

(19) World Intellectual Property Organization
International Bureau



(43) International Publication Date
8 February 2001 (08.02.2001)

PCT

(10) International Publication Number
WO 01/09576 A1

(51) International Patent Classification⁷: G01H 1/00

(21) International Application Number: PCT/GB00/02885

(22) International Filing Date: 31 July 2000 (31.07.2000)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
9917877.4 30 July 1999 (30.07.1999) GB

(71) Applicant and
(72) Inventor: ATHERTON, Eric [GB/GB]; PRP Limited,
Rowan Court One, North Leigh Business Park, Woodstock
Road, North Leigh, Witney, Oxon OX8 6RM (GB).

(74) Agent: ROCK, Olaf, Colin; Rock & Company, Trelawn,
Cassington, Witney, Oxon OX8 1DN (GB).

(81) Designated States (*national*): AE, AG, AL, AM, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CN, CR, CU, CZ, DM, DZ, EE, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, PL, RO, RU, SD, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZW.

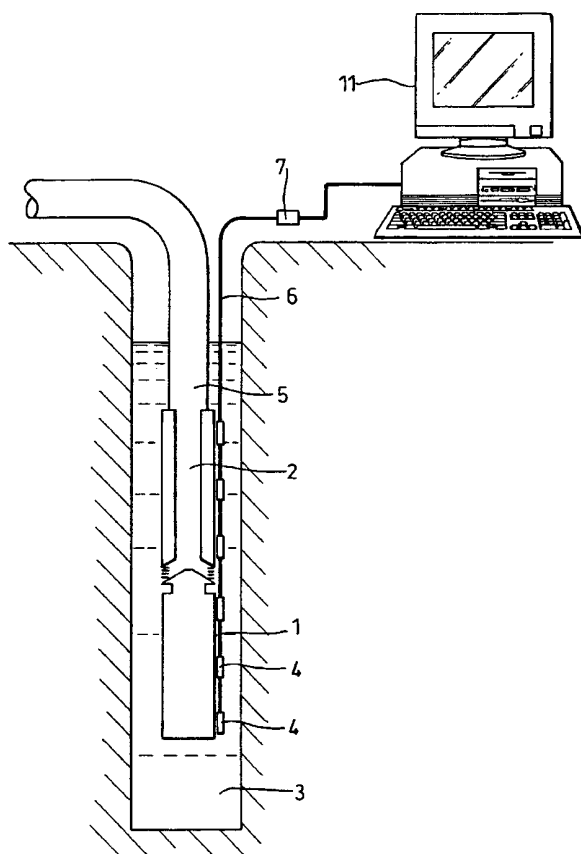
(84) Designated States (*regional*): European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).

Published:

- With international search report.
- Before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments.

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.

(54) Title: PLANT CONDITION MEASUREMENT



(57) Abstract: A method of monitoring remotely the condition of a machine which in operation generates vibration comprising the steps of: generating by means of an accelerometer (8) located on a selected position on the machinery (1) an output analogue signal representing a detected frequency of vibration as time domain data; converting the analogue signal to a digital signal and providing a sampled output of time domain data; all the aforesaid steps being undertaken by means located on or by way of the machine; and linking at least periodically the sampled output as aforesaid or data based on the sampled output to be transferred by a link to a remote data processing system (11).



WO 01/09576 A1

PLANT CONDITION MEASUREMENT

TECHNICAL FIELD

This invention relates to plant condition measurement. It is particularly, but not exclusively, concerned with an electrical submersible pump ('ESP') which is typically used to raise water or oil from boreholes. The ESP is supplied with power from the surface via an electrical cable. In some boreholes, no flow of fluid to the surface occurs without some sort of pumping mechanism such as an ESP. In other boreholes, the natural flow to surface is very slow, and can be enhanced by an ESP.

BACKGROUND ART

An ESP can be a very expensive device, and furthermore, the loss of production of an unscheduled failure may also be very costly. For this reason, attempts have been made to monitor the performance and condition of an ESP while in place at the bottom of a borehole. Such monitoring if successful may extend the life of the ESP, or at the very least provide an early warning of failure, so that a scheduled replacement may be undertaken.

Monitoring systems for an ESP can currently detect motor temperature, pump inlet and outlet pressures and also a vibration measurement, indicating the average vibration at one point in the ESP. The pressure values provide useful diagnostic information to monitor the efficiency of the pump in situ. The temperature of the motor can provide an early indication of an emerging problem. The averaged, single point, vibration reading however often proves less useful in detecting and diagnosing problems.

Condition monitoring of machinery at the surface is well known. Typically an accelerometer is mounted close to each likely area of failure, such as a bearing, so that many points on a machine are monitored. In addition, a broad range of frequencies is monitored, typically from a few cycles a second (Hz) up to 10kHz. The information is

obtained by rapidly sampling the vibration signal from the accelerometer, and then performing a mathematical manipulation known as a Fast Fourier Transform ('FFT') on this time domain data. The FFT is performed using a computer system, and the result is frequency domain data (the frequency spectrum). Analysis and trending of the frequency spectrum can often yield diagnostic information on the condition of the machine, and provide early warnings of impending failure.

To obtain a useful FFT for diagnostic purposes, high frequencies need to be transmitted from the accelerometer to the data acquisition equipment and computer system. This requires a relatively high bandwidth cable, such as coaxial cable. Unfortunately, it is difficult and expensive to obtain such cable suitable for permanent submersion, and so high bandwidth monitoring of an ESP has not been undertaken. In addition, if several points on the ESP are to be monitored, several high bandwidth cables to surface would be required.

The present invention allows multiple high bandwidth monitoring points on an ESP, using a standard submersible cable to convey the data to surface.

DISCLOSURE OF INVENTION

According to a first aspect of the present invention there is provided a method of monitoring remotely the condition of a machine which in operation generates vibration comprising the steps of:

generating by means of an accelerometer located on a selected position on the machinery an output analogue signal representing a detected frequency of vibration as time domain data;

converting the analogue signal to a digital signal and providing a sampled output of time domain data;

all the aforesaid steps being undertaken by means located on or by way of the machine; and

linking at least periodically the sampled output as aforesaid as aforesaid or data based on the sampled output to be transferred by a link to a remote data processing system. According to a first preferred version of the first aspect of the present invention there is provided the further steps following the converting step of undertaking a transform process such as a fast Fourier transform on the time domain data; and storing the results of the transform process; prior to the linking step.

According to a second preferred version of the first aspect or of the first preferred version thereof the linking step involves the transmission of data in digital format.

According to a third preferred version of the first aspect or of any preceding preferred version thereof the linking step is undertaken by way of a transmission line or a wireless link.

According to a second aspect of the present invention there is provided apparatus for monitoring remotely the condition of a machine comprising a unit for location on a selected position on the machine including:

- 1) an accelerometer having an output analogue signal representing a detected frequency of vibration at the location on the machine as time domain data;
- 2) an analogue to digital signal converter adapted to receive the output analogue signal and to provide a digital signal output representing the sampled data; and
- 3) a data storage device for the storage of the digital signal output; and a link output whereby, at least periodically, the data storage device or data based thereon can be transferred by way of the link to a remote data processing system.

According to a first preferred version of the second aspect of the present invention the unit further includes a processor adapted to undertake a transform process such as a fast Fourier transform on digital signal output representing frequency domain data time domain data prior to submission to the link output.

According to a second preferred version of the second aspect of the present invention or of the first preferred version thereof the processor is programmed to identify key elements or particular results following the transform process such as amplitude and frequency of highest peaks in the transform.

According to third [referred version of the second aspect of the present invention or of any preceding preferred version thereof the processor is used to establish operating parameters of the machine such as rotational speed by way of fundamental vibration frequency.

According to a fourth preferred version of the second aspect of the present invention or of any preceding preferred version thereof the unit includes a data logger.

According to a fifth preferred version of the second aspect of the present invention or of any preceding preferred versions thereof when adapted to provide information to a location remote from the unit by way of a transmission line or a wireless link

The present invention lends itself to a wide range of variants and applications.

In one embodiment a signal from the accelerometer is rapidly sampled using an analogue to digital converter ('ADC') in the same package as the accelerometer. The signal is sampled for a relatively short period of time. Typically the sample rate would be of the order of 20,000 times per second, and the sample period would be of the order of a tenth of a second, giving about 2000 samples. The data gathered during this period is stored in a local temporary memory, also in the same physical package. The data is then transmitted to a remote data logging or display instrument. The data is transmitted in digital format, allowing optional error correcting protocols to be used during transmission.

The rate of data transmission can be readily tailored to the quality of the transmission medium. For example, a slow radio telemetry link may take many seconds to transmit the data gathered during a small fraction of a second. In this way, the remote data logging or display instrument can obtain short bursts of high sample rate vibration data, containing information over a wide frequency range. This enables a 'Fast Fourier Transform ('FFT') to be performed on the data, and standard vibrational analysis methods to be used that require high frequencies to be analyzed, even though the transmission medium between the accelerometer and the remote data logging or display instrument has only a low bandwidth capability.

In another embodiment of the invention, the FFT is performed locally on the data stored in the temporary memory, by a local microprocessor. The total energy in specified frequency bands is then transmitted to the remote data logging or display instrument. This enables trends to be monitored, while only transmitting a fraction of the data contained in the entire set of samples, or full FFT. This takes even lower data transmission bandwidth. The local microprocessor may also be programmed to identify key elements in the FFT, and transmit an appropriate summary of the information. For example, the local microprocessor may identify the highest peaks in the FFT, and transmit their amplitude and frequency. In the case of monitoring rotating machinery, the frequency of the fundamental vibrational frequency can be used to indicate the rotational speed of the machine, which can be a useful diagnostic parameter.

In a further embodiment of the invention, a multi-drop transmission medium is used, so that many accelerometers, with their associated rapid sampling ADC and local temporary memory, can all share the same network.

A further embodiment of the invention enables the recording of vibrational information down a borehole, when there is no cable connection to the surface. In this case, the signal from a battery powered accelerometer is rapidly sampled using an

ADC for a relatively short period of time. The data gathered during this period is transferred to a battery powered data logger. A set of samples is only taken at infrequent intervals, so as to conserve the memory in the data logger. Typically, the accelerometer and ADC may be powered off between sets of samples, to conserve battery power. It is important to note that each set of samples contains high frequency vibrational information. Data logger memory is held to practical levels by only gathering sets of samples at long time intervals. The battery, accelerometer, memory and ADC are all housed in a waterproof case, suitable for submersion in boreholes.

The present invention has many applications other than for use in monitoring the condition of equipment in boreholes. It can usefully be applied to the monitoring of vibration in any location where it is not desirable to locate a computer system, and it is also not desirable to connect a high bandwidth data link to that location.

BRIEF DESCRIPTION OF DRAWINGS

The present invention will be illustrated with reference to the accompanying drawings of which:

Figure 1 shows diagrammatically a submersible pump located in a borehole;
and

Figure 2 shows in more detail a vibration monitoring package for use with the pump of Figure 1.

MODES FOR CARRYING OUT THE INVENTION

Figure 1 shows a motor 1 connected to submersible pump 2. The submersible pump 2 is located in a borehole 3 and water from the borehole is pumped to surface through tube 5. A power cable to the submersible pump is provided but is not shown. Six vibration monitoring packages 4 are positioned at strategic points on the motor 1 and pump 2 typically at bearing locations. The vibration monitoring packages 4 are connected together and to the surface interface box 7 by cable 6. The surface interface box 7 is connected to an external computer 11. The surface interface box 7 provides

power to the vibration monitoring package 4. The surface interface box 7 also interfaces a standard RS232 serial interface in the computer 11 for connection to a multi-drop RS485 interface to the vibration monitoring package 4 in a manner well known to those skilled in the art.

Figure 2 shows components inside a vibration monitoring package 4. Accelerometer 8 outputs an analogue voltage signal proportional to the acceleration being experienced by the accelerometer 8. This voltage signal is converted into a digital value by means of analogue to digital converter 9. The accelerometer 8 has a frequency response from 10Hz to 10,000Hz. The ADC 9 takes readings at the rate of 20,000 times per second. These readings are stored in microprocessor 10 that also contains memory. 2048 successive readings are taken and stored in microprocessor 10. After a set of 2048 readings have been taken, the microprocessor, 10, performs a FFT on the readings, storing the results in it's memory. The microprocessor 10 then scans the frequency spectrum, picking out the frequency and amplitude of the 10 largest peaks. The amplitude and frequency of these peaks are also stored in the memory.

The computer 11 interrogates each vibration monitoring package 4 in turn, and requests the amplitude and frequency data of the 10 largest peaks. The computer 11 then stores these values in a database, and displays trends of these values on the screen.

If a vibration fault trend is located at one particular vibration monitoring package 4 the operator of the computer 11 can request the full FFT from that location for detailed analysis on the surface.

Industrial Applicability

The particular application referred to is monitoring operation of an electrical submersible pump for water or oil in a bore hole. However the present invention can be adapted for use in a wide variety of applications. Given the existence of a machine

which in operation emits vibration then the present method and apparatus provides for vibrational frequency generated by the machine to be detected remotely and assessed as to whether it represents a value lying within an acceptable tolerance level or a value indicating the onset of a faulty condition in time to enable remedial action to be undertaken.

CLAIMS

- 1 A method of monitoring remotely the condition of a machine which in operation generates vibration comprising the steps of:
 - generating by means of an accelerometer located on a selected position on the machinery an output analogue signal representing a detected frequency of vibration as time domain data;
 - converting the analogue signal to a digital signal and providing a sampled output of time domain data;all the aforesaid steps being undertaken by means located on or by way of the machine; and
 - linking at least periodically the sampled output as aforesaid as aforesaid or data based on the sampled output to be transferred by a link to a remote data processing system.
- 2 A method of monitoring remotely as claimed in Claim 1 including the further steps following the converting step of
 - undertaking a transform process such as a fast Fourier transform on the time domain data; and
 - storing the results of the transform process;prior to the linking step.
- 3 A method of monitoring remotely as claimed in Claim 1 or Claim 2 wherein the linking step involves the transmission of data in digital format.
- 4 A method of monitoring remotely as claimed in any preceding claim wherein the linking step is undertaken by way of a transmission line or a wireless link.

- 5 Apparatus for monitoring remotely the condition of a machine comprising a unit for location on a selected position on the machine including:
- 1) an accelerometer having an output analogue signal representing a detected frequency of vibration at the location on the machine as time domain data;
 - 4) an analogue to digital signal converter adapted to receive the output analogue signal and to provide a digital signal output representing the sampled data; and
 - 5) a data storage device for the storage of the digital signal output; and
 - 4) a link output whereby, at least periodically, the data storage device or data based thereon can be transferred by way of the link to a remote data processing system.
- 6 Apparatus as claimed in Claim 5 wherein the unit further includes a processor adapted to undertake a transform process such as a fast Fourier transform on digital signal output representing frequency domain data time domain data; prior to submission to the link output.
- 7 Apparatus as claimed in Claim 5 or Claim 6 wherein the processor is programmed to identify key elements or particular results following the transform process such as amplitude and frequency of highest peaks in the transform.
- 8 Apparatus as claimed in Claim 5, 6 or 7 wherein the processor is used to establish operating parameters of the machine such as rotational speed by way of fundamental vibration frequency.
- 9 Apparatus as claimed in Claim 5, 6, 7 or 8 wherein the unit includes a data logger.

- 10 Apparatus as claimed in Claims 5, 6, 7, 8 or 9 adapted to provide information to a location remote from the unit by way of a transmission line or a wireless link.
- 11 A method of measuring plant condition as hereinbefore described with reference to the accompanying drawings.
- 12 Apparatus for measuring plant condition as hereinbefore described with reference to the accompanying drawings.

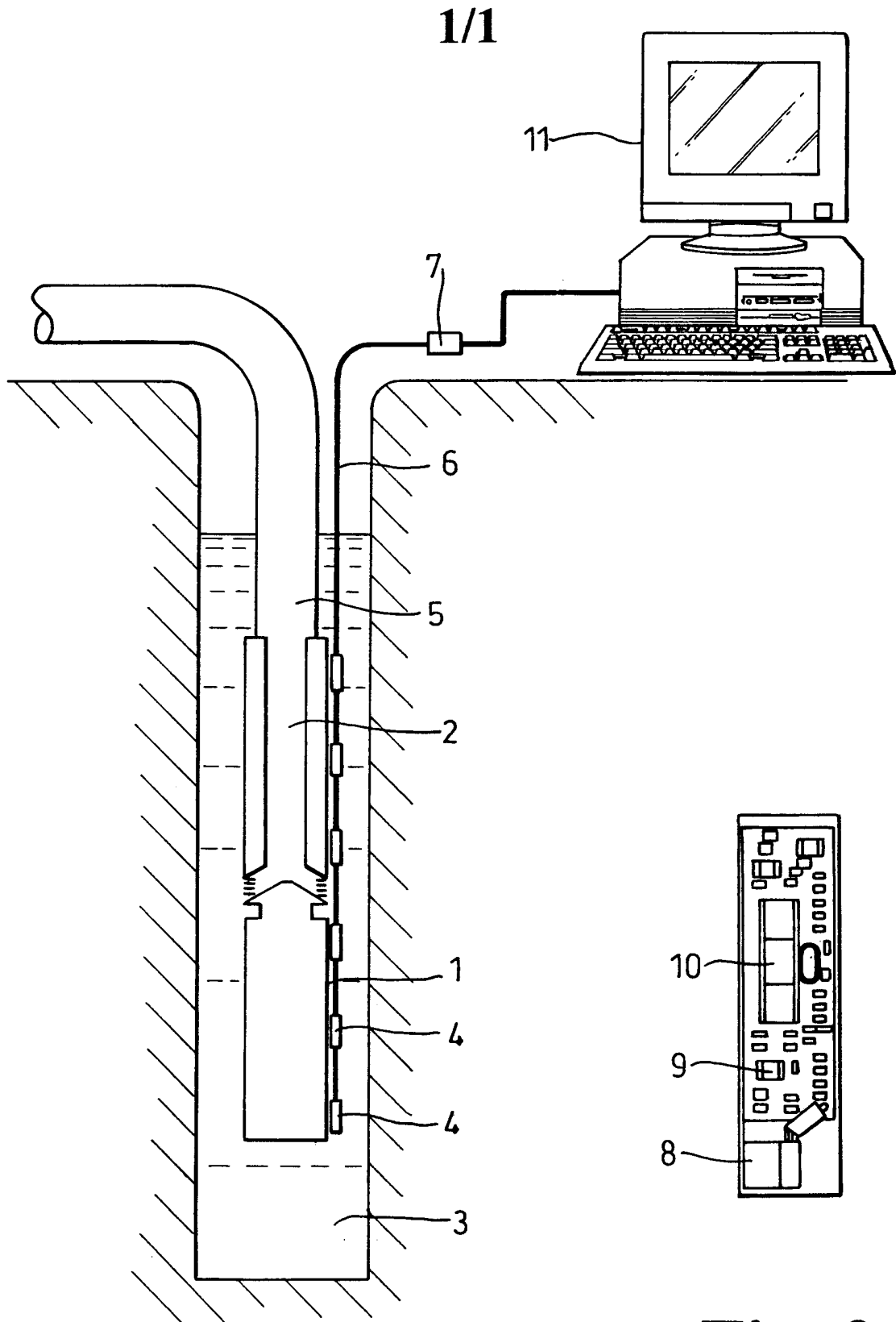


Fig. 1

Fig. 2

INTERNATIONAL SEARCH REPORT

Inter: nal Application No
PCT/GB 00/02885

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G01H1/00

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 G01H

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, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 4 885 707 A (NICHOL ROBERT E ET AL) 5 December 1989 (1989-12-05) column 1, line 58 -column 2, line 64 column 4, line 8 - line 58; claim 1	1-3,5,6, 9
Y	---	4,7,8,10
Y	US 5 907 491 A (CANADA RONALD G ET AL) 25 May 1999 (1999-05-25) claim 1	4,10
Y	---	7
Y	US 4 184 205 A (MORROW ROBERT S) 15 January 1980 (1980-01-15) claim 14	8
Y	US 4 903 245 A (CLOSE DAVID A ET AL) 20 February 1990 (1990-02-20) column 1, line 65 -column 2, line 28 claims 1,10	

Further documents are listed in the continuation of box C.

Patent family members are listed in annex.

° Special categories of cited documents :

- *A* document defining the general state of the art which is not considered to be of particular relevance
- *E* earlier document 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

30 November 2000

Date of mailing of the international search report

08/12/2000

Name and mailing address of the ISA
European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040, Tx. 31 651 epo nl.
Fax: (+31-70) 340-3016

Authorized officer

Schneiderbauer, K

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No

PCT/GB 00/02885

Patent document cited in search report	A	Publication date	Patent family member(s)	Publication date
US 4885707	A	05-12-1989	NONE	
US 5907491	A	25-05-1999	US 5854994 A EP 1023662 A WO 9845779 A DE 932890 T EP 0932890 A WO 9810393 A	29-12-1998 02-08-2000 15-10-1998 09-03-2000 04-08-1999 12-03-1998
US 4184205	A	15-01-1980	CA 1139881 A DE 2862285 D EP 0002232 A JP 54094061 A US RE31750 E	18-01-1983 28-07-1983 13-06-1979 25-07-1979 27-11-1984
US 4903245	A	20-02-1990	GB 2216661 A, B	11-10-1989