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Screwdriving System with Depth and Torque Cross-Check for Boss Integrity

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Abstract

This disclosure describes an automated assembly system for fastening components with threaded fasteners. The system employs a screwdriving mechanism that integrates both torque and depth monitoring to ensure proper fastener seating and detect integrity issues with the receiving boss. By establishing a dynamic depth window for applied torque, the system can differentiate between a correctly tightened fastener and one that has stripped its mating thread in the boss, which would otherwise exhibit similar torque characteristics. Parts failing this cross-check are marked for rework, preventing the propagation of assembly defects and enhancing product reliability.

1. Technical Field

[0001] This disclosure relates to automated assembly systems, particularly those involving the installation of threaded fasteners, and methods for verifying the integrity of such installations. More specifically, it concerns systems that employ a combination of depth and torque monitoring during a fastening operation to detect specific failure modes, such as the stripping of a threaded boss in a workpiece.

2. Technical Context

[0002] In automated assembly, the accurate and reliable installation of threaded fasteners is critical for product quality and function. Traditional methods for verifying fastener installation often rely primarily on monitoring the torque applied to the fastener. A common approach is to ensure that the final seating torque falls within a specified range. While effective for detecting under-tightened or over-tightened fasteners, torque-based verification alone can be insufficient for certain failure modes. For instance, if a threaded boss in the workpiece is stripped during the fastening process, the fastener may continue to rotate without advancing, and the torque applied can still reach a value within an acceptable range, particularly if the stripping occurs gradually or the fastener reaches the end of its travel against a shoulder despite the stripped threads. This can lead to a condition where the fastener appears to be correctly tightened based on torque data, but it is in fact loose or provides no clamping force due to the compromised boss threads. Such a defect can result in component rattling, reduced structural integrity, or complete failure in the field. There is a need for a system that can reliably identify such stripped boss conditions.

3. System Overview

[0003] The automated screwdriving system (10) is configured to install fasteners (12) into a workpiece (14) with an integral boss (16). The system integrates a screwdriving head (18) equipped with both torque and linear displacement (depth) sensors, a fastener feeder (20), a control unit (22), a workpiece fixture (24), and a marking unit (26). A data logger (28) records process parameters. The control unit (22) orchestrates the entire operation, receiving sensor data from the screwdriving head (18) and providing control signals to the feeder (20), head (18), and marking unit (26). The workpiece (14) is securely held in the workpiece fixture (24) to ensure precise positioning during the fastening operation. The screwdriving head (18) advances the fastener (12) into the boss (16) while continuously monitoring the applied torque and the linear depth of the fastener relative to a reference plane on the workpiece. This concurrent monitoring allows the system to establish a dynamic depth window against the applied torque profile. If the observed depth at a given torque deviates significantly from the expected range, it indicates an anomaly such as a stripped boss. Parts identified with such anomalies are then processed by the marking unit (26) and diverted for further inspection or rework. A block diagram illustrating the primary components and their interconnections is shown in FIG. 1.

4. Components

[0004]

- **Screwdriving Head (18):** This unit comprises an electric or pneumatic motor, a gearbox, a spindle with a driver bit, a torque transducer (30), and a linear displacement sensor (32). The torque transducer (30) is typically an inline sensor that measures the rotational force applied by the driver bit to the fastener (12). The linear displacement sensor (32) measures the vertical position of the driver bit or the fastener (12) relative to a fixed datum on the screwdriving head (18) or the workpiece fixture (24). This sensor can be an optical encoder, a magnetic linear scale, or a potentiometric device, providing a resolution of approximately 0.01 mm to 0.1 mm. The head (18) also includes a mechanism for automatic bit engagement with the fastener (12) and may incorporate a vacuum or magnetic pickup for fastener retention.
- **Fastener Feeder (20):** This unit stores and dispenses fasteners (12) to the screwdriving head (18). It typically consists of a vibratory bowl or a reel-fed system, a track, and a pneumatic escapement or blow-feed mechanism to present individual fasteners to the driver bit. The feeder (20) is controlled by the control unit (22) to provide a fastener (12) when required.
- **Workpiece Fixture (24):** This component securely holds the workpiece (14) in the correct orientation and position for the fastening operation. It may include pneumatic clamps, mechanical locators, or vacuum chucks. The fixture (24) provides a stable reference plane for the depth measurement by the linear displacement sensor (32).
- **Control Unit (22):** A programmable logic controller (PLC) or industrial PC that manages the entire assembly sequence. It receives torque and depth data from the screwdriving head (18), compares these values against pre-programmed profiles and windows, and issues commands to the feeder (20), screwdriving head (18), and marking unit (26). The control unit (22) stores the fastening profiles and the pass/fail criteria.
- **Marking Unit (26):** A device used to physically mark workpieces (14) that fail the fastening verification. This could be an inkjet printer, a laser marker, a pneumatic punch that creates a dimple, or a paint dispenser. The mark indicates that the part requires rework or further inspection.
- **Data Logger (28):** A system component, often integrated within the control unit (22) or as a separate industrial computer, responsible for recording all relevant process data,

including fastener ID, date/time, torque profiles, depth profiles, and pass/fail status for each fastening operation. This data is used for process monitoring and quality traceability.

- **Fastener (12):** A threaded screw, typically self-tapping or machine screw type, designed for installation into the boss (16) of the workpiece (14).
- **Workpiece (14):** The component being assembled, featuring a boss (16) designed to receive the fastener (12).
- **Boss (16):** A raised or protruding feature on the workpiece (14) that contains a pre-formed or self-tapped threaded hole intended to mate with the fastener (12). An elevation view showing the screwdriving head (18) with a fastener (12) approaching a workpiece (14) and its boss (16) is depicted in FIG. 2.

5. Operation

[0005] The operation of the system follows a defined sequence:

[0006]

- **Workpiece Loading:** A workpiece (14) is loaded into the workpiece fixture (24). Sensors confirm its correct presence and orientation.
- **Fastener Presentation:** The control unit (22) commands the fastener feeder (20) to present a fastener (12) to the screwdriving head (18). The head (18) picks up and retains the fastener.
- **Screwdriving Cycle Initiation:** The screwdriving head (18) moves into position over the boss (16) of the workpiece (14). The driver bit engages the fastener (12). The linear displacement sensor (32) establishes a zero or reference depth point, typically when the fastener (12) just begins to engage the boss (16) or the driver bit contacts a known surface of the workpiece (14).
- **Fastener Installation:** The screwdriving head (18) begins to rotate and advance the fastener (12) into the boss (16). Throughout this process, the torque transducer (30) measures the applied torque, and the linear displacement sensor (32) measures the fastener's (12) depth (H) of penetration.
- **Dynamic Monitoring:** The control unit (22) continuously acquires torque and depth data. It monitors the relationship between these two parameters against a pre-defined profile. For a properly forming thread in the boss (16), as the fastener (12) advances, both torque and depth increase in a predictable manner. The system establishes an expected "depth window" for each increment of torque or an expected "torque window" for each increment of depth. This window defines the acceptable range of depth for a given torque value, or vice-versa, at any point during the fastening cycle.
- **Stripped Boss Detection:** If the fastener (12) encounters a stripped boss (16), the linear advancement of the fastener (12) will significantly slow down or cease, even as the screwdriving head (18) continues to apply torque. This results in the observed depth falling below the lower limit of the expected depth window for the current torque value. Conversely, if the fastener (12) continues to rotate without achieving the expected depth, the system detects a deviation. The signature of a stripped boss (16) is characterized by the torque continuing to rise (or remaining steady at a higher value) while the depth of the fastener (12) remains constant or increases only minimally, falling outside the permissible depth window for that torque.
- **Final Seating and Torque Limit:** The screwdriving operation continues until a target torque is reached or a maximum depth is achieved. The control unit (22) verifies that the

final torque is within the specified range and that the final depth corresponds to the expected value for that final torque, within the established window.

- **Pass/Fail Determination:** If both the torque-depth profile throughout the installation and the final seating parameters (torque and depth) fall within their respective acceptable windows, the fastening operation is deemed successful. If any deviation outside the established windows is detected at any point during the cycle, or if the final parameters are out of specification, the operation is classified as a failure.
- **Post-Fastening Action:**
- **Pass:** The workpiece (14) is released from the fixture (24) for the next assembly step.
- **Fail:** The control unit (22) activates the marking unit (26) to apply a rework mark to the failed workpiece (14). This mark provides a clear visual indication that the part contains a defect and requires specific handling, such as removal from the main assembly line for inspection and rework. The workpiece (14) is then typically routed to a dedicated rework station or quarantine area.
- **Data Logging:** All torque, depth, and pass/fail data for each fastening cycle are recorded by the data logger (28) for quality assurance and process analysis.

6. Example Embodiments

[0007] **Embodiment 1:** A system for fastening a thermoplastic housing (14) to an internal component using self-tapping screws (12). The boss (16) in the housing (14) is designed for a specific thread formation. The depth window is narrow, approximately ±0.2 mm, around the ideal depth profile for the self-tapping operation, where torque increases steadily with depth. A stripped boss (16) is detected when the torque reaches 0.8 Nm but the depth has not advanced beyond 75% of the expected depth for that torque, indicating that the threads are no longer forming. The marking unit (26) applies a red paint dot to the housing (14) adjacent to the failed fastening location.

[0008] **Embodiment 2:** A system for attaching a metal bracket (14) to a cast aluminum part with machine screws (12). The boss (16) is pre-tapped. The system monitors the run-down torque and final seating torque in conjunction with depth. The depth window is wider during initial run-down (±0.5 mm) but tightens to ±0.1 mm during the final seating phase. A stripped boss (16) is identified if, after initial thread engagement, the torque rises above 1.5 Nm while the depth advances less than 0.1 mm over a period of 0.5 seconds, signifying rotation without axial progression. The marking unit (26) utilizes a pneumatic punch to create a small, identifiable dimple on a non-critical surface of the metal bracket (14).

[0009] **Embodiment 3:** A system for securing a circuit board (14) to a plastic enclosure using small machine screws (12) into molded plastic bosses (16). Given the delicate nature of the plastic, precise control is essential. The system monitors not just the final torque-depth relationship but also the rate of torque increase per unit depth. A stripped boss (16) is detected if the rate of depth increase falls below a predefined threshold (e.g., less than 0.05 mm per 0.1 Nm torque increase) for more than 100 milliseconds during the fastening phase. The marking unit (26) employs a laser marker to etch a unique failure code onto a designated area of the circuit board (14).

7. Alternative Configurations

[0010]

- The linear displacement sensor (32) could be implemented as a non-contact optical triangulation sensor measuring the distance to the top surface of the fastener (12) head or to a feature on the screwdriving head (18) itself, relative to the workpiece (14).
- Instead of a dedicated marking unit (26), the control unit (22) could trigger a diverter gate on a conveyor system to automatically route failed workpieces (14) to a separate line.
- The screwdriving head (18) could be mounted on a multi-axis robotic arm, providing greater flexibility for complex workpiece geometries or multiple fastening locations, with the robot controller acting as the control unit (22) or coordinating with it.
- The data logger (28) functionality could be expanded to include statistical process control (SPC) charting, generating real-time graphs of torque and depth distributions to proactively identify process drift before failures occur.
- The system could incorporate a pre-inspection station, such as a vision system, to verify the presence and integrity of the boss (16) threads before the fastening operation begins, providing an additional layer of defect prevention.

8. Parameter Variations

Parameter	Realistic Range	Effect of Moving Towards Lower End	Effect of Moving Towards Upper End
Fastening Torque (Nm)	0.1 to 10.0	Reduced clamping force, potential for looseness.	Increased risk of fastener or boss damage, material stress.
Depth Resolution (mm)	0.01 to 0.1	Higher sensitivity to subtle boss damage, more precise control.	Reduced ability to detect minor depth deviations, coarser control.
Depth Window Tolerance (mm)	±0.05 to ±0.5	Higher false failure rate, very tight process control required.	Increased risk of passing stripped bosses, lower defect detection.
Screwdriving Speed (RPM)	50 to 2000	Slower cycle time, potentially more stable torque readings.	Faster cycle time, increased risk of dynamic effects, heat generation.
Stripped Boss Detection Threshold (mm depth deviation at specified torque)	0.05 to 0.5	Detects minor stripping, can be overly sensitive.	Requires significant stripping for detection, misses incipient failures.
Fastener Material Hardness	Shore D 50 to Rockwell C 60	Easier thread formation, higher risk of stripping soft bosses.	Greater resistance to thread formation, increased stress on boss.
Boss Material Hardness	Shore D 40 to Rockwell C 50	More prone to stripping, requires lower torque/ speed settings.	More robust, allows higher torque, less risk of stripping.

9. Additional Implementations

[0012] The core principle of cross-referencing depth and torque can be extended to other assembly processes. For example, it could be applied to press-fit operations where the force required to achieve a certain depth of insertion is critical, with a sudden drop in force at a specific depth indicating component damage or misalignment. Similarly, in crimping or staking operations, the applied force and the final height or deformation could be monitored simultaneously to ensure proper material flow and structural integrity. For adhesive dispensing, the volume of adhesive dispensed could be correlated with the nozzle's linear travel and the resulting bead profile, ensuring consistent application. In welding applications, the power delivered could be cross-referenced with the material penetration depth, with deviations indicating inconsistent weld quality. The system's ability to identify a signature of failure (e.g., torque increase without depth advancement) can be adapted to any process where an expected physical response (like depth change) should correlate with an applied effort (like torque or force).

10. Figures

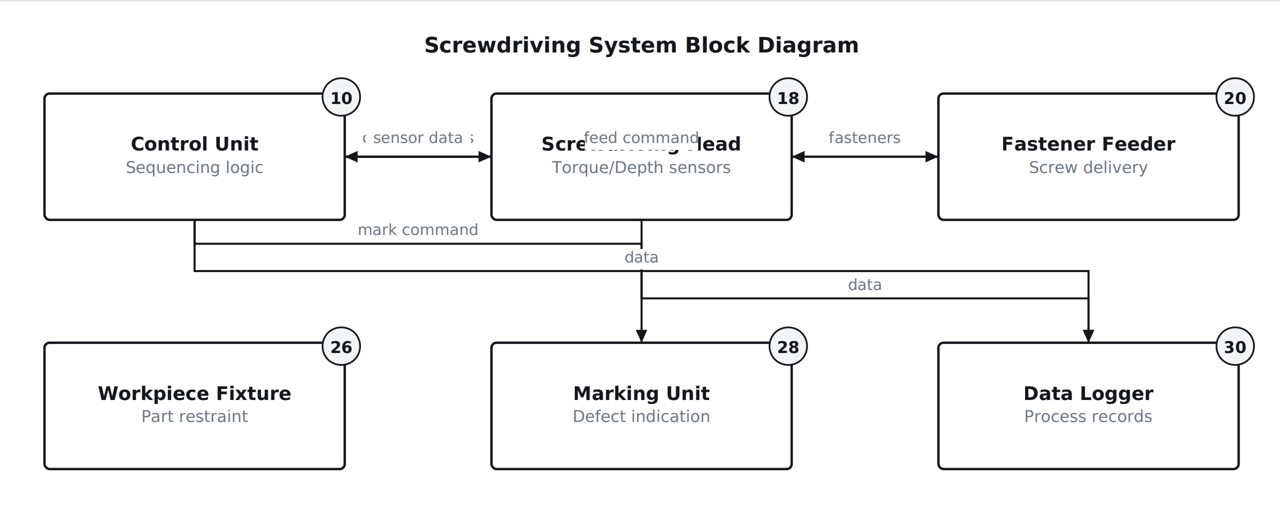

FIG. 1 A block diagram illustrating the main components and data flow within the automated screwdriving system. PNG

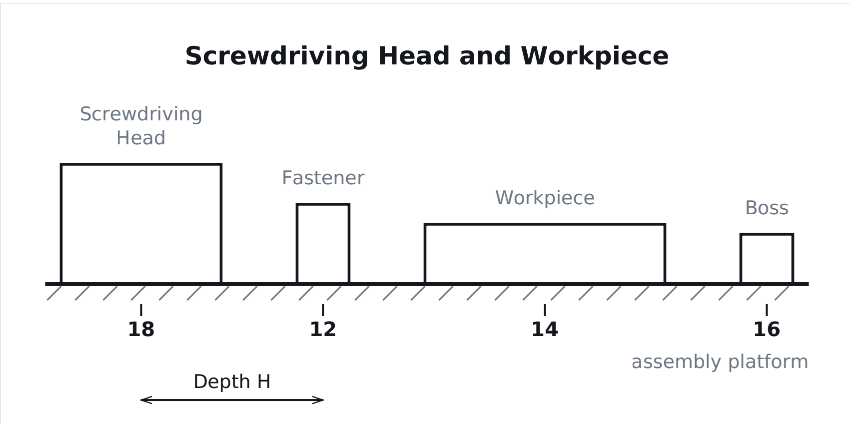

FIG. 2 An elevation view detailing the interaction between the screwdriving head, fastener, and workpiece with its boss. PNG

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