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(54) **IMPENDING FAILURE AND FAILURE ANNUNCIATION SYSTEMS FOR ACTUATORS AND DRIVE TRAIN COMPONENTS**

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(57) **ABSTRACT**

A method of determining variations in operating characteristics of a mechanical system having a rotatory mode of operation. There are provided the steps of first monitoring operating impulses generated by the mechanical system during a first interval of operation; first analyzing the operating impulses obtained during the first interval to determine the intensity and frequency of the operating impulses; first correlating the operating impulses obtained during the first interval to corresponding angular positions of the rotatory mode of operation; and first producing a first record of the intensity and frequency of the operating impulses obtained during the first interval correlated to the corresponding angular positions of the mechanical system. These steps are repeated to form trend data that results from comparing the first and second records to determine differences in the operating impulses obtained during the respective first and second intervals correlated to the corresponding angular positions of the mechanical system.

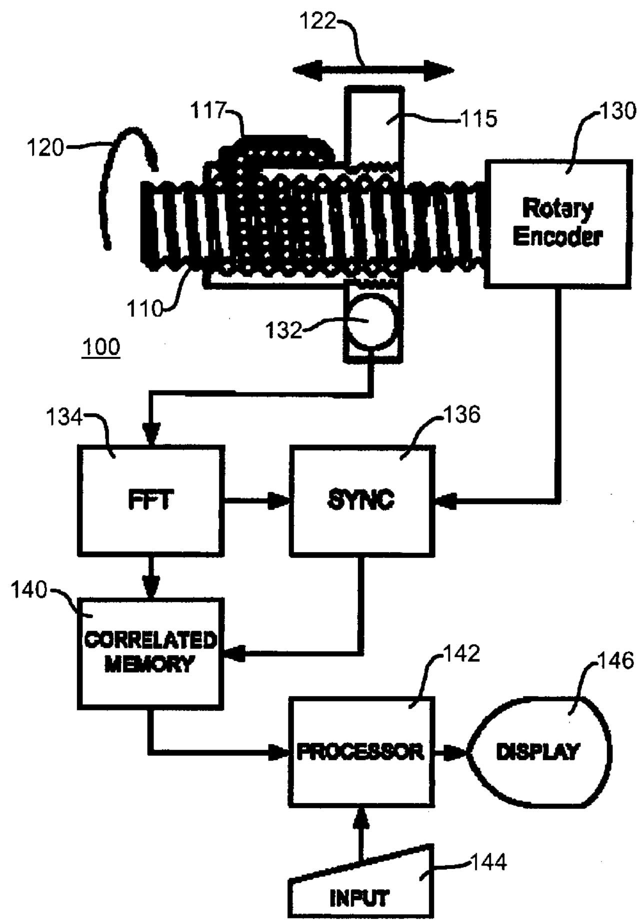
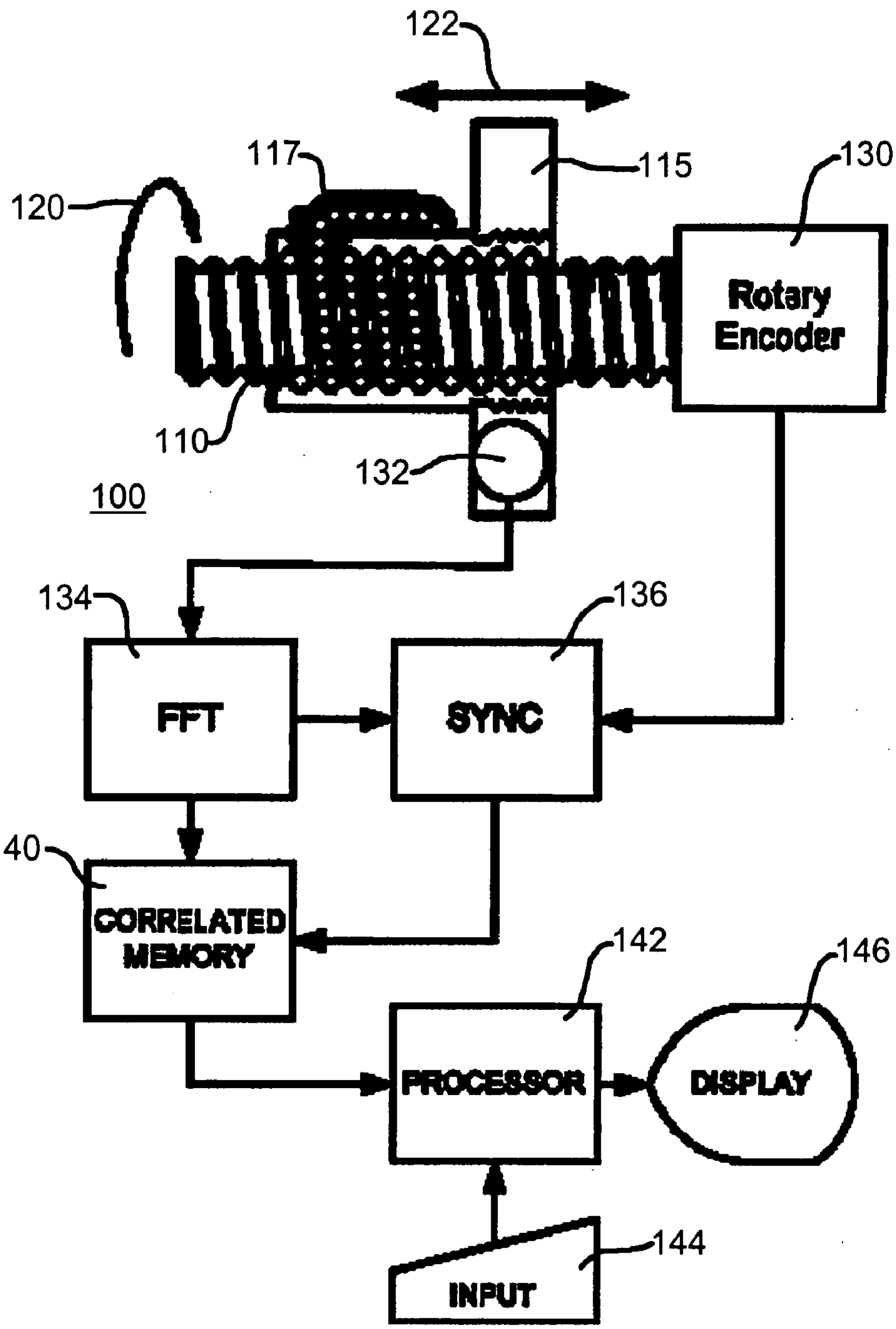


FIG. 1


122
117
115
130
120
Rotary Encoder
110
132
100
134
136
FFT
SYNC
140
CORRELATED MEMORY
142
146
PROCESSOR
DISPLAY
144
INPUT

IMPENDING FAILURE AND FAILURE ANNUNCIATION SYSTEMS FOR ACTUATORS AND DRIVE TRAIN COMPONENTS

RELATIONSHIP TO OTHER APPLICATION

[0001] This application claims the benefit of provisional patent application Ser. No. 60/______, filed Mar. 23, 2006, in the name of the inventor herein.

BACKGROUND OF THE INVENTION

[0002] 1. Field of the Invention

[0003] This invention relates generally to methods of annunciating impending failure and failure in actuators and drive train components, as well as vehicle braking systems.

[0004] 2. Description of the Prior Art

[0005] There are present in the prior art a variety of vibration test systems that enable vibration analysis of operating mechanical systems to determine machine conditions and operating characteristics. In some of these known systems, a handheld device has an associated probe that is touched to an operating machine. The vibrations of the operating machine cause vibrations sensors in the probe to issue corresponding electrical responses that are analyzed by the handheld monitoring device. Although useful in the determination of the operating characteristics of an operating machine, the known vibration test systems are of only limited utility in determining the operating characteristics of mechanical systems that spend little or no time in steady-state modes of operation.

[0006] It is a characteristic of actuators, drive train components, vehicle braking systems, that a significant portion of operation time is spent in transient mode. For example, in a screw drive arrangement of the type used for controlling aircraft control surfaces, the operation of the screw drive arrangement is bidirectional over a limited extent. Therefore, this type of drive spends considerable portions of its operating cycles in bidirectional ramp-up and ramp-down transient conditions. Only a small portion of the operating cycle, if any, is spent in a steady-state condition.

[0007] In the case of drive train components, it is known that these mechanical systems can be tested in steady-state condition on a bench. However, in actual use, these mechanical systems are operated in acceleration, deceleration, and reverse modes of operation. Again, the known vibration test systems are inadequate to analyze the operating characteristics of drive train components in actual use.

[0008] Vehicle braking systems are mechanical arrangements that clearly operate in transient modes. In conventional use, the vehicle brakes are applied while the vehicle is operating at speed, and almost immediately the rate of operation is reduced by deceleration. The effects of such transients are multiplied in vehicle braking systems that are subjected to the stresses of automatic braking systems (ABS).

[0009] There is a need in the art for an on-board vibration test system that monitors the operation of a mechanical system of the type that operates principally in transient modes, and develops trend, or historical, data that reflects changes in the operating characteristics of the mechanical system. There is additionally a need for such a system to be useful in the tracing back of the changes in the overall response of the mechanical system to a change in the operating characteristic of a specific component of the mechanical system.

[0010] There is, therefore, a need in the art for a system and methodology that facilitates the vibrational analysis of mechanical systems that operate largely in transient modes.

[0011] There is additionally a need for a system that facilitates the determination of impending failure of mechanical systems that operate largely in transient modes.

[0012] There is additionally a need for a system that facilitates the determination of actual failure of mechanical systems that operate largely in transient modes.

SUMMARY OF THE INVENTION

[0013] The present invention provides a method of determining variations in operating characteristics of a mechanical system having a rotatory mode of operation. In accordance with a first method aspect of the invention, there are provided the steps of:

[0014] first monitoring operating impulses generated by the mechanical system during a first interval of operation;

[0015] first analyzing the operating impulses obtained during the first interval to determine the intensity and frequency of the operating impulses;

[0016] first correlating the operating impulses obtained during the first interval to corresponding angular positions of the rotatory mode of operation;

[0017] first producing a first record of the intensity and frequency of the operating impulses obtained during the first interval correlated to the corresponding angular positions of the mechanical system;

[0018] second monitoring operating impulses generated by the mechanical system during a second interval of operation;

[0019] second analyzing the operating impulses obtained during the second interval to determine the intensity and frequency of the operating impulses;

[0020] second correlating the operating impulses obtained during the second interval to the corresponding angular positions of the rotatory mode of operation of the mechanical system;

[0021] second producing a second record of the intensity and frequency of the operating impulses obtained during the second interval correlated to the corresponding angular positions of the mechanical system; and

[0022] comparing the first and second records to determine differences in the operating impulses obtained during the respective first and second intervals correlated to the corresponding angular positions of the mechanical system.

[0023] In one embodiment, there are provided the further steps of:

[0024] further monitoring operating impulses generated by the mechanical system during subsequent intervals of operation of the mechanical system;

[0025] further analyzing the operating impulses obtained during the subsequent interval to determine the intensity and frequency of the operating impulses of the mechanical system during respective subsequent intervals;

[0026] further producing a plurality of further records of the intensity and frequency of the operating impulses obtained during respective ones of the subsequent intervals correlated to the corresponding angular positions of the mechanical system; and

[0027] comparing the first, second, and further records to determine a trend in the differences in the operating impulses obtained during the respective first, second, and subsequent intervals.

[0028] In a highly advantageous embodiment, there is further provided the step of identifying a cause in the mechanical system for the trend in the differences in the operating impulses obtained during the respective first, second, and subsequent intervals. In mechanical systems that are rotatory, there is provided the step of identifying a cause in the mechanical system for the trend in the differences in the operating impulses obtained during the respective first, second, and subsequent intervals comprises the further step of acquiring rotatory position data of the mechanical system. Such a rotary mechanical system is, in some embodiments, a ball screw system, an acme screw system, a vehicle drive train, a flight control actuator, or a vehicle braking system.

[0029] In a still further embodiment of the invention, there is further provided the step of quantifying the trend in the differences in the operating impulses obtained during the respective first, second, and subsequent intervals comprises the further step of acquiring rotatory position data of the mechanical system into respective qualities of operation of the mechanical system. Such quantification may include, for example, good, acceptable, and bad opera tinging conditions that are associated with respective levels of required maintenance.

[0030] The monitoring that is effected during the practice of the present invention may be any form of monitoring, such as acoustic signal monitoring, vibration signal monitoring; or displacement signal monitoring. The monitored signals, responsive to operating impulses generated by the mechanical system during the respective intervals of operation, are subjected to a Fourier analysis.

[0031] In accordance with a further method aspect of the invention directed to a flight control actuator, there are provided the steps of:

[0032] first monitoring operating impulses generated by the flight control actuator during a first interval of operation;

[0033] first analyzing the operating impulses obtained during the first interval to determine the intensity and frequency of the operating impulses;

[0034] first correlating the operating impulses obtained during the first interval to corresponding angular positions of the rotatory mode of operation;

[0035] first producing a first record of the intensity and frequency of the operating impulses obtained during the first interval;

[0036] second monitoring operating impulses generated by the flight control actuator during a second interval of operation;

[0037] second analyzing the operating impulses obtained during the second interval to determine the intensity and frequency of the operating impulses;

[0038] second correlating the operating impulses obtained during the second interval to the corresponding angular positions of the rotatory mode of operation;

[0039] second producing a second record of the intensity and frequency of the operating impulses obtained during the second interval;

[0040] comparing the first and second records to determine differences in the operating impulses obtained during the respective first and second intervals of operation of the flight control actuator; and

[0041] determining a mechanical reason for differences in the operating impulses obtained during the respective first and second intervals of operation of the flight control actuator.

[0042] In embodiments of this further method aspect where the flight control actuator is of the type having bearing elements, one mechanical reason for differences in the operating impulses obtained during the respective first and second intervals of operation of the flight control actuator is deformation in the bearing elements. Additionally, in embodiments where the flight control actuator is of the type having bearing races, mechanical reason for differences in the operating impulses obtained during the respective first and second intervals of operation of the flight control actuator is deformation in the bearing races. Still further, in embodiments where the flight control actuator is of the type having a ball screw containing ball bearings, a mechanical reason for differences in the operating impulses obtained during the respective first and second intervals of operation of the flight control actuator is reduced effectiveness of the ball bearings. In yet further embodiments where the flight control actuator is of the type having an acme screw, a mechanical reason for differences in the operating impulses obtained during the respective first and second intervals of operation of the flight control actuator is increased friction.

[0043] In embodiments where the flight control actuator is of the type having a screw shaft, a mechanical reason for differences in the operating impulses obtained during the respective first and second intervals of operation of the flight control actuator is damage to the screw shaft. A further reason for differences in the operating impulses obtained during the respective first and second intervals of operation of the flight control actuator is a change in the backlash.

[0044] The vibration monitoring sensor is installed in some embodiments on the ball nut. Alternatively, however, the vibration sensor can be installed on the screw shaft, or both. In embodiments where the sensor is installed on the screw shaft, there is additionally provided a data port for issuing the impulse data responsive to the steps of first and second monitoring.

[0045] The impulse data is responsive to the steps of first and second monitoring and is made available to a user at a data display system. Some of the data from the mechanical system is transmitted using a wireless transmission system.

BRIEF DESCRIPTION OF THE DRAWING

[0046] Comprehension of the invention is facilitated by the annexed drawing, in which

[0047] FIG. **1** is a schematic and function block representation of an annunciation arrangement for a ball screw actuator

DETAILED DESCRIPTION

[0048] FIG. **1** is a schematic and function block representation of an annunciation arrangement **100** for a ball screw actuator. As shown in this figure, a screw shaft **110** is configured to engage a ball nut **115**, and there is provided a ball recirculating system **117** that provides a multiplication of bearing balls (not specifically designated) in the interface between the screw shaft and the ball nut. As screw shaft **110** is rotated, illustratively in the direction of torque arrow **120**, ball nut **115** is urged in the linear direction in accordance with bidirectional arrow **122**.

[0049] In this embodiment of the invention, screw shaft **110** is coupled to a rotary encoder **130** that issues electrical signals that correspond to the angular position of the screw shaft. There is additionally provided in this specific illustrative embodiment of the invention a vibration transducer **132** that is shown to be directly coupled to the ball nut. Vibration transducer **132** receives acoustic or vibrational or displacement information from the ball nut, and produces corresponding signal that is propagated to a Fast Fourier Processor (FFT) **134**. The output of the FFT **134** is propagated to a synchronizer **136** that receives the angular position signals from rotary encoder **134**. Thus, FFT "snapshots" are correlated to the angular position of the screw shaft and stored in a correlated memory **140**. It is to be noted that in some embodiments of the invention the data from vibration transducer **132** is propagated to FFT **134** by means of a wireless transmission system. This, as noted herein, provides significant advantages in applications where the ball screw arrangement is inaccessibly disposed on the mechanical system (not shown). In applications where the present arrangement is installed in an aircraft (not shown), other items of data may wirelessly be transmitted. However, in some aircraft applications the rotary encoder data is available from the aircraft's system.

[0050] A processor **142** receives information from correlated memory **140**, which may, in certain embodiments, contain data corresponding to historical FFT snapshots obtained during prior test intervals. Processor **142** additionally will, in certain embodiments, maintain a count of the angular position data and correlate same to linear displacement of the ball nut along the screw shaft (in the direction of bidirectional arrow **122**. Thus, trend data responsive to angular position of the screw shaft, which corresponds to possible deflection of bending thereof, and trend data responsive to linear displacement, which corresponds to thread damage, is obtained. In some embodiments, the recirculation cycle of the bearing balls (not specifically designated) is counted to form a data cycle that will reveal damage to one or more of the bearing balls. All of the foregoing data is made available to a user (not shown) at a display **146**, in response to data and mode requests entered at an input **144**.

[0051] 1. Methods of annunciating failure in flight controls and aerospace jack screw actuators (ball screws, roller screws, and ACME screws), and rotary actuators.

[0052] a. Using System Vibration Signature Monitoring

[0053] A compact micro-processor controlled on-line data collection vibration signature monitoring system equipped with vibration and/or velocity and/or accelerometers allows early failure detection in jack screws.

[0054] Failure related to damage in the moving components of flight controls and aerospace electromechanical actuators, such as ball screws, roller screws, ACME screws, threads, bearing's outer races, inner races, ball bearings, rollers, cage, return tubes or return circuits, anti-backdrive devices, gear train components, clutches, motor assembly components can be diagnosed on-line by monitoring the impulses caused by material damage in these areas (features/components), measuring the intensity and frequency of the impulses, and observing the trend of these values over a period of time.

[0055] The following types of failures, without limitation, can be diagnosed using vibration monitoring:

[0056] i. deformation in the bearing elements or races;

[0057] ii. increased friction (scuffing, skidding);

[0058] iii. distortion or breakage of the screw shaft (shaft bending will cause unbalance in the system, therefore periodic vibrations, and the fracture of the shaft, if the actuator is still operational, would have a different resonance frequency due to the different length which would generate a different vibration signature (response) when excited by the system during actuation).

[0059] iv. separation/loss of ball bearings from the ball nut (due to any reasons, especially due to failure of the ball recirculation system).

[0060] v. distortion or breakage of the anti-backdrive (no back) components such as the pawl, the pawl shaft, the cage or the thrust plate.

[0061] The angular position of the mechanical system is determined from on-board encoders and resolvers that are coupled to a system shaft. In some embodiments, it is advantageous to know the RPM of the system so that the outside noise can be filtered out and a clean signal extracted for analysis.

[0062] If the failure monitoring pertains to a flight control actuator, and because vibration monitoring testing requires higher RPMs, the tests are, in certain embodiments, conducted on the ground, at predetermined maintenance cycles. In a preferred embodiment, however, the microprocessor unit is an integral part of the actuator system and, coupled with angular position determining circuitry, can be used to analyze the mechanical system during actual use in transient modes. However, depending on the test frequency, it can also be designed as aircraft ground maintenance equipment.

[0063] b. Using Strain Gages

[0064] The secondary load path elements in actuators are sometimes preloaded (e.g. tie rod mounted through the screw shaft of an actuator). The preload is necessary in some applications to increase the column buckling stability of the screw shaft under compressive stresses. The secondary load path in the case of a tie rod serves the purpose of carrying the total load in case of failure of the primary load path (e.g. screw shaft).

[0065] Detecting dormant failures of such elements is critical. The strain gage is, in some embodiments, permanently attached to a component operating under constant compressive or tension stress, and appropriate ports for effecting electrical communication can, in certain embodiments, be disposed in an accessible external socket of the actuator system. After the assembly operation is finalized and the subject component that needs to be monitored has been preloaded, an "initial condition" ("birth certificate") reading as supplied, for example, by OEM, can be taken and recorded (electronically or manually) by connecting a data reading or data-acquisition instrument to the external socket where the strain gage is connected.

[0066] At further maintenance cycles, or during on-line live monitoring, the preload variance can be monitored, studied for trends, and used for failure diagnostic and warning indicators triggering (e.g. a fracture in a tie rod operating in tension, would indicate zero stresses after fracture and the system would announce failure after comparing this new reading with the initial calibration reading recorded at the time the system was manufactured or placed in service after maintenance).

[0067] c. ACME Screw (Square Thread, Castle Thread, Etc.) Actuators—Using Sliding Friction Threads Backlash Indicator

[0068] A probe is attached to the end face, in lieu of a sector of thread inside the of the ACME nut, or in lieu of a sector of thread on the screw. The maximum allowable backlash in the unit resulting either due to wear of the nut threads or screw threads, depending on the geometry of the thread, will determine (using basic geometry and trigonometry math formulas), a set distance to the flanks of the threads.

[0069] Any excessive wear in the threads will cause the probe to engage with the threads and the failure to be detected.

[0070] Many faults and types of damage in linear and rotary actuator systems lead to mechanical vibrations with frequencies directly related to the rotational speed of their components or rotor. Of special interests are e.g., unbalance, alignment errors, ball bearing-pass frequencies, gear mesh frequencies in gearboxes, that occur as rotor-synchronous vibrations or harmonics (orders) of the rotor's rotational frequency.

[0071] The vibration behavior that the actuator system exhibits over the entire speed range will provide important information about the resonance profile of the actuator system, which later can be used for diagnostic purposes. The FFT spectrum can be used for the faults and damage analysis of an actuator system. In a highly advantageous embodiment po the invention, FFT snapshots are correlated to angular position of the mechanical system. In addition to enabling assessment of the operation of a mechanical system that operates in transient modes, such correlation to angular position facilitates identification of a mechanical system component that is about to fail, as evidenced by changes in the angular position correlated FFT snapshots over time. By employing a precise and accurate tracking analysis, an extremely fast and selective narrowband measurement of rotor synchronous vibrations can be measured. Thus the most significant vibration signals from the actuator system can be analyzed in any operating phase: stationary operation, run-up, coast-down, reverse, or over a longer time, to account for the thermal mechanical events of the actuator system.

[0072] The operation of the present invention is enhanced in certain embodiments by archiving the data locally (in a memory chip attached to the actuator), whether while performing online monitoring or off-line measurements, the overall readings, the current value, the previous value and the relationship with the alarm value shall always be available. Based on a pass or fail criteria an alarm signal is, in certain embodiments, provided when the vibration measurement instrumentation detects out-of-range or otherwise unacceptable values, or a modified profile of the readings compared to the baseline configuration and vibration signature model stored at the beginning of life of the actuator. Various failure modes (such as ball bearing damage, ball bearing escape and separation from the assembly, gear tooth breakage, skewered roller damage, ratchet or pawl fracture, radial bearings failure, slip clutch components failure, tie rod or torsion rod failure, etc.), can be simulated and induced into the system during qualification testing of the actuator, to ensure proper calibration and understanding of the impact produced by the failure of each of the different components onto the overall vibration signature of the assembly.

[0073] The use of such vibration diagnostic annunciation system allows early detection of impending failure, before its magnitude becomes critical or catastrophic. The vibration annunciation method of the present invention is useful to detect numerous failure types such as, but not limited to, ball escape, bearing race pitting or spalling, cracking or fracture of rotary or stationary components. Problems arising from unbalance, misalignment, gear damage, bearing damage, can be recognized at an early stage. Impulses caused by damage to the outer race or inner race of a bearing surface, to the roller(s) or ball bearing(s), or corresponding cages are a good indicator of the bearing condition. Reliable monitoring of the actuator assembly condition is possible by measuring the intensity and frequency of the impulses, and observation of the trend of these values over a period of time allows accurate diagnostic of the integrity and operation readiness of the jackscrew actuator.

[0074] Flight control actuator system damage and losses related to abnormal aircraft operations (unscheduled repairs or accidents), as a result of failed actuator can be successfully avoided by monitoring the "health" (structural integrity) of the actuator system by using the vibration monitoring failure annunciation.

[0075] In general aerospace applications, and specifically in flight controls actuation, weight control and reduction is very important. The advantage of using active vibration monitoring failure annunciation consists in minimum weight increase to the actuator system, consisting of two to three pickups (accelerometers), and wiring. The rest of the diagnostic logic can be supplied in a separate enclosure dedicated to data collection and monitoring the vibration signature of the actuator system, or it can easily be integrated into the existing flight control computers of the aircraft as an additional subroutine in the complex software programs that already govern the functionality of the flight control systems with today's modern aircraft.

[0076] The accelerometer probes can be mounted on the actuator assembly housing or attached directly to various subcomponents of the system. In some cases for the evaluation of the actuator system condition, simultaneous measurements from two points on this actuator system must be considered, i.e., a simultaneous acquisition through two channels of the instrument would be required for comprehensive diagnosis of the actuator system. A dual channel operation approach will be more accurate in providing reliable measurements on the system.

[0077] For systematic acquisition evaluation of all measurements types for predictive actuator maintenance, the following types of readings can be used: amplitude phase versus speed check amplitude phase versus time.

[0078] For efficient fault detection multiband pass space filters in the frequency range of measurement can be applied. The computer instrumentation software can be tailored to various operating ranges of the actuator system, and a database archiving system can provide information for predictive actuator system diagnostic and maintenance.

[0079] The vibration diagnostic method will allow predictive actuator system maintenance, therefore higher levels of aircraft availability for flight missions (dispatchability) prevention of unscheduled repairs, limitation of flight control system components damage or flight incidents, by early fault diagnosis, lengthening of intervals between inspections and timely planning to have optimally scheduled repair actions are the basis for the cost-effective significance of this strategy for an entire company.

[0080] The prerequisite for this is continuous knowledge of the current actuator system condition during operation. Mechanical vibrations, bearing condition values, speeds and process values are authoritative indicators with which the actuator system condition can be assessed and diagnosed. Which characteristic parameters should be acquired and how often, depends not only on the complexity and absolute value of the actuator system but also on the criticality of the aircraft system that is monitored.

[0081] The characteristic parameters will be calibrated on the monitoring system and initial vibration signature certificates will be recorded at entrance into service, as mounted on the aircraft. This represents a reference data set that will be used as a baseline, and will be therefore considered a normal operating condition data set.

[0082] The periodic readings, whether online with active sensors mounted on the actuator housing or attached directly to specific components, or off-line at predetermined maintenance checks intervals, can be archived via computer software and a common database for all measured data.

[0083] Standard acceleration, velocity and displacement sensors can be used.

[0084] The measuring functions that can be employed in the vibration diagnostic, are:

[0085] Absolute bearing vibrations relative shaft vibrations bearing condition speed measurement tempted to measurement damage to the internal and external lead screw threads, failure of the ratchet pawls of the anti-backlash brake (No Back), damage to the skewed roller clutch components (rollers, cage).

[0086] It is advisable to employ instrumentation that allows flexible configurations for various setups of the high and low pass filters for broadband measurement. This guarantees optimum adaptation to the individual measurement task. It is advisable to employ an averaging function for noise influence.

[0087] Damaging the internal components of an actuator system, such as material separation from the screw or nut threads, pitting and spalling of the rollers and ball bearings, breakage of the ratchet-pawls in a slip clutch, breakage in the cage of the skewed roller clutch, would result in a beat effect which will be easily detectable when recording frequency versus time.

[0088] If unacceptably high overall vibrations, intermittent beatings or bearing conditions, are found in the process of monitoring and diagnosing actuator system health, the causes can be identified by using frequency analysis (FFT) and envelope analysis. The anomalies (increased vibrations), can be traced to unbalance, misalignment, a bearing or gear fault or some other source.

[0089] The control and failure-detection in torsion, compression, or tension stressed beams using strain gage measurement can effectively be used in preventing catastrophic failures by early detection of dormant secondary load path failures, and is mostly beneficial in difficult to access areas of the airplane, where visual or direct access inspection can be accomplished only by disassembly of a multitude of components. As example, but not limited to, the hard to access internal tie rod or torsional spring assemblies are good candidates for this monitoring method.

[0090] The early detection of upcoming failure with minimum invasive disassembly and labor, is critical in flight controls actuators. The secondary load path failure through cracking, and ultimately through fracture of the tie rod or torsion rod inside the screw shaft of an actuator can be identified and diagnosed by employing strain gauges mounted directly on the broad shaft, either by using a single probe or multiple (odd number) probes setup for a logical voting decision making process within the monitoring or diagnostic instrumentation.

[0091] The strain gauges can be attached directly to the rod that is operating under tension, compression or torsion stresses. The corresponding wiring from these strain gauges shall be then routed in a specifically designed gap between the inner diameter of the screw shaft and the outside profile of the tie rod, or in a different manner (channels on the outside surface of the rod, drilled holes in the rod, etc.), towards the end face of the rod that protrudes outside of the screw shaft, and outside of the actuator where possible. In this location the wiring is routed to a connector that is available to be used by either the maintenance personnel, equipped with an off-line piece of instrumentation, or connected on-line directly to the flight control computers of the airplane for active monitoring of the secondary load path integrity inside the screw shaft of the actuator.

[0092] The use of noninvasive methods that allow continuous on-line remote monitoring and a highly reliable operation readiness of the internal components in a flight control actuator, is beneficial because it also minimizes the probability of errors that may occur in case maintenance personnel would have to disassemble many components to expose and inspect internal features that are provided for the safety of the actuator system. The probability of errors in reassembling the components in a prescribed order to ensure proper functionality of the actuator system is reduced or eliminated by using this method (strain gauges wired to an external connector or by using strain gauges that will report wirelessly the status of the stresses at their location), therefore the system safety will be increased when employing this type of monitoring and diagnostic method.

[0093] Although the invention has been described in terms of specific embodiments and applications, persons skilled in the art may, in light of this teaching, generate additional embodiments without exceeding the scope or departing from the spirit of the invention described herein. Accordingly, it is to be understood that the drawing and description in this disclosure are proffered to facilitate comprehension of the invention, and should not be construed to limit the scope thereof.

What is claimed is:

1. A method of determining variations in operating characteristics of a mechanical system having a rotatory mode of operation, the method comprising the steps of:

first monitoring operating impulses generated by the mechanical system during a first interval of operation;

first analyzing the operating impulses obtained during the first interval to determine the intensity and frequency of the operating impulses;

first correlating the operating impulses obtained during the first interval to corresponding angular positions of the rotatory mode of operation;

first producing a first record of the intensity and frequency of the operating impulses obtained during the first interval correlated to the corresponding angular positions of the mechanical system;

second monitoring operating impulses generated by the mechanical system during a second interval of operation;

second analyzing the operating impulses obtained during the second interval to determine the intensity and frequency of the operating impulses;

second correlating the operating impulses obtained during the second interval to the corresponding angular positions of the rotatory mode of operation of the mechanical system;

second producing a second record of the intensity and frequency of the operating impulses obtained during the second interval correlated to the corresponding angular positions of the mechanical system; and

comparing the first and second records to determine differences in the operating impulses obtained during the respective first and second intervals correlated to the corresponding angular positions of the mechanical system.

2. The method of claim 1, wherein there are provided the further steps of:

further monitoring operating impulses generated by the mechanical system during subsequent intervals of operation of the mechanical system;

further analyzing the operating impulses obtained during the subsequent interval to determine the intensity and frequency of the operating impulses of the mechanical system during respective subsequent intervals;

further producing a plurality of further records of the intensity and frequency of the operating impulses obtained during respective ones of the subsequent intervals correlated to the corresponding angular positions of the mechanical system; and

comparing the first, second, and further records to determine a trend in the differences in the operating impulses obtained during the respective first, second, and subsequent intervals.

3. The method of claim 2, wherein there is further provided the step of identifying a cause in the mechanical system for the trend in the differences in the operating impulses obtained during the respective first, second, and subsequent intervals.

4. The method of claim 3, wherein the mechanical system is a rotatory mechanical system and said step of identifying a cause in the mechanical system for the trend in the differences in the operating impulses obtained during the respective first, second, and subsequent intervals comprises the further step of acquiring rotatory position data of the mechanical system.

5. The method of claim 4, wherein the mechanical system is a ball screw system.

6. The method of claim 4, wherein the mechanical system is an acme screw system.

7. The method of claim 4, wherein the mechanical system is a vehicle drive train.

8. The method of claim 4, wherein the mechanical system is a flight control actuator.

9. The method of claim 4, wherein the mechanical system is a vehicle braking system.

10. The method of claim 4, wherein there is further provided the step of quantifying the trend in the differences in the operating impulses obtained during the respective first, second, and subsequent intervals comprises the further step of acquiring rotatory position data of the mechanical system into respective qualities of operation of the mechanical system.

11. The method of claim 10, wherein said respective qualities of operation of the mechanical system correspond to intervention maintenance states of the mechanical system.

12. The method of claim 1, wherein said steps of first and second monitoring each comprise the step of acoustic signal monitoring.

13. The method of claim 1, wherein said steps of first and second monitoring each comprise the step of vibration signal monitoring.

14. The method of claim 1, wherein said steps of first and second monitoring each comprise the step of displacement signal monitoring.

15. The method of claim 1, wherein said steps of first and second analyzing each comprise the step of subjecting the operating impulses generated by the mechanical system during the respective intervals of operation to a Fourier analysis.

16. A method of determining variations in operating characteristics of a flight control actuator having a rotatory mode of operation, the method comprising the steps of:

first monitoring operating impulses generated by the flight control actuator during a first interval of operation;

first analyzing the operating impulses obtained during the first interval to determine the intensity and frequency of the operating impulses;

first correlating the operating impulses obtained during the first interval to corresponding angular positions of the rotatory mode of operation;

first producing a first record of the intensity and frequency of the operating impulses obtained during the first interval;

second monitoring operating impulses generated by the flight control actuator during a second interval of operation;

second analyzing the operating impulses obtained during the second interval to determine the intensity and frequency of the operating impulses;

second correlating the operating impulses obtained during the second interval to the corresponding angular positions of the rotatory mode of operation;

second producing a second record of the intensity and frequency of the operating impulses obtained during the second interval;

comparing the first and second records to determine differences in the operating impulses obtained during the respective first and second intervals of operation of the flight control actuator; and

determining a mechanical reason for differences in the operating impulses obtained during the respective first and second intervals of operation of the flight control actuator.

17. The method of claim 16, wherein the flight control actuator is of the type having bearing elements, and the mechanical reason for differences in the operating impulses obtained during the respective first and second intervals of operation of the flight control actuator is deformation in the bearing elements.

18. The method of claim 16, wherein the flight control actuator is of the type having bearing races, and the mechanical reason for differences in the operating impulses obtained during the respective first and second intervals of operation of the flight control actuator is deformation in the bearing races.

19. The method of claim 16, wherein the flight control actuator is of the type having a ball screw containing ball bearings, and the mechanical reason for differences in the operating impulses obtained during the respective first and second intervals of operation of the flight control actuator is reduced effectiveness of the ball bearings.

20. The method of claim 16, wherein the flight control actuator is of the type having an acme screw, and the mechanical reason for differences in the operating impulses obtained during the respective first and second intervals of operation of the flight control actuator is increased friction.

21. The method of claim 16, wherein the flight control actuator is of the type having a screw shaft, and the mechanical reason for differences in the operating impulses obtained during the respective first and second intervals of operation of the flight control actuator is damage to the screw shaft.

22. The method of claim 16, wherein the flight control actuator is of the type having a screw shaft, and the mechanical reason for differences in the operating impulses obtained during the respective first and second intervals of operation of the flight control actuator is a change in the backlash.

23. The method of claim 16, wherein there is further provided the step of installing a monitoring system in the flight control actuator for performing said steps of first and second monitoring, the monitoring system having a data port for issuing impulse data responsive to said steps of first and second monitoring.

24. The method of claim 23, wherein there is further provided the step of transmitting the impulse data responsive to said steps of first and second monitoring to a data display system.

25. The method of claim 24, wherein said step of transmitting is performed using a wireless transmission system.

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