

# Machine Safeguarding Architecture and Hazard Mapping for Bearing Production Lines: A Framework for Safe Mounting, Dismounting, and Maintenance

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*Abstract- Bearing production lines combine high-speed rotating machinery, machining, heat treatment, grinding, cleaning, assembly, inspection, packaging, warehousing, and maintenance. These interconnected tasks generate cumulative risks, including entanglement, pinch points, flying particles, burns, chemical exposure, noise, ergonomic strain, and hazardous energy release during intervention. This paper develops a structured process-safety framework for bearing manufacturing. The framework integrates task-level hazard identification, layered machine safeguarding, safe mounting and dismounting workflow design, ergonomic material handling, and lockout/tagout control for maintenance. It is organized around representative production stages and aligned with established principles of occupational safety, machinery protection, risk reduction at source, guarding, interlocking, safety-related control functions, and verified energy isolation. Evidence from machine-guarding practice, lockout/tagout auditing, participatory safety management, and job safety analysis informs the proposed control logic. The resulting hazard map identifies key risk points across raw-material receiving, turning, heat treatment, grinding, cleaning, assembly, inspection, packaging, and warehouse operations. The safeguarding architecture combines inherent risk reduction, fixed guards, interlocked access points, presence-sensing devices, emergency stop functions, controlled energy isolation, safe work procedures, training, supervision, and inspection. Safe mounting, dismounting, and maintenance workflows are designed to reduce exposure to nip points, unexpected start-up, stored energy, and unstable components. Bearing production-line safety can be strengthened by integrating process hazard mapping, machine safeguarding, ergonomic handling, and rigorous lockout/tagout into a unified layered control system. The framework provides a practical basis for plant-specific safety programs in discrete manufacturing environments. It also supports continuous improvement through audits, worker feedback, and periodic verification of control effectiveness*

*Keywords: Bearing Manufacturing, Machine Guarding, Hazard Map, Lockout/Tagout, Maintenance Safety, Ergonomics, Industrial Safety*

## I. INTRODUCTION

Bearing manufacturing is a discrete-process industry with a dense concentration of mechanical, thermal, chemical, and ergonomic hazards. Typical operations include material handling, turning, grinding, heat treatment, washing, assembly, inspection, packaging, and maintenance. Across these steps, workers may be exposed to rotating parts, chips and fragments, hot surfaces, lubricants and cleaning agents, noise, lifting strain, and inadvertent energy release during servicing. Safety guidance for machinery therefore increasingly emphasizes prevention at the source, robust guarding, interlocking, control-system reliability, and energy isolation rather than reliance on personal protective equipment alone.

Evidence from manufacturing settings shows that task-level hazard identification can reveal concentrated risk points and that practical safety interventions depend on working-process analysis rather than abstract safety perceptions alone. In small metal fabrication businesses, the presence of a functioning safety committee was a better indicator of actionable safety management than safety climate measures, suggesting that organized governance structures matter for implementation. <sup>5</sup> Similarly, job safety analysis has been shown to identify major hazard clusters such as dust, noise, traffic, lifting, and machinery-related injury in process industries. <sup>6</sup> LOTO self-audits have also demonstrated strong reliability in manufacturing workplaces, supporting their use as a practical inspection and improvement tool.

Against this background, the present paper converts the bearing-production safety concept into a journal-style framework with four linked elements: (i) hazard mapping of the line, (ii) machine safeguarding architecture, (iii) safe mounting and dismounting workflow, and (iv) LOTO workflow for maintenance tasks. This structure is aligned with participatory safety management and ergonomics principles, which emphasize that safe production depends on both engineering controls and worker participation.

## II. MATERIALS AND METHODS

### 2.1 Study design and scope

This manuscript is written as a structured technical review and process-safety framework for a representative bearing production line. The scope covers the main production stages commonly present in bearing manufacturing: raw material receiving, turning/machining, heat treatment, grinding, cleaning, assembly, inspection, packaging, warehouse storage, and maintenance/service activities.

### 2.2 Hazard identification

Hazard identification was organized by process stage using a job safety analysis logic: task definition, hazard recognition, consequence analysis, and control selection. This approach is consistent with industrial hazard identification practice and with prior process-industry studies that use walk-through survey, JSA, and risk ranking to identify high-risk steps.

### 2.3 Safeguarding and workflow design

The safeguarding architecture was designed according to a hierarchy of controls: elimination or substitution where possible, engineering controls, administrative controls, and PPE as the last line of defense.

Figure 1. Hierarchy of Controls applied to bearing manufacturing



For machinery, this was translated into fixed guards, interlocked doors, light curtains or presence-sensing devices where appropriate, emergency stop functions, access control, and energy-isolation provisions. This control logic is consistent with current machine-guarding and hazardous-energy control guidance.

### 2.4 Safe mounting and dismounting workflow

The safe mounting/dismounting workflow was defined as a sequence of steps that minimizes manual pinch-point exposure and uncontrolled movement of parts: prepare the work area, verify tools and lifting aids, isolate mechanical motion, align parts using fixtures or jigs, verify fit by controlled movement, tighten or secure components to specification, remove temporary aids, and perform a final functional check.

Safe mounting and dismounting workflow



2.5 Lockout/Tagout workflow for maintenance

The LOTO workflow was designed to ensure zero-energy verification before maintenance tasks. The workflow includes identification of all energy sources, notification of affected personnel, shutdown, isolation, lock and tag application, dissipation of stored energy, verification of zero-energy state, maintenance execution, inspection, removal of tools and guards, authorized lock removal, and controlled restart. This is consistent with LOTO program principles used in manufacturing safety audits. 43

III. RESULTS

3.1 Typical hazard map in a bearing production line



Figure 2 presents a typical hazard map for a bearing production line, summarizing the main hazard clusters across the process flow from raw-material receiving to warehousing. The map shows that risks are not confined to a single operation but accumulate across machining, heat treatment, grinding, cleaning, assembly, inspection, packaging, and maintenance activities. Key hazard clusters include mechanical entanglement and pinch points around rotating equipment, flying particles during cutting and grinding, thermal exposure during heat treatment, chemical exposure during cleaning, noise from high-speed machinery, ergonomic strain during handling and assembly, and hazardous energy release during maintenance. By linking each production stage with its dominant hazards, the figure provides a practical overview for prioritizing machine safeguarding, safe

work procedures, ergonomic controls, and lockout/tagout measures. It also supports task-level risk assessment and helps safety managers identify where layered controls are most needed within the bearing manufacturing process.

Production stage	Typical hazards	Likely consequences	Preferred controls
Raw material receiving	forklift interaction, manual handling, slip/trip, striking hazards	crush injury, falls, musculoskeletal strain	traffic separation, floor marking, lift aids, housekeeping
Turning/machining	entanglement, pinch points, flying chips, rotating parts	laceration, amputation, eye injury	fixed guards, chip shields, interlocks, safe distance
Heat treatment	hot surfaces, thermal radiation, burns	burn injury, heat stress	insulation, access barriers, thermal PPE
Grinding	noise, sparks, abrasive burst, mist	hearing loss, eye injury, inhalation exposure	enclosure, wheel guard, extraction, hearing protection
Cleaning	chemical exposure, wet floors, splash	dermatitis, irritation, slips	substitution, containment, drainage, chemical PPE
Assembly	pinch points, repetitive work, hand-tool injury	crush injury, MSDs	fixtures, torque tools, ergonomic workstations
Inspection	electrical hazards, machine test movement	shock, unintended activation	safe test mode, interlocks, emergency stop readiness

Packaging/storage	lifting, stacking, pallet movement	back strain, struck-by injury	mechanical aids, stacking control, aisle discipline
Maintenance	residual energy, unexpected start-up	fatal crush/entrapment, electrocution	LOTO, verification, zero-energy state

The hazard map is consistent with findings from process-industry hazard analysis, where dust, noise, traffic, manual handling, and machine-related injuries concentrate in specific task zones.

### 3.2 Machine safeguarding architecture for bearing equipment

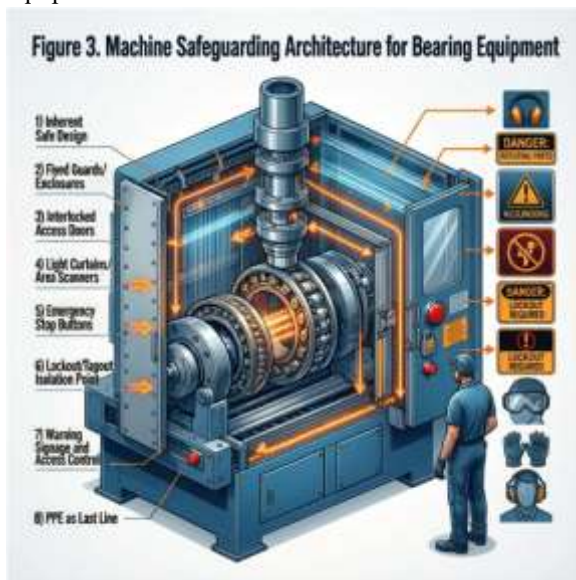


Figure 3 illustrates the machine safeguarding architecture for bearing equipment as a layered barrier system with five protection levels. The first level emphasizes inherent risk reduction, such as safer machine layout, minimized exposed moving parts, stable workpiece support, and reduced need for manual intervention near rotating components. The second level consists of physical safeguards, including fixed guards, covers, shields, and enclosures that prevent access to nip points, cutting zones, grinding wheels, and transmission elements. The third level introduces interlocked and sensing-based protection, such as interlocked doors, light curtains, area scanners, two-hand controls, and

presence-sensing devices that stop hazardous motion when access is detected. The fourth level covers control-system safety functions, including emergency stop circuits, safe torque off, safety-rated monitoring, and fail-safe machine responses. The fifth level addresses administrative and procedural controls, including lockout/tagout, standard operating procedures, inspection, training, supervision, and maintenance verification. Together, these five layers form a defense-in-depth approach that reduces exposure during normal production, setup, troubleshooting, mounting/dismounting, and maintenance activities. The figure highlights that effective safeguarding in bearing production depends not on a single device, but on the coordinated performance of engineering controls, safety-related control systems, and disciplined work practices.

1. Inherent safety by design  
Reduce hazard exposure through automation, tool selection, and layout optimization.
2. Primary engineering safeguards  
Fixed guards, enclosed transmissions, guarded feed points, and transparent protective covers.
3. Access control and interlocking  
Interlocked doors, safety switches, and controlled access to hazardous zones.
4. Presence-sensing and stopping functions  
Light curtains, laser scanners, two-hand controls, and emergency stop devices as needed.
5. Administrative control and PPE  
Permit-to-work, supervision, training, signage, and PPE as the last barrier.

This architecture is aligned with the principle that machine guarding must be designed to prevent contact with dangerous moving parts and should be supplemented by safe control logic and energy isolation. 123

3.3 Safe mounting and dismounting workflow  
Safe mounting and dismounting workflow can be positioned as an operational standard for bearing installation/removal tasks. The workflow reduces

exposure to hand injuries, crushed fingers, dropped parts, and misalignment-related failure.

**Figure 4. Safe mounting and dismounting workflow**



Recommended sequence:

- verify the machine is in a safe state;
- check compatibility of bearing, shaft, housing, and tools;
- use mechanical aids, alignment jigs, or induction/heating tools where appropriate;
- keep hands away from pinch zones;
- secure the bearing progressively and verify axial/radial seating;
- conduct a controlled rotation or test cycle;
- confirm guard restoration and housekeeping before release.

Task-based controls of this kind are consistent with JSA findings in manufacturing and sawmill settings, where alignment, lifting, and part-handling stages contribute heavily to injury risk.

### 3.4 Lockout/Tagout workflow for maintenance tasks

Lockout/Tagout workflow for maintenance tasks should be presented as the standard maintenance-energy control sequence.

**Figure 5. Lockout/Tagout workflow for maintenance tasks**



The major steps are:

1. identify machine and maintenance scope;
2. notify affected employees;
3. shut down equipment;
4. isolate all energy sources;
5. apply lock and tag devices;
6. release or restrain stored energy;
7. verify zero-energy state;
8. perform maintenance;
9. inspect area and reinstall guards;
10. remove tools and evacuate personnel;
11. remove lock/tag only by authorized personnel;
12. restore power and test under controlled conditions.

Manufacturing evidence indicates that LOTO self-audits can be reliable and practical for continuous improvement, especially when programs are structured, visible, and easy to inspect. The present workflow is therefore suitable not only for compliance but also for operational discipline and auditability.

## IV. DISCUSSION

The principal message of this framework is that bearing production safety should be designed as a layered system, not a single-control problem. The hazard map shows that most risks are not uniform across the line; instead, they cluster in specific tasks

such as machining, grinding, heat treatment, cleaning, assembly, and maintenance. This is important because targeted controls are usually more effective than generic plant-wide instructions.

The machine safeguarding architecture proposed here emphasizes engineering controls first. This is consistent with current machinery-safety standards and hazardous-energy control expectations, which prioritize guard design, access prevention, safety-related control functions, and verified isolation of energy sources. 123 For bearing equipment, this is especially relevant because operators are often tempted to bypass protective devices during adjustments, cleaning, or troubleshooting. The design therefore must make bypass difficult and safe access easy only when the machine is truly de-energized.

The LOTO workflow is equally critical. Manufacturing studies show that a reliable LOTO self-audit tool can improve program quality and identify gaps in practice. 4 In a bearing line, maintenance tasks often involve hidden or residual energy in rotating assemblies, pneumatic systems, press mechanisms, thermal systems, or stored mechanical load. The workflow therefore must include verification, not only tag application. This point is essential for preventing catastrophic maintenance injuries.

The safe mounting/dismounting workflow addresses an area that is often underwritten in plant procedures. Bearing installation and removal look routine, but they can produce pinch injuries, falls of heavy parts, incorrect seating, overheating, and rework-related exposure. Integrating fixtures, lifting aids, and controlled sequencing reduces these risks and also improves product quality. This aligns with participatory safety and ergonomics literature showing that combining worker involvement with practical task redesign produces more actionable improvements than perception-based safety messaging alone.

Finally, the governance layer matters. Evidence from the National Machine Guarding Program suggests that structured safety management elements, especially employee-management safety committees,

may be more actionable than broad safety climate measures. 5 In the same spirit, enterprise risk management frameworks increasingly encourage the integration of occupational health and safety into broader business governance. 10 For bearing manufacturers, this means that machine safety, maintenance safety, and ergonomics should be reported and managed as part of operational risk, not as isolated compliance tasks.

## V. CONCLUSIONS

This paper presents a publication-style framework for bearing production line safety built around four connected elements: hazard mapping, machine safeguarding architecture, safe mounting and dismounting workflow, and LOTO for maintenance. The framework demonstrates that the main hazards in bearing manufacturing are predictable and can be managed through layered engineering, administrative, and behavioral controls. The proposed structure is suitable for adaptation to factory-specific layouts, risk profiles, and local regulatory requirements.

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