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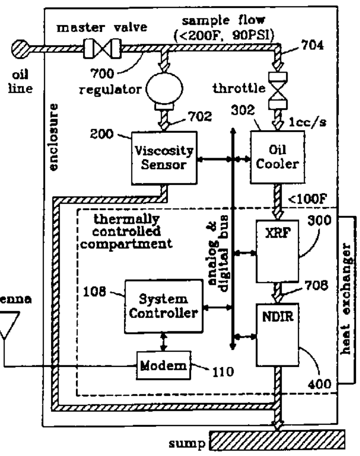
(54) Title: AN APPARATUS FOR MACHINE FLUID ANALYSIS



(57) Abstract: The present invention is an apparatus for analyzing a machine fluid used in a machine. The apparatus has at least one meter placed proximate the machine and in contact with the machine fluid for measuring at least one parameter related to the machine fluid. The at least one parameter is a standard laboratory analysis parameter. The at least one meter includes but is not limited to viscometer, element meter, optical meter, particle meter and combinations thereof.

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AN APPARATUS FOR MACHINE FLUID ANALYSIS

FIELD OF THE INVENTION

The present invention is an apparatus for machine fluid analysis, and more specifically, for the on-board analysis of multiple attributes of operating fluids necessary for large-engine health.

BACKGROUND OF THE INVENTION

It is well known that chemical and physical analysis of a machine fluid can provide information about the condition of the fluid as well as the wear status of the machine in which the fluid is used. Machine fluid analysis is widely used for determination of lubricant condition, lubricant contamination and wear status in engines, drive components and hydraulic systems in fleet or industrial service. For example, lubrication oil analysis is widely used for railroad engines and is conducted by the military on most motorized equipment including aircraft and naval engines and drive trains. In industry, commercial fluid analysis providers offer fluid analysis service for engine and drive train lubricants as well as hydraulic fluids.

Locomotive engine manufacturers such as General Electric (GE) and General Motors Electro-Motive Division (EMD) promulgate recommended limits for wear elements as determined by spectrographic analysis of lubrication oil samples. Manufactures and railroad operators also set limits on such parameters as water or fuel dilution of lubricating oil, soot and pentane insolubles (compounds in oil that do not dissolve in pentane). These limits indicate when maintenance is required to prevent impending component failures that may result in severe and expensive engine damage. Properly interpreted, the analytical data can also indicate specific maintenance operations that need to be performed on the engine.

Traditionally, an oil sample has been taken from the lubricant reservoir on the engine being analyzed, and each of these parameters was then measured in the laboratory by a different instrument for a different purpose. Viscosity is measured with a viscometer and provides an indication of possible dilution of the oil by fuel or water. Viscosity can also indicate oil degradation from heat or oxidation. Chemical degradation of the oil (oxidation, nitration, etc.) is commonly determined by infra- red (IR) spectrometric analysis, which may also be used to infer total acid number (TAN) and total base number (TBN) for the oil. Water in the oil may also be detected by IR analysis. Slow coolant leaks into the lubricating oil system may be detected by quantitative analysis of boron, chromium or other elements present in the coolant water as salts. Elemental analysis is typically accomplished by atomic emission spectrometry (AES) or spark source mass spectrometry, but may also be accomplished by X-ray fluorescence (XRF). Such analyses provide an indication of component wear according to the type and amount of metal(s) in the sample.

Monitoring of machine fluids to specifically determine the parameters described above presently requires that samples of the machine fluid(s) be obtained and sent to a laboratory for chemical and physical analysis. However, the machines for which laboratory analysis is most valuable are often mobile, and may at any time be in remote locations, making sampling and laboratory analysis impractical on a frequent or regular basis. Moreover, the small sample amounts obtained for analysis may not be representative of the bulk oil and analyses in the laboratory requires a day or more. The logistical impracticality of laboratory analysis is overcome in practice with scheduled maintenance and service for vehicle machines. Such routine maintenance schedules are designed so that lubricant change-out occurs prior to the time damage to the engine may result, and are scheduled to ensure that they provide sufficient leeway before a problem is projected to occur. It is believed that the frequency of maintenance and service could be reduced by the use of more frequent and regular oil analysis.

Additionally, there are environments where immediate indicators of engine health is critical. As an example, when an engine on a helicopter or airplane fails, the result to passengers can be disastrous. An indication to the pilot of a failing engine, prior to actual engine failure, may provide sufficient time to either save the engine from destruction, or provide time for the pilot to safely return to the ground under power.

On-board or in-situ machine fluid analysis has been investigated with several proposed approaches. For example, Voelker et al (**5,789,665**) described a method and apparatus for determining deterioration of lubricating oils by measuring electrical properties of a polymeric matrix or by exploiting volumetric change behavior of the polymeric matrix in the form of beads. Disadvantages of this approach include that it responds only to a single parameter (free water) but does not quantify the free water, and there is a need to replace used polymer beads.

Freese et al. (**5,604,441**) relies on measurement of changes in dielectric properties of a lubricant (oil) in a changing magnetic field. The change in dielectric properties indicates a change in oil condition. Dielectric constant is non-specific and at best may provide an indirect indication of oil degradation. The magnetic field is also used to attract and quantify ferromagnetic particles.

Finally, Boyle et al. (**5,964,318**) designed a system to measure the level and quantity of lubricant in an engine lubricant reservoir. On-board in-situ sensors are provided to measure the quantity of lubricant in the system, as well as the quality (temperature, pressure, dielectric and/or viscosity). If the quality drops below a predetermined level, the system diverts a portion of the lubricant to a reservoir for storage or reintroduction as a fuel additive, and a coincident addition of fresh lubricant to the system to maintain the desired level of lubricant. However, the '318 apparatus/process is a totally self-contained system; it does not provide an indication to those remotely monitoring engine health of the current status of lubricant within the engine—it is solely an internally-monitored lubricant quality indicator.

The above-cited patents describe measurements that do not provide to remote observers information sufficient to determine the wear status of the machine containing the measured fluid, and so they cannot be used in lieu of standard laboratory oil analysis. In particular the above cited patents do not describe a system which can be used to provide data such that real time and remote assessment of machine condition can be made.

On-board measurement and analysis of operational parameters, including determination of fluid levels and fluid and gas temperatures and pressures for a gas turbine engine, has been described (Greitzer et al, 1994). These authors described the use of sensors and artificial neural network software to analyze engine operational status and condition. This approach has been termed machine health monitoring. However, these authors did not attempt to measure standard laboratory analysis parameters for any engine fluid.

Hence, there remains a need for in-situ or on board analysis of machine fluid that provides information similar in nature and utility to that obtained from standard laboratory machine fluid analysis.

Any discussion of documents, devices, acts or knowledge in this specification is included to explain the context of the invention. It should not be taken as an admission that any of the material formed part of the prior art base or the common general knowledge in the relevant art in Australia on or before the priority date of the claims herein.

"Comprises/comprising" when used in this specification is taken to specify the presence of stated features, integers, steps or components but does not preclude the presence or addition of one or more other features, integers, steps, components or groups thereof."

SUMMARY OF THE INVENTION

It is desirable to provide an apparatus on a machine and in contact with a machine fluid for analysis of the machine fluid by measuring at least one standard laboratory analysis parameter.

It is also desirable to provide a system for determining on-board real time parameters of fluid systems relating to the health of an engine whereby a plurality of sensors are placed proximate the engine such that a plurality of standard laboratory analysis procedures are determined on-board the engine, with such characteristics being transmitted to a remote observer of engine health.

The present invention provides an apparatus, system and method for analyzing a machine fluid used in a machine. The apparatus has at least one meter (or sensor) placed proximate the machine and in contact with the machine fluid for measuring at least one parameter related to the machine fluid. The at least one parameter is a standard laboratory analysis parameter. The at least one meter includes but is not limited to viscometer, element meter, optical meter, particle meter and combinations thereof. Additionally, the results of this analysis are made immediately available to remote observers of engine-related system health, whether it be engine lubricants, hydraulic fluids, coolant fluids, or the like.

As used herein, "proximate" means on or near.

As used herein, "meter . . . in contact with the machine fluid" means that the machine fluid passes to the meter(s) or sensor(s) under pressure of the machine. This is in contrast to collecting a sample in a separate container and introducing the sample to the meter(s) independently of or separate and distinct from the machine and the machine pressure.

As used herein, the term or phrase "standard laboratory analysis parameter(s)" refers to parameters specified for direct determination of fluid or machine condition. More specifically, standard laboratory analysis parameter includes, but is in no way limited to, viscosity, low viscosity and high viscosity; pentane insolubles; water presence; boron concentration; elemental analysis concentrations of one or more of iron, lead, copper, silicon, chromium, aluminum, silver, and zinc. In contrast, a non-standard parameter would be an indirect measure including but not limited to dielectric constant, polymer swelling, and combinations thereof and are specifically excluded from "standard laboratory analysis parameter".

As used herein, the phrase "remote observer of engine health" means an individual or machine outside the engine itself, which is trained or programmed to recognize non-routine measurements transmitted by the meter in contact with the machine fluid. The remote observer may be a person, such as the machine operator, or it may be a machine programmed to issue a warning signal if a significantly non-routine measurement is transmitted.

One aspect of the present invention provides a machine fluid analysis system including:

at least first and second sensors contacting a machine fluid under pressure of the machine;

a controller operable to collect data from the sensors for transmission to a remote location; and

a two-way wireless communicator coupled to the controller for receiving interrogation signals and for transmitting the collected data to the remote location;

wherein the first sensor includes an X-ray fluorescence meter including an X-ray source providing source X-rays and a thin walled polymeric tube, the tube defining a fluid flow path past the X-ray source, and

wherein the second sensor includes at least one sensor selected from the group consisting of viscometer, optical meter, and particle counter.

A second aspect of the present invention provides a machine fluid analysis system including:

a plurality of different sensors contacting a fluid under pressure of a machine, wherein at least two of the plurality of different sensors are selected from the group consisting of optical meter, viscometer, element meter, and particle counter;

a controller operable to collect data from the plurality of sensors for transmission to a remote location; and

a two-way wireless communicator coupled to the controller for receiving interrogation signals and for transmitting the collected data to the remote location; and

a fluid cooler operably coupled to at least one of the sensors;

wherein fluid is provided to different ones of the plurality of different sensors at substantially different temperatures.

A third aspect of the present invention provides a fluid analysis system including:

a plurality of different sensors contacting a fluid under pressure of a machine, wherein each of the plurality of sensors are operable to determine a different standard laboratory analysis parameter;

a controller operable to collect data from the plurality of sensors for transmission to a remote location; and

a two-way wireless communicator coupled to the controller for receiving interrogation signals and for transmitting the collected data to the remote location; and a thermally controlled compartment wherein at least one of the sensors is inside of and another is outside of the thermally controlled compartment whereby fluid is provided to different ones of the plurality of sensors at substantially different temperatures.

An advantage of the present invention is an apparatus, system and method for providing to a remote observer of engine health an accurate on board determination of machine fluid and/or machine condition because of the use of the standard laboratory analysis parameter. Further advantages include real time oil data capture and oil data capture for remote locations of the machine.

In a preferred embodiment of the present invention, a plurality of standard laboratory analysis parameters is measured or obtained thereby permitting real time and/or remote assessment of machine and/or oil condition while the machine is in or available for service. An advantage of this preferred embodiment is more timely and cost effective machine condition dependent service and maintenance instead of the machine condition independent equal time interval scheduled maintenance and service.

While the present invention is disclosed with particular reference to an engine lubricant system, it is equally applicable to numerous other systems that determine engine health. Likewise, the invention is not limited to particular apparatus' disclosed herein, but is rather broad enough to encompass the entire system regardless of the particular apparatus utilized.

The subject matter of the present invention is particularly pointed out and distinctly claimed in the concluding portion of this specification. However, both the organization and method of operation, together with further advantages and objects thereof, may best be understood by reference to the following description

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taken in connection with accompanying drawings wherein like reference characters refer to like elements.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic diagram of a single meter embodiment of the present invention.

FIG. 2 is a cross section/schematic? of a viscometer according to the present invention.

FIG. 3 is a diagram of an X-ray fluorescence (XRF) spectrometer according to the present invention.

FIG. 4a is a schematic diagram of an optical meter with a tubular sample cell.

FIG. 4b is a schematic diagram of an optical meter with a planar sample cell.

FIG. 5 is a schematic representation of the communicator of the present invention.

FIG. 6 is a flow chart of software within the controller.

FIG. 7 is a schematic diagram of a multiple meter embodiment of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT(S)

The present invention is an improvement to an apparatus for analyzing a machine fluid used in or associated with a machine, wherein the machine is generally, but not necessarily, an engine. In **FIG. 1** the apparatus **100** has at least one meter **102** placed proximate the machine **104** and in contact with the machine fluid **106** for measuring at least one parameter of a standard laboratory analysis parameter related to the machine fluid **106**. The at least one meter includes but is not limited to a viscometer, element meter, optical meter, particle meter and combinations thereof.

Proximate is herein defined as the meter being either mounted directly on an operating machine, or mounted near the machine(s), rather than in a laboratory separate and remote from the machine(s).

Machine fluid **106** includes but is not limited to oil, engine oil, differential oil and combinations thereof; fuel; coolant, including water; transmission fluid; hydraulic fluid including but not limited to power steering fluid, brake fluid, hydraulic cylinder fluid and combinations thereof; electrical fluid including but not limited to battery fluid, condenser fluid (e.g. PCB), electrochemical electrolyte; refrigerant; cutting fluid; and combinations thereof.

Machine **104** is defined as an assembly of mechanical elements wherein at least one of the mechanical elements is in contact with the machine fluid **106** for at least one purpose including but not limited to lubrication, heat transfer, electrical charge isolation, electrical charge transfer, movement of another mechanical element and combinations thereof. Without intending to be limited by the following list, "machine" **104** can include an engine, turbine, transmission, differential, brakes, power steering, pump, air compressor, heat pump, refrigerator, machine tool, for example, lathe, milling machine, and saw, electrical elements including but not limited to batteries, and condensers.

Vehicle is defined as an assembly of machines including but not limited to railroad locomotives, railroad freight cars (especially refrigerated railroad cars), flatroad vehicles including but not limited to automobiles, trucks, motorcycles, and recreational vehicles, off road vehicles including but not limited to tractors, earth movers (e.g. buldozers, road graders, power shovels, backhoes), cranes, aquatic vehicles including but not limited to ships, boats, submarines, and hydrofoils, aircraft including fixed wing propeller, jet, or turboprop, and rotating wing (helicopter).

Standard laboratory analysis parameters for oil are shown in Table 1.

Table 1. Standard Laboratory AnalysisParameters for Oil

Standard Laboratory Parameter	Meter	Bandwidth (microns)
Directly Measured Parameters		
Concentration of wear metals including: Cu, Fe, Cr, Pb, Sn, Ti, Co, Mo, Ni, V, Zn	X-ray Fluorescence Spectrometer	N/A
Turbidity	Non-Dispersive[A] Visible Band	0.54 +/-0.05
Oxidation	Non-Dispersive Infra-Red[B]	5.71+/- 0.13
Nitration/Sulfation	Non Dispersive Infra-Red	6.12 – 6.28
Water Content	Non-Dispersive Infra-Red	2.96 +/- 0.8
Viscosity (Kinematic Viscosity)	Viscometer	N/A
Ferromagnetic Particles	Particle Meter	N/A
Fuel Dilution	Viscometer	N/A
Derived Measurements		
Coolant Dilution	NDIR + Viscosity	
Soot / Carbon Content	ND Visible	0.54 +/- 0.05
Total Acid Number	NDIR	
Total Base Number	NDIR	
Pentane Insolubles	NDIR+ Viscosity	
Particulate Content	NDIR+ Particle Meter	

[A] ND
[B] IR

Also shown are the meters that are used to determine these standard laboratory analysis parameters, both measured and derived. The standard laboratory analysis parameters for oil include but are not limited to viscosity; turbidity; particulate size and quantity; total acid number (TAN); total base number (TBN); water content (includes free water and dissolved water); concentrations of cooling water elements including but not limited to boron, magnesium, iodine and combinations thereof; wear metal including but not limited to iron, lead, copper, silicon, chromium, aluminum, silver, magnesium, tin, and zinc, and combinations thereof.

Standard laboratory analysis parameters for cooling water include but are not limited to concentration of carbon, oil presence, fuel presence, concentrations of inhibitors including but not limited to chromate and boron, concentrations of rust metals and rust oxides including but not limited to iron and iron oxides, and combinations thereof.

A meter **102** for providing these standard laboratory analysis parameters includes but is not limited to a viscometer (for viscosity), X-ray fluorescence spectrometer and/or Roentgen X-ray tube (for elemental analysis), non-dispersive infrared/visible light meter (for oxidation, nitration, turbidity), and electric or electromagnetic debris detectors (for particulate).

When a combination of meters **102** is used to obtain a combination of standard laboratory analysis parameters, both status or condition of the machine fluid **106** and the machine **104** may be determined in accordance with accepted standards. More specifically, viscosity provides an indication of possible dilution of the oil by fuel or water. Viscosity can also indicate oil degradation from heat or oxidation. Chemical degradation of the oil (oxidation, nitration, etc.) is commonly determined by infra- red (IR) spectrometric analysis, which may also be used to infer total acid number (TAN) and total base number (TBN) for the oil. Water in the oil may also be detected by IR analysis. Slow coolant leaks into the lubricating oil system may be detected by quantitative analysis of boron, chromium or other elements such as iodine or strontium added to the coolant water as salts.

Further advantages are realized by the use of a controller **108** for controlling the meter(s) **102** and collecting data therefrom. A two-way communicator **110** may also be used to make on-board in-situ information available to a remote observer of engine health.

In a preferred embodiment of the present invention, machine fluid **106**, specifically crankcase oil, condition and machine **104** (engine) wear on diesel engines of railroad locomotives is monitored by a combination of meters **102**.

Viscometer

The viscometer provides a measure of viscosity, specifically dynamic viscosity (the terms viscosity and dynamic viscosity are interchangeable herein) at a controlled fluid temperature from (a) the pressure drop across a tube of precise length and inside diameter and (b) the flow rate maintained by a pump. The flow rate is maintained at Reynolds number less than 1000, thereby ensuring laminar fluid flow through the tube. The viscosity is determined from classical expressions for laminar fluid flow.

Referring to **FIG. 2**, the viscometer **200** is comprised of several components including but not limited to: (1) an initial reservoir **202** with a heater **204** (preferably electric resistance heater) where fluid temperature is adjusted (by heating) to a temperature suitable for measurement, preferably about 100 °C for oil, (2) a differential pressure transducer **206** which measures the difference in pressure of the fluid **106** flowing through (3) a tube **208** of precise length from the inlet **210** to the outlet **212** of the tube **208** (4) a fluid flowmeter **214** downstream of the tube **208** which maintains a constant fluid flow rate through the tube **208**, and, (5) one or more thermocouples **216** for measurement of fluid temperature through the viscometer. The tube **208** is preferably of a length of about 40 cm, an inside radius of about 0.735 mm, and an outside diameter of about 0.3 cm (1/8 inch).. The flowmeter **214** may be any flowmeter, but is preferably a model FT0-1NYBBLHC-1 (turbine) with a model LN-5-CMAA-7 (signal conditioner) from Flow Technology, Phoenix AZ.

Because viscosity is a strong function of temperature, the temperature of the machine fluid must be accurately known to obtain reliable viscosity measurements. For machines that reject heat, it is preferred to measure viscosity at a stable temperature, preferably held slightly above the normal fluid temperature. Heating a fluid sample to a temperature slightly above the machine operating temperature is simpler and easier to control than cooling to maintain a lower temperature. The viscometer is preferably insulated to improve temperature stability and control, and preferably temperature controlled with a heater. Stable temperature is a temperature within about 10 °C, preferably within about 5 °C. Slightly above is a temperature difference of from about 0 °C to about 100 °C, preferably from about 5 °C to about 25 °C.

A standard viscometer permits viscosity measure over a wide range from about 1 cST to 10^5 cST with an absolute accuracy or uncertainty $\pm$ 3%. Because variation of viscosity of a machine fluid is much less than the range of a standard viscometer, the uncertainty of a standard viscometer is large enough to mask a change in fluid viscosity. Use of a limited range viscometer according to the present invention reduces the range to from about 10 cST to about 20 cST, preferably from about 12 cST to about 14 cST with an absolute accuracy or uncertainty of about $\pm$0.5%, thereby permitting more accurate measure of changes in viscosity of the machine fluid. Although the relative uncertainty is the same between standard and limited range viscometers, the absolute uncertainty is less for the limited range viscometer.

Element meter

The element meter may be a Roentgen X-ray tube, or X-ray fluorescence spectrometer (XRF), for the purpose of identifying chemical elements, preferably metals in the machine fluid. Referring to **FIG. 3**, a preferred XRF spectrometer **300** receives fluid that has been cooled in a small reservoir **302** so that its temperature is below 40 °C. An X-ray source **304** provides X-rays in a suitable energy range (approximately 10-30KeV) to the fluid. The X-ray emitting radionuclides useful as the X-ray source **304** include but are not limited to Cadmium 106, Iron 51 Americium 241 and combinations thereof.

Any metals in the fluid intercept the x-rays and produce an X-ray fluorescence signal. The resulting X-ray fluorescence signal is detected by an X-ray detector **306**, preferably a silicon based detector. The tube **308** exposed to the X-ray source **304** is preferably a polyamide material. The tube **308** must be thin to reduce x-ray attenuation and must withstand machine vibration.

The absorption of an x-ray by the detector produces an electronic output pulse with an amplitude proportional to the energy of the absorbed x-ray. Signals from the detector are amplified and shaped and then the individual pulses from individual x-rays are categorized according to amplitude and recorded with a multichannel analyzer. An X-ray fluorescence spectrometer model CT 5000 may be obtained from C-Thru Technologies Corp, Kennewick Washington.

In order to be used commercially, the XRF must provide shielding and containment of the radionuclide that is the X-ray source **304**. Shielding and containment must be such that no radiation or radionuclide material can escape unintentionally, even in the case of a collision or other high-energy impact to the source container. At the same time, the shield and containment must allow the machine fluid to pass directly in front of the unshielded X-ray source **304**. In the present invention, shielding and containment is accomplished by placing the X-ray source **304** in a block that has been machined and assembled such that there is no path for x-rays to escape the block. X-rays are constrained to travel in a straight line and are shielded or attenuated by several mm thickness of block material. Release of the X-ray source **304** from the block would require its intentional cutting or disassembly.

The block material may be any high Z material, but is preferably tungsten because of its lesser weight compared to other high Z materials with equivalent shielding and containment.

<u>Non-dispersive optical meter</u>

The Non-Dispersive (ND) optical meter, shown in **FIG. 4a**, consists of an optical energy source **400** that emits energy in the visible (V) and/or the infrared (IR) wavelengths, depending on the type of oil degradation that is being measured. The optical energy source **400** may be any non-coherent radiator **401** optical energy source including but not limited to a filament light source (the filament heats the glass envelope which then emits visible and infrared radiation), a blackbody emitter, in which a black material, such as black paint on metal, is heated so that it emits infrared radiation in combination with a collector

402 for guiding non-coherent optical energy through the cell **404** containing the machine fluid. Alternatively, the optical energy source **400** may be a coherent radiator, for example laser diode(s) operating at specific visible or infrared wavelengths with or without a collector **402** depending upon divergence of a laser and distance of the coherent radiator **401** from the cell **404**. In the case of a non-coherent optical energy source, the collector **402** may be a reflector and/or a lens. The transmitted energy is then collected by an imaging lens **406**. For coherent optical energy, an imaging lens **406** may or may not be needed.

Coherent optical energy is narrow band in terms of optical frequencies thereby permitting use of a detector **410** in the absence of a bandpass filter **408**. Multiple optical signals of different optical frequencies of coherent optical energy may be obtained by use of two or more coherent radiators **401** radiating at different optical wavelengths.

Non-coherent optical energy is wide band in terms of optical frequencies. Accordingly, non-choherent optical energy transmitted through the machine fluid is passed through a bandpass filter **408** that transmits only certain specific wavelengths to an optical detector **410**. The cell **404** must be able to transmit visible, as well as infrared radiation, and materials, such as a thin film of polyethelene, zinc selenide, or calcium fluoride, are commercially available that transmit in both the visible and infrared wavelength regions of interest. Multiple optical signals of different optical frequencies of non-choherent optical energy may be obtained by using a filter wheel **412** to hold two or more bandpass filters **408** that transmit at specific wavelength bands.

The transmission of a cell **404** with no oil in it is compared to a cell with oil in it, and the difference indicates the degradation of the oil. The wavelength bands that exhibit a certain type of degradation will vary depending on the type of fluid examined. Soot and fine particles will be detected by a decrease in the transmission of the fluid in selected wavelength regions.

In the optical meter, the cell **404** can be a mirror system, as shown in **FIG. 4b**. The principal is the same, except now the optical energy is transmitted through the machine fluid twice. in this case the cell includes a reflector **412**, which can be either a front surface glass mirror or a metal mirror. The optical energy reflected by the reflector **412** is retransmitted through the fluid, to the imaging lens **406** (for non-coherent optical energy), bandbass filter **408**, and optical detector **410**.

According to the present invention, this infrared meter lacks a dispersive element compared to standard infrared meters. Use of a dispersive element requires elimination of all relative motion between the dispersive element and other elements of the standard infrared meter which disqualifies its use on a machine subject to vibration. Omitting the dispersive element according to the present invention provides a non-dispersive infrared meter that is insensitive to the vibration of a machine.

Particulate meter

Particle meters used in the present invention may be one of several types commercially available, for example, the Vickers Tedeco Smart Zapper ™ or Vickers Tedeco IQ™ system. Particulate meters or debris monitors may be obtained from Tedeco Division 24 East Glenolden Ave. Glenolden, Pennsylvania 19036 USA.

Particulate meters or debris monitors attract and retain ferromagnetic particles with a magnet mounted concentric with and in close proximity to a conductive ring. The amount or mass of ferromagnetic particles collected is proportional to the conductivity across the gap between the magnet and the conducting ring. In the preferred embodiment, the controller of a Tedeco Smart Zapper has been modified to provide the total amount of ferromagnetic material collected even though the Smart Zapper may from time to time clear the collected material from the gap by means of an high voltage electric current discharge. The accumulated mass of ferromagnetic material collected is measured and recorded by the controller.

Controller

In **FIG. 5,** the controller **108** implements automated control and data acquisition such that standard parameters can be determined and recorded without human intervention. Continuous logging of data by the controller **108** creates a record that can be used to determine trends and predict maintenance schedules. It is preferred that the controller **108** contain one or more embedded controllers **502** and **504**, for example PK2500, Z-World, Davis, CA that is/are c-programmable. It is further preferred that each embedded controller **502** have a microprocessor, memory, digital input/output, analog input, and mass storage (optional) for control of the meter(s), recording of standard analysis parameter(s) and optional operation of a two-way communicator **110**. An 8-channel analog-to-digital converter **506, 510**, for example ND-6018, Circuit Specialists, Mesa, AZ, converts analog signals including but not limited to 4-20mA pressure transducer signals **508**, thermocouple signals **512**, meter signals and combinations thereof.

Preferably, an embedded controller **504** controls and acquires data from meters such as the XRF spectrometer which generate spectral data **516**, non-dispersive optical meter, viscometer, solid state cooling device, resistive heater(s), particulate meter(s) and combinations thereof. The embedded controller **504** has sufficient memory and, optionally, mass storage to record data over an extended period of time. Another embedded controller **502** communicates to a two-way communicator **110** or, optionally, a laptop computer over serial I/O **518** and provides control and data acquisition for additional optional meters over digital I/O **520**. The embedded controller **502** also performs reduction of the data produced by the meters and the resulting standard analysis parameters are stored in memory or, optionally, on mass storage. The embedded controller **502** also has sufficient storage and, optional mass storage to record standard analysis parameter(s) over an extended period of time. If standard analysis parameters exceed preset limits, the embedded controller **502** can initiate an emergency call through the two-way communicator **110**.

The controller **108** may be programmed according to the flow chart in **FIG. 6**. A reset may either be a user-initiated reset such as when the program is first loaded or a recovery-mode reset resulting from a power failure or software or hardware failure. After reset, interfaces are initialized **600** by setting variables to initial values for a user-initiated reset or restored to previous values for recovery-mode resets. The acquisition cycles are then started **602**. This initiates a separate process for each meter in the system. The main process then waits for download requests **604**. Upon receipt of a download request, the main process transfers logged data **606** to the two-way communicator **110** or optional laptop. All meter processes wait to be triggered **608** either by communications from the meter or by a timer. Data are retrieved from the meter(s) and processed and logged as required **610**. A test for data outside flag limits **612** causes an emergency call **614** for meter data outside the flag limits.

<u>Communicator</u>

Another improvement is a two-way communicator **110** connected to the controller **108** for receiving interrogation signals and for transmitting data, thereby obtaining an in-situ or on-board machine fluid analysis. Two-way communication enables remote monitoring of machine and machine fluid condition. A communicator **110** may be obtained as a two-way, cell-phone based communicator may be obtained from Highway Master Systems (Muldrow, Oklahoma 74948, USA).

<u>System</u>

A system for oil is shown in **FIG. 7**. A sample line **700** leads from the pressurized oil line between an oil cooler (not shown) and an oil filter (not shown). A first branch sample line **702** leads to the viscometer **200**, and a second branch sample line **704** leads through a throttle **706** to the sample volume **302** of the XRF spectrometer **300**. After passing through the XRF **300**, the oil flows through a connecting tube **708** to the optical meter **400**, preferably an infrared meter for oil. Thus, in this preferred embodiment, the oil sample is split such that one part runs through the viscometer **200** while the other part runs through both the XRF meter **300** and the NDIR meter **400**. Signals from the meter(s) is/are collected by the system controller **108** and may be transmitted by the communicator **110**.

For deployment on a machine in a machine environment including but not limited to vehicle, industrial plant, outdoors, airborne, outer space and combinations thereof, the system is preferably enclosed in a housing (not shown) that is shock mounted to reduce vibration and contains or is connected to an electrical power supply. Situated within the enclosure is/are a cooler(s) for cooling the x-ray and infra red detectors. In a preferred embodiment, the cooler(s) is/are solid state electrical cooling assemblies known as Peltier baffle devices.

CLOSURE

While a preferred embodiment of the present invention has been shown and described, it will be apparent to those skilled in the art that many changes and modifications may be made without departing from the invention in its broader aspects. The appended claims are therefore intended to cover all such changes and modifications as fall within the true spirit and scope of the invention.

THE CLAIMS DEFINING THE INVENTION ARE AS FOLLOWS:

1. A machine fluid analysis system including:

at least first and second sensors contacting a machine fluid under pressure of the machine;

a controller operable to collect data from the sensors for transmission to a remote location; and

a two-way wireless communicator coupled to the controller for receiving interrogation signals and for transmitting the collected data to the remote location;

wherein the first sensor includes an X-ray fluorescence meter including an X-ray source providing source X-rays and a thin walled polymeric tube, the tube defining a fluid flow path past the X-ray source, and

wherein the second sensor includes at least one sensor selected from the group consisting of viscometer, optical meter, and particle counter.

2. The system of claim 1 wherein the second sensor includes a viscometer and wherein machine fluid contacting the X-ray fluorescence meter is at a substantially lower temperature than machine fluid contacting the viscometer.

3. The system of claim 2 wherein the X-ray fluorescence meter and the viscometer are coupled to a machine fluid line in parallel and a machine fluid cooler is upstream and in series with the X-ray fluorescence meter.

4. The system of claim 2 wherein the viscometer includes a viscometer tube, a differential pressure transducer mounted on opposite ends of the viscometer tube, and a flowmeter in line with the viscometer tube.

5. The system of claim 1 wherein the controller includes at least one microprocessor, and wherein the X-ray fluorescence meter includes an X-ray detector for receiving a produced X-ray fluorescence signal and a multi-channel analyzer for analyzing individual X-rays.

6. The system of claim 1 further including a two-way communications bus between the controller and each of the plurality of sensors.

7. The system of claim 1 wherein the second sensor includes an optical meter including an optical source operable to pass optical energy through the machine fluid and an optical detector operable to receive the optical energy passed through the machine fluid, and wherein there is no optical dispersive element between the optical energy source and the machine fluid or between the machine fluid and the detector.

8. The system of claim 7 wherein machine fluid is passed through a tubular cell in the optical meter.

9. The system of claim 7 wherein machine fluid is passed over a planar cell in the optical meter.

10. The system of claim 7 wherein optical energy source includes a non-coherent radiator and the optical meter includes a bandpass filter for filtering optical energy passed through the machine fluid.

11. The system of claim 7 wherein the optical energy source includes a coherent radiator.

12. The system of claim 3 further including an optical meter connected in series with the X-ray fluorescence meter.

13. The system of claim 12 wherein the optical meter and the X-ray fluorescence meter are contained in a thermally controlled compartment and the viscometer is outside the thermally controlled compartment.

14. The system of claim 13 further including a particle counter.

15. The system of claim 1 wherein the second sensor includes an optical particle counter operable to detect the presence of metallic or non-metallic particles.

16. A machine fluid analysis system including:

a plurality of different sensors contacting a fluid under pressure of a machine, wherein at least two of the plurality of different sensors are selected from the group consisting of optical meter, viscometer, element meter, and particle counter;

a controller operable to collect data from the plurality of sensors for transmission to a remote location; and

a two-way wireless communicator coupled to the controller for receiving interrogation signals and for transmitting the collected data to the remote location; and

a fluid cooler operably coupled to at least one of the sensors;

wherein fluid is provided to different ones of the plurality of different sensors at substantially different temperatures.

17. The system of claim 16 wherein the plurality of sensors include an element meter operable to determine the concentration of at least one specific element in the fluid.

18. The system of claim 17 wherein the specific element is selected from the group consisting of boron, magnesium, iodine, iron, lead, copper, silicon, chromium, aluminum, silver, magnesium, tin and zinc.

19. The system of claim 17 wherein the element meter is an X-ray fluorescence meter including an X-ray source, a thin walled polymeric tube providing a flow path past the X-ray source, and an X-ray detector for receiving an X-ray fluorescence signal from the fluid in the tube.

20. The system of claim 19 wherein the X-ray fluorescence meter includes an X-ray detector for receiving a produced X-ray fluorescence signal and a multi-channel analyzer for analyzing individual X-rays.

21. The system of claim 20 wherein each of the plurality of different sensors are operable to determine a different standard laboratory analysis parameter.

22. The system of claim 19 wherein the X-ray fluorescence meter is provided in a thermally controlled compartment and the fluid cooler is provided in series with the X-ray fluorescence meter outside the thermally controlled compartment.

23. The system of claim 22 wherein a viscometer is outside the thermally controlled compartment and fluidly coupled in parallel with the X-ray fluorescence meter.

24. The system of claim 22 wherein the plurality of sensors includes an optical meter including an optical source operable to pass optical energy through the fluid and an optical detector operable to receive the optical energy passed through the fluid, and wherein there is no optical dispersive element between the optical energy source and the fluid or between the fluid and the detector.

25. The system of claim 24 wherein fluid is passed through a tubular cell in the optical meter.

26. The system of claim 24 wherein fluid is passed over a planar cell in the optical meter.

27. The system of claim 24 wherein optical energy source includes a non-coherent radiator and the optical meter includes a bandpass filter for filtering optical energy passed through the fluid.

28. The system of claim 24 wherein the optical energy source includes a coherent radiator.

29. A fluid analysis system including:

a plurality of different sensors contacting a fluid under pressure of a machine, wherein each of the plurality of sensors are operable to determine a different standard laboratory analysis parameter;

a controller operable to collect data from the plurality of sensors for transmission to a remote location; and a two-way wireless communicator coupled to the controller for receiving interrogation signals and for transmitting the collected data to the remote location; and

a thermally controlled compartment wherein at least one of the sensors is inside of and another is outside of the thermally controlled compartment whereby fluid is provided to different ones of the plurality of sensors at substantially different temperatures.

30 The system of claim 29 wherein a viscometer is outside the thermally controlled compartment.

31 The system of claim 29 wherein a non-dispersive optical meter is inside the thermally controlled compartment.

32. A system of claim 29 wherein an X-ray fluorescence meter is inside the thermally controlled compartment.

33. The system of claim 32 wherein the X-ray fluorescence meter includes an X-ray source, a thin walled polymeric tube substantially transparent to source X-rays and providing a flow path past the X-ray source, and an X-ray detector for receiving an X-ray fluorescence signal from the fluid in the tube.

34. The system of claim 29 wherein the plurality of different sensors are selected from the group consisting of viscometer, non-dispersive optical meter, element meter, and particle counter.

35. A machine fluid analysis system substantially as hereinbefore described with reference to the accompanying drawings.

DATED this 11th November 2004

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WATERMARK PATENT & TRADE MARK ATTORNEYS
290 BURWOOD ROAD
HAWTHORN VICTORIA 3122
AUSTRALIA

P21429AU00 : BJW/JJA

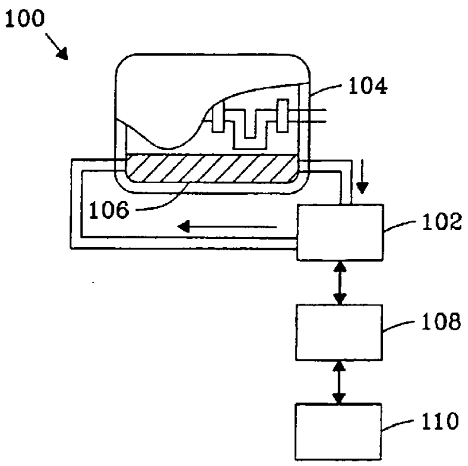
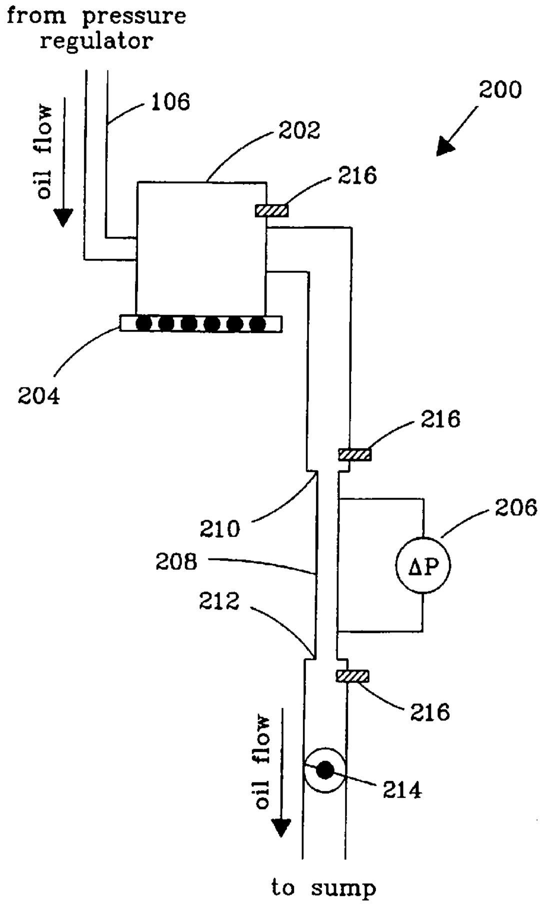


Fig. 1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200
216
204
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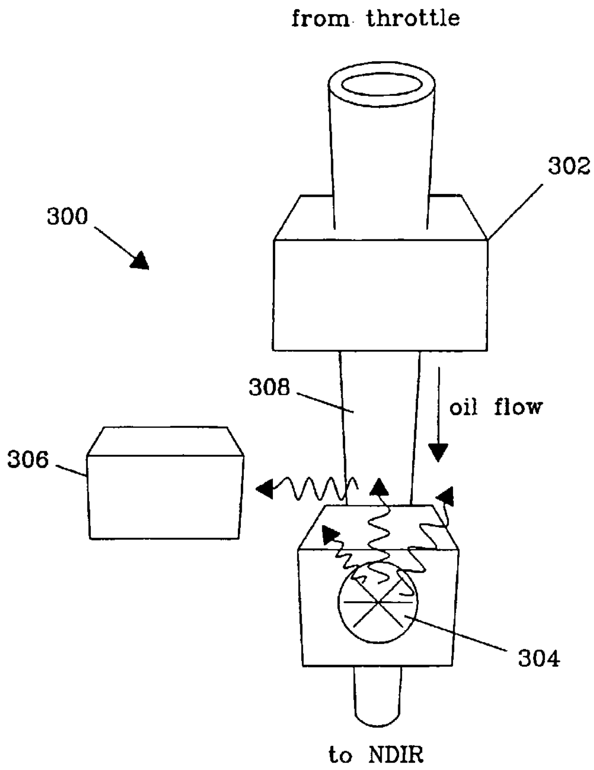
206
210
208
212
ΔP
216
oil flow
214
to sump

Fig. 2



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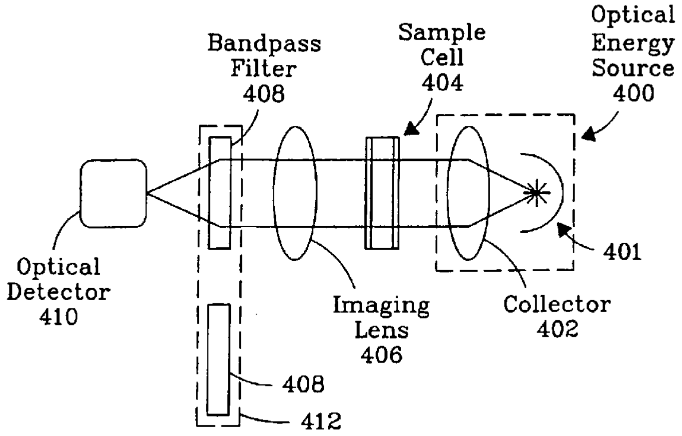
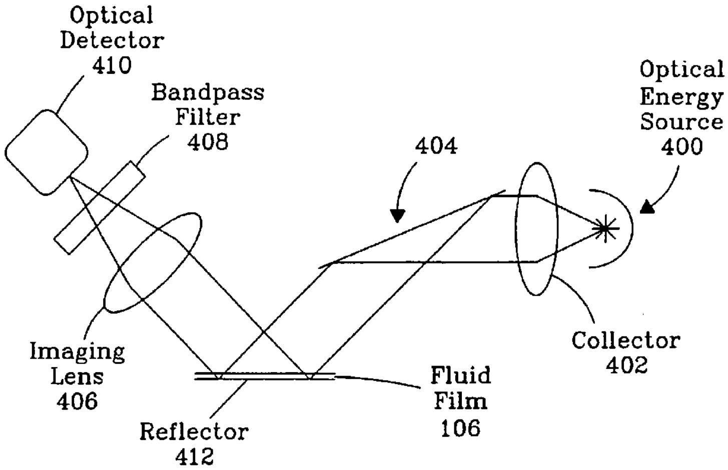


Bandpass Filter 408
Sample Cell 404
Optical Energy Source 400
Optical Detector 410
401
Imaging Lens 406
Collector 402
408
412

Fig. 4a



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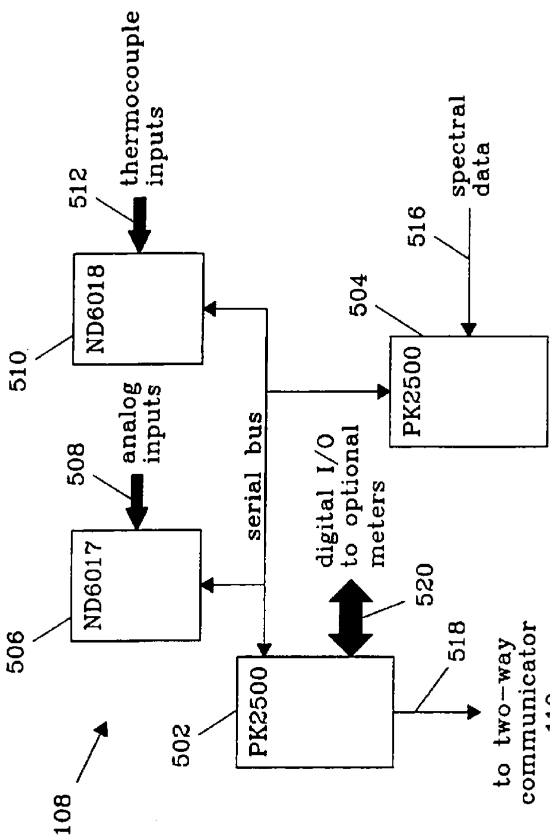
Optical Energy Source 400
Imaging Lens 406
Collector 402
Fluid Film 106
Reflector 412

Fig. 4b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ND6018
510
analog inputs
508
ND6017
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spectral data
504
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520
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PK2500
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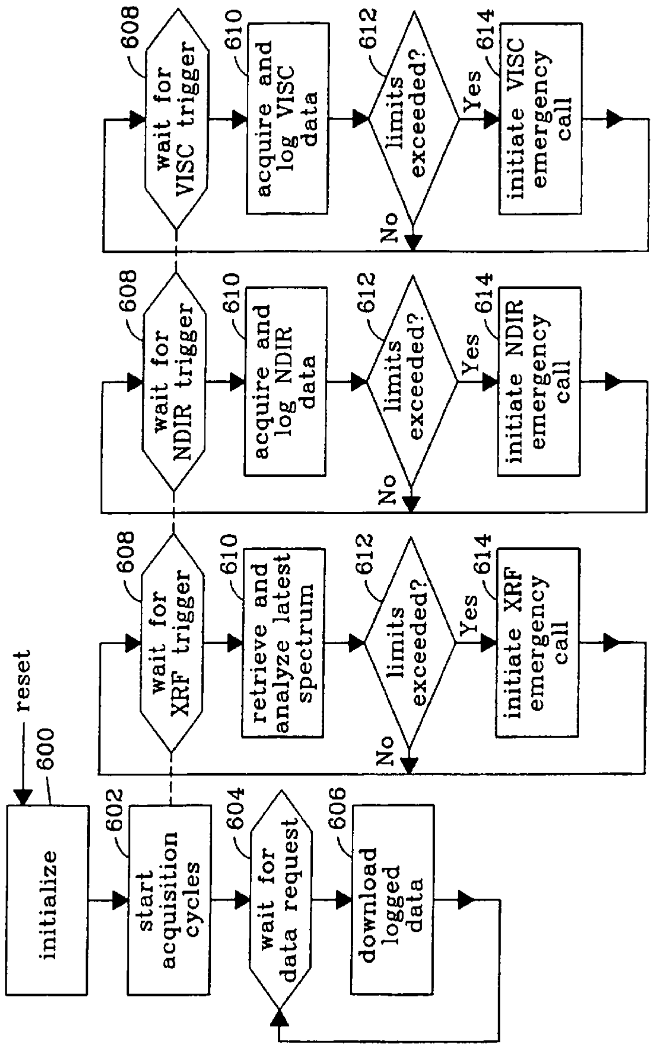
to two-way communicator 110
108

Fig. 5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initialize
602
start acquisition cycles
604
wait for data request
606
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608
wait for XRF trigger
610
retrieve and analyze latest spectrum
612
limits exceeded?
Yes
No
614
initiate XRF emergency call
608
wait for NDIR trigger
610
acquire and log NDIR data
612
limits exceeded?
Yes
No
614
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limits exceeded?
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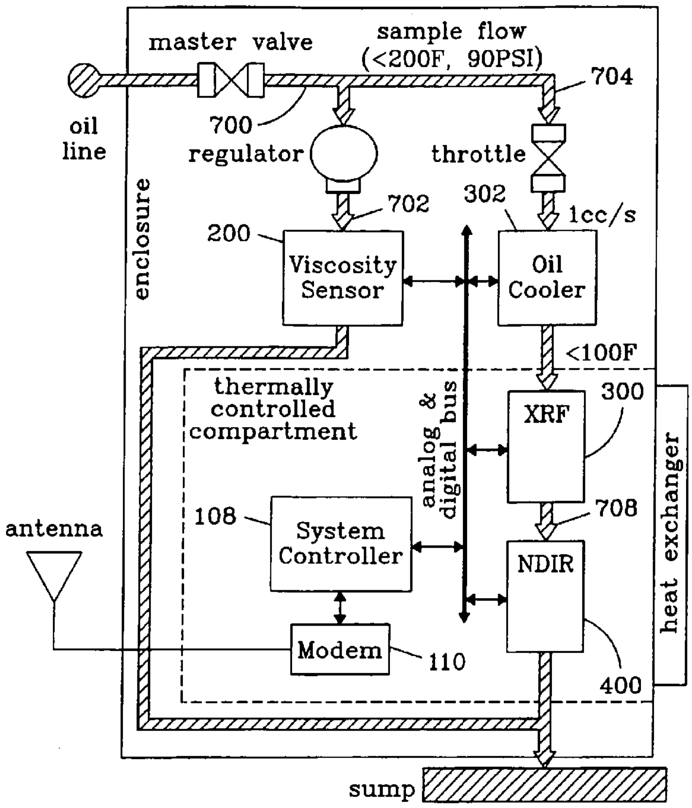
No
614
initiate VISC emergency call

Fig. 6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700
regulator
throttle
302
1cc/s
702
200
enclosure
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Sensor
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controlled
compartment
analog &
digital bus
XRF
300
heat exchanger
antenna
108
System
Controller
708
NDIR
Modem
110
400
sump

Fig. 7