Appendix G: Safety Standards

Contents

Appendix G: Safety and Regulatory Standards

G.1 Machine Safety Standards

G.1.1 International Safety Standards

Standard	Region	Scope	Key Requirements
ISO 12100	International	Machinery safety (general)	Risk assessment, hazard elimination hierarchy
ISO 13849-1	International	Safety-related control systems	Safety categories (B, 1, 2, 3, 4), SIL ratings
ISO 13850	International	Emergency stop function	E-stop button specs, circuit design
IEC 60204-1	International	Electrical equipment of machines	Wiring colors, voltage levels, control circuits
ANSI B11.0	USA	General machine safety	Guards, interlocks, operator training
NFPA 79	USA	Electrical standard for industrial machinery	Panel wiring, grounding, short-circuit protection
CE Marking	EU	Product safety directives	LVD, EMC, Machinery Directive compliance

G.1.2 Risk Assessment (ISO 12100)

Hierarchy of Risk Reduction: 1. **Inherent Safe Design:** Eliminate hazard (e.g., use 24V instead of 230V for controls) 2. **Engineering Controls:** Guards, interlocks, light curtains 3. **Information for Use:** Warning labels, training, procedures 4. **PPE (Last Resort):** Safety glasses, gloves, hearing protection

Risk Matrix:

Severity	Minor Injury	Moderate Injury	Serious Injury	Fatal
Frequent	Medium	High	Very High	Very High
Probable	Low	Medium	High	Very High
Occasional	Low	Low	Medium	High
Rare	Negligible	Low	Low	Medium

Example Hazards for CNC Machines: - **Rotating spindle:** Severity = Serious/Fatal, Probability = Occasional **High Risk** (requires interlock guard) - **Moving gantry:** Severity = Moderate, Probability = Rare **Low Risk** (requires warning labels, awareness)

G.2 Machine Guarding Requirements

G.2.1 Guard Types (ANSI B11.19)

Type	Description	Advantages	Disadvantages	Applications
Fixed Guard	Permanent barrier (bolted panels)	Simple, reliable	Limits access for setup	Full enclosures, chip guards
Interlocked Guard	Opens, stops machine via switch	Allows access, automatic protection	More complex, can be defeated	Access doors, spindle enclosure
Adjustable Guard	Position adjusted for operation	Flexible for different parts	Requires operator setup	Blade guards, chip shields
Self-Adjusting	Opens/closes with workpiece	Automatic, no adjustment	Limited applications	Table saw blade guards

Interlocking Safety Switch Requirements: - **Type 1 (coded):** Switch mechanically linked to guard, cannot be easily defeated - **Type 2 (magnetic):** Non-contact switch, higher security (coded magnets) - **Type 3 (RFID):** Unique coded transponder, highest security - **Type 4 (trapped key):** Physical key locks guard, key required to start machine

Recommendation for CNC: Type 1 or 2 interlocked switches on all access doors, wired to safety relay (dual-channel monitoring).

G.2.2 Safety Distances (ISO 13855)

Reach-Over Distance (top of guard to hazard):

$$D = K \times T + C$$

where: - D = minimum distance (mm) - K = approach speed (1600 mm/s hand, 2000 mm/s body) - T = stopping time of machine (s) - C = penetration depth (8mm minimum)

Example: CNC with 0.5s stopping time (E-stop circuit + axis deceleration)

$$D = 1600 \times 0.5 + 8 = 808 \text{ mm}$$

Guard height must be >=808mm above hazard, or hazard must stop within 0.5s

Reach-Through Distance (opening size to hazard):

Opening Size (mm)	Minimum Distance to Hazard (mm)
<4	0 (finger cannot pass)
4-6	35
6-8	50
8-10	80
10-12	100
20-30	180
30-40	230

Example: Chip tray vent holes (10mm diameter) hazard (spindle) must be >=100mm from opening.

G.3 Electrical Safety Standards

G.3.1 Voltage Isolation and Clearances (IEC 60204-1)

Minimum Clearance (Air Gap) Between Conductors:

Voltage	Clearance (mm)	Creepage (mm)
24V DC (SELV)	1.5	2.5
50V AC / 120V DC	3.0	5.0
230V AC	5.5	8.0
400V AC	8.0	10.0

Clearance: Shortest distance through air between conductors **Creepage:** Shortest distance along surface of insulation

Example: 230V AC terminal block adjacent terminals must be >=5.5mm apart (air), with >=8mm surface distance.

G.3.2 LOTO (Lock-Out Tag-Out) Procedures (OSHA 1910.147)

Purpose: Prevent unexpected machine startup during maintenance.

Procedure: 1. **Notify** affected personnel of shutdown 2. **Shut down** machine normally (controlled stop) 3. **Isolate** energy (open main disconnect, circuit breaker) 4. **Lock** disconnect in “off” position (padlock on breaker handle) 5. **Tag** disconnect (“Do Not Operate - Maintenance in Progress”) 6. **Verify** zero energy (test start button, measure voltage with multimeter) 7. **Release stored energy** (discharge capacitors, bleed hydraulics, lower raised components)

Lock Types: - Single-person lockout: One lock per person working - Group lockout: Multiple locks on hasp (each worker has own lock, all must remove for re-energization)

Tag Requirements: - Durable material (plastic-coated cardstock) - Text: “DANGER - DO NOT OPERATE” or “OUT OF SERVICE” - Name, date, reason for lockout

G.4 Personal Protective Equipment (PPE)

G.4.1 Minimum PPE for CNC Operations

PPE	Standard	Protection	Required For
Safety Glasses	ANSI Z87.1	Impact, flying chips	All CNC operations (mandatory)
Hearing Protection	ANSI S3.19	Noise >85 dB	Router, milling, plasma cutting

PPE	Standard	Protection	Required For
Gloves	ANSI/ISEA 105	Cut resistance, abrasion	Material handling (NOT during machine operation)
Steel-Toe Boots	ASTM F2413	Compression, impact	Heavy material handling, large machines
Respirator	NIOSH 42 CFR 84	Dust, fumes	Wood routing, composite machining, plasma fume

Warning: Never wear gloves during machine operation (risk of entanglement). Remove jewelry, tie back long hair, avoid loose clothing.

G.4.2 Noise Levels and Hearing Protection

Permissible Noise Exposure (OSHA 1910.95):

Noise Level (dBA)	Max Duration/Day
90	8 hours
95	4 hours
100	2 hours
105	1 hour
110	30 minutes
115	15 minutes or less

Typical CNC Machine Noise: - Small router (24,000 RPM): 95-105 dBA **hearing protection required** - Milling machine (6,000 RPM): 80-90 dBA **hearing protection recommended** - Plasma cutter (arc): 90-100 dBA **hearing protection required**

Hearing Protection Ratings: - **Foam earplugs:** NRR 29-33 dB (highest rating, correct insertion critical) - **Reusable earplugs:** NRR 25-27 dB (more comfortable, lower cost over time) - **Earmuffs:** NRR 22-31 dB (easy to use, works with safety glasses) - **Electronic earmuffs:** NRR 22-24 dB (amplifies speech, blocks loud noise)

Effective Noise Reduction:

$$\text{Effective NRR} = \frac{\text{Rated NRR} - 7}{2}$$

Example: NRR 30 earplugs Effective reduction = (30-7)/2 = 11.5 dB

G.5 Fire Safety

G.5.1 Fire Extinguisher Types (NFPA 10)

Class	Fuel Type	Extinguisher	Color	CNC Applications
A	Ordinary combustibles (wood, paper, plastic)	Water, foam	Green	Wood routing, plastic machining
B	Flammable liquids (oil, coolant, solvents)	CO_2, dry chemical	Red	Coolant fires, hydraulic leaks
C	Electrical equipment	CO_2, dry chemical	Blue	Electrical panel, motor fires
D	Combustible metals (Mg, Ti, Al powder)	Dry powder (special)	Yellow	Metal dust from grinding

Recommendation for CNC Shop: - **ABC dry chemical extinguisher** (10 lb minimum) mounted near machine exit - Inspect monthly (pressure gauge in green zone) - Replace/recharge every 6 years or after use

Combustible Dust Hazard: - Wood dust, aluminum chips, composite fibers can ignite if suspended in air - Clean dust daily (vacuum, not compressed air which suspends dust) - Ground metal chip bins (prevent static spark)

G.5.2 Coolant Fire Risks

Coolant Types and Flashpoint:

Coolant Type	Flashpoint (°C)	Fire Risk	Precautions
Water-based emulsion	>100	Very Low	Monitor bacteria growth (mold, odor)
Synthetic coolant	>120	Low	Change when contaminated
Soluble oil (mineral)	200-250	Low-Medium	Keep away from open flame
Straight cutting oil	150-200	Medium	Hot chip accumulation can ignite, clean regularly

Fire Prevention: - Clean chips from coolant tank weekly (prevent hotspots, bacterial growth) - Use coolant mist collector (reduces airborne oil, improves visibility) - Keep spindle clean (chip buildup + high RPM = heat + friction fire risk)

G.6 Material-Specific Safety

G.6.1 Wood and Composites

Hazards: - **Dust inhalation:** Hardwood dust is IARC Group 1 carcinogen (nasal cancer risk) - **Fire:** Fine dust suspended in air is explosive (minimum ignition energy ~10 mJ)

Safety Measures: - Dust collection: Minimum 400 CFM per machine, <0.5 micron filtration - Respirator: N95 minimum (P100 for very fine dust like MDF) - Grounding: Metal ducting bonded to ground (prevent static ignition)

G.6.2 Metals

Hazards: - **Sharp chips:** Lacerations from handling swarf - **Metal fumes:** Zinc (galvanized), lead (brass/bronze), cadmium (rare) - **Reactive metals:** Magnesium, titanium (fire risk if chips overheat)

Safety Measures: - Gloves for chip handling (cut-resistant, ANSI Level A4 minimum) - Fume extraction for zinc/brass (local exhaust ventilation) - Magnesium/titanium: Use flood coolant (prevent chip ignition), Class D extinguisher nearby

G.6.3 Plastics

Hazards: - **Fumes:** PVC releases HCl (hydrochloric acid vapor), acrylic releases methyl methacrylate (MMA) - **Static:** Acrylic builds static charge chip/dust attraction

Safety Measures: - Ventilation: 100 CFM minimum for enclosed area - Avoid PVC if possible (corrosive fumes damage machine, health hazard) - Anti-static spray or grounding for acrylic (reduce chip adhesion)

G.7 Laser Safety (Fiber/CO_2 Laser Systems)

G.7.1 Laser Classification (IEC 60825-1)

Class	Power	Hazard	Control Measures
1	<0.39 mW	Safe (enclosed)	None (fully enclosed laser cutter)
1M	<0.5 mW CW	Safe without optics	Do not use magnifiers/telescopes
2	<1 mW visible	Blink reflex protects	Avoid staring
3R	<5 mW	Eye hazard if direct	Laser warning signs, training
3B	<500 mW	Serious eye/skin hazard	Interlocked enclosure, laser goggles
4	>500 mW	Fire + diffuse reflection hazard	Full enclosure, interlocks, training, goggles

Fiber Laser (1064 nm): Class 4 (enclosed machine = Class 1 system)

Safety Requirements for Class 4 (Enclosed): - Interlocked doors (laser shuts off when opened) - Emergency stop accessible from operator position - Laser warning labels (Class 4 on interior, Class 1 on exterior if fully enclosed) - Laser safety officer (LSO) designated if multiple lasers

G.7.2 Laser Safety Eyewear

Optical Density (OD) Required:

$$OD = \log_{10}\left(\frac{P_{incident}}{P_{MPE}}\right)$$

where: - $P_{incident}$ = incident laser power (W) - P_{MPE} = maximum permeable exposure (W/cm^2)

Example: 100W fiber laser (1064 nm), beam diameter 5mm - $P_{incident} = 100$ W / $(0.25\text{ cm})^2/\pi = 5093$ W/cm^2 - P_{MPE} = 0.005 W/cm^2 (for 1064 nm, 10s exposure) - $OD = \log_{10}(5093/0.005) = 6.0$

Goggles required: OD 6+ at 1064 nm wavelength

Caution: Standard safety glasses do NOT protect against lasers. Use laser-specific eyewear with correct OD and wavelength.

G.8 Confined Space and Enclosure Safety

G.8.1 Confined Space Definition (OSHA 1910.146)

Criteria: 1. Large enough for worker to enter and perform work 2. Limited means of entry/exit 3. Not designed for continuous occupancy

Example: Large CNC enclosure (>2m^3) requiring internal maintenance = **confined space**

Hazards: - Oxygen deficiency (<19.5% O_2) or enrichment (>23.5% O_2) - Flammable atmosphere (coolant vapor, dust) - Toxic atmosphere (plasma fume, oil mist)

G.8.2 Permit-Required Confined Space (PRCS)

Additional Hazards Requiring Permit: - Engulfment risk (chips, coolant) - Internal configuration causing entrapment - Serious safety/health hazard

Entry Procedure: 1. Atmospheric testing (O_2, flammable gas, CO, H_2S) 2. Ventilation (forced air, 100+ CFM) 3. Entry permit (signed by supervisor) 4. Attendant outside (communication, rescue) 5. Retrieval equipment (harness, winch)

Recommendation: For large CNC enclosures, treat as PRCS if entry required during operation (e.g., waterjet tank maintenance).

End of Safety and Regulatory Standards Appendix