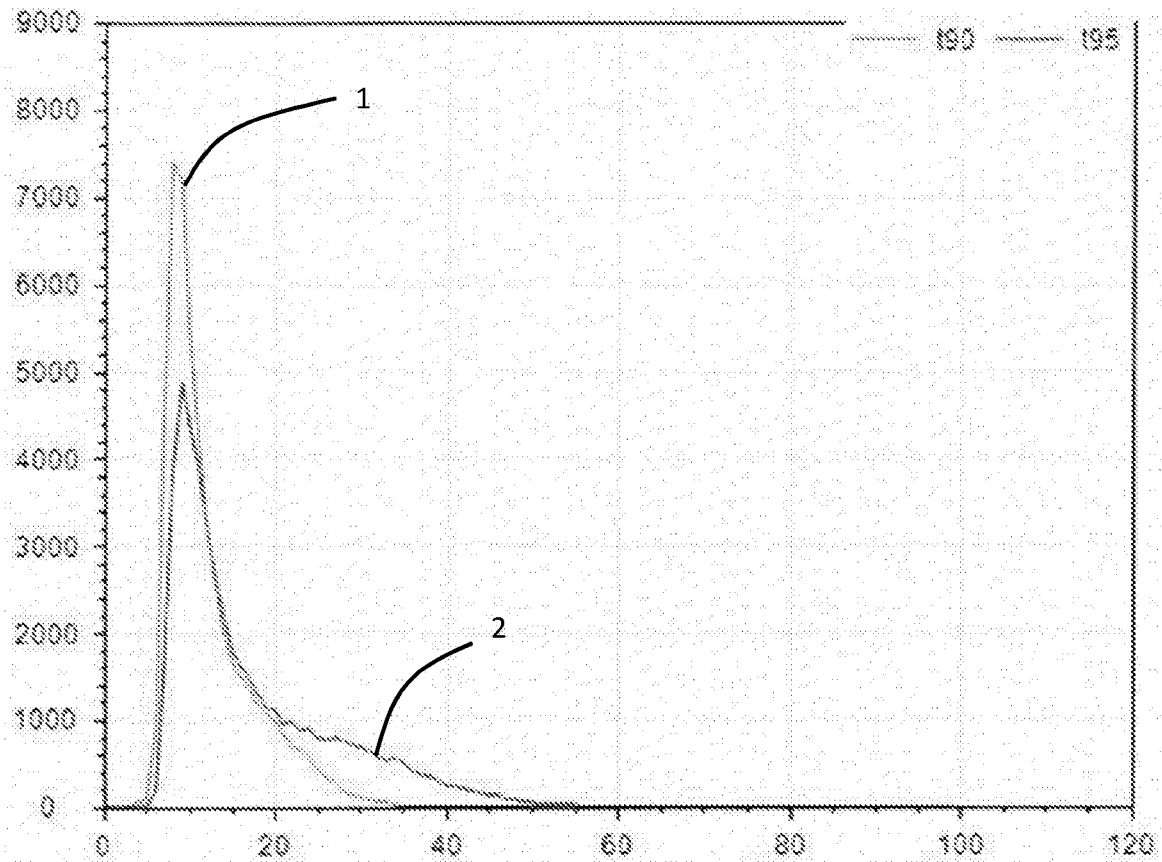


Fig. 1 (Prior Art)

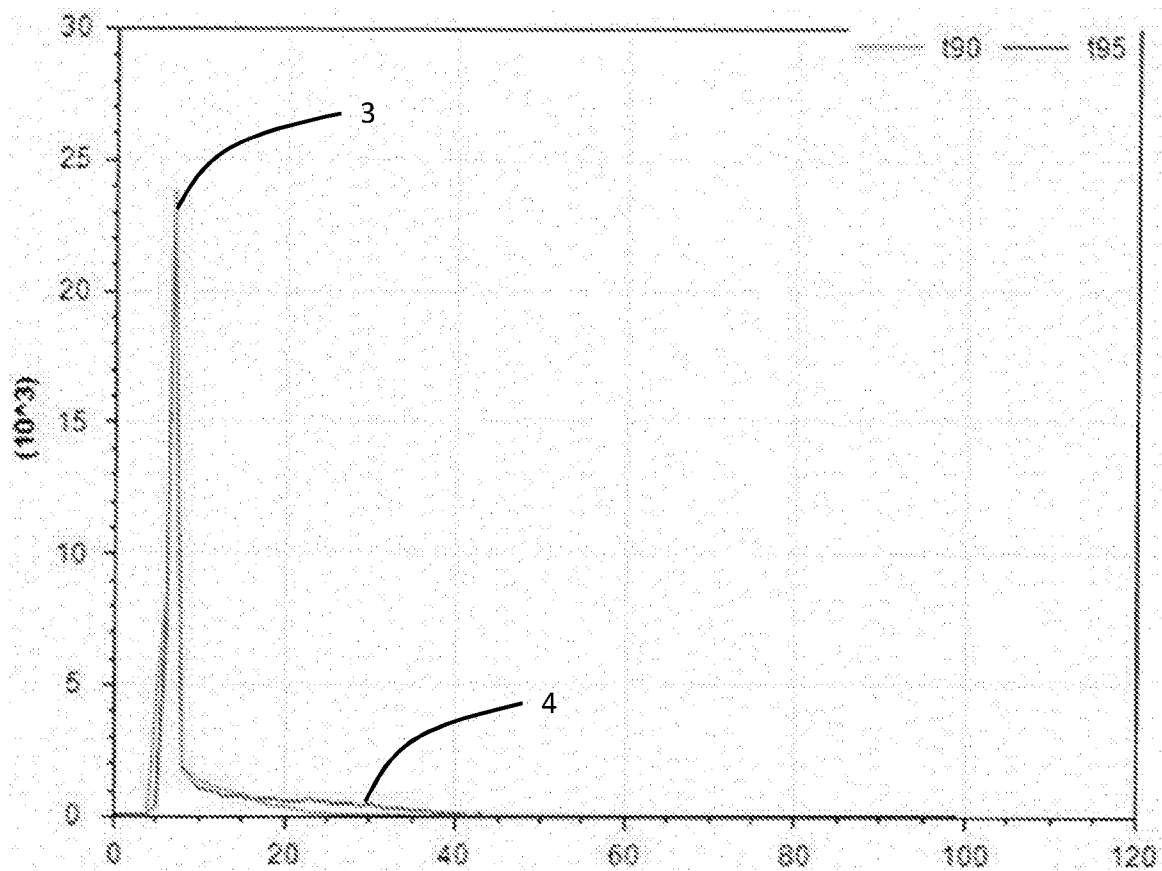


Fig. 2

2/8

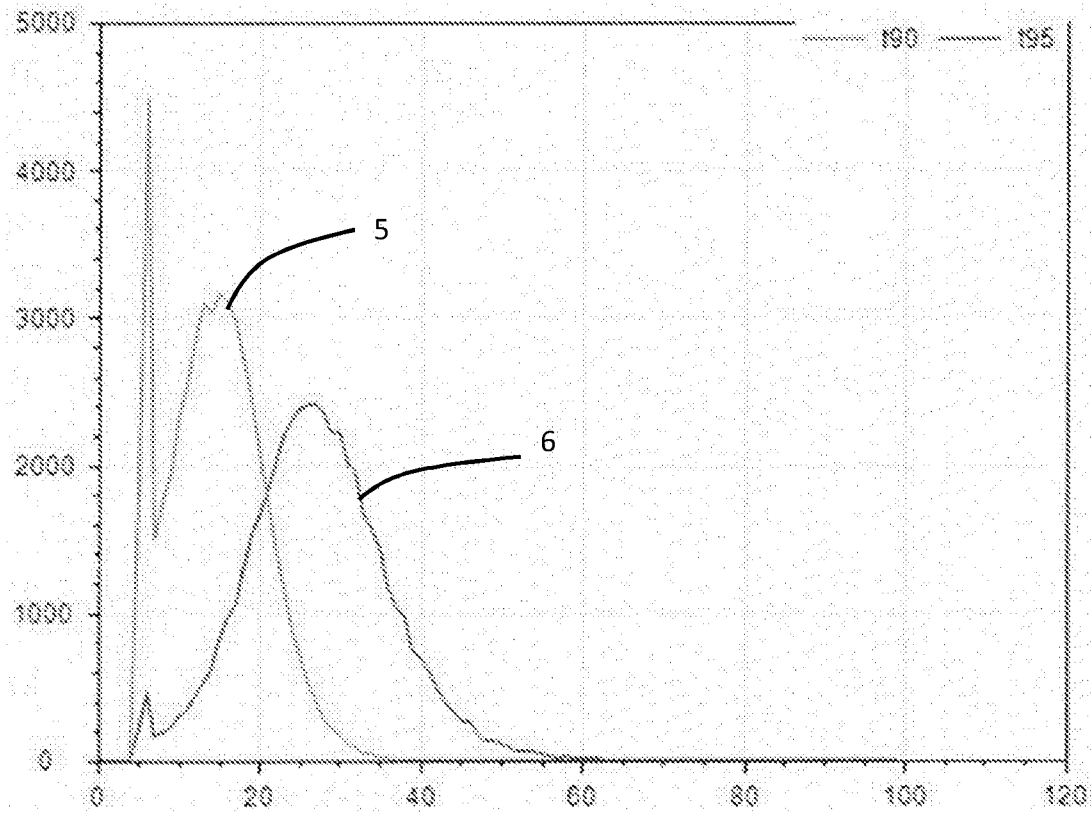


Fig. 3 (Not embodying the invention)

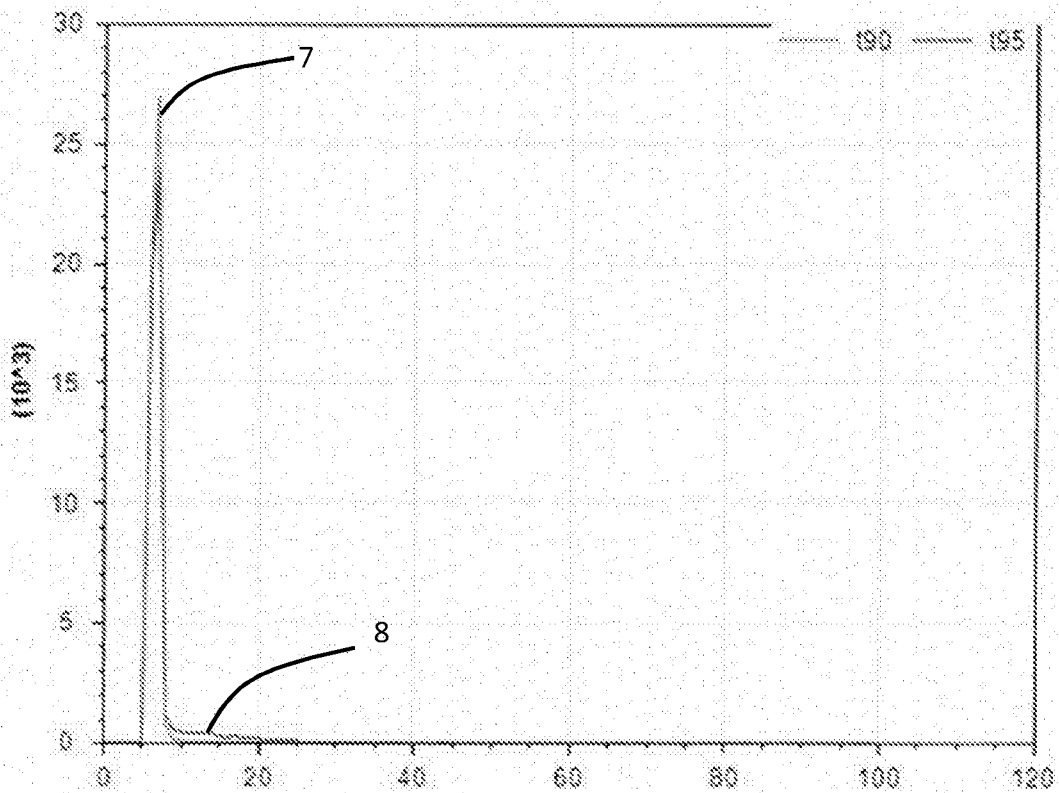


Fig. 4

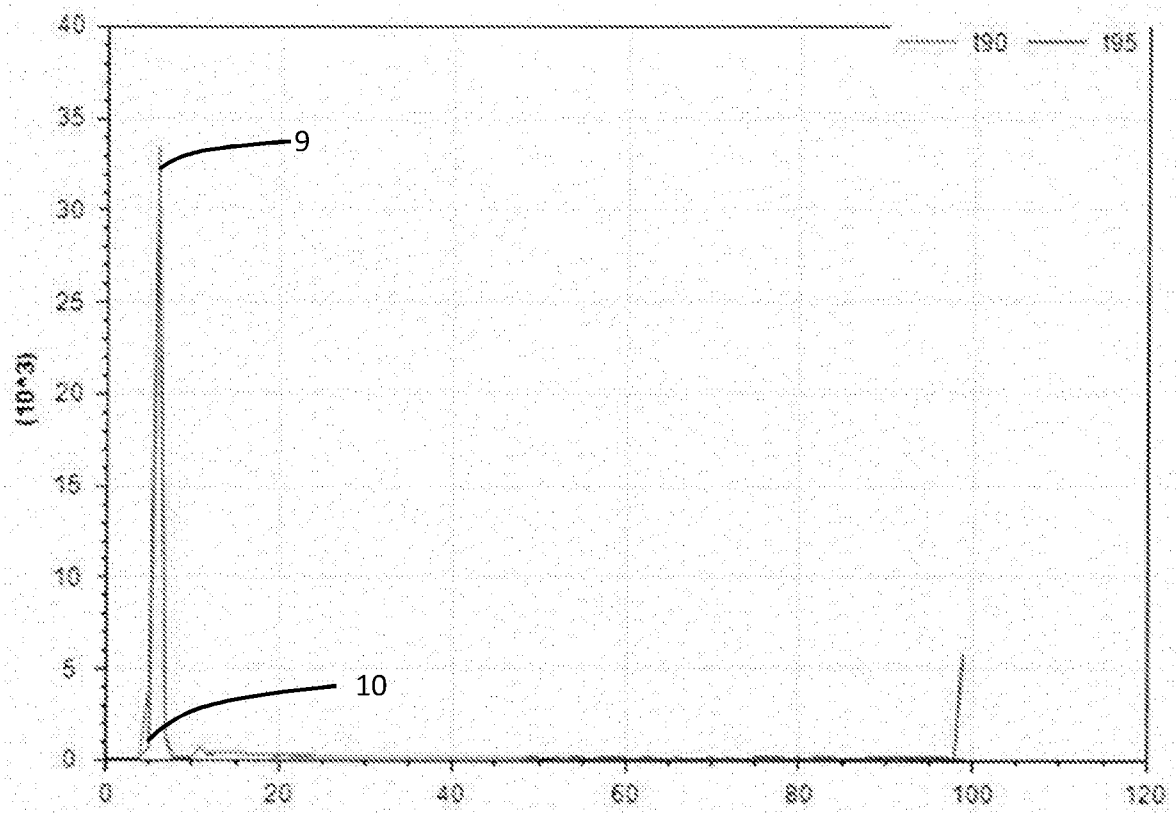


Fig. 5

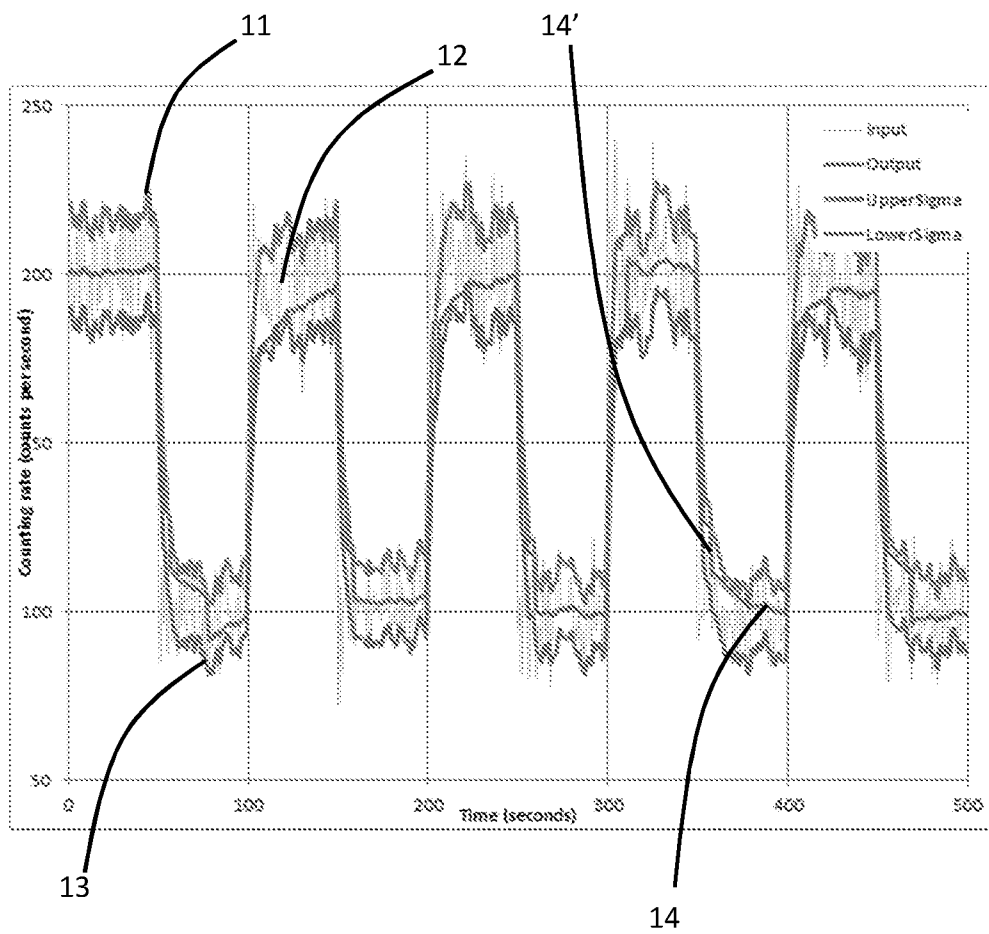


Fig. 6 (Prior Art)

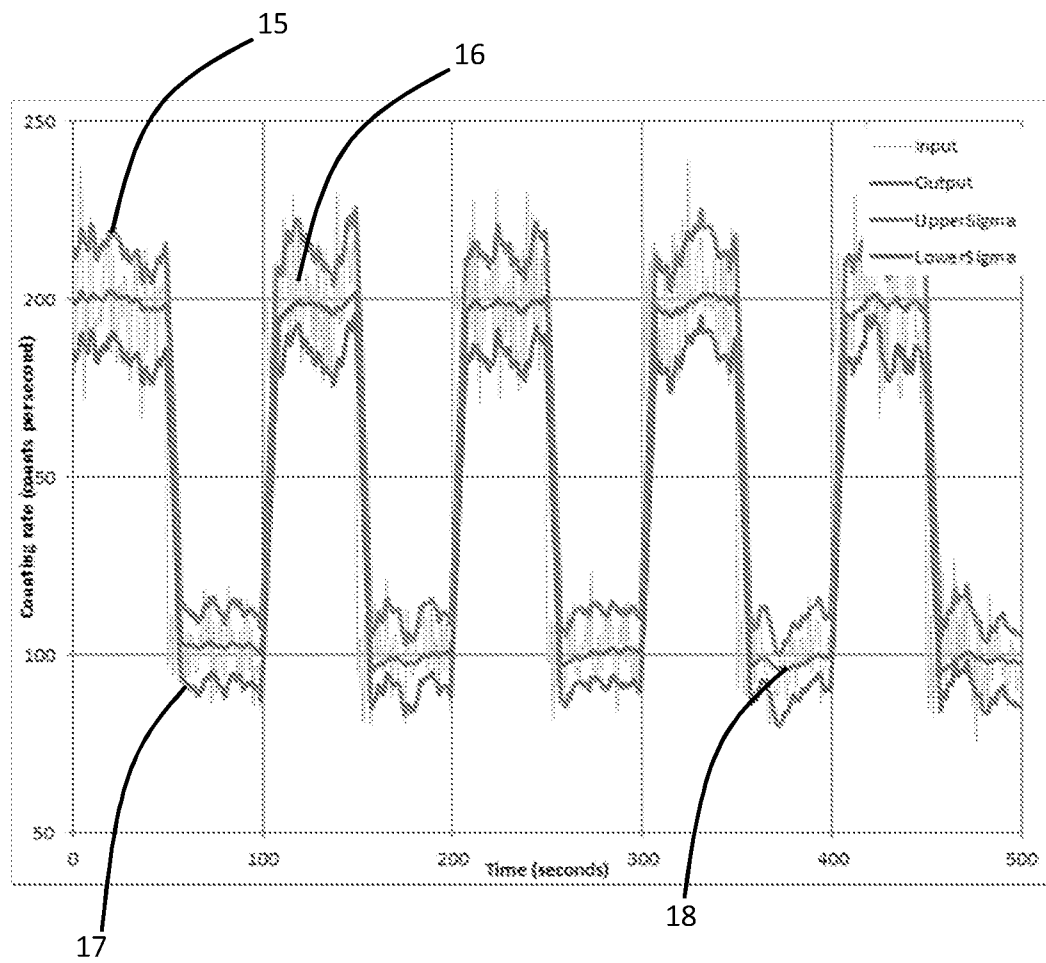


Fig. 7

6/8

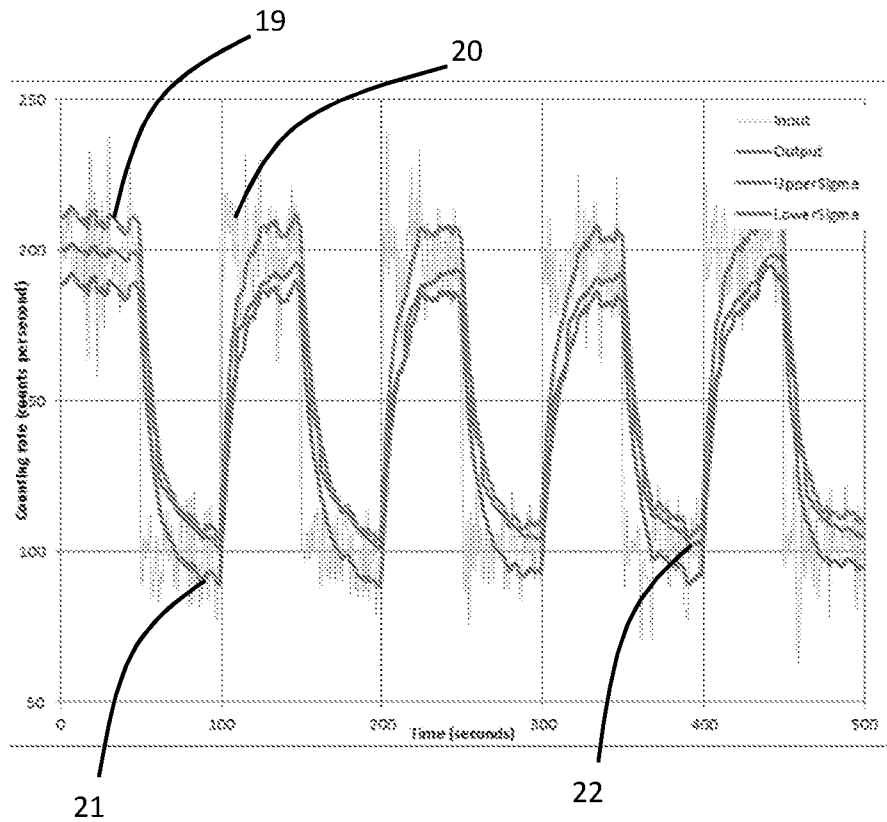


Fig. 8 (Prior Art)

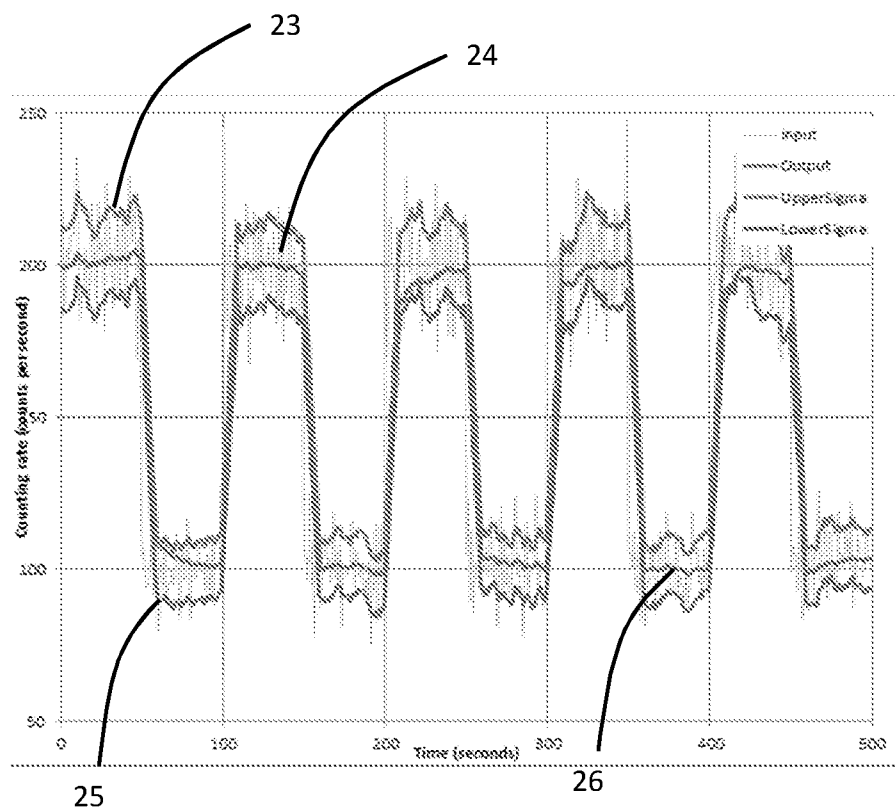


Fig. 9

7/8

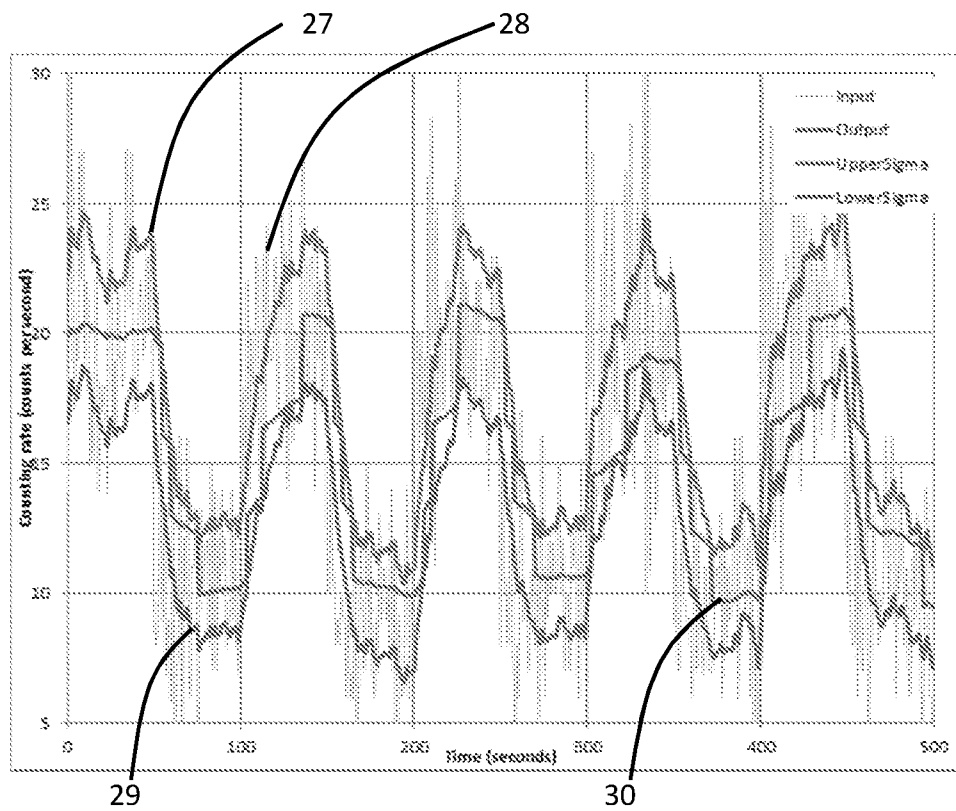


Fig. 10 (Prior Art)

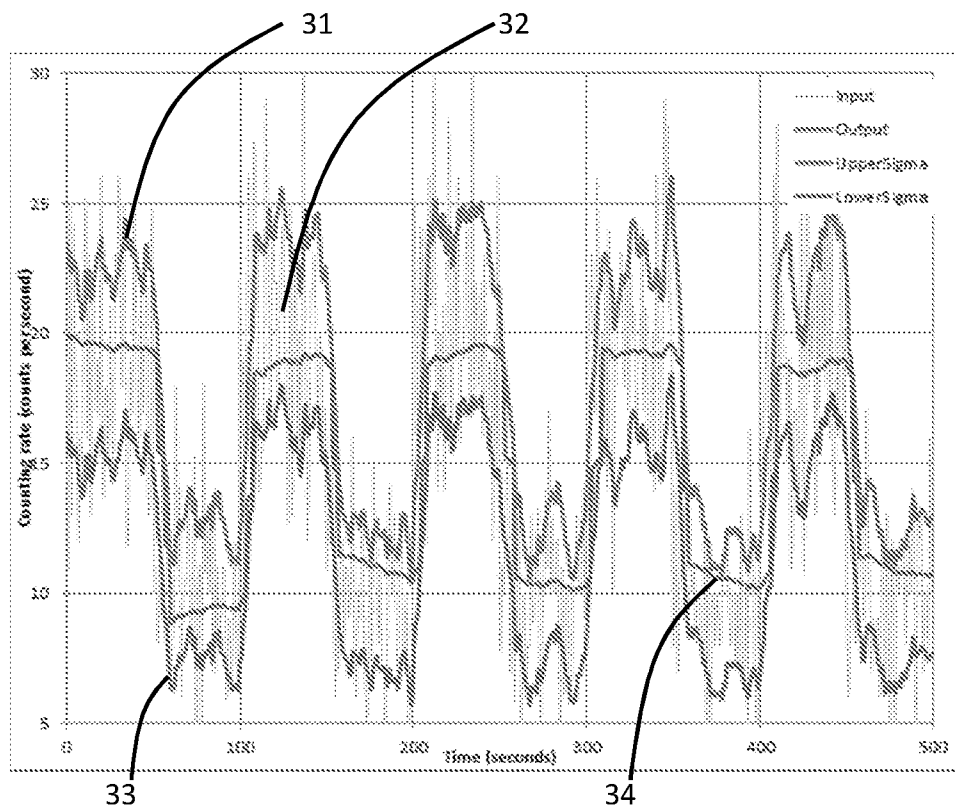


Fig. 11

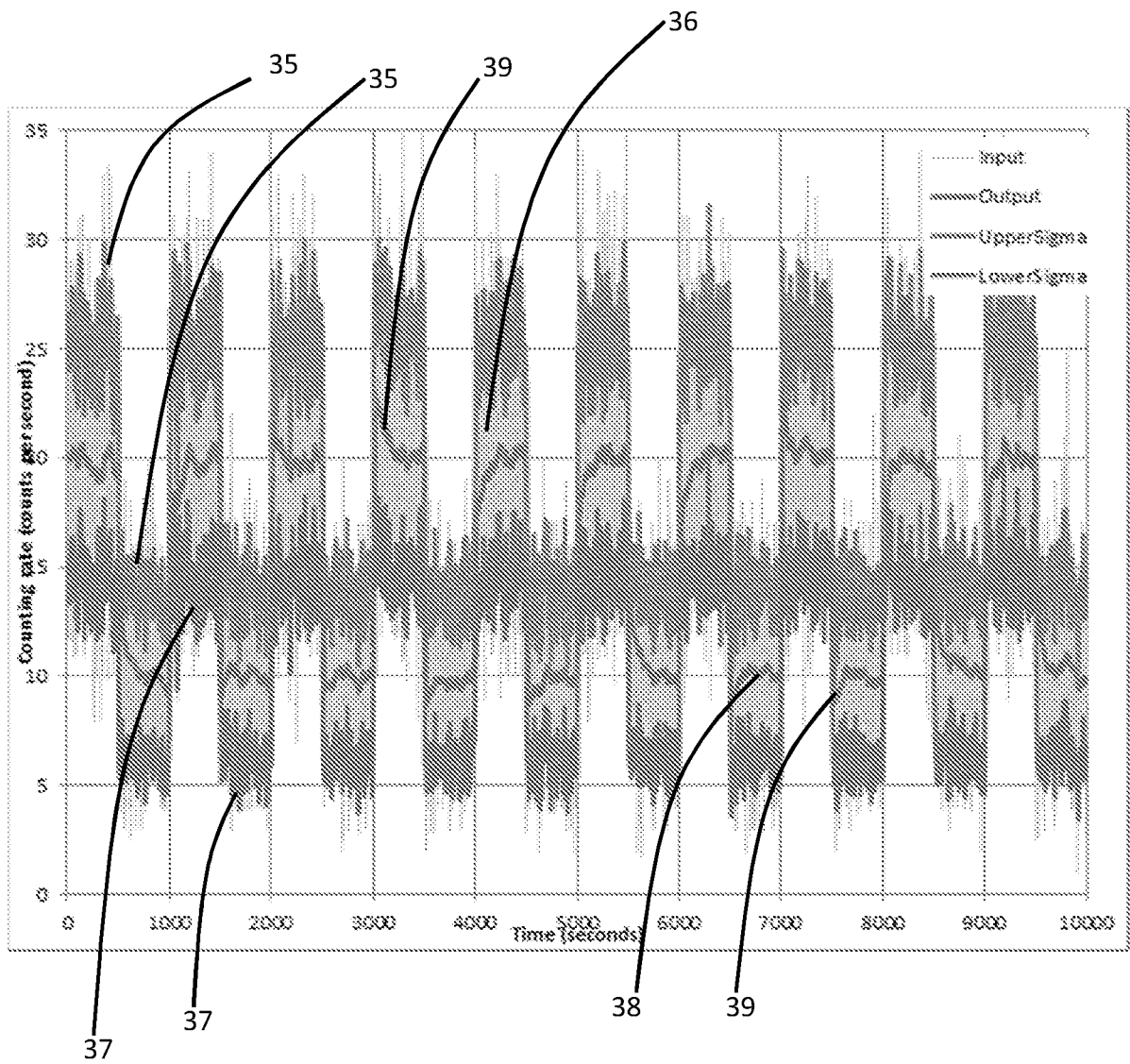


Fig. 12

INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2017/051378

A. CLASSIFICATION OF SUBJECT MATTER
INV. G01F23/00 G01F23/288
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G01F G01N

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 4 590 579 A (ERB TOM L [US]) 20 May 1986 (1986-05-20) column 2, lines 35-44; figures 1-5 column 2, line 67 - column 3, line 34 column 4, line 63 - column 5, line 14 -----	1-8
A	US 2006/287945 A1 (SPACCATROSI ANDREA [GB]) 21 December 2006 (2006-12-21) paragraph [0059] ----- -/--	1-8



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

14 August 2017

Date of mailing of the international search report

22/08/2017

Name and mailing address of the ISA/

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040,
Fax: (+31-70) 340-3016

Authorized officer

Tomasoni, Flora

INTERNATIONAL SEARCH REPORT

International application No.
PCT/GB2017/051378

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:
2. ☒ Claims Nos.: 9, 10
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
see FURTHER INFORMATION sheet PCT/ISA/210
3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
- ☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
- ☐ No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

Continuation of Box II.2

Claims Nos.: 9, 10

Claims 9 and 10 contain a reference to the drawings. According to Rule 6.2(a) PCT, claims should not contain such references except where absolutely necessary, which is not the case here. Furthermore, claim 9 recites a radiation measurement apparatus as described with reference to the figures, while in the figures nowhere such an apparatus appears and claim 10 recites a method as described with reference to the figures, while in the figures nowhere the steps of such a method appear. The non-compliance with the substantive provisions is to such an extent that no meaningful search of claims 9 and 10 could be carried out at all (Article 17(2) PCT).

The applicant's attention is drawn to the fact that claims relating to inventions in respect of which no international search report has been established need not be the subject of an international preliminary examination (Rule 66.1(e) PCT). The applicant is advised that the EPO policy when acting as an International Preliminary Examining Authority is normally not to carry out a preliminary examination on matter which has not been searched. This is the case irrespective of whether or not the claims are amended following receipt of the search report or during any Chapter II procedure. If the application proceeds into the regional phase before the EPO, the applicant is reminded that a search may be carried out during examination before the EPO (see EPO Guidelines C-IV, 7.2), should the problems which led to the Article 17(2) declaration be overcome.

INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2017/051378

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	Anonymous: "MACD - Wikipedia, the free encyclopedia", 3 February 2016 (2016-02-03), XP055398369, Retrieved from the Internet: URL:https://web.archive.org/web/20160603115752/https://en.wikipedia.org/wiki/MACD [retrieved on 2017-08-11] the whole document -----	1-8
A	US 2016/055587 A1 (CHAU MANUEL [MO]) 25 February 2016 (2016-02-25) the whole document -----	1-8

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/GB2017/051378

Patent document cited in search report		Publication date	Patent family member(s)	Publication date
US 4590579	A	20-05-1986	US 4590579 A	20-05-1986
			ZA 8406105 B	27-03-1985

US 2006287945	A1	21-12-2006	NONE	

US 2016055587	A1	25-02-2016	NONE	
