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

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

(43) **International Publication Date**
02 April 2020 (02.04.2020)

WIPO | PCT

(10) **International Publication Number**
WO 2020/061634 A1

(51) **International Patent Classification:**
F16D 66/02 (2006.01) ***G01N 27/04*** (2006.01) ***G01B 7/16*** (2006.01) ***G01N 3/56*** (2006.01) ***G01B 21/32*** (2006.01)

(21) **International Application Number:**
PCT/AU2019/051037

(22) **International Filing Date:**
26 September 2019 (26.09.2019)

(25) **Filing Language:** English

(26) **Publication Language:** English

(30) **Priority Data:**
2018903627 26 September 2018 (26.09.2018) AU

(71) **Applicant: BRIAN INVESTMENTS PTY LTD** [AU/AU]; 72 Boulder Road, Malaga, Western Australia 6090 (AU).

(72) **Inventors: CALLAGHAN, Mark**; 21 River Road, Bayswater, Western Australia 6053 (AU). **HOUSTON, Rodney**; 72 Boulder Road, Malaga, Western Australia 6090 (AU).

(74) **Agent: WRAYS PTY LTD**; Level 7, 863 Hay Street, Perth, Western Australia 6000 (AU).

(81) **Designated States** *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) **Designated States** *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM,

(54) **Title:** SYSTEM FOR FORECASTING WEAR AND A WEAR SENSOR

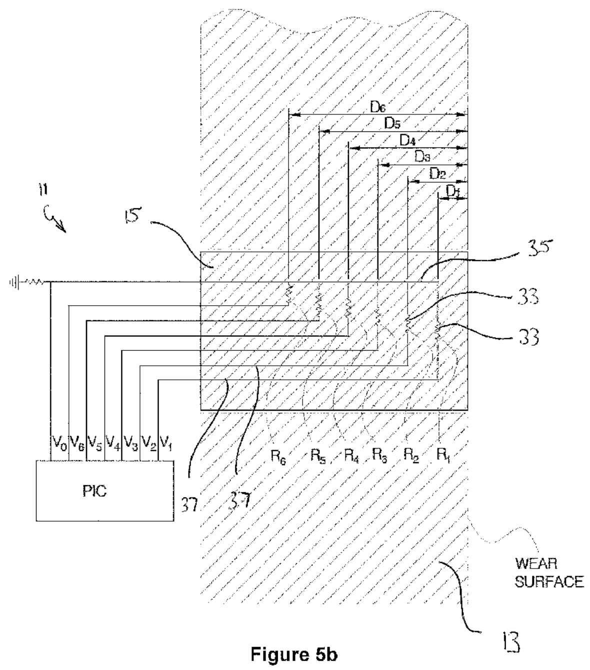

Figure 5b

(57) **Abstract:** A wear sensor for use in a wear sensing fastener, the wear sensor fastener comprising a head which in use is exposed to wear, the head has a shank extending therefrom, a sensor portion having a probe received within the shank such that an end of the probe terminates at or adjacent an exposed surface of the head, the probe comprising a plurality of resistive elements positioned along the probe, wherein each resistive element is individually measurable, whereby in use those resistive elements which do not return a result provide an indication of wear experienced by the probe.

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[Continued on next page]

TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:

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

System for Forecasting Wear and a Wear Sensor

TECHNICAL FIELD

[0001] The present invention generally relates to a system for forecasting wear of a wear plate and a wear sensor particularly suited for use in that system.

BACKGROUND ART

[0002] In many material handling applications, a wear liner is employed as a cost effective means of protecting equipment from wear or damage caused by the material being transported. Consequently, the liner takes up wear in preference to the equipment, and is replaced from time to time rather than replacing or repairing the equipment. This is particularly the case with mining transfer systems and chutes which are used to transfer ore from one location to another.

[0003] Wear liners are used extensively throughout the mining industry to protect those parts of structures which are exposed to wear. Due to their very nature, the wear liners are sacrificial and require regular replacement as they wear to a level where they no longer serve their purpose.

[0004] In many applications, it is necessary to assess the wear experienced by the wear liner to determine whether and/or when a wear liner requires repair or maintenance as a result of wear. Assessing wear of a wear liner is difficult and/or time consuming in mining environments. Conventional measurement tools are often inadequate to perform the task, either with respect to the precision of measurement, safety of performing the task, or economic factors associated with downtime of the site to allow wear measurements to be taken.

[0005] It is important that liner wear is accurately determined to ensure the liner is replaced before it wears to a point where it no longer protects the underlying equipment, but not before the life of the wear liner has been maximised.

[0006] Wear liners can be made of steel, iron, rubber, ceramics or combinations of these. Replacing wear liners requires significant site downtime which is undesirable from an economic point of view. The downtime is attributable to the time taken to assess the thickness of the liner, and the considerable time needed to replace the wear liner. Therefore, accurately assessing the thickness of the wear liner is of critical importance.

[0007] Difficulties arise when monitoring and determining the extent of wear of the wear liners.

[0008] One method that has been used to determine wear liner thickness is visual inspection. The problem with this approach is the downtime of the site required for safe inspection, as well as the inaccuracy of relying on the human eye to determine the wear of the wear liner

[0009] Another method of determining wear liner thickness is via ultrasonic thickness gauging. The readings are obtained using a hand-held device which is operated manually. The operator takes the readings by placing the sensor at selected points on the wear liner. The operator notes the thickness reading and the location on a graphical representation. There are several problems with ultrasonic thickness gauging. Firstly, as mentioned previously, the site must be shutdown in order for the operator to take the measurement. Secondly, temperature alters the performance of the measurement equipment, and hence calibration is regularly required to ensure accurate readings. Thirdly, it is slow, as each point must be recorded manually. Fourthly, it is difficult to accurately assess liner wear due to the need to ensure that the sensor measurement tool is perpendicular to the wear liner and the practical difficulty in achieving this.

[0010] Another method is the use of sensors within the wear liner system, in particular the fasteners. One means of securing a wear liner in place is the use of fasteners. Each fastener typically has a head which is received in a recess of the wear plate, the head having a shank extend therefrom. The shank extends through the wear plate and the structure to which the wear liner is protecting. The fastener also has a nut such that upon rotation of the head, the fastener is caused to clamp the wear liner relative to the surface.

[0011] Attempts have been made to incorporate a sensor within the fastener. One such system is described in WO 2010/096873 to the present applicant. This system has a probe which extends along the shank and into the head. As the head and the wear liner are exposed to the same environment the head wears as the wear liner wears. As the head wears the probe wears as well to provide the sensor with a representation of the extent of wear experienced by the wear liner.

[0012] The probe comprises a printed circuit board which has a pair of common tracks/rails and a number of resistive elements extending therebetween, whereby the resistive elements are arranged in parallel. The resistive elements are arranged one after the other such that they extend along the length of the probe at predetermined distances from each other. As the head wears the probe also wears, resulting in successive resistive elements being removed as the probe wears. The change in resistance can then be measured using an ohmeter, or a voltage may be applied thereto and the change in voltage is measured.

[0013] It has been found that there are several inherent disadvantages with this system. In particular the probe is prone to being short circuited as it wears, causing false readings to be recorded. These short circuits are created typically across the two tracks/rails due to moisture in the ore, ore engaging with and/or becoming stuck to the probe, and/or the probe being bent. These false readings render the sensor unreliable. Another disadvantage is the spacing required between each resistive element. As the resistive elements need to be spaced a distance from each other the sensor is unable to provide a high degree of resolution in terms of wear between those positions of the probe which correspond to a location of the resistive element. As a result the wear experienced by a wear liner can only be identified at specific intervals of wear.

[0014] Further, the comparative sparsity of measurement coverage of the liner is also a problem. Sensors provide an indication of wear of the wear liner in the area proximate to the sensor. However, the wear experienced by a wear liner system can vary significantly in the system. Depending upon the way the material engages the wear liner, adjacent wear liners can experience significantly different levels of wear. These different levels of wear may also be experienced at different regions of the same wear plate. Where this occurs it is difficult to predict when the wear liner needs to be replaced, particularly where no sensor is located in the region experiencing the highest wear.

[0015] The preceding discussion of the background art is intended to facilitate an understanding of the present invention only. The discussion is not an acknowledgement or admission that any of the material referred to is or was part of the common general knowledge as at the priority date of the application.

SUMMARY OF INVENTION

[0016] It is an object of this invention to provide a system for forecasting wear and a wear sensor particularly suited for use in that system, wherein the system and /or the wear sensor ameliorates, mitigates or overcomes, at least one disadvantage of the prior art, or which will at least provide the public with a practical choice.

[0017] Throughout the specification the term ‘wear plate’ is used to describe a plate, a liner or a part of a machine/equipment which is exposed to wear, and/or a plate, a liner or a part of a machine/equipment which is used to protect a surface from wear, and includes wear plates made from steel, iron, rubber, ceramics or combinations of these.

[0018] The present invention provides a wear sensor for use in a wear sensing fastener, the wear sensor fastener comprising a head which in use is exposed to wear, the head has a shank extending therefrom, a sensor portion having a probe received within the shank such that an end of the probe terminates at or adjacent an exposed surface of the head, the probe comprising a plurality of resistive elements positioned along the probe, wherein each resistive element is individually measurable, whereby in use those resistive elements which do not return a result provide an indication of wear experienced by the probe.

[0019] Each resistive element may be in the form of a resistor.

[0020] Each resistive element may be positioned such that removal of the resistive element from the wear sensor provides a measurement of wear.

[0021] Preferably each resistor is connected to a supply means through a common rail. The supply means may provide a voltage to each resistor. Each resistor may have an independent return rail connecting the end of the resistor to a detection means for detecting whether the resistor is present or not. With this arrangement each resistor is measured individually, typically sequentially, allowing the wear sensor to readily identify the number of resistors present. This then translates to the change in length of the probe which is representative of the change in thickness of the wear plate.

[0022] In an alternative arrangement each resistor has a dedicated rail connected to a supply means.

[0023] Each resistive element may be positioned such that its removal from the wear sensor provides a measurement of wear.

[0024] Each resistive element may be positioned between the common rail and its respective independent rail.

[0025] The resistors may be provided on a printed circuit board (PCB). The PCB may have a plurality of layers of resistors printed thereon. The number of layers may be selected to provide the desired wear resolution. For example the PCB may have eight layers of eight resistors placed on the PCB such that the resistors are offset from each other. With this arrangement the wear resolution on a 50mm wear plate provides detection of less than one millimetre of wear. In one arrangement the resistors may be evenly spaced from each other. In another embodiment the resistors may be more closely spaced at the end of the probe distal from the exposed surface of the head. This would allow finer measurements as the wear plate approaches the end of its service life.

[0026] In an alternative arrangement each resistor is connected to a supply means through a common first rail, and connected to a detection means through a common second rail wherein a zener-diode is positioned between adjacent resistors. Each zener-diode acts as a switch which may be selectively turned on/off to verify the presence of the resistor.

[0027] The sensor may comprise a housing adapted to be secured to the back of a wear surface. In an alternative arrangement the sensor may comprise a housing adapted to be secured to or integral with a nut which is threadingly received on the shank. The probe may extend from the housing and be embedded in the shank. The PCB may be housed in the housing whereby a portion of the PCB provides the probe.

[0028] The sensor may be adapted to detect one or more further characteristics experienced by the fastener. These characteristics may include one or more of the following: vibration, impact frequency, impact energy temperature, sensor temperature, sensor orientation, pressure, flex, ore hang up and moisture. The housing may incorporate one or more sensors devices to sense the further characteristics.

[0029] The housing may include a battery. The battery may be selectively activated at set intervals to collect data. The battery may be activated at set intervals to provide the required power to the sensor over the life of the wear plate. The battery may be exchanged, recharged or connected to an external battery pack.

[0030] The sensor may incorporate a communicating means to receive and send data. The communicating means may use wireless communications. The communicating means may incorporate an antenna. The antenna may be housed in the sensor housing at a position most distal from the probe. The housed portion of the PCB may be potted in the housing. When assembled, the probe may be potted in the shank.

[0031] The present invention further provides a wear sensor adapted to be fastened relative to a plate exposed to wear, the wear sensor comprises a housing and a probe extending therefrom, the probe is adapted to be positioned in a hole formed in the plate, the probe comprising a plurality of resistive elements positioned along the probe, wherein each resistive element is individually measurable, whereby in use those resistive elements which do not return a result provide an indication of wear experienced by the probe. Preferably the probe is tapered inwardly in a direction away from the sensor housing.

[0032] The probe may act as an alignment guide as it is guided through the hole to ensure the sensor is properly aligned. The probe may incorporate a probe housing which extends from the housing of the sensor to protect the probe.

[0033] The hole in which the probe is received is preferably as small as possible to minimise preferential wear associated with the hole. The hole may be 12mm in diameter.

[0034] The housing may be adapted to threadingly engage a complementary threaded portion on the plate. The threaded portion may be provided by a nut secured to a non-wear surface of the plate.

[0035] The housing may have a relatively low profile such that it may be mounted in applications where an over-extending projection is not desirable.

[0036] The sensor may incorporate one or more indicators, such as an LED. The one or more indicators can be programmed to visually provide a signal, the signal may represent a variety of statuses and/or functions. For instance the one or more indicators may visually display: the status of the battery; the status of the wear plate; whether the sensor is active and recording data.

[0037] The one or more indicators may illuminate, flash at certain rates, or change colour to visually provide the signal. The sensor may further comprise a controller which may be programmed to control the one or more indicators.

[0038] The probe may form part of the plate. The probe may be potted using a material having similar/equivalent wear characteristics as the wear plate.

[0001] The present invention further provides a system for forecasting the life of a wear plate, the system comprises:

at least one wear sensor as herein before described, the at least one wear sensor securing the wear plate in position, the at least one wear sensor collecting data representative of the thickness of the wear plate;

a gateway for receiving data from the at least one wear sensor;

a processing means for receiving and processing the data;

wherein the processing means provides a forecast of when the wear plate will reach the end of its service life.

[0002] The present invention further provides a system for forecasting the life of a wear plate, the system comprises:

a plurality of wear sensors as herein before described, the wear sensors being secured at various positions on the wear plate in spaced apart relation, each wear sensor collecting data representative of the thickness of the wear plate;

a gateway for receiving data from each wear sensor;

a processing means for receiving and processing the data;

wherein the processing means provides a forecast of when the wear plate will reach the end of its service life.

[0003] Preferably the system comprises an activation means for activating each wear sensors at predetermined times whereupon the data may be collected and logged. The activation means deactivates the wear sensor once the data has been logged and communicated to the gateway. In those embodiments where the data may not be communicated to the gateway, the sensor may still be deactivated but stores the data until the wear sensor is activated and can communicate with the gateway.

[0004] The activation means may be varied during the life of the wear sensor to accommodate changes associated with the wear plate. The activation means may be reprogrammed so that the predetermined times are varied. This may be required in order to preserve the battery life to ensure the battery is able to operate the wear sensor throughout the forecast life of the wear plate.

[0005] Preferably each sensor collects vibration data when activated. The vibration sensor may sense vibration in three axes. Once processed by the processing means the vibration data may indicate that the wear plate or fastener are not properly secure. The vibration data may also be used by the processing means to assess and accommodate periods when there is no flow of material across the wear plate and therefore identify periods of no wear.

[0006] The processed vibration data may also be used to identify unexpected changes in the flow of material across the wear plate which may affect the wear experienced by the wear plate, such as larger than expected impacts which may be caused by large pieces of material.

[0007] The vibration data may also be used to estimate the thickness of the plate based on the known natural frequencies of the wear plate at various thicknesses.

[0008] Preferably each sensor collects temperature data when activated. The temperature data may include the temperature of the sensor housing. This data can then be used to evaluate the effect the temperature has on the life of the battery.

[0009] The temperature data may include the temperature at the end of the probe. This data is indicative of the temperature of the wear plate and may be used by the processing means when forecasting the life of the wear plate.

[0010] The system may comprise a display means for visually displaying when one or more wear plates associated with the equipment require repair/replacement.

[0011] The system may comprise a historical data bank relevant to the wear plate being measured. The processing means may compare collected data against the historical data bank to verify its forecast.

[0012] The system may incorporate a scheduling means for scheduling the repair/replacement of wear plates forecast to require repair/replacement. The scheduling means may schedule repair/replacement to coincide with a shutdown, as may be the case with mining equipment.

[0013] The scheduling means may order the required materials for the repair/replacement.

[0014] The data may be transmitted by the gateway to a server/cloud from which the processing means can collect the data.

[0015] The processing means may receive input data relevant to changes associated with the wear plate. The input data may include periods of plant shutdown, changes in tonnages.

[0016] The present invention further provides a method of measuring wear plate thickness using an ultrasonic gauge placed on the end of the fastener distal from the wear face.

[0017] Another technique may be to incorporate the use of an ultrasonic thickness gauge which could be mounted onto the back of the bolt either as alternative to the aforementioned resistor method which sends the data out, or utilise a hand held ultrasonic thickness measurement device onto the back of the fastener which secures the wear plate in position to measure the length of the fastener to determine the thickness of the wear liner. The end of the fastener may be modified to allow the UT probe to go directly onto the threaded centre of a shank of the fastener giving a direct measurement of the length of the bolt. This is advantageous over using the UT sensor on the back wall of the chute as the air gap between the wall and the plate distorts the measurement. In the case of a stud welded onto the back of the liner this would also have problems with an accurate measurement of thickness given the air gap behind the stud.

BRIEF DESCRIPTION OF THE DRAWINGS

[0018] Further features of the present invention are more fully described in the following description of several non-limiting embodiments thereof. This description is included solely for the purposes of exemplifying the present invention. It should not be understood as a restriction on the broad summary, disclosure or description of the invention as set out above. The description will be made with reference to the accompanying drawings in which:

Figure 1 is a perspective view of a wear sensor in the form of a wear sensor fastener according to a first embodiment of the invention;

Figure 2 is a cross section side view of figure 1;

Figure 3 is an exploded view of figure 1;

Figure 4 is a rear perspective view of the wear sensor in figure 1 secured to a wear plate;

Figure 5a is a schematic of an array of resistors incorporated in the wear sensor in figure 1;

Figure 5b is a further schematic of an alternative array of resistors incorporated in the wear sensor in figure 1 and positioned in the wear plate;

Figure 6 is an alternative schematic of an array of resistors which may be incorporated in the wear sensor in figure 1;

Figure 7 is a bottom perspective view of a wear sensor according to a second embodiment of the invention;

Figure 8 is a cross section side view of figure 7;

Figure 9 is a rear perspective view of the wear sensor in figure 7 secured to a wear plate; and

Figure 10 is a schematic of a system for forecasting wear of a wear plate according to an embodiment of the invention.

[0019] In the drawings like structures are referred to by like numerals throughout the several views. The drawings shown are not necessarily to scale, with emphasis instead generally being placed upon illustrating the principles of the present invention.

DESCRIPTION OF EMBODIMENTS

[0020] The invention according to a first embodiment is in the form of a wear sensor 11 and a system incorporating such a wear sensor to forecast the life of a wear plate 13.

[0021] Referring to figures 1 to 5b, the wear sensor 11 is shown in combination with a fastener to provide a wear sensor fastener 15. The wear sensor fastener 15 comprises a head 17 and a hollow shank 19. In use the head 17 is received in the wear plate 13 such that it is exposed to the same wear as experienced by the wear plate 13. The fastener also comprises a nut 21 which co-operates with the head 17 to clamp the wear plate 13 to the structure 23.

[0022] The wear sensor 11 is adapted to be threadingly received in the nut 21 to secure the wear sensor 11 to the fastener 15.

[0023] The wear sensor 11 comprises a housing 25 which houses a printed circuit board (PCB) 27 and a battery 29. The PCB has a portion which projects out of the housing 25 to provide a probe 31. The probe 31 is adapted to be received in the hollow shank 19 such that it extends into the head 17, as best shown in figure 2.

[0024] Referring to figures 2 and 5, the probe 31 provides a plurality of resistive elements in the form of resistors 33. In this embodiment each resistor 33 has a common rail 35 connected to one end, and a dedicated independent rail 37 connected to the other end of each resistor 33. With this arrangement a signal, such as a voltage, passes along the common rail 35, through the resistor and returns to a detection means via each independent rail 37. On the basis of the returned signal, the detection means detects the number of resistors in the probe 31. The number of resistors is representative of the length of the probe 31 remaining, the thickness of the head 17 and therefore the thickness of the wear plate 13.

[0025] Prior art wear sensors are in the form of a simple resistor network, with resistors placed in a linear array on a printed circuit board. These are arranged so that the printed circuit board will be worn at the same time as the item for which wear measurement is required. Detection of wear is done by measuring the change of voltage or current through the network when a resistor is removed by the wearing process. However, with these prior art systems the wear condition may also cause a resistor short circuit, or result in a random resistor value in the presence of moisture and/or conductive materials. As a result some resistors can provide a false reading which is not representative of the wear.

[0026] The sensor of the present invention allows for these non-ideal conditions by performing a sequence of voltage/current measurements on a multi-terminal resistor network. The excitation and measurement of the network is designed to allow detection not only of missing resistors, but of shorted or changed value resistors.

[0027] Figure 5a provides an embodiment of the resistor network. Using a microcontroller (or other programmable system), a voltage "high" (e.g. 3.3V) or "low" (e.g. 0V) can be applied independently to any number of terminals of the resistor network. The resulting voltage at the undriven terminals can then be measured. Multiple measurements allow the independent measurement of all resistance values in the network.

[0028] Figure 5b is a schematic representation of the wear sensor 11 positioned within the wear plate 13, having six resistors 33 labelled R1 to R6. The resistors 33 are embedded in the probe 31 which is inserted into the wear plate 13 for detecting the wear of the wear plate 13.

[0029] Each resister 33 is at a known distance D1 to D6 from a wear surface 14. For the purpose of clarity only six resistors are noted in the present example. As would be readily understood by the person skilled in the art the present invention is not limited to having only six resistors, and could extend through to any number of resistors.

[0030] Each resistor is positioned between the common rail 35 and its respective independent rail 37. With this arrangement the resistor 33 will be removed from the wear sensor as the wear plate 13 wears to and past the position of the respective resistor 33. In this regard, for its respective circuit, the resistor is the closest component to the wear surface. This enables the wear sensor of the present invention to provide an accurate and defined wear measurement relative to the position of each resistor.

[0031] In operation a reference voltage Vr is applied to resistor R1, and the voltage across the remaining resistors, V2 through to V6, is measured, as well as the voltage, V0 of the common rail 35.

[0032] The reference voltage Vr is then applied to R2, and the voltage across the remaining resistors V1, V3 through V6 is measured as well as the voltage of the common line, V0

[0033] This process is then repeated for each resistor in turn, generating a 6x6 matrix of measurements (or NxN for N resistors). This provides an indication of which resistors are still present in the wear sensor, therefore providing a measurement of the wear experienced by the wear plate 13 in the vicinity of the wear sensor.

[0034] The application of the reference voltage Vr, and the measurement process is controlled via a Programmable Interface Controller PIC which contains a Digital-to-Analogue Converter for generating the reference voltage, Vr, an Analogue-to-Digital Converter for measuring the line voltages, and a means to control the application of the reference voltage, Vr, and the measurement of the voltage to each of the resistors 33.

[0035] The wear sensor 11 also enables the elimination of false readings as N measurements are taken for each resistor. This additional information is used to reduce the risk of erroneous conclusions being made as to the remaining number of resistors, and therefore the thickness of the wear material. These false readings could otherwise occur due to:

short circuiting across the open terminals as the sensor wears;

material/ore sitting across the open circuit and exhibiting a behaviour similar to that of a resistor; and/or

damage to the resistors or circuit below the wear surface caused by the impact of material/ore on the sensor .

[0036] Due to the position of the resistors 33 between the rails 35, 37, for a short circuit to provide a ‘believable’ reading, the material/ore would need to exhibit a resistance value that is very similar to that of the resistor that has been removed in order for a false measurement to be made.

[0037] The measurement algorithm takes into account the sequential removal of the resistors as the wear plate 13 wears. In fig 5b, removal being from R1 through to R6. This further reduces the risk of erroneous measurements even in the situation where the material across the open circuit exhibits a resistance value similar to the resistor that has been removed. For example, in the situation where the surface has progressively worn to a point where only resistors R5 and R6 remain, if a short then occurs across any of the resistors that have already been removed (R1 through R4), even if the resistance of the short matches that of the removed resistor, the algorithm would reject this value as it knows that these resistors have been removed.

[0038] Figure 6 shows an alternative configuration of resistors 33. In this configuration the resistors are connected by a first common rail 135 at one end of the resistors and a second common rail 136 at the other end of the resistors. The configuration incorporates zener diodes 138 between each resistor 33 which act as a switch to allow for verification of the presence of the resistor 33.

[0039] The configuration of this embodiment uses a combination of resistors 33 and non-linear elements being zener diodes 138. In this approach, only two common rails 135, 136 are required to connect to the network. To measure wear, a voltage ramp is applied to the network, while measuring current. While the voltage is lower than the sum of multiple zener breakdown voltages, the current remains unaffected by any resistance changes deep in the network. As the voltage increases, further stages are turned on, and the current becomes sensitive to any resistance changes deeper in the network.

[0040] The wear sensor 11 also comprises a vibration sensor 39 and a temperature sensor 41.

[0041] The wear sensor 11 further comprises an antenna 43 for wireless communication with a gateway, as will be described below.

[0042] A wear sensor 211 according to a second embodiment of the invention is illustrated in figures 7 to 9. For convenience features of the wear sensor 211 that are similar or correspond to features of the wear sensor 11 of the first embodiment have been referenced with the same reference numerals.

[0043] The wear sensor 211 is particularly suited to be fitted to a wear plate 213 wherein the wear plate 213 is part of the equipment, such as for example a tray of a truck. In this regard the wear sensor 211 has a low profile in order to provide a degree of robustness over the wear sensor 11 of the first embodiment

[0044] The wear sensor 211 has been designed for quick installation. The wear sensor 211 comprises a housing 225 which is adapted to threadingly engage a nut 221 (or similar threaded component) which is secured to a non-wear surface of the wear plate 213. The housing 225 has a hollow portion 251 extending from a bottom of the housing 225. The hollow portion 251 is adapted to be received in a hole 253 in the wear plate 213 during installation of the wear sensor, as best shown in figure 8. The hollow portion 251 and hole 253 act to guide and align the wear sensor 211 to ensure the wear sensor 211 is properly aligned.

[0045] The wear sensor 211 comprises a PCB 227 which is largely housed in the housing 225. The PCB has a portion which extends into the hollow portion 251 to provide a probe 231. The probe 231 provides a plurality of resistors 33, in the same manner as that of the first embodiment.

[0046] The wear sensor 211 also comprises a battery 229, a vibration sensor 39 and a temperature sensor 41.

[0047] The wear sensor 211 further comprises a visual indicator in the form of a light 255.

[0048] A plurality of wear sensors 11, 211 of either embodiment may be incorporated in a system 361 for forecasting the life of the wear plate 13, 213. Figure 10 provides a schematic representation of the system 361. In addition to a plurality of wear sensors 11, 211, the system comprises a gateway 363 which wirelessly receives data collected by the wear sensors before transmitting the data to a processing means 365 for processing.

[0049] The processing means 365 retrieves historical data from a historical database 367 relevant to the replaced wear plates, sensor data from the wear sensors as well as input data which may be input from an operator. The input data may relate to information associated with the nature and flow rate of material passing over the wear plate.

[0050] The sensor data which the processing means 365 may consider includes:

wear rate data (direct measurement using number of resistors);

impact energy based on the vibration sensor data;

temperature data;

bolt/wear plate tightness (based on interpreting vibration sensor data with baseline established on initial install);

position of wear sensor.

[0051] The input data which the processing means 365 may consider includes:

unscheduled changes in past flow rates of material across the wear plate;

expected changes in planned flow rates of material across the wear plate;

timing of next shutdown to allow the processing means to determine what wear plates require replacement based on forecast wear;

properties/configuration of wear plate;

tonnes since wear plate changed out;

[0052] The processing means 361 processes the data and determines a WearSense Indication Number (WIN) between, for example, 1-10 to indicate when the wear plate will need to be changed/repaired or checked (if wear plate is loose).

[0053] The system also comprises a display means 363 upon which the processing means 361 is designed to provide a simple visual display of the current status of each of the wear sensor's wear data along with the previous measurements to show a time-history of the wear of each chosen sensor since installation. This wear information can be provided in a number of different ways which can be chosen by the end user. For example this may include a colour display of each wear plate/sensor using a specified colour system to indicate how much of the wear liner life has been used. The operator can also show the same wear data on a chart showing historical wear data from sensor installation up to the current wear measurement figure.

[0054] The operator is therefore provided with a live update of the current wear status based on the individual wear sensor data.

[0055] The processing means provides a forecast for each wear plate to indicate when the wear plate will need to be changed (i.e. when the wear measurement reaches a pre-determined thickness of plate as specified by the operator when the new sensors are installed). This forecast process is a key parameter for the operator to understand when they should be planning for a shut down to replace the wear plates. If the operator waits too long then there is a likelihood of failure of the equipment and loss of ore which can be catastrophic to the overall supply chain. It is therefore important to ensure that the forecast process is as accurate as possible.

[0056] The improved forecast of wear plate life when incorporating vibration data provides a major benefit to the operator.

[0057] Modifications and variations such as would be apparent to the skilled addressee are considered to fall within the scope of the present invention. The present invention is not to be limited in scope by any of the specific embodiments described herein. These embodiments are intended for the purpose of exemplification only. Functionally equivalent products, formulations and methods are clearly within the scope of the invention as described herein.

[0058] Throughout this specification, unless the context requires otherwise, the word "comprise" or variations such as "comprises" or "comprising", will be understood to imply the inclusion of a stated integer or group of integers but not the exclusion of any other integer or group of integers.

[0059] While the invention has been shown and described with reference to certain exemplary embodiments thereof, it will be understood by those skilled in the art that various changes in form and details may be made therein without departing from the spirit and scope of the invention as defined by the appended claims.

[0060] Example embodiments are provided so that this disclosure will be thorough, and will fully convey the scope to those who are skilled in the art. Numerous specific details are set forth such as examples of specific components, devices, and methods, to provide a thorough understanding of embodiments of the present disclosure. It will be apparent to those skilled in the art that specific details need not be employed, that example embodiments may be embodied in many different forms and that neither should be construed to limit the scope of the disclosure. In some example embodiments, well-known processes, well-known device structures, and well-known technologies are not described in detail.

[0061] The method steps, processes, and operations described herein are not to be construed as necessarily requiring their performance in the particular order discussed or illustrated, unless specifically identified as an order of performance. It is also to be understood that additional or alternative steps may be employed.

[0062] When an element or layer is referred to as being “on”, “engaged to”, “connected to” or “coupled to” another element or layer, it may be directly on, engaged, connected or coupled to the other element or layer, or intervening elements or layers may be present. In contrast, when an element is referred to as being “directly on,” “directly engaged to”, “directly connected to” or “directly coupled to” another element or layer, there may be no intervening elements or layers present. Other words used to describe the relationship between elements should be interpreted in a like fashion (e.g., “between” versus “directly between,” “adjacent” versus “directly adjacent,” etc.). As used herein, the term “and/or” includes any and all combinations of one or more of the associated listed items.

[0063] Although the terms first, second, third, etc. may be used herein to describe various elements, components, regions, layers and/or sections, these elements, components, regions, layers and/or sections should not be limited by these terms. These terms may be only used to distinguish one element, component, region, layer or section from another region, layer or section. Terms such as “first,” “second,” and other numerical terms when used herein do not imply a sequence or order unless clearly indicated by the context. Thus, a first element, component, region, layer or section discussed below could be termed a second element, component, region, layer or section without departing from the teachings of the example embodiments.

Spatially relative terms, such as “inner,” “outer,” “beneath”, “below”, “lower”, “above”, “upper” and the like, may be used herein for ease of description to describe one element or feature’s relationship to another element(s) or feature(s) as illustrated in the figures. Spatially relative terms may be intended to encompass different orientations of the device in use or operation in addition to the orientation depicted in the figures. For example, if the device in the figures is turned over, elements described as “below” or “beneath” other elements or features would then be oriented “above” the other elements or features. Thus, the example term “below” can encompass both an orientation of above and below. The device may be otherwise oriented (rotated 90 degrees or at other orientations) and the spatially relative descriptors used herein interpreted accordingly.

[0064] Such variations are not to be regarded as a departure from the disclosure, and all such modifications are intended to be included within the scope of the disclosure.

Claims

1. A wear sensor for use in a wear sensing fastener, the wear sensor fastener comprising a head which in use is exposed to wear, the head has a shank extending therefrom, a sensor portion having a probe received within the shank such that an end of the probe terminates at or adjacent an exposed surface of the head, the probe comprising a plurality of resistive elements positioned along the probe, wherein each resistive element is individually measurable, whereby in use those resistive elements which do not return a result provide an indication of wear experienced by the probe.

2. The wear sensor according to claim 1 wherein each resistive element is in the form of a resistor.

3. The wear sensor according to claim 2 wherein each resistor is connected to a supply means through a common rail.

4. The wear sensor according to claim 2 or 3 wherein the supply means provides a voltage to each resistor.

5. The wear sensor according to claim 2, 3 or 4 wherein each resistor has an independent return rail connecting the end of the resistor to a detection means for detecting the presence of the resistor.

6. The wear sensor according to claim 2, 3 or 4 wherein each resistor has a dedicated rail connected to a supply means.

7. The wear sensor according to any one of claims 1 to 6 wherein each resistive element is positioned such that its removal from the wear sensor provides a measurement of wear.

8. The wear sensor according to claim 5 wherein each resistive element is positioned between the common rail and its respective independent rail such that its removal from the wear sensor provides a measurement of wear.

9. The wear sensor according to any one of claims 2 to 8 wherein the resistors are provided on a printed circuit board (PCB).

10. The wear sensor according to claim 9 wherein the PCB has a plurality of layers of resistors printed thereon, the number of layers being selected to provide the desired wear resolution.

11. The wear sensor according to any one of claims 2 to 10 wherein the resistors are more closely spaced at the end of the probe distal from the exposed surface of the head.

12. The wear sensor according to claim 2 wherein each resistor is connected to a supply means through a common first rail, and connected to a detection means through a common second rail wherein a zener-diode is positioned between adjacent resistors.

13. The wear sensor according to claim 12 wherein each zener-diode acts as a switch which can be selectively turned on/off to verify the presence of the resistor.

14. The wear sensor according to any one of claims 1 to 13 further comprising a housing adapted to be secured to the back of a wear surface.

15. The wear sensor according to any one of claims 1 to 13 further comprising a housing adapted to be secured to or integral with a nut which is threadingly received on the shank.

16. The wear sensor according to claim 14 or 15 wherein the probe extends from the housing and is embedded in the shank.

17. The wear sensor according to claim 15 or 16 when dependent on claim 9 wherein the PCB is housed in the housing whereby a portion of the PCB provides the probe.

18. The wear sensor according to any one of claims 1 to 17 further adapted to detect one or more further characteristics experienced by the fastener including one or more of the following characteristics: vibration, impact frequency, impact energy temperature, sensor temperature, sensor orientation, pressure, flex, ore hang up and moisture.

19. The wear sensor according to claim 18 wherein the housing incorporates one or more sensors devices to sense the further characteristics.

20. The wear sensor according to any one of claims 15 to 19 wherein the housing includes a battery, the battery is selectively activated at set intervals to collect data.

21. The wear sensor according to any one of claims 1 to 20 further comprising a communicating means to receive and send data.

22. The wear sensor according to claim 21 wherein the communicating means incorporates an antenna which is housed in the housing at a position most distal from the probe.

23. A wear sensor adapted to be fastened relative to a plate exposed to wear, the wear sensor comprises a housing and a probe extending therefrom, the probe is adapted to be positioned in a hole formed in the plate, the probe comprising a plurality of resistive elements positioned along the probe, wherein each resistive element is individually measurable, whereby in use those resistive elements which do not return a result provide an indication of wear experienced by the probe.

24. The wear sensor according to claim 23 wherein the probe is tapered inwardly in a direction away from the housing.

25. The wear sensor according to claim 23 or 24 wherein the probe provides an alignment guide as it is guided through the hole to ensure the sensor is properly aligned.

26. The wear sensor according to claim 23, 24 or 25 wherein the probe incorporates a probe housing which extends from the housing of the sensor to protect the probe.

27. The wear sensor according to claim 26 wherein the housing is adapted to threadingly engage a complementary threaded portion on the plate.

28. The wear sensor according to any one of claims 1 to 27 comprising one or more indicators, to provide a signal, the signal represents a variety of

statuses and/or functions including one or more of the following: the status of the battery; the status of the wear plate; whether the sensor is active and recording data.

29. The wear sensor according to any one of claims 1 to 28 wherein the probe forms part of the plate.

30. A system for forecasting the life of a wear plate, the system comprises:

at least one wear sensor according to any one of claims 1 to 29, the at least one wear sensor securing the wear plate in position, the at least one wear sensor collecting data representative of the thickness of the wear plate;

a gateway for receiving data from the at least one wear sensor;

a processing means for receiving and processing the data;

wherein the processing means provides a forecast of when the wear plate will reach the end of its service life.

31. A system for forecasting the life of a wear plate, the system comprises:

a plurality of wear sensors each according to any one of claims 1 to 29, the wear sensors being secured at various positions on the wear plate in spaced apart relation, each wear sensor collecting data representative of the thickness of the wear plate;

a gateway for receiving data from each wear sensor;

a processing means for receiving and processing the data;

wherein the processing means provides a forecast of when the wear plate will reach the end of its service life.

32. The system according to claim 30 or 31 further comprising an activation means for activating each wear sensor at predetermined times whereupon the data is collected and logged, the activation means deactivating the wear sensor once the data has been logged and communicated to the gateway.

33. The system according to claim 32 wherein the operation of the activation means is varied during the life of the wear sensor to accommodate changes associated with the wear plate.

34. The system according to any one of claims 30 to 33 wherein each sensor collects vibration data when activated, the vibration data being used to determine: whether the wear plate is properly secure; periods when there is no flow of material across the wear plate; unexpected changes in the volume of material across the wear plate; and/or the thickness of the plate based on the known natural frequencies of the wear plate.

35. The system according to any one of claims 30 to 34 wherein each sensor collects temperature data when activated, the temperature data being used to predict the life of the battery.

36. The system according to any one of claims 30 to 35 further comprising a display means for visually displaying when one or more wear plates associated with the equipment require repair/replacement.

37. The system according to any one of claims 30 to 36 further comprising a historical data bank relevant to the wear plate being measured, allowing for the collected data to be compared to the historical data bank to verify its forecast.

38. The system according to any one of claims 30 to 37 further comprising a scheduling means for scheduling the repair/replacement of wear plates forecast to require repair/replacement.

39. A method of measuring wear plate thickness using an ultrasonic gauge placed on the end of the wear sensing fastener distal from the wear face, the wear sensing fastener incorporating a wear sensor according to any one of claims 1 to 29.

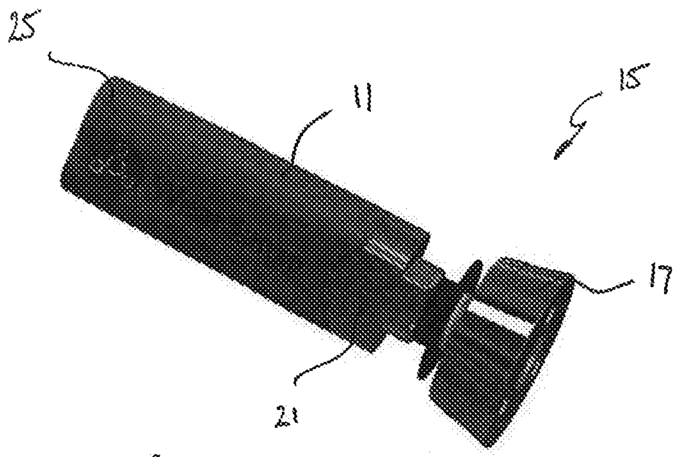


Figure 1

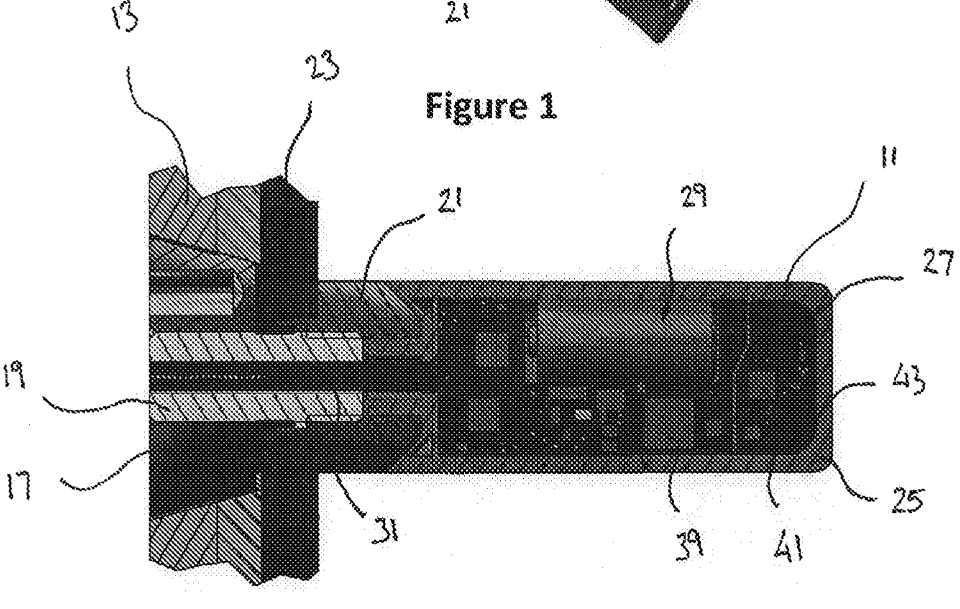
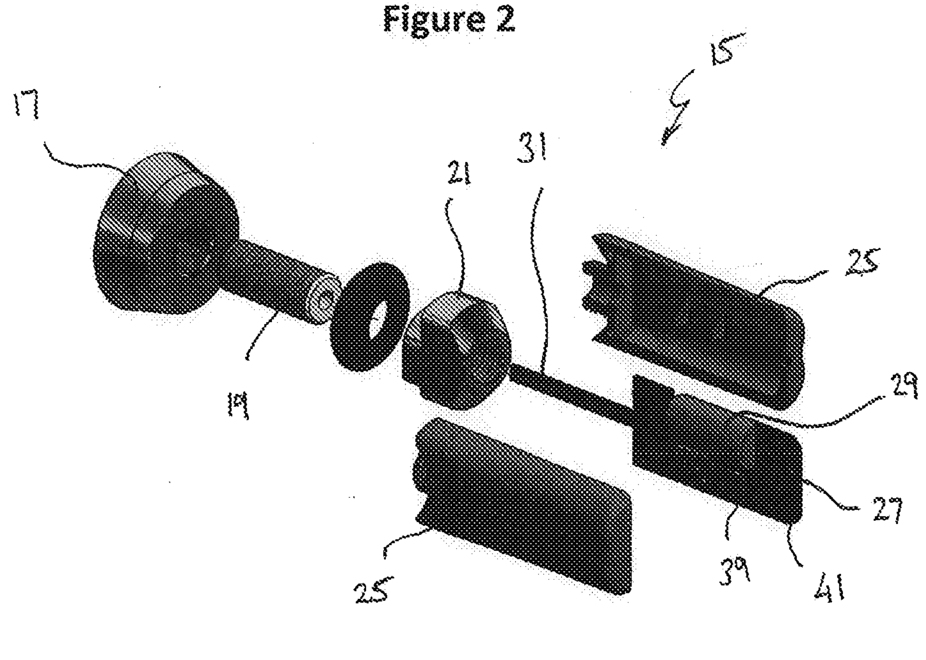


Figure 2



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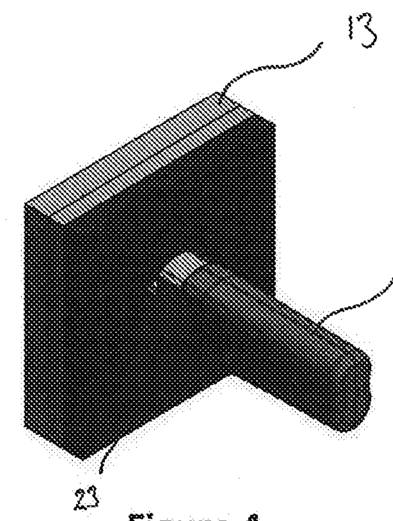

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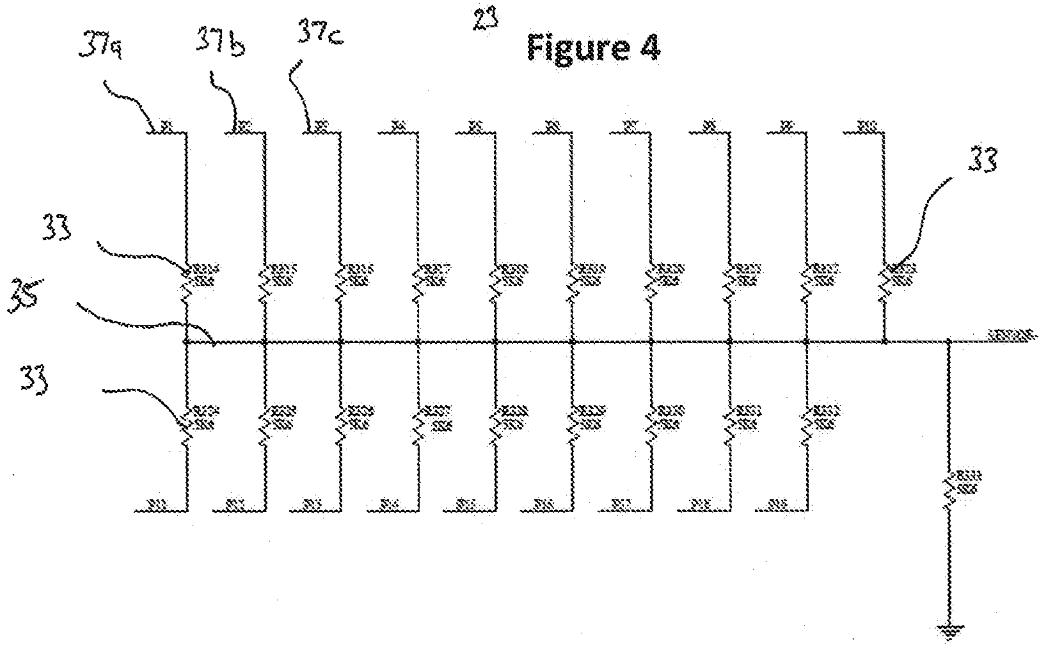


Figure 5a

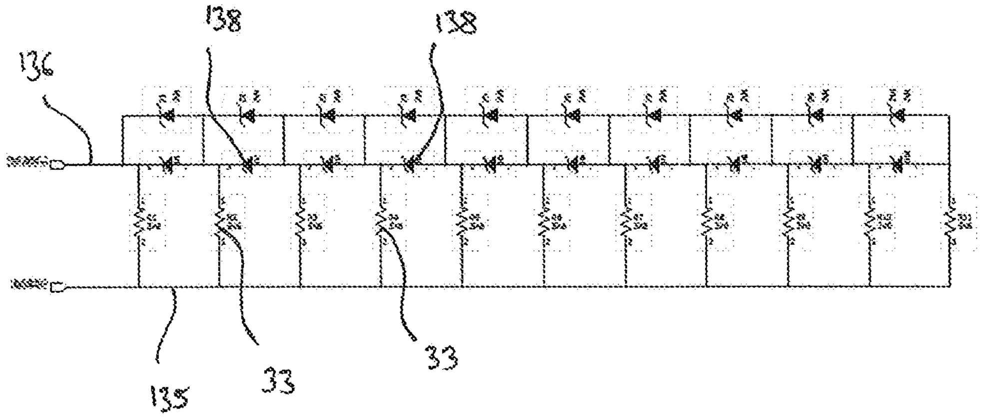


Figure 6

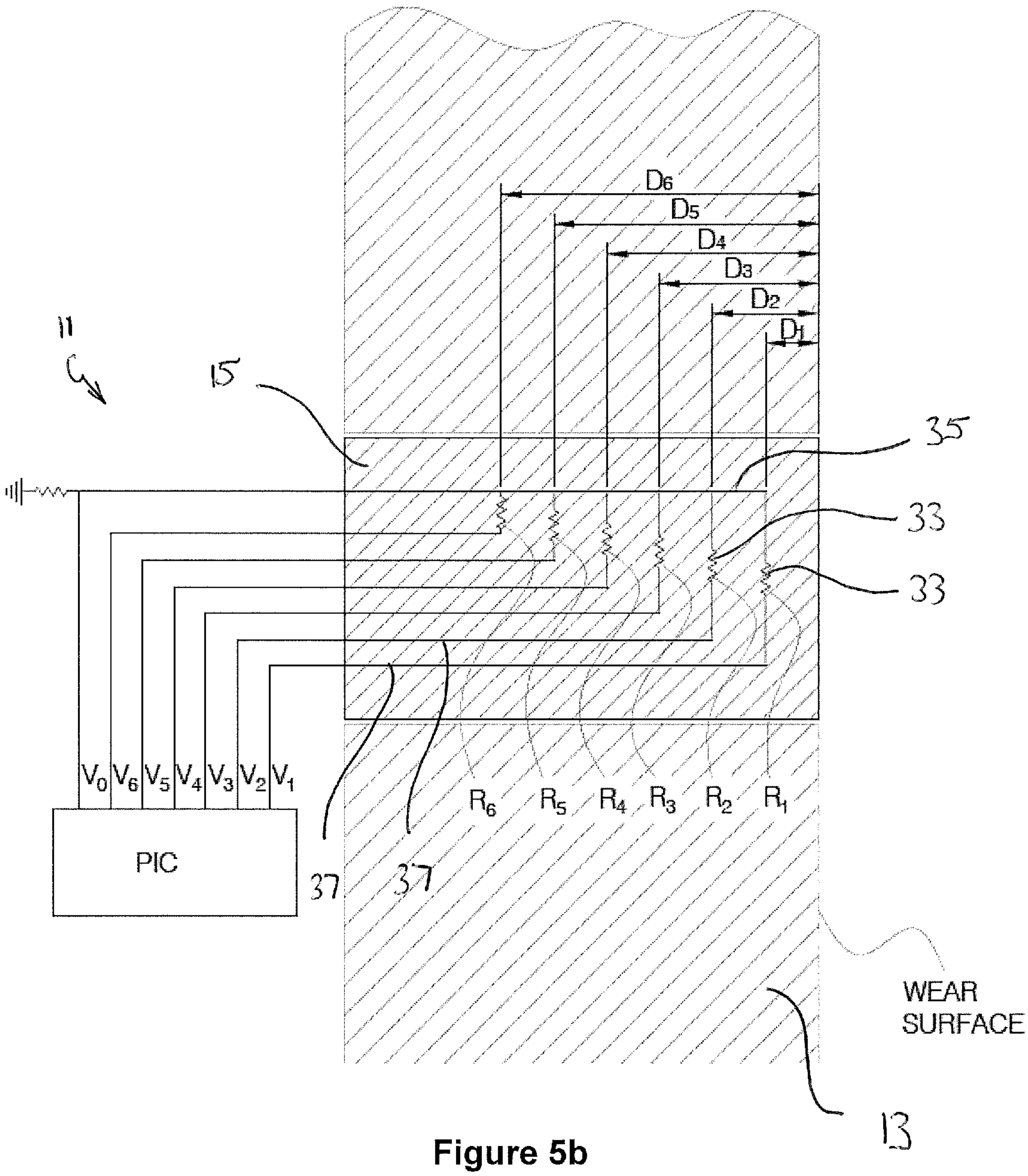

D6
D5
D4
D3
D2
D1
11
15
35
33
33
V0 V6 V5 V4 V3 V2 V1
PIC
R6 R5 R4 R3 R2 R1
37
37
WEAR SURFACE
13

Figure 5b

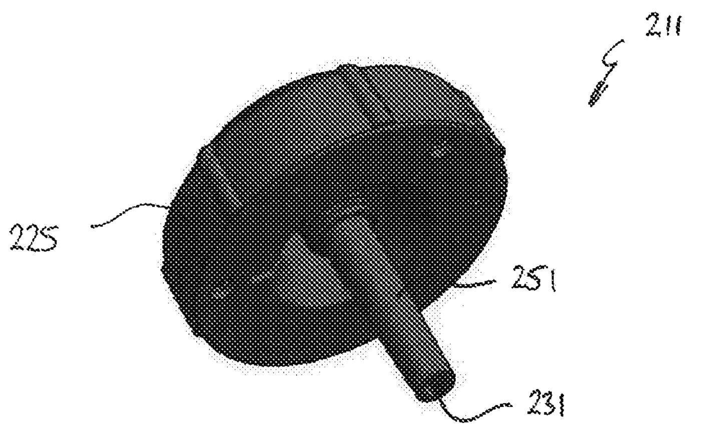


Figure 7

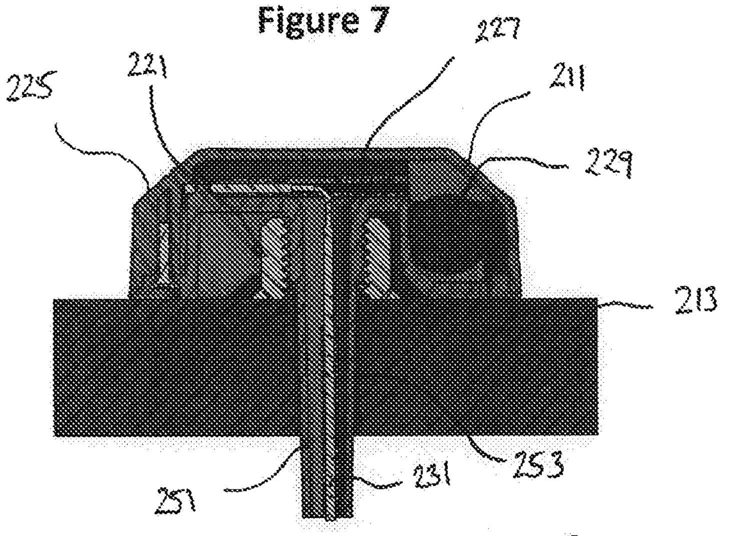


Figure 8

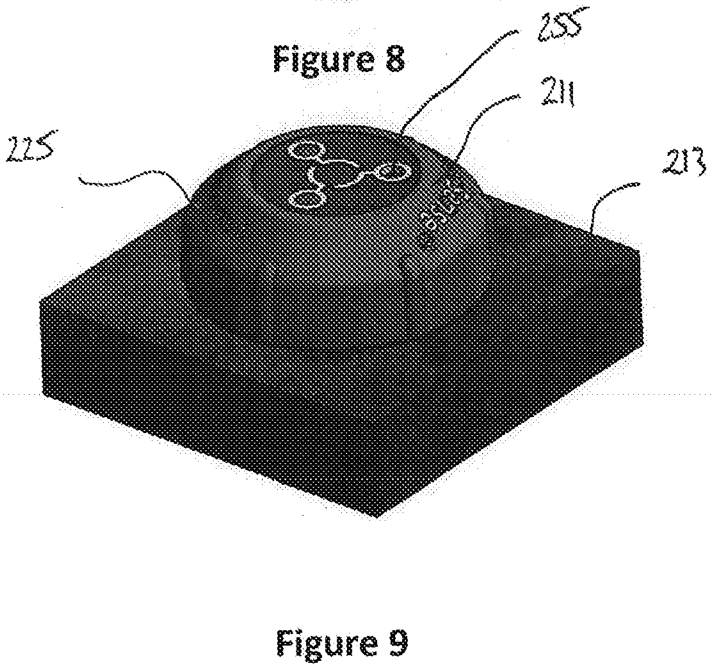
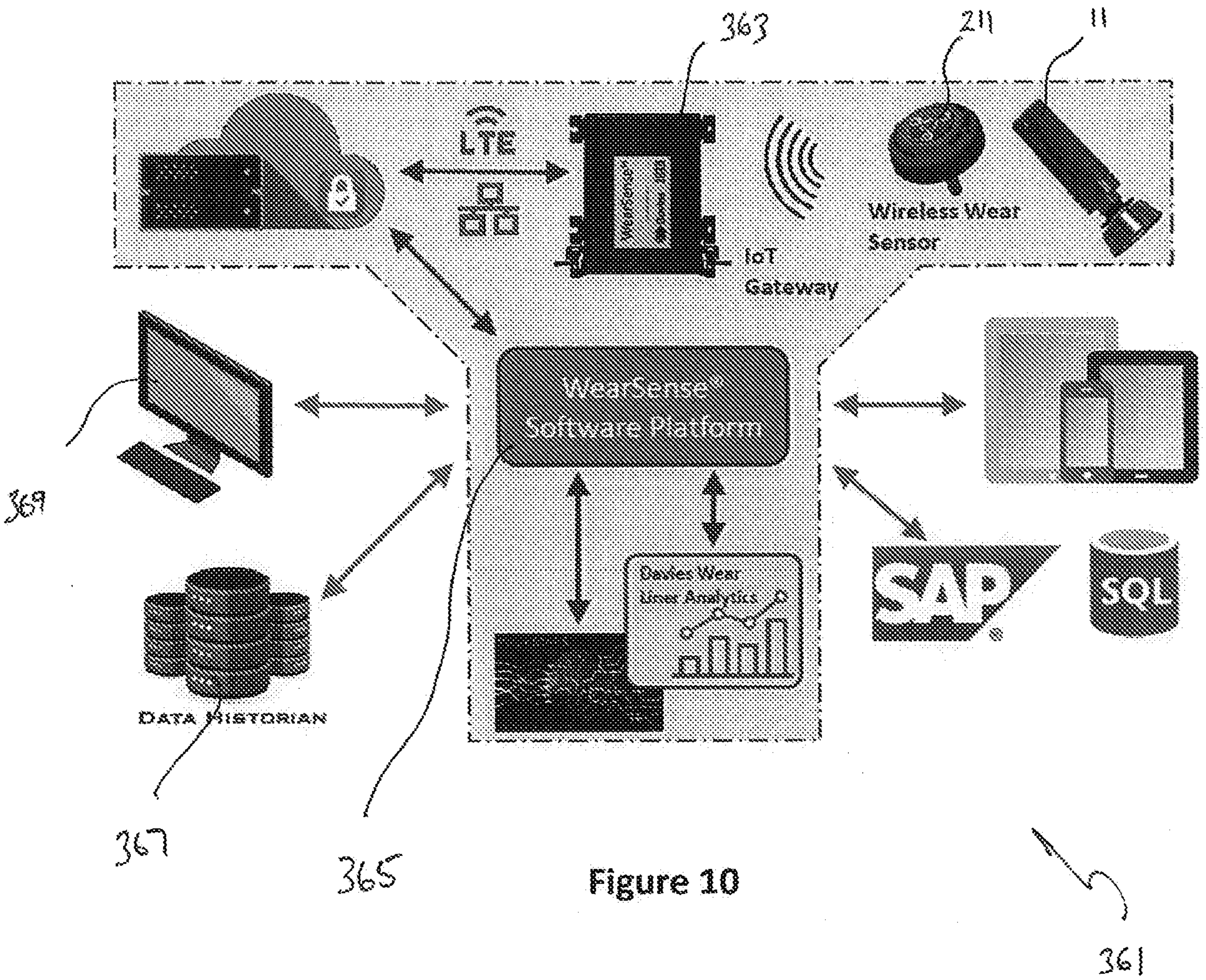


Figure 9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211
11
LTE
Wireless Wear
Sensor
IoT
Gateway
WearSense
Software Platform
Davies Wear
Liner Analytics
SAP
SQL
DATA HISTORIAN
369
367
365
361

Figure 10

INTERNATIONAL SEARCH REPORT

International application No.
PCT/AU2019/051037

A. CLASSIFICATION OF SUBJECT MATTER

F16D 66/02 (2006.01) G01B 7/16 (2006.01) G01B 21/32 (2006.01) G01N 27/04 (2006.01) G01N 3/56 (2006.01)

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

Databases: PATENW in Logical databases (WPIAP, EPODOC, Full text), IPC/CPC marks:G01B21/32, G01N3/56, F16D66/00, G01B7/00, B02C2210/01 and keywords: sensor, detector, resistance, resistive, resistor, multiple, plural, separate, individual, independent, rail, space, parallel, series, several, arrangement, sequence, measure, monitor, identify, wear, remove, decouple, change, and similar keywords.
Applicant(s)/Inventor(s) name searched in internal databases provided by IP Australia., Applicant(s)/Inventor(s) name search in Espacenet, AusPat and Google Patents/Google scholar/Google: Applicant name: Brian Investments Pty Ltd; Inventors name: Callaghan, Mark; Houston, Rodney; and keywords: resistance, individual measurement, wear, sensing, detecting and similar terms.

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
	Documents are listed in the continuation of Box C	

[X] Further documents are listed in the continuation of Box C [X] See patent family annex

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"D" document cited by the applicant in the international application
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
12 November 2019	12 November 2019
Name and mailing address of the ISA/AU	**Authorised officer**
AUSTRALIAN PATENT OFFICE PO BOX 200, WODEN ACT 2606, AUSTRALIA Email address: pct@ipaustralia.gov.au	Jayati Ray AUSTRALIAN PATENT OFFICE (ISO 9001 Quality Certified Service) Telephone No. +61262223654

INTERNATIONAL SEARCH REPORT

International application No. **PCT/AU2019/051037**

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2010/096873 A1 (BRIAN INVESTMENTS PTY LTD) 02 September 2010 Figs. 1, 6-7, page 5, line 23-page 6, line 13, page 9, line 5-page 11, line 15	1-39
X	US 2005/0158511 A1 (Sabol et al.) 21 July 2005 Figs. 6a, 6b, paragraphs 0062-0063	1-39
X	CN 203732016 U (HYDROCHINA ZHONGNAN ENGINEERING CORP) 23 July 2014 Figs. 3-6 and the associated text	1-39
X	JP H109310 A (YAZAKI CORP) 13 January 1998 Fig. 1 and the associated text	1-39
A	US 2013/0162266 A1 (Fargo et al.) 27 June 2013 Figs. 3, 4 and the associated text	1-39

INTERNATIONAL SEARCH REPORT Information on patent family members	International application No. **PCT/AU2019/051037**

This Annex lists known patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent Document/s Cited in Search Report		**Patent Family Member/s**	
Publication Number	**Publication Date**	**Publication Number**	**Publication Date**
WO 2010/096873 A1	02 September 2010	WO 2010096873 A1	02 Sep 2010
		AU 2010217195 A1	20 Oct 2011
		CL 2011002099 A1	09 Apr 2012
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		US 2012043980 A1	23 Feb 2012
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		WO 2010135011 A1	25 Nov 2010
CN 203732016 U	23 July 2014		
JP H109310 A	13 January 1998	JP H109310 A	13 Jan 1998

Due to data integration issues this family listing may not include 10 digit Australian applications filed since May 2001.

INTERNATIONAL SEARCH REPORT Information on patent family members	International application No. **PCT/AU2019/051037**

This Annex lists known patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent Document/s Cited in Search Report		**Patent Family Member/s**	
Publication Number	**Publication Date**	**Publication Number**	**Publication Date**
US 2013/0162266 A1	27 June 2013	US 2013162266 A1	27 Jun 2013
		US 9423369 B2	23 Aug 2016
		BR 112013002462 A2	24 May 2016
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		CN 103068711 B	17 Jun 2015
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		JP 2013541479 A	14 Nov 2013
		JP 5925781 B2	25 May 2016
		KR 20130054397 A	24 May 2013
		KR 101447535 B1	06 Oct 2014
		RU 2013103210 A	10 Oct 2014
		US 2013207668 A1	15 Aug 2013
		US 9599582 B2	21 Mar 2017
		WO 2012030332 A1	08 Mar 2012

End of Annex

Due to data integration issues this family listing may not include 10 digit Australian applications filed since May 2001.