(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) **World Intellectual Property Organization**
International Bureau

(43) **International Publication Date**
11 May 2018 (11.05.2018)

WIPO | PCT

(10) **International Publication Number**
WO 2018/085403 A1

(51) **International Patent Classification:**
B08B 7/02 (2006.01) ***G03B 29/00*** (2006.01)

(21) **International Application Number:**
PCT/US2017/059536

(22) **International Filing Date:**
01 November 2017 (01.11.2017)

(25) **Filing Language:** English

(26) **Publication Language:** English

(30) **Priority Data:**
62/415,554 01 November 2016 (01.11.2016) US
15/497,624 26 April 2017 (26.04.2017) US

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(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, JO, 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, 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).

WO 2018/085403 A1

(54) **Title:** ULTRASONIC LENS CLEANING SYSTEM WITH IMPEDANCE MONITORING TO DETECT FAULTS OR DEGRADATION

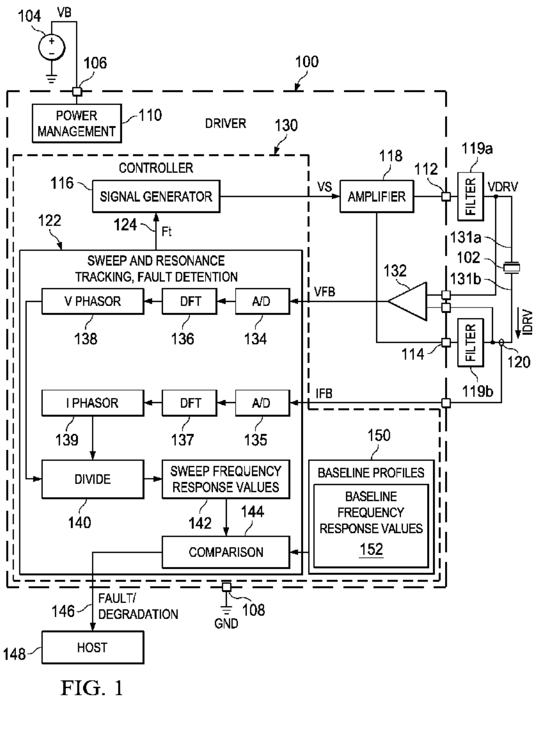


FIG. 1

(57) **Abstract:** In described examples of a driver system (100) to detect faults or degradation in a lens cleaning system, the driver (100) includes a controller (130) to control a lens transducer drive signal frequency (Ft) to vibrate the lens in a frequency range of interest and measure frequency response values (142) according to driver feedback signals (VFB, IFB), and to compare the measured frequency response values (142) to baseline frequency response values (152) for a healthy system, and to selectively determine the existence of a fault or degradation in the lens cleaning system according to dissimilarities between the measured frequency response values (142) and the baseline frequency response values (152).

[Continued on next page]

Declarations under Rule 4.17:

— *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*

— *as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))*

Published:

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

— *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments (Rule 48.2(h))*

ULTRASONIC LENS CLEANING SYSTEM WITH IMPEDANCE MONITORING TO DETECT FAULTS OR DEGRADATION

BACKGROUND

[0001] Camera systems are becoming more prevalent in automotive and other applications, such as vehicle cameras, security cameras, industrial automation systems, and in other applications and end-use systems. Operation of camera and lighting systems is facilitated by clean optical paths, which can be hindered by dirt, water or other debris, particularly in outdoor applications such as vehicle mounted camera systems, outdoor security camera systems, camera systems in industrial facilities, etc. For example, camera or light source lenses may be subject to ambient weather conditions, dirt and debris, and other contaminants which can obstruct or interfere with optical transmission through the lens. Automatic lens cleaning systems (LCSs) have been developed for vehicle and security cameras to self-clean a lens or lens cover. Such systems may include air or water spray apparatus to wash a lens surface. Other lens cleaning systems electronically vibrate the lens to expel contaminants, water or other unwanted material from the lens cover to improve image quality or light transmission efficiency. In certain applications, the optical system and the lens cleaning apparatus may be subjected to mechanical stresses, thermal stresses and other adverse environmental conditions that can degrade the cleaning system components. For example, a lens or lens cover may become cracked, a vibration transducer may fail, a seal structure may be compromised, an adhesive bond between the lens and a transducer may fail, or a number of other failures or degradation types may occur. In vehicle-based systems or other applications where a camera or light source cannot be conveniently accessed, it is desirable to maintain proper operation of the lens cleaning system to ensure continued optical transmission through a lens or lens cover.

SUMMARY

[0002] Described examples include lens cleaning systems, drivers and methods to detect faults or degradation in a lens cleaning system, including a controller to control a lens transducer drive signal frequency to vibrate the lens in a frequency range of interest and measure frequency response values according to driver feedback signals and to compare the measured frequency response values to baseline frequency response values for a healthy system. The controller

determines the existence of a fault or degradation in the lens cleaning system according to dissimilarities between the measured frequency response values and the baseline frequency response values at multiple frequencies. The frequency response can be measured as an impedance response, admittance response or other frequency domain equivalent. The impedance response is useful to convey techniques in this description.

[0003] In described examples of a lens cleaning system and a lens cleaning system driver, the driver includes an output that provides an oscillating drive signal to a transducer to vibrate a lens and a feedback circuit that receives transducer voltage and current feedback signals. The driver further includes a controller that controls the frequency of the drive signal to vibrate the lens at frequencies in a frequency range of interest and determines measured frequency response values according to the current and voltage feedback signals. The controller compares the measured frequency response values to baseline frequency response values for a healthy lens cleaning system in the frequency range of interest and selectively determines the existence of a lens cleaning system fault or degradation according to dissimilarities between the measured frequency response values and the baseline frequency response values. The driver in certain examples provides an indication of a fault or degradation type based on analysis of multiple ranges of interest. In certain implementations, the controller operates in a second mode to measure and store a baseline impedance profile including frequency response values measured for the healthy lens cleaning system across a wide range of frequencies that includes the frequency range of interest, and the controller identifies one or more frequency ranges of interest that include a pole or zero of the baseline impedance profile.

[0004] Methods are described for detecting lens cleaning system faults or degradation, which include controlling a drive signal frequency to vibrate a lens at multiple frequencies in a frequency range of interest, and determining measured frequency response values individually corresponding to one of the frequencies in the frequency range of interest. The method further includes comparing the measured frequency response values to baseline frequency response values in the frequency range of interest for a healthy lens cleaning system and selectively determining lens cleaning system faults or degradation according to dissimilarities between the measured frequency response values and the baseline frequency response values.

BRIEF DESCRIPTION OF THE DRAWINGS

[0005] FIG. 1 is a schematic diagram of a lens cleaning system.

[0006] FIG. 2 is a partial sectional side elevation view of a camera lens assembly including a lens cleaning system.

[0007] FIG. 3 is a flow diagram of an example process or method of detecting and identifying lens cleaning system degradation or faults.

[0008] FIG. 4 is a graph of an example impedance magnitude response curve as a function of excitation frequency.

[0009] FIG. 5 is a graph of an example impedance phase angle response curve as a function of excitation frequency.

[0010] FIG. 6 is a graph of example impedance magnitude response curves at different voltage amplitudes in a first range of frequencies for a healthy lens cleaning system.

[0011] FIG. 7 is a graph of example impedance magnitude response curves at different voltage amplitudes in the first range of frequencies for a lens cleaning system with a degraded or faulty transducer.

[0012] FIG. 8 is a graph of example impedance magnitude response curves at a given operating voltage in a second range of frequencies for a healthy lens cleaning system and a lens cleaning system with a degraded or faulty bond between the lens or lens cover and the transducer.

DETAILED DESCRIPTION OF EXAMPLE EMBODIMENTS

[0013] In the drawings, like reference numerals refer to like elements throughout, and the various features are not necessarily drawn to scale. In this description, the term "couple" or "couples" includes indirect or direct electrical or mechanical connection or combinations thereof. For example, if a first device couples to or is coupled with a second device, that connection may be through a direct electrical connection, or through an indirect electrical connection via one or more intervening devices and connections.

[0014] FIG. 1 shows an ultrasonic lens cleaning system with a driver integrated circuit (IC) 100, and FIG. 2 shows a camera lens assembly 200 including an ultrasonic lens cleaning system. As shown in FIG. 2, the lens assembly 200 includes a cylindrical or “ring” transducer 102 which is mechanically coupled to vibrate a lens 202. In one example, the transducer 102 is glued to the lens 202. Although illustrated in the context of a camera lens system, various techniques of this description are further useful in lighting systems or other optical systems, with or without a camera. Described apparatus and techniques facilitate automatic fault or degradation detection in lens cleaning systems using a controller and a transducer which can also be used for automatic lens cleaning operations. As used herein, a lens can be a focusing element or other lens that implements optical shaping or other optical effect to aid camera imaging, and a lens cover or optical window that merely provide protection for further optical elements without performing any imaging functions. Described examples provide apparatus and techniques to assess the mechanical frequency response of the lens and associated mechanical structures based on one or more electrical feedback signals, which can include determining impedance values or admittance values across multiple frequencies to determine or infer frequency response values, and comparison of baseline and measured frequency response values.

[0015] The lens 202 in one example is a "fisheye" lens having a curved outer surface as shown in FIG. 2. In other examples, a flat lens or a lens having a different profile can be used. The lens assembly in this example is mounted to a generally cylindrical housing 204 using a cylindrical cap fastener 201 and is sealed using an O-ring 208 extending between an edge of the lens 202 and the fastener 201 to prevent ingress of water or debris into the interior of the housing 204. In one example, the housing 204 can be mounted to a motor vehicle to operate as lens cover for a rear backup camera, a forward-facing camera or a side-facing camera. In other examples, the assembly 200 can be mounted to a building or a light pole, such as for security camera or lighting applications. In other examples, the assembly 200 can be used for interior security monitoring systems, such as within a commercial or residential building. In this example, a series of generally flat secondary lenses 210 are disposed within the inner surfaces of the spacer 206. The secondary lenses 210 and the fisheye lens 202 provide an optical path for imaging by a camera 212. The transducer 102 includes lead wires or terminals 131a and 131b that extend through an opening 216 in a base 214 of the housing 204 for connection with the driver IC 100. In the example of FIG. 2, the lens 202 is mounted into the cylindrical housing 204 with a cylindrical inner spacer structure 206. The transducer 102 in this example is a cylindrical ring-shaped piezo-electric transducer disposed between the inner spacer 206 and the outer wall of the housing 204.

[0016] As best shown in FIG. 1, the driver IC 100 includes a power input pin or pad 106 that receives input power from a power supply or power source 104, such as a battery providing a battery voltage signal VB with respect to a reference node 108 having a reference voltage (e.g., GND). The driver IC 100 includes a power management circuit 110 that receives the battery voltage signal VB and provides one or more supply voltages (not shown) to power the internal circuitry of the driver 100. Also, the IC 100 includes an output with terminals 112 and 114 for connection to the lead wires 131a and 131b, respectively, of the transducer 102. In operation, the driver 100 output provides an oscillating drive signal VDRV at a non-zero frequency Ft to the transducer 102 to vibrate a lens 202. As described hereinbelow, the controlled vibration of the lens 202 via excitation of the transducer 102 facilitates cleaning or removal of contaminants or debris from the outer surface of the lens 202. Also, the transducer 102 is controlled by the driver 100 in first and second modes for assessing the health of the lens cleaning system. In specific examples, the driver 100 can detect the existence of one or more faults or degradation in the lens cleaning system in a first mode. In a second mode, the driver 100 can characterize or calibrate a healthy system to determine one or more baseline profiles as described hereinbelow.

[0017] As shown in FIG. 1, the driver IC 100 includes a controller or control circuit 130 with a signal generator 116. In one example, the controller 130 is a processor with an associated electronic memory. The controller 130 implements various cleaning, fault or degradation detection, and optional calibration or baseline processing functions by controlling the oscillatory frequency Ft of the transducer 102. In one example, the controller 130 includes a sweep and resonance tracking, fault detection circuit 122 with an output 124 that provides a desired frequency Ft to a signal generator circuit 116. In another possible implementation, the controller 130 is implemented in a processor, such as a DSP or other programmable digital circuit, which implements sweep and resonance tracking and fault detection and calibration functions through execution of instructions stored in an associated memory to generate the frequency Ft as a digital value representing a desired frequency Ft of the drive signal VDRV. In one example, the signal generator 116 is a pulse width modulation (PWM) output of the processor that implements the controller 130. The signal generator circuit 116 provides an output signal VS that oscillates at a non-zero frequency Ft. In certain implementations, the controller 130 includes an integral electronic memory, or is operatively connected to an external electronic memory 150 that stores program instructions implemented by the processor, and stores baseline frequency response values 152, such as baseline impedance values as described hereinbelow. The illustrated example employees impedance values 152 that represent the frequency response of the system. Other values can be used, such as admittance values or other values that represent the frequency response of the system.

[0018] The driver IC 100 further includes an amplifier 118 which amplifies the output signal VS to generate the oscillating drive signal VDRV. In this manner, the controller 130 provides the desired frequency Ft of the drive signal VDRV, and thereby controls the oscillatory frequency of the transducer 102 for cleaning the lens 202 and/or to implement calibration and fault/degradation detection functions as described herein. In one example, the amplifier 118 is a full H-bridge amplifier circuit with first and second outputs individually coupled with the transducer terminals 131a and 131b to provide the oscillating drive signal VDRV to the transducer 102. In the example of FIG. 1, moreover, an L-C filter circuit 119 is connected between the amplifier outputs and the transducer terminals 131a and 131b. In one possible implementation, the filter 119 includes a first filter circuit 119a connected between a first output of the amplifier 118 and the first transducer terminal 131a, and a second filter circuit 119b connected between the second output of the amplifier 118 and the second transducer terminal 131b. A variety of different signal generator circuits 116 can be used, including a PWM processor output that generates a square wave signal VS, or other signal generator circuitry to provide sinusoidal, triangular, saw tooth or other waveforms having a non-zero signal frequency Ft. In one example, the first output of the amplifier 118 delivers an oscillating drive signal to the transducer 102 and the second amplifier output delivers an oscillating drive signal to the transducer 102 which is 180 degrees out of phase with respect to the first output.

[0019] In certain examples, the amplifier 118 can provide a single ended output through the first filter circuit 119a to the first output terminal 112, and the return current from the transducer 102 flows through the second filter circuit 119b to return to the second output of the amplifier 118. In the illustrated example, the amplifier 118 provides a differential output to the filters 119a, 119b. In this case, the individual filter circuits 119a and 119b each include a series inductor and a capacitor connected between the second inductor terminal and a common reference voltage (e.g., GND) to deliver the amplified signal to the transducer 102. In this manner, the amplifier 118 amplifies the signal generator output signal VS and delivers an oscillating drive signal VDRV to the transducer 102. The filter circuit 119 advantageously allows the use of a square wave output from the PWM signal generator 116 to provide a generally sinusoidal oscillating signal VDRV to vibrate the transducer 102 and the mechanically coupled lens 202.

[0020] The driver IC 100 also includes a feedback circuit with a current sensor or current transducer 120 that generates a current feedback signal IFB representing a current IDRV flowing in the transducer 102. The feedback circuitry also includes a differential amplifier 132 with inputs connected to the transducer output terminals 112 and 114, and an amplifier output that generates a voltage feedback signal VFB representing the transducer voltage. The feedback signals IFB and VFB are provided to the controller 130. In one example, the controller 130 includes analog-to-digital (A/D) converters 134 and 135 to convert the current and voltage feedback signals IFB and VFB to digital values. In one possible implementation, the controller 130, the amplifier 118 and the feedback circuitry are fabricated in a single integrated circuit 100. The driver 100 can be provided on a single printed circuit board (PCB) along with a camera 212 (or a light source) to provide a compact solution for various vehicle-based and/or security camera systems for lighting systems generally.

[0021] The driver IC 100 operates in a normal mode to selectively provide ultrasonic lens cleaning functions in conjunction with the associated transducer 102. The outer surface of the lens 202 in FIG. 2 may be exposed to dirt, debris, water and other optical obstructions, referred to herein as contaminants, particularly in outdoor installations. The driver 100 provides an oscillating signal to cause the transducer 102 to vibrate the lens 202 to facilitate or promote cleaning of the lens 202. In one example, the driver 100 provides an ultrasonic drive signal or voltage waveform VDRV to actuate the transducer 102 and cause the transducer 102 to mechanically vibrate the lens 202 using ultrasonic waves to remove dirt and/or water from the surface of the lens 202. Mechanical oscillation or motion of the lens 202 at ultrasonic waves of a frequency at or close to a system resonant frequency can facilitate energy efficient removal of water, dirt and/or debris from the lens 202. The driver IC 100 in one example provides a closed loop system using the feedback signals IFB and/or VFB during lens cleaning operation. In one example, the driver IC 100 regulates operation at or near a local minima or maxima in a current or impedance signal value ascertained from current feedback signal IFB. In one example, the driver IC 100 regulates operation at or near the local minima or between the minima and the maxima. The controller in one example uses the converted values from the A/D converters 134 and/or 135 to implement closed-loop control in driving the transducer 102 for lens cleaning operations.

[0022] The controller 130 also operates in a first mode (e.g., DETECT mode in FIG. 3 described hereinbelow) for detecting degradation or faults in the lens cleaning system. As shown in FIG. 1, the analog feedback signals VFB and IFB are converted to digital values by the A/D converters 134 and 135. The controller 130 in one example calculates discrete Fourier transform (DFT) components 136 and 137 to respectively provide voltage and current phasor values 138 and 139 based on time domain digital voltage and current feedback values from the converters 134 and 135. The controller 130 also implements a complex division (DIVIDE) function 140 to compute sweep frequency response values, such as sweep impedance values 142 as the ratio of the voltage phasor value 138 to the current phasor value 139 for a given sample. In this regard, the A/D converters operate at a sufficiently high sample frequency to obtain a stream of digital values representing the feedback voltage and current associated with the driven transducer 102. The processing implemented by execution of program instructions by the processor of the controller 130 provides a stream of frequency response values (e.g., impedance values) 142.

[0023] In the degradation/fault detection operation in the first mode, the controller 130 controls the frequency Ft of the drive signal VDRV to vibrate the lens 202 at multiple frequencies in a frequency range of interest. In one implementation, the controller 130 performs a frequency sweep for one or more predetermined frequency ranges of interest. The controller 130 digitally converts the feedback signals during the frequency sweep, obtains frequency spectrum phasor information 138 and 139, and divides these values 140 to obtain sweep frequency response values 142 corresponding to the frequencies in the range of interest. The controller 130 also implements a comparison function 144 that compares the measured frequency response values 142 to baseline frequency response values 152 associated with corresponding ones of the frequencies in a given frequency range of interest for a healthy lens cleaning system. The controller 130 uses the comparison to selectively determine the existence of a fault in the system or degradation in the lens cleaning system according to dissimilarities between the measured frequency response values 142 and the baseline frequency response values 152. The controller 130 does not need to perform a continuous sweep, and instead controls the lens transducer drive signal frequency Ft to vibrate the lens 202 at one or more frequencies included in a predetermined frequency range of interest and computes the corresponding frequency response values 142 according to the driver feedback signals VFB, IFB.

[0024] The controller 130 compares the measured frequency response values 142 to corresponding baseline frequency response values 152 for a healthy system. The controller 130 selectively determines the existence of a fault or degradation in the lens cleaning system according to dissimilarities between the measured frequency response values 142 and the baseline frequency response values 152. In certain implementations, the controller 130 compares the difference between the measured and baseline values 142, 152 with a threshold to make an initial determination of whether the system is healthy. If a fault or degradation is determined (e.g., the difference exceeds a first threshold), then the amount of the difference can be used to distinguish between suspected faults and suspected degradation, using a second threshold comparison. The controller 130 in one example includes an output 146 that selectively provides a signal FAULT/DEGRADATION to a host system 148 in response to determination of the existence of a fault or degradation. This architecture facilitates appropriate remedial action by the host system. For example, in a vehicle-mounted driving assistance application, automated vehicle control systems that use a camera output for vehicle navigation, braking control, steering control, driver warnings, etc. can be automatically notified by the driver IC 100 that the lens cleaning system is degraded or faulty.

[0025] In one example, the controller 130 is further operable in a second mode (e.g., BASELINE mode in FIG. 3 described hereinbelow). The second mode can be used to calibrate a known healthy system by characterizing the frequency response of the healthy system as one or more baseline profiles. In one example, the controller 130 measures one or more baseline frequency response profiles, such as impedance profiles (e.g., profiles in the memory 150 in FIG. 1). The individual baseline profiles include frequency response values 152 measured for the healthy lens cleaning system across a wide range of frequencies that includes one or more frequency ranges of interest. The controller 130 stores the baseline impedance profile or profiles in the memory 150 of the lens cleaning system, and identifies one or more frequency ranges of interest that include a pole FP or zero FZ of the baseline impedance profile as described hereinbelow in connection with FIGS. 4 and 5.

[0026] In certain examples, the controller 130 determines one or more baseline profiles for each of multiple different transducer voltages, and stores these multiple baseline frequency response profiles in the memory of the lens cleaner system. In these examples, the controller 130 operates in the first (DETECT) mode for each of multiple different transducer voltages to drive the transducer 102 in order to vibrate the lens 202 at frequencies in a predetermined range of interest for the corresponding transducer voltage. In this case, the controller 130 determines measured frequency response values 142 that individually correspond to one of the frequencies in the predetermined frequency range of interest according to the current feedback signal IFB and the voltage feedback signal VFB. The controller 130 compares the measured frequency response values to the corresponding baseline frequency response values 152 in the predetermined frequency range of interest for the corresponding transducer voltage. The controller 130 selectively determines existence of a fault or degradation according to dissimilarities identified in the comparison. In this regard, the normal cleaning operation of the system can operate at certain transducer voltages tailored to removing contaminants from the lens 202, whereas the fault or degradation detection operations of the system may be performed at these voltages and/or at different (e.g., lower) voltages tailored to detecting the existence of one or more failures or faults in the system while potentially reducing power consumption. This architecture is particularly advantageous where the lens cleaning system operates from a battery power source 104 and is also advantageous in terms of reducing thermal stress on the transducer.

[0027] In certain implementations, moreover, the controller 130 selectively identifies a particular determined fault or degradation type according a specific frequency range of interest for which the dissimilarities indicate existence of the fault or degradation. In this manner, the driver 100 can selectively issue a FAULT/DEGRADATION signal to the host system 148 to initially indicate that the lens cleaning system has a degradation or a fault, and also optionally identify the fault type according to particular dissimilarities. Such implementations facilitate providing advanced information to the host system 148 to indicate a particular fault or degradation type based on impedance response or more generally on frequency response. Such discernible types can include lens cracking or breaking, transducer cracking or depolarization, seal failure, glue failure, etc. Accordingly, the described examples facilitate identification of when a failure has occurred in the lens cover system, and identification of failure type and the controller 130 and/or the host system 148 can provide appropriate corrective or remedial action. This design, in turn, facilitates improved readiness and availability of the lens cleaning system, by proactively identifying failure and allowing replacement of faulty or degrading system components so that system is operational at high availability.

[0028] Referring to FIGS. 3-8, FIG. 3 illustrates a process or method 300 of detecting and identifying lens cleaning system degradation or faults. The method 300 can be implemented in certain examples by a controller or processor, such as the lens cleaning system driver controller 130 described hereinabove. The process 300 includes an initial calibration or baseline establishment mode (“BASELINE” mode in FIG. 3) at 302 and 304 to establish the baseline profiles 150 and corresponding baseline frequency response values 152 stored in the memory of the controller 130 of FIG. 1 when the associated lens cleaning system is known to be operational or "healthy". For example, a healthy system has no known faults or degradation of the system components including the transducer 102, the mechanical structure (FIG. 2) including the mechanical coupling of the transducer 102 with the corresponding lens 202, the mounting of the lens 202 and/or the transducer 102 in the housing 204, the structural integrity and positioning of the seal structure 208, etc. At 306-316, the system is operated in a detection mode ("DETECT" mode in FIG. 3) to selectively detect and optionally identify lens cleaning system degradation and/or faults.

[0029] Operation in the BASELINE mode begins at 302 in FIG. 3, where the controller 130 measures baseline frequency response profiles at different voltages and frequencies for a healthy system and preferably stores these profiles in non-volatile storage such as FLASH, EPROM, etc. In one example, this design includes controlling the transducer drive signal frequency Ft to vibrate the lens 202 at multiple frequencies over a wide frequency range, while measuring sampled current and voltage values to determine (e.g., compute) frequency response values 152. As described hereinabove, this approach can be implemented as a continuous frequency sweep by control of the frequency Ft (e.g., upward or downward throughout a wide frequency range), or by selective operation at discrete frequencies throughout the wide frequency range in any suitable sequence. In one example, the baseline frequency response profiles are measured or otherwise established at 302 for multiple transducer voltages. The controller 130 then analyzes the resulting frequency response profiles at 304 to identify one or more frequency ranges of interest that include a pole or zero corresponding to a given fault type for each transducer voltage. A correspondence between a given degradation/fault type and one or more specific frequency ranges of interest for a corresponding transducer voltage can be established beforehand, such as based on empirical testing, factory manufacturing testing, or any other suitable analysis or data source.

[0030] FIG. 4 shows a graph 400 that illustrates an example impedance magnitude response curve 402 as a function of transducer excitation frequency over a wide range 403, such as 10 to 1000 kHz in one implementation. Other ranges may be used, preferably covering a usable range depending on the various masses of the structural components used in the optical system generally and the lens cleaning system in particular. FIG. 5 provides a corresponding graph 500 showing an example phase angle response curve 502 as a function of transducer excitation frequency over the same wide frequency range 403. In this example, the impedance curve 402 includes a number of local maxima corresponding to poles of the mechanical system, and a number of local minima corresponding to system zeros. A local maxima of the phase curve 502 is at the geometric mean between the pole and zero frequencies of the impedance curve 402. The graphs 400 and 500 depict several distinct frequency ranges having corresponding poles FP and zeros FZ, including a first identified frequency range of interest 404-1 having a pole FP1 and a zero FZ1, and a second identified frequency range of interest 404-2 that includes a pole FP2 and a zero FZ2.

[0031] Faults and/or degradation of one or more components or aspects of the lens cleaning system can cause changes in the frequency spectrum of the impedance curve 402 and/or the phase spectrum curve 502. Described systems and methods provide for automatically analyzing specific frequency ranges of interest 404 to ascertain the existence of one or more faults or degradation of the system. Also, the described examples use the system components that are already present for cleaning purposes. The controller 130 in certain examples also implements calibration or "BASELINE" operation to characterize or calibrate the system with respect to a known or believed healthy system at 302 and 304. In one example at 304, the controller identifies one or more frequency ranges of interest that include a pole or zero of the baseline impedance profile that corresponds with an associated fault type or degradation type. Also, as described hereinabove, this characterization can be done at multiple operating voltages to establish baseline profiles for each operating voltage, and to identify one or more frequency ranges of interest for each baseline profile 150. In the example of FIGS. 4 and 5, the system controller 130 identifies the first and second ranges of interest 404-1 and 404-2 as corresponding with distinct fault or degradation types. In this example, the first frequency range of interest 404-1 is indicative of depolarization of the transducer 102, and the second frequency range of interest 404-2 is associated with faulty bonding between the lens or lens cover 202 and the transducer 102 in the system of FIG. 2. Further fault-specific frequency ranges of interest 404 can be determined by the controller 130 at 304. This flexibility allows separate analysis and fault identification among multiple fault types, and accordingly facilitates advanced diagnostic information that can be provided to a host system 148 (FIG. 1) by the controller 130. The controller 130 in this example identifies relationships between faults or degradation and behavior of corresponding resonances in the mechanical system constituted by the lens cleaning system components.

[0032] Continuing in FIG. 3, the controller 130 operates in the "DETECT" mode at 306-310. At 306, the controller 130 controls the frequency Ft of the drive signal VDRV to vibrate the lens 202 at multiple frequencies in a frequency range of interest 404. In one example, the controller 130 sweeps the frequency Ft through the frequency range of interest 404. In other examples, the controller 130 operates the transducer 102 at multiple distinct frequencies Ft within the range of interest 404, where continuous sweeping is not a strict requirement of all possible implementations. At 306, the controller 130 also determines measured frequency response values 142 that individually correspond to one of the frequencies in the frequency range of interest 404 according to the current and voltage feedback signals IFB and VFB. As described hereinabove, the controller 130 uses one or more suitable techniques (e.g., DFT operations, divide operations, etc.) to determine corresponding impedance sweep profiles for each of two or more working voltages at 306. Although the illustrated method 300 involves baseline correlation and fault/degradation detection at multiple operating transducer voltages, other implementations are possible in which the steps are done for only a single voltage.

[0033] At 308 in FIG. 3, the controller 130 compares the impedance sweep profile or profiles corresponding to one or more frequency ranges of interest 404 with corresponding baseline frequency response values 152 of the corresponding baseline profile or profiles in the memory 150. The controller 130 determines at 310 whether all the sweep profiles are similar to the corresponding baseline profiles. Similarity or dissimilarity can be established by any suitable comparison technique at 308 and 310. Mathematical techniques can be implemented by the controller 130. For example, a correlation function can be evaluated to determine whether a certain amount of dissimilarity exists, in which case the controller 130 provides the FAULT/DEGRADATION signal at the output 146 to alert the host system 148 that a fault or degradation has been detected.

[0034] In another example, the controller 130 computes a sum of squares difference value based on the comparison, and selectively determines the existence of a fault or degradation in the lens cleaning system if the difference value exceeds a predetermined threshold. In certain examples, different thresholds can be used for different profiles and comparisons, with a specific threshold being used for each frequency range of interest, and for each operating transducer voltage. In one example, the controller 130 computes a root-mean-square (RMS) difference between the baseline and sweep frequency response values at the measured points, and compares this value with a corresponding threshold. If the controller 130 determines that all of the sweep profiles are similar to the corresponding baseline profiles (YES at 310), the process 300 returns to 306 as described hereinabove.

[0035] The detection mode processing can be implemented at any suitable time in a normal operational implementation of a system. For example, a lens cleaning system may be instantiated or started according to a schedule established by the host system 148, such as periodic cleaning. The controller 130 in one example implements the fault/degradation detection operation at 306-310 is a prelude to actual cleaning. If the system is determined to be operational (e.g., no identified or determined faults or degradation), the controller 130 drives the transducer 102 to implement lens cleaning according to any suitable transducer drive parameters (e.g., voltage, frequency, duration, etc.) after the positive determination (YES at 310). The next time the lens cleaning system is actuated by the host system 148, the process is repeated.

[0036] If a threshold amount of dissimilarity is determined by the controller 130 in one or more of the frequency ranges 404 of interest (NO at 310), the process 300 continues at 312 where the controller 130 determines that a system fault or degradation exists. In certain examples, the controller 130 issues a system fault or degradation warning (e.g., provides the FAULT/DEGRADATION signal to the host system 148) at 313 in FIG. 3. In certain examples, moreover, the controller 130 evaluates multiple frequency ranges of interest 404 (e.g., the ranges 404-1 and 404-2 in FIGS. 4 and 5). In this case, the controller 130 distinguishes between faults/degradation sources by selectively identifying a fault or degradation type at 314 according the specific one of the frequency ranges of interest 404 for which the dissimilarities indicate existence of the fault or degradation. The controller 130 can then selectively identify fault type according to the particular dissimilarity at 316. Also, the controller 130 can implement one or more remedial or safety actions in response to detection of a system fault or degradation. For example, the controller 130 can prevent further operation (e.g., cleaning) of the system pending repair or replacement of faulty or degraded components. Alternatively, the controller 130 can continue operation, particularly if only slight degradation is detected. For example, the lens cleaning system may be part of a vehicle-based camera system used in conjunction with one or more vehicle control actuators, and complete shutdown of the camera system may be unnecessary or inappropriate until the vehicle is stopped or a driver is alerted that automatic control functions are not available. In this case, the controller 130 can issue an alert to the host system 148 even though the cleaning operation is continued. In one possible implementation, the controller 130 can issue an alert to the host system 148 upon determination that system degradation exists, and then continue operation of the lens cleaning system until a determination is made that the system includes a fault, whereupon the controller 130 can prevent further cleaning operation of the system.

[0037] FIGS. 6-8 illustrate example graphs to further illustrate operation of the controller 130 in for selectively identifying faults and/or degradation of the system components. A graph 600 in FIG. 6 shows example impedance magnitude response curves 602, 604, 606 and 608 at different operating voltages in the first frequency range of interest 404-1 of FIGS. 4 and 5 for a healthy lens cleaning system. In this example, the range of interest 404-1 extends from approximately 280 kHz through 320 kHz, including zeros around 285 kHz-298 kHz and poles around 305 kHz-315 kHz for different transducer operating voltages. For example, the curve 602 shows the impedance magnitude response of a healthy cleaning system at an input voltage of 20 V; the curve 604 shows the impedance magnitude response of a healthy cleaning system at an input voltage of 40 V; the curve 606 shows the impedance magnitude response of a healthy cleaning system at an input voltage of 60 V; and the curve 608 shows the impedance magnitude response of the healthy lens cleaning system at an input voltage of 80 V.

[0038] FIG. 7 provides a graph 700 showing example impedance magnitude response curves 702, 704 and 708 corresponding to transducer operating voltages of 20 V, 40 V and 80 V in the system corresponding to FIG. 6 after the transducer 102 has been subjected to transducer depolarization degradation or fault. As with FIG. 6, the curves 702, 704 and 708 in the graph 700 of FIG. 7 illustrates the impedance magnitude response of the system at the corresponding transducer voltages over the first frequency range of interest 404-1 (e.g., 280-320 kHz). With respect to the illustrated 20 V transducer voltage curve 702, both the pole and zero locations have changed due to the faulty or degraded (e.g., depolarized) transducer 102. The curve 702 in this example exhibits a local maxima or pole FP1' that is shifted by a change amount ΔFP1 (e.g., approximately 2-3 kHz) relative to the healthy system pole location FP1 in FIG. 6. Also, the 20 V curve 702 in FIG. 7 exhibits a relatively weak local minima or zero FZ1' that is shifted by a change amount ΔFZ1 (e.g., approximately 5 kHz) relative to the healthy system zero location FZ1. Also, the corresponding 20 V curves 602 and 702 in FIGS. 6 and 7 have significantly different shapes across the frequency range of interest 404-1. The same is true of the 40 V curves 604 and 704 and the comparative 80 V curves 608 and 708 in FIGS. 6 and 7. As described hereinabove, RMS or sum of squares type analysis can be performed on the corresponding curve pairs by the controller

130 in order to provide a value indicating the similarity or dissimilarity of the sweep frequency response profiles 702, 704, 708 with respect to the baseline profiles 602, 604, 608. FIGS. 6 and 7 illustrate a frequency shift-based similarity comparison technique which can also be used, in which a local minima or local maxima is identified in the sweep profile and its corresponding frequency is compared with a corresponding local maxima or minima to determine a frequency change value ΔF. A fault or degradation can be detected based on the magnitude of the value ΔF. This fault or degradation can result from transducer overheating beyond the Curie temperature when too much current is driven thru the device during the cleaning process, leading to depolarization of the transducer piezo-electric material. This condition can result from the transducer being excited at different resonant frequencies with a fixed voltage level, where the transducer electrical impedance can change by an order of magnitude across the resonances of interest. In this example, the zero near 290 kHz no longer has a resonant effect when the voltage level increases to the required level to excite the transducer (e.g., the 40 and 80 V curves 704 and 708). The described systems facilitate monitoring the impedance response of the transducer 102 periodically or at any suitable point during the life of the transducer 102. If the response indicates that the resonant frequency is no longer present, then the transducer is determined by the controller 130 to be degraded or faulted, and a suitable warning signal or message can be issued to the host system 148.

[0039] FIG. 8 provides a graph 800 showing a further example implemented with respect to the second identified frequency range of interest 404-2 described hereinabove. In this case, the controller 130 has previously determined that this frequency range of interest 404-2 is relevant to detection of faults or degradation in a bond (e.g., glue) between the lens 202 and the transducer 102 of the lens cleaning system. The graph 800 includes a first curve 802 representing impedance magnitude response operation of the healthy system at a given operating voltage across the second example frequency range of interest 404-2 (e.g., 20-30 kHz). In this case, the healthy system exhibits a pole FP2 (e.g., slightly above 29 kHz) and a healthy system zero FZ2 at approximately 28 kHz. A second curve 804 in FIG. 8 shows subsequent impedance magnitude response throughout the range of interest 404-2 for a degraded or faulty bond between the lens 202 and the transducer 102. In this case, the pole location has changed by an amount ΔFP2 to a new location FP2', and the zero location has shifted by an amount ΔFZ2 to a new location FZ2'. The controller 130 in one example implements one or more numerical computations and mathematical techniques to ascertain a dissimilarity value or amount relating to the shapes of the curves 802, 804, and/or according to the frequency shift or shifts ΔFP2 and/or ΔFZ2. The amount of dissimilarity is compared with a corresponding threshold for the given transducer voltage used in the initial baseline characterization and the detection sweep in order to selectively determine the existence (or lack thereof) of a fault or degradation in the lens cleaning system.

[0040] Modifications are possible in the described embodiments, and other embodiments are possible, within the scope of the claims.

CLAIMS

What is claimed is:

1. A driver for a lens cleaning system, comprising:

an output configured to provide an oscillating drive signal at a non-zero frequency to an associated transducer to vibrate a lens;

a feedback circuit configured to measure a current feedback signal representing a current flowing in the transducer, and to generate a voltage feedback signal representing a voltage of the transducer; and

a controller configured to operate in a first mode to:

control the frequency of the drive signal to vibrate the lens at a plurality of frequencies in a frequency range of interest,

determine a plurality of measured frequency response values individually corresponding to one of the plurality of frequencies in the frequency range of interest according to the current feedback signal and the voltage feedback signal,

compare the measured frequency response values to baseline frequency response values associated with corresponding ones of the plurality of frequencies in the frequency range of interest for a healthy lens cleaning system, and

selectively determine existence of a fault or degradation in the lens cleaning system according to dissimilarities between the measured frequency response values and the baseline frequency response values.

2. The driver of claim 1, further comprising:

a signal generator circuit configured to provide a first output signal that oscillates at the non-zero frequency according to a frequency control signal;

an amplifier to amplify the first output signal to deliver an oscillating drive signal to the associated transducer; and

wherein the controller is configured to provide the frequency control signal to control the frequency of the drive signal.

3. The driver of claim 2,

wherein the controller comprises a processor to provide the frequency control signal as a digital value representing a desired output frequency for the drive signal, and a memory to store the baseline frequency response values;

wherein the signal generator is a pulse width modulation output of the processor; and

wherein the amplifier is a full H-bridge amplifier circuit with first and second outputs individually coupled with first and second transducer terminals to provide the oscillating drive signal to the transducer.

4. The driver of claim 1, wherein the controller is configured to operate in a second mode to:

measure a baseline frequency response profile including frequency response values measured for the healthy lens cleaning system across a wide range of frequencies that includes the frequency range of interest;

store the baseline frequency response profile in the lens cleaning system; and

identify one or more frequency ranges of interest that include a pole or zero of the baseline frequency response profile.

5. The driver of claim 4,

wherein the controller is configured to operate in the second mode to, for each of a plurality of the different transducer voltages:

measure and store multiple baseline frequency response profiles across the wide range of frequencies for a corresponding one of the transducer voltages, and

identify one or more frequency ranges of interest that include a pole or zero of the baseline frequency response profile for the corresponding one of the transducer voltages; and

wherein the controller is configured to operate in the first mode to, for each of a plurality of the different transducer voltages:

control the frequency of the drive signal to vibrate the lens at a plurality of frequencies in a predetermined frequency range of interest for the corresponding one of the transducer voltages,

determine a plurality of measured frequency response values individually corresponding to one of the plurality of frequencies in the predetermined frequency range of interest according to the current feedback signal and the voltage feedback signal,

compare the measured frequency response values to baseline frequency response values of the baseline frequency response profile associated with corresponding ones of the plurality of frequencies in the predetermined frequency range of interest for the corresponding one of the transducer voltages, and selectively determine existence of a fault or degradation in the lens cleaning system according to dissimilarities between the measured frequency response values and the baseline frequency response values for the corresponding one of the transducer voltages.

6. The driver of claim 4,

wherein the controller is configured to operate in the second mode to identify a plurality of frequency ranges of interest that include a pole or zero of the baseline frequency response profile; and

wherein the controller is configured to operate in the first mode to:

control the frequency of the drive signal to vibrate the lens at a plurality of frequencies in each of the plurality of frequency ranges of interest,

determine a plurality of measured frequency response values individually corresponding to one of the plurality of frequencies in each of the plurality of frequency ranges of interest according to the current feedback signal and the voltage feedback signal,

compare the measured frequency response values to baseline frequency response values of the baseline frequency response profiles associated with corresponding ones of the plurality of frequencies in the each of the plurality of frequency ranges of interest,

selectively determine existence of a fault or degradation in the lens cleaning system according to dissimilarities between the measured frequency response values and the baseline frequency response values in a specific one of the frequency ranges of interest, and

selectively identify a type of a determined fault or degradation according the specific one of the frequency ranges of interest for which the dissimilarities indicate existence of the fault or degradation.

7. The driver of claim 1, wherein the controller is configured to operate in the first mode to, for each of a plurality of different transducer voltages:

control the frequency of the drive signal to vibrate the lens at a plurality of frequencies in a predetermined frequency range of interest for a corresponding one of the transducer voltages;

determine a plurality of measured frequency response values individually corresponding to one of the plurality of frequencies in the predetermined frequency range of interest according to the current feedback signal and the voltage feedback signal;

compare the measured frequency response values to baseline frequency response values of the baseline frequency response profile associated with corresponding ones of the plurality of frequencies in the predetermined frequency range of interest for the corresponding one of the transducer voltages; and

selectively determine existence of a fault or degradation in the lens cleaning system according to dissimilarities between the measured frequency response values and the baseline frequency response values for the corresponding one of the transducer voltages.

8. The driver of claim 7, wherein the controller is configured to operate in the first mode to:

control the frequency of the drive signal to vibrate the lens at a plurality of frequencies in each of a plurality of frequency ranges of interest;

determine a plurality of measured frequency response values individually corresponding to one of the plurality of frequencies in each of the plurality of frequency ranges of interest according to the current feedback signal and the voltage feedback signal;

compare the measured frequency response values to baseline frequency response values of the baseline frequency response profiles associated with corresponding ones of the plurality of frequencies in the each of the plurality of frequency ranges of interest;

selectively determine existence of a fault or degradation in the lens cleaning system according to dissimilarities between the measured frequency response values and the baseline frequency response values in a specific one of the frequency ranges of interest; and

selectively identify a type of a determined fault or degradation according the specific one of the frequency ranges of interest for which the dissimilarities indicate existence of the fault or degradation.

9. The driver of claim 1, wherein the controller is configured to operate in the first mode to:

control the frequency of the drive signal to vibrate the lens at a plurality of frequencies in each of a plurality of frequency ranges of interest;

determine a plurality of measured frequency response values individually corresponding to one of the plurality of frequencies in each of the plurality of frequency ranges of interest according to the current feedback signal and the voltage feedback signal;

compare the measured frequency response values to baseline frequency response values of the baseline frequency response profiles associated with corresponding ones of the plurality of frequencies in the each of the plurality of frequency ranges of interest;

selectively determine existence of a fault or degradation in the lens cleaning system according to dissimilarities between the measured frequency response values and the baseline frequency response values in a specific one of the frequency ranges of interest; and

selectively identify a type of a determined fault or degradation according the specific one of the frequency ranges of interest for which the dissimilarities indicate existence of the fault or degradation.

10. The driver of claim 1, wherein the output, the feedback circuit, and the controller are fabricated in a single integrated circuit.

11. The driver of claim 1, wherein the controller includes an output configured to selectively provide a signal in response to determination of the existence of a fault or degradation.

12. A lens cleaning system to clean a lens, comprising:

a transducer mechanically coupled to the lens;

a driver configured to provide an oscillating drive signal at a non-zero frequency to the transducer to vibrate the lens;

a feedback circuit configured to measure a current feedback signal representing a current flowing in the transducer, and to generate a voltage feedback signal representing a voltage of the transducer; and

a controller configured to operate in a first mode to:

control the frequency of the drive signal to cause the driver to vibrate the lens at a plurality of frequencies in a frequency range of interest,

determine a plurality of measured frequency response values individually corresponding to one of the plurality of frequencies in the frequency range of interest according to the current feedback signal and the voltage feedback signal,

compare the measured frequency response values to baseline frequency response values associated with corresponding ones of the plurality of frequencies in the frequency range of interest for a healthy lens cleaning system, and

selectively determine existence of a fault or degradation in the lens cleaning system according to dissimilarities between the measured frequency response values and the baseline frequency response values.

13. The lens cleaning system of claim 12, wherein the controller is configured to operate in a second mode to:

measure a baseline frequency response profile including frequency response values measured for the healthy lens cleaning system across a wide range of frequencies that includes the frequency range of interest;

store the baseline frequency response profile in the lens cleaning system; and

identify one or more frequency ranges of interest that include a pole or zero of the baseline frequency response profile.

14. The lens cleaning system of claim 13,

wherein the controller is configured to operate in the second mode to, for each of a plurality of the different transducer voltages:

measure and store multiple baseline frequency response profiles across the wide range of frequencies for a corresponding one of the transducer voltages, and

identify one or more frequency ranges of interest that include a pole or zero of the baseline frequency response profile for the corresponding one of the transducer voltages; and

wherein the controller is configured to operate in the first mode to, for each of a plurality of the different transducer voltages:

control the frequency of the drive signal to cause the driver to vibrate the lens at a plurality of frequencies in a predetermined frequency range of interest for the corresponding one of the transducer voltages,

determine a plurality of measured frequency response values individually corresponding to one of the plurality of frequencies in the predetermined frequency range of interest according to the current feedback signal and the voltage feedback signal,

compare the measured frequency response values to baseline frequency response values of the baseline frequency response profile associated with corresponding ones of the plurality of frequencies in the predetermined frequency range of interest for the corresponding one of the transducer voltages, and

selectively determine existence of a fault or degradation in the lens cleaning system according to dissimilarities between the measured frequency response values and the baseline frequency response values for the corresponding one of the transducer voltages.

15. The lens cleaning system of claim 13,

wherein the controller is configured to operate in the second mode to identify a plurality of frequency ranges of interest that include a pole or zero of the baseline frequency response profile;

and

wherein the controller is configured to operate in the first mode to:

control the frequency of the drive signal to cause the driver to vibrate the lens at a plurality of frequencies in each of the plurality of frequency ranges of interest,

determine a plurality of measured frequency response values individually corresponding to one of the plurality of frequencies in each of the plurality of frequency ranges of interest according to the current feedback signal and the voltage feedback signal,

compare the measured frequency response values to baseline frequency response values of the baseline frequency response profiles associated with corresponding ones of the plurality of frequencies in the each of the plurality of frequency ranges of interest,

selectively determine existence of a fault or degradation in the lens cleaning system according to dissimilarities between the measured frequency response values and the baseline frequency response values in a specific one of the frequency ranges of interest, and

selectively identify a type of a determined fault or degradation according the specific one of the frequency ranges of interest for which the dissimilarities indicate existence of the fault or degradation.

16. The lens cleaning system of claim 12, wherein the controller is configured to operate in the first mode to, for each of a plurality of different transducer voltages:

control the frequency of the drive signal to cause the driver to vibrate the lens at a plurality of frequencies in a predetermined frequency range of interest for a corresponding one of the transducer voltages;

determine a plurality of measured frequency response values individually corresponding to one of the plurality of frequencies in the predetermined frequency range of interest according to the current feedback signal and the voltage feedback signal;

compare the measured frequency response values to baseline frequency response values of the baseline frequency response profile associated with corresponding ones of the plurality of frequencies in the predetermined frequency range of interest for the corresponding one of the transducer voltages; and

selectively determine existence of a fault or degradation in the lens cleaning system according to dissimilarities between the measured frequency response values and the baseline frequency response values for the corresponding one of the transducer voltages.

17. The lens cleaning system of claim 12, wherein the controller is configured to operate in the first mode to:

control the frequency of the drive signal to cause the driver to vibrate the lens at a plurality of frequencies in each of a plurality of frequency ranges of interest;

determine a plurality of measured frequency response values individually corresponding to one of the plurality of frequencies in each of the plurality of frequency ranges of interest according to the current feedback signal and the voltage feedback signal;

compare the measured frequency response values to baseline frequency response values of the baseline frequency response profiles associated with corresponding ones of the plurality of frequencies in the each of the plurality of frequency ranges of interest;

selectively determine existence of a fault or degradation in the lens cleaning system according to dissimilarities between the measured frequency response values and the baseline frequency response values in a specific one of the frequency ranges of interest; and

selectively identify a type of a determined fault or degradation according the specific one of the frequency ranges of interest for which the dissimilarities indicate existence of the fault or degradation.

18. The lens cleaning system of claim 12, wherein the controller includes an output configured to selectively provide a signal in response to determination of the existence of a fault or degradation.

19. A method to detect faults or degradation in a lens cleaning system, the method comprising:

controlling a frequency of a drive signal to vibrate a lens at a plurality of frequencies in a frequency range of interest;

determining a plurality of measured frequency response values individually corresponding to one of the plurality of frequencies in the frequency range of interest according to a current feedback signal and a voltage feedback signal;

comparing the measured frequency response values to baseline frequency response values associated with corresponding ones of the plurality of frequencies in the frequency range of interest for a healthy lens cleaning system; and

selectively determining existence of a fault or degradation in the lens cleaning system according to dissimilarities between the measured frequency response values and the baseline frequency response values.

20. The method of claim 19, further comprising:

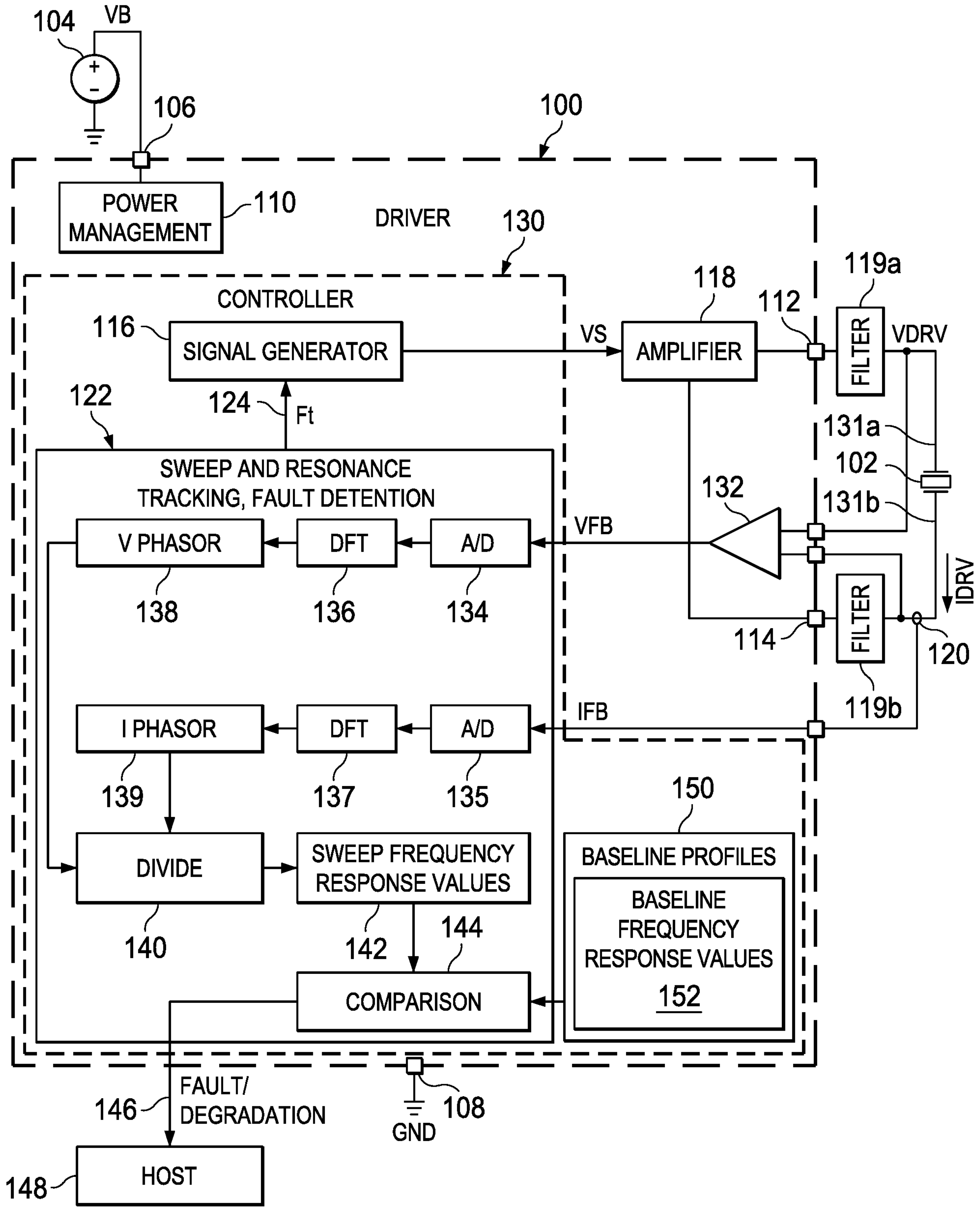
controlling the frequency of the drive signal to vibrate the lens at a plurality of frequencies in each of a plurality of frequency ranges of interest;

determining a plurality of measured frequency response values individually corresponding to one of the plurality of frequencies in each of the plurality of frequency ranges of interest according to the current feedback signal and the voltage feedback signal;

comparing the measured frequency response values to baseline frequency response values of the baseline frequency response profiles associated with corresponding ones of the plurality of frequencies in the each of the plurality of frequency ranges of interest;

selectively determining existence of a fault or degradation in the lens cleaning system according to dissimilarities between the measured frequency response values and the baseline frequency response values in a specific one of the frequency ranges of interest; and

selectively identifying a type of a determined fault or degradation according the specific one of the frequency ranges of interest for which the dissimilarities indicate existence of the fault or degradation.



104
VB
106
100
POWER MANAGEMENT
110
DRIVER
130
CONTROLLER
116
SIGNAL GENERATOR
VS
AMPLIFIER
118
112
119a
FILTER
VDRV
122
124
Ft
131a
102
SWEEP AND RESONANCE TRACKING, FAULT DETENTION
132
131b
V PHASOR
DFT
A/D
VFB
IDRV
138
136
134
114
FILTER
120
119b
I PHASOR
DFT
A/D
IFB
139
137
135
150
DIVIDE
SWEEP FREQUENCY RESPONSE VALUES
BASELINE PROFILES
BASELINE FREQUENCY RESPONSE VALUES
152
140
142
144
COMPARISON
146
FAULT/ DEGRADATION
108
GND
148
HOST

FIG. 1

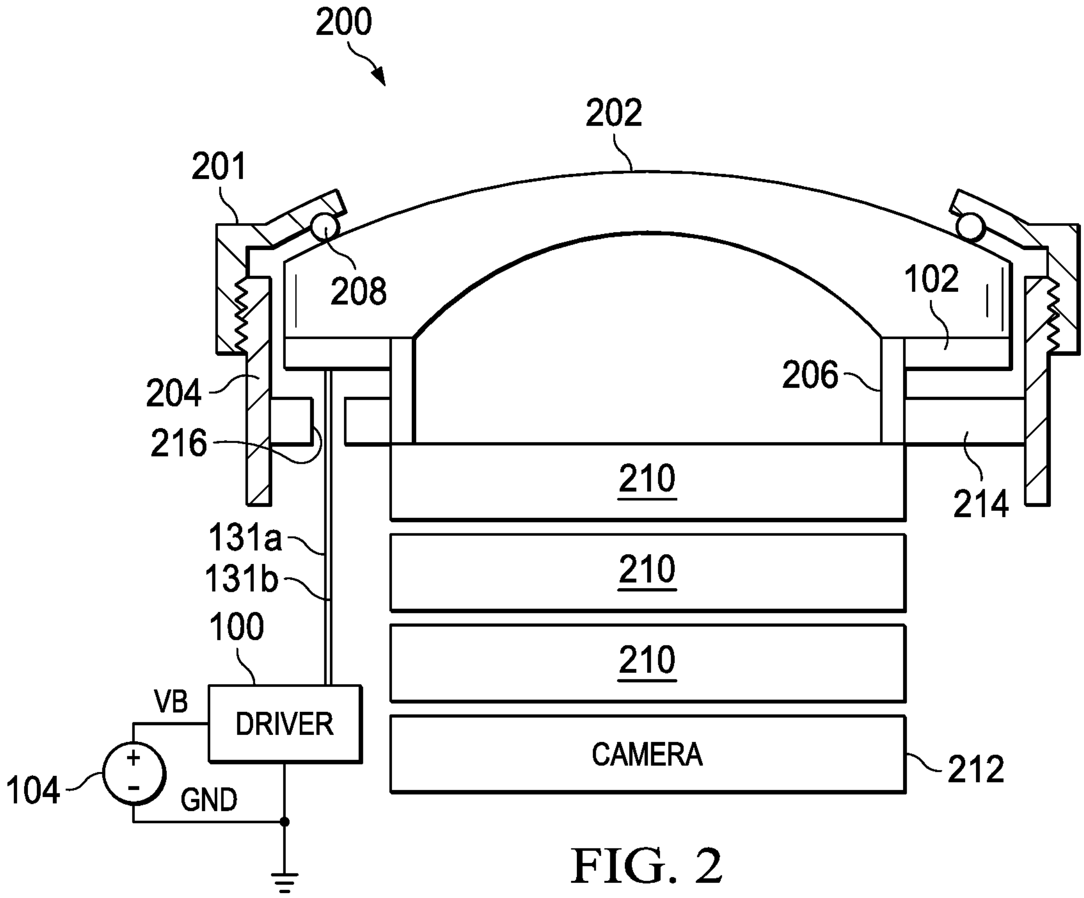

200
202
201
208
102
206
204
216
214
210
210
210
131a
131b
100
VB
DRIVER
CAMERA
212
104
GND

FIG. 2

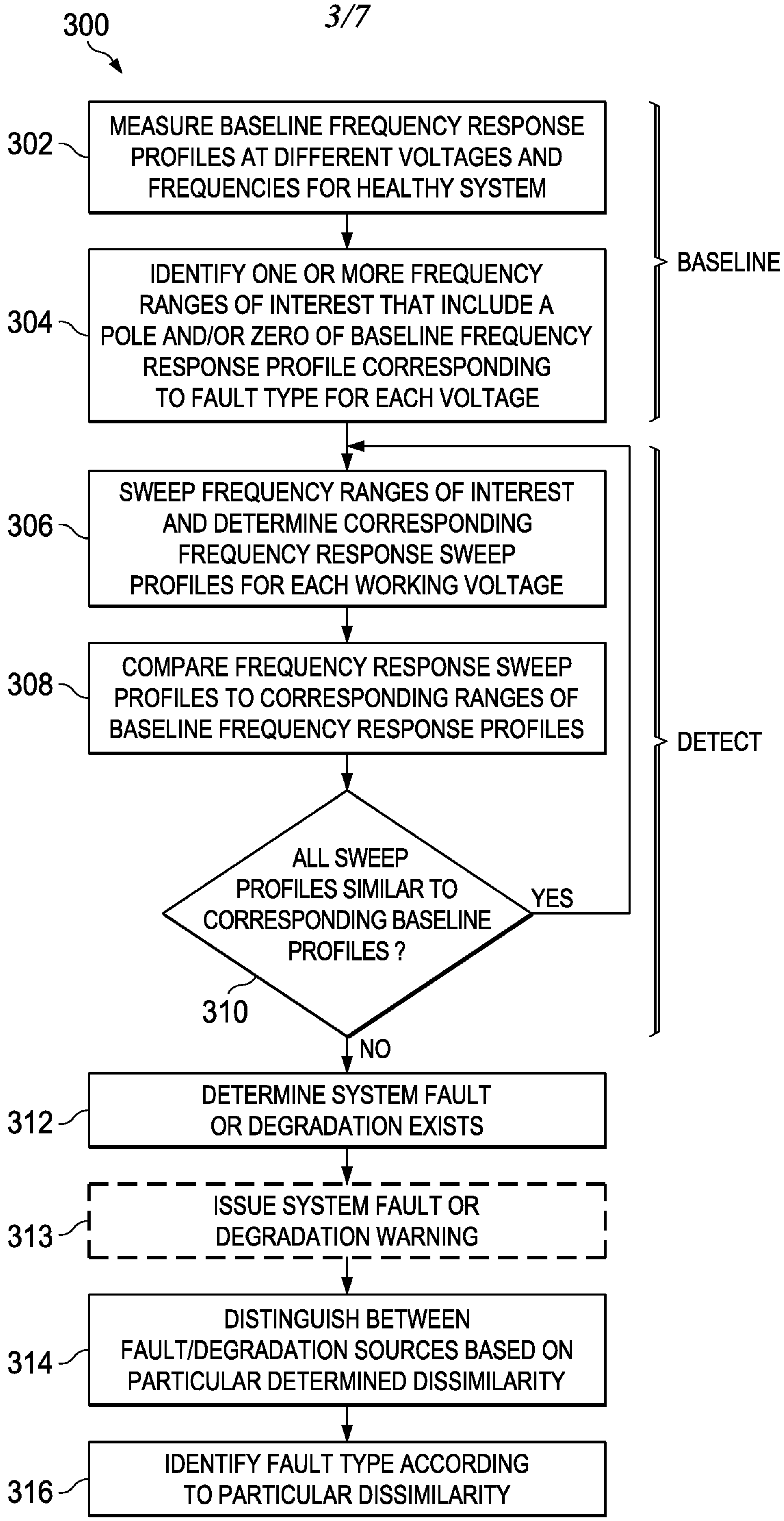

300
302
MEASURE BASELINE FREQUENCY RESPONSE PROFILES AT DIFFERENT VOLTAGES AND FREQUENCIES FOR HEALTHY SYSTEM
304
IDENTIFY ONE OR MORE FREQUENCY RANGES OF INTEREST THAT INCLUDE A POLE AND/OR ZERO OF BASELINE FREQUENCY RESPONSE PROFILE CORRESPONDING TO FAULT TYPE FOR EACH VOLTAGE
BASELINE
306
SWEEP FREQUENCY RANGES OF INTEREST AND DETERMINE CORRESPONDING FREQUENCY RESPONSE SWEEP PROFILES FOR EACH WORKING VOLTAGE
308
COMPARE FREQUENCY RESPONSE SWEEP PROFILES TO CORRESPONDING RANGES OF BASELINE FREQUENCY RESPONSE PROFILES
DETECT
ALL SWEEP PROFILES SIMILAR TO CORRESPONDING BASELINE PROFILES ?
YES
310
NO
312
DETERMINE SYSTEM FAULT OR DEGRADATION EXISTS
313
ISSUE SYSTEM FAULT OR DEGRADATION WARNING
314
DISTINGUISH BETWEEN FAULT/DEGRADATION SOURCES BASED ON PARTICULAR DETERMINED DISSIMILARITY
316
IDENTIFY FAULT TYPE ACCORDING TO PARTICULAR DISSIMILARITY

FIG. 3

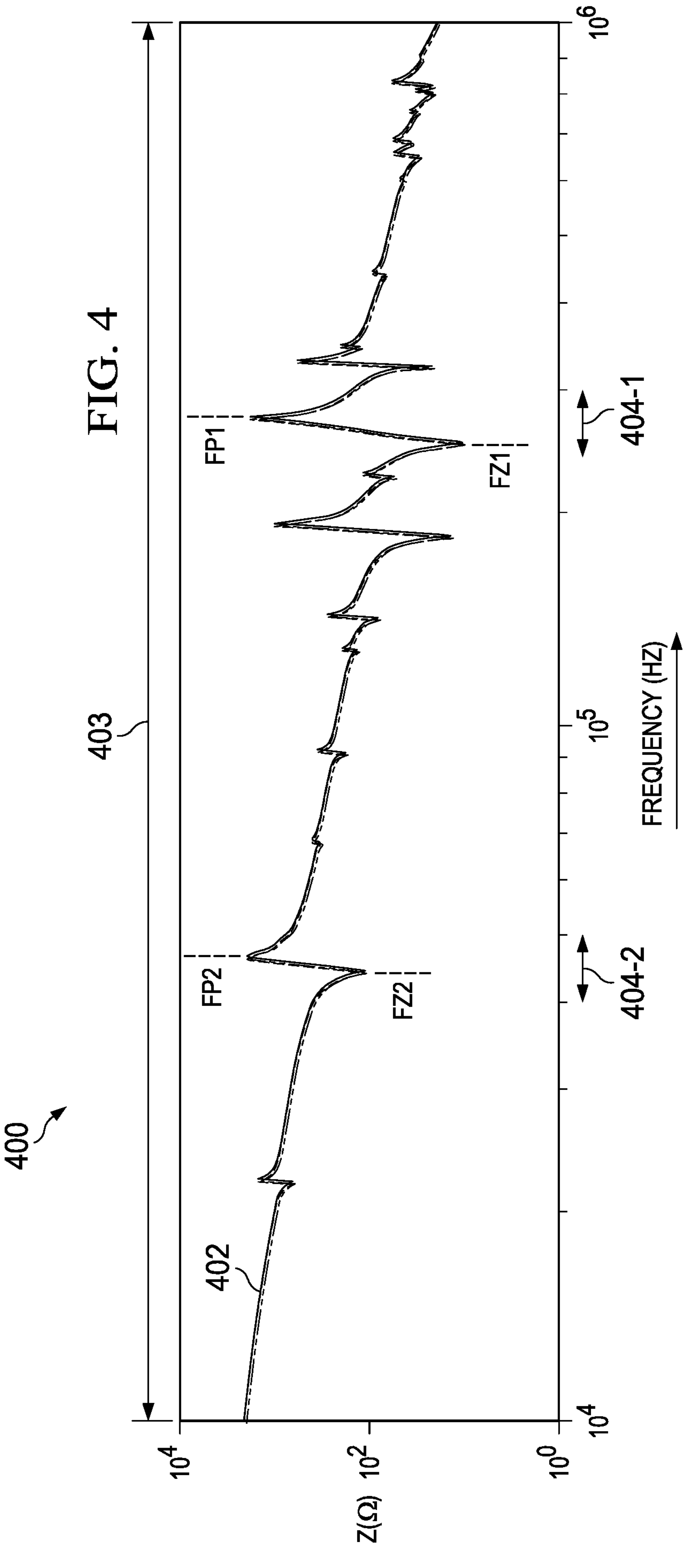

400
403
402
FP1
FZ1
FP2
FZ2
404-1
404-2
Z(Ω)
10^4
10^2
10^0
10^4
10^5
10^6
FREQUENCY (HZ)

FIG. 4

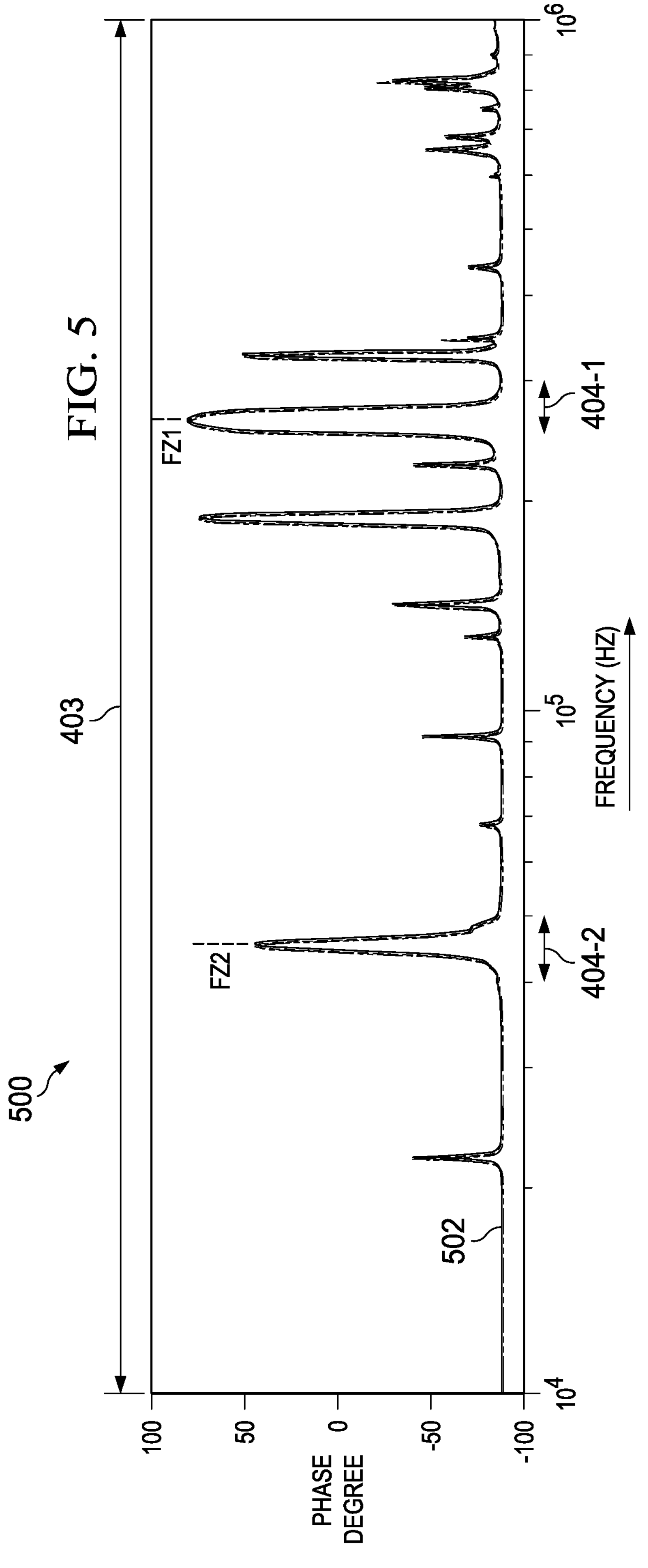

500
403
502
FZ1
FZ2
404-1
404-2
PHASE
DEGREE
100
50
0
-50
-100
10^4
10^5
10^6
FREQUENCY (HZ)

FIG. 5

FIG. 6

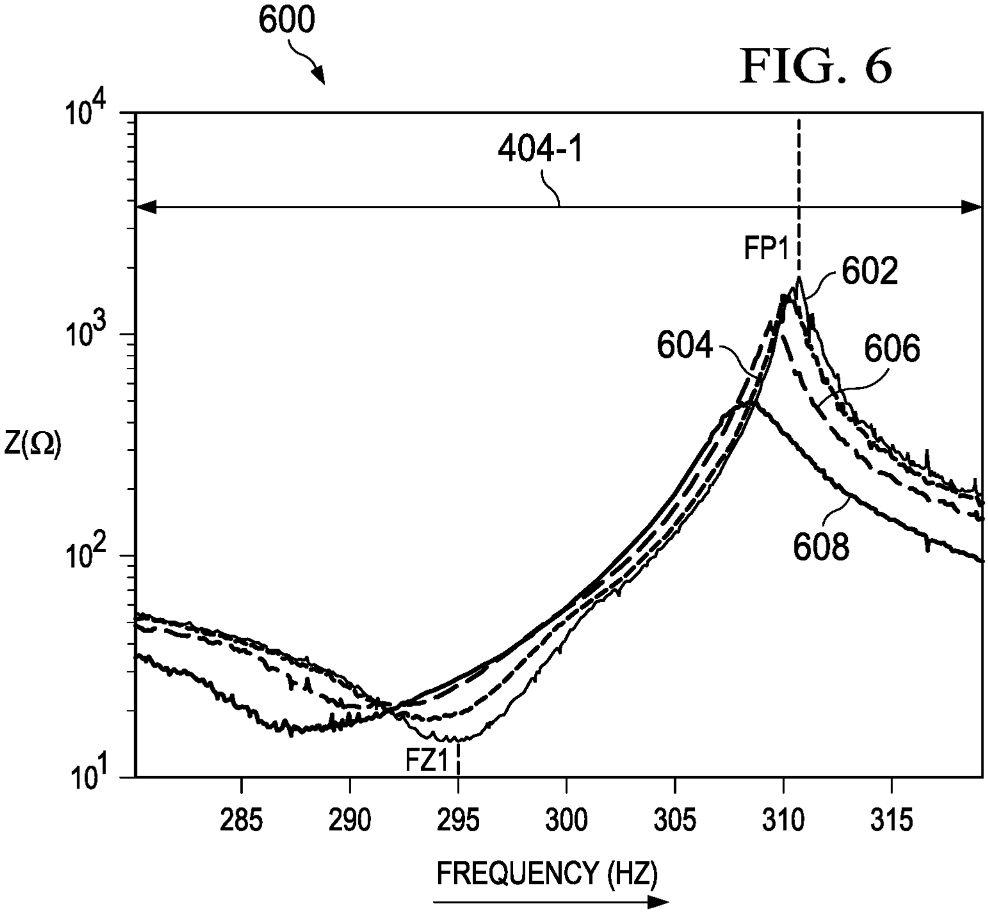
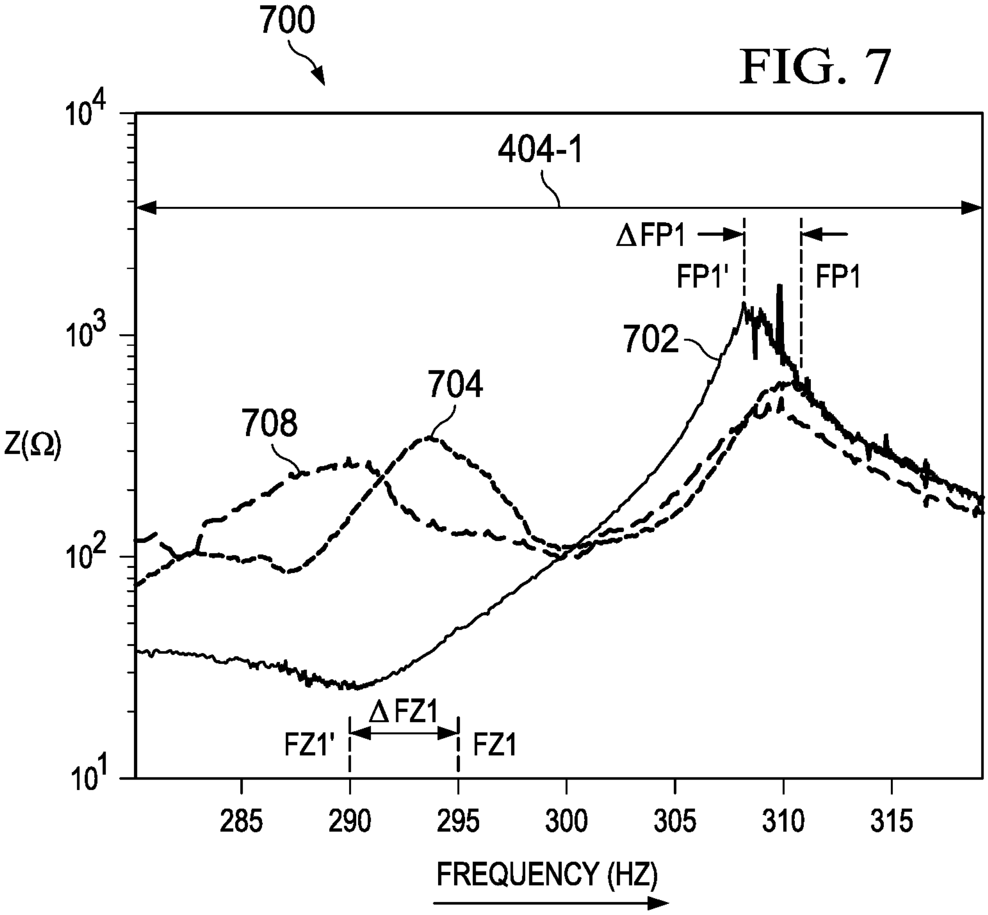
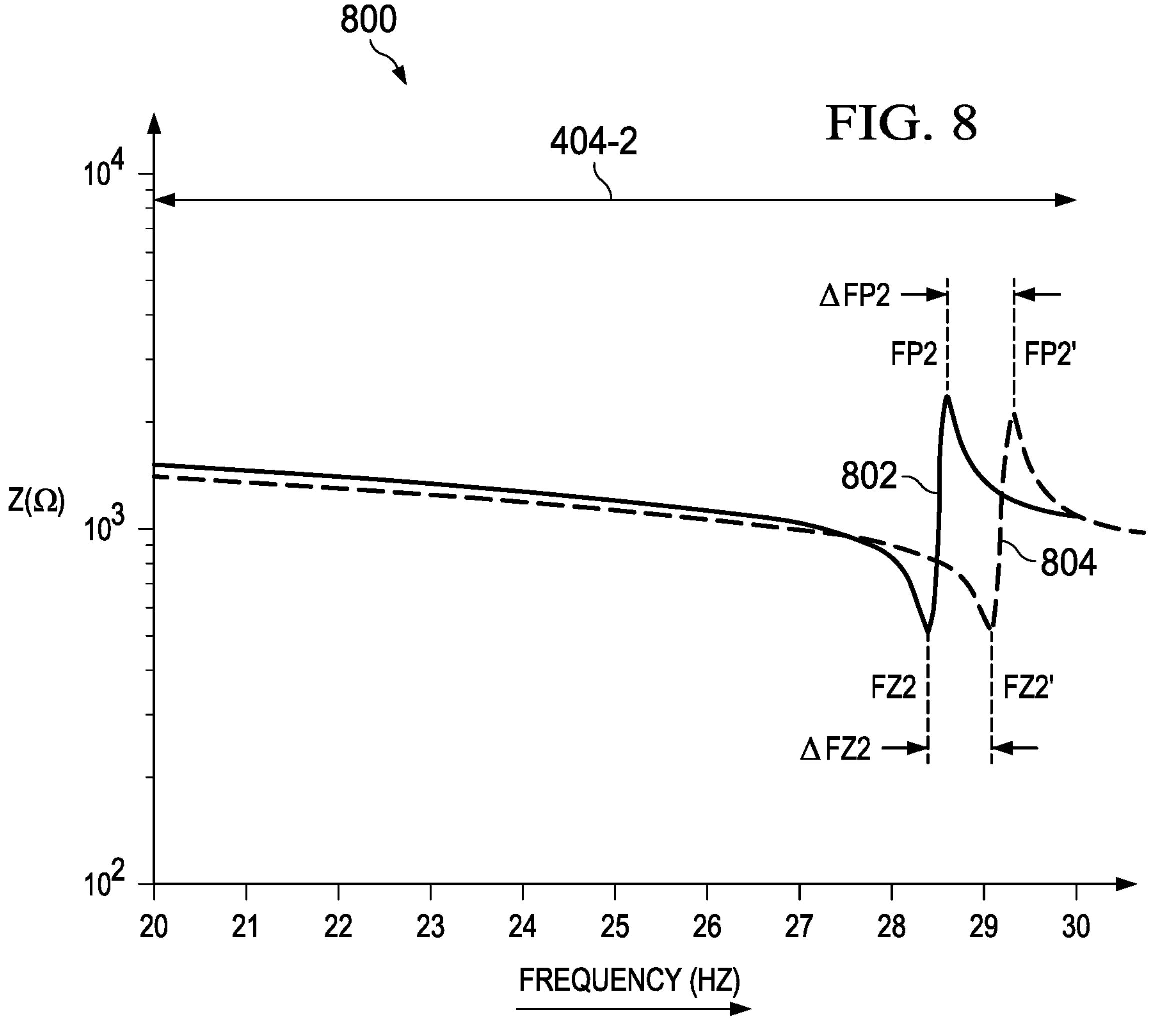

600
404-1
FP1
602
604
606
608
FZ1
Z(Ω)
10^4
10^3
10^2
10^1
285
290
295
300
305
310
315
FREQUENCY (HZ)

FIG. 7


700
404-1
ΔFP1
FP1'
FP1
702
704
708
Z(Ω)
ΔFZ1
FZ1'
FZ1
10^4
10^3
10^2
10^1
285
290
295
300
305
310
315
FREQUENCY (HZ)



800
404-2
10^4
10^3
10^2
Z(Ω)
ΔFP2
FP2
FP2'
802
804
FZ2
FZ2'
ΔFZ2
20
21
22
23
24
25
26
27
28
29
30
FREQUENCY (HZ)

FIG. 8

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 2017/059536

A. CLASSIFICATION OF SUBJECT MATTER

B08B 7/02 *(2006.01)*
G03B 29/00 *(2006.01)*

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)

B08B 7/02, G02B 27/00, B06B 1/02, B08B 11/00, 3/12, G03B 29/00

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)

Esp@cenet, PatSearch (RUPTO internal), RUPAT, RUPAT-OLD, RUPTO, USPTO

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y A	US 2016/0266379 A1 (TEXAS INSTRUMENTS INCORPORATED) 15.09.2016, abstract, claim 1, paragraphs [0017] - [0041]	1-3, 7-12, 16-20 4-6, 13-15
Y	EP 2777579 A1 (COVIDIEN LP) 17.09.2014, paragraph [0017]	1-3, 7-12, 16-20
Y	US 6064259 A (NIKON CORPORATION OF AMERICA) 16.05.2000, claim 1, abstract	3
A	US 5178173 A (ROBERT J. PACE) 12.01.1993	1-20

☐ 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 document 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	Date of mailing of the international search report
12 February 2018 (12.02.2018)	28 February 2018 (28.02.2018)

Name and mailing address of the ISA/RU:
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