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Slewing Ring Bolt Preload Monitoring System Using Load-Sensing Washers

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Abstract

This disclosure describes an arrangement for monitoring the preload of mounting bolts securing a slewing ring. The system utilizes a subset of load-sensing washers integrated with select bolts to measure axial clamping force. By acquiring and analyzing these preload signals over time, the system can detect progressive bolt loosening, which, if unaddressed, can lead to uneven load distribution and eventual structural failure of the slewing ring. Early detection of preload degradation enables proactive maintenance, ensuring the continued structural integrity and safe operation of the assembly.

1. Technical Field

[0001] The technical field relates to the monitoring of structural integrity in large rotary assemblies, specifically focusing on the preload condition of fastening bolts in slewing rings. This includes applications in heavy machinery, industrial robots, wind turbines, and other equipment where large rotating components are subjected to significant operational loads.

2. Technical Context

[0002] Slewing rings are critical components that facilitate rotational movement in various types of machinery. They typically consist of an inner and an outer ring, often incorporating gear teeth, connected by a series of rolling elements. These rings are mounted to a supporting structure and a rotating structure using a substantial number of high-strength bolts. The proper functioning and service life of a slewing ring assembly are highly dependent on maintaining adequate and uniform bolt preload.

[0003] Over time, or due to dynamic operational loads, vibrations, or thermal cycling, the preload in some of the mounting bolts can diminish. When one or more bolts lose preload, the operational loads that would normally be distributed across all fasteners become concentrated on the remaining properly tensioned bolts. This redistribution of stress can lead to overstressing and fatigue of the remaining bolts, potentially causing a cascade of progressive preload loss and, ultimately, structural failure of the entire slewing ring assembly or the connected components. The problem is exacerbated by the difficulty of visually inspecting or manually checking the preload of numerous bolts in inaccessible or continuously operating machinery. A method for continuous or periodic monitoring of bolt preload is therefore advantageous for preventing such progressive failures and enabling timely maintenance interventions.

3. System Overview

[0004] The disclosed system provides a method for monitoring the preload of mounting bolts that secure a slewing ring. The system utilizes a subset of the total number of mounting bolts, instrumenting these selected bolts with load-sensing washers (10). These washers convert the axial clamping force exerted by the bolt into an electrical signal. This signal is then acquired by a data acquisition unit (20), processed by a processor unit (30), and analyzed to detect changes in preload over time. A significant reduction in preload below a predefined threshold triggers an alert through an alert interface (40), indicating a potential loosening event and the need for inspection or maintenance. By monitoring a strategic subset of bolts, the system aims to provide an indicator of the overall preload condition of the slewing ring assembly, thereby mitigating the risk of progressive bolt failure and ensuring structural integrity. FIG. 1 illustrates the overall system architecture.

4. Components

[0005] The primary components of the system include:

[0006]

- **Slewing Ring (50):** The large-diameter bearing assembly that provides rotational capability. It consists of an inner ring and an outer ring, one of which is typically bolted to a stationary structure (60) and the other to a rotating structure.
- **Mounting Structure (60):** The stationary or rotating frame or foundation to which the slewing ring (50) is attached. This structure must be sufficiently rigid to support the loads transmitted through the slewing ring.
- **Mounting Bolts (70):** High-strength fasteners (e.g., M24 to M64, Class 10.9 or 12.9) used to clamp the slewing ring (50) to the mounting structure (60). These bolts are typically pre-tensioned to a specified torque or elongation to achieve a target preload.
- **Load-Sensing Washer (10):** This is a specialized washer designed to measure the axial force passing through it. It is placed under the head of a mounting bolt (70) or under its nut, as depicted in FIG. 2. The washer contains an internal sensing element, such as strain gauges arranged in a Wheatstone bridge configuration, or a piezoelectric element. As the bolt (70) is tightened, the washer (10) deforms slightly under the clamping force, and this deformation is converted into an electrical signal proportional to the preload. These washers are typically constructed from high-strength steel or alloys, sized to match the bolt diameter, and designed for preload capacities ranging from 100 kN to 2000 kN, with an accuracy within 1 to 2% of the full-scale output. The output signal is typically a low-level analog voltage (e.g., 0-10 mV/V) or a current loop (e.g., 4-20 mA), or a digital signal via an integrated amplifier.
- **Data Acquisition Unit (DAU) (20):** This unit receives the analog electrical signals from multiple load-sensing washers (10). It typically includes analog-to-digital converters (ADCs) to digitize the signals, signal conditioning circuitry (e.g., amplification, filtering), and multiplexing capabilities to handle inputs from several washers. The sampling rate can be configured, for example, from 0.1 Hz for slow-changing loads to 100 Hz for dynamic monitoring.
- **Processor Unit (30):** A microcontroller, industrial PC, or embedded system that processes the digitized data from the DAU (20). Its functions include applying calibration factors to convert raw sensor signals into preload values (e.g., in kN), performing data filtering and averaging, trend analysis, and comparing current preload values against predefined

thresholds. The processor unit (30) often includes non-volatile data storage (32) for logging historical preload data and a communication interface (34) for transmitting data or alerts.

- **Alert Interface (40):** This component provides visual or audible alerts to operators or maintenance personnel. It may include indicator lights, an alarm siren, or a display screen showing the status of each monitored bolt. It can also interface with a larger control system (e.g., SCADA) to generate notifications via email or SMS.

5. Operation

[0007] The operation of the slewing ring bolt preload monitoring system proceeds through several phases:

[0008] **Initialization and Baseline Establishment:** Upon installation of the slewing ring (50) and its mounting bolts (70), a subset of these bolts is fitted with load-sensing washers (10). These bolts are then tightened to their specified preload according to the design requirements. During this tightening process, the DAU (20) and processor unit (30) record the initial preload values from each instrumented washer (10). These initial readings establish a baseline for each monitored bolt. This baseline represents the nominal, desired preload for the assembly and is stored in the data storage (32).

[0009] **Continuous Monitoring (Steady Running):** During normal operation of the machinery, the DAU (20) continuously or periodically acquires signals from the load-sensing washers (10) at a configurable interval (e.g., every minute, every hour). The processor unit (30) converts these raw signals into engineering units (e.g., kilonewtons). It then performs signal processing, which may include digital filtering to remove noise and averaging over short periods to reduce transient fluctuations. The processed preload data for each instrumented bolt is then stored in the data storage (32) and compared against its established baseline and predefined thresholds.

[0010] **Trend Analysis and Loosening Detection:** The processor unit (30) performs trend analysis on the historical preload data for each bolt. It looks for a sustained, statistically significant decrease in preload from the baseline. A short-term fluctuation due to operational loads is typically filtered out or averaged. The trend that indicates loosening is a gradual but persistent downward shift in the average preload value over a defined period (e.g., hours, days, or operational cycles), as conceptually illustrated by the transition from state P1 to P2 in FIG. 3.

[0011] **Response Threshold and Alert Generation:** An alert threshold (P3 in FIG. 3) is configured for each instrumented bolt, typically set as a percentage reduction from the initial baseline preload (e.g., 10% to 20% reduction from the initial design preload). If the calculated average preload for any monitored bolt consistently drops below this threshold, the processor unit (30) triggers an alert via the alert interface (40). This alert signifies that the bolt has lost a critical amount of its initial preload and requires attention. The system may also implement multiple thresholds, such as a "warning" threshold for minor reductions and an "alarm" threshold for critical reductions.

[0012] **Fault or Interruption:** In the event of a power interruption, the processor unit (30) is designed to safely shut down and retain the last recorded data in non-volatile memory (32). Upon restoration of power, the system reinitializes and resumes monitoring, continuing from the last recorded data point or, if necessary, performing a system check. If a load-sensing washer (10) or its connection fails, the system is designed to detect a signal loss or an out-of-range signal and generate a fault alert specifically for that sensor, indicating a need for sensor inspection or replacement.

6. Example Embodiments

[0013] **Embodiment 1: Distributed Monitoring for Large Slewing Rings** For a slewing ring with a circumference of 4 meters and 96 mounting bolts, a subset of 8 to 12 bolts could be instrumented. These bolts would be strategically selected to provide comprehensive coverage: typically, two opposing bolts (180 degrees apart) on each quadrant of the ring. For instance, four bolts at 0, 90, 180, and 270 degrees, with additional bolts located midway between these main positions, or near known high-stress areas. Each instrumented bolt would have a dedicated load-sensing washer (10) wired to a local DAU (20) positioned within 5 meters. The DAU (20) would then communicate with a central processor unit (30) via a bus network. This distribution minimizes cable lengths and simplifies installation while ensuring representative monitoring of the entire bolt circle.

[0014] **Embodiment 2: Redundant Monitoring for Critical Applications** In critical applications, such as a wind turbine yaw bearing or a heavy-lift crane slewing ring, a higher density of instrumented bolts might be used, combined with redundancy. For example, if 20% of the total bolts are instrumented, an additional 5% might be chosen for redundant monitoring, located adjacent to or in the same high-stress zones as other instrumented bolts. Each pair of adjacent instrumented bolts could be cross-referenced, where a significant preload loss in one bolt without a corresponding loss in an adjacent instrumented bolt might indicate a localized issue rather than a systemic loosening trend. This embodiment could also employ dual data acquisition units (20) and processor units (30) operating in parallel, providing fail-safe monitoring.

[0015] **Embodiment 3: Wireless Monitoring System** This embodiment replaces the wired connections between the load-sensing washers (10) and the DAU (20) with short-range wireless transmitters integrated directly into or coupled with each washer. Each load-sensing washer (10) would incorporate a low-power wireless transceiver and a compact battery or energy harvesting module. The DAU (20) would then act as a wireless receiver, collecting data from multiple instrumented bolts without requiring physical cabling across the rotating or vibrating structure. This reduces installation complexity and eliminates potential cable fatigue issues. The processor unit (30) would be located remotely, receiving aggregated data from the wireless DAU (20).

7. Alternative Configurations

[0016] The load-sensing washers (10) can incorporate various sensing technologies. Instead of strain gauges, some washers might use piezoelectric sensors for dynamic load measurement, or magnetostrictive principles. The data acquisition unit (20) could be integrated directly into the load-sensing washer (10) itself, forming a smart sensor that outputs a digital signal directly, reducing the need for external signal conditioning. The communication interface (34) can be adapted to various industrial protocols, such as Ethernet/IP, Modbus TCP, or PROFIBUS, to integrate with existing control systems. Instead of a dedicated processor unit (30), the data analysis and alerting functions could be performed by an existing programmable logic controller (PLC) or supervisory control and data acquisition (SCADA) system already present in the machinery, reducing overall hardware complexity.

8. Parameter Variations

Parameter	Realistic Range	Effect of Variation
Number of Monitored Bolts	4 to 25% of total bolts	Fewer bolts reduce cost/complexity but may miss localized issues; more bolts increase coverage but also cost.
Sampling Rate (DAU)	0.1 Hz to 100 Hz	Lower rates are suitable for long-term trending; higher rates allow for analysis of dynamic load effects.
Alert Threshold (Preload Drop)	10% to 25% of baseline	A lower percentage (e.g., 10%) provides earlier warning but may generate more false positives; higher (25%) delays warning.
Data Averaging Window	1 minute to 1 hour	Shorter windows react faster to changes but are more susceptible to transient noise; longer windows smooth data.
Washer Preload Capacity	100 kN to 2000 kN	Must match bolt size and design preload; undersized capacity leads to sensor saturation, oversized reduces resolution.
Sensor Accuracy	0.5% to 2% of full scale	Higher accuracy provides more precise preload readings, reducing uncertainty in trend analysis.

9. Additional Implementations

[0018] This monitoring system can be extended to include environmental compensation. Temperature variations can affect both the mechanical properties of the bolts and the electrical output of strain gauge-based load-sensing washers (10). An additional implementation could include temperature sensors integrated with the washers or in the vicinity of the bolts, allowing the processor unit (30) to apply temperature compensation algorithms to the preload readings, improving accuracy. Furthermore, the system could incorporate algorithms to correlate detected preload losses with specific operational events (e.g., high-load cycles, extreme rotational speeds) or ambient conditions, providing more insights into the root causes of loosening. The data collected by the system could also be used for predictive maintenance scheduling, where the rate of preload decay is analyzed to estimate the time until a bolt reaches its critical threshold, allowing for planned, rather than reactive, re-tensioning or replacement. The system could also be configured to monitor the relative rotational position of the slewing ring to provide context for preload variations that might occur at specific angular positions under load.

10. Figures

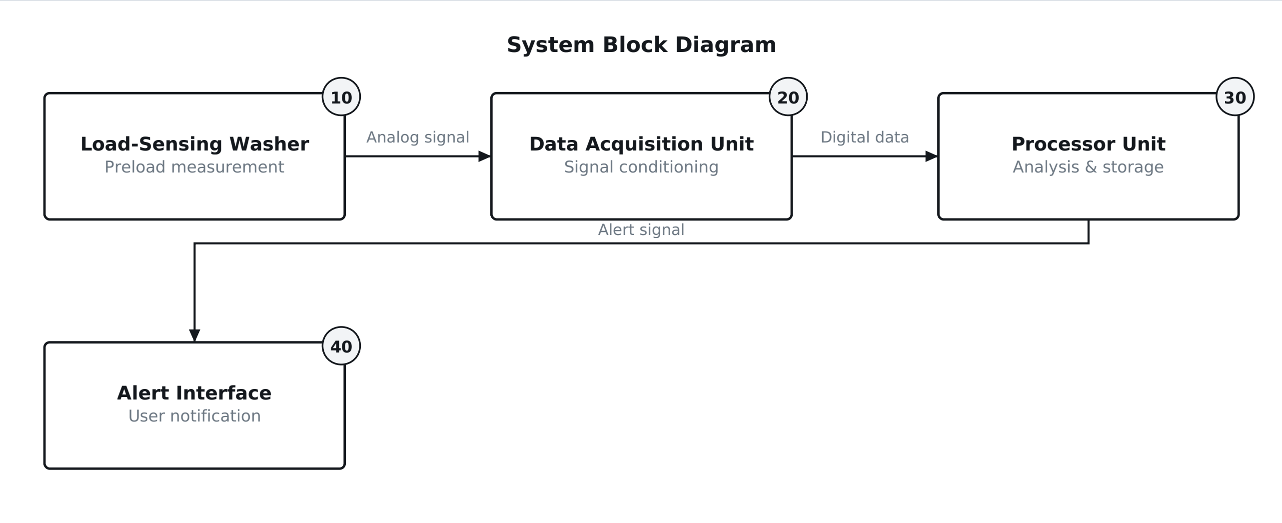

FIG. 1 A block diagram illustrating the primary components and data flow of the bolt preload monitoring system. PNG

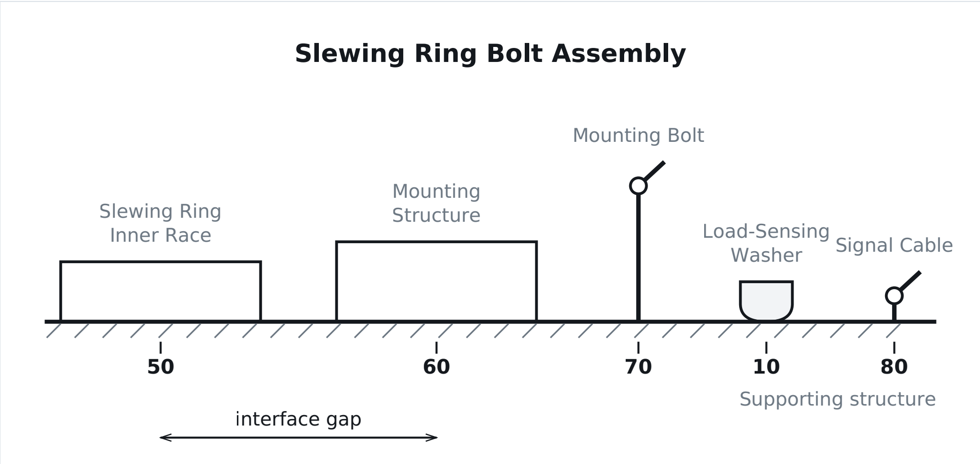

FIG. 2 An elevation view showing a conceptual arrangement of a load-sensing washer integrated into a slewing ring mounting. PNG

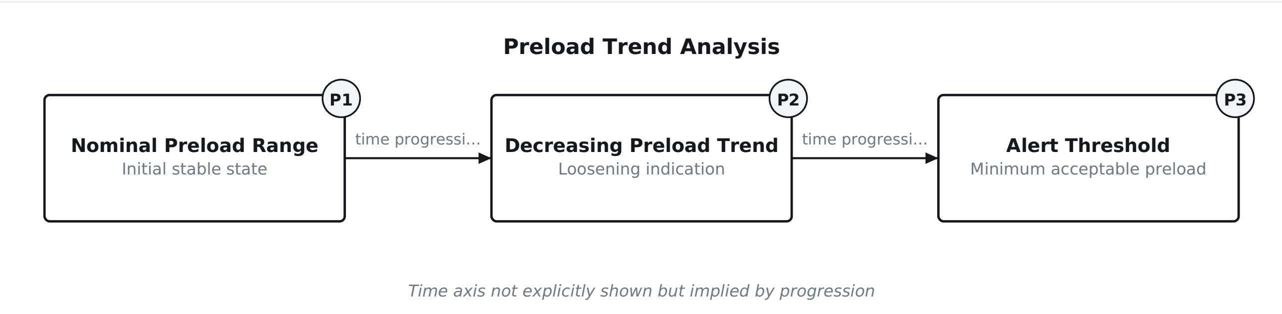

FIG. 3 A conceptual representation of preload over time, showing a stable state, a decreasing trend, and an alert threshold. PNG

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