

(19)



(11)

EP 2 400 466 A1

(12)

EUROPEAN PATENT APPLICATION

(43) Date of publication:

28.12.2011 Bulletin 2011/52

(51) Int Cl.:

G07C 5/00 (2006.01)

F01D 21/00 (2006.01)

(21) Application number: **10175368.9**

(22) Date of filing: **06.09.2010**

(84) Designated Contracting States:

**AL AT BE BG CH CY CZ DE DK EE ES FI FR GB
GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO
PL PT RO SE SI SK SM TR**

Designated Extension States:

BA ME RS

(71) Applicant: **MTU Aero Engines GmbH**
80995 München (DE)

(72) Inventor: **Pfoertner, Hugo**
82041 Oberhaching (DE)

(30) Priority: **24.06.2010 EP 10167224**

(54) **A method and a system for monitoring a life usage of an engine part**

(57) A method for monitoring a life usage of at least one engine part of an engine (2) comprising the steps of:
(a) detecting (S1) engine parameters of each monitored engine part of said engine (2) to provide engine parameter data of the respective engine part;
(b) synchronizing (S2) the detected engine parameter data of said engine part to a common time basis;
(c) converting (S3) the synchronized engine parameter data of the respective engine part to derived stress-like parameter data for all detected engine parameters of said engine part; and
(d) calculating (S4) a damage value for the respective engine part on the basis of the converted stress-like parameter data to assess the life usage of the engine part.

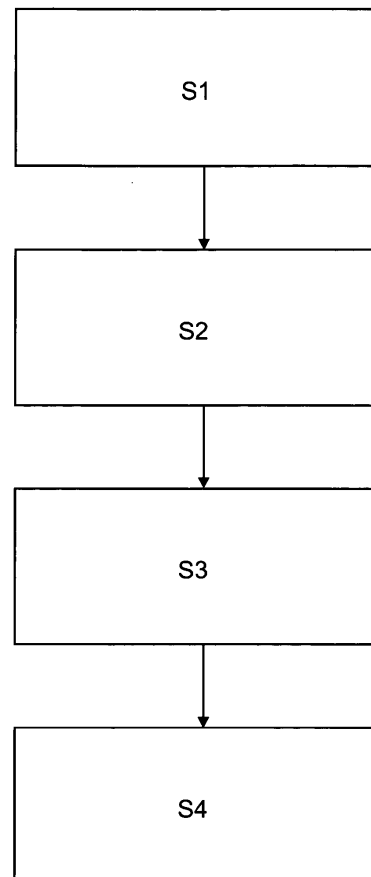


Fig. 3

EP 2 400 466 A1

Description

[0001] The invention relates to a method and a system for monitoring a life usage of at least one engine part of an engine which can be provided for powering a vehicle such as aircraft.

[0002] Life usage monitoring systems have been proposed for aircraft which use an embedded computer installed in the aircraft or as part of the engine control system to assess the life usage of a fixed selection of components of the aircraft by means of specific algorithms. These algorithms are typically developed during the development process of the engine or the aircraft. A major disadvantage of such conventional life usage monitoring systems is that the implemented algorithms can not take into account experiences from actual engine operations in a realistic environment. There are numeral examples of components starting to fail, e. g. by occurrence of cracks, at unexpected areas and by damage mechanisms that had not been adequately considered during the definition of the life usage algorithms employed by these conventional life usage monitoring systems.

[0003] Accordingly, it is an object of the present invention to provide a method and a system for monitoring a life usage of engine parts which allow a more reliable monitoring of life usages of engine components.

[0004] This object is achieved by a system for monitoring a life usage of at least one engine part of an engine comprising:

detectors for detecting engine parameters of said engine to provide engine parameter data affecting the physical conditions relevant for the respective engine part,
a synchronization unit which synchronizes the detected parameter data of said monitored engine part to a common time basis,
a conversion unit which converts the synchronized parameter data of the respective engine part to derived stress-like parameter data of said engine part, and
a calculation unit which calculates a damage value for the respective engine part on the basis of the converted stress-like parameter data to compute the life usage of said engine part.

[0005] In a possible embodiment the monitored engine part is a rotating engine part of an engine within a vehicle such as an aircraft.

[0006] In an alternative embodiment the monitored engine part is a non-rotating engine part of an engine provided within a vehicle such as an aircraft.

[0007] The monitored engine part can be any engine part of a complex device within a vehicle such as an aircraft.

[0008] In a possible embodiment of the system for monitoring a life usage of an engine part according to the present invention the detectors comprise sensors attached to the engine or located within the vicinity of the engine, wherein said sensors measure engine parameters of the monitored engine parts of said engine to provide engine parameter data of all monitored engine parts which are stored temporarily in a local data storage.

[0009] In a possible embodiment the detected engine parameter data stored in the local data storage are uploaded via a wireless or wired data interface to the synchronization unit of the system or stored on a removable storage medium which can be removed and be replaced by an empty medium.

[0010] The invention further provides a vehicle comprising at least one engine and an onboard system for monitoring a life usage of at least one engine part of the engine wherein said monitoring system for monitoring a life usage of at least one engine part of the engine comprises:

detectors for detecting engine parameters for each monitored engine part of said engine to provide engine parameter data of the respective engine part,
a synchronization unit which synchronizes the detected parameter data of the monitored engine part to a common time basis,
a conversion unit, which converts the synchronized parameter data of the respective engine part to derived stress-like parameter data for all detected engine parameters of said engine part and a calculation unit which calculates a damage value for the respective engine part on the basis of the converted stress-like parameter data to compute the life usage of said engine part.

[0011] In a possible embodiment the vehicle is an aircraft.

[0012] In a further possible embodiment the vehicle is a helicopter.

[0013] The invention further provides a method for monitoring a life usage of at least one engine part of an engine comprising the steps of

detecting engine parameters for the monitored engine part of said engine to provide engine parameter data of the respective engine part;

synchronizing the detected engine parameter data of said engine part to a common time basis; converting the synchronized engine parameter data of the respective engine part to derived stress-like parameter data for all detected engine

parameters of said engine part; and calculating a damage value for the respective engine part on the basis of the converted stress-like parameter data to assess the life usage of said engine part.

[0014] In a possible embodiment of the method according to the present invention the engine parameters are detected by means of sensors which generate engine parameter data stored temporarily in a data storage.

[0015] This data storage can be a local data storage connected to parameter detectors of the engine.

[0016] In a further possible embodiment of the method according to the present invention engine parameter data provided by sensors with a high acquisition rate by detectors are low-pass filtered before being uploaded from the data storage to a synchronizing unit performing a synchronization of the received engine parameter data.

[0017] In an embodiment of the method according to the present invention the uploaded engine parameter data are synchronized to a common time basis by the synchronization unit by interpolation over time.

[0018] In a possible embodiment of the method according to the present invention the synchronization unit performs a blended quadratic interpolation of the uploaded parameter data over time.

[0019] In a still further embodiment of the method according to the present invention the synchronization unit performs a linear interpolation of the uploaded parameter data over time.

[0020] In an embodiment of the method according to the present invention the detected engine parameter data is tagged with time information data indicating the time of the detection of the respective data.

[0021] In a further possible embodiment the detected engine parameter data is tagged with engine information data indicating the type and configuration of the respective engine.

[0022] In a still further embodiment of the method according to the present invention the uploaded engine parameter data and the calculated damage values of engine parts are stored over the whole engine life of said engine in a data base for further processing.

[0023] In a possible embodiment of the method according to the present invention if the calculated damage value of the engine part exceeds a threshold value an indication signal is generated indicating that the respective engine part is to be replaced or is to be maintained.

[0024] In a possible embodiment the threshold value can be adapted.

[0025] In a further embodiment if the engine part is a critical engine part the engine start can be inhibited automatically if the calculated damage value of the engine part exceeds a certain threshold value.

[0026] In a further possible embodiment of the method according to the present invention the life usage of the respective engine part is assessed depending on the calculated damage value of said engine part and engine operation data of the engine.

[0027] In a possible embodiment the engine operation data of the engine comprises engine running time data, engine temperature data, engine speed data, engine torque data, and engine pressure data.

[0028] In the following possible embodiments of the system and method for monitoring a life usage of at least one engine part of an engine are described with reference to the enclosed figures.

Fig. 1 shows a block diagram of a possible embodiment of a system for monitoring a life usage of an engine part according to the present invention;

Fig. 2 shows a block diagram of a further possible embodiment of a system for monitoring a life usage of an engine part according to the present invention,

Fig. 3 shows a flowchart of a possible embodiment of a method for monitoring a life usage of an engine part according to the present invention.

[0029] As can be seen from Fig. 1 a system 1 for monitoring a life usage according to the present invention is provided for at least one engine 2 consisting of several or a plurality of engine parts or engine components. In the embodiment shown in Fig. 1 the system 1 monitors engine parts of one engine 2. In alternative embodiments the system 1 can be provided for monitoring a life usage of engine parts of different engines 2 in parallel. The engine 2 shown in Fig. 2 can be an engine of a vehicle in particular of an aircraft or of an helicopter. The engine 2 consists of a plurality of engine components or engine parts. These engine parts can be rotating engine parts or non-rotating engine parts. The engine parts can be for example blades, a turbine rotor or non-rotating parts with high thermal loads leading to thermo-mechanical stress or other damaging processes like oxidation or creep.

[0030] Accordingly, the engine 2 shown in Fig. 2 can be integrated in the vehicle or can form a stand-alone device such as a turbo machine in a power plant or in a chemical processing plant or in transport an conversion of natural oil or gas. The system 1 for monitoring a life usage of at least one engine part within the engine 2 comprises several detectors 3-1, 3-2, 3-3, 3-4 for detecting engine parameters of monitored engine parts of said engine 2 to provide engine parameter data of the respective engine part. The detectors 3-1, 3-2, 3-3, 3-4 can comprise sensors which are attached to the engine 2 or located within the vicinity of the engine 2. The detectors as shown in Fig. 4 can detect engine parameters

of the engine 2 such as rotational speeds, torques, gas, temperatures, pressures, fuel flow, actuator positions but also environmental conditions such as air temperature or pressure.

[0031] The detected engine parameters of all monitored engine part of the engine 2 are supplied via signal lines or a data bus to a synchronization unit 4. The synchronization unit 4 synchronizes the detected parameter data received from the detectors of the respective monitored engine part of the engine 2 to a common time basis. In a possible embodiment the detected engine parameter data is stored first temporarily in a local data storage before being supplied to the synchronization unit 4. The detected engine parameter data stored in this local data storage can be uploaded via a wireless or wired data interface, or by a removable storage medium to the synchronization unit 4.

[0032] It is possible to store first the measured engine parameters in a raw data format before supplying the data to the synchronization unit 4. In a possible embodiment the engine parameter data provided by the detectors 3-1, 3-2, 3-3, 3-4 is stored in the local data storage and can be preprocessed. For example, engine parameter data provided by sensors with a high acquisition rate can be low-pass filtered before being uploaded from the data storage to the synchronization unit 4. The engine parameter data of one monitored engine part can come from different data sources or sensors. In a possible embodiment the detected engine parameter data is tagged with information data allowing to merge data from different data sources or sensors using real time tags attached to the parameter data. In a possible embodiment the engine parameter data is tagged with time information data indicating the time when the engine parameter data is detected by the corresponding detector 3-1, 3-2, 3-3, 3-4. Furthermore, the detected engine parameter data can be tagged with engine information data indicating the type and configuration of the respective engine part or engine 2, from which the detected engine parameter data are derived. Merging of data from different data sources is performed using these kind of real time tags attached to all data. Afterwards the merged data is synchronized by the synchronization unit 4 to a common time basis by interpolation of a time. This can be performed after a preprocessing or rate reduction by a combination of low-pass filtering, discarding of superfluous data and interpolation. Such data can be tagged with calendar and time information and with information about the engine 2 or even about the vehicle in which the engine 2 is implemented. The vehicle can be an aircraft but also a car or a truck moving on land. Furthermore, it is possible that the vehicle is a ship or a boat run by the engine 2. The time and configuration tags are maintained in a preferred embodiment with the engine parameter data over the whole life of the engine 2 and its associated parts in a database. If several engines 2 are installed within the same vehicle the location of the engine 2 within the vehicle can also be part of the stored data. In a possible embodiment also global configuration information data of the vehicle is stored in the data base.

[0033] As can be seen in Fig. 1 the synchronization unit 4 is connected to a conversion unit 5 which converts synchronized parameter data received from the synchronization unit 4. In a possible embodiment the synchronization unit 4 performs a blended quadratic interpolation of the uploaded parameter data over time. The data can be interpolated independently for each signal or fixed points in absolute time, e. g. at full seconds of UTC (in real time). In a preferred embodiment the synchronization unit 4 performs a blended quadratic interpolation in which the interpolated value within the segment of overlap is computed from a weighted mean of two parabolas.

[0034] When a longer period of discarded data has to be filled and any of the ratios of lengths between the involved intervals exceeds a given factor such as 5 then a linear interpolation is used instead of the blended quadratic interpolation by the synchronization unit 4.

[0035] The conversion unit 5 receiving the synchronized parameter data from the synchronization unit 4 converts the synchronized parameter data of the respective engine part to derived stress-like parameter data for all detected engine parameters of the respective engine part within the engine 2. Life usage associated with a cyclic damage mechanism can be assessed using the assumption that every cycle of a stress-like derived parameter can be independently converted into a damage increment, the summation of which produces a total damage of the respective engine part. To derive stress-like parameters from the set of measured input parameters conversions have to be applied since most engine parameters do not have the dimension of stress or force, with the exception of measured pressure which is already of proper dimension. Further input engine parameters received by the conversion unit 5 from the synchronizing unit 4 are converted as follows.

[0036] Spool speeds of rotating engine parts are squared, assuming the main stress contribution is caused by centrifugal forces. Torques can be used without conversion assuming that shear stresses are proportional to torques. Temperatures are used as differences assuming that thermal stresses are proportional to differences of temperatures at different locations of the components. The converted parameter data is applied by the conversion unit 5 to a calculation unit 6. The calculation unit 6 calculates a damage value for the respective engine part on the basis of the converted stress-like parameter data received from the conversion unit 4. The calculation unit 6 calculates a damage value for the respective engine part on the basis of the converted stress-like parameter data of the engine part to compute a life usage of the respective engine part. If the calculated damage value of the engine part exceeds a threshold value the calculation unit 6 can output a warning or indication signal to an operator 7 as shown in Fig. 1. The generated indication signal can indicate that the respective engine part has to be replaced or to be maintained. If the engine part is a critical part and the calculated damage value exceeds a certain threshold to a certain extent the calculation unit 6 can apply in a possible

embodiment a inhibit start control signal to inhibit start of the engine 2 or to switch the engine 2 into a safe operation mode to avoid damages.

[0037] In a possible embodiment the calculation unit 6 calculates the damage value of said engine part by using also engine operation data of the engine 2. The engine operation data can comprise engine running time, engine temperature data, engine speed data, engine torque data and engine pressure data of the engine 2. The data can also be used for assessment of the component life usage. For example, a detector can measure the inlet temperature occurring with maximum power of the engine 2 or the inlet temperature average over the whole engine run. Engine operation can comprise data maximum values of most important engine parameters such as spool speeds, compressor exit temperature and compressor exit pressure. In a possible embodiment engine operation data can be turbine blade temperature, turbine exit gas temperature, torque of power producing shaft and maximum speed of the vehicle during operation. Furthermore, a possible engine operation data can be a maximum altitude reached during a mission of a an vehicle or aircraft. In a further possible embodiment the engine operation data comprises energy produced by the engine 2, i.e. by a summation of the product shaft speed time torque.

[0038] In the system 1 according to the present invention cycles of stress-like parameters are used to calculate one or more artificial damage values. The cycles can consist of a pair of stress-like parameters that are extremes in the time history of the considered stress-like parameter and can be independently converted into an artificial damage according to the so-called Miner's rule. Damage computed by the calculation unit 6 from stress-like values can be expressed in units of so-called reference cycles. A reference cycle is a damage that results from a change of a stress-like parameter between its value when the engine 2 or apparatus is not running and the value that the stress-like parameter assumes when the engine 2 is working at the maximum design load, but excluding conditions when the engine 2 works outside its normal operating range, i.e. for emergency situations in which significant overload with serious damage and subsequent part change or repair is known to occur.

[0039] For a civil aircraft engine the reference operating conditions are typically those that occur when maximum power is needed, e.g. during take-off or climb of the fully loaded aircraft under adverse environmental conditions. For certain stress-like parameters other operating points might be those determining the reference conditions.

[0040] Damage is to be understood as an increase in the probability of the engine part to fail by failure mechanisms which is understood to be driven by the application of a time history of loads that are strongly correlated with one or more stress-like parameters. This is usually associated with changes in the micro-structure of the loaded material. Damage in this sense can usually not be seen by measurement or the inspection of an engine part, unless it is already in a late phase where the engine part exhibits cracks that are visible or can be detected by one of the non destructive inspection methods. Accordingly, the system and method according to the present invention allows to detect a possible damage at an early stage so that the effected engine part can be maintained or replaced in time thus avoiding failure of the engine part and even a possible failure of the complete engine 2. The system and method according to the present invention increase the safety when operating an engine 2 implemented in a vehicle.

[0041] Fig. 2 shows a further possible embodiment in the system 1 for monitoring a life usage of at least one engine part of an engine 2. In the shown embodiments the engine 2 is implemented in a vehicle 8 such as an aircraft. Detectors 3-1, 3-2, 3-3, 3-4 detect engine parameters of the monitored engine parts of the engine 2 to provide engine parameter data of the respective monitored engine part to a local data storage 9 located within the aircraft 8. The parameter data in the local storage 9 can be preprocessed by low-pass filtering and be supplied to a transmitting unit 10 of the aircraft 8 which uploads the data via a wireless link to a receiving unit 11 being connected to the synchronizing unit 4.

[0042] In alternative embodiment the data stored in the local data storage 9 is uploaded by the transmitting unit 10 via a wired data interface to the receiving unit or the data is written to a removable storage medium which is physically removed and replaced by an empty medium. For example if the aircraft 8 is grounded and stands at an airport a wired data interface can be provided between the transmitter 10 and the receiver 11. In case that the aircraft is airborne with the embodiment shown in Fig. 2 it is possible to transmit engine parameter data stored in the local data storage 9 of the aircraft during flight to ground.

[0043] In a possible embodiment the data is for example transmitted via a satellite link to an on ground monitoring station. This embodiment provides the advantage that an engine part of the engine 2 which has to be maintained or replaced can be detected before the aircraft 8 is landing. Accordingly, the maintenance crew on the target airport can make the necessary preparations for replacing or maintaining the affected engine part. Therefore the time necessary for replacing or maintaining the engine part can be significantly reduced. In a possible embodiment the monitoring system can send the necessary information via a data network such as the Internet to a terminal of the target airport informing the maintenance crew at the target airport about the necessary maintenance. If the affected engine part as a critical part and the detected damage is high the security system can also inform the crew of the aircraft 8 about the defect engine part.

[0044] Fig. 3 shows a flowchart of a possible embodiment of a method for monitoring a life usage of at least one engine part of an engine 2.

[0045] In a first step S1 parameters for each monitored engine part of the engine 2 are detected to provide engine parameter data of the respective engine part. These engine parameter data can be provided by sensors with a certain

acquisition rate. The engine parameter data can be detected by means of sensors which generate parameter data which are stored temporarily in a data storage. Sensors can be located in the vicinity of the observed engine part or attached to the respective engine part. In a possible embodiment the detected parameter data can be preprocessed. For example engine parameter data provided by a sensor with a high acquisition rate can be low-pass filtered before being uploaded from a data storage to a synchronization unit.

[0046] In a still a further embodiment a plausibility check of the input data can be performed during preprocessing. The plausibility check of data can consider the range, change rate of the received data and perform a necessary correction by discarding non plausible input data. Low-pass filtering can be applied to data with a high constant acquisition rate. In an embodiment of the filter output every K-th value is retained, where K is chosen as large as possible to fulfil the conditions of the remaining data having an update rate equal or greater than the repetition rate of the processing steps of the life usage algorithms employed by the system. For example, if the update rate of data is every 40 ms and the repetition rate of life usage functions is every 500 ms every 12th value of the filter output is fed into the subsequent interpolation step performed by the synchronization unit 4. Thus, the interpolation can use data with an update time of 480 ms.

[0047] After having detected the engine parameters in step S1, the processing of the detected data as well as the synchronizing in step S 2, the synchronized engine parameter data of the respective engine part is converted in step S3 to derived stress-like parameter data for all detected engine parameters of said engine part. The parameter data which does not have a dimension of stress or force are converted. Approximation of temperatures at areas that are considered as life limiting areas are determined. In a possible embodiment the approximation or conversion of a temperature is determined by lookup tables as a function of measured engine parameters or by application of low order polynomials or combinations of powers of the measured parameters. Engine parameters can be spool speeds, measured temperatures in the gas path, fuel flow, pressure or torque.

[0048] For example a metal temperature of a turbine blade as an engine part can be expressed as a function of turbine exit gas temperature by:

$$T_{\text{blade}} = c1 * T_{\text{gas_exit}} + c0,$$

Wherein c1 is a positive constant and c0 is another constant value of arbitrary sign.

[0049] For engine parts that have metal temperatures that do not instantaneously follow the gas temperature in the main gas path a model involving a first order delay can be applied.

[0050] First an asymptotic value of the metal temperature at the area under consideration, as a function of measured signals is determined. A preferred method is to express asymptotic metal temperatures as linear combinations of measured gas temperatures in the main gas path and of engine inlet temperature.

[0051] Examples: Asymptotic temperatures at a life-limiting area of a compressor $T_{\text{as_area}} = C1 * T_{\text{inlet}} + C2 * T_{\text{compressor_exit}} + C3$, with C1, C2, C3 being constants.

[0052] Preferred form: $c2 = 1 - c1$, $c3 = 0$. i.e. the asymptotic metal temperature is assumed as a weighted average of two gas temperatures.

[0053] The initial values for metal temperatures to be used are set when the LUM calculation is started at the beginning of an engine run. Initial temperature values are set to ambient temperature or to a multiple of ambient temperature plus a constant offset in those cases where it is known that the metal temperature calculation in the LUM starts when the engine 2 is already in the engine start sequence such that the considered areas are no longer at the conditions seen in a cold engine.

$$T_{\text{ini}} = c * T_{\text{inlet}} + d$$

with specific constants c, d for every considered area. Set the temperature of a considered area to its initial value

$$T_area = T_area_ini$$

5

[0054] For every time step the following steps are requested:

Save the temperature at the area $T0 = T_area$

10

Calculate asymptotic temperature from current input parameters.

[0055] The asymptotic temperature is calculated by a linear combination from measured gas temperatures or from gas temperatures calculated by a thermodynamic model, potentially including performance maps.

15

$$TAS = C0 + C1 * T1 + C2 * T2 + C3 * T3$$

20

with coefficients Ci being selected to approximate a measured or analytically modeled thermal behaviour at the area under consideration. In a specific example one of the temperatures could be measured compressor exit gas temperature and another temperature could be a measured gas temperature in the turbine area or a function of engine exhaust temperature. The asymptotic temperature in the example can be the temperature reached after a long time of running at stable conditions.

25

[0056] The inverse characteristic time is calculated, by which metal temperature approaches asymptotic conditions by a sum of a constant $a0$ and a term proportional to a positive power (ETA) of a normalized spool speed $RSPEED$. This spool speed need not be the one associated with the rotor of the engine module in which the area under consideration is located, but may also be the rotational speed of an upstream rotor, which determines gas flow and consequentially the rate of heat transfer in the downstream component.

30

$$TAUINV = a0 + a1 * RSPEED ^ ETA$$

35

[0057] This equation represents a typical behaviour of an area on a rotor or a non-rotating part in the gas path of a turbine engine. When the engine 2 is at rest, the temperature at an area changes very slowly, caused e.g. by heat conduction, whereas the area more rapidly follows the temperatures in the gas path, when the engine 2 runs at high rotational speed causing increased heat transfer between gas and metal.

40

[0058] The metal temperature $TNEXT$ is calculated at the considered area from its metal temperature at the previous time step, asymptotic temperature TAS as specified above and inverse time constant $TAUINV$ for the time step length $TSTEP$.

45

$$TNEXT = TAS + (T0 - TAS) * \exp(-TSTEP * TAUINV)$$

50

$$\text{Set } T_area = TNEXT$$

55

[0059] The value of stress-like variables is calculated. In a special case stress at life-limiting area is calculated as a function of the defined stress-like variables.

[0060] A parameter representing material strength at the considered life-limiting area is calculated as a function of the current metal temperature T_area . In a special case the ultimate tensile strength of the material is used. The dependency

of UTS on temperature is either represented by piecewise linear interpolation or expressed by polynomials, rational functions or power functions, or a combination of those functions. In a preferred case UTS is expressed by a sum of a polynomial P and a rational function.

5

$$UTS(T) = P(T/T_{ref}) + c1/(c2-T/T_{ref}),$$

10 where P is a polynomial with given fixed coefficients, Tref is a reference temperature, and c1, c2 are fixed coefficients specific for the material used at the considered area.

[0061] The applicable stress or the value of the stress-like variable is divided by the value of a function indicating the dependency of sustained test cycles for a given load sequence on the temperature. In special cases also UTS or Young's Modulus as functions of metal temperature are used. The quotient "stress/(temperature-dependent weighting function)" is called "normalized stress".

15

[0062] Cycles of the normalized stress are determined, by application of a method as described in Downing / Socie "Simple Rainflow Counting Algorithms" INT.J.FATIGUE, January 1982, pages 31-40. The method produces a list of pairs of stresses and corresponding metal temperatures.

[0063] For every extracted cycle consisting of stresses or stress-like parameters and associated temperatures an increment of damage is calculated. In a preferred form this is done as follows:

20

The arbitrary cycle (S₁, T_{S₁}), (S₂, T_{S₂}) is converted into a normalized auxiliary stress parameter

25

$$S_{aux} = \text{abs}(S_1 - S_2) / (S_{lim} - \min(S_1, S_2)) - FCUT$$

30 where S_{lim} is a limit stress, usually greater than the maximum of occurring stresses. FCUT indicates a percentage of the reference stress level, below which no damage occurs (endurance limit).

[0064] S_{lim} and FCUT are selected to represent a typical fatigue behaviour at a considered area.

[0065] In a special case, S_{lim} and FCUT are functions of temperature, described either by value tables in which linear interpolation is performed, or by functional relationships (e.g. polynomials, rational functions, power functions or combinations of those functions). The temperature to be used is either the temperature belonging to the stress value with maximum absolute value or more conservative the maximum of the two temperatures. If the auxiliary stress parameter is positive, use a power m of this parameter to determine the damage increment of the considered pair or stresses or stress-like parameters:

35

40 $D = (c_{ref} * S_{aux})^m$, where c_{ref} is a scaling coefficient and m is a positive exponent related to the slope of the S/N curve of the material at the area under consideration. If the auxiliary normalized stress parameter S_{aux} becomes negative, the corresponding cycle of the stress or stress-like parameter does not contribute to the accumulated damage.

45 **[0066]** The sequence described above is applied to the whole data wherein of an engine run, repeating the applicable steps in every single time step beginning with the start of the engine 2 and ending with running down and stop of the engine 2.

[0067] Damage assessment and accumulation can both be performed for a set of selected stress-like variables such as squared spool speeds, pressures, torques and for feature specific stresses and temperatures where every damage account has an associated set of input parameters and model coefficients.

50

[0068] Damage accounts for cyclic processes can be accompanied by other run related information, e. g. running time of the considered engine run, maximum values reached by the physical input parameters and counted durations that selected engine parameters spent between defined values (histograms).

[0069] In step S4 of the method shown in Fig. 3 a calculation unit 6 of the monitoring system calculates a damage value for the respective engine part on the basis of the converted stress-like parameter data to compute a life usage of the respective engine part.

55

[0070] The calculation computes summed results of the contributions of extracted cycles, counters and non cyclic damage processes for all considered non feature-specific and parts or component-specific damage accounts in the

associated accumulating accounts and provides the results in files and protocols for further processing.

[0071] In the system and method according to the present invention transient time histories of all measured physical engine parameters can be stored over the whole engine life of the engine 2 in a data base. The data base can comprise as a main organizing selection an engine serial number. In this data base every engine with its complete running history can be stored and kept as long as any engine part used in the engine 2 is still in service. The time histories in this data base can cover all parameters potentially influencing damaging mechanisms. In a possible embodiment 5 to 20 physical parameters can be stored including standard parameters used in engine control like rotational speeds, torques, gas temperatures and pressures, fuel flow, actuator positions and environmental conditions like air temperature and pressure.

[0072] With the method and system according to the present invention a data recording of the full time histories of a selection of measured physical engine parameters potentially influencing damage for all life limited and high value parts is performed. Furthermore, the method and system provides a synchronization of parameters to a common time basis. It is possible to apply both generic and parts specific damage assessment methods to the synchronized parameter data. Damage assessment methods include among others a modelled low cycle fatigue damage based on accumulation of failure probability increments derived from cycles of stresses and stress-like variables extracted for example by a rainfall algorithm. The method and system computes temperature weighted damage increments.

[0073] The method and system according to the present invention is flexible and has low implementation costs for update of an algorithm. Thus, the method and system keeps the measured and recorded physical engine parameters of the full engine running history for reassessment if an unanticipated damage mechanism is possible. Accordingly, a need for updates resulting from a modification of the engine and/or from the detection of unforeseen damage mechanisms and corresponding life limitations is reduced.

[0074] In an embodiment the converted functions by the conversion unit 5 can be configured via a configuration interface. With the method and system according to the present invention it is possible to monitor a usable life of life limited and of high value engine parts dependent on the recorded and stored operation history of the engine 2 in which the engine parts are being used. The method and system according to the present invention provides a set of damage accounts that include a subset of generic damage accounts characterizing the severity of engine operation and another subset of damage accounts that are specific for a certain module or engine part. Life usage per run of the engine 2 or the increase of parts' failure probability is correlated against a single account in the set or also against functions of one or more than one account where the conversion function is applied to every single engine run.

[0075] The application of the proposed monitoring method combines a potential extension of the usable life of life limited critical parts or high value parts with the detection of unexpectedly severe usage. A potential extension of usable life can for example occur in case of operation at lower loads than those assumed during design of the respective engine part. Unexpectedly severe usage can for instance occur at non design conditions. The detection of unexpectedly severe usage can avoid use of parts beyond a specific failure probability. In contrast to conventional life usage monitoring systems the system according to the present invention avoids disadvantages caused by non reconstructable operation histories if re-assessment of parts' life usage becomes necessary. A further advantage of the method and system according to the present invention is the avoidance of high costs to change parts specific life usage algorithms when they are implemented in a computer that is embedded in an on board environment of a vehicle.

[0076] In a possible embodiment the method and system according to the present invention allows to monitor the engine parts in real time to react appropriately if the failure probability of a monitored engine part becomes too high. In a further possible embodiment the method and system according to the present invention can evaluate the parameter data stored in the database. For example it can analyse why an engine 2 or an engine part has failed. For example, if an engine part within an engine 2 failed the stored data of the engine part can be analysed to find out what has led to this failure. Data can also be used to improve respective model functions for conversion of parameter data to stress-like parameter data and for calculating a damage value on the basis of the converted stress-like parameter data. With the method and system according to the present invention a current state of an engine part can be assessed very accurately. It can be predicted when the usable life of the respective engine part is exhausted and the part has to be replaced.

Claims

1. A method for monitoring a life usage of at least one engine part of an engine (2) comprising the steps of:

- (a) detecting (S1) engine parameters of each monitored engine part of said engine (2) to provide engine parameter data of the respective engine part;
- (b) synchronizing (S2) the detected engine parameter data of said engine part to a common time basis;
- (c) converting (S3) the synchronized engine parameter data of the respective engine part to derived stress-like parameter data for all detected engine parameters of said engine part; and
- (d) calculating (S4) a damage value for the respective engine part on the basis of the converted stress-like

parameter data to assess the life usage of the engine part.

2. The method according to claim 1,
wherein the engine parameters are detected by means of sensors (3) which generate engine parameter data stored temporarily in a data storage.
3. The method according to claim 2, wherein the engine parameter data provided by sensors (3) with a high acquisition rate are low-pass filtered before being uploaded from said data storage to a synchronizing unit (4) performing the synchronization of the received engine parameter data.
4. The method according to claim 3 wherein the uploaded engine parameter data are synchronized to a common time basis by said synchronization unit (4) by interpolation over time.
5. The method according to claim 4,
wherein the synchronization unit (4) performs a blended quadratic interpolation or a linear interpolation of the uploaded parameter data over time.
6. The method according to claims 1 to 5,
wherein the detected engine parameter data is tagged with time information data and engine information data.
7. The method according to claim 6,
wherein the uploaded engine parameter data and the calculated damage values of the engine parts are stored over the whole engine life of said engine (2) in a data base for further processing.
8. The method according to claims 1 to 7,
wherein if the calculated damage value of the engine part exceeds a threshold value an indication signal is generated indicating that the respective engine part is to be replaced or to be maintained.
9. The method according to claims 1 to 8,
wherein the life usage of the respective engine part is assessed depending on the calculated damage value of said engine (2) part and depending on engine operation data of the engine comprising engine running time data, engine temperature data, engine speed data and engine pressure data.
10. A system for monitoring a life usage of at least one engine part of an engine (2) comprising:
 - (a) detectors (3) for detecting engine parameters of each monitored engine part of said engine (2) to provide engine parameter data of the respective engine part;
 - (b) a synchronization unit (4), which synchronizes the detected parameter data of said monitored engine part to a common time basis;
 - (c) a conversion unit (5) which converts the synchronized parameter data of the respective engine part to derived stress-like parameter data for all detected engine parameters of said engine part; and
 - (d) a calculation unit (6) which calculates a damage value for the respective engine part on the basis of the converted stress-like parameter data to compute the life usage of the engine part.
11. The system according to claim 10,
wherein said engine part is a rotating or a non-rotating engine part of an engine (2) of a vehicle.
12. The system according to claims 10 or 11,
wherein the detectors (3) comprise sensors attached to the engine (2) or located within the vicinity of the engine (2), when said sensors (3) measure engine parameters of the monitored engine parts of said engine (2) to provide engine parameter data of all monitored engine parts which are stored temporarily in a local data storage.
13. The system according to claim 12,
wherein the detected engine parameter data stored in the local data storage are uploaded via a wireless or wired data interface to said synchronisation unit (4) where data are stored on a removable storage medium.
14. A vehicle comprising at least one engine (2) and an onboard system for monitoring a life usage of at least one engine part of the engine (2) according to claims 10 to 13.

15. The vehicle according to claim 14,
wherein said vehicle is an aircraft or a helicopter.

5

10

15

20

25

30

35

40

45

50

55

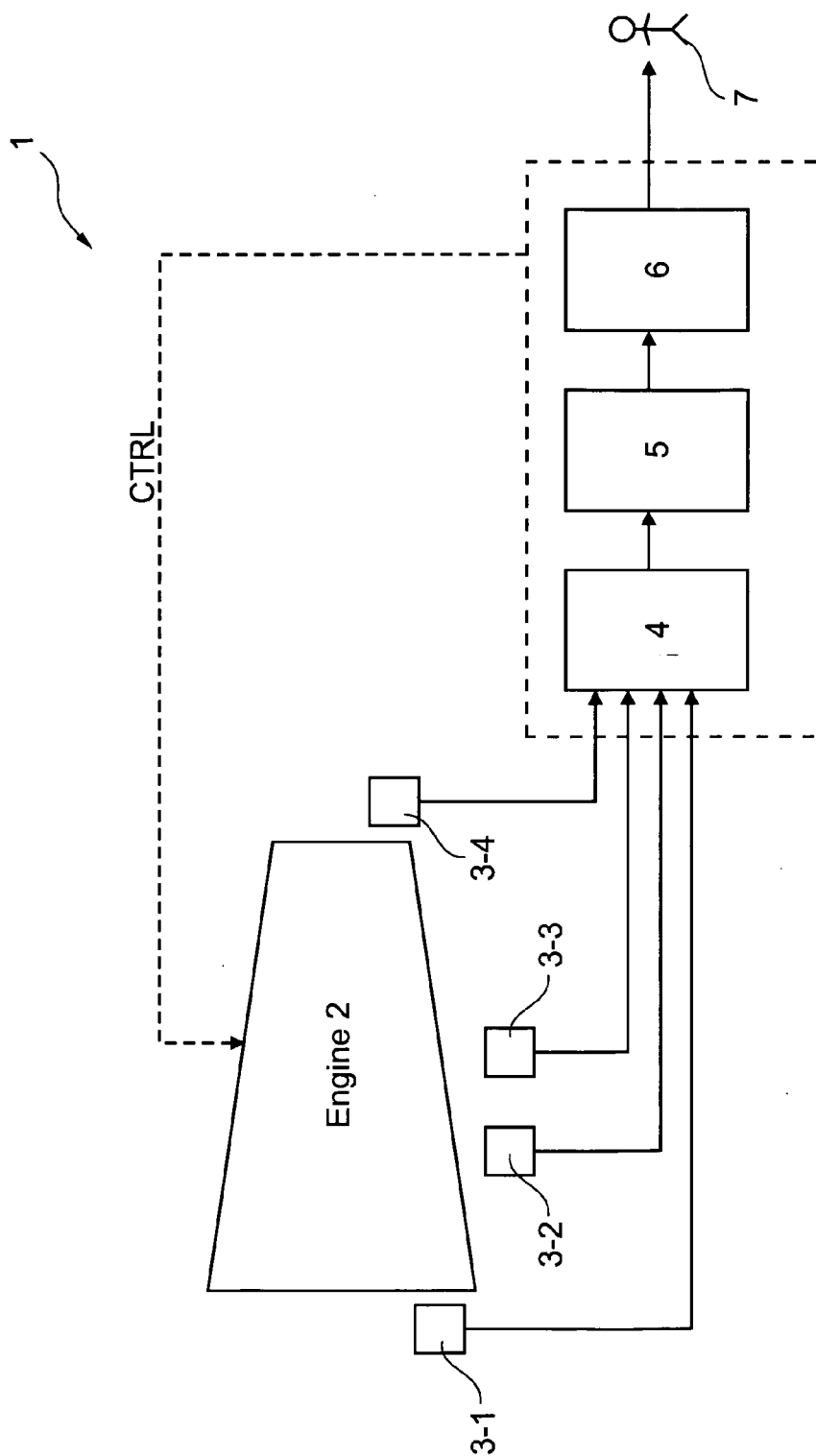


Fig. 1

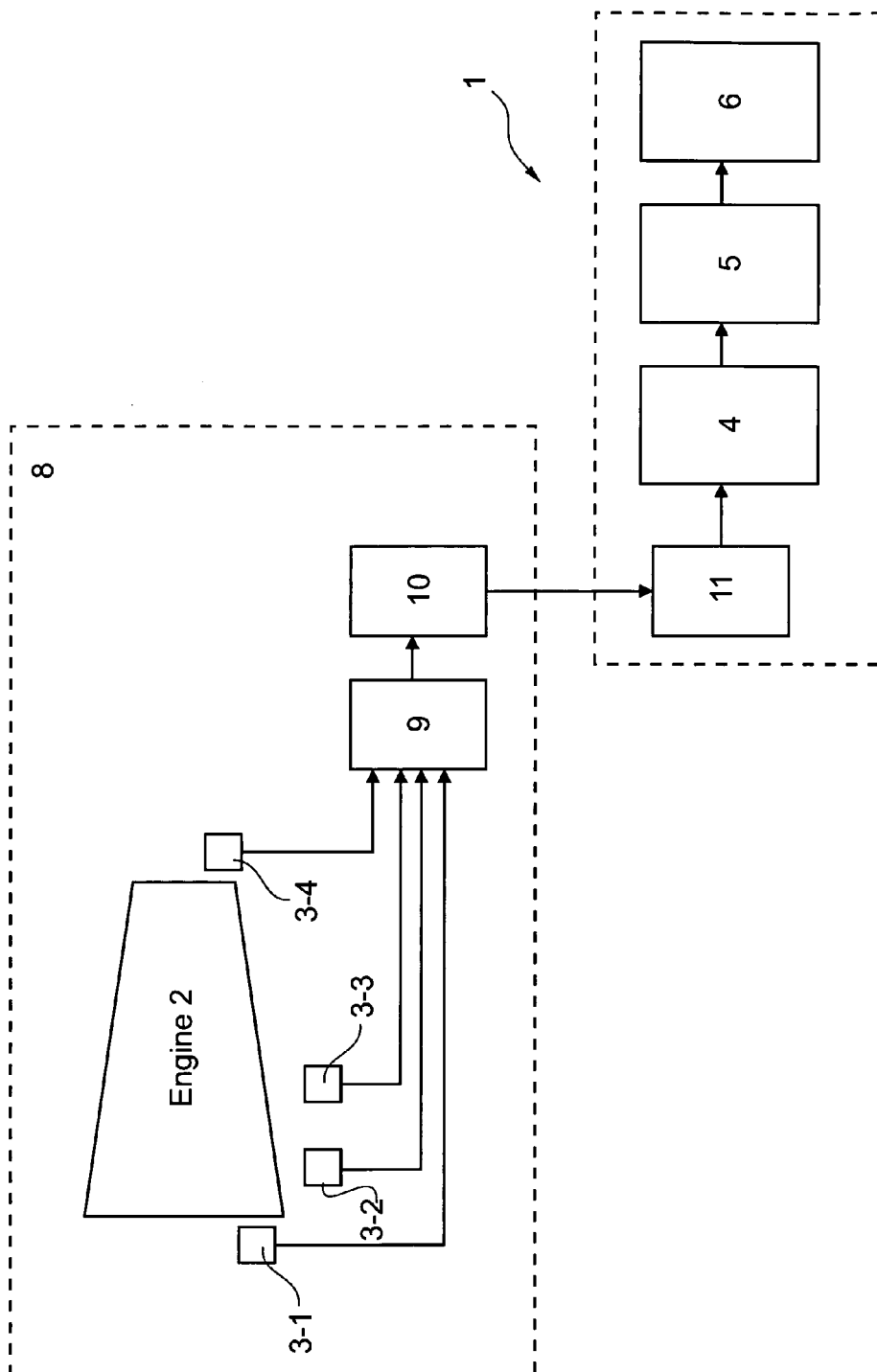


Fig. 2

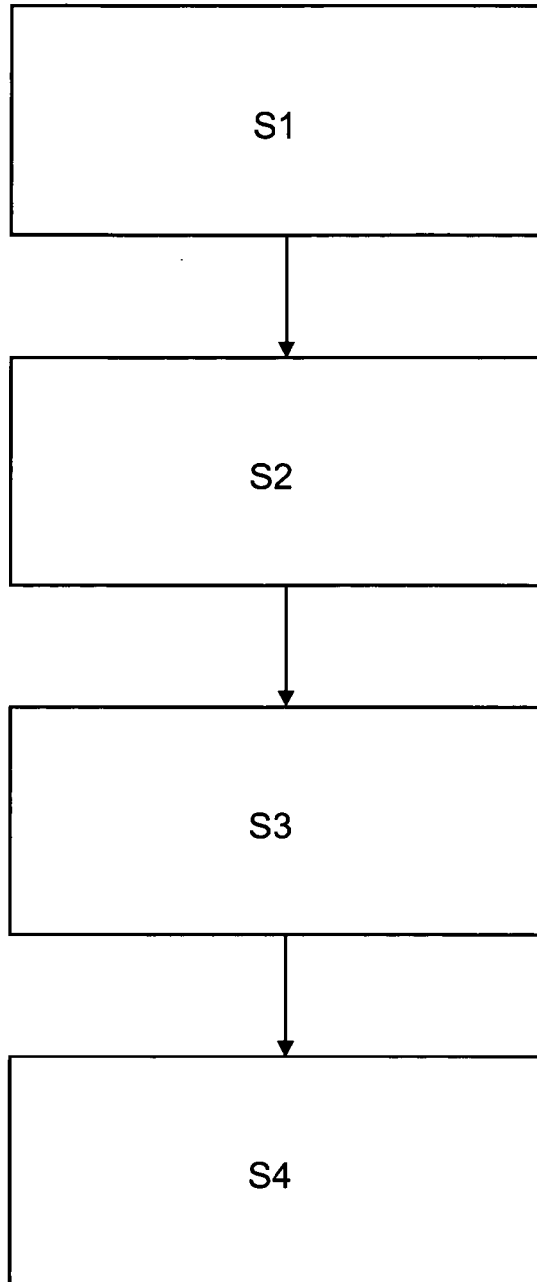


Fig. 3



EUROPEAN SEARCH REPORT

Application Number
EP 10 17 5368

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
L	The technical aspects identified in the present application (Art. 92 EPC) are considered part of common general knowledge. Due to their notoriety no documentary evidence is found to be required. For further details see the accompanying Opinion and the reference below. -----	1-15	INV. G07C5/00 F01D21/00
			TECHNICAL FIELDS SEARCHED (IPC) G07C F01D
The present search report has been drawn up for all claims			
Place of search Munich		Date of completion of the search 3 February 2011	Examiner Rother, Stefan
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			

1
EPO FORM 1503 03/02 (P04C01)

REFERENCES CITED IN THE DESCRIPTION

This list of references cited by the applicant is for the reader's convenience only. It does not form part of the European patent document. Even though great care has been taken in compiling the references, errors or omissions cannot be excluded and the EPO disclaims all liability in this regard.

Non-patent literature cited in the description

- **DOWNING ; SOCIE.** Simple Rainflow Counting Algorithms. *INT.J.FATIGUE*, January 1982, 31-40
[0062]