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(54) DATA ACQUISITION SYSTEM FOR SYSTEM MONITORING

(76) Inventors: **Jeffrey L. Wiles**, Southgate, KY (US); **Victor M. Ivers**, Amelia, OH (US); **Sarah A. Cox**, Carmel, IN (US); **Larry D. O'Cull**, Westfield, IN (US)

Correspondence Address:
Michael J. Nieberding
Thompson Hine LLP
2000 Courthouse Plaza N.E., 10 W. Second Street
Dayton, OH 45402-1758 (US)

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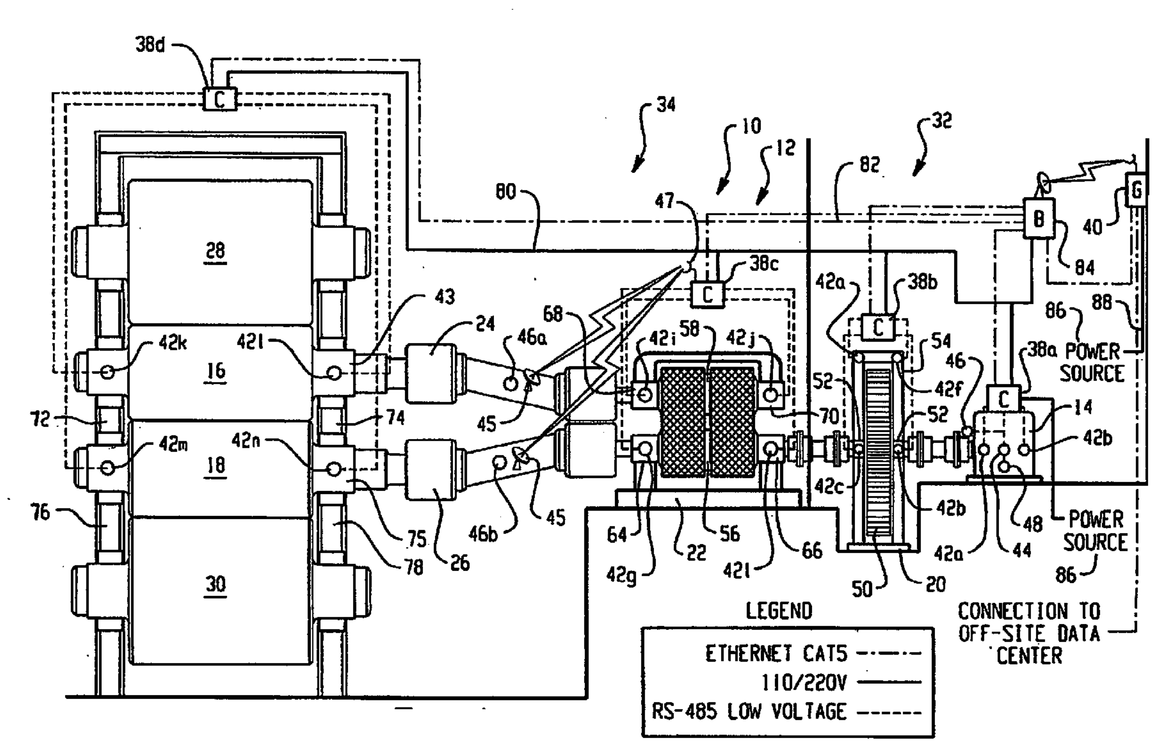
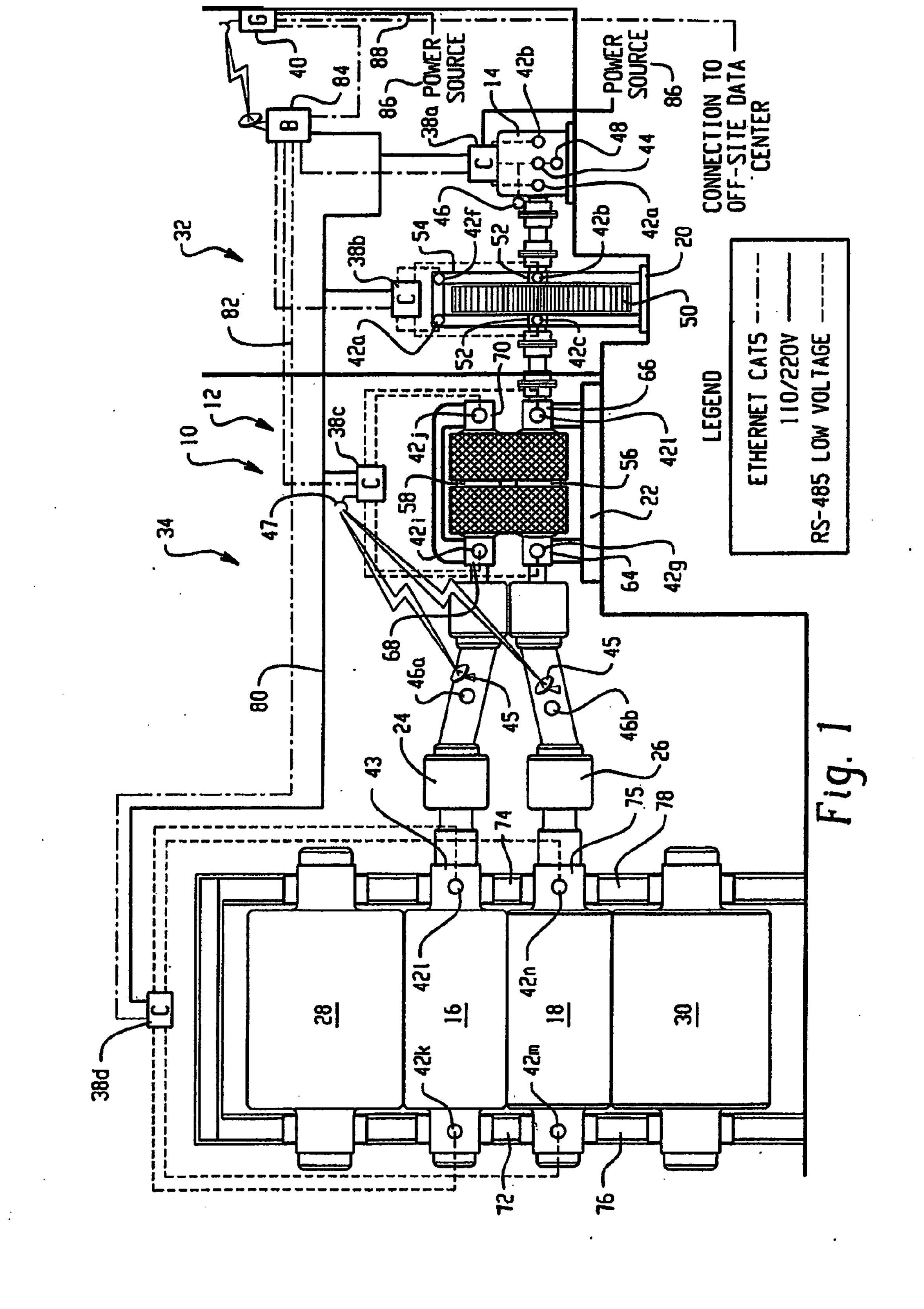
(52) **U.S. Cl.** **340/635**; 702/77; 702/56

(57) **ABSTRACT**

A method and monitoring system for tracking operational parameters of a drive train of a monitored system includes a sensor unit affixed to the drive train. The sensor unit includes a sensor for generating an analog signal in response to an operating condition of the monitored system and an integrated local processor for processing the analog signal generated by the sensor. Actions of a sensor unit associated that is mounted from movement of a component of the drive system may be initiated via wireless receipt of instructions from another processing unit. FFT analysis may be performed by the sensor unit directly under certain speed conditions for alarm generation.




POWER SOURCE
POWER SOURCE
CONNECTION TO OFF-SITE DATA CENTER
LEGEND
ETHERNET CAT5
110/220V
RS-485 LOW VOLTAGE
G
B
C
C
C
C
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38c
38d
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42a
42b
42c
42f
42g
42i
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42k
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Fig. 1

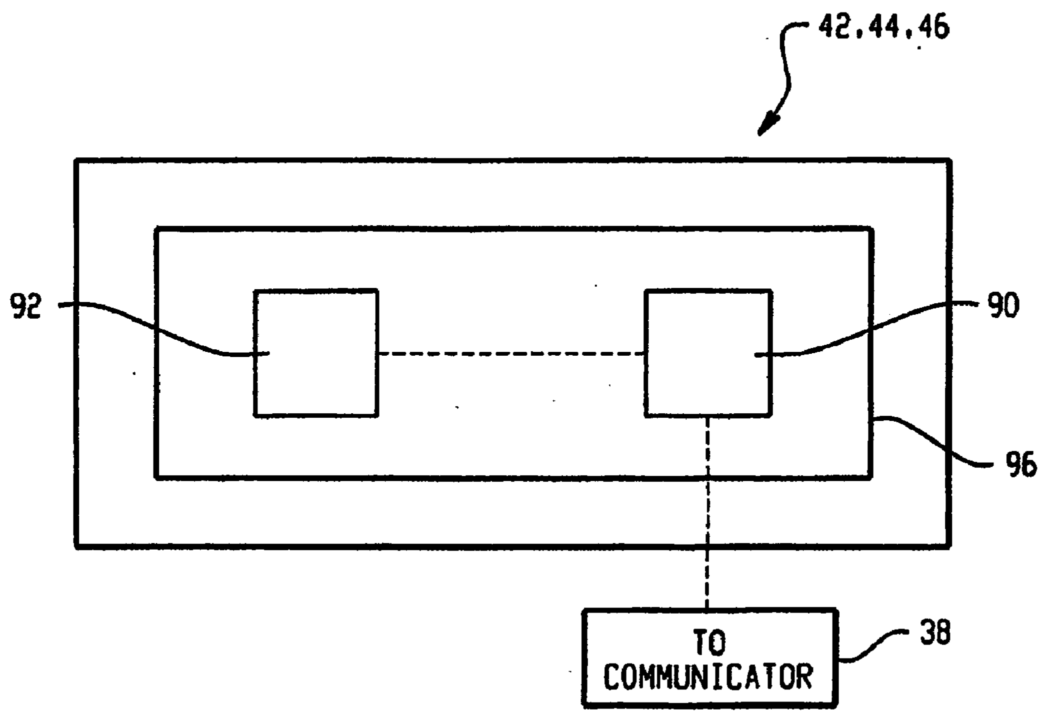


Fig. 2

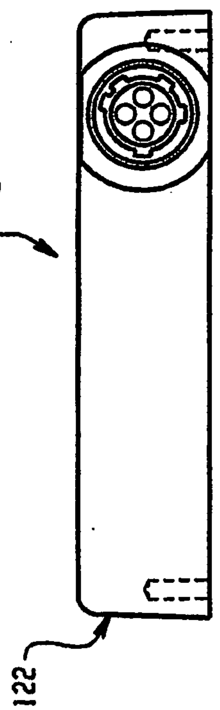


Fig. 3C

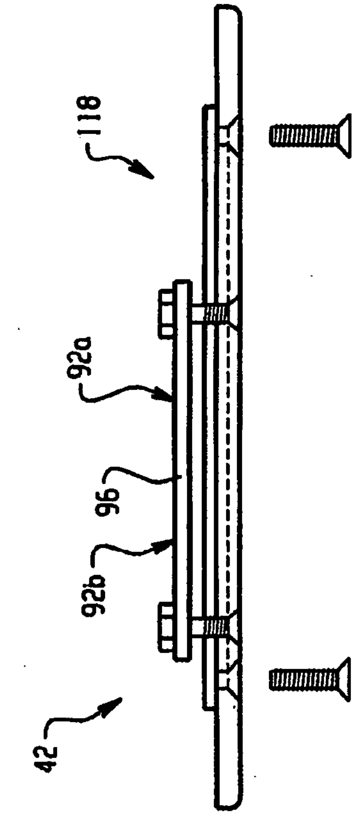


Fig. 3D

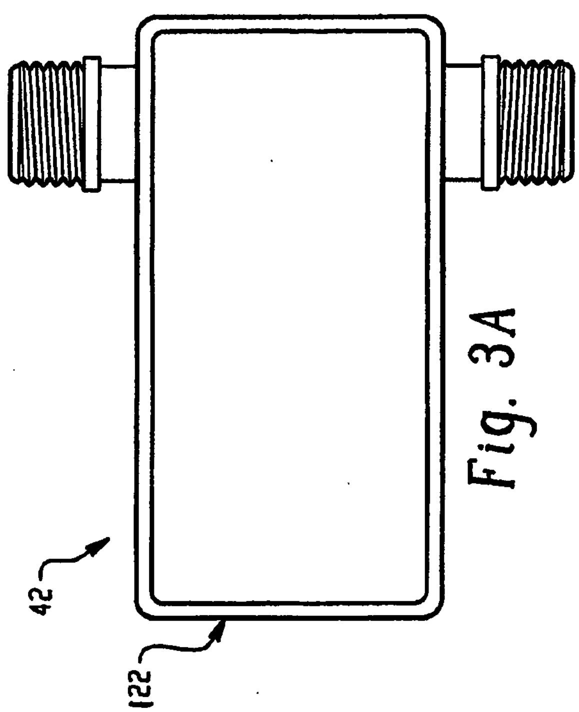


Fig. 3A

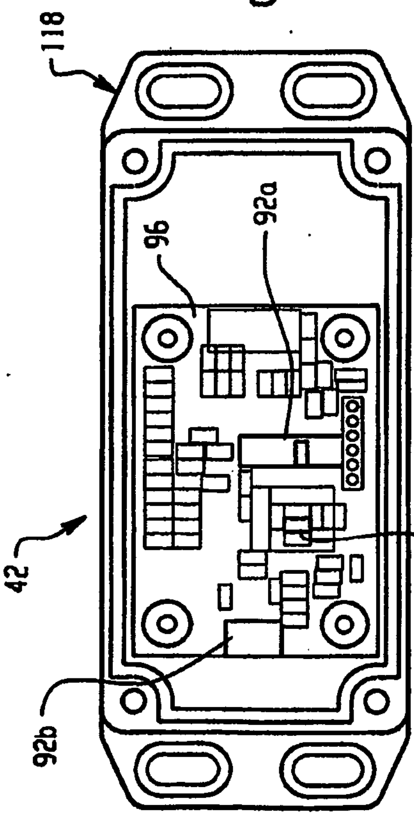


Fig. 3B

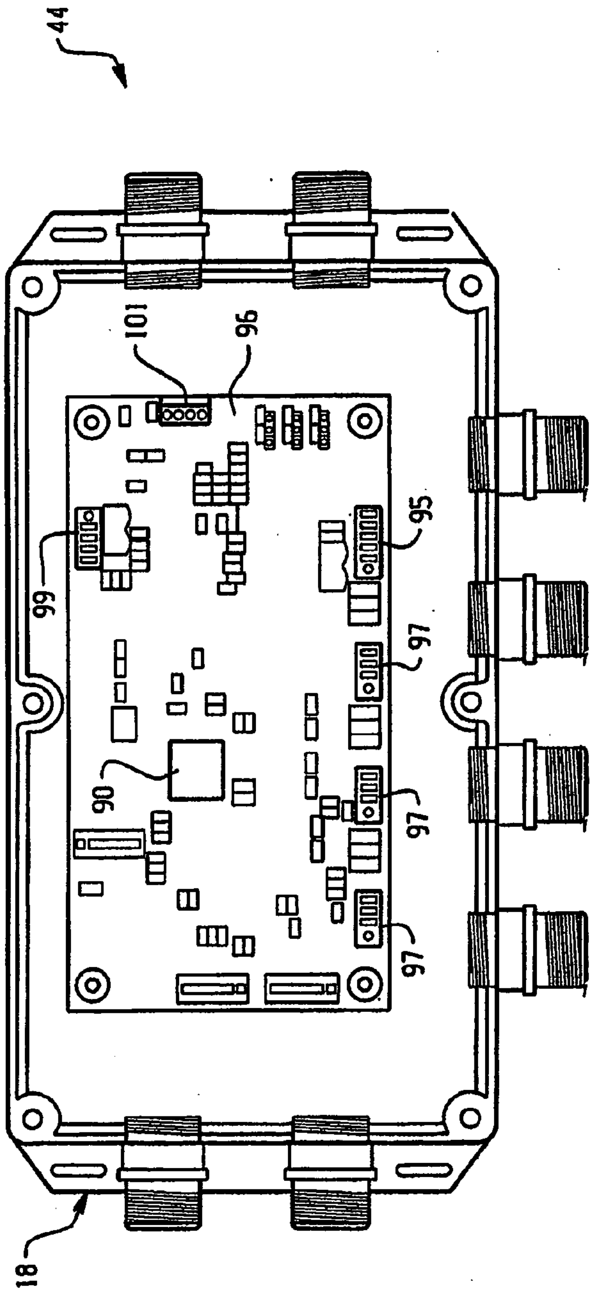


Fig. 4A

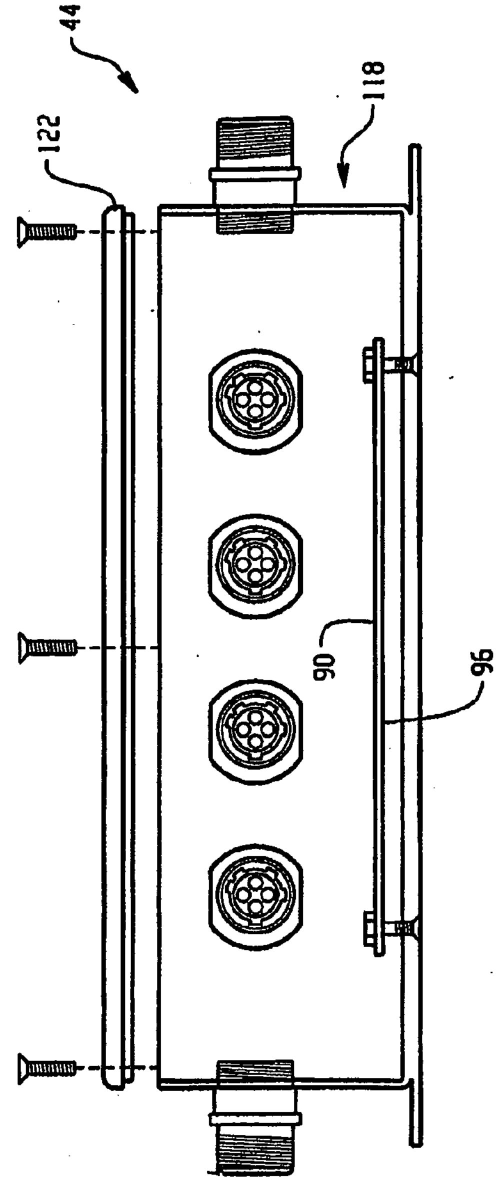


Fig. 4B

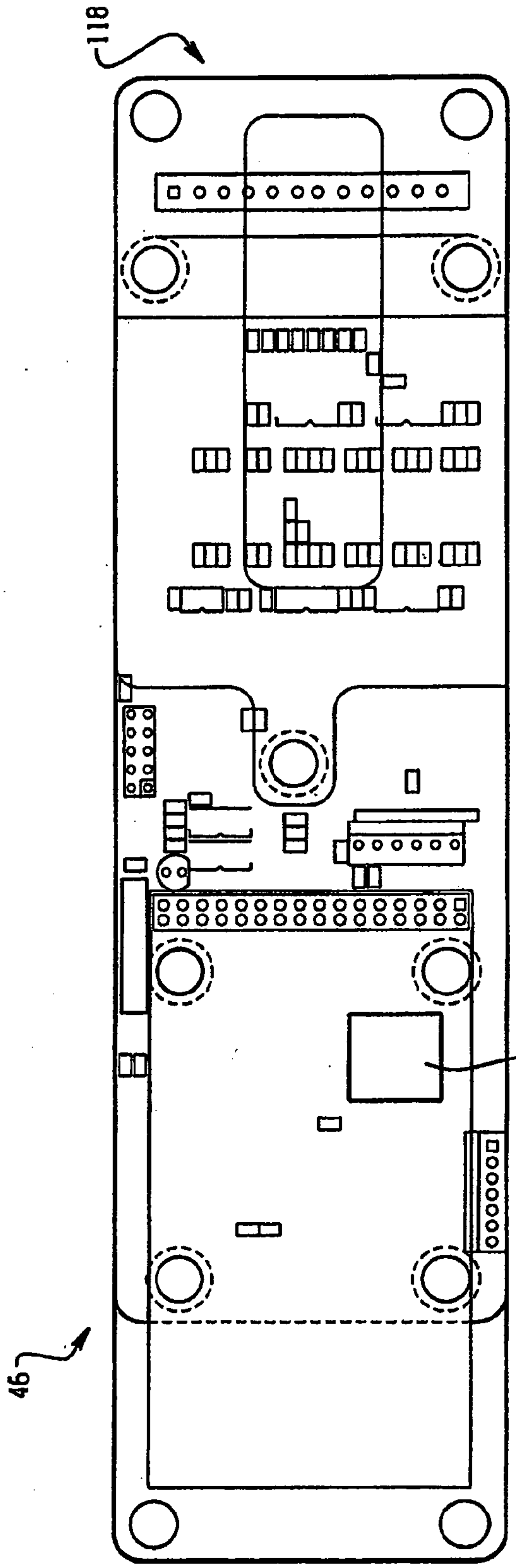


Fig. 5A

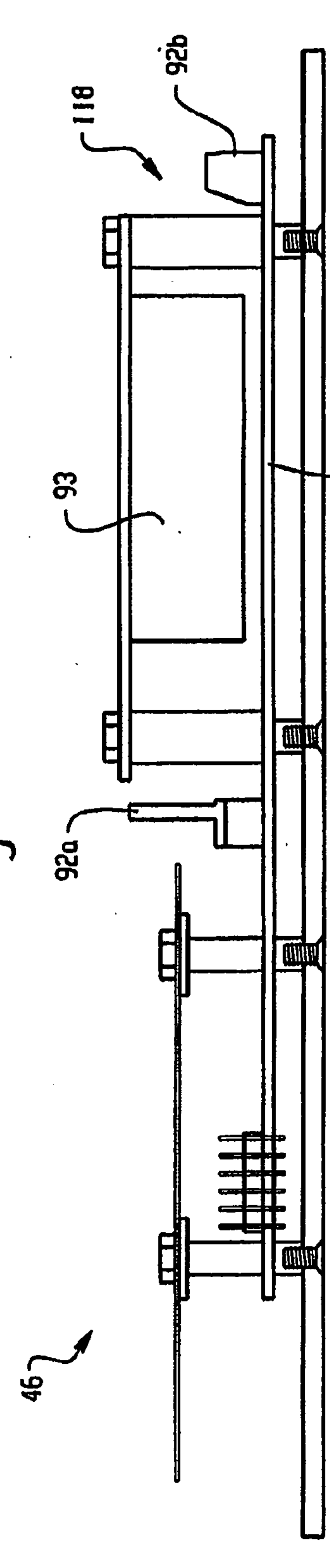
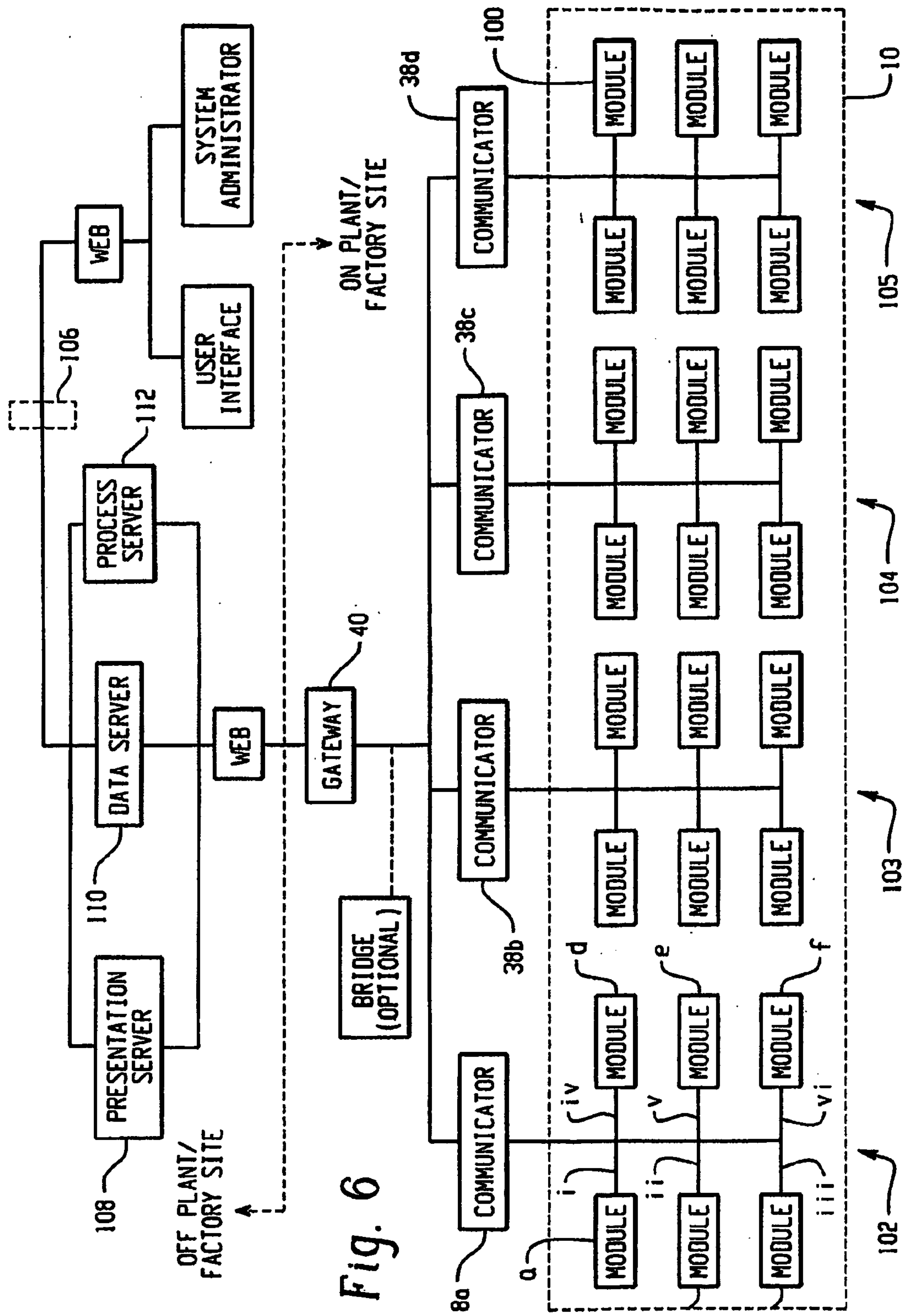


Fig. 5B



PRESENTATION SERVER
108
DATA SERVER
110
PROCESS SERVER
112
WEB
106
WEB
SYSTEM ADMINISTRATOR
USER INTERFACE
GATEWAY
40
BRIDGE (OPTIONAL)
OFF PLANT/ FACTORY SITE
ON PLANT/ FACTORY SITE
COMMUNICATOR
8a
COMMUNICATOR
38b
COMMUNICATOR
38c
COMMUNICATOR
38d
MODULE
100
a
d
e
f
i
ii
iii
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v
vi
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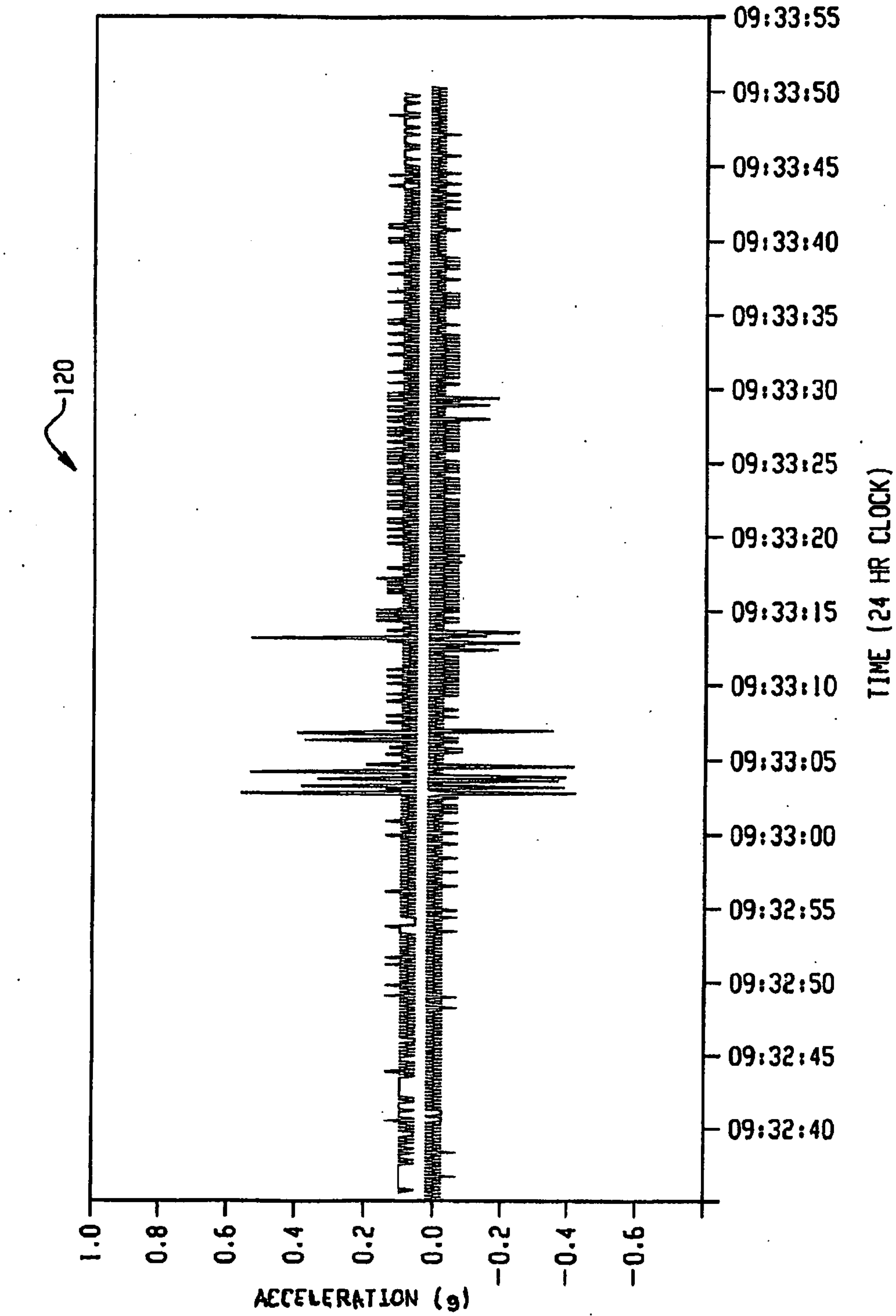
103
104
105
10

Fig. 6


120
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09:33:40
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09:33:25
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09:33:15
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09:32:55
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09:32:45
09:32:40
TIME (24 HR CLOCK)
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
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-0.6
ACCELERATION (g)

Fig. 7

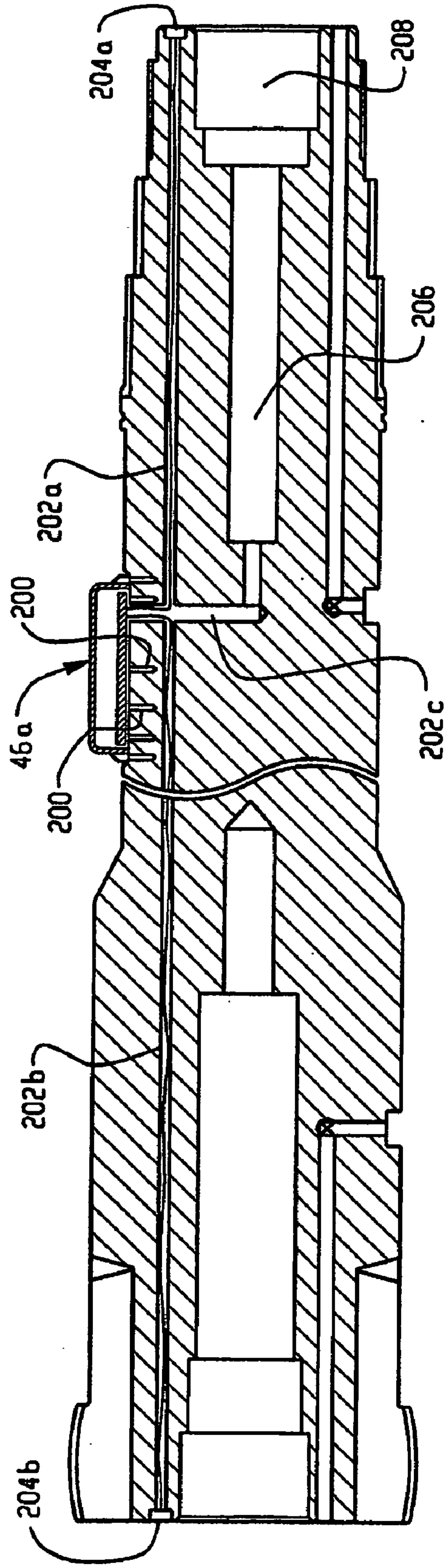


Fig. 8

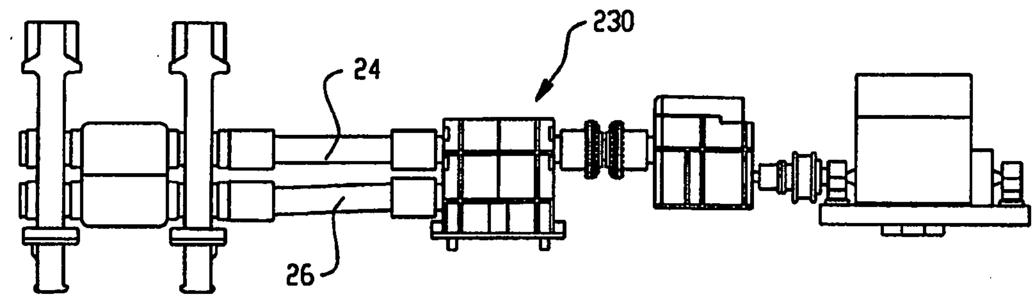


Fig. 9

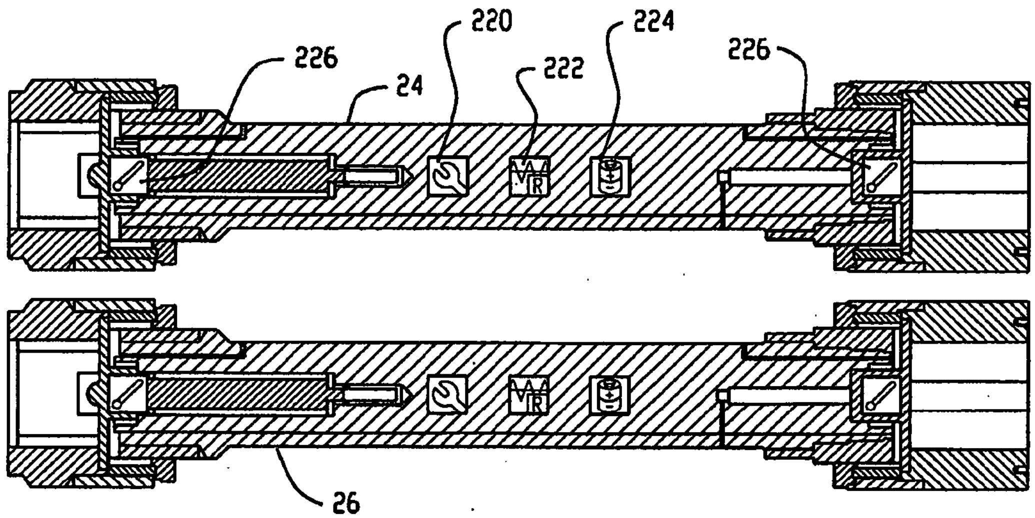


Fig. 10

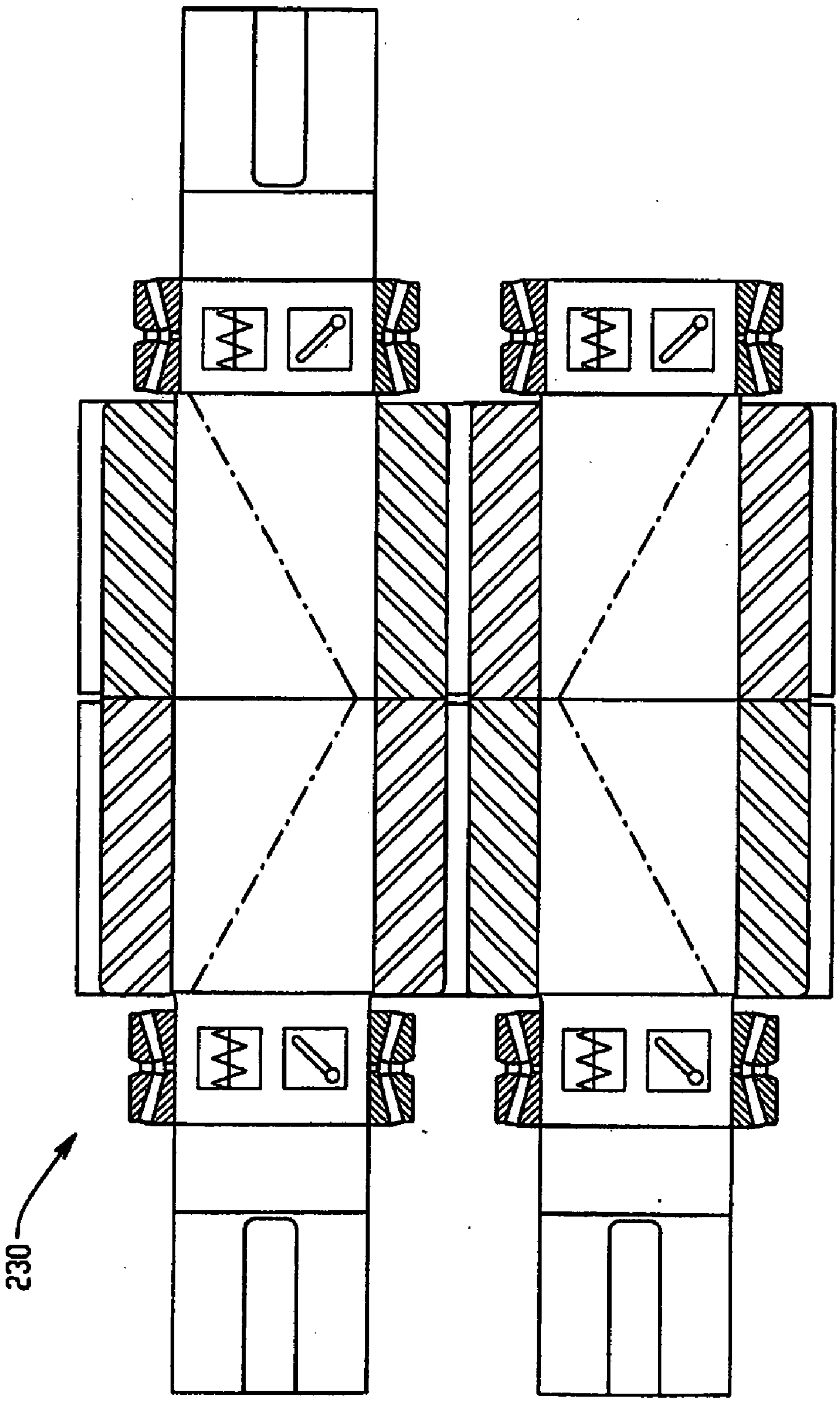
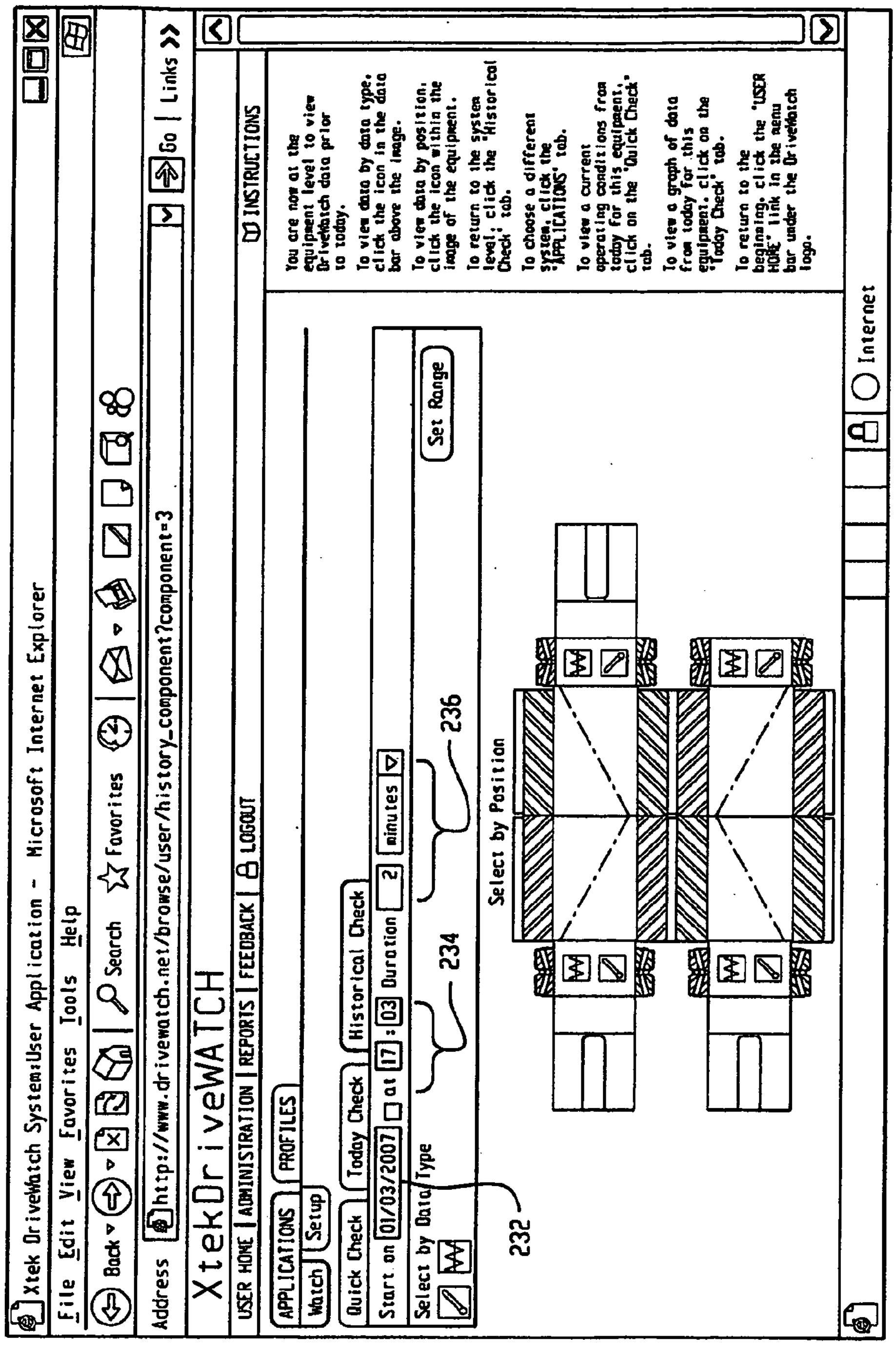


Fig. 11


Xtek DriveWatch System:User Application - Microsoft Internet Explorer
File Edit View Favorites Tools Help
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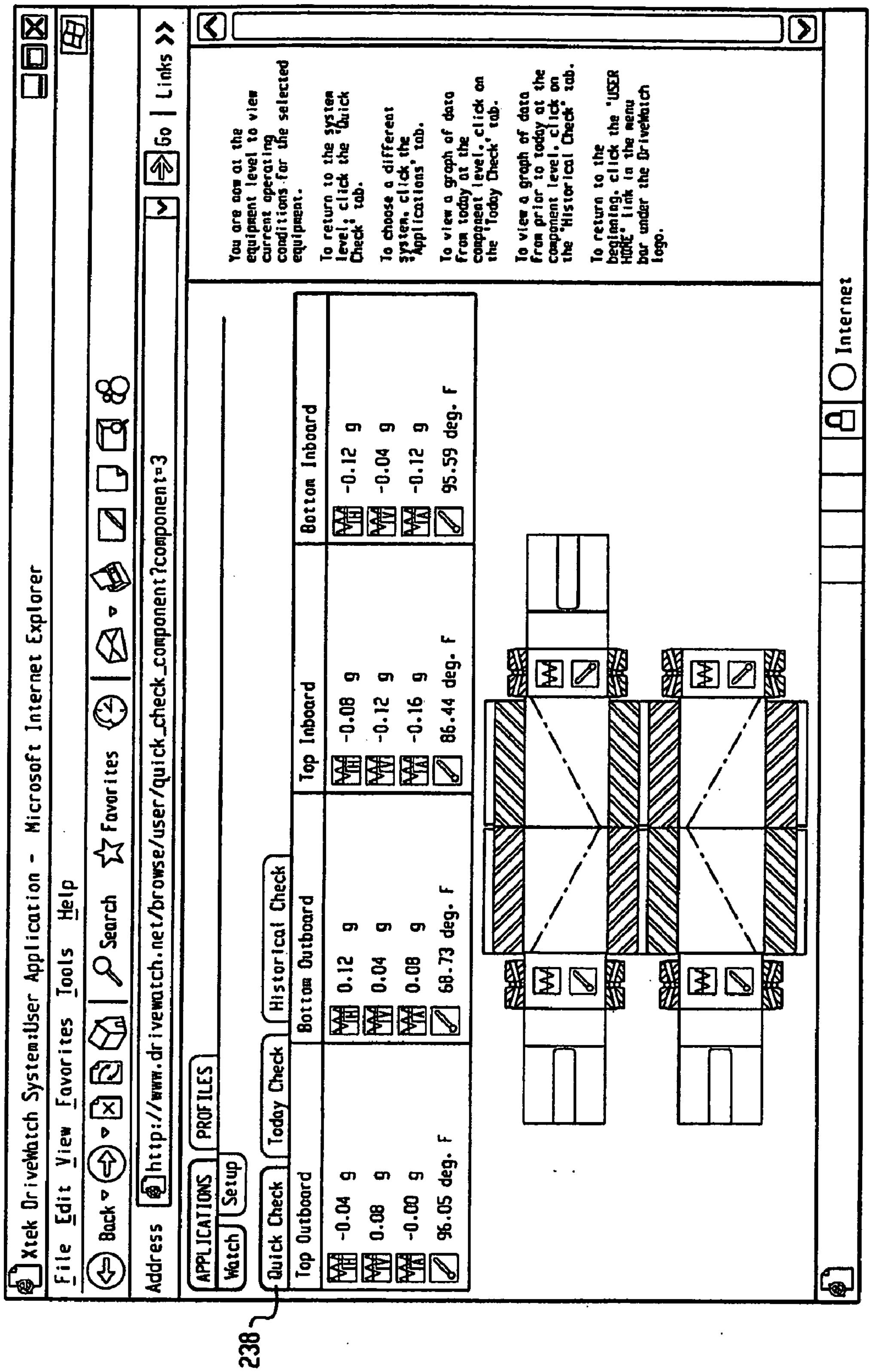
Set Range
Select by Data Type
Select by Position
INSTRUCTIONS
You are now at the equipment level to view DriveWatch data prior to today.
To view data by data type, click the icon in the data bar above the image.
To view data by position, click the icon within the image of the equipment.
To return to the system level, click the "Historical Check" tab.
To choose a different system, click the "APPLICATIONS" tab.
To view a current operating conditions from today for this equipment, click on the "Quick Check" tab.
To view a graph of data from today for this equipment, click on the "Today Check" tab.
To return to the beginning, click the "USER HOME" link in the menu bar under the DriveWatch logo.
Internet
232
234
236

Fig. 12


Xtek DriveWatch System:User Application - Microsoft Internet Explorer
File Edit View Favorites Tools Help
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Quick Check
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Historical Check
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0.08 g
-0.00 g
96.05 deg. F
Bottom Outboard
0.12 g
0.04 g
0.08 g
68.73 deg. F
Top Inboard
-0.08 g
-0.12 g
-0.16 g
86.44 deg. F
Bottom Inboard
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-0.04 g
-0.12 g
95.59 deg. F
You are now at the equipment level to view current operating conditions for the selected equipment.
To return to the system level, click the 'Quick Check' tab.
To choose a different system, click the 'Applications' tab.
To view a graph of data from today at the component level, click on the 'Today Check' tab.
To view a graph of data from prior to today at the component level, click on the 'Historical Check' tab.
To return to the beginning, click the 'USER HOME' link in the menu bar under the DriveWatch logo.
Internet
238

Fig. 13

DATA ACQUISITION SYSTEM FOR SYSTEM MONITORING

CROSS-REFERENCES

[0001] This application is a continuation-in-part of PCT International Application No. PCT/US2008/050687, filed Jan. 10, 2008, which in turn is a continuation of U.S. application Ser. No. 11/622,852, filed Jan. 12, 2007 (now issued as U.S. Pat. No. 7,398,186) which in turn is a continuation-in-part of U.S. application Ser. No. 11/205,985, filed Aug. 17, 2005 (now issued as U.S. Pat. No. 7,328,130).

TECHNICAL FIELD

[0002] The present application relates generally to data acquisition systems and more particularly to a data acquisition system for system monitoring.

BACKGROUND

[0003] Machines are often monitored to detect and measure certain operating conditions. For example, it may be desirable to monitor vibrations or oscillations in machines having moving parts. As another example, it may be desirable to measure load, such as torque, in a machine used to rotate a shaft. Sometimes, a machine, itself, may provide some capability of monitoring an operating condition, such as revolutions per minute (RPM) of a rotating shaft, as an example. However, in many cases, the machine does not have the capability to provide data relevant to at least some of the operating characteristics that an operator may want to track.

[0004] Monitoring systems have been proposed that can perform desired measuring tasks. As one example, a system has been proposed that includes a transportable, hand-held measuring apparatus. The measuring apparatus is connected by a transmission cable to a point on a machine that is excited by oscillations and the measuring apparatus is used to measure operating conditions at that point. A central computer is used to process the measured data from the measuring apparatus. The central computer also stores the data collected by the measuring apparatus.

[0005] Such a hand-held measuring apparatus can measure a condition at a location on the machine, providing a "snap shot" of the operating conditions at a specific point and moment in time the data is acquired. There is a need for a monitoring system capable of monitoring a number of a machine's operating parameters simultaneously.

SUMMARY

[0006] In some aspects, a method and monitoring system for tracking operational parameters of a monitored system including a member driven by a drive motor operatively coupled with the member via a drive arrangement including a geared coupling are provided. A sensor unit is provided on one of the drive motor and the geared coupling. The sensor unit includes a sensor for generating an analog signal in response to an operating condition of the monitored system and an integrated local processor for processing the analog signal generated by the sensor. The integrated local processor has an associated timer for processing the analog signal generated by the sensor to (i) produce a first plurality of digital signal samples and (ii) package the first plurality of digital signal samples together as a packet for transmission. The packet includes an associated timestamp value for a digital signal sample of the plurality of digital signal samples and an associated reporting rate value from which a relative timing of the other digital signal samples can be determined.

[0007] In another aspect, a method of tracking operational parameters of a drive system including first and second members driven respectively by first and second coupling shafts is provided. The method involves: providing a first sensor unit on the first coupling shaft, the first sensor unit adapted for wireless communication with a remote processing unit, the first sensor unit including an integrated local processor and local memory; providing a second sensor unit on the second coupling shaft, the second sensor unit adapted for wireless communication with the remote processing unit, the second sensor unit including an integrated local processor and local memory; the first sensor unit operating to acquire and store sensor data in its local memory until the first sensor unit receives a data transmit trigger from the remote processing unit; the second sensor unit operating to acquire and store sensor data in its local memory until the second sensor unit receives a data transmit trigger from the remote processing unit; sending a transmit trigger wirelessly from the remote processing unit to the first sensor unit, the first sensor unit responsively wirelessly transmits sensor data to the remote processing unit; sending a transmit trigger wirelessly from the remote processing unit to the second sensor unit, the second sensor unit responsively wirelessly transmits sensor data to the remote processing unit; wherein the sending of the transmit trigger to the second sensor unit is offset in time from the sending of the transmit trigger to the first sensor unit so as to assure that transmission of sensor data from the first sensor unit to the remote processing unit is completed before transmission of sensor data from the second sensor unit to the remote processing unit takes place.

[0008] In a further aspect, a method of tracking operational parameters of a drive system is provided. The method involves: providing a first sensor unit on a first component of the drive system, the first sensor unit including an integrated local processor; providing a second sensor unit on a second component of the drive system, the second sensor unit including an integrated local processor; detecting working condition of the drive system; responsive to detection of the working condition, sending a data acquire instruction to the first sensor unit, and sending a data acquire instruction to the second sensor unit, causing both the first and second sensor units to acquire sensor data during a common time period that overlaps with the drive system operating in the working condition.

[0009] In yet another aspect, a method of tracking operational parameters of a drive system including at least one drive component involves the steps of: associating a sensor unit with the drive component, the sensor unit including an integrated local processor and a vibration sensor, the sensor unit converting analog vibration signals from the vibration sensor into digital signal samples; the integrated local processor performing an FFT operation on the digital signal samples to produce an FFT spectrum; the integrated local processor generating an alarm based upon analysis of the FFT spectrum.

[0010] In still another aspect, a method of tracking operational parameters of a drive system including at least one drive component involves the steps of: associating a sensor unit with the drive component, the sensor unit including an integrated local processor and a vibration sensor, the sensor unit converting analog vibration signals from the vibration sensor into digital signal samples; where the integrated local

processor: identifying a drive system speed condition; performing an FFT operation on digital signal samples produced during the drive system speed condition to produce an FFT spectrum; analyzing the FFT spectrum using an alarm band filter associated with the drive system speed condition; and generating an alarm if the analysis indicates the FFT spectrum is outside bounds defined by the alarm band filter.

[0011] The details of one or more embodiments of the invention are set forth in the accompanying drawings and the description below. Other features, objects and advantages of the invention will be apparent from the description and drawings, and from the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] FIG. **1** is a diagrammatic view of an embodiment of a method and apparatus for monitoring a machine using a monitoring system;

[0013] FIG. **2** is a diagrammatic view of an embodiment of a sensor unit for use in the monitoring system of FIG. **1**;

[0014] FIG. **3**A is a top view of an embodiment of a portion of a sensor unit enclosure;

[0015] FIG. **3**B is a plan view of an embodiment of a sensor unit with the portion of FIG. **3**A removed;

[0016] FIG. **3**C is a side view of the portion of FIG. **3**A;

[0017] FIG. **3**D is a side view of the sensor unit of FIG. **3**B with the portion of FIG. **3**A removed;

[0018] FIG. **4**A is a plan view of an embodiment of a sensor unit showing a printed circuit board;

[0019] FIG. **4**B is a side, partially exploded view of the sensor unit of FIG. **4**A;

[0020] FIG. **5**A is a plan view of another embodiment of a sensor unit showing a printed circuit board;

[0021] FIG. **5**B is a side view of the sensor unit of FIG. **5**A;

[0022] FIG. **6** is an embodiment of a data flow diagram for a monitoring system;

[0023] FIG. **7** is an embodiment of a record; and

[0024] FIG. **8** is an embodiment of a coupling shaft adapted for use with a wireless sensor unit;

[0025] FIGS. **9-13** are embodiments interfaces presented to a user seeking data regarding a monitored drive system.

DETAILED DESCRIPTION

[0026] For purposes of describing an embodiment, this description will focus on monitoring of a rolling mill power transmission drive train. However, this embodiment is exemplary and is in no way intended as a limitation, as other drive train and machine types may be monitored. Other machines and equipment that may be monitored include, for example, overhead crane gear drives, process machinery such as slitters, levelers and shear drives that incorporate power transmission, and other transmission drive applications where monitoring of operational conditions may be desirable.

[0027] Referring to FIG. **1**, a rolling mill drive train **10**, e.g., for use in rolling metal such as steel is shown with a monitoring system **12** connected thereto. Rolling mill drive train **10** includes a motor **14** that is operatively connected to work rolls **16** and **18** through a drive train power transmission that includes a gear reducer **20**, pinion assembly **22** and couplings shown as shaft couplings **24** and **26**. Backup rolls **28** and **30** are located adjacent work rolls **16** and **18** to form a gap or nip through which a work piece (e.g., a metal plate) can pass during a rolling operation. The motor **14** and gear reducer **20** are located in a motor room portion **32** of a mill, while the pinion assembly **22**, shaft couplings **24**, **26**, work rolls **16**, **18** and backup rolls **28**, **30** are located in a mill portion **34** separated from the motor room portion **32**.

[0028] In the illustrated example, monitoring system **12** is used to monitor and evaluate operating conditions, such as vibration, temperature, torque, current, speed, rotational position, etc., of rolling mill drive train components. Monitoring system **12** includes a number of sensor units generally designated as **42**, **44** and **46** that are affixed locally to (i.e., at or close to) various drive train power transmission components, such as those described above. By affixing the sensor units **42**, **44** and **46** locally to a number of components of the drive train power transmission, relative comparisons of the operating conditions of the components can be made using data generated by the sensor units, which, in some instances, may provide for a more reliable analysis of the operating conditions of the rolling mill drive train **10**. As will be described in greater detail below, the sensor units **42**, **44**, **46** include both a sensor and a microprocessor that send data to associated communicators generally designated as **38** (sometimes referred to as a hub or a collector) which gather the data. The gathered data is then sent to a gateway **40** (e.g., a server) that is connected to a remote server system (not shown), for example, via the Internet.

[0029] Referring still to FIG. **1**, motor **14** includes sensor units **42***a*, **42***b* and **44** operatively affixed thereto with sensor unit **44** also connected to a proximity sensor **46** and a current transformer **48**. More particularly, sensor unit **42***a* is affixed to a bearing housing (not shown) of the motor **14** and is used to monitor vibration at the bearing housing. Affixed to an opposite bearing housing (not shown) of the motor **14** is sensor unit **42***b*, which is also used to monitor vibration at the opposite bearing housing. Sensor unit **44** is affixed to a base of the motor **14** and is also connected to external sensor inputs, e.g., as shown, proximity sensor **46** and current transformer **48**. Proximity sensor **46** may be used to measure shaft speed of the motor **14**, in some embodiments, by measuring rotational pulses. Current transformer **48** provides a signal output representing the current wave form supplied to the motor **14**. Sensor unit **44** can collect data using the signals supplied by the proximity sensor **46** and current transformer **48** to monitor motor operation.

[0030] Gear reducer **20** includes four sensor units **42***c*, **42***d*, **42***e*, **42***f*. Sensor units **42***c* and **42***d* are affixed to a bearing housing **52** of a drive shaft of output gear **50** and are used to monitor vibration and temperature at the bearing housing **52**. Sensor units **42***e* and **42***f* are affixed to a bearing housing of an input drive shaft of input pinion gear **54** and are used to monitor vibration and temperature at the bearing housing of the gear **54**.

[0031] Pinion assembly **22** includes four sensor units **42***g*, **42***h*, **42***i*, **42***j*, each affixed at an associated bearing housing **64**, **66**, **68**, **70**. Sensor units **42***g* and **42***h* are affixed to bearing housing **64** and **66** of pinion shaft **56**. Sensor units **42***i* and **42***j* are affixed to bearing housing **68** and **70** of pinion shaft **58**. Each sensor unit **42***g*, **42***h*, **42***i*, **42***j* is used to monitor vibration and temperature at its respective bearing housings **64**, **66**, **68**, **70**.

[0032] Each shaft coupling **24** and **26** includes a respective sensor unit **46***a*, **46***b* affixed thereto that rotates with the shaft coupling. Sensor units **46***a* and **46***b* are used to monitor vibration, torque, temperature and shaft position of their respective shaft couplings **24** and **26**. In some sensor unit **46***a* and **46***b* embodiments including a battery, the sensor units **46***a* and

46*b* are used to monitor battery voltage for an indication of battery power level and need for battery replacement and/or recharging.

[0033] Work rolls **16**, **18** include associated pairs of sensor units **42***k* and **42***l*, **42***m* and **42***n* affixed thereto. Sensor units **42***k* and **42***l* are affixed at respective bearings **72** and **74** of work roll shaft **43** while sensor units **42***m* and **42***n* are affixed at respective bearings **76** and **78** of work roll shaft **75**. Each sensor unit **42***k*-**42***n* is used to monitor vibration and temperature at its respective bearing location.

[0034] Any suitable method can be employed to operatively mount the sensor units **42**, **44**, **46** to the machine drive train **10**. In some embodiments, the sensor units **42**, **44** and **46** are fastened to the machine drive train **10** with fasteners, such as screws, bolts, etc. for a permanent installation. Other mounting methods are possible, such as by welding.

[0035] As represented by FIG. **1**, each sensor unit **42**, **44**, **46** is capable of communicating with a communicator **38***a*, **38***b*, **38***c*, **38***d* (e.g., through a RS 485, 4-wire connection and/or a wireless connection such as by RF transmission), with sensor units **42***a*, **42***b* and **44** connected to communicator **38***a*, sensor units **42***c*-**42***f* connected to communicator **38***b*, sensor units **42***g*-**42***j* and sensor units **46***a* and **46***b* connected to communicator **38***c* and sensor units **42***k*-**42***n* connected to communicator **38***d*. Sensor units **46***a* and **46***b* communicate wirelessly (e.g., using an RF transmitter **45**) with communicator **38***c* (e.g., using a RF receiver including an omni-directional RF antennae **47**), while the other sensor units **42***a*-**42***n* and **44** communicate with their respective communicators **38***a*-**38***d* via a wired connection. Use of an omni-directional RF antennae may reduce communication interruptions between sensor units **46***a*, **46***b* and the communicator **38***c* due to rotation of the sensor units **46***a* and **46***b* with the shaft couplings **24** and **26**. Other configurations are possible whereby one or more of sensor units **42***a*-**42***n*, **44** communicate wirelessly. In some embodiments, none of the sensor units may communicate wirelessly. For example, each of the sensor units **42***a*-**42***n*, **46***a*, **46***b* and **44** may be connected to a communicator via a wired connection. Communicators **38***a*-**38***d* supply power (e.g., DC low voltage, such as 8-28VDC) to associated sensor units **42***a*-**42***n* and **44** through the wire connections. Sensor units **46***a* and **46***b* each include an internal power supply (e.g., a battery) providing power thereto. Each of the communicators **38***b*-**38***d* are connected (as shown by lines **80**) to a power source **86** (e.g., a 110/220V AC source) through communicator **38***a*.

[0036] Communicators **38** gather data received from the sensor units **42**, **44**, **46** and send data to the gateway **40**. Gateway **40** acts as a local server to host communications from each communicator **38** and can provide Internet connectivity to an off-site system host via a local network connection (e.g., a LAN connection) illustrated by dotted lines **82** and bridge component **84**. Gateway **40** is connected to a power source **86** via line **88**.

[0037] Referring to the diagrammatic illustration of FIG. **2**, the sensor units **42**, **44** and **46** may include a sensor **92** (e.g., an accelerometer) or a set of sensors and an integral local microprocessor **90** as part of the same unit. In some embodiments such as the one shown, both the microprocessor **90** and the sensor **92** electronics reside on the same circuit board **96**. In other embodiments, the microprocessor **90** electronics may reside in the same module, but separated from the board **96** carrying the sensor **92** electronics.

[0038] As noted above, sensor units **42** and **46** acquire specific operational data for determining, for example, vibration, temperature, torque/strain, electric current, rotational speed and/or rotational position through the use of sensors **92**, which are responsive to the machine's operating conditions. Additional physical data acquisition is possible utilizing sensor unit **44**, which may include standard voltage or current output sensors.

[0039] FIGS. **3**A-**3**D show an embodiment of sensor unit **42** that includes sensor **92***a* responsive to three axes of vibration and sensor **92***b* responsive to temperature or, in some embodiments, strain. Sensor **92***a* may be carried by circuit board **96** which also carries microprocessor **90**, while sensor **92***b* includes an input for a connection with a remote temperature detector. In some embodiments, sensor **92***a* may be included separate from the circuit board **96** carrying the microprocessor **90**. In some instances, sensor unit **42** may not include a temperature and/or stain sensor **92***b*.

[0040] Referring to FIGS. **4**A and **4**B, sensor unit **44** includes three ±10 volt inputs **95**, three 4-20 mA current inputs **97**, optical encoder inputs **99** and a proximity switch input **101**. Sensor unit **44** may also include a temperature sensor **92***b* and a power supply, such as a battery.

[0041] Referring to FIGS. **5**A and **5**B, sensor units **46** are wireless and are capable of being attached to a rotating shaft. Sensor unit **46** includes a one axis vibration sensor **92***a* and three temperature and/or strain sensors **92***b*. As shown, each of the sensors **92***a* and **92***b* are included on the same circuit board **96** as microprocessor **90**. A power supply **93** provides power to the sensor unit **46**. In some embodiments, sensor unit **46** includes a sensor **92***b* that is separate from the circuit board **96** carrying the microprocessor **90**.

[0042] Referring now to FIGS. **3**A-**5**B, the sensor **92** and microprocessor **90** are housed within an enclosure, in some embodiments, formed by a base portion **118** that can be mounted to the respective drive train **10** component and a cover portion **122** that can be connected to the base portion. In some embodiments, the cover portion **122** and base portion **118** when connected together form a seal (e.g., a water-tight seal).

[0043] The microprocessors **90** can receive information or data from the sensors **92**, for example, in the form of electric analog signals in order to pre-process the data prior to sending the data to the communicator **38** (FIG. **1**). The microprocessor **90** may include an integral timer, read-only memory, flash memory, serial communications and/or an analog-to-digital (A/D) converter (in some embodiments, an 8 channel, 10 bit A/D converter). Analog signals are sent from sensors **92** (in some embodiments, continuously) and captured by microprocessor **90**. Microprocessor **90** converts the analog signal to digital data in the sensor unit **42**, **44**, **46**. The microprocessor **90** measures the analog signal level at predetermined intervals of time (sometimes referred to as sampling) and converts the analog signal to an integer value (sometimes referred to as a count) between, for example, 0 and 1023. Microprocessor may sample the analog signal at a rate of about 8,000 Hz or more as an example. The integer value can later be converted to a "real" value (e.g., at an off-site host processor) using a transformation formula dependent on the type of measurement and sensor unit. For example, in one embodiment, data received from an off-board temperature sensor **92***b*, e.g., of the sensor unit of FIG. **3**A may be converted from a digital count to a temperature value using

$$\mathrm{Temp(F)} = -0.457478(\mathrm{count}) + 500.0.$$

[0044] It should be appreciated from the foregoing that numerous digital data records can be generated by the sensor units **42**, **44**, **46** with each record relating to an operating condition of an associated machine component. To manage data record volume, the microprocessors **90** may have a respective reporting rate where the microprocessors select predetermined ones of the digital data values output by the A/D converter to report and further process. In these embodiments, the reporting rate (e.g., 100 Hz, 1000 Hz, etc.) may be less than the sampling rate (e.g., 8000 Hz). This can reduce the amount of data processing by reducing the amount of records to be processed, while providing for continuous data acquisition using the microprocessors **90**. Advantageously, this can provide flexibility in increasing or decreasing the reporting rate of the sensor unit **42**, **44**, **46** without any need to change sensor **92** output or sampling rate of the microprocessor **90**.

[0045] Microprocessors **90** of the sensor units **42**, **44**, **46** mark at least some or all of the digital values output by the A/D converter to facilitate downstream processing and analysis. To illustrate, each microprocessor **90** may timestamp digital data values at each sensor unit **42**, **44**, **46**, for example, with a 32-bit integer at the designated reporting rate. The timestamp can begin at zero and can be incremented at predetermined intervals, such as every 1/125th of a second (e.g., corresponding to the sampling rate) or less, as an example. In some implementations, all of the sensor units **42**, **44**, **46** of the monitoring system **12** are initiated or reset substantially simultaneously (in some embodiments, upon user command or automatically) such that the timestamps of all of the sensor units begin at the same value at substantially the same instance in time (e.g., within about ±0.5 millisecond of each other). In some instances, the timestamp of each microprocessor **90** rolls over back to zero, e.g., once the integer reaches its maximum value. The timestamp can be transmitted with the digitized data from the sensor units **42**, **44**, **46** to the communicators **38** and be used during downstream processing for, e.g., data synchronization, sorting operations, queries, etc.

[0046] Microprocessor **90** may perform other pre-processing of incoming analog signals. In some embodiments, microprocessor **90** may run data through alarm and processing filters. Alarm trips (e.g., generated when a value falls outside a predetermined range) and processed values can be reported to the associated communicator **38**. In certain embodiments, microprocessor **90** can perform Fast Fourier Transforms (FFT) and generate alarms and further processing that are triggered by threshold values in the resultant FFT spectrum. In some embodiments, microprocessor **90** may run data through other filters, such as, for example, a low pass filter or moving average filter.

[0047] A digitized data record for a sensor unit **42**, **44**, **46** may include a sensor type identifier, a data reporting rate, a data type identifier (e.g., real-time, moving average, filtered data), sensor channel (which identifies which sensor from which the data is derived) and timestamp. In some embodiments, multiple digital signal values may be packaged (e.g., at a respective sensor unit **42**, **44**, **46** using microprocessor **90**) and each packet may further include number of samples in the packet, timestamp of the first data sample in the packet and a sample stream including readings for each active sensor channel. In some implementations, about 100 or more digital signal values, such as about 200 digital signal values may be packaged together for transmission. An exemplary data record or packet structure is provided below:

Data Record/Packet

(2 Bytes) Sensor Type

(2 Bytes) Data Reporting Rate

(2 Bytes) Data Type Mask

(2 Bytes) A/D Channel Select Mask

(4 Bytes) Timestamp of the First Data Sample

(2 Bytes) Number of Samples in Packet

[0048] (x Bytes) Data Samples where

[0049] x=(Bytes per Data Sample×Number of Samples×Number of A/D Channels×Number of Data Types)

In this embodiment, multiple digital signal values (i.e., samples) are packaged together for transmission with a single timestamp for the first sample. By including the reporting rate in the packet, the relative timing of each subsequent sample in the packet can be determined by a remote processing unit. While it is possible to include a timestamp for each sample in a packet, doing so would require a larger data file.

[0050] Referring to FIG. **6**, an exemplary data flow diagram is shown. Sensor units **42**, **44**, **46**, here collectively referred to as **100** for ease of description, are mounted locally to rolling mill machine **10** (represented by dotted lines). The sensor units **100** are each capable of generating data corresponding to operating conditions of the rolling mill machine, as described above. The sensor units **100** are connected to communicators **38** to allow the sensor units to send pre-processed data to the communicators. While four communicators **38** are shown connected to gateway **40**, there may be more communicators such as six communicators or, alternatively, there may be less than four communicators such as two communicators for a given gateway **40**.

[0051] Communicators **38** can be intermediate devices that provide a bridge and a meta-controller for an associated group **102**, **103**, **104**, **105** of sensor units **100** and gateway **40**. Each communicator **38** has six serial communications channels, each channel providing a connection to a respective sensor unit **100**. For example, communicator **38***a* has six serial communications channels i-vi, each channel providing a connection to respective sensor units a-f. Each communications channel is controlled by a dedicated microprocessor, e.g., one microprocessor per channel at the respective communicator **38**. The digital data signal values (e.g., in packets) are passed to the gateway **40**, for example, every two seconds. In some embodiments, an additional microprocessor may be included at the communicator **38** to control a wireless communications channel for communicating to wireless sensor units (e.g., see sensor units **46***a* and **46***b* of FIG. **1**). Communicators **38** may further include another microprocessor for controlling a network connection (e.g., LAN connection, IP protocol) with the gateway **40**. In some instances, the communicators **38** provide a self-healing direct current power to each associated sensor unit **100** and can discontinue communications through a selected channel while allowing communications through the remaining channels.

[0052] In some embodiments, monitoring system **12** includes independent, current-limited voltage regulators on one or more channel connections. The regulators can be monitored and controlled by the dedicated channel microprocessors to provide self-healing in that a channel power supply can identify and recover from wiring and/or sensor electrical failure. As an example, in an instance where sensor power is shorted to ground, the current limiting regulator can fold the sensor supply voltage back to prevent immediate damage. The channel microprocessor can detect that the channel voltage is at an abnormal level and can discontinue power to the malfunctioning sensor and issue a fault message. In some embodiments, the channel microprocessor can periodically retry applying sensor power to detect normal operation.

[0053] Gateway **40** can be a server or personal computer (e.g., an Intel® based computer having a Linux operating system with open source and software tools). In some embodiments, the gateway **40** includes multiple network cards, for example, one for connections to the communicators **38** and another for providing access to a user network and the Internet. In certain embodiments, there may be more than one gateway **40**. In some of these embodiments including multiple gateways **40**, one gateway can serve as a master and handle all Internet communications.

[0054] Gateway **40** is connected to the communicators **38** and receives and adds a date/time value, e.g., accurate to a second to the timestamps generated by the sensor units and a communicator identifier. The date and time value added by the gateway **40** and the timestamp generated at each sensor unit **100** is used as an identifier for each data record value packet. In some embodiments, the gateway performs additional processing of the data received such as alarm processing and processing that involves data from more than one sensor unit **100** or module A/D channel, as examples. The gateway **40** can store data for a period of time in memory and send the data (and associated alarm information and other processing results) to a group of servers, e.g., a presentation server **108**, a data server **110** and/or a process server **112** continuously.

[0055] The combination of the sensor unit **100** hardware timestamp and the date/time value added by the gateway **40** server can be used to pinpoint each data record sample in time. A UDP protocol can be used to communicate between the gateway **40** and the communicators **38**. The UDP protocol may require less data overhead, for example, compared to a fully synchronous protocol like TCP and allows for reservation of bandwidth for data. Because UDP is asynchronous, packets may be received by the gateway out of order. The hardware timestamp and the date/time value combination allows for rebuilding of a data packet stream in time in the system, for example, regardless of how the packets came in.

[0056] Gateway **40** can communicate with the presentation server **108**, data server **110** and process server **112** using any suitable manner. In some embodiments, the communication between the gateway **40** and servers **108**, **110** and **112** is achieved using HTTP protocol and TCP/IP. The gateway **40** provides diagnostic tools to monitor the health of the rolling mill machine **10** and can notify a user of alarms and processing results via e-mail, phone, pager and other communication devices.

[0057] Servers **108**, **110** and **112** can be of any suitable configurations, such as Intel® based having a Linux operating system with open source and software tools. Presentation server **108** is located remote from the motor room portion **32** (FIG. **1**) and can provide a central communications point for all the servers. The presentation server **108** collects data from all the gateways (i.e., gateway **40**) and provides a web-based interface **114** to users. Support servers, e.g., the database server **110** and the process server **112** exist within a firewall **106** and include servers and server clusters dedicated to data storage and access, generation of graphics and data processing for analysis purposes.

[0058] Synchronization of data samples in a packet is performed by the data server **110** using the timestamp value of the first data sample, the packet size, data reporting rate and number of A/D channels. This information is used to calculate the timestamp for each individual data sample, for example, during a dwdata process on the database server, which reads data samples collected by the presentation server **108** from the gateway(s) **40** and splits up the data packets and stores the data samples as individual rows in one or more database table.

[0059] Data samples may be synchronized upon user command, for example, for display in reports and graphs and/or for use in post analysis such as for creating Fast Fourier Transforms of vibration data. Data sample packets can be selected using the date/time values that lie in a user-specified range. The data samples of the data sample packets lying in the user specified range can then be sorted by the timestamps, as described above.

[0060] Sorting the data samples by their timestamps, whether assigned at the sensor unit for example to the first data sample of the packet, or whether calculated by the data server **110** as described above will better ensure that data samples are aligned across sensors and in time across the sensors. This alignment of data samples can be important to show operating conditions at a variety of positions across the drive train, for example, as vibrations travel through the drive train. In some embodiments, data samples originating from about 100 sensors or more, such as 420 sensors or more can be synchronized using timestamps, for example, by setting all sensors to a timestamp of 0 at substantially the same time (i.e., within an acceptable error band of ½ a millisecond of one another).

[0061] Components of the monitoring system **12** including the sensor units **100** are reconfigurable automatically and/or by user command. In some embodiments, data acquisition and data reporting of the sensor unit **100** is configurable by commands sent to the sensor unit from the gateway **40** and/or the communicator **38** over the serial communications link therebetween. Reporting of data from the sensor unit **100** to the communicator **38** is configurable with parameters such as reporting rate, data type, and A/D channels to be reported. In some implementations, reporting rates are automatically changed based on, for example, measured rotational speed of a given data location of a component. Such reconfiguration is achieved through locating microprocessor **90** in the sensor unit **100**, as described above, which provides each sensor unit with a capability to process incoming data locally. In some instances, operating software for the microprocessors in the sensor units **100** and the sensor units **38** can be reprogrammed remotely, which can be used to upgrade installed components of the monitoring system **12**, for example, from a central location via the Internet.

[0062] Gateway **40** includes software that runs various processes including dwconfig, dwmonitor and dwsend. Dwconfig retrieves pending commands from the servers **108**, **110** and **112** and queues the commands for dwmonitor. Dwmonitor passes the commands to the communicator/sensor unit network, receives data and stores data in memory (e.g., at a local database). Alarm and processing applications can be attached to the dwmonitor process at system startup and during operation in response to commands received from the gateway **40**. Dwsend retrieves stored data and sends the data to the servers **108**, **110** and **112**. Presentation server **108** includes a web service that receives data from the gateway **40** and stores the data in a table at a staging database. Database server **110** runs the dwdata process that takes data from the staging database and spreads the data across a series of databases and database tables. Each sensor unit **100** may have a respective series of tables stored in a database and each sensor unit **100** A/D channel may have a respective table in the series of tables. Process server **112** runs a web service, e.g., that can generate graphs and can provide processed data on demand for the presentation server **108**.

[0063] Monitoring system **12** may include a number of software tools and applications that can be utilized in analyzing machine operating conditions. In one embodiment, monitoring system **12** includes case-based reasoning (CBR), which is an artificial intelligence technique that mimics how the human mind stores experimental knowledge. Situations are characterized as a series of parameters called cases. New cases are created on demand and characterized by often incomplete parameter sets. A nearest-neighbor algorithm selects cases from the database that resemble the parameter sets of the new cases and are used to provide direction on how to react to or further process new cases. CBR can be used to mimic basic experimental knowledge of vibration and maintenance personnel.

[0064] FIG. **7** shows an exemplary report **120** showing vibration values measured using monitoring system **12**. Report **120** can be accessed, for example, remotely via a user interface such as a personal computer capable of communication with the servers **108**, **110** and **112** as described above.

[0065] The above-described monitoring system **12** can provide an intelligent data acquisition network. This is accomplished, in part, by locating microprocessors **90** at the sensor units **100** that are capable of receiving and carrying out a variety of data acquisition commands. The monitoring system **12** can be setup for a variety of different data acquisition modes. In one embodiment, the monitoring system **12** may include a routine mode and an analysis mode. In the routine mode, the monitoring system **12** can acquire data in a predetermined, consistent and repeatable fashion to provide trending analysis. If a potential problem is detected (e.g., by the monitoring system **12** and/or by a user, for example, remotely), the analysis mode may be initiated to provide data acquisition for detailed diagnostic purposes. The date/time value added by the gateway **40** can be accurate to one second. The sensor unit applied timestamp can be accurate to 0.000125 seconds. That can allow the monitoring system **12** to maintain synchronization of data samples at reporting rates of up to about 8000 Hz. The monitoring system's architecture can be adaptable to a variety of protocols to accommodate other existing, in-house monitoring systems and can be added to an existing equipment monitoring system. Monitoring system **12** software may contain analysis capabilities for drive train diagnostics. Component geography and specification information can be included which can provide a detailed and accurate assessment of operating conditions.

[0066] Referring now to FIG. **8**, an embodiment of a drive shaft adapted for use with wireless sensor units **46***a* and **46***b*. Specifically, a wireless sensor unit **46***a* is mounted at the exterior of the shaft and may be held thereto by fasteners **200**. Multiple wiring paths **202***a*, **202***b* and **202***c* are provided internal of the shaft. Wiring paths **202***a* and **202***b* carry wiring from the sensor unit electronics to sensors **204***a* and **204***b* located toward the ends of the shaft. Wiring path **202***c* extends from the sensor unit location to a battery pack space **206** located internal of the shaft, the space preferably centered on the axis of the shaft. Access to the battery pack space is via open end **208** of the shaft to enable installation, removal and replacement of battery packs as necessary. In one example the battery pack is formed by a cylindrical shell having multiple "standard" batteries loaded therein and connected in series, with a filler material located in the space between the batteries and an end cap with positive and negative terminals that connected to the wiring running from the sensor unit **46***a*.

[0067] As explained above, sensor units **46***a* and **46***b* may be adapted for wireless communication with the communicator **38***c* in view of the rotation of such sensor units with the coupling shaft. Various modes, in addition to those described above, can be implemented in such sensor units.

[0068] In one example, the sensor units **46***a* and **46***b* can include a listening mode. Once the sensor unit is powered up, the unit may automatically default to the listening mode. In this mode the unit is able to be "called" by a radio partner (e.g., Bluetooth protocol from the communicator **38***c*) in order to execute set commands issued by the communicator. The listening mode operation draws relatively low power consumption compared to the transmission mode (e.g., when the unit is transmitting data to the communicator). This mode enables the unit to be activated at strategic times to initiate data acquisition during events of interest. For example, data acquisition might be triggered when another part of the system identifies an increase in operating speed of the drive system, which typically occurs when the drive is being ramped up from an idle mode to a speed suitable for functional operation. In this manner, the system will more reliably obtain data during critical time periods of drive operation. Moreover, by triggering the activation mode of sensor units (be they wireless or wired) the system assures that all sensor units are acquiring data at during the critical time periods. In addition, in the listening mode, the sensor unit can also receive changes in configuration settings such as A/D activation, data reporting rates, data type and filter settings.

[0069] As mentioned above, while in the listening mode, the sensor unit can be given commands to transition it from listening to another operation mode such as acquisition mode. In this mode the sensor unit performs data acquisition functions. The acquisition mode is "scheduled" in a command that includes start time and stop time. As an example, the sensor unit can be given a data acquisition command that would include; start data acquisition in 10 seconds and acquire data for 60 seconds. The start time and stop time can be varied in an unlimited fashion. The data that is acquired is instantly stored in the onboard memory of the unit itself. The data remains in the unit's memory indefinitely until retrieved via the transmission mode. Data may be stored as first-in-first-out. The memory is upgradeable as technology improves. The acquisition mode can be "triggered" by an external event or setup as an internal routine that is activated at system start up.

[0070] In order to off-load data or receive configuration responses, the unit goes into transmission mode to transmit data to the host radio installed in the communicator. In the case of data transmission, a request can be made by the communicator to transmit all or only portions of the data stored in memory. Data may be stored in memory based on time and specific data "time slices" can be requested. Once the data is transmitted, the host conducts a reconciliation procedure to insure that the host received the data requested. Once confirmed, the host will then issue a "mark data" command which instructs the sensor unit to mark data in memory which then allows that data to be cleared from memory. This provision insures that wireless data transmission is successful. The transmission mode will consume the most power, and therefore it is desirable to perform this operation as efficiently and reliably as possibly.

[0071] In a system such as that shown in FIG. **1**, implementation of the listening mode, acquisition mode and transmission mode on a controlled basis via commands from the communicator enables a store and forward type of data process that eliminates interfering communications between the two sensor units **46***a* and **46***b* and the communicator **38***c*. In other words, the communicator can trigger each sensor unit to transmit data on a one at a time basis in order to avoid both sensor units attempting to transmit data simultaneously to the communicator, which could occur if the two sensor units **46***a* and **46***b* were configured to simply transmit data automatically without being triggered by the communicator.

[0072] The sensor units **46***a* and **46***b* may also be configured to include an alarm monitor feature during the data acquisition mode. Specifically, during a normal acquisition mode as described above the acquired data is automatically stored in on-board memory for later transmission to the communicator. Inclusion or activation of the alarm feature would result in the sensor unit monitoring the acquired data for an alarm condition and, upon identification of the alarm condition, automatically transmitting to the communicator a notification of the alarm condition and/or specific details regarding the nature of the alarm condition. The parameters for an alarm condition may include items such as A/D channel, threshold, alarm if over or alarm if under, and duration. The sensor unit may also run in a alarm only data acquisition mode where it will only send messages to the communicator when an alarm condition is detected.

[0073] The on-board processor of the sensor units will typically include multiple A/D channels for connection to multiple respective sensors. In this regard, the sensor unit may be configured with an A/D channel mask feature when in the data acquisition mode. Specifically, the sensor unit may to store and/or report data at multiple different rates across its various A/D channels (this feature may also be included into wired sensor units). The sensor unit may include two report rates and two sets of A/D channel masks, one for each report rate. The A/D sampling and data packing routines are configured to support these two separate report rates. The data for each report rate will be kept in its own buffer on the sensor unit. When the buffer is 'full', the data will either be shipped out via radio transmission if in live mode or stored on the external RAM if in store and forward mode. The header information for the data packet will be similar to that described above, informing the Gateway of the starting timestamp for the data, the A/D channels involved in the data, the sample rate, the report rate and the data mask.

[0074] The sensor units **46***a* and **46***b* may include a download-over-the-air (DOTA) feature to that wireless downloading or firmware upgrading is performed successfully. The DOTA feature may implemented by incorporating a hardware device such as a credit card size PCB assembly that plugs into an ISP header of the main board. The DOTA card would include an on-board processor and a serial data flash to provide storage to contain required programming, control and backup data. On reset, the main processor of the sensor unit sends version information to the DOTA card. If the software version on the DOTA card is newer, to DOTA card would reset the main processor and bootload it from the file located on the DOTA card. If new application data is wirelessly sent to the sensor unit, the main processor's application code would redirect the data to DOTA card via signals over the ISP connector. Once a complete file is downloaded and validated, the existing application file could be stored as back-up and the new application file can be bootloaded to the main processor. If the sensor unit receives a "rollback" command the DOTA card could bootload the older, backup version of the application file to the main processor. If the sensor unit is unable to communicate with the communicator for some time period after a bootload, the main processor may be configured to directly request a "rollback" from the DOTA card.

[0075] To facilitate the DOTA function and as well as download upgrades for wires sensor units, a bootload-overe-ethernet (BOE) function may be incorporated into the monitoring system. If new application data is sent to the communicator, the data is routed and stored on an SD-Card located in an SD-Socket of the communicator. Once a complete file is downloaded and validated, the current application file is copied to back-up and the new file becomes the "active" application file. Interlocks may be used to prevent partial loads and make sure that all application data is downloaded, in total, before allowing it to be used as an update file. At any time a "rollback" command can be sent to the communicator causing the communicator to make the back-up application file the new "active" application file for rebootloading purposes.

[0076] As mentioned above with reference to FIG. **7**, data that is acquired and stored by the monitoring system can be made available, for example, remotely via a user interface such as a personal computer capable of communication with the servers **108**, **110** and **112**. By way of example, an owner of the drive system being monitored may be given access to reports and data via a secure web site that associates specific drive systems with specific users (e.g., as by user id and password). Thus when a user logs in the user may be presented with an interface listing the various monitored drive systems associated with that user. A user may select to view information about a given drive system by clicking on that drive system listing (e.g., the drive system listing includes a link to another page that provides information about that drive system. In one implementation, the user may be presented with a web page showing a schematic or drawing of the configuration of the drive system as shown by example in FIG. **9**. The schematic of FIG. **9** corresponds to a drive system comparable to that shown in FIG. **1**. The user may then select a component of the drive system for which he/she wishes to see further data (e.g., the depiction of certain components may be set up as links).

[0077] FIG. **10** represents the next interface screen that might be presented to a user that selects the coupling shafts shown in FIG. **9**. The schematic of FIG. **10** shows the individual drive component, along with visual icons reflecting the type of data that are available for the component. By way of example, FIG. **10** includes icons **220**, **222**, **224** and **226** representing torque strain, vibration, battery power and temperature respectively. Each of these icons may also act as a link enabling a user to drill down further and obtain more detailed data. FIG. **11** shows an example of a schematic presented to a user that selects the pinion stand of FIG. **9**.

[0078] The interface presented to the user may also enable the user to specify a timeframe of interest. By way of example, referring to FIG. **12**, the interface may enable a user to specify a start date **232**, start time **234** and duration **236** of interest The system responsively collects and presents data from the specified time frame. This feature enables a user to look at short time periods, long time periods, recent data of older data at will, making the system more useful. The interface may also provide a "quick check" option **238** that provides current data for the component in question as shown in

FIG. **13**. This option shows most recent or "near instantaneous" data on the monitored drive system.

[0079] In one implementation of a sensor unit including a microprocessor **90** that performs FFT analysis as mentioned above, the unit includes an alarm band mode with FFT alarm bands being established for the monitored component based upon certain vibration metrics, such as:

[0080] Maximum Frequency (Fmax): This is the maximum value of a given frequency spectrum. This value will part of the configuration setting for each unit. It may be based on the rotational speed, bearing fault frequencies (BFF) or gear mesh frequency (GMF) which ever produces the highest value. Harmonics are generally included as follows:

- **[0081]** if GMF or BFF produce largest frequency, harmonics or number of orders=5×; Fmax=5×GMF or BFF;
- **[0082]** in the case where gear elements are not applicable, harmonics or number of orders=50× running speed; Fmax=50× shaft speed.

[0083] Number of Orders or harmonics (No): As noted above this number will be based on the application and elements involved. It may be necessary to use values other than 5 or 50. However this number will dictate the Fmax value.

[0084] Lines of Resolution (L_{OR}: The number of data points to be displayed within a given frequency spectrum, from 0 to Fmax. Typically, this value will be 400, 800, 1600, 3200. This is NOT the same as the number of samples or sampling rate. This value only applies to the FFT spectrum that is generated in the alarm band mode and will be part of the sensor configuration.

[0085] Number of Samples (Ns): This is the number of data samples required to produce an FFT. Traditional methods require this value to be *2.56×L_{OR}. This may be changed to 10× or more.

[0086] Bandwidth (B): The value of the spacing between each data point within the spectrum. This value will be important to make sure that the desired alarm fundamentals are distinguishable. B=Fmax/L_{OR}

[0087] Sample Time per Sweep (St): The amount of time it takes to generate the necessary number of samples required for each spectrum. St=1/B

[0088] Sampling Rate (Sr): The rate (samples per second) at which data is acquired by a given sensor unit. Sr=Ns/St.

[0089] Number of Averages (Na): This value will be the number of spectrums to average for a given "analysis". In the case of the Alarm Band Mode, this value will default to (1) since this mode will perform a daily trend average of several single spectrums.

[0090] Total Collection Time (Tct): Total data acquisition time based on number of averages required and sample sweep time. In alarm band mode, this value will be the same as sample sweep time. Tct=Na×St

[0091] Perhaps the most critical component of the data acquisition process will be the determination of the speed at which the vibration data is acquired. Each shaft within a drive train may be designated as either the direct speed input or a derived speed value based on gear ratios. As an example, given a double reduction gear drive that has (3) drive shafts, the input or shaft #**1** will be the direct input from an installed UNV unit with a proximity transducer. Shaft #**2** & shaft #**3** of the gear drive will be assigned a speed value based on the gear ratio from the shaft #**1**.

[0092] Before the vibration units can be configured, the shaft speed must be determined for the event of interest. In the case of a rolling mill application, this would be the speed at which steel production is processed. The expectations are that part of the setup for a given application will be the determination of the speed of interest. This will then provide the basis for determining the fundamentals above and also the basis for the alarm band settings. Each shaft within the drive train will be required to have a speed component, direct or derived. The sensor unit could monitor speed directly, poll the communicator or another module for speed information or simply regularly receive speed information from the communicator or other module.

[0093] In the Alarm Band Mode, the post processing of the FFT will depend upon the actual speed acquired during the sample sweep time (St) or (Tct). Speed will also provide a "trigger" determination to govern the operation of a given sensor unit.

[0094] As part of the system setup for a drive monitoring application, several pieces of information will be recorded to facilitate data acquisition and post processing of data. Each piece of equipment within a given application will be defined in detail to aid in the sensor setup and configuration as well as the post processing of data. With regard to vibration data acquisition, specific geometry information will be required to support sensor configuration and setup.

[0095] The basic function of the alarm band modes is to acquire data at a predetermined trigger point, post process data and perform an FFT and integration, "filter" results and determine if threshold values have been exceed, initiate an internal system alarm that would notify a designated contact (s) via email, perform a summary of each post process and save data for trending.

[0096] Data Acquisition Trigger—Data acquisition may be governed by a predetermined trigger event that could include an internal event such as speed change (e.g, from idle speed to processing speed) or an external event. An internal trigger would be consider some data type acquired by the system directly from any sensor within a given system or application. An external event would be considered a data type acquired from a system not directly connected to the monitoring network. The data acquisition trigger would be a component of a given sensor configuration or data handling module. The data acquisition volume and duration would be governed in accordance with the fundamentals defined above, Sr and Tct.

[0097] Post Processing—FFT/Integration—Once the data acquisition event was completed, the sensor would then perform post processing functions to generate a frequency spectrum that could then be filtered for alarm banding (e.g., an alarm event indicated by FFT magnitude above a defined threshold at a set speed). The frequency spectrum would be based on the fundamentals described above. It will be important that the methods and formulas used to produce the sensor spectrum be consistent with post processing software used for the manual mode. The frequency spectrum should be integrated from acceleration units to velocity units for filtering. FFT data may be sent from individual sensor units to a downstream module, such as the Gateway, and stored for a specified time period.

[0098] Alarm Band Filter—At each sensor location, fault frequencies will be determined utilizing the above system setup criteria. The known fault frequencies will then be used to filter each spectrum to determine condition changes. The filter value will be a magnitude (e.g., in/sec) corresponding to each fault frequency and harmonics of each. The filter value will be determined based on the speed of interest and preset in the sensor configuration. The actual fault frequency will be determined by the corresponding speed during data acquisition. It will be important to allow for some speed variation in the filter values to accommodate these variations.

[0099] By way of example, the chart below is representative of a defined alarm band filter that might apply to a specific speed range of interest:

TABLE I

Exemplary FFT Alarm Band Filter

Fault	Fundamental Hz	Fundamental in/sec	1st Harmonic Hz	1st Harmonic in/sec	2nd Harmonic Hz	2nd Harmonic in/sec	3rd Harmonic Hz	3rd Harmonic in/sec	4th Harmonic Hz	4th Harmonic in/sec
GMF	78.79	.015	157.58	.009	236.37	.016	315.16	.023	393.95	.034
BPFI	85.37	.015	170.74	.009	256.11	.016	341.48	.023	426.85	.034
BPFO	85.37	.015	170.74	.009	256.11	.016	341.48	.023	426.85	.034
BSF	37.25	.015	74.50	.009	111.75	.016	149.00	.023	186.25	.034
FTF	1.62	.015	3.24	.009	4.86	.016	6.48	.023	8.10	.034

This table is an example of the proposed filter values for a given specific VRT, one axis ONLY. Each A/D (axis) would have similar structure in terms of filter values. The key to the above would be the post processing of the speed information so that the actual fundamental and harmonic values would be as accurate as possible even though the magnitude (in/sec) values would be preset. The magnitudes are also based on a integration from the acceleration data gathered. It may be possible to derive the magnitude values on acceleration and eliminate the integral math required if processing capabilities are questionable.

[0100] Additional alarm band filter methods that may increase the overall effectiveness. The goal with this mode is to electronically filter machine responses and alert when preset conditions deteriorate. This alert would then prompt an analyst to conduct further "manual" evaluation of the specific A/D location.

[0101] Manual Mode—The basic function of this mode would be to allow for manual analysis of data similar to traditional processes and equipment. The strategy would be to incorporate this mode in cases where the alarm band mode alerted the user or analyst that a negative trend was evident. The data acquisition of this mode will be similar to the alarm band mode except that the data will not be filtered and instead will be made available for post processing by a "software" module dedicated for analysis purposes. The details of this module are to be determined but the goal would be for the data to be stored in a suitable format to facilitate post processing. The sensor configuration and fundamentals for this mode will be similar to the alarm band mode. Data may be acquired utilizing triggers or schedules already in place.

[0102] A number of detailed embodiments have been described. Nevertheless, it will be understood that various modifications may be made. Accordingly, other embodiments are within the scope of the following claims.

What is claimed is:

1. A method of tracking operational parameters of a drive system including at least one drive component, the method comprising:

associating a sensor unit with the drive component, the sensor unit including an integrated local processor and a vibration sensor,

the sensor unit converting analog vibration signals from the vibration sensor into digital signal samples;

the integrated local processor performing an FFT operation on the digital signal samples to produce an FFT spectrum;

the integrated local processor generating an alarm based upon analysis of the FFT spectrum.

2. The method of claim **1** wherein the alarm is generated if the FFT spectrum exceeds one or more threshold values.

3. The method of claim **2** wherein the alarm is communicated to a downstream processing unit that is in communication with the integrated local processor of the sensor unit.

4. The method of claim **1** wherein a filter is established for analyzing the FFT spectrum.

5. The method of claim **4** wherein the filter includes a fundamental frequency of the drive component and multiple harmonics of the fundamental frequency.

6. The method of claim **1** wherein the integrated local processor evaluates a speed of the drive component during the operation that produced the alarm and disregards the alarm if the speed is not within a predefined speed range.

7. The method of claim **1** wherein the FFT spectrum is sent to a downstream processing unit that is in communication with the integrated local processor and the downstream processing unit stores the FFT spectrum for at least a certain time period.

8. The method of claim **7** wherein the FFT spectrum is deleted after the certain time period.

9. A method of tracking operational parameters of a drive system including at least one drive component, the method comprising:

associating a sensor unit with the drive component, the sensor unit including an integrated local processor and a vibration sensor,

the sensor unit converting analog vibration signals from the vibration sensor into digital signal samples;

the integrated local processor:

identifying a drive system speed condition;

performing an FFT operation on digital signal samples produced during the drive system speed condition to produce an FFT spectrum;

analyzing the FFT spectrum using an alarm band filter associated with the drive system speed condition; and

generating an alarm if the analysis indicates the FFT spectrum is outside bounds defined by the alarm band filter.

10. The method of claim **9** wherein the alarm band filter is stored in on-board memory of the sensor unit.

11. The method of claim **10** where the alarm band filter is one of multiple alarm band filters stored in on-board memory of the sensor unit for evaluating multiple drive system speed conditions.

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