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Coded Magnetic Guarding Interlock with Defeat-Resistant Mounting System

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Abstract

This disclosure describes a guarding interlock system employing a coded magnetic sensor and a defeat-resistant mounting arrangement. The system addresses the common problem of guard defeat due to operational inconvenience, which can lead to hazardous conditions. By utilizing a unique magnetic code and a mounting method that integrates the sensor and actuator into the guard structure, the system ensures that the guard's closed position is reliably detected while making unauthorized bypass attempts difficult and detectable. Furthermore, features are incorporated to facilitate routine access without compromising safety integrity, thereby improving usability and reducing motivation for defeat.

1. Technical Field

[0001] The present disclosure relates to machine safety systems, specifically addressing interlocks for movable guards. It pertains to arrangements designed to prevent unauthorized access to hazardous areas of machinery during operation, focusing on solutions that resist defeat mechanisms.

2. Technical Context

[0002] Industrial machinery often incorporates physical guards to protect operators and maintenance personnel from moving parts, high temperatures, electrical hazards, or ejected materials. These guards can be fixed, adjustable, or movable, with movable guards typically linked to an interlock system. An interlock system prevents machine operation when the guard is open or allows the guard to be opened only when the machine is in a safe state.

[0003] A significant challenge in machine safety is the intentional defeat of guard interlocks. This often occurs when guards are perceived as inconvenient, hindering production efficiency, or complicating routine tasks such as material feeding, setup, or minor adjustments. Operators, under pressure to maintain output, may bypass or disable interlocks using readily available tools or simple magnets, creating a false sense of security where the machine is believed to be safe, but the protective function is compromised. This defeated state is often more hazardous than having no guard at all, as the safety system indicates a safe condition while an unsafe condition persists.

[0004] Conventional interlocks, such as mechanical limit switches or uncoded magnetic sensors, are particularly susceptible to such defeat. For example, a simple magnetic interlock can be defeated by placing a spare magnet in proximity to the sensor. More sophisticated solutions, such as coded magnetic sensors, offer improved resistance to simple defeat, but their mounting and integration into the machine system remain critical for preventing more determined bypass attempts. There is a need for interlock arrangements that not only employ robust sensing technology but also integrate physically with the machine and guard in a manner that intrinsically resists defeat while accommodating necessary operational access, thereby reducing the motivation for bypassing the safety system. This disclosure details an arrangement designed to fulfill these requirements.

3. System Overview

[0005] The interlock system described herein comprises three primary functional units: a coded magnetic sensor unit (10), a coded magnetic actuator unit (22), and a control unit (30). The sensor unit (10) is typically mounted on a stationary machine frame (20), while the actuator unit (22) is integrated into the movable guard (24). When the guard (24) is in the closed and locked position, the actuator unit (22) aligns with the sensor unit (10), allowing the sensor to detect a specific, pre-programmed magnetic code. This code detection confirms the guard's closed state to the control unit (30). The system is engineered to provide specific feedback to the control unit (30) if an incorrect code is detected, if no code is detected, or if the magnetic field strength is outside design parameters, indicating a potential defeat attempt or malfunction. The physical integration of the sensor (10) and actuator (22) into the guard and frame structures, as well as their specific mounting, is designed to be highly resistant to tampering or bypass using common methods. FIG. 1 illustrates the functional interaction between these main components.

4. Components

[0006] The interlock system consists of the following key components:

[0007]

- **Coded Magnetic Sensor Unit (10):** This unit is typically housed in a durable, sealed enclosure (16), often constructed from a robust polymer or stainless steel, designed to withstand industrial environments. It contains an array of magnetic field sensors (14), such as Hall effect sensors or magnetostrictive elements, strategically positioned to detect the specific magnetic pattern emitted by the actuator unit (22). An embedded microcontroller (15) within the sensor unit (10) processes the raw sensor data, decodes the detected magnetic pattern, and verifies its authenticity against a stored, unique code. The microcontroller (15) also monitors signal strength and consistency. The sensor unit (10) communicates its status (e.g., guard closed/open, valid/invalid code, fault condition) to the control unit (30) via a safety-rated communication protocol (e.g., OSSD outputs, safety bus). Mounting features (18) are integral to the housing (16), designed for secure and defeat-resistant attachment to the machine frame (20). These features may include tamper-proof fasteners or a mounting method that conceals fasteners once installed.

[0008]

- **Coded Magnetic Actuator Unit (22):** This passive unit consists of an arrangement of permanent magnets (26) embedded within a non-magnetic, robust housing (27). The magnets (26) are arranged in a specific spatial orientation and polarity sequence to generate a unique magnetic field pattern, which serves as the "code." This code corresponds precisely to the detection pattern expected by the sensor unit (10). The actuator unit (22) contains no active electronics and is designed to be highly durable and resistant to environmental factors. It is specifically shaped and sized for integration into a corresponding recess (28) within the movable guard (24). The recess (28) and actuator unit

(22) are designed to form a nearly flush surface, making it difficult to pry or remove the actuator (22) without damaging the guard (24) or the actuator itself.

[0009]

- **Control Unit (30):** This is a safety-rated programmable logic controller or safety relay module. It receives the interlock status and diagnostic signals from the sensor unit (10). Upon receiving a "guard closed and valid code" signal, the control unit (30) allows the machine to operate. If it receives an "open," "invalid code," "tamper detected," or "fault" signal, it initiates a safe stop of the machine and prevents restart until the condition is rectified. The control unit (30) also monitors the diagnostic data for inconsistencies indicative of defeat attempts.

[0010]

- **Machine Frame (20):** The stationary structural component of the machine to which the sensor unit (10) is securely mounted. The frame (20) may incorporate specific features, such as a milled pocket or an integrated bracket, to further enhance the defeat resistance of the sensor unit's (10) mounting.

[0011]

- **Movable Guard (24):** The physical barrier that protects personnel from hazardous machine areas. It is designed to move (e.g., slide, hinge, pivot) to allow access. The actuator unit (22) is integrated into this guard (24). The guard (24) itself may include features to facilitate convenient opening and closing, such as ergonomic handles (25) or assisted opening mechanisms (e29) (e.g., gas struts, counterweights), to reduce the inconvenience that often leads to defeat attempts. FIG. 2 provides an illustration of the sensor and actuator unit integration with the machine frame and guard.

[0012]

- **Mounting Features (18):** These refer to the specific design elements on the sensor unit (10) and actuator unit (22), and their corresponding counterparts on the machine frame (20) and movable guard (24), that ensure secure and tamper-resistant attachment. This can include non-reversible fasteners, concealed mounting points, or geometries that prevent the insertion of foreign objects to simulate the actuator.

5. Operation

[0013] The operation of the coded magnetic interlock system follows a defined sequence:

[0014] **Start-up:** Upon system power-up, the control unit (30) performs self-diagnostics and verifies communication with the sensor unit (10). The sensor unit (10) performs its own internal diagnostics and checks for the presence of the actuator unit (22). If the guard (24) is closed and the actuator unit (22) is correctly aligned, the sensor unit (10) detects its unique magnetic code. It transmits a "guard closed and valid" signal to the control unit (30). If the guard (24) is open, or if the magnetic code is not detected or is invalid, the sensor unit (10) transmits an "open" or "invalid code" signal. The control unit (30) prevents machine start-up until a "guard closed and valid" signal is received.

[0015] **Steady Running (Guard Closed):** During machine operation, the guard (24) remains closed, and the actuator unit (22) remains in close proximity to the sensor unit (10). The sensor unit (10) continuously monitors the magnetic field pattern from the actuator (22) and periodically transmits its status to the control unit (30). The control unit (30) continuously monitors this signal. If the guard (24) is opened, even momentarily, the magnetic code is lost or altered beyond recognition by the sensor unit (10). This causes the sensor unit (10) to immediately switch its output to an "open" or "unsafe" state. The control unit (30) detects this change and initiates a rapid and safe shutdown of the machine.

[0016] **Guard Opening for Access:** When access to the hazardous area is required (e.g., for maintenance, material loading), the machine is first brought to a safe stop by the operator or process. Once the machine is in a safe state, the operator opens the movable guard (24). As the guard (24) moves away from the machine frame (20), the actuator unit (22) moves out of the sensing range of the sensor unit (10). The sensor unit (10) detects the loss of the correct magnetic code and transmits an "open" signal to the control unit (30), confirming the guard's status. The ergonomic design of the guard (24) and any assisted opening mechanisms (29) facilitate this process, reducing physical effort and time for the operator.

[0017] **Fault or Interruption (Defeat Attempt):**

[0018]

- **Attempted Bypass with Simple Magnet:** If an operator attempts to defeat the interlock by placing an un-coded or incorrectly coded magnet near the sensor unit (10) while the guard (24) is open, the sensor unit (10) will detect a magnetic field. However, because the field does not match the specific, unique magnetic code of its paired actuator unit (22) in terms of spatial pattern and field strength, the microcontroller (15) within the sensor unit (10) will identify it as an "invalid code" or "tamper detected" condition. This diagnostic information is communicated to the control unit (30), which then enters a safe state and may log the event.
- **Attempted Removal of Actuator:** The actuator unit (22) is integrated into a recess (28) in the guard (24) using a method that makes removal difficult without visible damage. If an attempt is made to remove the actuator (22) from the guard (24), it is likely to damage the guard (24) or the actuator (22) itself. Even if removed, the bare actuator (22) still needs to be correctly positioned relative to the sensor (10), which is challenging due to the defeat-resistant mounting features (18) of the sensor (10). Furthermore, the sensor unit (10) monitors magnetic field strength. An actuator (22) held at an incorrect distance or angle may not provide the expected field strength, triggering a "magnetic field anomaly" diagnostic.
- **Attempted Damage to Sensor:** If the sensor unit (10) itself is physically damaged, its internal diagnostics will likely detect a malfunction. The control unit (30) is designed to interpret any fault or loss of communication from the sensor unit (10) as an unsafe condition, leading to a machine stop.
- **Diagnostic Outputs:** The sensor unit (10) provides detailed diagnostic feedback beyond a simple open/closed state. This includes "invalid code detected," "magnetic field out of range," "internal fault," or "communication error." The control unit (30) uses this information to distinguish between an open guard and a potential defeat attempt or sensor malfunction, allowing for targeted troubleshooting and logging of defeat attempts. This diagnostic capability acts as a deterrent and provides valuable data for safety audits.

6. Example Embodiments

[0019] **Embodiment 1** In this configuration, the sensor unit (10) is fully encapsulated in a stainless steel housing (16) with tamper-proof fasteners securing it to a machined pocket in the machine frame (20). The mounting fasteners (18) are accessible only when the guard (24) is fully open and the machine is powered off, or are covered by a sealed plate once installed. The actuator unit (22) is molded directly into the composite material of the movable guard (24) during its manufacturing, making it an integral part of the guard structure. This prevents its removal without destroying the guard (24) itself. The magnetic code is a 3x3 array of magnets (26) with alternating polarities, detected by a corresponding 3x3 array of Hall effect sensors (14). The sensor unit (10) includes integrated light-emitting diodes (LEDs) that provide local status indication (e.g., green for closed/valid, red for open/invalid, flashing for fault), aiding in diagnostics without needing to consult the control unit (30). The guard (24) incorporates a pneumatic assist mechanism (29) that makes opening and closing the guard (24) physically effortless.

[0020] **Embodiment 2** This embodiment utilizes a sensor unit (10) mounted using a dovetailed slide mechanism. The sensor unit (10) slides into a precisely machined track on the machine frame (20) from one side, and then a locking plate (18) is installed from the other side, securing it. The locking plate (18) is then welded or fastened with one-way screws, making the sensor unit (10) non-removable without destructive action. The actuator unit (22) is a compact, cylindrical array of rare-earth magnets (26) housed in a polymer capsule. This capsule is pressed and bonded into a bore within the guard (24) material, such that its face is flush with the guard's (24) surface. A laser-etched serial number on the guard (24) and sensor unit (10) links them for traceability. The magnetic code for this embodiment is based on magnetic field gradient detection, where the sensor unit (10) specifically analyzes the rate of change of magnetic field strength across its sensing elements (14), rather than absolute field strength, making it more resilient to external, non-coded magnetic interference.

[0021] **Embodiment 3** In this configuration, the guard (24) is a large, heavy panel that slides horizontally. To facilitate its movement, the guard (24) is supported by linear bearings and includes an electrically driven actuator (29) for automatic opening and closing upon command from the control unit (30) after a safe machine state is confirmed. The sensor unit (10) and actuator unit (22) are positioned such that they engage only when the guard (24) is fully closed and the guard's (24) leading edge is seated against a stop. The sensor unit (10) is mounted inside a sealed conduit (18) within the machine frame (20), with only its sensing face exposed through a small, precisely toleranced opening. This prevents external manipulation of the sensor (10). The actuator unit (22) is similarly encased within the guard's (24) internal structure. The magnetic code uses a pulse-width modulated magnetic field, where the sensor (10) detects specific temporal variations in the magnetic field rather than a static pattern, making it highly unique. The control unit (30) includes a display that provides a detailed readout of the interlock status, including specific fault codes for different defeat attempts.

7. Alternative Configurations

[0022] The described system can be adapted for various guard types and machine applications.

[0023]

- **Alternative Guard Types:** While described for a movable guard (24), the principle can be applied to interlocked access panels or covers that are not frequently opened but require secure closure. For example, a hinged access panel could use a similar sensor and actuator arrangement at its free edge.
- **Integrated Locking Mechanism:** The interlock system can be integrated with a guard locking mechanism. The control unit (30) would only release the lock on the guard (24) once the machine is in a safe state, and the guard (24) would only be unlocked after a

specific delay. The sensor unit (10) would then confirm the physical opening of the guard (24) after the lock is released.

- **Multiple Sensors:** For large guards or guards that require detection of multiple positions (e.g., fully closed, partially open, fully open), multiple sensor units (10) and actuator units (22) can be employed, each with its own unique code or combined into a logic scheme by the control unit (30).
- **Wireless Communication:** While wired communication is typical for safety systems, a wireless communication module (not shown) employing a safety-rated protocol could be integrated into the sensor unit (10) for applications where wiring is problematic, such as rotating guards or remote access points, provided the wireless link maintains the required safety integrity level.
- **Dynamic Code Generation:** Instead of a static magnetic code, a system could be envisioned where the magnetic code emitted by the actuator unit (22) changes dynamically (e.g., based on a secure handshake protocol with the sensor unit (10)). This would further enhance defeat resistance but would require active electronics in the actuator unit (22).

8. Parameter Variations

Parameter	Range	Effect of Moving Towards Lower End	Effect of Moving Towards Higher End
Sensing Distance	1 mm to 10 mm	Increased precision, more robust against minor misalignment, but requires tighter guard tolerances.	More tolerance for guard misalignment, but more susceptible to external magnetic fields.
Magnetic Code Complexity	4-bit to 16-bit equivalent	Easier to defeat with non-specific magnets, lower computational burden for sensor.	Significantly higher defeat resistance, increased computational burden for sensor, potentially more expensive.
Actuator Magnet Strength	0.1 Tesla to 0.8 Tesla (surface)	Reduced sensing distance, lower resistance to magnetic interference.	Increased sensing distance, improved resistance to magnetic interference, larger physical size for magnets.
Housing Material Hardness	50 Shore D to 80 Shore D	More flexible, lower impact resistance, easier to damage or deform.	More rigid, higher impact resistance, better protection against physical defeat.
Communication Baud Rate	9.6 kbps to 1 Mbps	Slower response time for safety signals, lower data throughput for diagnostics.	Faster response time, higher diagnostic data throughput, potentially more complex communication hardware.
Guard Opening Force	10 N to 100 N (without assist)	Easier for operator to open, lower risk of ergonomic injury.	More difficult for operator to open, higher risk of ergonomic injury (increases defeat motivation).

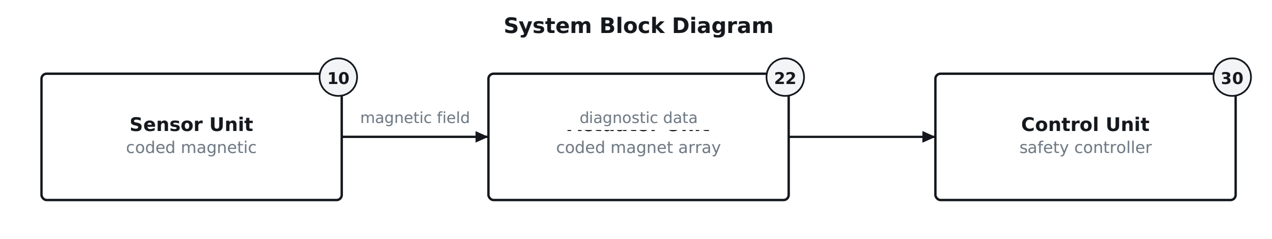
9. Additional Implementations

[0025] Beyond primary machine guarding, the principles of a coded magnetic interlock with defeat-resistant mounting can be applied to other industrial safety and security contexts.

[0026]

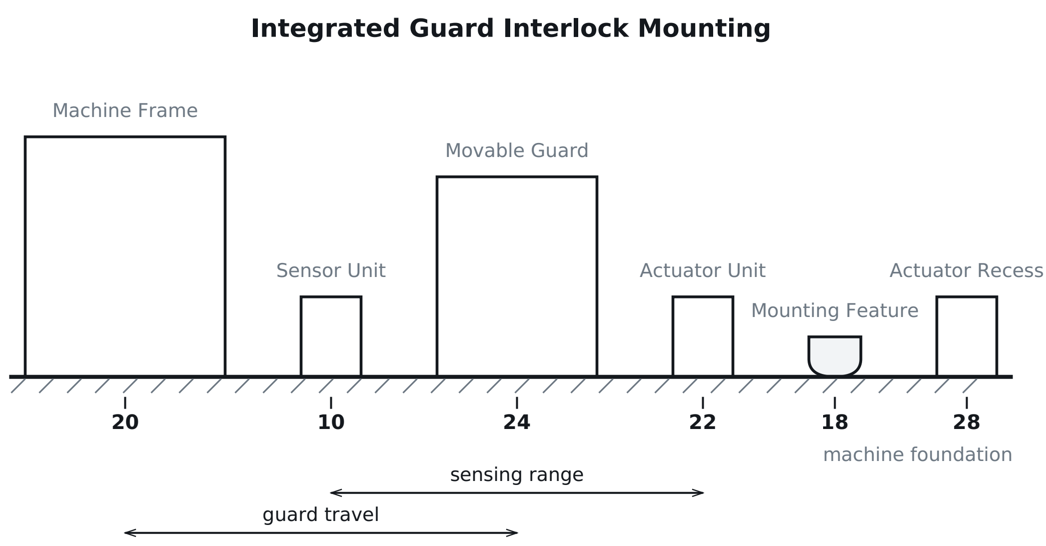
- **Tooling Interlocks:** In scenarios where specific tooling must be present and correctly seated before machine operation (e.g., press brakes, robotic end-effectors), a coded magnetic sensor (10) and actuator (22) can confirm the presence and correct configuration of the tooling. The defeat-resistant mounting ensures that generic or incorrect tooling cannot bypass the interlock.
- **Access Control for Sensitive Equipment:** The system can be used to control access to sensitive or critical control cabinets, calibration ports, or emergency stops. A coded magnetic key (acting as the actuator unit (22)) could be required to enable access, with the sensor unit (10) mounted in a defeat-resistant manner within the cabinet.
- **Material Presence Detection:** In some processes, confirming the presence of a specific material or component in a loading zone is critical for safety or process integrity. A coded magnetic tag on the material or carrier (actuator unit (22)) could be detected by a fixed sensor (10) to initiate or permit a process step, resisting attempts to fool the system with non-conforming items.
- **Mobile Equipment Safety:** On mobile industrial equipment (e.g., forklifts, automated guided vehicles), interlocks are often required for battery compartments, maintenance hatches, or personnel access points. The defeat-resistant design can ensure that these critical access points remain secured during operation, preventing tampering while the vehicle is in motion or powered.

10. Figures



The Sensor Unit (10) and Actuator Unit (22) interact magnetically.

FIG. 1 This block diagram illustrates the principal components and connections of the coded magnetic interlock system. PNG



The Actuator Unit (22) fits into a recess (28) in the Movable Guard (24).

FIG. 2 This elevation view shows a conceptual integration of the interlock sensor and actuator into a machine guard and frame. PNG

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