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CERTIFICATE OF CORRECTION

PATENT NO. : 5,723,980
DATED : March 3, 1998
INVENTOR(S) : Haase et al.

Page 1 of 8

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Title page,
The title page should be deleted to appear as per attached title page.

Please delete columns 1-8 and substitute columns 1-12 as per attached.

Signed and Sealed this

Fourth Day of June, 2002

Attest:

JAMES E. ROGAN

Attesting Officer

Director of the United States Patent and Trademark Office

United States Patent [19]

Haase et al.

[11] **Patent Number: 5,723,980**

[45] **Date of Patent: Mar. 3, 1998**

[54] CLEARANCE MEASUREMENT SYSTEM

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[51] **Int. Cl.**^{6} **G01R 27/26**

[52] **U.S. Cl.** **324/662**; 324/601; 324/671

[58] **Field of Search** 324/661, 662, 324/663, 601, 671, 672

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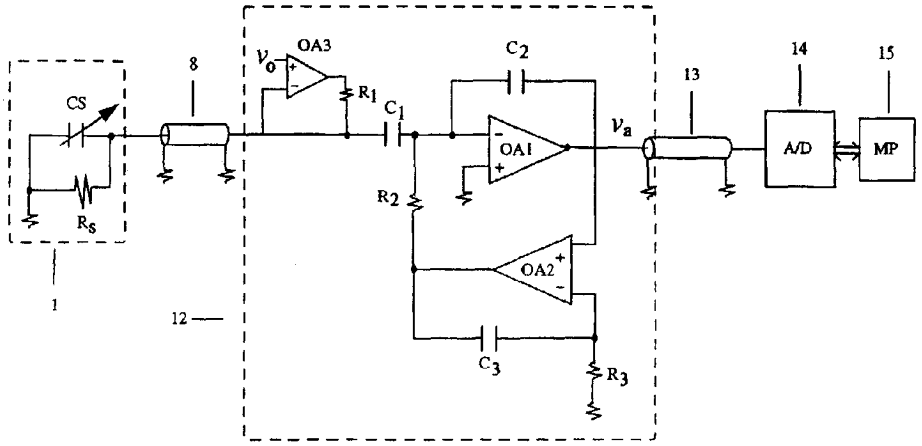
[57] **ABSTRACT**

Disclosed are a system and method for the accurately calibrated non-contact capacitive measurement of small distances between relatively movable elements. The system and method are particularly well-suited for use in environments of high temperature, pressure, and vibration, including in jet engines to measure the gap between fan blades and the engine wall. A sensor disposed in a housing wall receives constant bias voltage and forms a sensing capacitor with the moving targets, which move past the sensor. A blocking capacitor allows a signal generated at the sensor to pass to a constant gain amplifier, which amplifies the signal and passes the amplified signal to a computer for calculating the small distances between the relatively movable elements using the bias voltage, the gain, and the maxima and/or minima of the amplified output signal.

20 Claims, 4 Drawing Sheets



CLEARANCE MEASUREMENT SYSTEM

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to an efficient, accurately calibrated system for the non-contact measurement of small distances between two relatively movable elements based on the variation in capacitance between the elements. More particularly, the invention relates to a capacitive sensor system that continuously measures the clearance or gap between a large number of fast moving targets, such as the tips of a rotor blade in the turbine or compressor sections of a gas turbine engine, and the adjacent housing wall.

2. Description of Related Art

Numerous performance characteristics of gas turbine engines, such as fuel efficiency, compression ratio and thrust, depend strongly on the clearance or gap distance between the tips of the rotor blades and the adjacent housing. A number of different methods have been proposed to measure this gap, including eddy current, capacitance, magnetic proximity, optics and near-contact spark discharge. For example, eddy current sensors are described in U.S. Pat. Nos. 4,518,917 and 5,097,711. Single-electrode capacitive sensors are described in U.S. Pat. No. 4,813,273. Multiple-electrode capacitive sensors are described in U.S. Pat. Nos. 2,842,738, 4,063,167, 4,122,708, and 4,823,071. Capacitive sensors with integral electrical components are described in U.S. Pat. No. 5,119,036. Methods employing magnets embedded in the rotor blades are described in U.S. Pat. Nos. 2,575,710 and 4,922,757. An optical triangulation method is referenced in U.S. Pat. No. 4,823,071. A near contact electrical discharge method is referenced in U.S. Pat. No. 4,823,071. However, these measurement methods are either unsuitable to or are less effective in the hostile environment of equipment such as turbine engines, in which the sensors must be able to withstand temperatures exceeding 1000 degrees Centigrade, pressures in excess of twenty-five atmospheres, and excessive vibration. Furthermore, the high rotational speed of the blades in a turbine engine requires high bandwidth, which limits the signal-to-noise ratio of the measurement.

Past use of capacitive sensors in gas turbine engines has been ineffective for a number of reasons. Some capacitive sensor systems place an amplifier very close to the sensor, but these systems do not perform well in this environment because of the extremely high operating temperatures near the sensor. The sensor may experience temperatures in the 500 to 1000 degrees C. range, while a nearby amplifier may experience temperatures in the 100 to 400 degrees C. range.

Other capacitive sensor systems use electronic components, such as inductors or diodes, in the sensor in an effort to reduce the effects induced by temperature changes and vibration in the connecting cable between the sensor and amplifier. Such components are also intended to reduce the loading effect of cable capacitance. However, these electronic components are affected similarly by the high temperatures and vibration near the sensor, severely degrading system performance.

Other capacitive sensor systems (for example, those described in U.S. Pat. Nos. 4,122,708 and 4,831,071) use no electrical components in the sensor and have attempted to overcome the effects of vibration and high temperature on the interconnecting cable by means of guarding. These systems are based on the theory that vibration causes a change in the cable capacitance, and that providing a zero DC voltage between the cable center conductor and its shield should prevent vibration from creating an output signal.

In fact, guarding is not an effective solution because vibration of a cable causes more effects than simply a change in capacitance. If the dielectric material is slightly piezoelectric, then a bending of the cable will generate a charge or voltage difference between the cable center conductor and its shield. For example, all ferroelectric dielectrics (those whose molecules exhibit a dipole moment) are piezoelectric. Even quartz—one of the most stable of dielectrics exhibits piezoelectric effects without being ferroelectric due to a three-fold symmetry axis. In this situation, a zero DC voltage bias will not prevent an output signal due to vibration.

Similarly, if the dielectric material is slightly pyroelectric, then a temperature change will produce an output signal. A zero DC voltage again will not prevent the undesired output signal. Further, triboelectric effects, which arise due to very small sliding motions between the inner conductor, dielectric, and outer conductor of the cable, can cause a charge or voltage difference between the cable center conductor and outer shield. In many measurement situations, the change in the preamp output because of a change in the sensor capacitance resulting from a change in the measured parameter (e.g., blade tip clearance) is often of the same order of magnitude as the piezoelectric, triboelectric, and pyroelectric effects caused by cable vibration. None of the prior art systems are able to compensate for these effects.

Many capacitive measurement systems use modulation techniques to determine the value of the sensor capacitance. The frequency response of these systems is consequently constrained by the Nyquist criterion to be less than half of the modulation frequency. This restriction, in turn, severely limits their application to the measurement of rotating turbine blades.

In all of the above-mentioned measurement systems, calibration is accomplished by placing the sensor at one or several specific positions in front of a target and adjusting the output of the system so that it indicates the correct position. Thus the calibration methods are based on positions of known distance from the sensor. Calibration is therefore a cumbersome process which may require stopping the movable elements or fan blades in order to be performed. As disclosed in this specification, the calibration method of the present invention is substantially more convenient, and allows constant calibration without stopping the movable elements.

SUMMARY OF THE INVENTION

In a broad sense, the present invention relates to an efficient, accurately calibrated system for noncontact measurement of the distance between two relatively movable elements based on the variation in electrical capacitance between the two elements. More specifically, the present invention relates to a capacitive sensor system that continuously measures the clearance or gap between a large number of fast moving targets, such as gas turbine rotor blades, and their surrounding housing by use of a small, uncooled sensor. The variation in electrical capacitance between the sensor and the blade tip provides the mechanism for the measurement of the gap.

Therefore, an object of the present invention is to provide a measurement system having wide bandwidth and high signal-to-noise ratio, which enables measurements to be made on individual fast-moving elements or fan blades.

A further object of the invention is to provide a measurement system having a simple calibration mechanism and to maintain calibration accuracy over a long period of time (for example, in excess of 10,000 hours) even in the adverse environment of a gas turbine engine, which produces high temperature and pressure (for example, 1000 degrees C. and 25 atmospheres) and high vibration.

Another object of the present invention is to provide a simple sensor and connecting cable architecture and to allow for a large distance (for example, 10 to 50 feet) between the sensor and the first stage of electronic amplification; this in turn allows the amplifier to be remotely located from the movable elements in a more benign environment and uses minimal space within a housing.

A further object of the present invention is to reduce the sensitivity of the measurement to error signals caused by the environmental effects of temperature and vibration on connecting cables. Such error signals include but are not limited to those caused by changes in cable capacitance and charge or voltages induced by piezoelectric, triboelectric or pyroelectric mechanisms.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 shows a cross-sectional view of a sensor of the present invention embedded in the wall of a turbine engine housing, with a rotor blade passing the face of the sensor.

FIG. 2 is an electrical schematic diagram of a circuit that may be used in of one embodiment of the present invention.

FIG. 3 shows a typical analog waveform for a sensor of the present invention at the output of the charge amplifier 12 of FIG. 2 which results from a plurality of turbine blades passing the sensor.

FIG. 4 is an electrical schematic diagram of a circuit that may be used in an embodiment of the present invention to compensate for a resistive path created in parallel with the sensor capacitance.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

The present invention uses a non-contact, capacitive method to measure the gap between a sensor and a rapidly moving target or group of targets at substantially ground potential passing by the sensor. As an example, FIG. 1 shows a sensor **1**, located in the outer wall 2 of a turbine engine, which faces the tip 3 of the rotating turbine or compressor blade 4. The three primary components of the sensor 1 are the outer electrode 5, the dielectric 6, and the inner electrode 7. The outer electrode 5 is connected both mechanically and electrically to the engine outer wall 2. The inner electrode 7 is electrically insulated from the outer electrode 5 by means of the dielectric 6. The physical shapes depicted in FIG. 1 may be modified to insure that the high pressures exerted inside the engine do not cause relative motion of the inner electrode 7 or dielectric 6. The use of a separate outer electrode 5 is not necessary, because the outer wall 2 can perform the function of the outer electrode.

As the turbine blade 4 passes the sensor inner electrode 7, a parallel-plate capacitor is formed. Ignoring fringing fields, the capacitance of this structure is described by Equation (1):

$$C_s = \epsilon A/D \qquad (1)$$

where ϵ is the dielectric constant of the dielectric material 6 between the plates of the capacitor, A is the area of the face of the plates, and D is the distance or clearance gap between the plates. Thus by measuring the value of C_s, the value of the tip clearance or tip-to-wall distance D can be determined. As shown below, deviations from Equation (1) because of fringing fields, variations in the shape of the physical parts, and the presence of insulating or conductive structures can be easily accommodated in more precise calculations of D.

For the method and apparatus used in the present invention, the basic measurement parameter, capacitance, should be asymptotic in nature. A plot of Equation (1) would show that the capacitance C_s asymptotically approaches a constant value (zero) as the distance D increases without bound. This feature enables the present invention to accomplish an extremely accurate calibration of the measurement of D. The present invention does not require the more conventional calibration method of putting a target at a series of known distances in front of the sensor, and adjusting the system output. Instead, because C_s is sufficiently close to a known value (in this case, zero) at a given point in the measurement cycle, the present invention achieves accurate measurements of D. Additionally, this known value enables the present invention to achieve excellent long-term stability of the measurement of D, without the need for stopping the engine and recalibrating.

A coaxial cable **8** is coupled to the sensor **1**. The coaxial cable consists of an outer shield **9**, a dielectric **10**, and an inner conductor **11**. The inner conductor **11** is electrically insulated from the outer shield **9** by the dielectric **10**. The outer shield **9** is electrically connected to the sensor outer electrode **5**. The inner conductor **11** is electrically connected to the sensor inner electrode **7**.

In a preferred embodiment as shown in FIG. **2**, a combination of analog and digital circuits perform the function of determining the value of the tip clearance D. Sensor **1** and cable **8** are connected to a charge amplifier **12**, which generates an output voltage V_A. The output of charge amplifier **12** is connected by means of cable **13** to an analog-to-digital (A/D) converter **14**, which is controlled by a microprocessor **15**. In its simplest form, the charge amplifier **12** consists of operational amplifier OA_1 around which a feedback capacitor C_2 is connected. A DC restoration circuit prevents operational amplifier OA_1 from saturating. While the restoration could be accomplished by a single resistor in parallel with C_2, much better performance is obtained by the use of a circuit composed of operational amplifier OA_2, resistors R_2 and R_3, and capacitor C_3.

Charge amplifier **12** may also include series connected capacitor C_1, which acts as a blocking capacitor, and resistor R_1. When voltage V_0 is applied across resistor R_1, the network of resistor R_1 and capacitor C_1 allows a DC voltage to be applied to the inner electrode 7 of the sensor 1 but not to the amplifier input. Thus the polarity and value of the voltage V_0 can be set independently of the characteristics of amplifier OA_1, which is important because calculation shows that the gain of the system is proportional to V_0. Thus to achieve a high signal-to-noise ratio in the measurement, a large value of V_0 is desired, and this high value can be achieved by the apparatus and method of this invention.

In many measurement systems, the use of series-connected capacitor C_1 would normally introduce an AC coupling problem that would prevent accurate DC measurements. This problem occurs because series connected capacitor C_1 would normally cause the average voltage output at amplifier OA_1 to be constant, independent of the variation in gap. If the distance between sensor 1 and the blade tip 4 remained constant, then capacitor C_1 would normally prevent absolute calibration of the clearance gap D. Capacitor C_3 also would normally be capable of introducing AC coupling. However, the signal processing used in the present invention overcomes the AC coupling problem and is able to accomplish absolute calibration of the clearance gap D.

An additional feature of the present invention is that charge amplifier **12** can exhibit very high frequency response, which is necessary to allow separate measurements on each of the fast moving elements **4**. Other methods that use a carrier frequency (typically 10 kHz to 1 MHz) result in a high frequency response that is even less than half the carrier frequency. In contrast, the use of a DC voltage in conjunction with the motion of the element or blade allows the measurement bandwidth to be as wide as the charge amplifier bandwidth, which can easily be up to 10 MHz for charge amplifiers built with commercially available integrated circuits, and even higher for charge amplifiers built with discrete components.

The output v_A of charge amplifier **12** may be fed to an analog/digital converter **14** by means of a coaxial cable **13**. The A/D converter **14** converts the output analog signal v_A to digital form for subsequent processing. In practice, the cable **13** can be of substantial length (on the order of several hundred feet, if needed) to separate the converter **14** from the high temperature, high vibration environment of the moving elements, without degrading the performance of the system. If desired, the system can use a cable driver to allow even longer distances between the charge amplifier **12** and the analog/digital converter **14**.

In a preferred embodiment, microprocessor **15** controls the sampling times of A/D converter **14** and performs the mathematical calculations that are used to determine clearance gap D. Microprocessor **15** calculates the value of the gap D using the exact relationship between gap D and the sensor capacitance C_s. Equation (1) describes this relationship for an ideal parallel-plate capacitor. For more typical capacitance structures, the D-C_s relationship deviates from Equation (1) because of fringing fields and the exact shape of the sensor inner electrode **7**, the rotating blade **4**, the sensor dielectric **6**, and the presence of any nearby conductive or insulating structures, such as the sensor outer conductor **5** and the engine outer wall **2**. The exact relationship between D and C_s can be either derived by known mathematical techniques or measured in laboratory test fixtures. In addition, any calculations related to the measurement of the gap D, such as spectral analysis, total indicated runout, non-repetitive runout, minimum gap, and average gap, can be performed by microprocessor **15**. The use of a combination of analog and digital techniques thus provides additional capabilities in the measurement system.

A typical waveform for the output voltage v_A of charge amplifier **12** is shown in FIG. **3**, which depicts the motion of several turbine blades past sensor **1**. The figure shows several points in time labeled t_0 through t_4 and five corresponding voltage samples labeled v_{A0} through V_{A4}. Together, these five voltage samples may be used to calculate the blade gap at time t_0, as shown in the following discussion. For the particular waveform shown in FIG. 3, the voltage V_o is negative.

If constant voltage V_o is applied to the center electrode **7** of the sensor **1**, the current I required to maintain the voltage is defined by differential Equation (2):

$$I=dQ/dT \tag{2}$$

where

$$Q=C_s\,V_o \tag{3}$$

and where C_s is the capacitance of sensor **1**. When the effects of the cable **8** between the sensor **1** and amplifier **12** are considered, Equation (3) becomes:

$$Q=(C_s+C_o)V_o+Q_n \tag{4}$$

where C_o accounts for the cable and amplifier capacitance and Q_n accounts for the various effects of the cable, including piezoelectric, pyroelectric and triboelectric charge-producing mechanisms. Combining Equations (2) and (4) yields:

$$I=(C_s+C_o)dV_o/dt+V_o\,dC_x/dt+V_o\,dC_o/dt+dQ_n/dt \tag{5}$$

In Equation (5), because the voltage V_o is a constant, the first term on the right hand side is zero and the equation for current becomes:

$$I=V_o\,dC_s/dt+V_o\,dC_o/dt+dQ_n/dt \tag{6}$$

Charge amplifier **12** integrates the current to produce an output voltage v_A which is defined by Equation (7) as:

$$v_A=G\int I\,dt \tag{7}$$

where G is a constant and represents the gain of the amplifier **12**. For the amplifier schematic shown in FIG. **2**,

$$G=-1/C_2 \tag{8}$$

Combining Equations (6) and (7),

$$v_A=G\,V_o\,C_s+G\,V_o\,C_o+G\,Q_n+K \tag{9}$$

where K is a constant of integration and includes such effects as amplifier offset voltage, as well as AC coupling effects because of capacitors C_1 and C_3.

In Equation 9, the first term ($G\ V_o\ C_s$) represents the desired signal. The second term ($G\ V_o\ C_o$) represents an undesired signal which results from changes in cable and amplifier input capacitances because of vibration and temperature changes. The third term ($G\ Q_n$) also represents an undesired signal which results from charge-producing mechanisms of the cable, including piezoelectric, pyroelectric and triboelectric mechanisms.

In addition, carbon deposits or other impurities on the sensor could create an undesired DC resistive path to ground in parallel with C_s, causing the voltage on sensor **1** to vary from V_o. This effect can be overcome either by measuring the voltage on C_s and modifying the calculations, or by using a feedback circuit to force the voltage at sensor **1** to be equal to V_o. An example of such a feedback circuit is shown in FIG. 4, which shows a DC resistive path to ground as R_5 in parallel with C_s and an operational amplifier OA_3 between V_o and R_1.

If the blade tip **3** were in front of sensor **1** at all times, then there would be no way to distinguish any of the right hand terms in Equation 9. However, because a portion of time exists during which no blade is in front of the sensor **1**, during this time the value of D in Equation (1) is very large and hence C_s will be zero. If C_o, Q_n, and K are constant, then under Equation (9) the value of v_A with no blade present would be:

$$v_A[\text{no blade}]=G\,V_o\,C_o+G\,Q_n+K \tag{10}$$

Subtracting the value of the amplifier output voltage when no blade is present (V_a [no blade]) from the value when the blade is present (V_a) and solving for C_s yields:

$$C_s=(1/G\,V_o)\,(v_A-v_A[\text{no blade}]) \tag{11}$$

The subtraction of Equation (11) overcomes the AC coupling problem previously discussed by removing from consideration the DC component of the amplifier **12** output voltage, that is, by removing from consideration the term K.

While the above discussion assumes that C_s goes to zero when no blade is present, the calculations will still work where C_s approaches some known value different from zero. This would be the case where, for example, the gap when no blade is present is not enough for C_s to reach zero, but is still much larger than the gap when a blade is present. Accuracy using these calculations therefore depends upon uncertainty in the C_s value when there is the largest gap, that is, when no blade is present.

In reality, the values of C_o and Q_n are generally not constant and are strongly affected by vibration. Therefore C_o and Q_n must be considered to be functions of time, and a more exact form of Equation (9) is:

$$v_A=G\ V_o\ C_s+G\ V_o\ C_o(t)+G\ Q_n(t)+K \qquad (12)$$

Approximating the values of C_o(t) and Q_n(t) as a Taylor series about the time of a particular blade, shown as to in FIG. 3, improves the accuracy of the system substantially, as follows:

$$C_o(t)=C_{o0}+C_{o1}(t-t_0)+C_{o2}9t-t_0)^2+C_{o3}(t-t_0)^3+\ldots \qquad (13)$$

and

$$Q_n(t)=Q_{n0}+Q_{n1}9t-t_0)+Q_{n2}(t-t_0)^2+Q_{n3}(t-t_0)^3+\ldots \qquad (14)$$

If, as shown in FIG. 3, the system measures the output voltage v_A at times t_1 through t_4 and performs a weighted sum of the voltages (v_{A1} through v_{A4}), the result will correct for all terms through the cubic in Equations (13) and (14). If the times are shown as in FIG. 3, then the particular solution is:

$$v_A[\text{no blade}]=(9(v_{A2}+v_{A3})-(v_{A1}+v_{A4}))/16 \qquad (15)$$

Thus:

$$C_s=(1/G\ V_o)\ (v_{A0}-(9(v_{A2}+v_{A3})-(v_{A1}+v_{A4}))/16)+E \qquad (16)$$

where E is an error that is due to terms in t^4 and higher for both C_o and Q_n and is quite small. Thus errors whose frequency components are small compared to the reciprocal of the sampling period (defined as the difference between sample times) are eliminated by the preferred method of the present invention.

If a particular vibration environment is more benign, then simpler methods of calculation can be used. For example, in the simplest situation, only two measurements (for example, at t_0 and t_2) can compensate for the zero-order errors in Equations (13) and (14) (that is, C_{o0}, and Q_{n0}). Similarly, the use of three measurements (at t_0, t_2 and t_3) can compensate for the first two error terms; in this case the appropriate calculation would be:

$$C_s=(1/G\ V_o)\ (v_{A0}-(v_{A2}+v_{A3})+2)+E \qquad (17)$$

On the other hand, if the vibration is more severe, then terms of higher order than t^4 in Equations (13) and (14) could be accommodated by more baseline samples.

Generally speaking, error terms in t^n in Equations (13) and (14) can be compensated for by making (n+1) measurements at times during which no element or blade is in front of the sensor. There is no specific requirement that the additional measurements be each separated by element or blade measurements, and measurements can be taken more than once on a single element or blade, or on less than every element or blade.

Thus the system's ability to measure the tip capacitance C_s depends on the ability to estimate what the amplifier output v_A would have been at the blade measurement time if no blade were present. If this estimate can be performed accurately, then the system is able to measure C_s with only two calibration constants, G and V_o, and both of these can be tightly controlled. The voltage V_o can be generated by a precision voltage supply with excellent long term stability. As shown at Equation (8), the gain of the charge amplifier **12** depends only on the value of a single component (C_2 in the embodiment of FIG. 3), and the value of this component can also be tightly controlled. In addition, because amplifier **12** can be located away from the heat and vibration of an engine and in a more benign environment because the length of cable **8** can be quite large, changes in the value of C_2 caused by heat and vibration can be minimized. Maintaining tight control of the calibration constants G and V_o produces excellent long term stability of the measurement and reduces the need to recalibrate the system of the present invention. For example, the possibility of maintaining accurate calibration for time periods in excess of 10,000 hours is quite feasible.

An additional advantage of the method and apparatus of the present invention is that errors due to amplifier offset voltage and amplifier input current are reduced virtually to zero. Thus the only errors in the measurement are those due to high-frequency terms in the cable and amplifier capacitance C and in the unwanted cable mechanisms Q_n. That is, in order to produce a measurement error, either C_o or Q_n must change rapidly compared to the sampling interval. For example, because the number of samples per revolution can be at least as high as the number of moving elements (typically 50 to 100 in the case of jet engine fan blades), the measurement techniques will compensate for cable effects up to frequencies on the order of 25 to 50 times the rotation rate of the turbine. In the case of the larger jet engines, the rotation rate is typically 5,000 to 10,000 RPM. Thus the present invention will be insensitive to cable effects up to about 5 kHz or higher. In the case of smaller engines, the rotation rate may be higher by a factor of five or more. In this case, the present invention will be insensitive to cable effects up to about 25 kHz or higher. Because cables are generally designed to be relatively insensitive to external vibration, the method in the present invention virtually eliminates errors from the interconnect cable **8** between the sensor **1** and the charge amplifier **12** as well as errors associated with the charge amplifier **12** itself.

If desired when measuring blade gap in an engine, a user can eliminate variations in blade gap D that are asynchronous with the rotation of the blade **4** by averaging the gap measurement of the same blade over successive rotations. Averaging would also improve the signal-to-noise ratio of the measurement by reducing the noise component by the square root of the number of measurements averaged. Similarly, the asynchronous motion could be estimated by calculating the variance of successive measurements of the same blade gap. Averaging over successive revolutions also improves the signal-to-noise ratio of blade profile measurements, which are made as multiple measurements at short intervals on a single blade.

While both the apparatus and method of this invention have been described in connection with several specific embodiments, it should be understood that numerous modifications in dimensions, materials and/or techniques could be made by persons of ordinary skill in this art without departing from the scope of this invention. Accordingly, the foregoing description is intended to be merely illustrative and is not limiting. The scope of the invention as claimed should be understood to include all those alternatives and modifications which the above specification and drawings would suggest or which would readily occur or be apparent to one skilled in the art upon study of the same.

What is claimed is:

1. A measurement system, comprising:

a sensor disposed in a housing in which one or more elements are movable relative to the housing, the sensor and each of the elements being separated by a distance and forming a sensing capacitor having a first value dependent on the distance between the sensor and each element as each element passes the sensor, and having a second value when no element is passing the sensor, the sensor generating a signal representative of the capacitance of the sensing capacitor;

an amplifier coupled to the sensor and having a substantially constant gain, the amplifier amplifying the signal generated by the sensor to create an output signal which includes maxima and minima, the maxima corresponding to instances when an element passes the sensor and the minima corresponding to instances when no element is passing the sensor, wherein the maxima includes a first noise component and the minima includes a second noise component;

a biasing network coupled between the amplifier and the sensor, the biasing network including a voltage source for providing a substantially constant voltage to the sensor; and

a processor coupled to the amplifier for: (i) determining the difference between at least one of the maxima of the amplified output signal, and at least one of the minima of the amplified output signal wherein the first noise component and the second noise component are substantially canceled in determining the difference, (ii) determining the capacitance of the sensing capacitor by multiplying the voltage provided by the voltage source, by the gain provided by the amplifier, and by the difference between the at least one of the maxima of the amplified signal and the at least one of the minima of the amplified signal, and (iii) determining the distance between the sensor and each of the elements using the capacitance.

2. A measurement system according to claim 1, wherein the amplifier comprises a first operational amplifier, a first feedback capacitor, and a restoration circuit.

3. A measurement system according to claim 2, wherein the restoration circuit comprises a first resistor in parallel with the first feedback capacitor.

4. A measurement system according to claim 3, wherein the restoration circuit further comprises a second operational amplifier connected at its output to the first resistor, a second feedback capacitor, and a second resistor connected to the second operational amplifier, the second feedback capacitor, and ground.

5. A measurement system according to claim 4, wherein the housing comprises a turbine engine and the elements comprise fan blades.

6. A measurement system, comprising:

a sensor disposed in a housing in which one or more elements are movable relative to the housing, the sensor and each of the elements being separated by a distance and forming a sensing capacitor having a first value dependent on the distance between the sensor and each element as each element passes the sensor, and having a second value when no element is passing the sensor, the sensor generating a signal representative of the capacitance of the sensing capacitor;

an amplifier coupled to the sensor and having a substantially constant gain, the amplifier amplifying the signal generated by the sensor to create an output signal which includes maxima and minima, the maxima corresponding to instances when an element passes the sensor and the minima corresponding to instances when no element is passing the sensor, wherein each of the maxima and the minima include a substantially equivalent noise component;

a biasing network coupled between the amplifier and the sensor, the biasing network including a voltage source for providing a substantially constant voltage to the sensor, and a blocking capacitor for preventing the substantially constant voltage from being applied to the amplifier; and

a processor coupled to the amplifier for determining the capacitance of the sensing capacitor and the distance between the sensor and each of the elements by determining the difference between at least one of the maxima of the amplified output signal and at least one of the minima of the amplified output signal, thereby eliminating the noise components of the maxima and minima, multiplying the voltage provided by the voltage source, by the gain provided by the amplifier, and by the difference between at least one of the maxima of the amplified output signal, and at least one of the minima of the amplified output signal.

7. A measurement system according to claim 6, wherein the amplifier comprises a first operational amplifier, a first feedback capacitor, and a restoration circuit.

8. A measurement system according to claim 7, wherein the restoration circuit comprises a first resistor in parallel with the first feedback capacitor.

9. A measurement system according to claim 8, wherein the restoration circuit further comprises a second operational amplifier connected at its output to the first resistor, a second feedback capicator, and a second resistor connected to the second operational amplifier, the second feedback capacitor, and ground.

10. A measurement system according to claim 9, wherein the housing comprises a turbine engine and the elements comprise fan blades.

11. A measurement system, comprising:

a sensor disposed in a housing in which one or more elements are movable relative to the housing, the sensor and each of the elements being separated by a distance and forming a sensing capacitor having a first value dependent on the distance between the sensor and each element as each element passes the sensor, and having a second value when no element is passing the sensor, the sensor generating a signal representative of the capacitance of the sensing capacitor;

an amplifier coupled to the sensor and having a substantially constant gain, the amplifier amplifying the signal generated by the sensor to create an output signal which includes maxima and minima, the maxima corresponding to instances when an element passes the sensor and the minima corresponding to instances when no element is passing the sensor;

a feedback circuit coupled between the amplifier and the sensor, and a voltage source applied to the feedback circuit, for providing a substantially constant voltage to the sensor;

a blocking capacitor coupled between the feedback circuit and the voltage source for substantially preventing the voltage source from providing a voltage at the amplifier; and a processor coupled to the amplifier, for determining the capacitance of the sensing capacitor and the distance between the sensor and each of the elements by multiplying the voltage provided by the voltage source, by the gain provided by the amplifier, and by the difference between at least one of the maxima of the amplified output signal, and at least one of the minima of the amplified output signal.

12. A measurement system according to claim **11**, wherein the amplifier comprises a first operational amplifier, a first feedback capacitor, and a restoration circuit.

13. A measurement system according to claim **12**, wherein the restoration circuit comprises a first resistor in parallel with the first feedback capacitor.

14. A measurement system according to claim **13**, wherein the restoration circuit further comprises a second operational amplifier connected at its output to the first resistor, a second feedback capacitor, and a second resistor connected to the second operational amplifier, the second feedback capacitor, and ground.

15. A measurement system according to claim **11**, further comprising a resistor in series with the blocking capacitor and the feedback circuit.

16. A measurement system according to claim **15**, wherein the feedback circuit comprises a third operational amplifier and a third resistor.

17. A measurement system according to claim **16**, wherein the housing comprises a turbine engine and the elements comprise fan blades.

18. A method of measuring distance, comprising:

providing a sensor disposed in a housing in which one or more elements are movable relative to the housing, the sensor and each of the elements being separated by a distance and forming a sensing capacitor having a capacitance dependent on the distance between the sensor and each element as each element passes the sensor and having substantially zero capacitance when no element is passing the sensor;

supplying substantially constant voltage to the sensor;

generating a signal with the sensor, the signal being representative of the capacitance of the sensing capacitor;

amplifying the signal generated by the sensor with an amplifier having a substantially constant gain to create an output signal having maxima and minima, the maxima corresponding to instances when an element passes the sensor and the minima corresponding to instances when no element is passing the sensor, wherein each of the maxima and minima have a noise component associated therewith;

preventing the substantially constant voltage from being applied to the amplifier;

determining the difference between at least one of the maxima of the amplified output signal and at least one of the minima of the amplified output signal and obtaining a difference value that is substantially free of the noise components; and

determining the capacitance of the sensing capacitor and the distance between the sensor and each of the elements by multiplying the voltage provided by the voltage source, by the gain provided by the amplifier, and by the difference value.

19. A method of measuring distance according to claim **18**, wherein the housing comprises a turbine engine and the elements comprise fan blades.

20. A method of measuring distance according to claim **18**, further comprising determining the distance using the capacitance of the sensing capacitor.

* * * * *

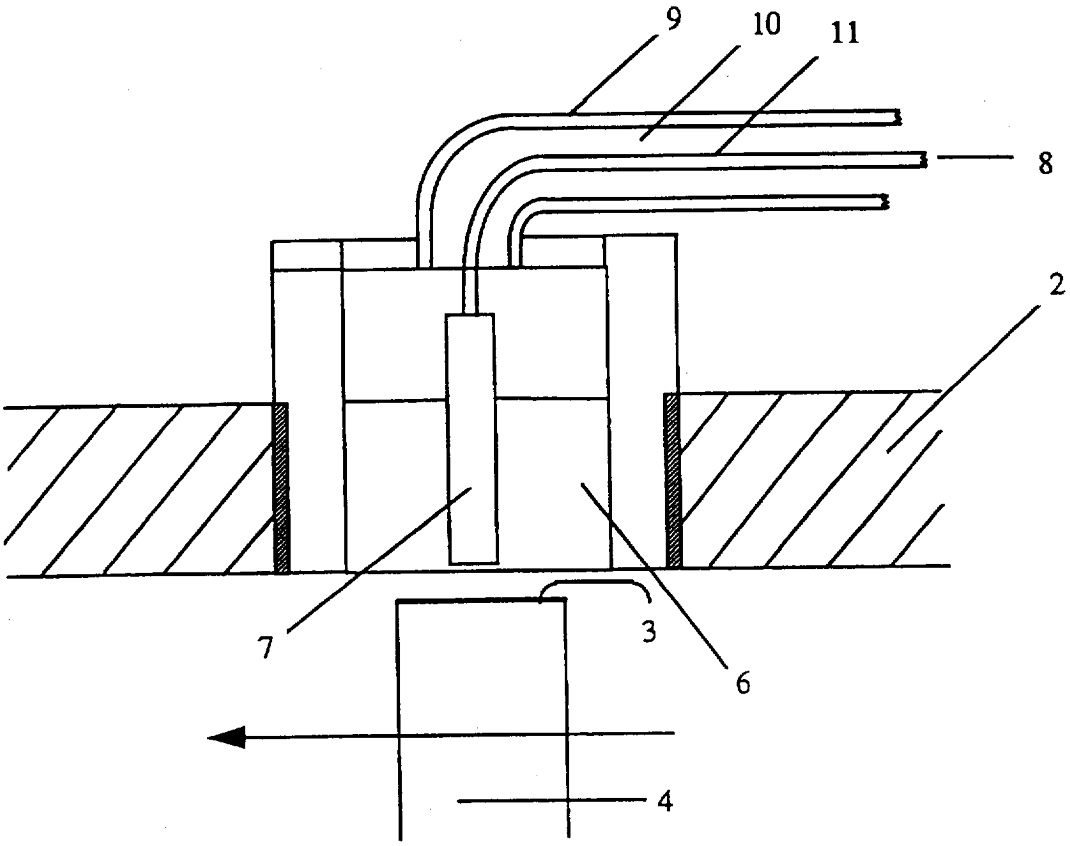


FIG. 1

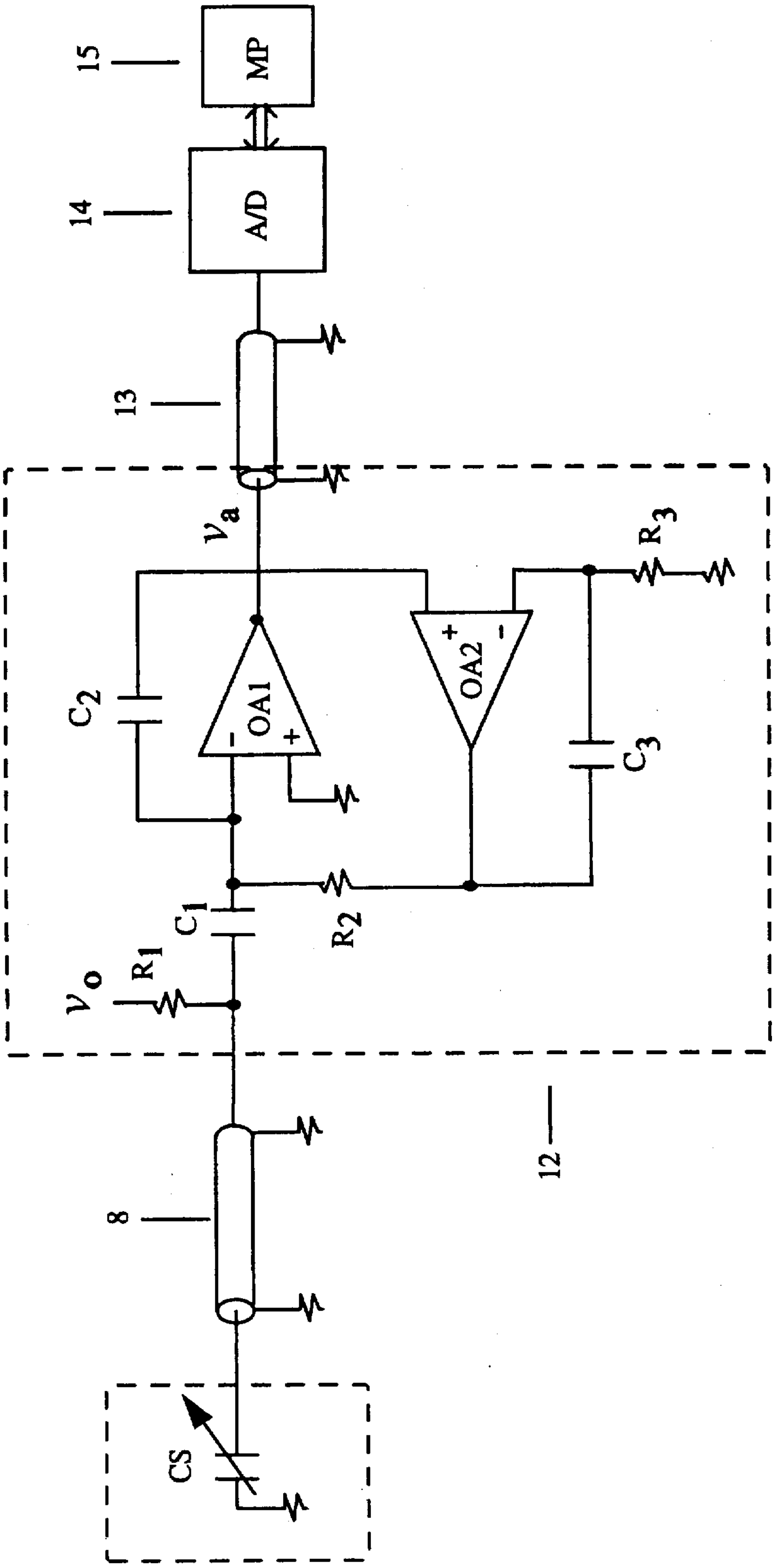


FIG. 2

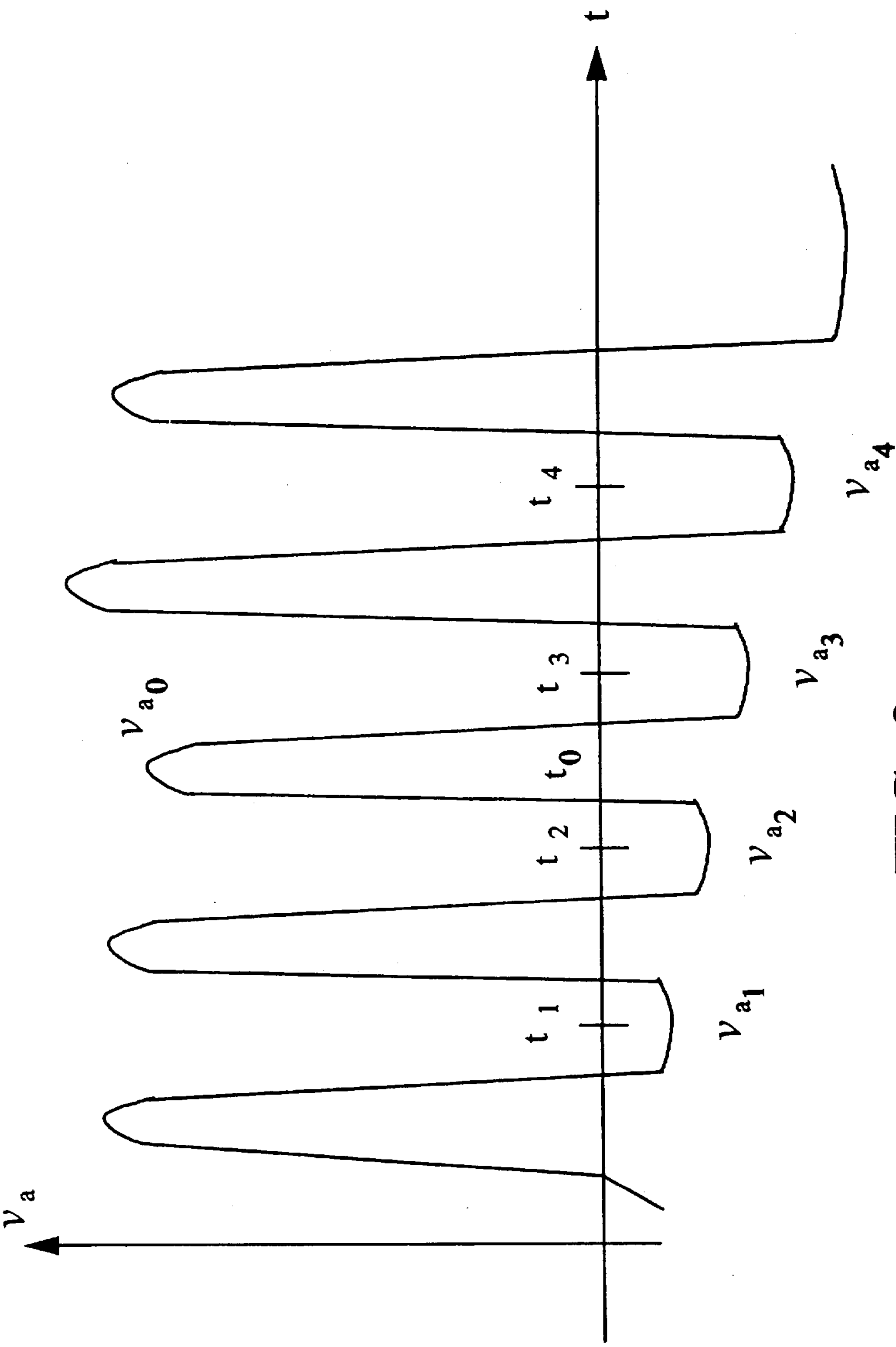


FIG. 3

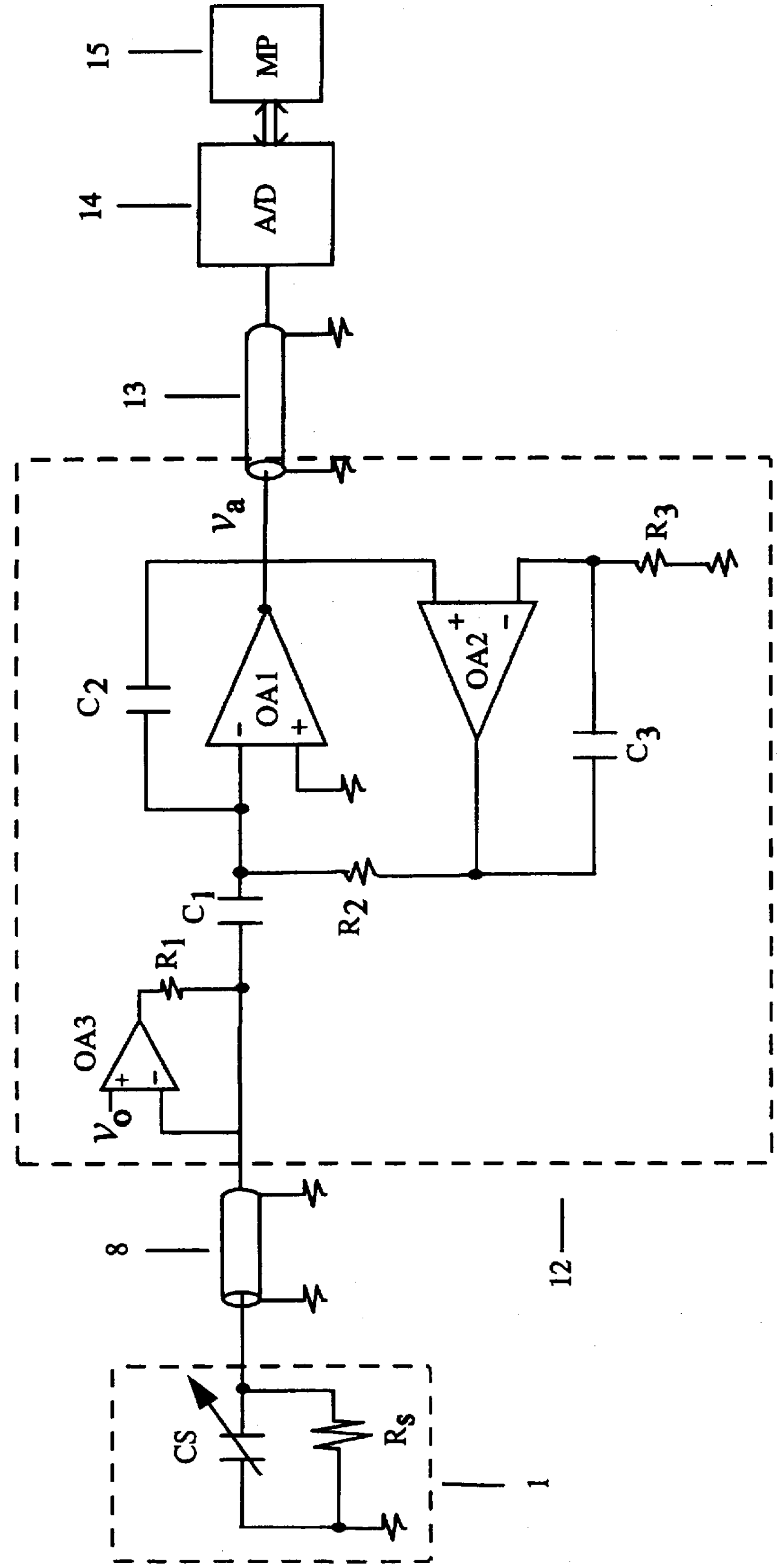


FIG. 4