(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 0 836 159 A2

(12) EUROPEAN PATENT APPLICATION

(43) Date of publication:
**15.04.1998 Bulletin 1998/16**

(51) Int Cl.[6]: **G07C 3/00**, G07C 5/00

(21) Application number: **97650041.3**

(22) Date of filing: **07.10.1997**

(84) Designated Contracting States:
**AT BE CH DE DK ES FI FR GB GR IE IT LI LU MC NL PT SE**

(30) Priority: **09.10.1996 IE 960715**
**04.04.1997 IE 970250**

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(54) **Improvements in and relating to prime movers**

(57) A method of determining the probable wear experienced by a prime mover having moving parts which involves measuring the useful life of the prime mover under one particular operating condition and thus one rate of energy input e.g. fuel to arrive at an optimum life and then measuring the life under other operating conditions such as load and environment to obtain compensating factors which can be applied to the energy input under these operating conditions to get a measure of the probable accumulated wear and thus its potential future useful life.

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**Description**

The present invention relates to general wear and useful life assessment of prime movers having moving parts.

There are major problems in the running of internal combustion engines, motors, turbines and the like in that it is necessary to assess for maintenance and indeed for replacement the useful life of such prime movers. The extent of the problem can be relatively easily understood when one considers there are approximately 100,000,000 internal combustion engines produced in the world every year. Many of these and indeed the vast majority of them will operate under variable load conditions. The assessment of useful life under certain conditions, as well as the assessment as to when regular maintenance should be carried out, are major problems for the operators of the machines, equipment, vehicles, etc. incorporating such internal combustion engines. The problem becomes even more important when one considers the number of electric motors produced every year.

Heretofore one of the obvious and logical ways of assessing wear and the need for preventive maintenance has been to, for example with electric motors, measure the number of working hours and at pre-set time intervals either replace the electric motor or send it for maintenance. With vehicles and machinery generally, whether they be road vehicles, construction vehicles or stationary installations, one of the ways of assessing the wear and the necessity for either replacement as the wear was such as to make them uneconomic or the need for preventive maintenance has been to base such decisions on hours used, miles travelled or some other simple criteria.

These are obviously relatively crude indicators of wear. The only thing to be said in their defence is that over a useful life of a vehicle it will tend to run unladen a certain proportion of the time and thus laden the rest of the time. However, this takes no account whatsoever of the terrain or ambient operating conditions. Thus, for example, to suggest that a vehicle which travels 100 miles unladen or even laden on level terrain will experience the same wear on its engine as will a vehicle heavily laden operating in relatively hilly countryside is completely inaccurate.

What is required is a simple reliable method of assessing the wear on an engine or other prime mover so that at any time during its operation the operator may know its potential useful life or its potential useful life prior to a major overhaul being required.

In general terms, one could suggest that if one were to disassemble the prime mover, measure and examine the moving parts, it is possible to assess its potential wear. Nobody suggests this is not true, however, this is time consuming and expensive.

What is needed is a method of determining the wear experienced by a prime mover, having moving parts, during its useful life. Strictly speaking except by an exact measurement of the wear experienced it is obvious that any such measurement can only measure the probable wear experienced by a prime mover.

One of the more important problems which is experienced by those involved in the maintenance and operation of prime movers is the need in many situations to be over-cautious and careful in removing prime movers from service. Obviously examples are machines and prime movers where their malfunctioning could cause serious financial loss or even more importantly, such as for example, in the aerospace industry the loss of life. Thus, in the maintenance of aero-engines the engines are taken out of service for major overhauls in many instances a fraction of the time before such service is required: even though indeed the manufacturers and maintainers of jet engines have built up an impressive array of information which allows them predict with considerable accuracy the probable wear experienced by an engine. However, most of the collection techniques for information are not sufficient to enable the predictions to be made with sufficient accuracy and reliability. It is important not to ignore other forms of apparatus liable to wear such as stone and other materials crushers and grinders and process equipment generally through it is appreciated that in many instances these generally work at full or substantially full load or not at all and thus hours working may in many but not all instances form a relatively efficient measurement of potential wear.

For example it has been appreciated by, for example, engine manufacturers such as a described in U.S. Patent Specification No. 4,630,027 that total fuel consumption serves as a basic parameter for determining the service intervals within which a motor vehicle should be attended to, rather than simply distance travelled as was previously used. It has long been known that the distance travelled does not allow for sufficient monitoring of the actual load on an engine. It has been suggested that total fuel consumption is a good measure of total engine wear and indeed is in many instances, however, it is not sufficient because what is needed is to know what is the useful engine wear having regard to the total fuel input. U.S. Patent Specification No. 4,551,703 has another solution to this problem in which the maintenance service is indicated as a function of the total number of revolutions of an output shaft or any other rotary part and indeed the specification refers to optionally one or a plurality of additional operational parameters. However, neither of these specifications teaches how to achieve the aim of the present invention and what indeed should be the way of achieving it.

In this specification the term "prime mover" is used to include internal combustion engines, turbines, pumps, electric motors, and indeed any other machine or apparatus which converts one source of energy into an output which involves moving parts, which by their very nature are subject to wear and tear due to frictional and other losses. It must also be appreciated that the term "wear" is intended to embrace a somewhat wider meaning than simple wear as it is commonly understood in erosion of a part. For example lubricants may over time and when subject to certain use conditions will loose their effectiveness. Thus while this invention is primarily directed to wear per se and thus useful life of an engine the accumulated energy input over a period since for example the last replacement of a lubricant or operating fluid for the prime mover or parts associated therewith eg. brakes, of a vehicle may be a very accurate indication that other parts need to be attended to.

Further, the term "energy input" in this specification is used in the broadest sense of potential energy input. For example, the total energy available from a fossil fuel such as petrol may be many times in excess of the actual energy that can be converted efficiently by a petrol driven internal combustion engine. However, the energy input to the engine is directly related to the volume of petrol delivered to the engine. Thus, measuring the volume of petrol delivered to an engine effectively measures the energy input, not strictly speaking the gross energy inputted to the engine, but the amount of energy which the engine can efficiently convert into work output. Substantially the same considerations apply to other fuels such as diesel, natural gas, etc. and indeed the same applies, for example, to electricity where there is a much higher usage of the potential energy in an electric motor. However, whether one is delivering electricity which can be measured in kilowatts or fluidized or solid fuels, the total volume, weight or quantity of those fuels when measured effectively measures the energy input and for ease of reference in this specification they are referred to generally as energy inputs and fuels except when specific examples are being discussed.

In this specification the term "optimum base energy input" is a term used to indicate that total energy input to the engine which when the engine has received that total energy input would be such as to mean that the engine has experienced such wear as to have reached either its total useful life, when it should be scrapped, or some period within its life when it should be subjected to some form of maintenance procedure. This may in its simplest be an estimated total energy input or may be determined according to the invention. The term "environmental conditions" is used in this specification to cover general operating conditions of temperature, heat, altitude, dust, corrosive marine and other such conditions.

The present invention is directed towards providing a method of determining the probable wear experienced by a prime mover having moving parts at any stage during its operating life.

## Statements of Invention

According to the invention there is provided a method of determining the probable wear experienced by a prime mover having moving parts comprising the steps of:

measuring the energy input to the prime mover;

recording the accumulated energy input; and

comparing the accumulated energy input to the optimum base energy input to get a measure of the probable wear.

Thus, the present invention envisages storing in an information processor a measure of the amount of work that a prime mover is designed to perform and then feeding into the information processor the cumulative amount of work performed and then producing a measure of the useful life remaining or the percentage of the useful life expended and hence the prime mover wear. The fuel used and the fuel that should be used for the design life providing the necessary measure of output. It should be noted that this is not the same as in the prior attempts at achieving this result.

Essentially, for example, with a truck operating a diesel engine, what is measured is the amount of fuel being used by the engine which is a much more accurate assessment of the wear of the engine, than, for example, miles travelled or hours operated which can be relatively easily obtained from a tachometer. However, the measurement must be compared with a predetermined optimum base energy input.

The invention provides a method of determining the optimum base energy input which comprises the steps of:

measuring the energy input for a prime mover for idling, no load conditions;

determining the optimum life of the prime mover for idle conditions; and

determining the aggregate energy input for the optimum life to provide the optimum base energy input.

It has to be appreciated that engine manufacturers use dynamometers and other test equipment to provide this information and thus, accordingly, most of this information is already available from engine manufacturers. By simply determining this, one gets a relatively accurate measure of the potential life of the prime mover. Then, measuring the fuel input throughout the life, using the example mentioned above of a diesel engine, it is possible to get a relatively accurate assessment at any point in time of the probable wear of the moving parts of that particular diesel engine. Strictly speaking measuring for idling no load conditions is merely one measurement for a specific load output however it will generally be the case but not always that operating at idling or no load conditions under the most favourable environmental conditions will lead to the longest workable life and is thus useful.

The invention further provides a method in which the steps of:

measuring the energy input for a prime mover for a predetermined load output;

determining the optimum life of the prime mover for that load output;

determining the aggregate energy input for that optimum life;

dividing that energy input into the optimum base energy input to obtain a load compensating factor for that load output; and

storing that load compensating factor for that rate of energy input.

It will be appreciated that if this is done, then it is possible to carry out the method of the invention by the additional steps of:

measuring the energy input;

averaging the energy input over predetermined time intervals;

determining the correct load compensating factor for that energy input rate;

multiplying the energy input for that load compensating factor to get a corrected energy input; and

adding that corrected energy input to the previously accumulated base energy input.

This is a relatively simple method of further sophisticating and making more accurate the method of measurement according to the present invention. By taking account of particular load conditions such as maximum load, overload, idle conditions and ordinary operating conditions, it is possible to further increase the accuracy of the measurement of the actual work done by the engine or prime mover.

In a still further embodiment of the invention there is provided the steps of measuring the energy input of an auxiliary prime mover having at least two sources of energy input, namely a primary source and an auxiliary source comprising:

measuring the energy input from the primary source;

applying any load compensating factors to the energy input from the primary source;

storing the compensated primary energy inputted to the prime mover;

measuring the energy input from the auxiliary power source;

applying any load compensating factor and the source change compensating factor to the energy input from the auxiliary power source to obtain a corrected auxiliary power source input;

aggregating this auxiliary power source input with the stored primary energy input to obtain an accumulated energy input; and

comparing this accumulated energy input with the optimum base energy input to get a measure of probable wear.

It will be appreciated that this is a relatively simple way of, for example, assessing the wear on an internal combustion engine which operates, for example, both on petroleum spirit and gas.

According to the invention the method of the invention also comprises:

measuring the energy input to the prime mover for idling no load conditions;

(a) stopping the prime mover at a pre-set time interval;

(b) allowing the prime mover to remain stopped for a set time interval;

(c) re-starting the prime mover;

repeating steps (a) to (c) inclusive;

accumulating the energy input for optimum life;

subtracting this accumulated energy input from the base energy input to provide an accumulated lost energy input;

dividing the accumulated lost energy input by the number of stop/start cycles (a) to (c) to obtain a stop/start energy input equivalent to each stop/start of the engine.

The invention further provides measuring each time the engine starts adding a stop/start energy input to the accumulated energy input. The advantage of this is that in addition to having a correction factor for wear experienced due to different load conditions, it is possible to input a factor for stopping and starting. It has long been appreciated that an engine which is stopped and started regularly, for example, a motor car on relatively short runs is a lot more prone to wear than an engine which is run, for example, for 100 miles without stopping. Much more wear will be experienced by an internal combustion engine which has in 100 miles of running experienced forty stops and starts from cold, than will an engine which has been run continuously for 100 miles under favourable conditions or even one doing forty stops and starts but not from cold. A not inconsiderable advantage to a manufacturer of such equipment is that the data gathered in respect of the operating characteristics of a specific prime mover will allow a much more accurate assessment of claims by customers of non-performance or failure of prime movers supplied. A purchaser of equipment is also in a better position to assess the value of a potential purchase with this information available.

There are obvious safety implications for the invention not alone for the efficient running for example of aero-engines but for subsequent assessment in the event of failure within what is now a more correctly determined useful life.

It is also envisaged that the information obtained on taking a prime mover out of service may be compared with the actual wear achieved so that the measurement figures and base figures may be more accurately calculated.

It is envisaged that this measurement and assessment function may be ideally provided by standard instrumentation and by well known electronic equipment. Ideally a microchip will be provided carrying the necessary programming. Further the information may be recorded in some transfer proof instrumentation.

Detailed Description of the Invention

Some methods according to the invention will be described with reference to the accompanying diagrammatic sketches in which:-

Fig. 1 is a diagrammatic sketch of a layout of a measuring and recording apparatus according to the invention; and

Fig. 2 is a layout similar to Fig. 1 of another measuring and recording apparatus.

Referring to Fig. 1 there is illustrated a prime mover in this example a diesel engine 1 having a diesel supply pump 2 which incorporates a flow recording meter. The flow recording meter in turn feeds a micro-processor 3 which in turn delivers information to a recording instrument 4 on the dashboard of the vehicle.

In use, the flow of fuel is measured in the pump 2 and the micro-processor 3 receives the information, analyses in accordance with the methods described above, depending on the sophistication of the method being used and delivers the information to the instrument 4 so that the driver has displayed on the instrument the potential wear which potential wear will allow the driver to decide when routine maintenance is required, as it will be appreciated that the engine may not have worn appreciably, but if the amount of potential wear is such to suggest that possibly oil needs replacing etc. It will also give a much more accurate assessment of the wear on the engine to any potential purchaser.

Referring to Fig. 2 there is illustrated another prime mover in this case a petrol I.C. engine 10 having a petrol pump 11 and a gas pump 12. It will be appreciated that both the petrol pump 11 and the gas pump 12 have ancillary equipment. Both the petrol pump 11 and the gas pump 12 feed information to a micro-processor 13 which in turn feeds information to a recording dial 14 on the dashboard of the vehicle.

In this embodiment of the invention methods as described above are carried out. The necessary corrections being made for the fact that the gas is now an auxiliary fuel and source of energy input to the engine.

There are provided a plurality of suitable environmental and prime mover condition sensing devices which may be used to provide various load compensating factors.

For example, the altitude, ambient temperatures, humidity and air composition generally may have a considerable effect on the operation of an IC engine and thus it is envisaged that suitable ambient condition analysis and recorders may be used to further provide load compensating factors.

Similarly it has long been appreciated that temperature is a major factor in the wear of many materials whether they be subject to friction inducing wear between contacting parts or simply subjected to heat, an example of the former being a reciprocating piston and the latter an indirect combustion chamber. Thus, measurements of temperature will in many instances be the prime data required.

It is envisaged therefore that in addition to measuring the energy input from the primary source that the load compensating factors applied will be those appropriate for not just simply the environmental conditions but also for the actual prime mover conditions of which temperature will in most instances be the most important. The particular parts or portion of the prime mover the temperature of which will be measured will vary from prime mover to prime mover. In some instances it will be bearing temperatures, in others lubricant temperatures, engine wall temperatures, etc.

A further problem particularly with respect to internal combustion engines and other fume or other pollutant emitting prime movers is the need to control this. In some countries for example it is obligatory for safety and environmental reasons to carry out routine maintenance and inspections after preset time intervals. These again are relatively crude controls. However, the recording of the wear of a prime mover in a manner that cannot be tampered with would allow inspections to be more easily carried out by the relevant authorities.

Further the invention envisages the determination by measurement of environmental and prime mover conditions and the recording and comparison of these against energy input and the existing measure of probable wear to determine the potential pollutant emission of the prime mover under those conditions.

Further, there is envisaged means for preventing the operation of the prime mover above a predetermined level of potential pollutant emission.

It will be appreciated that on further consideration of the various factors affecting the wear of an engine for its particular operating conditions that other correction factors and other measurements may be required.

It will also be appreciated with the present construction of micro-processor, programmable chip, etc. that this can be relatively easily and cheaply achieved. It is also envisaged that manufacturers already have most of this information available to them, which information is achieved from test results carried out in their factories prior to launching a new engine on the market.

In many instances particularly for assessment of the operation of an engine at design and testing stages it will be advantageous to run the prime mover outside design capacity eg. overload, adverse environmental conditions generally and assess the likely effect on overall useful life of such operation.

It is also envisaged that initially there may not be enough data available on the operating characteristics of many a prime mover to provide accurate load compensating factors as described above. In the initial stages it may be necessary to either estimate those or gather the data by recorders and the equipment described above from a number of prime movers after removal from service to provide data which can be subsequently mathematically analysed eg. by inputting into linear equations.

Such analysis will undoubtedly lead to the provision of graphical representations of likely engine performance under predicted conditions.

While in the embodiments above relatively elaborate methods have been used and described to achieve the objects of the invention it is envisaged that after operation of the methods of the invention for some considerable time that different measurement parameters may be achieved. For example, and purely for illustrative purpose, it may be found that after all the measurements have ben carried out on a type of diesel engine fitted to various road vehicles and operating under different conditions that for example the fuel usage per mile is as accurate a measure of engine condition as any other.

## Claims

**1.** A method of determining the probable wear experienced by a prime mover having moving parts comprising the steps of:

measuring the energy input to the prime mover;

recording the accumulated energy input; and

comparing the accumulated energy input to the optimum base energy input to get a measure of the probable wear.

**2.** A method according to claim 1 comprising the steps of:

measuring the energy input for a prime mover for idling, no load conditions;

determining the optimum life of the prime mover for idle conditions; and

determining the aggregate energy input for the optimum life to provide the optimum base energy input.

**3.** A method according to claim 1 or 2 comprising:

measuring the energy input for a prime mover for a predetermined load output;

determining the optimum life of the prime mover for that load output;

determining the aggregate energy input for that optimum life;

dividing that energy input into the optimum base energy input to obtain a load compensating factor for that load output; and

storing that load compensating factor for that rate of energy input.

**4.** A method according to claim 3 in which the environmental conditions are measured and the load compensating factor is determined for specified load output and environmental conditions.

**5.** A method according to claim 3 or 4 in which a predetermined operating condition of the prime mover is measured and the load compensating factor is determined for specified load output and prime mover operating conditions.

**6.** A method according to any of claims 3 or 5 in which load conditions are chosen from optimum load, maximum load overload by different amounts and other load conditions.

**7.** A method according to any of claims 3 to 6 in which there is carried out the additional steps of:

measuring the energy input;

averaging the energy input over predetermined time intervals;

retrieving the correct load compensating factor for that energy input rate;

multiplying the energy input for that load compensating factor to get a corrected energy input; and

adding that corrected energy input to the previously accumulated base energy input.

**8.** A method according to any preceding claim applied to a prime mover having at least two sources of energy input, namely a primary source and an auxiliary source comprising:

measuring the energy input from the primary source;

applying any load compensating factors determined for the primary source to the energy input from the primary source;

storing the compensated primary energy inputted to the prime mover;

measuring the energy input from the auxiliary power source;

applying any load compensating factor determined for the auxiliary source to the energy input from the auxiliary power source to obtain a corrected auxiliary power source input;

aggregating this auxiliary power source input with the stored primary energy input to obtain an accumulated energy input; and

comparing this accumulated energy input with the optimum base energy input to get a measure of probable wear.

**9.** A method according to any preceding claim comprising:

measuring the energy input to the prime mover for idling no load conditions;

(a) stopping the prime mover at a pre-set time interval;

(b) allowing the prime mover to remain stopped for a set time interval;

(c) re-starting the prime mover;

repeating steps (a) to (c) inclusive;

accumulating the energy input for optimum life;

subtracting this accumulated energy input from the base energy input to provide an accumulated lost energy input;

**10.** A method according to claim 8 in which the stop/start energy input is calculated under idling conditions.

**11.** A method according to claim 10 or 11 in which each time the engine is stopped a stop/start energy input is added to the accumulated energy input.

**12.** A method according to any preceding claim in which any of the energy inputs and other operating conditions measured over the prime movers life to provide the measure of probable wear are stored to provide an assessment of the accuracy of the prediction.

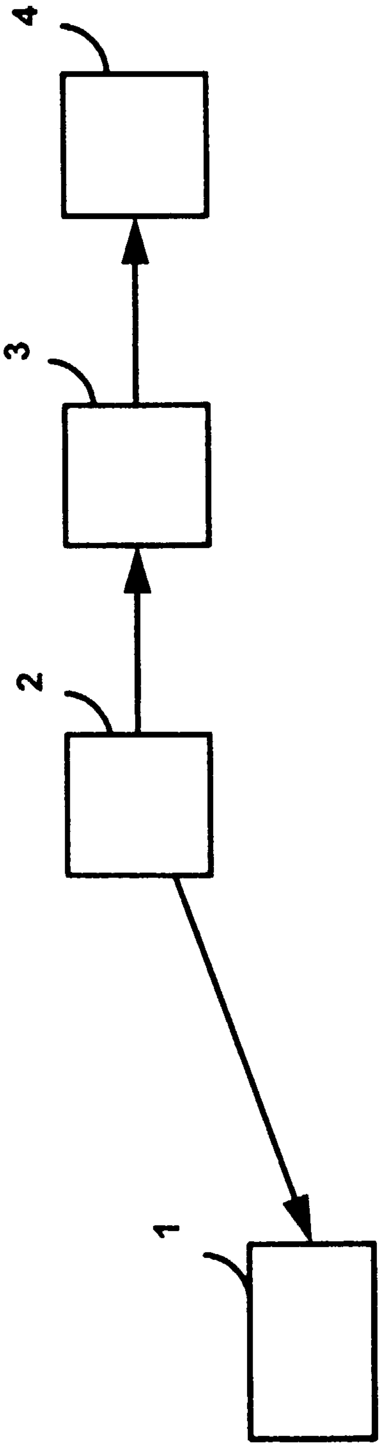


Fig.1

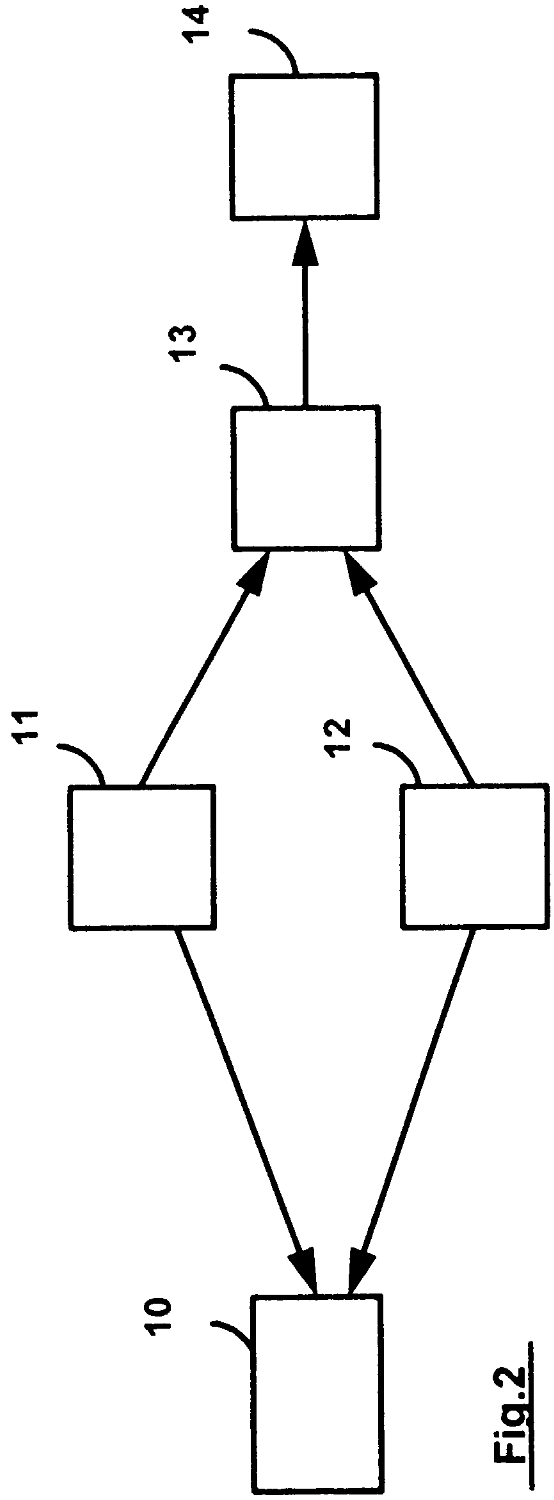


Fig.2