Use of Temperature Safety Limits In the Semiconductor Industry

This paper will offer guidance on the selection and use of Thermal Limit devices within applications in the semiconductor fabrication industry. It will explain the differences between mechanical, electronic analog, and electronic microprocessor controlled limits as well as integrated control-limit devices. It will explain the differences between fail-safe, fail-to-safe equipment control system and high reliability limits. Thermal limits, interlocks or thermal disconnects are used to safely shut down the heater in the event of overtemperature conditions. This protects equipment and product being manufactured from damage. This guidance will be based on SEMI S2 and also based on my experience of nineteen years in the electronics industry the last thirteen as the primary Electro-Magnetic Compatibility (EMC) and Safety Agency Coordinator for Watlow, Inc., Control's Division.

SEMI S2-0706b Environmental, Health, and Safety Guideline for Semiconductor Manufacturing Equipment Clause 6.5 requires evaluation of the system to mitigate against a single point of failure caused by control malfunction or operator error. The standard requires the control and safety device to be approved by a third party (i.e. other than self declaration of the manufacturer). Many third party agencies exist, Watlow has chosen to use Underwriters Laboratories (UL®) and Factory Mutual (FM) as our primary safety agencies. Provisions exist in the standard to help with guidance on the type of limit required depending on the level of risk within the system. Clause 11.4 states upon activation, a safety interlock should alert the operator immediately. It is also preferred that both local and remote notification are provided.

FM Class 3545 Temperature Limit Switches: *http://www.fmglobal.com/assets/pdf/fmapprovals/3545.pdf*. This standard defines functional performance requirements for safety limit devices, calibration accuracy at worst case ambient, supply voltage, and endurance conditions. It also covers dielectric requirements for equipment. This standard can be used for electronic analog, electronic microprocessor based, and combined control-limit devices. It does not require equipment to be fail-safe, but does require sensor failure detection and safe shutdown.

UL 991 Tests for Safety-Related Controls Employing Solid-State Devices – UL® standards are available at http://www.comm-2000.com/. This is a companion standard used with other UL standards such as UL 508 Industrial Control Equipment or UL 61010-1 Safety requirements for measurement, control and laboratory equipment. It adds tests for calibration accuracy before and after environmental, supply voltage, electromagnetic compatibility (EMC) and transient tests. It requires a reliability analysis of the device to ensure robustness. This standard can be used for electronic analog, electronic microprocessor based, and combined control-limit devices. It does not require equipment to be fail-safe, but does require sensor failure detection and safe shutdown.

UL 1998 Software in Programmable Components is a companion standard specific for analysis of the reliability of firmware used in microprocessor based devices. It is typically used with UL/EN 60730 Automatic electronic controls for household and similar use. These standards test for calibration accuracy before and after environmental, supply voltage, electromagnetic compatibility (EMC) and transient tests. It requires a reliability analysis of the device to ensure robustness. This standard can be used for electronic microprocessor based, and combined control-limit devices. In addition, it adds requirements for the function, detection and recovery or safe shutdown of microprocessor based errors. Limits approved to these requirements are considered fail-safe devices (i.e. any component fault or firmware error is detected and system either continues to operate at normal capacity or shuts down safely.)

Mechanical limits used are either of the Snap action bimetallic type or bulb and capillary type of devices. These devices are the lowest cost devices and provide reliable operation. Snap action switches are factory configured for temperature setting providing security, but this also requires many models to be stored for use in multiple applications. Bulb and capillary devices usually overcome this by being field adjustable. The disadvantages of these devices are lack of notification of operation without additional monitoring equipment being used and difficulty of replacing a bulb and capillary device as both the limit and sensor are integrated. These devices have a slower response time and are not suitable for operating close to the systems thermal limit.

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Electronic analog are the next level of technology, they employ solid state circuitry to monitor and trip the limit. They offer low cost limit options with more features than mechanical devices. Local and remote notifications may be included along with the limit function. Limit and sensor can be replaced independently of each other for easier maintenance. These devices typically have a faster response time than mechanical limits. The disadvantages of these devices are that they typically only offer one sensor type configured at time of purchase requiring multiple models to be stocked for various applications, they do not offer the flexibility and enhanced performance features of microprocessor based devices.

Electronic microprocessor based limits employ solid state technology as well as firmware to control limit action. They offer high flexibility in configuration options, multiple sensor input options, local and remote notification of limit tripping along with availability of communications. These enhanced features can allow one model of device to be used in many different applications requiring different sensor systems or notification methods. Use of communications with the device allows for trend analysis and process verification. With the use of UL 1998 and UL 60730 Type 2 classification, these devices can obtain fail-safe status and can be used for critical limit functions. The disadvantages of these devices are that extra caution in setup and design needs to be taken to ensure limited access to setpoint changes. Use of lockout functions in firmware and Upper/Lower setpoint limits can be used to mitigate this issue. Communication programs must also have limited access to setpoint parameters.

Combination Control Limit devices are also being offered. While SEMI S2 requires independent devices, some models fulfill this requirement even though they are packaged together. Use of separate control and limit modules within the same device is allowed if no single point of failure can cause the system to become unsafe. Most devices operate independent of each other with the exception of the power supply. In the event of a power supply failure, both the control and the limit modules would shut down ensuring safety. The advantages of these systems are reduced footprint in cabinet and reduced cost due to wiring and inventory management. Disadvantages are potential down time in the event of failure due to both the limit and the control would not be functional. However, due to flexibility of these devices in multiple applications having a backup device available and automated parameter recovery can mitigate this risk.

Depending on the criticality of a fault, several different approaches to safety can be used. For minor faults, use of an alarm on the control device can be used. This is a cost effective method, however sensor or control failure could cause loss of fault protection. Additional protection can be added by using open loop detectors provided in control firmware to detect a sensor failure, this monitors control output and current flow and based on thermal parameters determines if the sensor or output has failed. Moderate faults can use a combination of alarm plus open loop detection and a separate limit device to provide some additional redundancy in the system. A lower cost limit can be used for these situations. Use of external communications programs that talk to both the control and limit devices and based on sensor deviations initiate alarms can also be used to create system redundancy. High level faults will require use of fail-safe or Fail-to-safe Equipment Control System (FECS). A FECS is obtained by use of several lower reliability limit devices in a series or parallel voting setup such that multiple devices would need to fail simultaneously to have a loss of protection. See IEC 61508 Functional safety of electronic safety-related systems for further details on this type of system.

As systems become more complex, a thorough risk analysis of the hazards presented in a machine needs to be done, and the appropriate type of protection should be used. A balance between cost and the risk present needs to be established. Use of microprocessor based limits and combination control-limits can provide a cost effective and safe solution by proper use of control alarms, open loop detection, limit setpoint lockout menus, and monitoring and automated shutdown based on communications with all devices in system. The additional features and benefits of these devices can offer trend analysis of system and help predict maintenance intervals to reduce down time of the system. Fail-safe microprocessor based limits exist and they offer advanced features to help monitor and protect semiconductor equipment.

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Product	Type of Limit Technology.	FM Class 3545	UL 991	UL/EN 60730 Type 2 Limit + UL 1998 "Fail-Safe Limit"	Combined Control - Limit Device	Local Notification	Remote Notification	Communication Options	Sensor Options
Series LV, LF Limit	Microprocessor	X				Unit Display	N.C. contacts of Limit Relay	None	Factory Configured Thermocouple J, K, T, E and RTD
Series LF_4 Limit	Microprocessor	X	X			Unit Display	N.C. contacts of Limit Relay	None	Factory Configured Thermocouple J, K, T, E and RTD
Series 94 Limit	Microprocessor	X				Unit Display	Secondary Alarm	None	Field Selectable Thermocouples J, K, T, N, S, B and RTD
Series 97 Limit	Microprocessor	X				Unit Display	Multiple alarms, Communications, Retransmit	RS-232 or RS-485	Event input, Field Selectable Thermocouples J, K, T, E, F, N, C, D, R, S, B and RTD
Series SD Limit	Microprocessor	X				Unit Display	Secondary Alarm, communications, Retransmit	RS-232, RS-485 or Infrared	Field Selectable Thermocouples J, K, T, E, F, N, C, D, R, S, B, RTD or Process Input.
Series EZ-Zone ST	Microprocessor	X			X	LED Display, RUI Display Option	Secondary Alarms, Communications, Retransmit, Digital I/O	WatBus, ModBus RTU (485)	Integrated Limit Contactor, Integrated current measurement, Digital I/O, Field Selectable Thermocouples J, K, T, E, F, N, C, D, R, S, B, RTD or Process Input.
Series PM	Microprocessor	X			X	Unit Display	Secondary Alarms, communications, Retransmit, Digital I/O	WatBus, ModBus RTU, Ethernet/IP, Devicenet, Datalogging	Digital I/O, Field Selectable Thermocouples J, K, T, E, F, N, C, D, R, S, B, RTD or Process Input
EHG SL10	Microprocessor			X	X	Unit Display	Secondary Alarm, communications	RS-485	Type K Thermocouple
Series TLM	Analog	X				LED Display	Global Supervisor Alarms	None	Factory Configured

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