Abstract: A condition of at least one structural part (8, 8a, 8b) of a mining machine (1) is monitored by at least one optical fibre (6) provided in connection with the mining machine (1) for sensing a condition of at least one structural part (8, 8a, 8b) of the mining machine by a beam of light transmitted to the optical fibre (6) and by the optical fibre used as a sensing element. The mining machine (1) is further provided with at least one monitoring unit (7) for converting light returning from the at least one optical fibre (6) into at least one measured quantity value describing the condition of the structural part (8, 8a, 8b).

Title: MONITORING CONDITION OF STRUCTURAL PART OF MINING MACHINE

FIG. 3
MONITORING CONDITION OF STRUCTURAL PART OF MINING MACHINE

BACKGROUND

The invention relates to mining machines, and more particularly to a method and arrangement for monitoring a condition of a structural part of a mining machine.

Condition monitoring in mining machines is typically based on using conventional sensors or using operating life estimates for estimating need for service and maintenance.

The conventional sensors are typically electrical sensors that convert physical effect on the sensor element into an electrical signal. Electrical sensors require electrical connections, wires and electronics which require mechanical engineering and space and are vulnerable to environmental disturbances. Each measurement signal or measured quantity usually also requires a separate sensor or multiple sensors, which makes the system and the installations complicated.

Typical electronic sensor systems used commonly in mining equipment consist of a power source, a sensor element, a measurement transceiver, I/O cabling, analogue to digital converter and a bus or network cabling. A considerable amount of vulnerable and space consuming electronics and cabling is, thus, needed to get the measured a physical value from the sensor element to be usable by the computing hardware and algorithms. On a system level, for instance hundreds of electrical connections may be required.

Operating life estimates, on the other hand, are not sufficiently accurate for many purposes, and interruptions still occur in use due to unexpected failures and/or unnecessary maintenance breaks for ensuring the working condition of the structural parts.

BRIEF DESCRIPTION

An object of the present solution is to provide a new method and arrangement for monitoring condition of a structural part of a mining machine. The objects of the solution are achieved by a method and an arrangement, which are characterized by what is stated in the independent claims. Some embodiments of the invention are disclosed in the dependent claims.

The solution is based on the idea of providing a mining machine with at least one optical fibre and at least one monitoring unit, and using the optical fibre itself as a sensing element to monitor condition of a structural part of a min-
ing machine. Thus, a need for electrical connections arranged on the mining machine is eliminated or at least decreased considerably. In addition, the optical fibre based sensing is naturally flameproof, which is beneficial in many applications and required for required for instance in coal mining. As added electrical connections and separate conventional sensor elements are no longer needed, a larger number of measurements can be made in a manner that is simpler and more robust in harsh environments.

Some other advantages of the solution are discussed in connection with the detailed description.

BRIEF DESCRIPTION OF THE DRAWINGS

In the following the invention will be described in greater detail by means of preferred embodiments with reference to the accompanying drawings, in which

Figure 1 illustrates an example of a mining machine and an arrangement in the mining machine;

Figure 2 illustrates schematically an arrangement in connection with a mining machine;

Figure 3 illustrates schematically a method for monitoring condition of a structural part of a mining machine;

Figure 4 illustrates schematically another method for monitoring a condition of a structural part of a mining machine;

Figures 5a, 5b, 5c and 5d illustrate schematically cross sections of optical fibres according to different embodiments; and

Figure 6 illustrates schematically an embodiment of a control system for an arrangement for monitoring a condition of a structural part of a mining machine.

DETAILED DESCRIPTION OF THE INVENTION

Different types of mining machines are known in the art and it is clear for a person skilled in the art that the figures are provided for illustrative purposes only and the solutions described in this description are applicable also for mining machines with different configurations and structure. The mining machine 1 may, thus, comprise for instance at least one of the following: a rock drilling rig, a crusher, a continuous mining machine, a loader, and a dump truck.

Figure 1 illustrates an example of a mining machine 1 and an ar-
rangement for monitoring a condition of at least one structural part of the mining machine 1 and Figure 2 illustrates schematically an arrangement for monitoring a condition of a structural part of a mining machine 1 schematically. In the embodiment of Figure 1, the mining machine 1 comprises a mobile rock drilling rig comprising a movable carrier 2 provided with several wheels 3, a driver cabin 4 and booms 5. These are also some examples of structural parts of a mining machine 1, but a mining machine may also comprise numerous other types of structural parts, such as actuators, joints, boom sections arranged pivotally to one another, tools and so on. The mining machine 1 is further provided with a control system which includes at least a first control unit (not shown) configured to control actuators in the mining machine 1 for controlling and driving the machine. However, the mining machine may, thus, comprise a different type of a mining machine instead of a rock drilling rig.

The arrangement for monitoring a condition of at least one structural part 8 of a mining machine 1 may comprise at least one optical fibre 6 provided in connection with the mining machine 1 for sensing a condition of at least one structural part of the mining machine 1 by a beam of light transmitted to the optical fibre 6. The optical fibre 6 may, thus, be used as a sensing element. This kind of an approach where an optical fibre 6 is used as a sensing element, in other words as a sensor, is referred to as distributed sensing, such as in distributed strain sensing, distributed temperature sensing and distributed acoustic sensing, in this description. Similar approach also enables three-dimensional shape sensing. In other words, in distributed sensing an optical fibre as a whole acts as a sensor/sensing element.

The arrangement for monitoring a condition of at least one structural part 8 of a mining machine 1 may also comprise at least one monitoring unit 7 for converting light returning from the at least one optical fibre 6 into at least one measured quantity value describing the condition of the structural part 8, wherein each optical fibre 6 may be connected to the monitoring unit 7 at least at one end of the optical fibre. In different embodiments, the monitoring unit may be arranged fixedly or removably in connection with the mining machine 1. According to an embodiment, the monitoring unit 7 may comprise a fibre interrogator. According to a further embodiment, another controller, such as a control unit of the mining machine, may be used to further process the data provided by the optical fibre 6 and the monitoring unit 7 for use for monitoring and controlling of a mining machine or for some other purpose. According to an embodiment, a min-
ing machine 1 comprises an arrangement for monitoring a condition of at least one structural part 8 of the mining machine 1 as described in this description.

Figure 3 illustrates schematically a method for monitoring a condition of at least one structural part of a mining machine. Such a method may be executed by a mining machine 1 and/or an arrangement such as described in this description. The method may comprise providing 31 at least one optical fibre in connection with the mining machine for sensing a condition of at least one structural part of the mining machine by a beam of light transmitted to the optical fibre 6. The optical fibre 6 may, thus, be used as a sensing element in the method. The method may also comprise providing 32 the mining machine 1 with at least one monitoring unit 7 for converting light returning from the at least one optical fibre 6 into at least one measured quantity value describing the condition of the structural part.

According to an embodiment, the measured quantity value may comprise at least one of the following: a temperature on the surface of the structural part, a temperature inside the structural part, an acoustic spectrum at a position of the structural part, and a strain measurement from the structural part. Thus, converting light returning from the at least one optical fibre 6 into at least one measured quantity value describing the condition of the structural part 8 may comprise analysing the backscattered light from the optical fibre 6 to determine the measured quantity.

Determination of the condition of a structural part based on the temperature on the surface or inside the structural part or based on the acoustic spectrum emitted by the structural part is known as and is not described in more detail. It is clear for a person skilled in the art that the light returning from the at least one optical fibre 6 may also be converted into at least one measured quantity value in any other manner known as such in connection with optical fibres.

Figure 4 illustrates schematically another method for monitoring a condition of a structural part of a mining machine 1. This method may comprise sensing 41 a condition of at least one structural part 8 of the mining machine 1 by a beam of light transmitted to at least one optical fibre 6 provided in connection with the mining machine 1. The optical fibre 6 may, thus, be used as a sensing element. The method may further comprise converting 42 light returning from the at least one optical fibre 6 by at least one monitoring unit provided in connection with the mining machine into at least one measured quantity value describing the condition of the structural part 8.
According to an embodiment, the condition of the structural part may comprise the condition of the structural part 8 at least at one position, section or area of the structural part 8.

According to an embodiment, the condition of the structural part may comprise at least one of the following: wear of the structural part 8 and ageing of the structural part 8. The wear of the structural part 8 may comprise for instance removal or deforming of the material of the structural part 8. The wear typically takes place where the structural part 8 is physically in contact with another material and especially if these material move in relation to one another. The aging is typically a process taking place in the structural part 8 itself and it is related to the concept of an operating life of a component or other type of a structural part, but it can be accelerated by external factors such as temperature changes, electrical charges and such applied to the structural part. In the method, arrangement and mining machine according to this description, wear and aging may be detected by monitoring heating based on temperature sensing, by monitoring vibrations based on acoustic spectrum sensing and/or by monitoring different strains in structural part during normal use, for example.

According to an embodiment, monitoring a condition of a structural part 8 of a mining machine 1 may comprise at least one of the following: comparing the measured quantity to an upper and/or lower control limit, comparing the measured quantity to a predetermined variation range, comparing the measured quantity to earlier values of the same measured quantity, that is the historical data related to the measured quantity, displaying the current value of the measured quantity on a display unit (not shown) of the mining machine 1, and displaying a graphical presentation of a trend of the measured quantity over a predetermined time span on a display unit of the mining machine 1. According to an embodiment, monitoring may also comprise taking pre-determined actions based on the measured quantity values, such as alerting the operator of the mining machine 1 about the measured quantity value crossing a control limit, alerting the operator of the mining machine 1 about a trend, unusual value of the measured quantity or the structural part 8 reaching the end of its operating life by an acoustic or visual signal, adjusting the operation of the mining machine 1 automatically or in another manner known as such in connection with conventional condition monitoring methods.

According to an embodiment, the measured quantity may be utilized in the control and/or monitoring of the mining machine 1 in a manner similar to
corresponding measured quantities provided by conventional methods, but the method and the arrangement described in this description provides many benefits over the conventional data gathering methods, such as those related to flame proof monitoring, simple monitoring configuration that is easy assemble even to an existing machine and the numerous measured quantities that may be provided by a single optical fibre 6 provided in connection with the mining machine 1. For example, the condition of the mining machine 1 may be monitored by utilizing measured quantities of strain for monitoring the structure load and pressure, such as hydraulic pressure; measured quantities of temperature for monitoring the temperature of components and/or the temperature of pressure medium, such as hydraulic oil, or other fluids in reservoirs, hoses, pipes or conduits of the mining machine; and/or measured quantities of vibrations/acoustics to monitor acoustic signals or other vibrations in structures, components and/or in air or fluids; wherein the measured quantities are based on the information received from the optical fibre(s) used as a sensing element.

According to an embodiment, the at least one optical fibre may be used for distributed acoustic sensing. The distributed acoustic sensing may be used for determining temperatures and/or acoustic spectrums of sections or segments as measured quantities along the optical fibre 6.

According to an embodiment, the condition of at least two structural parts 8 of the mining machine 1 is monitored by a single optical fibre. According to an embodiment, the condition of three or more structural parts 8 of the mining machine 1 is monitored by a single optical fibre. According to an embodiment, the condition of a subsystem of the mining machine 1, such as a boom 5, a carrier 2 or a drilling unit is monitored by a single optical fibre.

According to an embodiment, the optical fibre 6 may be wrapped at least one time around the structural part 8. According to another embodiment, multiple sensors may be multiplexed along the length of the at least one optical fibre 6. This is one way of monitoring several measured quantities or the same measured quantity at several locations and/or structural parts 8 along the length of the optical fibre 6.

According to an embodiment, two or more optical fibres 6 are provided in connection with the mining machine.

Figures 5a, 5b, 5c and 5d illustrate schematically cross sections of optical fibres according to different embodiments. These embodiments comprise at least one optical fibre core 6a and a protective layer 6b surrounding the optical
fibre core 6a. The optical fibre cores and the protective layer are not shown to scale but to illustrate the principle only.

According to an embodiment, the optical fibre 6 may comprise at least one fibre core 6a and a protective layer 6b surrounding the fibre core. In such an embodiment, an optical fibre core 6a and a protective layer 6b surrounding the optical fibre core 6a may thus form a single cable. Such an embodiment is illustrated in Figure 5a. According to an embodiment, the optical fibre 6 may comprise at least three optical fibre cores 6a provided together as a single cable with a common protective layer 6b. Such embodiments are illustrated in Figures 5c and 5d. According to a further embodiment, the optical fibre 6 may comprise at least three optical fibre cores 6a provided together as a single cable with a common protective layer 6b and with a 120 degree alignment between the optical fibres within the cable. An example of such an embodiment is illustrated in Figure 5c. According to another embodiment, the optical fibre 6 may comprise at least three optical fibre cores 6a provided as separate cables with separate protective layers 6b and arranged fixedly to one another. According to a further embodiment, the optical fibre 6 may comprise at least three optical fibre cores 6a provided as separate cables with separate protective layers 6b and arranged fixedly to one another with a 120 degree alignment between the optical fibres. An example of such an embodiment is shown in Figure 5b. These embodiments enable more advanced measuring possibilities, such as 3D shape sensing. According to an embodiment, the optical fibre 6 may comprise four or more optical fibre cores provided as a bundle comprising a common protective layer and/or separate protective layers. This may enable even more advanced, complex and accurate measurements to be made. In such embodiments, each optical fibre core 6a or each cable comprising optical fibre core(s) and protective layer(s) may be considered as an optical fibre 6 in the sense of the other embodiments described in this description. According to an embodiment, the protective layer comprises a shock absorbing rubber material.

Figure 6 illustrates schematically an embodiment of a control system for an arrangement for monitoring a condition of a structural part of a mining machine 1. This is only an example of a control system that may be used for monitoring a condition of a structural part of a mining machine and for executing the methods described in this description and utilizing the arrangements described in this description for controlling and/or monitoring of the mining machine. The control system may comprise graphical user interfaces (GUI1, GUI2) provided in
connection with the mining machine 1 for user interaction and for visualizing the measured quantities, for example, for the end user; interfaces to external networks, data transfer in and out and for remote user interfaces (Remote); controllers such as a master controller for mining machine level control and diagnostics, and other controllers for power, boom(s), carrier, valve(s) and controllers for other components and operations related to the mining machine; monitoring unit(s) (Optic interrogator) and/or optical fibres 6. The control system may also comprise valves (V) for instance for controlling tools, actuators and operations of the mining machine 1. According to an embodiment, the control system may comprise conventional sensors as well.

According to an embodiment, the at least one optical fibre 6 may be provided at least partly within at least one structural part 8, 8a, 8b of the mining machine 1. According to an embodiment, the at least one optical fibre 6 may be provided at least partly on a surface of at least one structural part 8, 8a, 8b of the mining machine 1 instead of or in additional to being provided partly within a structural part 8, 8a, 8b.

According to an embodiment, the at least one optical fibre 6 is retrofitted to an existing mining machine 1.

According to an embodiment, at a least part of the at least one optical fibre 6 may be arranged in connection with hydraulic hoses of the mining machine 1.

According to an aspect, a mining machine 1 may comprise an arrangement described above. The mining machine 1 may, thus, comprise for instance at least one of the following: a rock drilling rig, a crusher, a continuous mining machine, a loader, and a dump truck.

The frequency at which the measured quantity is measured and updated may vary depending on the measured quantity and the structural part 8 the condition of which is being monitored. For instance, a sufficient update rate for a temperature measurement may be once in a second or minute, for example, whereas acoustic measurements may be updated at a frequency of thousands of hertz. This provides substantially continuous measurement of the condition and enables using the data for example for controlling the mining machine 1. Continuous updating of the measured quantity value may take place during use of the mining machine 1, the operation, work phase and/or structural part of the mining machine 1.

It will be obvious to a person skilled in the art that, as the technology
advances, the inventive concept can be implemented in various ways. The invention and its embodiments are not limited to the examples described above but may vary within the scope of the claims.
CLAIMS

1. A method for monitoring a condition of at least one structural part of a mining machine, characterized by

   providing at least one optical fibre in connection with the mining machine for sensing a condition of at least one structural part of the mining machine by a beam of light transmitted to the optical fibre and by the optical fibre used as a sensing element; and

   providing the mining machine with at least one monitoring unit for converting light returning from the at least one optical fibre into at least one measured quantity value describing the condition of the structural part.

2. A method according to claim 1, characterized in that the at least one optical fibre is used for distributed acoustic sensing.

3. A method according to claim 1 or 2, characterized by the condition of the structural part comprises at least one of the following: wear of the structural part and ageing of the structural part.

4. A method according to any one of claims 1 to 3, characterized by wrapping the optical fibre at least one time around said structural part.

5. A method according to any one of claims 1 to 4, characterized by multiplexing multiple sensors along the length of the at least one optical fibre.

6. A method according to claim 5, characterized by monitoring the condition of at least two structural parts by a single optical fibre.

7. A method according to any one of claims 1 to 6, characterized in that measured quantity value comprises at least one of the following: a temperature on the surface of the structural part, a temperature inside the structural part, an acoustic spectrum at a position of said structural part, and a strain measurement from the structural part.

8. A method according to any one of the claims 1 to 7, characterized in that two or more optical fibres are provided in connection with the mining machine.

9. A method according to any one of claims 1 to 8, characterized in that the optical fibre comprises at least one fibre core and a protective layer surrounding the fibre core.

10. A method according to claim 9, characterized in that the protective layer comprises a shock absorbing rubber material.
11. A method according to any one of the claims 1 to 12, characterized by providing the at least one optical fibre at least partly within at least one structural part of the mining machine.

12. A method according to any one of claims 1 to 11, characterized by providing the at least one optical fibre at least partly on a surface of at least one structural part of the mining machine.

13. A method according to any one of the claims 1 to 12, characterized by retrofitting the at least one optical fibre to an existing mining machine.

14. An arrangement for monitoring a condition of a structural part of a mining machine, characterized in that the arrangement comprises at least one optical fibre in connection with the mining machine for sensing a condition of at least one structural part of the mining machine by a beam of light transmitted to the optical fibre and by the optical fibre used as a sensing element; and at least one monitoring unit provided in connection with the mining machine for converting light returning from the at least one optical fibre into at least one measured quantity value describing the condition of the structural part.

15. A mining machine comprising an arrangement according to claim 14.
Provide optical fibre in connection with mining machine for sensing condition of at least one structural part of mining machine by beam of light transmitted to the optical fibre and use optical fibre used as a sensing element.

Provide mining machine with monitoring unit for converting light returning from optical fibre into measured quantity value describing the condition of structural part.

FIG. 3

Sense condition of structural part of mining machine by beam of light transmitted to optical fibre provided in connection with mining machine.

Convert light returning from optical fibre by monitoring unit provided in connection with mining machine into measured quantity value describing the condition of structural part.

FIG. 4
## INTERNATIONAL SEARCH REPORT

### A. CLASSIFICATION OF SUBJECT MATTER

**INV.** E21C35/00 E02F9/26

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

### B. FIELDS SEARCHED

<table>
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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)

- EPO-Internal
- WPI Data

### C. DOCUMENTS CONSIDERED TO BE RELEVANT

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Date of the actual completion of the international search: 17 February 2017

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European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016

Authorized officer: Ott, Stephane
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