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(54) **METHOD FOR DETERMINING LONG TERM STABILITY**

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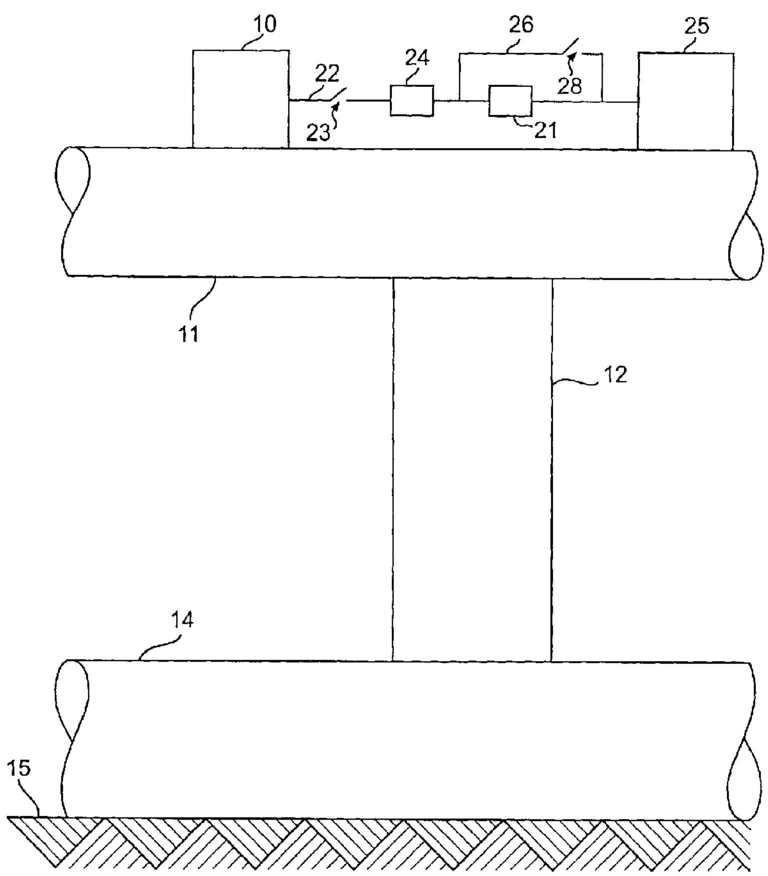
(57) **ABSTRACT**

A method of determining long term power variation, as an indication of long term stability of power output, by steps of measuring power output at successive intervals of time, determining variations in power output, from an average power output, at corresponding intervals of time, making a Fourier transform of each variation in power output, calculating a power spectral density from each Fourier transform, plotting a log of each power spectral density, extrapolating the plot to find a value, designated as a log of a power spectral density, from the plot, calculating a power spectral density from the found value of the log of the power spectral density, and making an inverse Fourier transform of the calculated power spectral density, to determine the long term power variation.

1 Claim, 2 Drawing Sheets



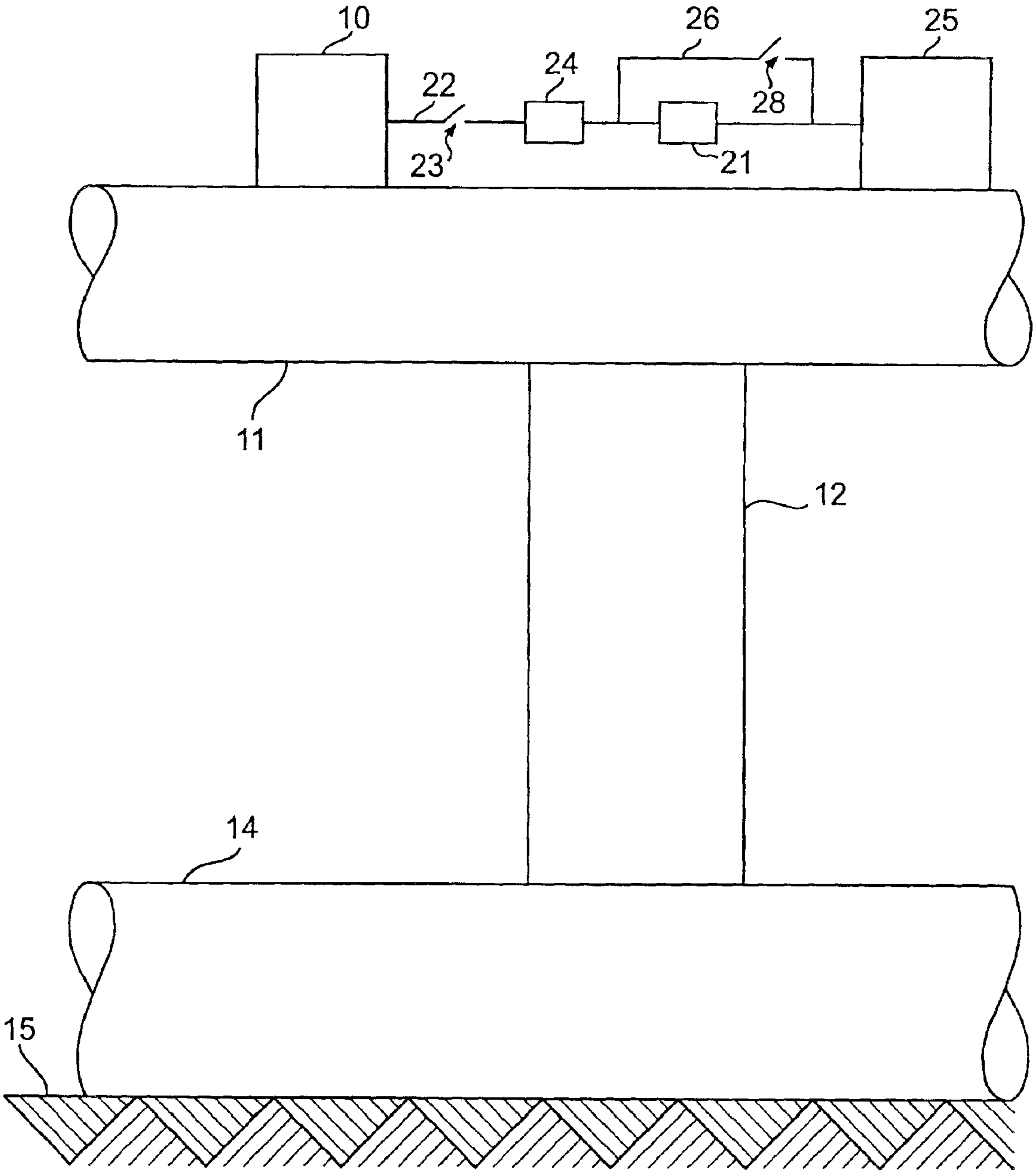
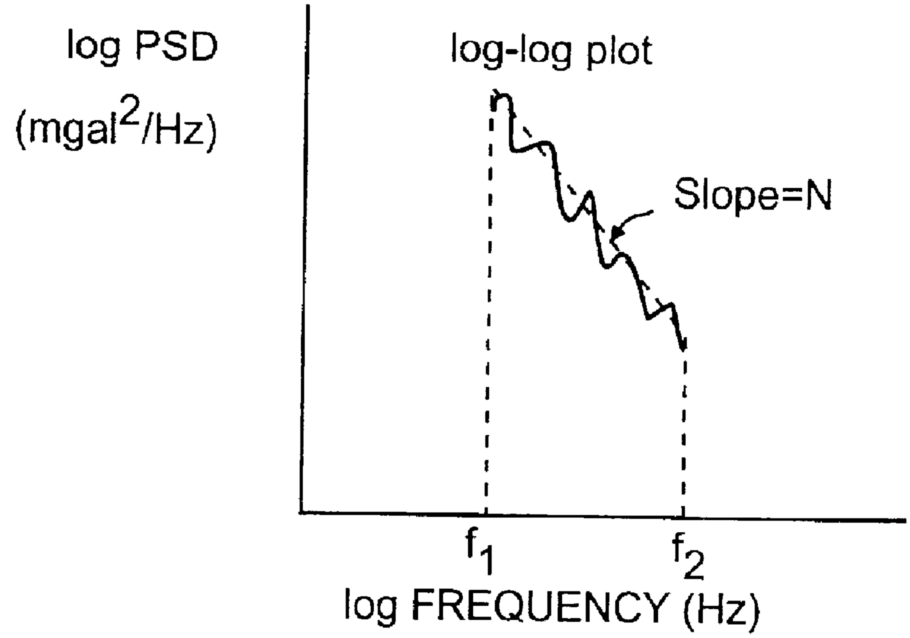


FIG. 1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(mgal^2/Hz)
log-log plot
Slope=N
f_1
f_2
log FREQUENCY (Hz)

FIG. 2

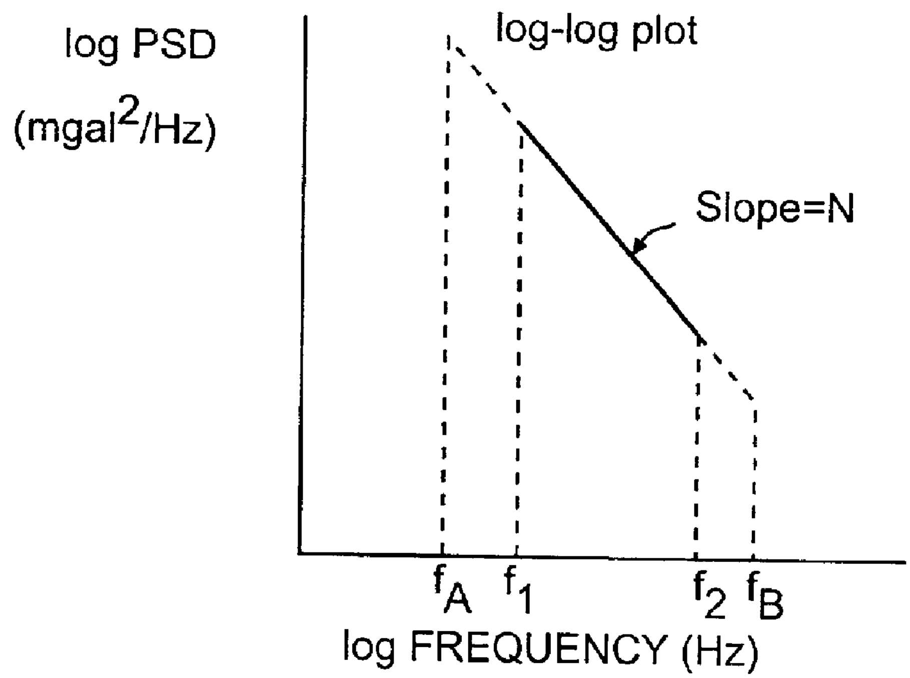
log PSD
(mgal^2/Hz)
log-log plot
Slope=N
f_A
f_1
f_2
f_B
log FREQUENCY (Hz)

FIG. 3

METHOD FOR DETERMINING LONG TERM STABILITY

FIELD OF THE INVENTION

The present invention relates to a method of determining an indication of long term stability of power output from a device such as a gravity meter.

BACKGROUND OF THE INVENTION

In the past, power output from a device such as a gravity meter had to be measured over a long term T_A, in order to determine long term stability of the power output from the device. Variations, Delta P_{T2}, Delta P_{T3} . . . Delta P_{TA} from a null power output value, P, of the device would be measured over the term T_A. This period of time T_A would be needed to determine a long term variation Delta P_{TA} from the null power output value P. T_A is an empirically determined drift cycle time for power output variations of such devices.

The present method allows one to determine Delta P_{TA}, as an indication of long term stability of power output, without having to take measurements of power output over a long term T_A. The present method allows one to determine long term stability of power output of the device, even though measurements are not taken over a period of a drift cycle time, T_A.

In the present method, measurements of the power output values P_{T2}, P_{T3} etc. of the gravity meter are made at intervals of time T_2, T_3, T_4 etc, until a length of time T_1 is reached. Here T_3 equals twice T_2. T_4 equals three times T_2. A power output plot versus time, is formed from the set of power output values.

A center line is drawn through the power output plot. This center line represents the constant power output,P, of the gravity meter. A set of power output variation values, Delta P_{T2}, Delta P_{T3} . . . Delta P_{T1} from value P is calculated. The vavalues in this set is correspond to the regular intervals of time from T_2 to T_1.

A Fourier transform of each power output variation, Delta P_{T2}, Delta P_{T3}, . . . Delta P_{T1}, is made. A power spectral density value PSD is calculated. PSD is the value of the Fourier transform at a particula frequency f_T, where f_T equals 1/T. For example, a power spectral density value, $(PSD)_{T2}$, is the value of the Fourier transform of Delta P_{T2}, at the frequency $f_2=1/T_2$. A power spectral density value $(PSD)_{T3}$ is the value of the Fourier transform of Delta P_{T3} at the frequency $f_3=1/T_3$. A power spectral density value $(PSD)_{T1}$ is the value of the Fourier transform of Delta P_{T1} at the frequency $f_1=1/T_1$.

The log of each calculated power spectral density value is ploted against the log of a frequency associated with the length of time required to find a power output variation associate with each calculated power spectral density value. The plotting is done on log-log paper. This log-log paper is an example of a log-log form.

The power spectral density log plot can be extrapolated, in order to find a log of a power spectral density value $(PSD)_{TA}$ a a value that is the log of a frequency $f_A=1/T_A$. The value of $(PSD)_{TA}$ and f_A are found from the log values of $(PSD)_{TA}$ and f_A.

The inverse Fourier transform of the power spectral density value $(PSD)_{TA}$ is taken in order to find the variation, Delta P_{TA}.

One can determine a line of slope of the power spectral density plot, and can therefore extrapolate the line of slop. plot. This determination of a lione of slope is performed by examining the power spectral densty plot generated from data taken over a length of time T_1, that is at intervals T_2, T_3, T_4 . . . T_1.

One does not have to measure a power variation, Delta P_{TA}, in the power output of a gravity meter at a time T_A, in order to determine the power output drift, or variation, for this time T_A. One can merely measure the slope of the power spectral density curve in order to predict the value of the power spectral density at a time, T_A, and take the inverse Fourier transform of that value.

Further one can find noise power, P_{TATB}, in a bandwith between f_A and f_B, where f_B is smaller than f_2. One first integrates a power density function, S(f), that gives the ploted power spectral density, $(PSD)_T$, between f_1 and f_2, to find a noise power P_{T1T2}. Then one uses the value P_{T1T2} in an algorithm to find P_{TATB}.

SUMMARY OF THE INVENTION

A method of determining power variation Delta P_{TA} as an indication of long term stability of power output comprising determining power output at successive intervals of time T beginning at a first interval of time T_2 and continuing to an interval of time T_1, where time T_1 is shorter than an interval of time T_A, determining variations, Delta P_{T2} to Delta P_{T1}, in power output, from an average power output P, at corresponding intervals of time from T_2 to T_1, making a Fourier transform of each variation in power output, calculating a power spectral density, from $(PSD)_{T2}$ to $(PSD)_{T1}$, from each Fourier transform, at a frequency f, where f equals 1 over an interval of time T associated with each Fourier transform, plotting a log of each power spectral density, from $(PSD)_{T2}$ to $(PSD)_{T1}$ at a log of the associated frequency f, on a log-log plot form, extrapolating value designated as a a log of a power spectral density, $(PSD)_{TA}$, at a log of a frequency f_A, where f_A equals $1/T_A$, from the plot form, calculating the power spectral density $(PSD)_{TA}$ from the log of the power spectral density $(PSA)_{TA}$, making an inverse Fourier transform of the power spectral density $(PSD)_{TA}$ to determine power variation Delta P_{TA}.

DESCRIPTION OF THE DRAWING

FIG. **1** is a plan diagram of a test setup to determine power output of a gravity meter,

FIG. **2** is a power spectral density curve, using power output variation measurements over a length of time T_1.

FIG. **3** is an extrapolated power spectral density curve that predicts power spectral density at a long period of time T_A, where T_A is an empirically determined drift cycle time in power output of a gravity meter.

DESCRIPTION OF THE PREFERRED EMBODIMENT

In FIG. **1**, a gravity meter **10** is located on a table **11**. The table **11** is rigidly attached to a pedestal **12**. The pedestal **12** is anchored to a concrete floor **14**. The concrete floor **14** extends for 50 feet horizontally over the earth **15** in all directions from the gravity meter **10**. The concrete floor **14** is solidly joined to the earth **15**.

The gravity meter **10** is electrically connected to a capacitor **21** be means of an electrical cable **22**, the connection being through a switch **23** and also through a full wave rectifier **24**. The gravity meter **10** is shown as energized. Power output of the gravity meter **10** is nulled to a nominal zero voltage output while gravity meter **10** is measuring acceleration due to local gravity. The power out of the gravity meter **10** has a nominally nulled zero voltage value due to a constant force of gravity of 1 g.

Noise energy E_2, due to drift in the gavity meter **10**, is collected by the capacitor **21** for one hour and produces a voltage V_2 in capacitor **21**. The noise energy E_2, due to drift, is accumulated in capacitor **21** over an interval T_2 of one hour. That is, the energy, generated due to unstable circuit elements within the gravity meter **10**, for a period T_2 of one hour, is gathered in an energy accumulator, such as capacitor **21**.

A volt meter **25** is connected through an electrical cable **26** and a switch **28**. Switch **23** is opened and switch **28** is closed. The voltage reading V_2 of the capacitor **21** is taken after one hour by volt meter **25**. The associated frequency for this reading is f_2. f_2 equals $1/T_2$.

Switch **28** is then opened and switch **23** is closed.

The voltage reading V_3 of the capacitor **21** is repeated after a second hour. The associated energy-gathering period T_3 for this latter voltage reading, V_3, is two hours. T_3 equals twice T_2. The associated frequency for the latter reading is f_3. f_3 equals $1/T_3$. The energy collected after two hours is E_3.

Reading of voltages, V_2, V_3 . . . etc. of capacitor **21** are taken at periodic intervals T_2, T_3 . . . etc. The associated frequencies for the readings are $f_2=1/T_2$, $f_3=1/T_3$ . . . etc. The associated noise energies are E_2, E_3 . . . etc.

Twenty four voltage readings of capacitor **21** are taken, at one hour intervals. The twenty four voltage readings are thus obtained over a length of time of 24 hours, a time designated as T_1.

Again, an accumulation of drift energy is continued in capacitor **21** for twenty four intervals, each period being greater than the previous interval by a time T_2. The first interval, T_2, is one hour long. The twenty-fourth interval, T_1, is twenty four hours long. The twenty fourth accumulation of energy is the total noise energy E_1 that is generated by the gravity meter **10** over a twenty-four hour period T_1. The noise energy E_1, due to drift over a 24 hour period T_1, is thus determined.

A power value P_{T2}, where $P_{T2}=E_2/T_2$, is determined. A power value P_{T3}, where $P_{T3}=E_3/T_3$, is also determined. This determination is repeated until a power value P_{T1}, where $P_{T1}=E_1/T_1$, is determined.

The noise power values P_{T2}, P_{T3} . . . P_{T1} are plotted and a straight line drawn through the plot. This straight line represents the average noise power out of the gravity meter **10** over the twenty four one hour lengths of time.

Twenty four power variations, Delta P_{T2}, Delta P_{T3} . . . Delta P_{T1}, from the straight line, are obtained.

The power variations, Delta P, are determined after reading voltage levels, V_2, V_3, V_4, . . . V_1 of the capacitor **21**. Since $E=CV_2$, where C is the capacitance of capacitor **21**, the energy values E can be determined. Then twenty four noise power values P_{T2}, P_{T3}, P_{T4} . . . P_{T1} are determined using the energy values E_2, E_3, E_4 . . . E_1 that are determined for the twenty four periods of time T_2, T_3, T_4 . . . T_1 during which energy, collected by capacitor **21**, is measured. A frequency f_2, equal to $1/T_2$, is calculated. f_2 is associated with a power variation Delta P_{T2}. A frequency f_3, equal to $1/T_3$, is also calculated. f_3 is associated with power variation Delta P_{T3}. This is repeated until a frequency f_1, equal to $1/T_1$, is calculated. f_1 is associated with power variation Delta P_{T1}.

Each of these power variations, Delta P, is operated on by a Fourier transform process. A Fourier transform, FT, for each power variation, Delta P, is found.

A power spectral density value (PSD) for each power variation is found. A power spectral density value (PSD) is the value of a Fourier transform FT of a power variation Delta P, at as associated frequency f. For instance, a power spectral density value $(PSD)_{T2}$ is found from Fourier transform, FT, of Delta P_{T2} at f_2.

Power spectral density values $(PSD)_{T2}$, $(PSD)_{T3}$ . . . $(PSD)_{T1}$ are the values of the twenty four Fourier transforms of the power variation values Delta P_{T2}, Delta P_{T3} . . . Delta P_{T1} at the frequencies f_2, f_3 . . . f_1. A book on how to take a Fourier transform of a value, is entitled "Signal Analysis And Estimation" by Ronald L. Frante, John Wiley & Sons (1988). This book is incorporated herein by reference.

As shown in FIG. **2**, a log of a power spectral density value (PSD) associated with each of the twenty four frequencies f_2, f_3 . . . f_1 is plotted on a log-log plot. The value of the log of a power spectral density value (PSD) is plotted at the value of the log of the frequency f used in finding (PSD).

An algorithm is generated. The algorithm describes a line through the points of the log-log plot, as shown in FIG. **2**. The algorithm is used to evaluate the stability of the gravity meter **10**. The algorithm is:

$$\log(PSD)=\log(k)+N\log(f),$$

where (PSD) is power spectral density associated with an energy E collected over an interval of time T, and f equals 1/T. N is the slope of the straight line, shown in FIG. **2**, drawn through the log-log plot. N is a negative number.

Thus,

$$\log(PSD)_{T1}=\log(k)+N\log(f_1).$$

Also,

$$\log(PSD)_{T2}=\log(k)+N\log(f_2).$$

By extrapolation of the line of FIG. **2**, the point $\log(PSD)_{TA}=\log(k)+N\log(f_A)$, is reached, as shown in FIG. **3**.

Also, $\log(PSD)=\log(k)-N\log(T)$, where (PSD) is power spectral density associated with an energy E collected over an interval of time T, and T equals 1/f.

Thus,

$$\log(PSD)_{T1}=\log(k)-N\log(T_1).$$

Also,

$$\log(PSD)_{T2}=\log(k)-N\log(T_2).$$

To find the value of N, $\log(PSD)_{T2}$ is subtracted from $\log(PSD)_{T1}$. Then $\log(PSD)_{T1}-\log(PSD)_{T2}=N\log(T_2)-N\log(T_1)$. $N=[(\log(PSD)_{T1}-\log(PSD)_{T2})/(\log(T_2)-\log(T_1))]$.

To find the value of log (k), the found value for N is substituted into $\log(PSD)_{T1}=\log(k)-N\log(T_1)$. Thus,

$$\log(k)=\log(PSD)_{T1}=[(\log(PSD)_{T1}-\log(PSD)_{T2})/(\log(T_2)-\log(T_1))](\log T_1).$$

I. Determination of P_{TA}

Substituting the values for N and log (k) into $\log(PSD)_{TA}=\log(k)-N\log(T_A)$, the value for $\log(PSD)_{TA}$ is $\log(PSD)_{TA}=\log(PSD)_{T1}+[(\log(PSD)_{T1}-\log(PSD)_{T2})/(\log(T_2)-\log(T_1))](\log T_1)-[(\log(PSD)_{T1}-\log(PSD)_{T2})/(\log$

$(T_2)-\log(T_1))](\log T_A)$. The log of the power spectral density $(PSA)_{TA}$, $\log(PSD)_{TA}$, due to an amount of drift after a thirty day time T_A, is thusly determined.

The power spectral density $(PSA)_{TA}$, for a time T_A, is found by taking the inverse log of log $(PSD)_{TA}$. Delta P_{TA} is found by taking the inverse Fourier transform of $(PSA)_{TA}$.

From the power spectral density $(PSA)_{TA}$, one can find the variation, Delta P_{TA}, that is, the output noise power variation from the average output noise power P, of the gravity meter **10**, after a relatively long time T_A. Again, delta P_{TA} is found by taking the inverse Fourier transform of the power spectral density $(PSD)_{TA}$.

Further

$$(PSD)_{T2}=kf_2^{\,N}=k(1/T_2)^N=k(T_2^{-1})^N=kT_2^{-N}.$$

$$(PSD)_{T1}=kf_1^{\,N}=K(1/T_1)^N=k(T_1^{-1})^N=kT_1^{-N}.$$

N is the slope of the straight line drawn through the log-log plot of FIG. **2**. Again N is a negative number.

The capacitor **21** collects energy when the drift of gravity meter **10** is positive. Capacitor **21** also collects energy when the drift of gravity meter **10** is negative. The capacitor **21** should be a very low noise capacitor. The values of noise energy for 24 intervals are measured. The power spectral densities are determined by taking the Fourier transforms of variations from an average power, for the 24 measured energies involved.

It is found that an algorithm, such that log of the power spectral density (PSD) equals the log of k, where k is a constant, minus N times the log of the frequency for the particular power spectral density, defines the line shown in the log-log plot of FIG. **2**. N is the slope of the straight line fitted to the log-log plot of FIG. **2**.

II. Determination of P_{TATB}

The above found value of N is used in another algorithm to find the noise power, P_{TATB}, in the bandwith between frequencies f_A and f_B. $P_{TATB=PT1T2}[(f_B^{\,N+1}-f_A^{\,N+1})/(f_2^{\,N+1}-f_1^{\,N+1})]$. P_{T1T2} is found by first integrating a power spectral function S(f) from the log of the frequency f_1 to the log of the frequency f_2. S(f) is a mathematical expression generated to mathematically express the plot of the log of the power spectral density of FIG. **2**. P_{T1T2} is the noise power in the bandwith between frequencies f_1 and f_2. One can thus determine the noise power, P_{TATB}, in the bandwith between frequencies f_A and f_B.

f_1=/(24 hours) where T1 is 24 hours. f_2=1/(1 hour) where T_2 is 1 hour. f_A is 1/(720 hours) where T_A is 720 hours. f_B could be a lower frequency, such as f_B=1/(½ hour). T_B is a period of ½ hour.

In the above example:

$$f_1=1/T_1\quad T_1=24\text{ hours}$$

$$f_2=1/T_2\quad T_2=1\text{ hour}$$

$$f_A=1/T_A\quad T_A=720\text{ hours}$$

$$f_B=1/T_B\quad T_B=½\text{ hour}$$

While the present invention has been disclosed in connection with the preferred embodiment thereof, it should be understood that there may be other embodiments which fall within the spirit and scope of the invention as defined by the following claims.

What is claimed is:

1. A method of determining power variation Delta P_{TA} as an indication of long term stability of power output, comprising:

(a) determing power output at successive intervals of time T beginning at a first interval of time T_2 and continuing to an interval of time T_1, where time T_1 is shorter than an interval of time T_A;

(b) determining variations, Delta P_{T2} to Delta P_{T1}, in power output, from an average power output P, at corresponding intervals of time T_2 to T_1;

(c) making a Fourier transform of each variation in power output;

(d) calculating a power spectral density, from $(PSD)_{T2}$ to $(PSD)_{T1}$, from each Fourier transform, at a frequency f_T, where T is the interval of time associated with each Fourier transform;

(e) plotting of a log of each power spectral density $(PSD)_{T2}$ to $(PSD)_{T1}$ at a log of the associated frequency f, on a log-log plot form;

(f) extrapolating a value designated as a log of a power spectral density $(PSD)_{TA}$, at a log of frequency f_A, where f_A equals $1/T_A$, from the plot form;

(g) calculating the power spectral density $(PSD)_{TA}$ from the log of the power spectral density $(PSD)_{TA}$;

(h) making an inverse Fourier transform of the power spectral density $(PSD)_{TA}$ to determine power variation Delta P_{TA}.

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