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DESCRIPTION

[0001] The present invention relates to methods for determining residual useful life of rotating machinery including drive trains, gearboxes, and generators. The approaches relate to determination of an Equivalent Operating Hours limit for the machinery and comparing it with an Equivalent Operating Hours value for the machinery. In particular it relates to methods for determining residual useful life of wind and water turbines and components thereof, and using these data to operate and manage turbine installations.

[0002] US 2010/0206058 A1 discloses a method for determining the life cycle of a power station component on the basis of an equivalence or calculation rule for equivalent operating hours.

[0003] Although the design life of a wind turbine gearbox is typically more than twenty years, failures of wind turbine gearboxes within four to five years are not uncommon. This is because residual useful life (RUL) calculation procedures are based on assumed operating profiles, whereas in operation, the actual profile could be very different.

[0004] Monitoring operating parameters related to the operation of a wind or water turbine or component thereof, and determining when these parameters move outside an operating window, may indicate that some kind of maintenance or investigation is needed. Operating parameters that are monitored could include lubrication temperature, lubrication debris, vibration, and power output.

[0005] Vibration is commonly measured by Condition Monitoring Systems. Generally speaking, large vibrations compared to a norm is indicative of damage.

[0006] Vibration analysis generally relies on a measurement provided by a sensor exceeding a predetermined threshold, which is prone to false alarms if the threshold is set too low. The threshold level is not necessarily constant and may vary with frequency (and hence speed). The presence of shocks and extraneous vibrations means that the threshold level must be set sufficiently high to minimise the risk of false-alarms. Furthermore, the threshold must be sufficiently high to avoid any negative effects caused by 'creep' in sensor performance which may occur over its lifetime. In addition, there is no discrimination between vibrations associated with failure or damage and those which are not indicative of failure or damage.

[0007] Faults developing during operation, such as an imbalance in a rotor, can create loads on a bearing in excess of that expected resulting in a reduction in its design life. Incipient faults, such as unbalance, can be detected from analysis of vibration signatures. This gives the magnitude of an imbalance, and an excitation force due to imbalance is a function of the magnitude of the imbalance and square of the speed. An excitation force due to faults can thus be calculated from field operational conditions and used to calculate individual component loads. Deviation from the assumed operating profile can be addressed by using a generic wind

simulation model to determine load at the turbine shaft, which allows individual component loads based on the field operational conditions to be calculated. Combining these gives the total load at each component, which can be used to estimate the remaining life of the individual components and the life of the gearbox.

[0008] However, shortcomings in wind simulation models mean that the load at the turbine shaft may not be reliably or accurately determined.

[0009] Equivalent Operating Hours (EOH), in simple terms, defines damage as being equivalent to the damage caused to a wind or water turbine or components thereof by one hour of operation under rated operating conditions. The EOH is equal to a weighting factor related to the operational condition multiplied by a duration (or alternatively, frequency) of that condition. For any operation in which damage caused is the same as that expected to be caused under rated conditions, the EOH of a component after 1 h will be 1 h, and the weighting factor will be 1.0. If an operational event causes greater damage, then the EOH will be reduced accordingly. Thus, an operational event of duration of 0.2h of duration and having a weighting factor of 0.7, then the EOH after 1 h will be $0.8 \times 1 + 0.2 \times 0.7 = 0.94$.

[0010] According to a first aspect, the present invention provides a method for predicting remaining useful life of a wind or water turbine or component thereof, the method comprising the steps of:

determining an EOH for the wind or water turbine or component thereof according to the steps of:

providing data relating to one or more operating conditions; and

providing one or more EOH coefficients relating to the one or more operating conditions;

wherein the EOH is a function of the data relating to the one or more operating conditions and the one or more EOH coefficients relating to the one or more operating conditions;

obtaining an EOH limit value for the wind or water turbine or component thereof; and

comparing the EOH and the EOH limit,

wherein the EOH coefficients are obtained from assessing damage to the wind or water turbine or a component thereof under field operating conditions and damage to the wind or water turbine or a component thereof under rated operating conditions of the same duration,

wherein the component is a gearbox,

wherein assessing damage includes:

monitoring outputs of one or more condition monitoring sensors placed in or on the gearbox at predetermined locations; and

based on said outputs, calculating damage using a meta-model of the gearbox, the meta-

model being constructed by obtaining a number of data samples from a gearbox model prior to the start of gearbox operation and determining an underlying trend using response surface methodology.

[0011] The EOH coefficient may be a function of a ratio of damage under rated operating conditions to damage under field operating conditions, or a ratio of damage under rated operating conditions to damage under field operating conditions.

[0012] The operating conditions may be steady state operating conditions or transient operating conditions.

[0013] If the EOH is greater than the EOH limit, the method may additionally comprise the step of: maintaining the wind or water turbine or component thereof.

[0014] If the wind or water turbine or a component thereof has failed, and in which the EOH being less than the EOH limit, the method may additionally comprise the step of: maintaining the wind or water turbine or component thereof.

[0015] The step of maintaining the wind or water turbine or component thereof may comprise investigating for damage to the wind or water turbine or component thereof.

[0016] The step of investigating for damage may be selected from the group consisting of: using an endoscope, performing vibration analysis and performing lubrication analysis.

[0017] If the wind or water turbine or component thereof has damage, the method may comprise scheduling maintenance of the wind or water turbine or component thereof, refurbishing the wind or water turbine or component thereof, or replacing the wind or water turbine or component thereof.

[0018] The method may comprise the additional step of: setting EOH of the wind or water turbine or component to zero.

[0019] Also disclosed is a computer readable product comprising code means designed for implementing the steps of the method according to any of the methods disclosed above.

[0020] Also disclosed is a computer system comprising means designed for implementing the steps of the method according to any of the methods disclosed above.

[0021] The present invention will now be described, by way of example only, with reference to the accompanying drawing, in which:

Figure 1 shows a flow chart for predicting remaining useful life of a wind or water turbine or components thereof;

Figure 2 shows a flow chart for the determination of damage to a wind or water turbine or component thereof;

Figure 3 shows the steps in a method for calculating damage to a wind or water turbine or a component thereof using a model-based approach;

Figures 4, 5 and 6 show stages in the construction of a meta model.

Figure 7 shows a flow chart for scheduling maintenance of a wind or water turbine or components thereof based on an EOH analysis;

Figure 8 shows a flow chart for gearbox refurbishment based on EOH analysis; and;

Figure 9 shows a graph combining EOH operating life models with vibration data for a number of turbines operating in a wind farm; and

Figure 10 illustrates a schematic diagram of an apparatus according to various embodiments of the invention.

[0022] Methods for determining damage to a rotating machine, such as a gearbox, drive train, generator, wind turbine or a water turbine, or individual components of these rotating machines, is illustrated in Figure 1.

[0023] In a first step 100 turbine load data (which may be simulated or measured) is collected and operating conditions, such as temperature of various bearings, oil conditions, and the like are sensed and logged. Operating condition data can be chosen to represent a typical range of conditions, or they can be obtained from historical logged data such as SCADA or a condition monitoring system.

[0024] This data can be used in step 102 in a damage-determining model or meta model to determine EOH coefficients 108 relating to steady-state operating conditions.

[0025] Corresponding EOH coefficients 106 for non-steady state (transient) conditions can be determined in step 104 using a dynamic model of wind turbine and components, and/or a bearing skidding model, model of the lubrication system or the like.

[0026] In step 116, current or historical operating data 110 are provided and EOH is derived from this data and the EOH coefficients determined in steps 106 and 108 according to the relationship:

$$\text{EOH} = f(\text{operating condition, EOH coefficient})$$

[0027] In steps 112 and 114, EOH limit is determined from field data (failure records and the like). EOH limit is simply the expected life of the wind or water turbine or component thereof.

[0028] In step 118, a comparison of EOH limit and EOH yields a value for the remaining useful life (RUL) of the component.

[0029] In the present invention, EOH weighting factors or coefficients are obtained from assessing damage to the wind or water turbine or a component thereof under field operating conditions and damage to the wind or water turbine or a component thereof under rated operating conditions of the same duration.

[0030] According to the invention, the wind or water turbine or component thereof is a gearbox.

[0031] The EOH weighting factor or coefficient is a function of the damage under rated operating conditions and damage under field operating conditions of the same duration. It can be a function of a ratio of damage under rated operating conditions to damage under field operating conditions of the same duration.

[0032] Figure 2 shows a flow chart for the determination of damage 202 to a wind or water turbine or component thereof.

[0033] Load data 204, 206, for example forces and / or moments, acting on the wind or water turbine or component thereof is provided.

[0034] Load data 204 relates to operation under rated operating conditions (C_R), which can be the conditions for which the wind or water turbine or a component thereof was designed. Load data 204 can be obtained or derived from design data 208.

[0035] Load data 206 relates to loading under field operating conditions (C_O).

[0036] Field operating conditions can be historical sensor data 210 or SCADA data obtained from or derived from a CMS.

[0037] Field operating conditions can be real time sensor data 212 from actual operating conditions under which the wind or water turbine or a component thereof is being operated. This means that EOH weighting factors or coefficients can be calculated in real time. These EOH weighting factors or coefficients can be stored and used again when similar field operating conditions are experienced, leading to a reduction in computing capability required over time.

[0038] Field operating conditions can be a library of anticipated conditions 214 which is a range of operating conditions under which the wind or water turbine or a component thereof may be expected to operate. Alternatively or additionally, a library of anticipated conditions 214 can be populated by historical sensor data 210 or real time sensor data 212. This means that EOH weighting factors or coefficients can be calculated in advance of operation, reducing the amount of computing capability required during operation.

[0039] Design data 208, historical data 210, real time data 212 and library data 214 can comprise continuous ranges of data, or the data can be stratified into bins to simplify calculations.

[0040] The operating conditions can be steady state operating conditions or transient operating conditions.

[0041] Damage 202 under rated and field operating conditions is determined from information relating to the wind or water turbine or a component thereof. The information can be provided by inspection 216, or by using a model 218 of the wind or water turbine or component thereof.

[0042] The EOH weighting factor or damage coefficient 220 is a function of the damage under rated operating conditions and damage under field operating conditions of the same duration. It can be a function of a ratio of damage under rated operating conditions to damage under field operating conditions of the same duration. It can be a ratio of damage under rated operating conditions to damage under field operating conditions of the same duration.

[0043] Where design data 208, historical data 210, real time data 212 or library data 214 does not contain measured or specified load information, data 204, 206 can be derived from other specified or measured parameters present in the data. The derivation can be a simple manipulation of the data available, or it can be obtained using model 218 of the wind or water turbine or component thereof (not shown).

[0044] Various models may be used. For example, a unique model may be generated for one or more of each of the components of the wind or water turbine that leaves a production line. Each unique model is generated using the dimensions and clearances inferred from an end of line test and may remain related to the corresponding component throughout its operational life. The unique model can be used to calculate the loads, for example forces and/or moments, that may act on a component at any location or particular locations in or on the component according to the operating conditions. This in turn permits the calculation of the damage sustained by each component under rated or field operating conditions.

[0045] Figure 3 shows the steps in a method for calculating damage to a wind or water turbine or a component thereof using a model-based approach. According to the invention, the component is a gearbox.

[0046] In a first step 36, information on a gearbox is provided. This may include a fully coupled model with six degrees of freedom. The model may also be unique to the gearbox. The information may include information relating to one or more manufacturing variations in the dimensions and clearances of components of a gearbox.

[0047] In a second step 38, loads, for example forces and/or moments, acting on the gearbox during field operating conditions can be monitored during operation or provided from historical

data (eg SCADA). Alternatively the loads can be calculated from anticipated field operating conditions. Similarly the loads can be calculated from rated operating conditions. Where loads acting on the gearbox are continuously monitored during operation, these measurements may be taken at a regular sampling frequency of e.g. 50 Hz. In various embodiments of the invention, step 38 may include monitoring one or more loads over time. Monitoring one or more loads includes monitoring outputs of one or more condition monitoring sensors placed in or on the gearbox at predetermined locations.

[0048] In third step 40, the damage caused to each component by the one or more loads, in each sample of data, however determined is calculated. To do this, the fully coupled system model described above is used to calculate the system deflections and component loads. The contact between gear teeth is modelled using finite elements taking into account the tooth bending stiffness and gear mesh contact stiffness. These stiffnesses can be calculated or based on empirical data and are taken into account in the static deflection analysis of the full model. The tooth face load distribution, tooth contact stress or bending stress may be calculated for each gear mesh. These values may then be compared with empirical data or empirical methods used to calculate the operating contact stress, e.g. according to methods given in ISO 6336-2. The tooth bending stress may be calculated using finite element models or may be calculated using empirical methods, e.g. methods in ISO 6336-3. S-N curves for gear contact failure and gear bending failure may be employed and may be based on mathematical simulations or may be based on empirical data, e.g. data provided in ISO 6336. A prediction of the cumulative damage on each component is continuously updated, thus allowing the remaining life of each component to be predicted using empirical data e.g. S-N curves and bearing life data available from ISO standards.

[0049] The calculation of bearing damage can be performed using the RomaxDesigner software. This calculation takes into account factors such as bearing internal geometry, stiffness and deformation of bearing components, contact between bearing components and considers the bearing loads and stiffness.

[0050] It is possible that the provided gearbox information cannot be analysed at as high a frequency as the data is sampled. For example, the model analysis required to predict the damage due to each sample of data may take 1 second, but the data may be sampled at 50 Hz. According to the invention, approximation (a meta-model) is employed so that the damages are predicted more quickly.

[0051] The meta-model is constructed in three stages:

1. 1) a number of data samples are obtained from a gearbox model prior to the start of gearbox operation;
2. 2) an underlying trend is determined using response surface methodology (RSM);
3. 3) Gaussian deviations from this trend are introduced using a Gaussian kernel centred on each sample point.

[0052] The meta-model may be constructed using only steps 1) and 2) above.

[0053] Figures 4 to 6 show the three stages listed above applied to a two-variable problem. Figure 4 shows the plotted raw data points. Figure 5 shows the approximation function constructed from a second order polynomial. Figure 5 shows the approximation function including Gaussian kernels.

[0054] The variables in the meta-model can be one or more of the following loads which may be defined anywhere in the gearbox model, drivetrain or generator: force in the x-direction (F_x); force in the y-direction (F_y); force in the z-direction (F_z); moment about the x-axis (M_x); moment about the y-axis (M_y), moment about the z-axis (M_z). Alternatively, the variables may include displacements in any of the x, y and z directions or rotations about any of the x, y, and z axes or temperature.

[0055] The meta-model is constructed from data samples each of which corresponds to a different combination of any of the variables listed above. The accuracy of the meta model can depend on the method used to determine the variables used to generate each data sample. A sampling regime in which the sample points are randomly determined is possible but is not ideal because it can result in some data samples having similar variables which may result in the meta-model being inaccurate. Spacing the data samples uniformly in the design space represented by the meta-model variables is preferred.

[0056] Uniform sampling of data in the meta-model variables design space is achieved by optimising the sampling strategy using a genetic algorithm. One method is to maximise the minimum distance between any two neighbouring sample points. Many other suitable sampling strategies exist in literature including minimising the maximum distance between any two neighbouring sample points; L2 optimality; latin hypercube sampling.

[0057] The process of identifying the underlying trend using Response Surface Methodology (RSM) consists of fitting a polynomial to the sample data using linear regression. The polynomial can be of any order and may include some or all of the possible terms. The number of variables in the polynomial is equal to the number of variables in the meta-model. A transformation can be applied to the sampled data before fitting the polynomial in order to decrease the 'model bias' which can arise due to the assumption that the data follows a polynomial trend. For example, if the behaviour of the response is observed to follow a trend similar to an exponential, then a polynomial can be fitted to the natural log of the variables in order to improve the meta-model accuracy.

[0058] The Gaussian deviations (step 3 above) may be represented by Gaussian functions with a number of dimensions equal to the number of variables in the meta-model. The deviations are not required to be Gaussian functions and may be represented by another mathematical function. The amplitude of each deviation may be equal to or related to the difference between the output of the polynomial model and the response level of the data

sample.

[0059] A unique meta-model is constructed for each component in the gearbox (i.e. for each gear and bearing) to relate the measured variables with the resulting tooth face load distribution factor, KH_{β} , (for gears, as defined in ISO 6336) and load zone factor (for bearings, as defined in ISO 281). Any number of loads, for example forces and/or moments, acting at any point on the gearbox, drive train or generator may be related to these factors by the meta-models. The load zone factors and KH_{β} values may then be used to calculate a corresponding amount of damage caused to each component. The meta-models may alternatively relate the measured variables with component stresses, component lives or percentage damages.

[0060] Figure 7 shows a method for scheduling maintenance of wind or water turbine or components thereof based on an EOH analysis.

[0061] In step 700, the current EOH of the turbines in the turbine farm is determined, for example as disclosed above in relation to Figure 1.

[0062] In step 702, a turbine or turbines having the highest EOH on one or more components is identified.

[0063] In step 704, the EOH value or values from step 702 are compared with a preset EOH limit for further forensic investigation. If the EOH value is less than this value, then no action is taken and the turbine continues operation.

[0064] If the EOH value is higher than this value, then in step 706 further investigations of the turbine are undertaken, for example endoscope inspection, vibration analysis, oil analysis and the like.

[0065] In step 708, the results of the investigation are assessed: if the investigation indicates that the turbine does not have an operational problem, then no action is taken and the turbine continues operation.

[0066] If the investigation indicates that the turbine does have an operational problem, then maintenance is scheduled and the turbine may be concomitantly down-rated.

[0067] Figure 8 shows a method for gearbox refurbishment based on EOH analysis.

[0068] In step 800, a failed turbine gearbox is provided, and in step 802 a corresponding gearbox and/or gearbox component history is provided.

[0069] In steps 804 and 806, an EOH of a component and a corresponding RUL of the component are respectively determined as disclosed above in relation to Figure 1.

[0070] In step 808, an evaluation is made as to whether or not the RUL for the component

indicates that refurbishment of the component may be worthwhile. If it is not, then the component is discarded.

[0071] If it is, then in step 810, the component is inspected.

[0072] In step 814, if the inspection indicates that refurbishment of the component is not worthwhile, the component is discarded.

[0073] In step 814, if the inspection indicates that component is suitable for refurbishment, the component is retained to provide a refurbished gearbox.

[0074] In step 816, if the component has been replaced, the EOH for the new component is set to zero.

[0075] According to a further aspect of the invention a method for operating a wind or water turbine or component thereof is based on a quantitative measure of vibration in relation to EOH for a wind or water turbine or component thereof.

[0076] The method may be illustrated by a simple example, in which operating parameter levels are stratified into three levels: low, medium and high.

[0077] As mentioned above, the danger or damage from increased vibration is dependent to a certain extent to the age of the wind or water turbine or component thereof, in other words, to EOH. EOH can be similarly stratified into three zones, low, medium and high.

[0078] This simple approach enables the wind or water turbine operator to prioritise maintenance activities based on EOH and CMS data, as for example in Table 1.

Table 1. Action needed according to a value for EOH and a level of an operating parameter

		EOH	
Operating parameter	Low	Medium	High
High			Turbine inspection recommended
Medium	Investigation needed		
Low			

[0079] The same approach may be adopted for other CMS data which may be used to monitor wind turbines by identifying wind turbines which exceed a threshold value.

[0080] Figure 9 shows a graph combining EOH operating life models with vibration data for a

number of turbines (T01 to T38) operating in a wind farm. Vibration levels in this context can be based on vibration signature analysis

[0081] Turbines with moderate EOH and vibration typically require routine monitoring and planned inspections over a longer period.

[0082] Moderate levels of vibration when EOH values are low, for example turbine T02 in Figure 9, may indicate that the wind or water turbine or component thereof should be investigated to see if one or more components are suffering damage and need to be repaired or replaced.

[0083] However, moderate levels of vibration at median values of EOH are probably normal, and should be merely monitored routinely. Moderate levels of vibration at high values of EOH require no action.

[0084] High levels of vibration at high EOH values may be indicative of a need for turbine inspection. Turbines with high EOH and high vibration (circled) can clearly be identified, and these require inspection.

[0085] Turbine T34 in Figure 9 has a similar vibration level to turbine T05, but turbine T34 has a low EOH life. The former turbine is clearly operating better than other turbines of a similar EOH. Using a system for identifying turbines in need of maintenance based on thresholds alone would consider these two turbines to have the same status.

[0086] In addition to the approaches above, an additional indicator of a requirement for maintenance may be obtained by collecting data relating to vibration of the wind or water turbine or component thereof on a test rig prior to installation. This can be taken as a subsequent baseline: increases in vibration after installation may be due to damage during transport or poor assembly.

[0087] Figure 10 illustrates a schematic diagram of an apparatus 46 according to various embodiments of the present invention. The apparatus 46 includes means 48 for performing the steps illustrated in Figures 1 to 9. Means 48 includes a processor 50 and a memory 52. The processor 50 (e.g. a microprocessor) is configured to read from and write to the memory 52. The processor 50 may also comprise an output interface via which data and/or commands are output by the processor 50 and an input interface via which data and/or commands are input to the processor 50.

[0088] The memory 52 stores a computer program 54 comprising computer program instructions that control the operation of the apparatus 46 when loaded into the processor 50. The computer program instructions 54 provide the logic and routines that enables the apparatus 46 to perform at least some of steps of the methods illustrated in Figures 1 to 9. The processor 50 by reading the memory 52 is able to load and execute the computer program 54.

[0089] The computer program may arrive at the apparatus 46 via any suitable delivery mechanism 56. The delivery mechanism 56 may be, for example, a computer-readable storage medium, a computer program product, a memory device, a record medium such as a Blue-ray disk, CD-ROM or DVD, an article of manufacture that tangibly embodies the computer program 54. The delivery mechanism may be a signal configured to reliably transfer the computer program 54. The apparatus 46 may propagate or transmit the computer program 54 as a computer data signal.

[0090] Although the memory 52 is illustrated as a single component it may be implemented as one or more separate components some or all of which may be integrated/removable and/or may provide permanent/semi-permanent/ dynamic/cached storage.

[0091] References to computer-readable storage medium', computer program product', 'tangibly embodied computer program' etc. or a 'controller', 'computer', 'processor' etc. should be understood to encompass not only computers having different architectures such as single /multi-processor architectures and sequential (Von Neumann)/parallel architectures but also specialized circuits such as field-programmable gate arrays (FPGA), application specific circuits (ASIC), signal processing devices and other devices. References to computer program, instructions, code etc. should be understood to encompass software for a programmable processor or firmware such as, for example, the programmable content of a hardware device whether instructions for a processor, or configuration settings for a fixed-function device, gate array or programmable logic device etc.

[0092] The steps illustrated in the Figures 1 to 9 may represent steps in a method and/or sections of code in the computer program 54. The illustration of a particular order to the steps does not necessarily imply that there is a required or preferred order for the steps and the order and arrangement of the steps may be varied. Furthermore, it may be possible for some steps to be omitted.

REFERENCES CITED IN THE DESCRIPTION

Cited references

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Patentkrav

- 1.** Fremgangsmåde til forudsigelse af resterende brugbar levetid af en vind- eller vandturbin eller en komponent deraf, hvilken fremgangsmåde omfatter trinnene:
- bestemmelse af en EOH (116) for vind- eller vandturbinen eller
- 5 komponenten deraf ifølge trinnene:
- tilvejebringelse af data (100) vedrørende en eller flere driftsbetingelser (110); og
- tilvejebringelse af en eller flere EOH-koefficienter (106,108,220) vedrørende den ene eller flere driftsbetingelser;
- 10 hvor EOH'en (116) er en funktion af data (100) vedrørende den ene eller flere driftsbetingelser (110) og den ene eller flere EOH-koefficienter (106,108,220) vedrørende den ene eller flere driftsbetingelser (110);
- opnåelse af en EOH-grænseværdi (114) for vind- eller vandturbinen eller komponenten deraf; og
- 15 sammenligning af EOH'en (116) og EOH-grænsen (114),
- hvor sammenligningen af EOH-grænse (114) og EOH (116) giver en værdi for den resterende levetid af vind- eller vandturbinen eller komponenten deraf,
- hvor EOH-koefficienterne (106, 108, 220) er opnået fra vurdering af skade
- 20 på vind- eller vandturbinen eller en komponent deraf under reelle driftsbetingelser og skade på vind- eller vandturbinen eller en komponent deraf under nominelle driftsbetingelser med den samme varighed,
- hvor komponenten er en gearkasse,
- hvor vurdering af skade inkluderer:
- 25 overvågning af output fra en eller flere betingelsesovervågningssensorer placeret i eller på gearkassen ved forudbestemte lokationer; og
- baseret på nævnte output, beregning af skade under anvendelse af en meta-model af gearkassen, idet meta-modellen er konstrueret ved
- opnåelse af et antal dataprøver fra en gearkassemodel forud for starten af
- 30 gearkassedriften og bestemmelse af en tilgrundliggende trend under anvendelse af responsoverflademethodik.

2. Fremgangsmåde ifølge krav 1, i hvilken EOH-koefficienten (106,108,220) er en af følgende:

- 5 en funktion af et forhold mellem skaden under nominelle driftsbetingelser (208) og skaden under de reelle driftsbetingelser (210,214); eller
 et forhold mellem skade under de nominelle driftsbetingelser (208) og skade under de reelle driftsbetingelser (210,214).

3. Fremgangsmåde ifølge krav 1 eller krav 2, hvor driftsbetingelserne er stationære driftsbetingelser eller midlertidige driftsbetingelser.

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4. Fremgangsmåde ifølge et hvilket som helst foregående krav, i hvilken, hvis EOH'en (116) er større end EOH-grænsen (114), yderligere omfattende trin: vedligeholdelse af vind- eller vandturbinen eller komponenten deraf.

15 **5.** Fremgangsmåde ifølge et hvilket som helst foregående krav, i hvilken vind- eller vandturbinen eller en komponent deraf ikke fungerer, og i hvilken, hvis EOH'en (116) er mindre end EOH-grænsen (114), yderligere omfattende trinnet: vedligeholdelse af vind- eller vandturbinen eller komponenten deraf.

20 **6.** Fremgangsmåde ifølge krav 4 eller krav 5, i hvilken trinnet til vedligeholdelse af vind- eller vandturbinen eller komponenten deraf omfatter undersøgelse af skaden på vind- eller vandturbinen eller komponenten deraf.

7. Fremgangsmåde ifølge krav 6, i hvilken trinnet til undersøgelse af en skade er
25 valgt fra gruppen bestående af: anvendelse af et endoskop, udførelse af vibrationsanalyse og udførelse af smøringsanalyse.

8. Fremgangsmåde ifølge krav 6 eller krav 7, i hvilken, hvis vind- eller vandturbinen eller komponenten deraf er beskadiget,

- 30 planlægning af vedligeholdelse af vind- eller vandturbinen eller komponenten deraf;
 renovering af vind- eller vandturbinen eller komponenten deraf; eller
 udskiftning af vind- eller vandturbinen eller komponenten deraf.

35

9. Fremgangsmåde ifølge krav 8, omfattende det yderligere trin: indstilling af EOH (116) af vind- eller vandturbinen eller komponenten til nul.

10. Computerlæsbart produkt omfattende kodeorgan udformet til implementering
5 af trinnene af fremgangsmåden ifølge et hvilket som helst af kravene 1 til 3.

11. Computersystem omfattende organ udformet til implementering af trinnene af fremgangsmåden ifølge et hvilket som helst af kravene 1 til 3.

DRAWINGS

Figure 1

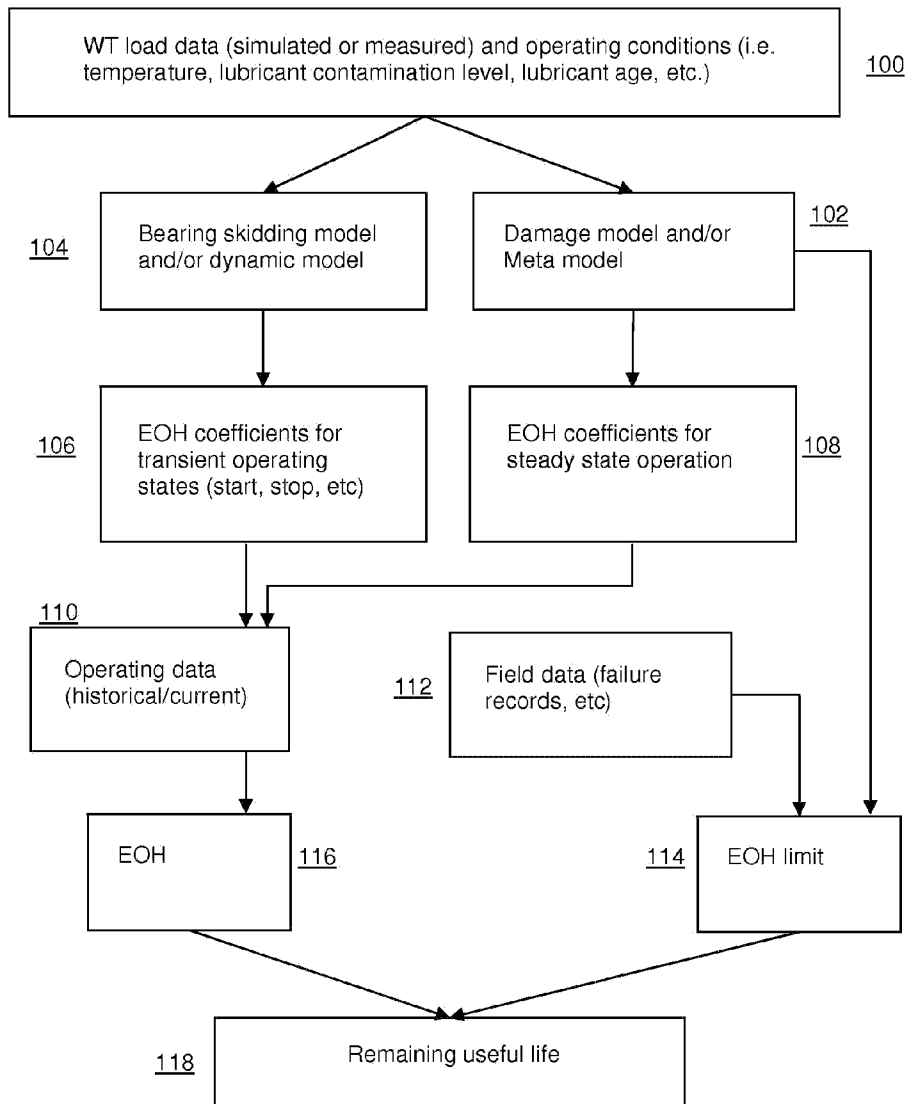


Figure 2

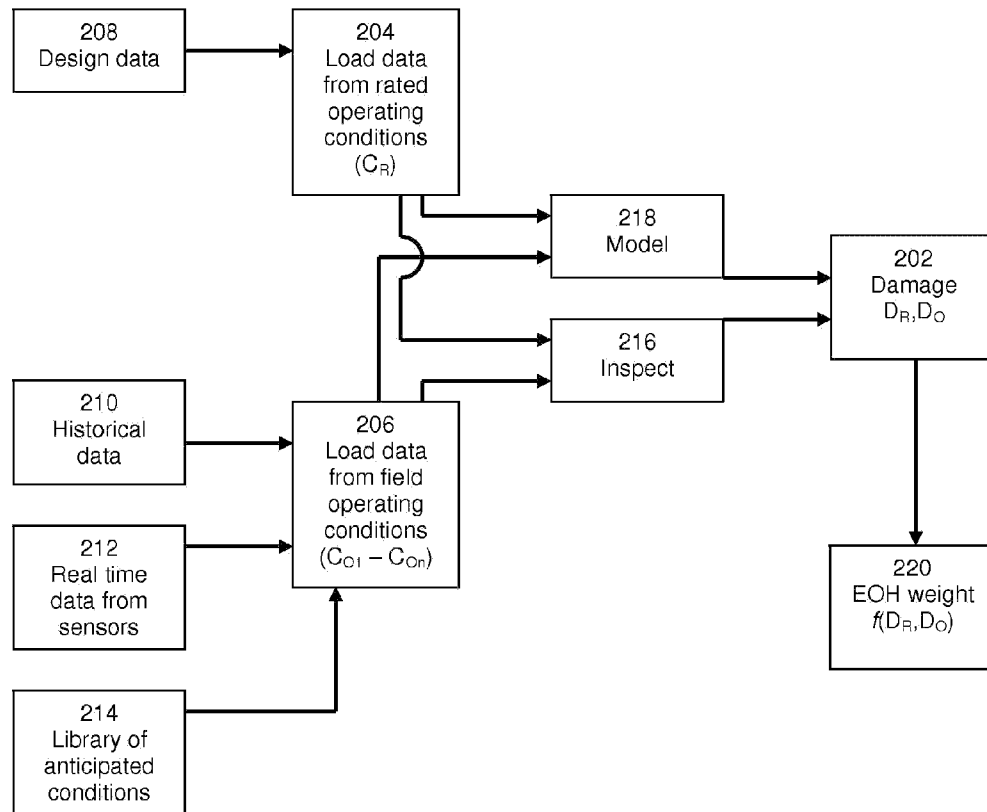


Figure 3

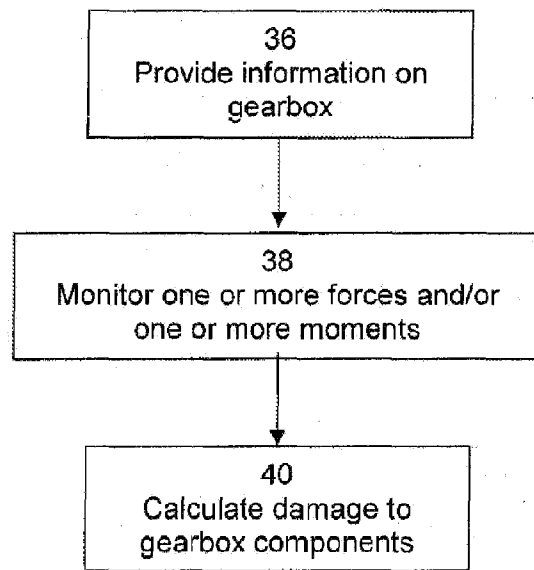


Figure 4

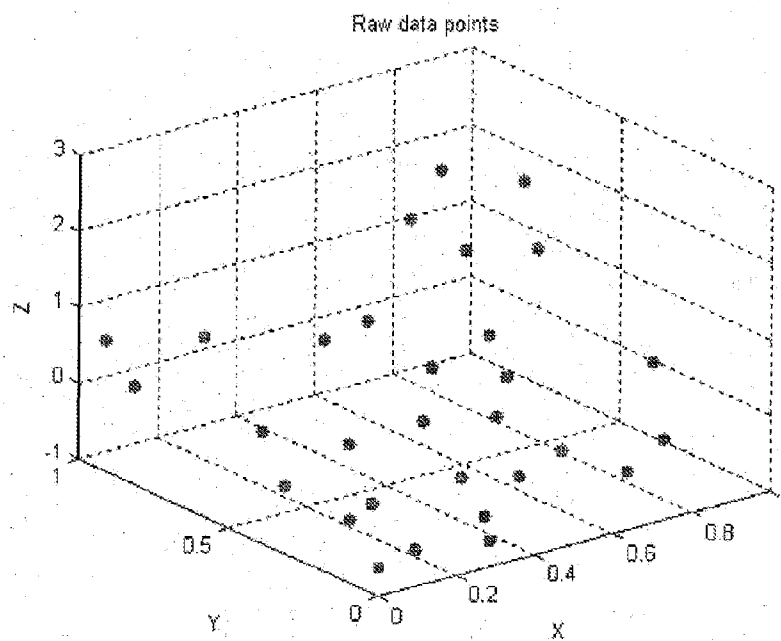


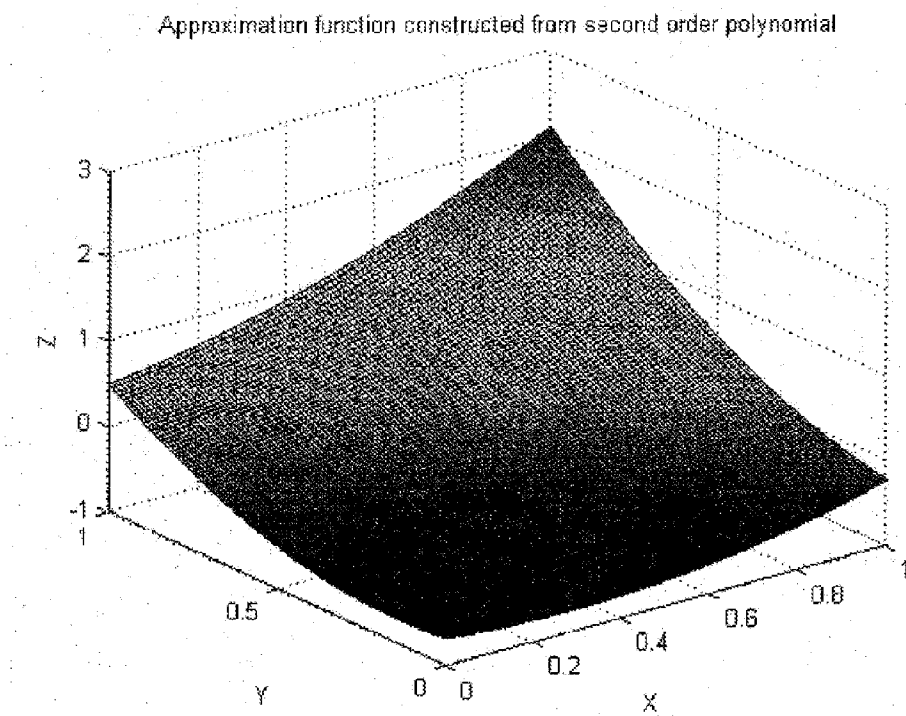
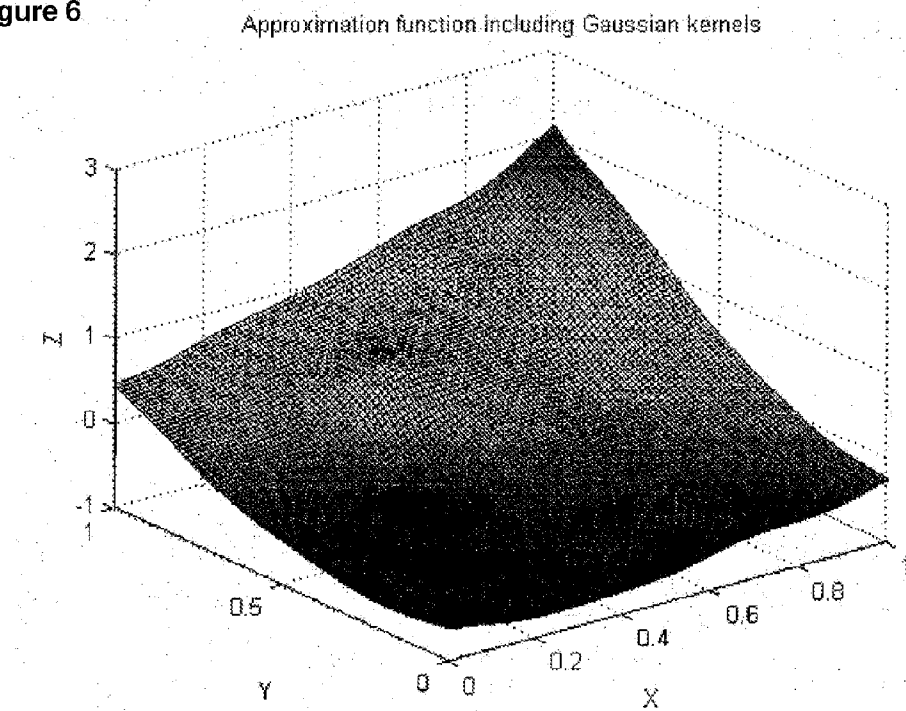
Figure 5**Figure 6**

Figure 7

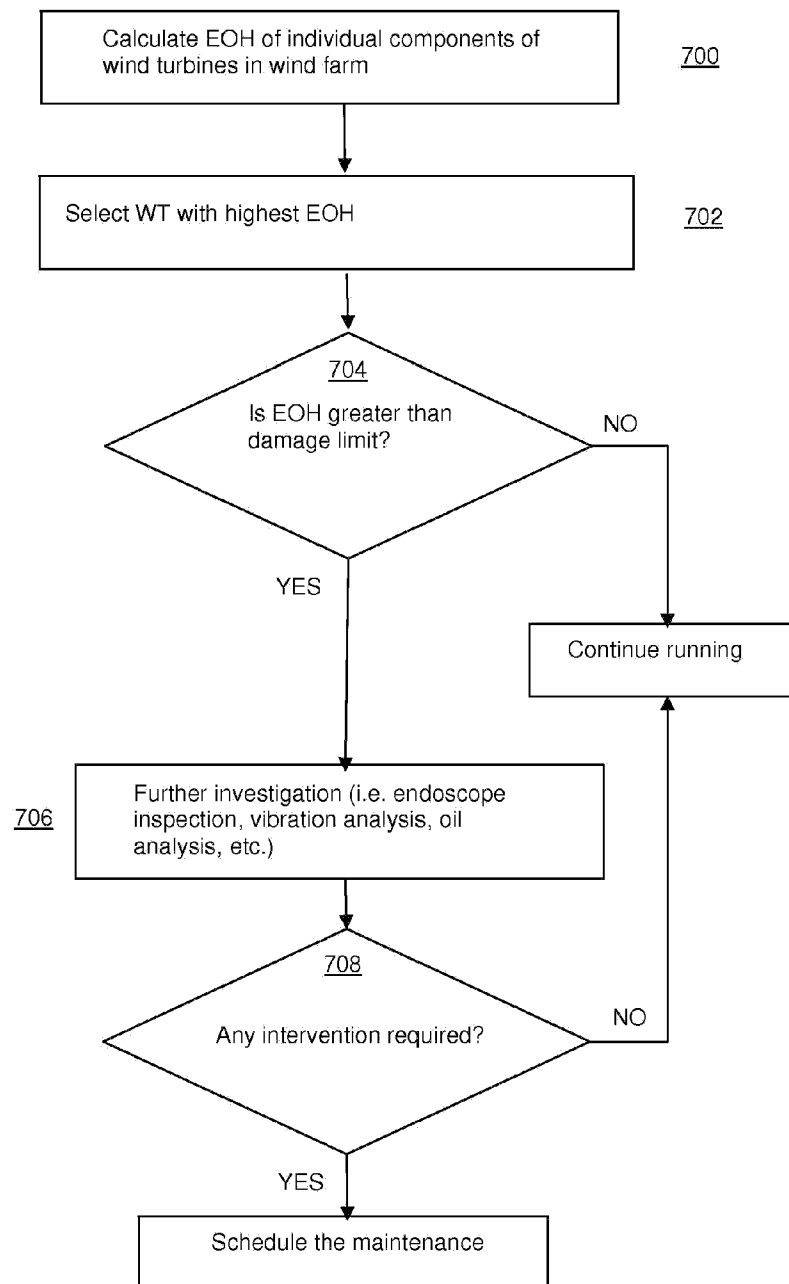


Figure 8

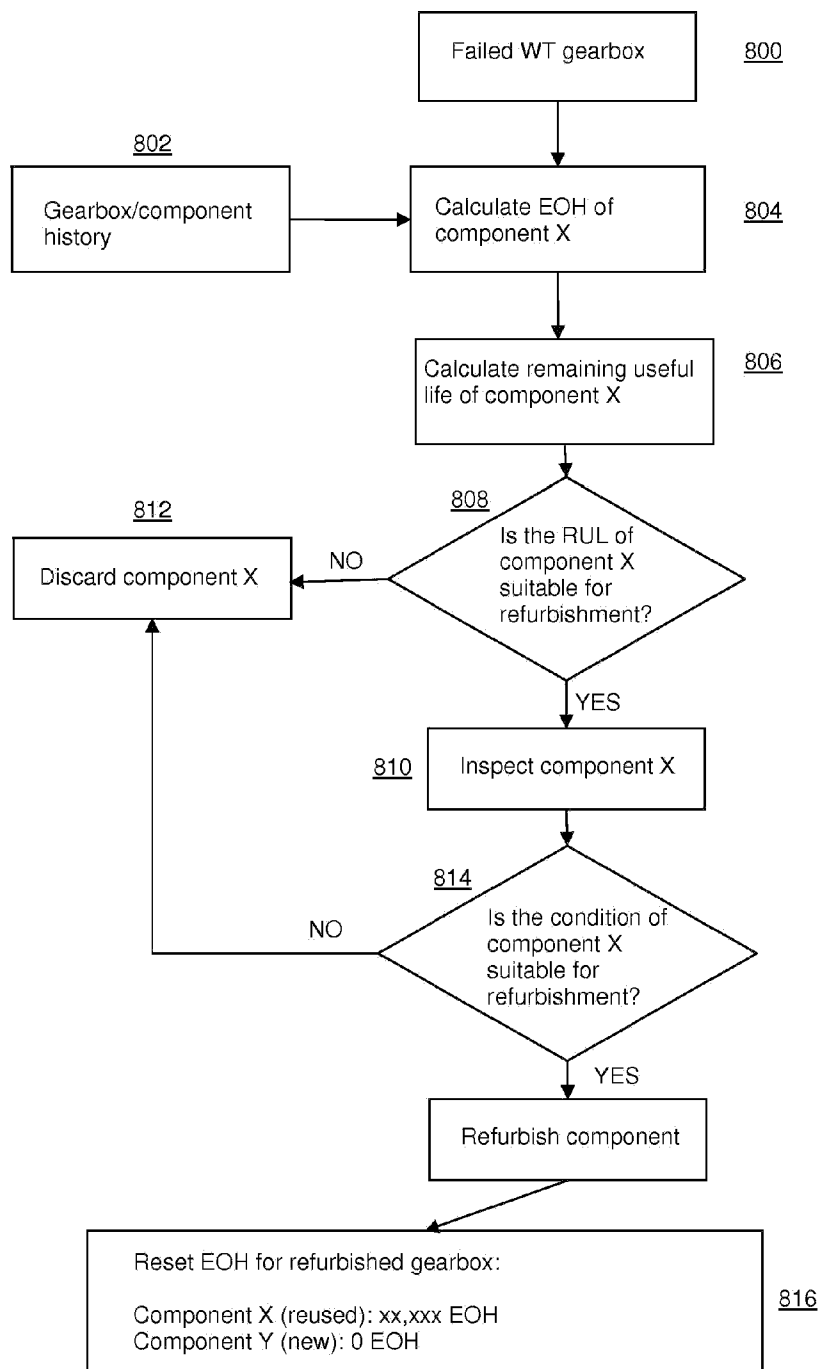


Figure 9

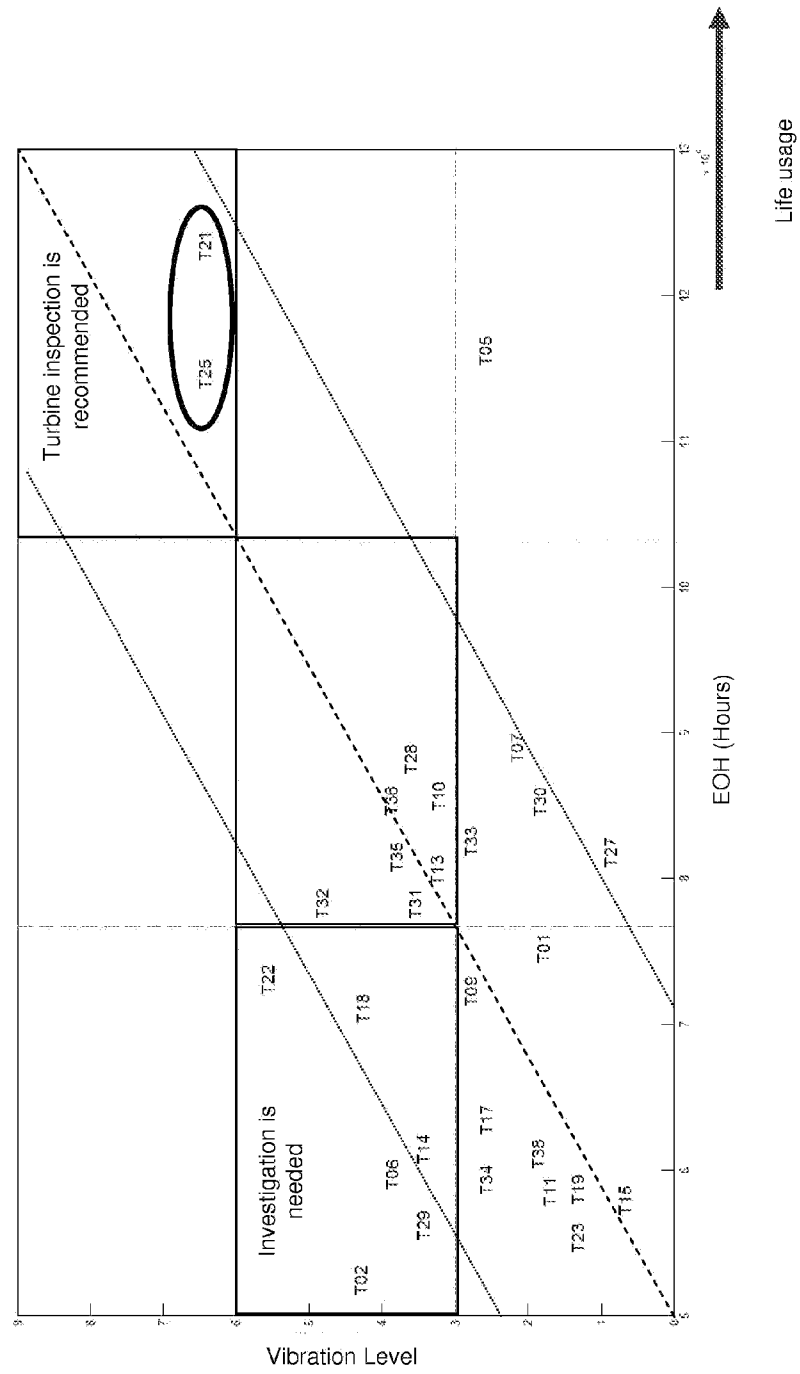


Figure 10

