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Design and Development of an Automated Bead Laying System Using a Three-Axis Gantry Platform

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In the manufacture of electrical meters, junction boxes, and control panels, soft rubber sealing beads are widely used to prevent the ingress of dust, moisture, and environmental contaminants. In the studied production line, bead laying is performed manually by four operators working eight-hour shifts, limiting output to about 1200 components per day, while upstream injection molding produces 1500 units. This imbalance creates a throughput bottleneck and increases labor costs, while fatigue-related errors cause bead misalignment and inconsistent seating, leading to quality variations. Although automated dispensing systems exist, most are designed for liquid adhesives and are unsuitable for handling solid, deformable rubber beads, especially within narrow grooves and curved paths. The absence of dedicated solutions capable of managing bead deformation, orientation, and seating force highlights a significant gap in current manufacturing practice. This study aims to design and experimentally validate a compact automated bead-laying system that improves consistency, reduces operator dependency, and aligns production rates with upstream processes. The system employs a three-axis Cartesian gantry to provide precise and programmable motion for bead placement along straight and curved grooves in plastic and metal enclosures. The key contribution is a custom multifunctional end-tool specifically developed for deformable bead handling. It integrates continuous bead feeding through an extruder-type mechanism, uniform seating with a spring-loaded roller, tangential alignment using a servo-driven rotary module, and clean termination via an integrated gripper-cutter. This compliance-aware design enables one-pass placement while controlling deformation, contact force, and orientation. The system is optimized for 1.4 mm diameter beads in 1.2 mm grooves. Developed using 3D CAD modeling, finite element analysis, and stepper motor drives, the prototype achieved an 80% success rate during testing on 50 samples. Compared with manual operation, the system reached 1500 units per day with a 45-second cycle time, requiring only one operator. The solution provides a scalable and retrofit-friendly approach for high-mix, low-volume sealing applications.

Keywords: Automated bead laying system, Cartesian gantry system, End-tool design, Sealing bead, Rubber sealing bead, Rubber bead dispensing system