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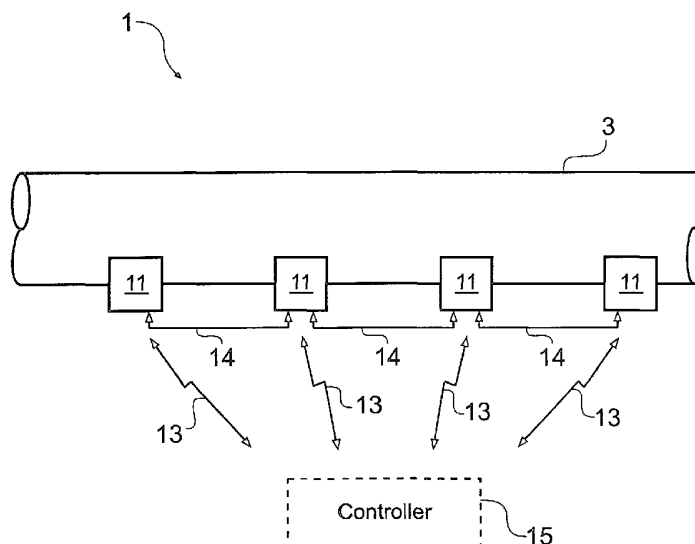
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(54) Title: MOVING SENSOR ARRAY (WITH AXIAL PISTON PUMP) WITH WIRELESS MONITORING AND POWER GENERATION



(57) Abstract: A monitoring system comprises an array of sensors (1), having a plurality of sensors that move during use in relation to a remote monitoring device. At least one sensor in the array comprises sensing means for sensing a parameter in the system being monitored, the sensing means producing sensed data. The sensor also comprises power generating means for powering the sensor, and digital signal processing means for processing the sensed data. The sensor also comprises wireless communication means (13) for transmitting the sensed data to the remote monitoring device (15). The sensor transmits data and generates power without the need for any physical cables between the sensor and the remote monitoring means. Used with an axial piston pump. Power may be generated from a pressure being monitored.

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*For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.*

Moving sensor array (with axial piston pump) with wireless  
monitoring and power generation

#### FIELD OF INVENTION

The invention relates to an array of sensors for  
5 monitoring a system and, in particular, to an  
interactive, self-powered, intelligent pressure sensor  
array for condition monitoring and fault diagnosis of  
applications such as fluid power systems.

#### 10 BACKGROUND OF THE INVENTION

Fluid power control is used in a diverse range of  
applications such as: base material production and  
processing; pumping systems; power generation; mobile  
and automated machines; transport over land, sea and  
15 air; mining; quarrying and leisure industries.  
Advanced techniques for condition monitoring and  
control are continually sought to improve the  
performance and safety of such fluid power systems.

20 Figure 1 shows a simplified fluid power element 1  
comprising a fluid chamber 3, having a number of  
sensors 5 for monitoring the fluid within the chamber  
3. The sensors 5 are interconnected using cables 7,  
and connected to a controller 9 which performs  
25 condition monitoring, control and fault diagnosis using  
the data gathered from the sensors 5. The sensors 5  
gather data which is then transmitted to the controller  
9 for processing. In this respect, the sensors 5 are  
non intelligent devices which merely act to gather data  
30 from the system being monitored. The cables 7 serve a  
dual function, on the one hand providing a power supply  
to each of the sensors 5 and, on the other, enabling  
the data to be returned from the sensors 5 to the  
controller 9.

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The provision of such cabling 5 can be impractical in many applications, particularly ones in which the fluid power system being monitored is moving, for example when the sensors are mounted on a rotating body in an axial piston pump.

The aim of the present invention is to provide an improved monitoring system and sensor array, which avoids the disadvantages of the above-mentioned prior art.

#### SUMMARY OF THE INVENTION

According to a first aspect of the invention, there is provided an array of sensors for monitoring a system, the array comprising a plurality of sensors that move during use in relation to a remote monitoring device, wherein at least one sensor in the array comprises sensing means for sensing a parameter in the system being monitored, the sensing means producing sensed data; power generating means for powering the sensor; digital signal processing means for processing the sensed data; and wireless communication means for transmitting the sensed data to the remote monitoring device.

According to another aspect of the present invention, there is provided a fluid power system as defined in the appended claims.

#### BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 shows a simplified schematic of a known fluid power element;

Figure 2 shows a schematic view of a fluid power system having pressure sensors according to one aspect of the

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present invention;

Figure 3 shows a pressure sensor according to another aspect of the present invention;

5

Figure 4 shows an application of an embodiment of the present invention;

Figure 5 illustrates how pressure can vary in a typical application;

10

Figure 6 shows an example of remote data transmission according to another aspect of the present invention;

Figure 7 shows another example of remote data transmission according to the present invention;

15

Figure 8 shows a further application of the present invention;

20

Figure 9 shows an electrical circuit adapted for use with a sensor array in an axial piston pump.

#### DETAILED DESCRIPTION OF A PREFERRED EMBODIMENT OF THE PRESENT INVENTION

25

Referring to Figure 2, a fluid pressure system 1 comprises an array of interactive intelligent pressure sensors 11. Each sensor 11 is autonomous, in that it has an in-situ power generating unit, and a low power digital signal processing (DSP) unit for processing the sensed data. In addition, each sensor comprises a wireless communications link 13, for example a RF communications link, for transmitting data to, or receiving data from, a remote device 15. The remote device 15 acts as a master controller. Each sensor 11

30

35

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may also communicate with any of the other sensors 11.

The sensors 11 are physically connected to one another using cabling 14, thereby allowing data and/or power to  
5 be shared between the sensors 11.

Figure 3 shows the sensor 11 of Figure 2 in greater detail. According to one embodiment, the power generating unit 17 takes advantage of the energy  
10 available in the system being monitored. For example, if pressure is being monitored, the pressure differentials in the fluid pressure system can be used to generate the power supply required by the sensor. The pressure differentials in the fluid power system  
15 can be used, for example, to drive electromechanical or piezoelectric devices, or to generate a charge in a micro-capacitor. Further embodiments relating to the power generating unit are described later in the application.

20 The sensor therefore serves a dual purpose, in that it monitors the fluid pressure of the fluid power system being monitored, whilst also generating its own power supply.

25 The manner in which the sensors 11 are connected in the form of an array means that sensors which are not being interrogated in the array loop may be used to provide power to the remaining sensors via the physical  
30 connections 14 shown in Figure 2. This forms an intelligent power boost.

The provision of two or more sensors in the sensor array also enables sensor integrity to be monitored.  
35 For example the sensed data from one or more sensors

can be used to show that another sensor in the array is failing, or producing inaccurate data.

5 The sensor 11 also includes a digital signal processing (DSP) unit 19 which is powered by the power generation unit 17. The DSP "core" comprises standard features such as data acquisition, noise reduction (filtering) and basic condition monitoring. However, in addition to the standard features, the DSP unit 19 is equipped  
10 with an intelligent processing capability, which enables a distributed control function to be carried out. This allows the sensor 11 to make decisions based on the data gathered, and present diagnostic or corrective results. For example, the data can be used  
15 to identify faults as they occur, or predict that faults are going to occur in the future.

The DSP unit 19 preferably comprises a time domain algorithm for fault detection using the sensed data.  
20 For example, the data being sensed could relate to detected pump pressure ripples in a pumping system, or axial pump piston pressure waveforms in an axial pump.

The processing requirements of the DSP unit 19 are  
25 adapted to ensure low power consumption. This includes selecting filtering techniques, algorithms and digital processing techniques that consume the least amount of power.

30 Preferably, the DSP unit 19 comprises artificial intelligent heuristics for providing high performance with minimal processing complexity. The DSP unit 19 works on sparse data, obtained via a snapshot sampling approach to transient data capture.

Preferably, the DSP unit 19 provides advanced diagnostic routines and the capability of adaptation based on the acquired data, for example, automatic error correction (calibration). It can also be  
5 programmable, thereby enabling programs to be downloaded to the sensor as the diagnosis techniques evolve, or monitoring requirements change.

The tradeoff between the processing complexity of the  
10 DSP and the power requirements of the DSP means that, if desired, data processing can be adaptively shared between a sensor 11 and the master controller 15. For example, the sensor 11 could handle certain processing tasks, while other tasks are passed to the master  
15 controller 15 for further processing.

This enables a single sensor to be used in a variety of applications. The requirements of the system are completely characterised to ensure that the minimum  
20 amount of processing and communication is required to consume the least amount of energy. This involves careful analysis of the required diagnosis data, which is created by carefully tuning the system to a particular application.

25

The DSP unit 19 can therefore be used to sample and classify data, and communicate data between sensors 11.

Alternatively, the DSP unit 19 can be arranged to carry  
30 out very little data processing, whereby the data is streamed from the sensors to the master controller 15. Processing of the data can then be undertaken at the master controller 15.

35 The provision of a plurality of sensors in any given

application will create a distributed diagnosis and control system that enables possible failures to be highlighted in their early stages. The early diagnosis of failures can significantly minimise the expense of such failures.

The sensor 11 further includes a wireless communications unit 21, which provides the required non-contact data link. Preferably the wireless communications unit 21 is bi-directional, although it will be appreciated that one way communication from the sensor 11 to the master controller 15 is also possible. According to one aspect of the invention, the communications link utilises radio frequency identification (RFID) technology. The typical operating frequency of such a system can range from 125 KHz up to 24.125 GHz. A key feature of the RFID approach is that the transmitter on the sensor 11 (RFID tag) can be powered from the energy in the radiating field of a remote transceiver (for example the controller 15). Hence, the communications link 21 on the sensor 11 can operate without the need for an electrical power source.

Furthermore, the RFID approach enables two-way communication (read/write) to be provided. As a result, each sensor can be interrogated or programmed from a remote location, as necessary.

In addition, high frequency RFID systems provide the ability to interrogate tags. This allows communication with a sensor which is moving, for example, in a rotating pump where a sensor may be used to measure the pressure within each piston chamber of a multi-piston chamber. Further embodiments relating to other methods

of remote data transmission are discussed later in the application. For example, as an alternative to RF, ultrasound can be used as the communication link.

5 One advantage of the intelligent sensor described above is that it enables all of the components of the sensor to be placed on the same substrate. Thus, the power generation unit 17, DSP 19 and communications unit can be miniaturised and placed on the same substrate,  
10 thereby reducing the overall size of the sensor. This enables the sensor to be used in certain environments which would otherwise be impracticable.

Figure 4 shows one application of the invention in a  
15 high power positive displacement pump 40. The pump 40 comprises one or more pistons 41a, 41b. Sensors 43a, 43b are provided for monitoring the pistons. Preferably one sensor is provided for each piston. Alternatively, fewer sensors are provided, whereby one  
20 sensor is used to monitor two or more pistons.

A DSP management unit 45 controls the data gathering and processing functions, while a RF signal transmission unit 47 is provided for transmitting data  
25 to and/or from a remote location

Although the sensor 43, DSP unit 45 and RF unit 47 are shown as being separately located, it is possible that one or more of these elements may be co-located. For  
30 example, as mentioned above, the sensor 43, DSP unit 45 and RF unit 47 may be co-located on the same substrate. When the elements are co-located, the need for interconnecting wires within the pump 40 may be reduced or even eliminated. Certain physical connections may  
35 be retained, however, for functions such as power

sharing or intelligent power boost.

Thus, although Figure 4 shows the RF unit 47 being mounted in a static position on the body of the pump 40, a fully integrated sensor will involve the RF link 47 being mounted with the sensor 43. Furthermore, in certain applications, the sensor 43 and RF link 47 are mounted on a moving object, such as the barrel of a pump.

10 Since there is no physical link to the remote location, the invention provides a number of alternate ways of powering the intelligent sensor. Reference will now be made to the various aspects of the invention relating to the powering of the intelligent sensors.

According to one embodiment, the intelligent sensor is battery powered. Each sensor can have its own battery. Alternatively, a particular battery can be used to power one or more sensors in the array. Whilst the provision of battery power is simple to implement, it has the disadvantage that the battery power must be replenished or replaced at regular intervals.

25 According to another embodiment, the intelligent sensor is powered by the inherent vibration of the system being monitored. For example, as mentioned earlier a piezoelectric device can be used to convert vibration into electrical energy for powering the sensor. In a fluid system, pressure fluctuations can be used to drive a piezoelectric element, or the like. The power generating capability is preferably enhanced by matching the power generator to the amplitude and/or frequency characteristics of the pressure fluctuations in the pump being monitored.

Figure 5 shows how pressure varies over time in a typical system. This may correspond, for example, to the piston pressure of a pump. The pressure 48 corresponds to the maximum pressure developed by the piston. In addition to the maximum pressure 48, the system also exhibits pressure fluctuations, 49. The pressure fluctuations 49 may be caused by a number of factors, including the effects of other pistons operating in the system being monitored. The pressure fluctuations 49 can therefore be used to drive the piezoelectric device. It is noted that the pressure fluctuations can be used in addition to the maximum pressure 48, or as an alternative to the maximum pressure 48.

According to another embodiment, the intelligent sensor is powered using solar energy. The solar cell can be placed on the exterior of the pump 40 with wires feeding power to the other elements of the sensor within the body of the pump. Alternatively, with a fully integrated sensor, the solar cell itself could form part of the moving sensor within the body of the pump 40. With such an arrangement, the body of the pump must be capable of allowing solar energy to pass to the solar cell.

According to another embodiment, the intelligent sensor is powered using laser light. The laser light is converted through the body of the pump to the power generating element of the sensor. Alternatively, the laser light can be aimed directly at a moving sensor through an aperture in the body of the pump.

According to another embodiment of the invention, power

is derived from static electricity which is generated by the movement of the sensor in relation to the system being monitored. For example, in a pump, a thin oil film is smeared around the barrel of the pump. As the  
5 barrel of the pump moves in close proximity to the sensor, static electricity is generated and used to power the sensor.

According to another embodiment, power is obtained by  
10 mounting the sensor on the barrel of the pump. The sensor picks up acoustic/ultrasonic energy from the barrel, which is converted into electrical energy for powering the sensor. Further details of the acoustic/ultrasonic features are given later in the  
15 application.

According to yet another embodiment of the invention, the intelligent sensor is powered using inductive coupling, whereby an air gap transformer has its  
20 primary winding mounted on the casing of the pump, with the secondary winding mounted on the moving part of the pump. Further details of the inductive coupling embodiment are given later in the application.

25 Reference will now be made to various embodiments for remote data transmission according to further aspects of the present invention. It is noted that references to remote data transmission include both the transmission of data from the system being monitored to  
30 a remote location, plus the transmission of data within the system being monitored, for example between a sensor mounted on the moving part of a pump and a DSP mounted on the static part of the pump.

35 Figure 6 shows how the data can be obtained from a

moving sensor in an acoustic/ultrasonic system. The elements mounted on the moving sensor are shown at 51. Analogue or digital data from the pump being monitored is fed to a coding circuit 53. An acoustic or  
5 ultrasonic transmitter 55 transmits the output of the coding circuit 53 to an acoustic/ultrasonic receiver 57. The acoustic/ultrasonic receiver 57 is mounted on the static part 58 or outside the boundary of the pump. The output from the receiver 57 is decoded by a  
10 decoding circuit 59.

Figure 7 shows a further embodiment in which data is transmitted from the moving sensor using inductive coupling. According to this embodiment, an AC power  
15 signal 60 is fed to a primary coil 61 of a transformer. The primary coil 61 of the transformer is mounted on the static part of the pump 62, while the secondary coil 63 is mounted on the moving part of the pump 64. The primary signal is induced into the secondary coil  
20 63 where it is rectified by a rectifier 65 and used to power the sensor electronics connected across terminals 66. The digital or analogue data from the system being monitored is fed into a de-coupling circuit 67 and thus reflected back into the primary side 61 of the  
25 transformer. A band pass filter or tuned circuit 68 extracts the data signal from the incoming power supply signal.

Thus, it can be seen that the embodiment shown in  
30 Figure 7 uses inductive coupling both to power the sensor, and to gather sensed data from the sensor. In other words, the electrical power is induced at a first frequency, and the data signal superimposed on this signal at a higher frequency.

Further embodiments for remote data transmission include arrangements in which the data is transmitted between the moving part of the pump and the static part of the pump using laser pulses or capacitive discharge.

5 Alternatively, RF or ultrasound can be used to transmit data between the moving and static parts of the system, and/or provide power to the moving part.

Figure 9 shows an electrical circuit for a sensor array

10 formed on a flexible band 80. The flexible band 80 has been developed for use with a sensor array in an axial piston pump as shown in Figures 4 and 8. In an axial piston pump of this kind each sensor 43a, 43b is mounted on the periphery of a rotating barrel. The

15 flexible band 80 is adapted for a sensor array comprising three sensors, which are connected to electrical pads 81, 83, 85 on the flexible band 80. The electronic components associated with each sensor are distributed over the flexible band 80, and encapsulated

20 in a manner that allows the flexible band 80 to be bent along its length. In use, the flexible band 80 is wrapped around the barrel of an axial pump, such that each electrical pad 81, 83, 85 is adjacent its associated sensor 43a, 43b, 43c (not shown). The use

25 of a flexible band enables the sensors and associated circuitry to rotate at high speed on the rotating barrel, without having any degrading effects on the sensor array.

30 Preferably, the application of the sensor array in an axial piston pump includes a hall effect device for generating a strobe signal as the chamber rotates, the strobe signal being used to synchronise the data sensed by the plurality of sensors.

The invention described above results in a completely autonomous sensor array that can be used without the need for an external power supply or cabling.

- 5 It is particularly suited to applications in which the sensor may be moving, for example when monitoring a rotating pump such as an axial piston pump. The autonomous sensor avoids the need for conventional power supply arrangements used in these applications,  
10 such as slip-ring techniques for supplying power and signal acquisition.

- Although the invention has been described using ways of avoiding the need for slip rings, the intelligent  
15 sensor may also be used with conventional slip ring methodology for external data retrieval, as shown in Figure 8 of the drawings. This embodiment allows the multi-sensor of the present invention to be adapted for use with existing slip ring arrangements 49, 51, 53.  
20 Alternatively, the slip rings can be used for providing power supply to the sensors, while data is retrieved using any one of the wireless communication means described above.

- 25 The inclusion of an intelligent digital signal processing capability within the sensor allows a distributed control system to be created.

- The pressure sensing concept proposed above may be  
30 applied to a wide range of industrial activities, using compressed air, pneumatic control, turbo machinery, and water or oil hydraulic systems. In this respect, the fluid being monitored may be air, water, oil or any other suitable fluid. Alternatively, the sensor may be  
35 used to monitor other parameters such as temperature or

velocity, whereby these parameters are used to provide the power source to the sensor.

More specifically, the invention can help minimise  
5 plant downtime costs, or environmental oil pollution risks, that could be caused by the failure of components, actuators, and power supplies in a high pressure fluid power industry.

10 The invention has many other potential application areas such as automotive engine monitoring, active damping and active control of suspensions. The power generating unit according to the invention may also be used in other applications, such as biotechnology  
15 applications which require in-situ power supplies for applications such as heart pacemakers. In such an application, the power generating unit may derive its power by motion activation rather than pressure differentials.

20 Although one embodiment of the invention shows all the sensors in the array being physically connected, the invention could equally be used in a system where only some, or none of the sensors are physically  
25 interconnected, but instead are remotely connected to at least one other sensor or the DSP.

The references above to the DSP "classifying data" includes classifying data according to any one of a  
30 number of well known techniques, including time and frequency domain classification.

Furthermore, although one embodiment shows a separate master controller, this may be considered optional, in  
35 which case one of the other sensors could operate as a

master controller.

The RFID approach may also use the backscatter modulation technique.

5

The sensor array has the advantage of transmitting data and generating power without the need for any physical cables between the sensor array and the remote monitoring device.

10

Other modifications to the invention will be apparent to those skilled in the art, as defined by the scope of the attached claims.

15

**CLAIMS**

1. An array of sensors for monitoring a system, the array comprising a plurality of sensors that move during use in relation to a remote monitoring device, wherein at least one sensor in the array comprises:
- sensing means for sensing a parameter in the system being monitored, the sensing means producing sensed data; ,
- power generating means for powering the sensor;
- digital signal processing means for processing the sensed data; and
- wireless communication means for transmitting the sensed data to the remote monitoring device.
2. An array as claimed in claim 1, wherein the power generating means generates power from the parameter being monitored.
3. An array as claimed in claim 2, wherein the power generating means generates power from a pressure being monitored.
4. An array as claimed in claim 2 or 3, wherein the power generating means generates power from pressure differentials in a pressure being monitored.
5. An array as claimed in claim 2, wherein the power generating means comprises an electromechanical device.
6. An array as claimed in claim 2, wherein the power generating means comprises a piezoelectric device.
7. An array as claimed in claim 2, wherein the power generating means comprises a micro-capacitor.

8. An array as claimed in claim 1, wherein the power  
5 generating means comprises a solar cell.

9. An array as claimed in claim 1, wherein the power  
generating means generates power from laser light  
directed at the power generating means.

10

10. An array as claimed in claim 1, wherein the power  
generating means generates power from static  
electricity generated by the moving parts of the system  
being monitored.

15

11. An array as claimed in claim 1, wherein the power  
generating means generates power from the acoustic or  
ultrasonic energy generated by the system being  
monitored.

20

12. An array as claimed in claim 1, wherein the power  
generating means comprises a battery.

13. An array as claimed in claim 1, wherein the power  
25 generating means comprises part of an inductive  
coupling.

14. An array as claimed in claim 13, wherein the power  
generating means comprises a secondary coil forming  
30 part of an inducting coupling, wherein a primary coil  
is mounted on a static part of the system being  
monitored, the primary coil being connected to a source  
of electrical power, and transferring energy to the  
secondary coil in the power generating means.

35

15. An array as claimed in claim 1, wherein the power generating means of one sensor can be used to supply power to another sensor in the array.

5 16. An array as claimed in claim 15, wherein two or more sensors in the array have power generating means that share power, thereby permitting one power generating means to boost the power supply of the other, and vice versa.

10

17. An array as claimed in claim 1, wherein the power generating means generates power using motion activation.

15 18. An array as claimed in any one of the preceding claims, wherein the wireless communication means comprises an inductive loop.

20 19. An array as claimed in claim 18 when dependent on claim 13, wherein the same inductive coupling is used for supplying induced power to the sensor, and for transmitting wireless data from the sensor to the remote device.

25 20. An array as claimed in claim 19, wherein the inductive coupling transmits electrical energy at a first frequency, and wherein a data signal is superimposed on the electrical signal at a higher frequency.

30

21. An array as claimed in any one of claims 1 to 17, wherein the wireless communication means comprises laser transmission.

35 22. An array as claimed in any one of claims 1 to 17,

wherein the wireless communication means comprises acoustic transmission between a static element and a moving element.

- 5     23. An array as claimed in any one of claims 1 to 17, wherein the wireless communication means comprises capacitive discharge between a moving element and a static element.
- 10    24. An array as claimed in any one of the preceding claims, wherein the sensor further comprises an intelligent digital signal processing (DSP) unit for processing the data being monitored.
- 15    25. An array as claimed in claim 24, wherein the DSP unit samples the data, classifies the data, and communicates the data to other sensors.
- 20    26. An array as claimed in claim 24 or 25, wherein the DSP unit comprises artificial intelligent heuristics, for providing high performance with minimal processing complexity.
- 25    27. An array as claimed in any one of claims 24 to 26, wherein the DSP unit is programmable.
- 30    28. An array as claimed in any one of claims 24 to 27, wherein the DSP unit can be interrogated.
- 30    29. An array as claimed in any one of claims 24 to 28, wherein the DSP unit uses adaptive power supply voltages.
- 35    30. An array as claimed in any one of claims 24 to 29, wherein the DSP unit has sleep modes for lowering power

consumption.

31. An array as claimed in any one of the preceding  
claims, wherein the communications link is  
5 bidirectional.

32. An array as claimed in claim 1, wherein the  
wireless communications means is a radio frequency  
identification (RFID) system or ultrasound system.  
10

33. An array as claimed in claim 1, wherein the  
communications means comprises a communications  
transmitter, the communications transmitter being  
powered by a radiating field of a remote transceiver.  
15

34. An array as claimed in claim 1, wherein  
backscatter modulation is used to transmit data from  
the sensor to a remote transceiver.

20 35. A fluid power system comprising an array of  
sensors as claimed in any one of claims 1 to 34.

36. A fluid power system as claimed in claim 35,  
wherein the fluid power system comprises an axial  
25 piston pump having a plurality of pistons mounted in a  
rotating chamber, wherein two or more sensors in the  
array of sensors are positioned radially on the  
rotating chamber.

30 37. A fluid power system as claimed in claim 36,  
wherein the two or more sensors are interconnected by  
an electrical circuit encapsulated in a flexible band.

38. A fluid power system as claimed in claim 37,  
35 further comprising a hall effect device for generating

a strobe signal, the strobe signal being used to synchronise the data sensed from the system.

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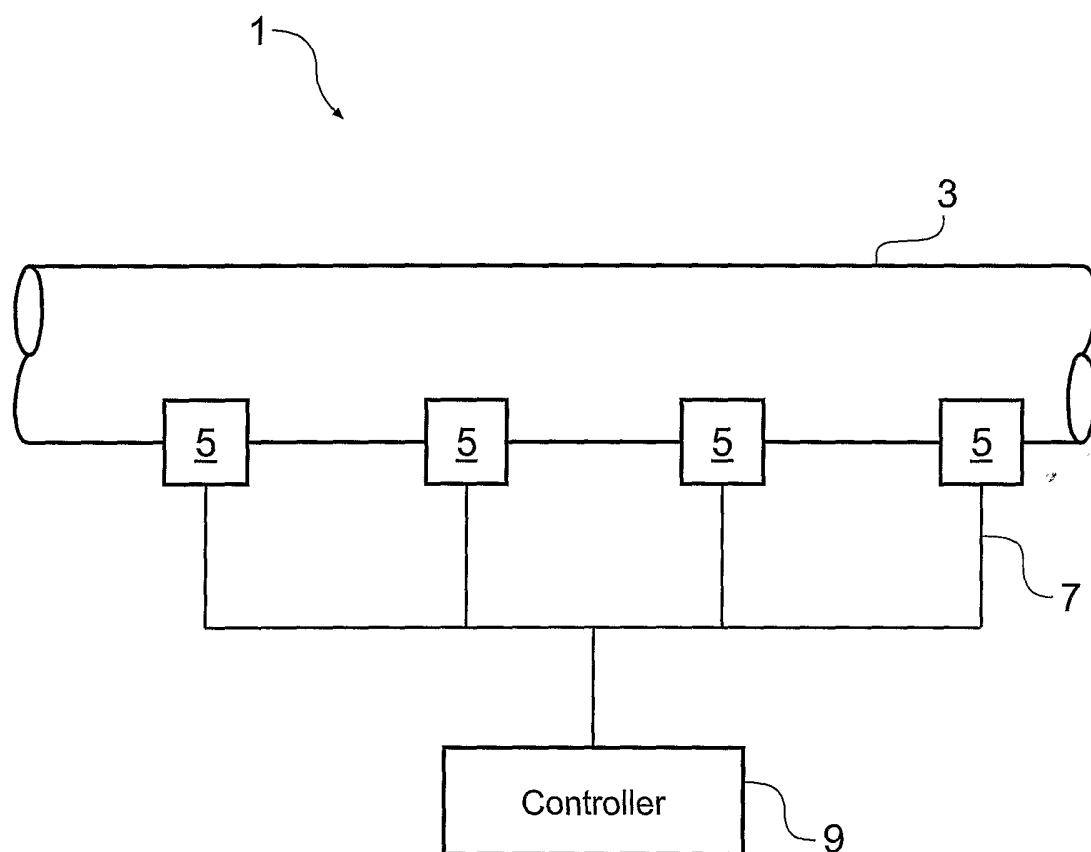


Fig. 1

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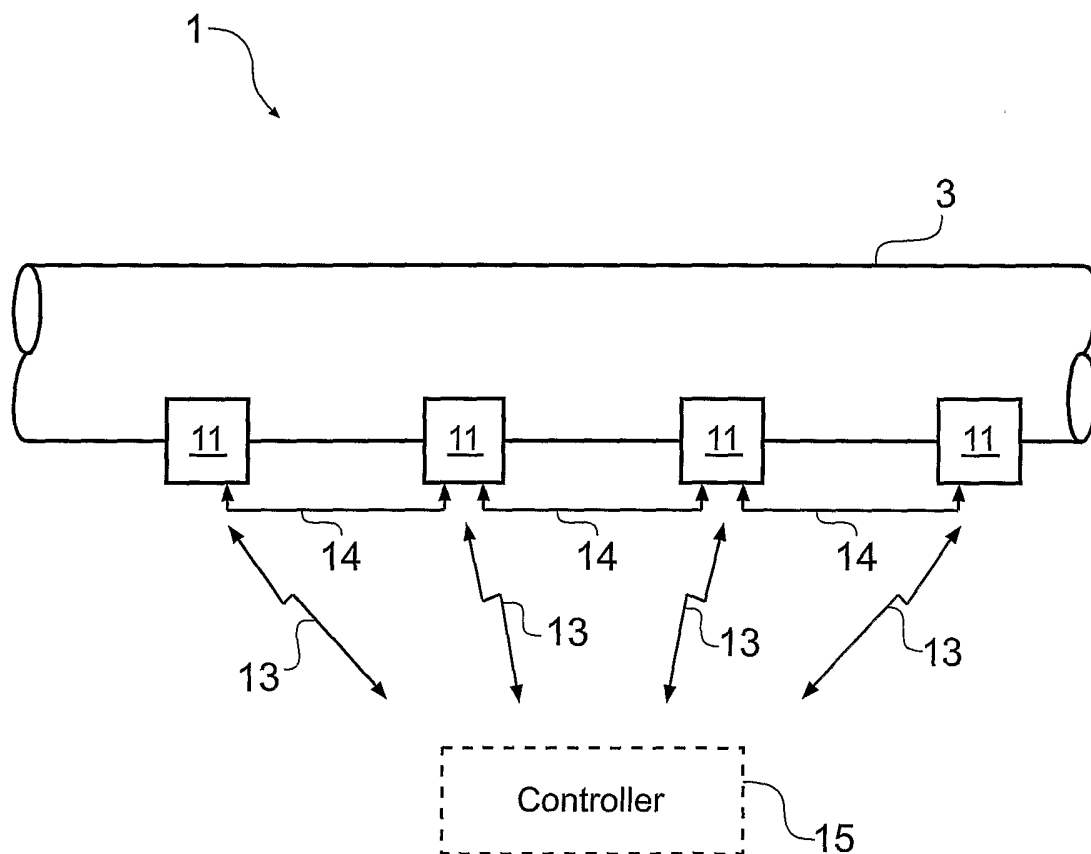


Fig. 2

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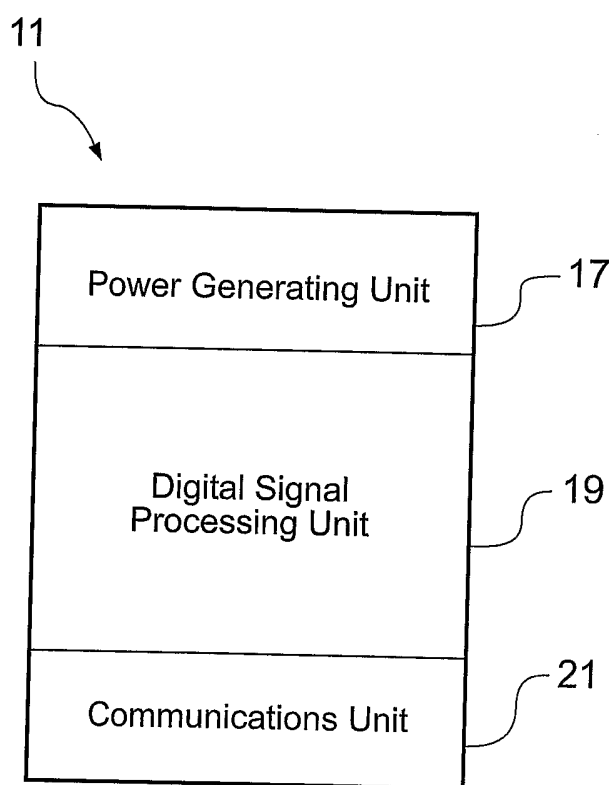


Fig. 3

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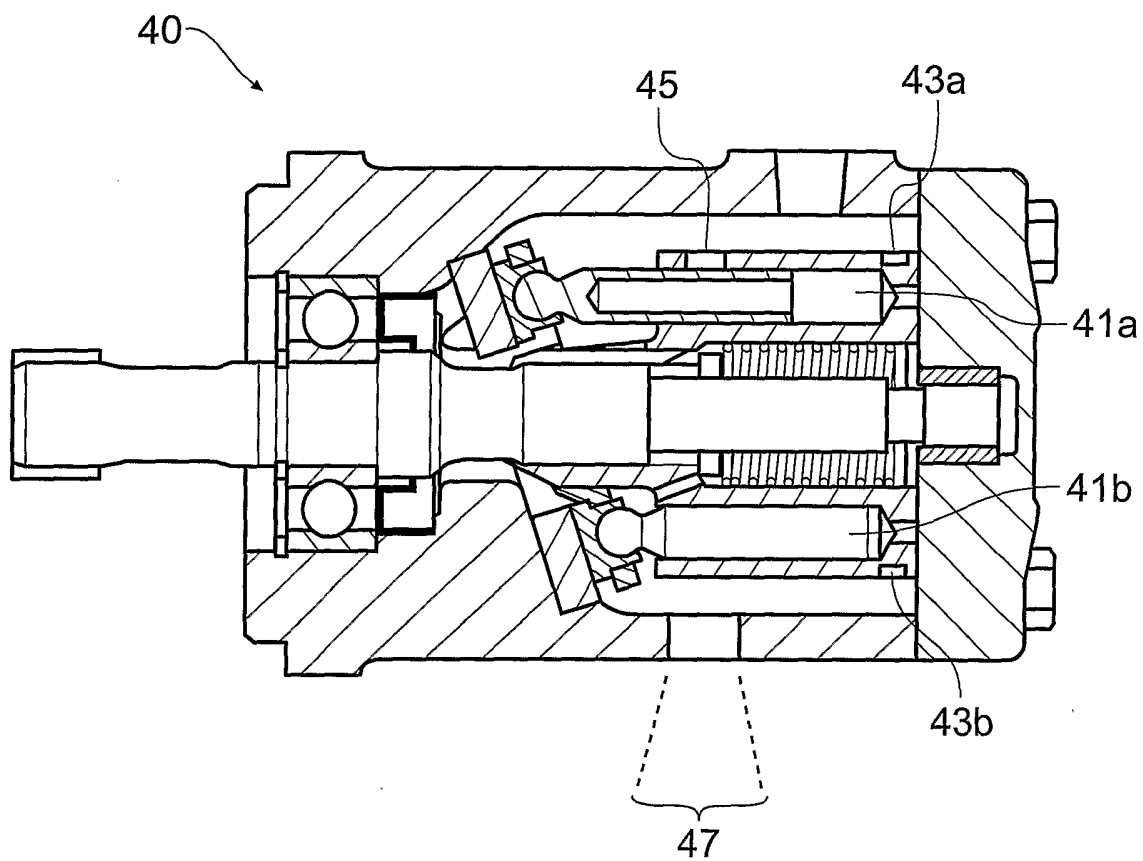


Fig. 4

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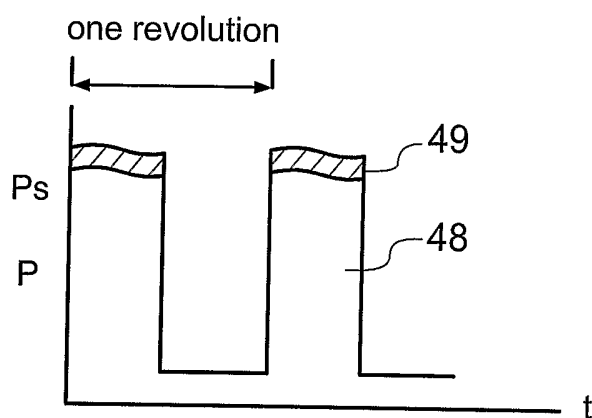


Fig. 5

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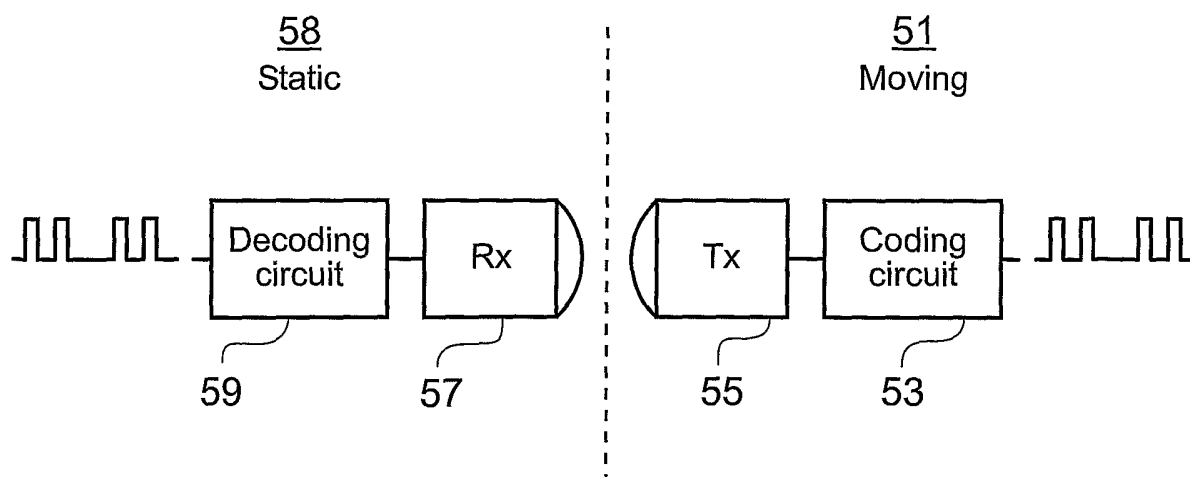


Fig. 6

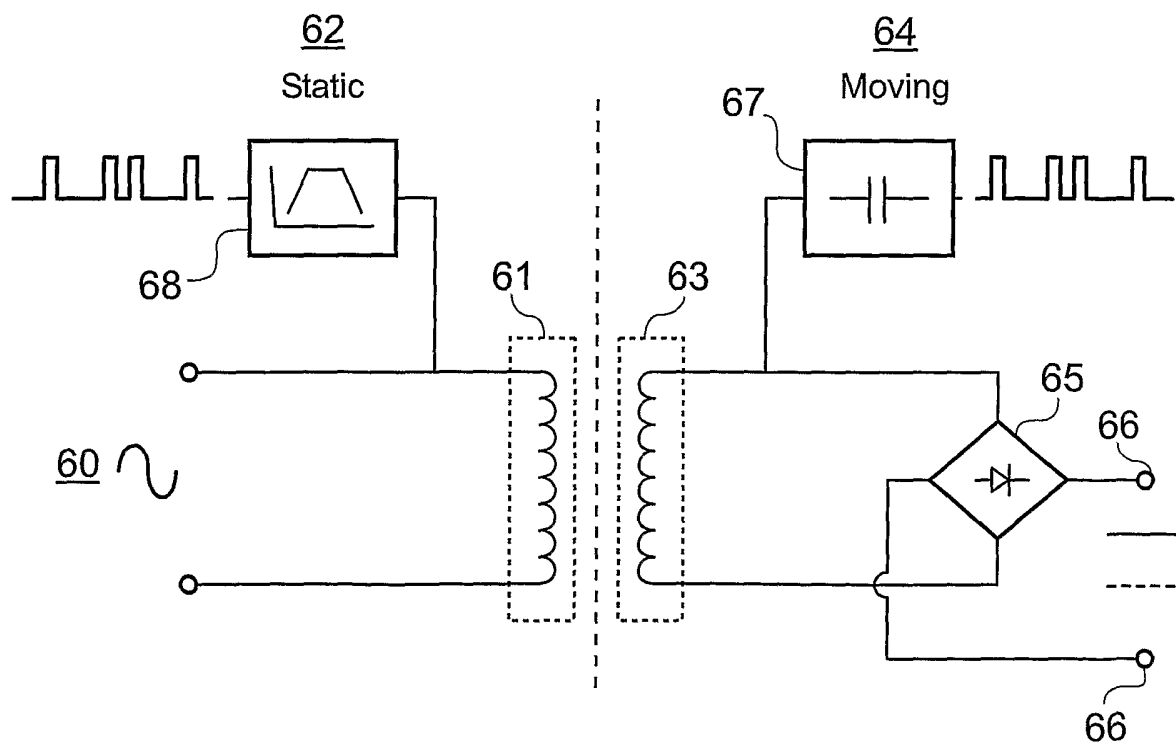


Fig. 7

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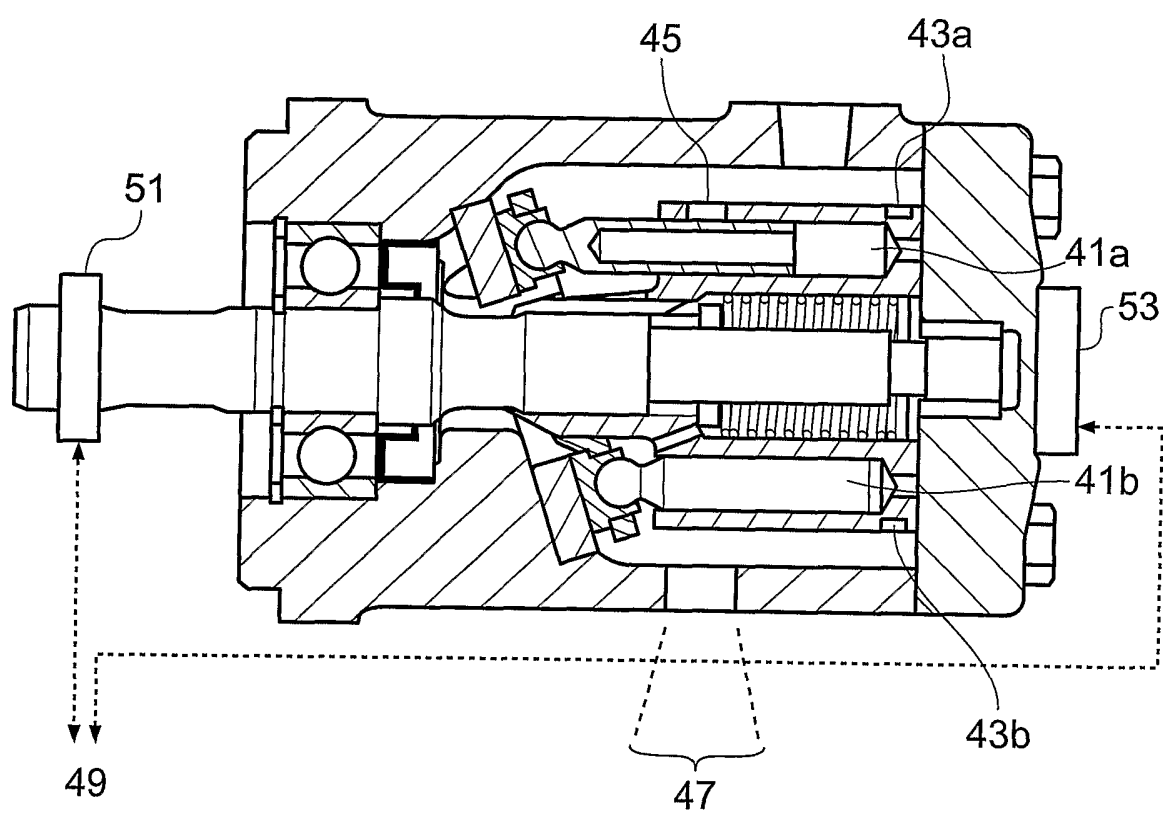


Fig. 8

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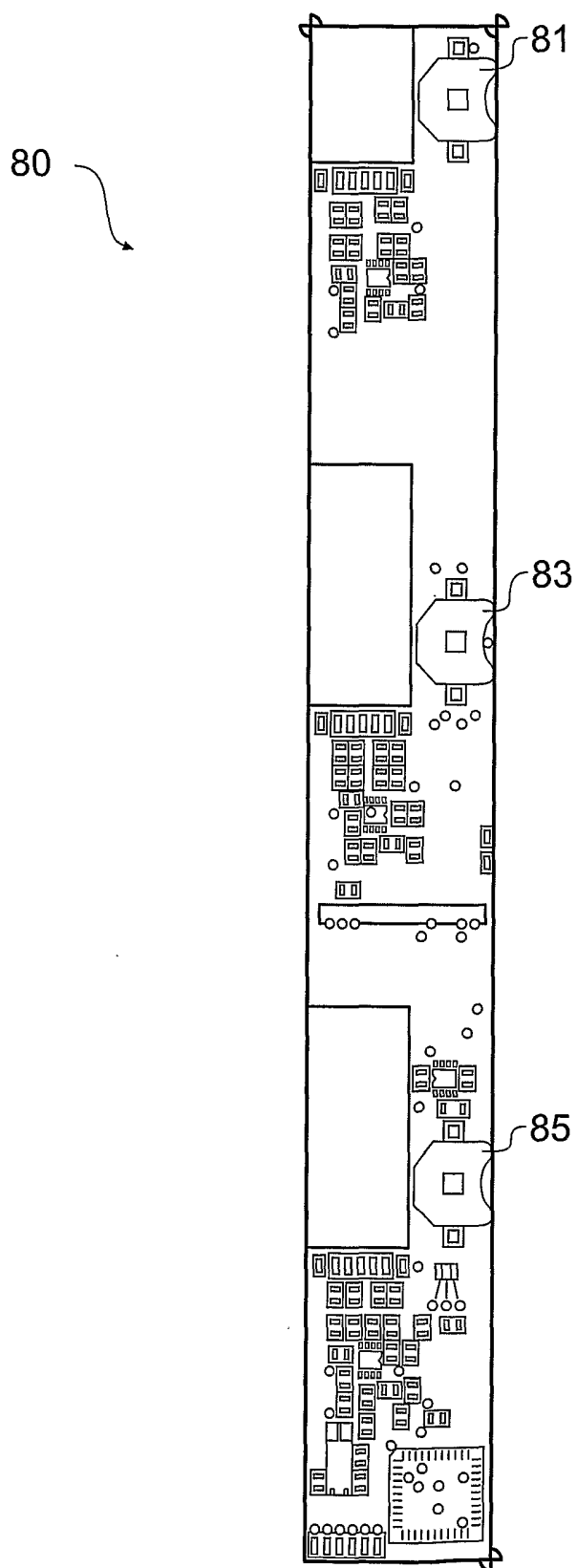


Fig. 9

# INTERNATIONAL SEARCH REPORT

International Application No

PCT/GB 03/03140

## A. CLASSIFICATION OF SUBJECT MATTER

IPC 7 G01L19/08 G01D5/00 G08C17/00 F04B49/00

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)

IPC 7 G01L G01D G08C F04B

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 practical, search terms used)

EPO-Internal

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category * | Citation of document, with indication, where appropriate, of the relevant passages                                   | Relevant to claim No. |
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| X          | DE 198 06 121 A (BMW ROLLS-ROYCE)<br>9 September 1999 (1999-09-09)<br>figure 1<br>---                                | 1                     |
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Further documents are listed in the continuation of box C.



Patent family members are listed in annex.

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"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.

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Date of the actual completion of the international search

26 September 2003

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## C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

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| A          | US 2002/050925 A1 (MR. ARMS ET AL.)<br>2 May 2002 (2002-05-02)<br>figure 1<br>-----                                                                                          |                       |

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Information on patent family members

International Application No

PCT/GB 03/03140

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