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Rotational torque measurement device

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A device for measuring torque applied through a rotating member. A first torsion reference member is fixedly coupled to the rotating member at a first axial position and a second torsion reference member is fixedly coupled to the rotating member at a second axial position. A first detector detects the passage of the first torsion reference member past the first detector upon each full rotation of the rotating member and to generate a first signal upon each passage of the first torsion reference member. A second detector detects the passage of the second torsion reference member past the second detector upon each full rotation of the rotating member and to generate a second signal upon each passage of the second torsion reference member. A controller calculates a phase difference between the first signal and the second signal relative during rotation of the rotating member under a torsional load.
FIG. 4

Signal Conditioning

First Detector

Second Detector

90 → 94

66 → 70

102 → 104
FIG. 5

ZERO TORQUE APPLIED, PHASE CONSTANT

PHASE CHANGES WITH APPLIED TORQUE

PHASE RETURNS TO ZERO TORQUE SPACING
ROTATIONAL TORQUE MEASUREMENT DEVICE

This application claims priority to U.S. Provisional Patent Application No. 61/225,834, filed on Jul. 15, 2009, the entire content of which is incorporated herein by reference.

BACKGROUND

The present invention relates to a torque measurement device, and more particularly to a rotational torque measurement device with a reference member and detector.

Torque measurement devices typically utilize a torque transducer or sensor, which convert an applied torque into an electrical signal. A strain gauge is a torque transducer that converts applied torque into a change in electrical resistance. Typically, a strain gauge is attached to a deformable member, a torque is applied, and a change in electrical resistance is measured as the member deforms. The change in electrical resistance is converted into a torque measurement. Inertia of rotating components can cause measurement error. Additionally, due to their wires, such strain gauges are not applicable to rotating members.

SUMMARY

In one embodiment, the invention provides a device for measuring the torque applied through a rotating member rotating about a longitudinal axis, relative to a fixed member. The device includes a first torsion reference member fixedly coupled to the rotating member at a first axial position and a second torsion reference member fixedly coupled to the rotating member at a second axial position. A first detector is coupled to the fixed member and configured to detect the passage of the first torsion reference member past the first detector upon each full rotation of the rotating member and to generate a first signal upon each passage of the first torsion reference member. A second detector is coupled to the fixed member and configured to detect the passage of the second torsion reference member past the second detector upon each full rotation of the rotating member and to generate a second signal upon each passage of the second torsion reference member. A controller is configured to calculate a phase difference between the first signal and the second signal relative to a time reference during rotation of the rotating member under a torsional load. The controller compares the phase difference to a reference value and calculates a torque loading on the rotating member resulting from the torsional load based on the phase difference.

In another embodiment, the invention provides a method of measuring torque applied through a rotating member rotating about a longitudinal axis relative to a fixed member. The method includes applying a torsional load to the rotating member. Rotation of the rotating member is detected at a first axial position and a first signal is generated. Rotation of the rotating member is detected at a second axial position and a second signal is generated. A phase difference is calculated between the first signal and the second signal and compared to a reference value. A torque applied to the rotating member is calculated based at least upon the magnitude of the phase difference.

In yet another embodiment, the invention provides a system for calculating a torque load on a shaft. The system includes a first sensor generating a first signal in response to rotation of the first portion of the shaft and a second sensor generating a second signal in response to rotation of the second portion of the shaft. A processor compares the first signal to the second signal to arrive at a loaded phase difference between the first and second signals while the shaft is rotating under a load. The loaded phase difference is compared to a baseline phase difference. A twist in the shaft between the first and second portions of the shaft is calculated based on a difference between the loaded phase difference and the baseline phase difference.

DETAILED DESCRIPTION

Before any embodiments of the invention are explained in detail, it is to be understood that the invention is not limited in its application to the details of construction and the arrangement of components set forth in the following description or illustrated in the following drawings. The invention is capable of other embodiments and of being practiced or of being carried out in various ways.

FIG. 1 is a perspective view of a shaft with an applied torque. FIG. 2 is a perspective view of shaft with a torque measuring device according to one aspect of the invention. FIG. 3 is a side view of a first torsion reference member and a first detector of the torque measuring device of FIG. 2. FIG. 4 is a block diagram of a controller of the torque measurement device of FIG. 2. FIG. 5 is a graph comparing a signal generated by the first detector to a signal generated by the second detector of the torque measuring device of FIG. 2. FIG. 6 is a perspective view of a shaft with a torque measuring device according to another aspect of the invention. FIG. 7 is a perspective view of a shaft with a torque measuring device according to yet another aspect of the invention. FIG. 8 is a side view of a first torsion reference member and a first detector of the torque measuring device of FIG. 7. FIG. 9 is a perspective view of a shaft with a torque measuring device according to still yet another aspect of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a perspective view of a shaft with an applied torque. FIG. 2 is a perspective view of shaft with a torque measuring device according to one aspect of the invention. FIG. 3 is a side view of a first torsion reference member and a first detector of the torque measuring device of FIG. 2. FIG. 4 is a block diagram of a controller of the torque measurement device of FIG. 2. FIG. 5 is a graph comparing a signal generated by the first detector to a signal generated by the second detector of the torque measuring device of FIG. 2. FIG. 6 is a perspective view of a shaft with a torque measuring device according to another aspect of the invention. FIG. 7 is a perspective view of a shaft with a torque measuring device according to yet another aspect of the invention. FIG. 8 is a side view of a first torsion reference member and a first detector of the torque measuring device of FIG. 7. FIG. 9 is a perspective view of a shaft with a torque measuring device according to still yet another aspect of the invention.
member. The shaft 10 is rotatably supported by the fixed member 42 about the axis 14, for rotation with respect to the fixed member 42.

A first torsion reference member 46 is fixedly coupled to the shaft 10, for rotation with the shaft, at the first axial position 30. A second torsion reference member 50 is fixedly coupled to the shaft 10, for rotation with the shaft, at the second axial position 34. Although the torsion reference members 46 and 50 are illustrated as being located at first and second ends of the shaft, respectively, the torsion reference members can be placed anywhere along the shaft so long as a distance L between the reference members is known. In the embodiment of FIG. 1, each of the first torsion reference member 46 and the second torsion reference member 50 is a circular disk, though in other embodiments they may be triangular, square, star, or other polygonal shapes. The reference members 46 and 50 are oriented perpendicular to the axis 14, concentric with the axis. In the embodiment of FIG. 2, each reference member 46 and 50 includes a pattern of alternating light reflective areas 54 and light absorbing areas 58 arranged in a ring 62 concentric about the axis 14.

A first detector (i.e., sensor) 66 is coupled to the fixed member 42 adjacent the first reference member 46. A second detector 70 is coupled to the fixed member 42 adjacent the second reference member 50. The detectors 66 and 70 in the embodiment of FIG. 2 are optical and substantially identical. In other embodiments, the first detector and the second detector may differ in form or function. As shown in FIG. 3, the detector 66 emits an emitted light 74 from an emitter portion 78 against the reference member 46. The detector 66 receives reflected light 82 reflected off the reference member 46 at a receiver portion 86.

Each detector 66 and 70 receives reflected light 82 when a light reflective area 54 passes in front of the detector and does not receive reflected light when a light absorbing area 58 passes in front of the detector. In this regard, it is not important in the broader scope of the invention that the areas between the light reflective area 54 be light absorbing per se. In other embodiments, the light absorbing area 58 may be replaced with an area that is light reflecting, but is angled such that the reflected light 82 does not reach the receiver portion 86, and achieve the same purpose as the light absorbing area 58. In other embodiments, the light absorbing area 58 could be reflective, but light scattering (e.g., a many faceted surface) and achieve the same purpose as the light absorbing area 58. In some embodiments, the emitted and reflected light may be in the visible spectrum. In other embodiments, the light may be ultraviolet, infrared, or other ranges of the electromagnetic spectrum. The emitter portion may also be a laser. Similarly, the reflective areas and absorbing areas may be optimized for specific wavelengths of a corresponding detector.

Each detector 66 and 70 produces a signal with a first amplitude in response to receiving light at the receiver portion 86, and a second amplitude in response to receiving no light or light of insufficient intensity or brightness at the receiver portion 86. In some embodiments, the first amplitude may be "on" and the second amplitude may be "off," such that the detectors each generate a binary on-off signal in response to the alternating sequence of the pattern when the rotating member rotates. However, in other embodiments the signals could be sinusoidal, sawtooth, or have other waveforms. The first detector 66 generates a first signal, and the second detector 70 generates a second signal.

As illustrated in FIG. 4, signals from the first detector 66 and second detector 70 are received by a controller 90. In the illustrated embodiment, the detectors 66 and 70 are hardwired to the controller 90. In other embodiments, the first signal and/or second signal may be transmitted wirelessly to the controller. The signals received by the controller 90 may first be processed by a signal conditioning circuit 94 configured to filter or otherwise condition the raw signals from the detectors 66 and 70. After signal conditioning, the first signal and second signal are received by a micro-processor 98. The micro-processor 98 is configured to analyze the signals and determining the torque T. A memory module 102 is provided to store data, such as constants or baseline values which may be used by the micro-processor 98 as part of determining the applied torque T. The controller 90 may also receive inputs from and send outputs to additional sensors user inputs, or other user interfaces, indicated generally at 106. Examples of a user interface include a keyboard and display by which an operator may enter data related to the mechanical characteristics of the shaft.

FIG. 5 is a graph comparing a representative first signal 110 and a representative second signal 114. In the illustrated embodiment, each of the first signal 110 and the second signal 114 is binary (i.e., "on" or "off"), with a square wave form. However, in other embodiments the signals could be sinusoidal, sawtooth, or have other waveforms that may require signal conditioning. It is the phase of the signals, rather than the amplitude or waveform, that is used to derive the torque and/or torque. Because the first signal 110 and second signal 114 relate to the same shaft, under steady-state conditions, and assuming that both reference members 46, 50 and detectors 66, 70 are identical, both signals will have the same frequency.

At any given time, the first signal 110 has a first phase, and the second signal 114 has a second phase. Comparing the first phase to the second phase with respect to the same time reference t results in a phase difference \( \Phi \). A phase difference \( \Phi \) may be expressed in terms of time or in terms of degrees.

When the rotating member rotates at steady state under known load, such as at time \( t_1 \), a baseline phase difference \( \Phi_0 \) between the first signal 110 and second signal 114 is constant. The baseline phase difference \( \Phi_0 \) may be a programmed constant value or an input determined by direct observation. Where the first reference member and second reference member have identical orientations relative to the shaft under a no load condition (i.e., zero torsion), the baseline phase difference \( \Phi_0 \) at \( t_1 \) will be zero. Regardless of how or when the baseline phase difference \( \Phi_0 \) is determined, it is later used by the controller as a comparative value for determining the applied torque T. Thus, any baseline value may be used, so long as the conditions under which it occurs are known. The baseline value is stored in memory 102.

When the applied torque T is applied to the rotating member (e.g., with a dynamometer or a prime mover) at a time \( t_2 \), the phase difference changes from \( \Phi_0 \) to a loaded phase difference \( \Phi_L \). Based on additional inputs including the mechanical characteristics of the rotating member, the applied torque T can be calculated by comparing the loaded phase difference \( \Phi_L \) to the baseline phase difference \( \Phi_0 \). The comparison may be expressed either as a difference or a ratio:

\[
\frac{\Delta \Phi}{\Phi_0} = \frac{\text{change in phase difference}}{\text{baseline phase difference}} = \frac{\Phi_L - \Phi_0}{\Phi_0} = \text{phase difference ratio}
\]

Either value may be used calculate the applied torque T since both the change in the phase difference or phase difference ratio relates to a change in torsion of the shaft. For a shaft of known mechanical characteristics, the applied torque T may be directly calculated from the torsion by well known mechanical principles. Measurement error is minimized since actual deformation, not including inertia affects, causes
For a shaft of known mechanical characteristics, the degrees of torsion may be used to calculate, correlate, or derive the applied torque $T$ applied to the shaft. Dividing the change in the phase difference $\Delta \Phi$ by seconds per degree provides the change in degrees of torsion due to the applied torque:

$$\Delta \Phi \text{ (Seconds per Degree)} = \text{Degrees of Torsion}$$

For a shaft of known mechanical characteristics, the degrees of torsion may be used to calculate, correlate, or derive the applied torque $T$ applied to the shaft.

FIGS. 6-9 illustrate additional aspects of the invention embodied in alternative embodiments. Each of the embodiments of the invention disclosed herein shares the common principle of deriving a torque loading from the phase difference between a first signal generated by a first detector and a second signal generated by a second detector. Similar components have been given similar reference numerals, with different prefixes to distinguish the different embodiments.

FIG. 6 illustrates a second embodiment of a torque measurement device 238 in which a first reference member 246 and a second reference member 250 take the form of notch or castellated disks. Solid portions, or teeth 254, of the disks protrude outwardly radially. The teeth 254 are separated by radial gaps 258. Each tooth 254 has a magnetic or electromagnetic characteristic distinguishable from the radial gaps 258. Each of a first detector 266 and a second detector 270 in this embodiment includes an electromagnetic sensor, such as an inductive element, or Hall effect sensor (not shown).
that is received by the light receiver. In the magnetic embodiments, the reference members vary a magnetic field at the detectors.

Thus, the invention provides, among other things, a device and method for measuring torque in rotating machinery. Various features and advantages of the invention are set forth in the following claims.

What is claimed is:

1. A device for measuring the torque applied through a rotating member rotating about a longitudinal axis relative to a fixed member, the device comprising:
   a first torsion reference member fixedly coupled to the rotating member at a first axial position;
   a second torsion reference member fixedly coupled to the rotating member at a second axial position;
   a first detector coupled to the fixed member and configured to detect the passage of the first torsion reference member past the first detector upon each full rotation of the rotating member and to generate a first signal upon each passage of the first torsion reference member;
   a second detector coupled to the fixed member and configured to detect the passage of the second torsion reference member past the second detector upon each full rotation of the rotating member and to generate a second signal upon each passage of the second torsion reference member;
   and
   a controller configured to:
   calculate a phase difference between the first signal and the second signal relative to a time reference during rotation of the rotating member under a torsional load; compare the phase difference to a reference value; and calculate a torque loading on the rotating member resulting from the torsional load based on the phase difference,

wherein the controller is configured to calculate the torque loading based upon a ratio of the phase difference and the reference value.

2. The device of claim 1, wherein the first torsion reference member includes a pattern that is sensed by the first detector; and wherein the pattern comprises gaps and protrusions.

3. The device of claim 1, wherein the first torsion reference member includes a pattern of reflective and non-reflective portions; and wherein the first detector comprises a light emitting portion and a light receiving portion for sensing the pattern of reflective and non-reflective portions.

4. The device of claim 1, wherein the first torsion reference member is integrally formed as one with the rotating member.

5. The device of claim 1, wherein the first torsion reference member comprises areas of a first texture and areas of a second texture on a surface of the rotating member; and wherein the first detector is configured to receive a light reflected off of the first texture.

6. The device of claim 1, wherein the first torsion reference member comprises a radial pattern of protrusions; and wherein the first detector senses the radial pattern.

7. The device of claim 1, wherein the reference value is a reference phase difference calculated under a known torsional load.

8. The device of claim 1, wherein the reference value is a reference phase difference calculated under a no-load condition.

9. The device of claim 1, wherein the reference value is a constant.

10. The device of claim 1, wherein the controller is configured to calculate the torque loading based upon a difference between the phase difference and the reference value.

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