Machine Manual & Standard Operating Procedure (SOP)

Document purpose: This is a machine manual and SOP designed to diagnose, respond to, and prevent six failure modes: No Failure, Heat Dissipation Failure, Over-stress Failure, Power Failure, Random Failure, and Tool Wear Failure. Use as a template. Replace the example thresholds and actions with your real machine's validated values before applying to a physical system.

1. Machine overview

Machine variables (placeholders)

- **Type**: [L / M / H] — Low, Medium, High throughput configuration
- **Air temperature**: [K] — ambient intake temperature in Kelvin
- **Process temperature**: [K] — measured at process-critical node in Kelvin
- **Rotational speed**: [rpm]
- **Torque**: [Nm]
- **Tool wear**: [min] — minutes of cumulative use or a wear index

Assumptions

- Sensors provide real-time readout of all listed variables.
- Actuators include fan(s), cooling circuit, motor controller, and power monitor.
- Machine contains a maintenance log and an event log.

2. Definitions of failure modes

1. **No Failure** — Operating within acceptable tolerances for all parameters. Normal monitoring only.
2. **Heat Dissipation Failure** — Machine cannot remove process heat; process temperature rises above safe threshold and/or cooling fans/pumps underperform.
3. **Over-stress Failure** — Mechanical stress (torque, rpm) exceeds design limits or sudden spikes occur that risk structural/mechanical damage.
4. **Power Failure** — Loss of input power, undervoltage, or power quality issues (brownouts, surges) affecting operation.
5. **Random Failure** — Intermittent, non-deterministic faults (electrical noise, sensor dropout, transient control errors) not attributable to other categories.
6. **Tool Wear Failure** — Progressive degradation of the tool beyond acceptable wear limits, causing poor process outcomes or increased load.

3. Thresholds & example alarm setpoints (example values — change to match real machine)

These example thresholds are conservative defaults for a general-purpose machine. Validate with engineering.

- **Air temperature (ambient)**
  - Normal: 273–303 K (0–30°C)
  - Warning: 303–313 K (30–40°C)
  - Alarm / Action: >313 K (>40°C)
- **Process temperature**
  - Normal: setpoint ± 5 K
  - Warning: setpoint ± 10 K
  - Critical: > setpoint + 15 K or absolute > 350 K (example)
- **Rotational speed (rpm)**
  - Normal: nominal rpm ± 5%
  - Warning: ± 10%

    - Critical: > design limit or abrupt change > 20% in <1s
- **Torque (Nm)**
    - Normal: nominal torque ± 10%
    - Warning: sustained >110% nominal
    - Critical: >130% nominal or rapid spike
- **Tool wear (minutes / index)**
    - Normal: 0 — wear_limit*0.6
    - Warning: wear_limit*0.6 — wear_limit*0.9
    - Replace: ≥ wear_limit (or when quality metrics fail)
- **Power**
    - Normal: voltage within ±5% of nominal
    - Warning: ±5–10% or transients detected
    - Critical: undervoltage, outage, or sustained harmonics above spec

4. Monitoring & diagnostic indicators (what to watch)

- **No Failure**: steady sensors, no alarms, process temperature stable, torque and rpm within band, tool wear increasing slowly.
- **Heat Dissipation Failure**: rising process temperature, fan RPM lower than commanded, coolant inlet/outlet delta T increases, thermal trip alarms, throttling events by controller.
- **Over-stress Failure**: torque spikes, sudden rpm drops or surges, increased vibration, acoustic change, abnormal motor current.
- **Power Failure**: mains disconnect, UPS switching events, voltage sag/spike logs, motor driver fault, PLC restart.
- **Random Failure**: mismatched timestamps in logs, sensor dropout, transient alarms that clear without operator action, CRC errors on instrument bus.
- **Tool Wear Failure**: increasing torque for same rpm, degraded product quality metrics, rising surface roughness/defect counts, tool wear counter exceeding warning band.

5. SOP: general safe response flow (applies to all failures)

1. **Alert & log**
    a. Acknowledge alarm on HMI. Log timestamp, operator ID, machine type, and current sensor snapshots.
2. **Immediate safe state**
    a. If critical: execute emergency stop (E-stop) per machine spec.
    b. If non-critical: move to controlled slowdown, reduce rpm to safe value (e.g., 50% nominal) and hold.
3. **Isolation**
    a. For electrical/power issues: isolate mains if indicated.
    b. For thermal issues: engage emergency cooling (forced fan at max), open bypass vents if available.
4. **Diagnosis**
    a. Use diagnostic checklist per failure type (see Section 6).
5. **Corrective action**
    a. Perform actions in the checklist. If quick fix applied, return to slow ramp-up monitoring for at least 30 minutes.
6. **Restart**
    a. Only resume full operation after verifying sensors are stable, and no residual warnings remain. Perform a short production validation run (3–5 cycles) and check product quality.
7. **Report & Preventive maintenance**
    a. Fill out an incident report. If failure is recurring, schedule preventive maintenance or part replacement.

6. Failure-specific diagnostic checklist & step-by-step SOP

A — No Failure (routine operation)

- Confirm all parameters within normal thresholds.

- Execute standard pre-run checklist: lubrication, visual inspection, tool wear reading, verify cooling airflow.
- Start production run.

B — Heat Dissipation Failure

Symptoms: process temperature above critical threshold; cooling fans/pumps underperform.

Immediate actions:

1. Alert operator; increase fan/pump to max via manual override.
2. If cooling fails or temperature continues to rise: reduce process load (reduce rpm/torque) and pause feed.
3. If temp reaches emergency trip: perform controlled shutdown.

Diagnostic steps:

1. Check fan RPM sensor and drive output. Confirm fans receive voltage and speed command.
2. Inspect coolant level, flow sensor, pump current draw.
3. Check heat exchanger / radiator for blockage; inspect filters.
4. Review airflow paths for obstruction or closed dampers.
5. Validate temperature sensor (swap with known good sensor if possible).

Corrective actions:

- Clean or replace filters; remove obstructions.
- Replace failed fan or pump. Tighten electrical connectors.
- Refill or bleed coolant system.
- If thermal runaway is due to process setpoint, lower setpoint and revalidate.

Post-repair verification:

- Monitor process temperature and delta T for 30 minutes under nominal load.
- Record event, corrective actions, and time to recovery.

C — Over-stress Failure

Symptoms: torque and/or rpm beyond limits, high vibration, mechanical noise.

Immediate actions:

1. Reduce RPM immediately to safe slow speed (e.g., 30–50% nominal) or perform controlled stop.
2. Hold spindle/brake engaging if necessary.

Diagnostic steps:

1. Check motor current and torque sensor logs for spikes or sustained overload.
2. Inspect tool/chuck/clamp for slippage or foreign object.
3. Look for mechanical binding (bearing failure, debris in mechanism).
4. Review recent process recipe changes and tooling history.

Corrective actions:

- Remove foreign object, re-mount tooling, reseat chuck.
- Replace failed bearings or other mechanical parts.
- Recalibrate torque limits and controller gains if oscillation due to tuning.

Post-repair verification:

- Run no-load spindle test at incremental rpm steps while monitoring vibration and current.
- Run short verification cuts, measure product geometry/quality.

D — Power Failure

Symptoms: mains drop, PLC reboot, inconsistent motor supply, fault codes from power modules.

Immediate actions:

1. If safe to continue on UPS: follow UPS transfer procedure. If not, perform controlled shutdown to safe state.
2. Isolate load from mains and check mains input.

Diagnostic steps:

1. Check mains voltage, breaker status, and UPS logs.
2. Inspect power distribution panel for tripped breakers or blown fuses.
3. Verify power supply modules (filter capacitors, DC rails) for health.
4. Check for ground faults or loose conductors.

Corrective actions:

- Reset/replace tripped protection devices.
- Replace faulty power modules or batteries.
- Engage facility electrical team for upstream issues.

Post-repair verification:

- Confirm mains stability for 1 hour under normal load.
- Monitor for harmonics or repeated trips.

E — Random Failure

Symptoms: transient alarms, sensor dropout, unexplained resets.

Immediate actions:

1. Put machine in controlled hold; do not resume full operation until initial checks.
2. Collect logs and timestamps for the event window.

Diagnostic steps:

1. Correlate events in PLC, HMI, motor drives, and sensors by timestamp.
2. Check communication buses (CAN, Modbus, Ethernet) for CRC errors or cable faults.
3. Inspect connectors for corrosion or loose pins.
4. Swap or isolate suspect sensors/IO modules.

Corrective actions:

- Replace faulty cable, connector, or module.
- Harden grounding and shielding if electrical noise suspected.
- Update firmware if known bug matches symptoms.

Post-repair verification:

- Run stress test for several cycles to try to reproduce the fault.
- If intermittency persists, escalate to root-cause study with trace capture equipment.

F — Tool Wear Failure

Symptoms: rising torque at same rpm, poor quality output, tool wear counter exceeded.

Immediate actions:

1. Pause production at a convenient break and inspect tool.
2. If dangerous to continue (excessive force or chatter): perform controlled stop.

Diagnostic steps:

1. Measure tool wear physically if possible (microscope/inspection) or use wear index sensor.
2. Review process logs for cutting forces, torque trends, time since last change.
3. Check coolant / lubrication affecting wear.

Corrective actions:

- Replace or resharpen tool.
- Adjust feed/speed if premature wear caused by aggressive settings.
- Improve tool holding, check runout.

Post-repair verification:

- Run reference part and check dimensional/visual quality.
- Document cumulative tool life; update replacement interval if needed.

7. Maintenance & preventive schedule (example)

- **Daily**: Visual inspection, check filters, log ambient/process temps, quick tool check.
- **Weekly**: Fan/pump current checks, verify coolant level, tighten accessible fasteners, check belts/chains.
- **Monthly**: Vibration analysis, motor current signature analysis, replace fine filters.
- **Quarterly**: Replace air filters, inspect bearings, recalibrate sensors, full electrical panel inspection.
- **Yearly**: Overhaul critical mechanical subassemblies, thermal imaging survey under load.

8. Incident log template (fill after event)

- Date / time:
- Operator:
- Machine Type:
- Observed symptoms:
- Sensor snapshots (air T, process T, rpm, torque, tool wear):
- Immediate actions taken:
- Diagnostic steps performed:
- Corrective actions:
- Time to recovery:
- Preventive actions recommended:

9. Quick troubleshooting matrix (one-page view)

- **High process temp** → check fans/pumps → clean filters → replace fan/pump → reduce load
- **High torque** → reduce RPM → inspect tool/chuck → remove obstruction → replace bearing/tool

- **Power trip** → check mains/UPS → reset breaker → replace fuse → call electrician
- **Intermittent sensor** → check connector → swap sensor → check bus errors → tighten shielding
- **Poor quality / wear** → stop → inspect tool → replace/resurface → review rpm/feed

10. Safety notes

- Always follow lockout/tagout (LOTO) before opening electrical panels or mechanical housings.
- Wear appropriate PPE when inspecting rotating machinery and hot components.
- Do not bypass safety interlocks to troubleshoot.

11. Change log & validation

- This manual is a template. Any change to thresholds or SOP steps must be validated and signed off by the responsible engineer.

End of document — replace placeholder values with your machine's validated numbers before use.