HIGH TEMPERATURE OPERATION OF ELEVATORS

by Vincent P. Robibero

ABSTRACT

Solid state elevator controls are complex systems which meet the demand for efficient vertical traffic flow in modern high rise buildings. They are also considered an essential tool for high rise building fire operations. Exposure to rising machine room temperatures pose special problems for the control equipment and the users of elevators during a fire. To date, there is little in the way of codes or regulations which will make these systems react in a consistent manner during exposure to elevated temperatures. The response of the elevator control is, for the most part left, up to the manufacturers. An understanding of how solid state controls are temperature rated and what problems they may present to the fire fighter when in use, will help in the development of new code requirements which the fireman can rely upon. The advanced technology used in solid state controls provides plenty of opportunity to help the fire fighter maintain control of her situation while using an elevator for fire operations.

INTRODUCTION

Elevator systems are commonly used as an important tool for fighting fires in high rise buildings. O'Hagan points out that "...reliable elevator service is a necessity for effective fire fighting and rescue operations in high rise buildings".[1] However, he also points out that "Elevators have probably contributed to more loss of life in high rise fires in the United States than any other component or building system."[2]

Since an elevator system is vertically located the entire length of a building, its components are extremely vulnerable to the hazards of fire. Many elevator system components have malfunctioned due to the heat generated from building fires. Electric hoistway door contacts and hall call buttons are just two examples.

This paper will address the possible effects of building fire heat on modern solid state elevator controls. This equipment is typically located in a machine room over the elevator shaft and may be exposed to increasing temperatures generated from fires below. The malfunction of the elevator control system is an important consideration which the fire fighter must take into account when selecting an elevator for fireman service.

I will explain what the elevator designer must consider when specifying an acceptable operating temperature for their control equipment. The possible effect on the solid state elevator controls resulting from temperature rising above the designers specification will also be discussed. The possible system effects which may be experienced by the user of an elevator control exposed to the rising temperatures will then be explored.

Finally, I will present ASME/ANSI A17.1 elevator codes which require a specific elevator response as a result of malfunctions which may be caused by rising machine room temperatures. Final analysis and recommendations for improvement are provided in the conclusion of this paper.

In this paper, the term semiconductor refers to all solid state devices such as micro electronics and power semiconductors.

TEMPERATURE THRESHOLDS

When establishing a specified maximum allowable operating ambient temperature for their control equipment, the manufacturers designer will work to incorporate the following with cost and performance objectives:

(1) The grade of the individual devices used in the design. This establishes device temperature limits.

(2) The design of electrical power stress on the devices.

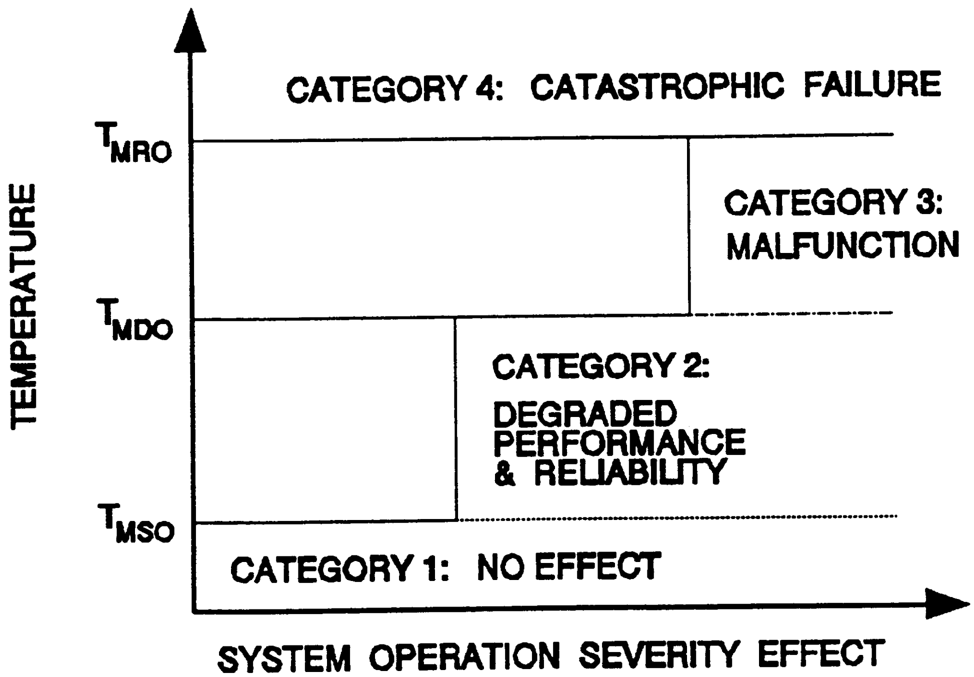


FIG. 1

(3) The design of the thermal transfer of heat from the devices, assemblies, and enclosure to the outside ambient.

(4) Design and reliability safety margins.

To discuss the possible response modes of the elevator control system to rising machine room temperatures, it is helpful to categorize maximum ambient operating temperature thresholds. The temperature thresholds are considered to be the ambient air temperature of the machine room surrounding the equipment enclosure, vents, heat sinks, etc. With each threshold, I am defining a level of degradation the control will suffer as a result of being exposed to temperatures within the thresholds.

Figure 1 provides a presentation on the relationship between the critical temperature thresholds and the response categories.

They are defined as follows:

Category 1: No Effect.

Temperature threshold: maximum specified operating temperature (T_{MSO}). This is the elevator equipment manufacturers specified maximum temperature in which the equipment can operate while assuring no degradation in the manufactures reliability and performance specifications. It normally includes the manufactures design and reliability safety margins.

Category 2: Degraded Performance/Reliability

Temperature threshold: maximum design operating temperature (T_{MDO}). This is the maximum temperature in which the equipment can operate, without design or reliability safety margins. Degraded performance and long term reliability may result when operating between T_{MSO} and T_{MDO}. The performance degradation is limited to degraded ride quality. Once the equipment temperature returns to T_{MSO}, performance returns to normal.

Category 3: Performance Malfunction (Recoverable)

Temperature threshold: maximum recoverable operating temperature (T_{MRO}). This is the maximum temperature in which the equipment can operate under reduced load conditions. The equipment will most likely malfunction as load is increased. Once the equipment is allowed to cool, it will function again, although the system may not automatically resume service without the aid of a service mechanic.

Category 4: Catastrophic failure

Operation above T_{MRO}, will result in non-recoverable failure of the system.

DESIGN

Elevator controls have come a long way from utilizing electro-mechanical devices for the control, signaling and drive functions of the elevator system. Today, solid state devices and micro-processor circuitry, similar to that which is found in modern computers, are used to perform these functions. Although solid state controls may be more sensitive to elevating temperatures than older electro-mechanical controls, they permit more complex functions and efficient control of the elevator, along with improved performance and reliability, than that which can be achieved with electro-mechanical control systems.

In order to meet acceptable cost and reliability requirements, the designer of solid state elevator controls must make use of devices and equipment cooling design necessary for elevator operation in normal machine room ambient temperature. This temperature is established between the customer and industry. Today, machine room ambient temperatures are typically rated at 32.2 °C (90 °F).

Solid state chips for example, may be acquired in commercial, industrial or military grades. Typically, commercial grade solid state chips have maximum ambient operating temperature ratings of 70 °C (158 °F), industrial devices are typically rated at 85 °C (185 °F) maximum and most military grade devices are rated at 125 °C (257 °F) maximum operating temperature.[3] If the maximum allowable operating temperature of a device is exceeded, the performance characteristics of the device can no longer be assured. Normally, higher temperature rated devices are more expensive then lower temperature rated devices.

When the operating temperature rises above the maximum allowable, solid state devices will begin to go out of design tolerance and will not properly operate together in the design circuit. This will most likely lead to an elevator control malfunction. If the temperature of a solid state device rises sufficiently, it will go into a condition known as thermal runaway and fail catastrophically.

Solid state devices must be derated to lower than maximum rated operating temperatures. There are two reasons for this, (1) power dissipation capability and (2) reliability.

Performance specifications for solid state devices operating in an ambient above 25 °C (77 °F), normally require a trade off between the maximum power demanded from the device and its maximum operating temperature. In most devices, such as micro processors, power demand increases with increased operating speed (switching losses) and/or increased current demand (conduction losses). The designer must either sacrifice the devices available power dissipation for higher operating temperatures or vice versa.

A similar trade off must also be made between the long term reliability of the device and the operating temperature. Models for the predicted reliability of electronic components is provided in MIL-STD-217.[4] Semiconductor failure rates are modeled as a function of the semiconductor junction rating, operating temperature and power dissipation (electrical stress). At a given junction temperature, when operating temperature or power dissipation is increased, the predicted failure rate of the device also increases.

The mean time between failure (MTBF) is a measure of the predicted reliability of the elevator control and is equal to: 1/sum of the individual failure rates of all the control devices. An increase in device failure rates will result in a lower MTBF (reliability) for the control system.

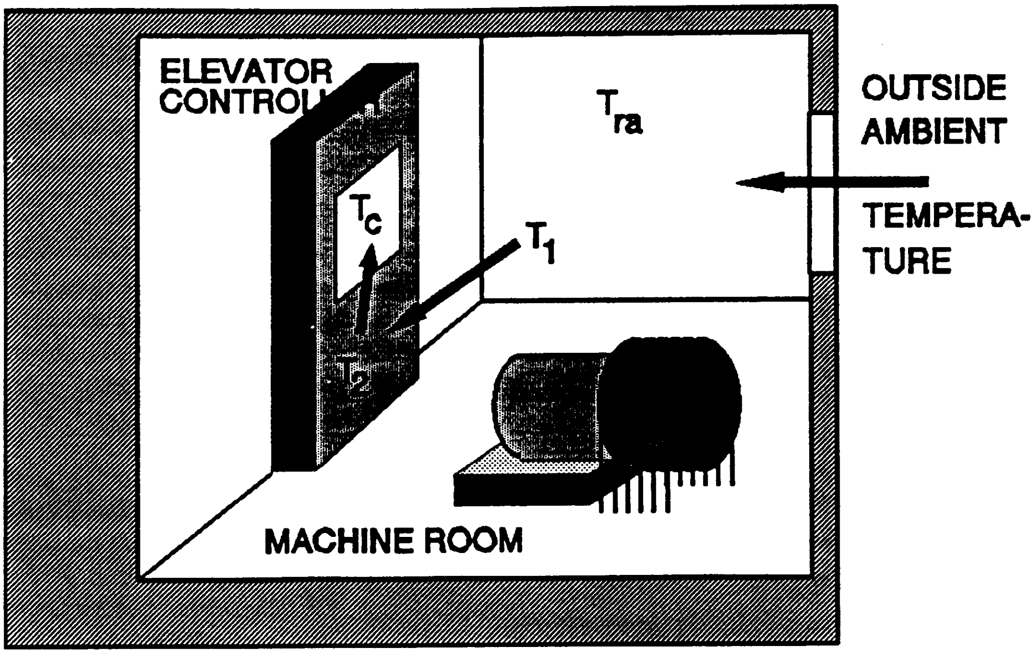
Designers will most likely add a thermal safety margin to establish to T_{MSO}. This may be represented by an additional temperature rise from the enclosure to all devices in it. We can call it T_{sf}. The purpose of this safety margin is to provide an acceptable confidence level in the specified performance and reliability of the system. It is used to minimize the risk of statistical variability of the component thermal characteristics on system performance.

Because the cooling design of the system effects the temperature rise from machine room ambient to the device ambient, the ambient temperature of a device (T_{da}) can be expressed as:

$$T_{da} = T_{ra} + T_{sf} + T_1 + T_2 + \dots + T_n$$

where

T_{ra} is the room ambient temperature,
T_{sf} is the design thermal safety factor,
T_1, T_2, and T_n are the temperature rises from the machine room ambient to the device.



$$T_c = T_{ra} + T_{sf} + T_1 + T_2$$

T_c = Component temperature
T_{sf} = Design safety margin
T_{ra} = Machine room Ambient temperature
T_1 = Temperature rise into controller
T_2 = Temperature rise into assembly

FIG. 2

Figure 2 provides an elevator machine room illustration of this consideration. The temperature rise inside of the control enclosure is a function of the total power dissipation inside the enclosure and the ability of the design to transfer heat to the external air at a given altitude. Heat sinks, fans, and cooling vents are some the techniques used by designers to minimize this temperature rise. However, cost and size constraints will limit the designers ability to achieve ideally no temperature rise between the machine room ambient air temperature and the device temperature in the control enclosure.

As an example, consider an elevator control made up of industrial grade components rated at 85 °C. Taking a 40% thermal derating for worst case design power dissipation, the components are now limited to 51 deg, C maximum operating temperature. Adding 5 °C for thermal safety margin and given 32 °C (90 °F) as the maximum machine room ambient temperature, the designer must provide a thermal transfer design which will allow no more than a 14 °C temperature rise from external ambient to the devices in the enclosure. In this case , T_{MSO} would be 32 °C (90 °F), T_{MDO} would be 37 °C (99 °F), T_{MRO} is 71 °C (160 °F) maximum.

In summary, the designer must negotiate between the maximum specified operating temperature, performance/reliability requirements and the cost constraints of the elevator control.

SYSTEM RESPONSE TO ELEVATING TEMPERATURE

Having defined temperature thresholds, I will now examine possible system response modes which may result from the elevator control being exposed to rising temperatures. There are two basic system response modes: emergency stop and orderly shut down. An emergency stop occurs when the elevator stops as a result of power being removed from the hoist machine motor and brake. In this mode, the car may stop anywhere in the hoistway. An orderly shut down will allow for a predetermined elevator stopping sequence which can permit the elevator car to reach a landing before shutting down the control.

Elevator controls with solid state motor drives or power supplies, may have thermal sensing devices such as thermistors, which monitor the temperature of power components. When conditions cause temperature thresholds to be reached, these monitoring devices are designed protect the power devices. Depending on design philosophy, the elevator may be brought to an orderly shut down. If the car is in motion and conditions permit, the car may be brought to a stop at the next available landing and open its doors prior to shutting down. Designers may set the monitoring devices to trip at temperatures between T_{MSO} and T_{MDO} to protect the passengers from an abrupt emergency stop which might otherwise occur if the equipment was allowed to operate beyond T_{MDO}. This type of response mode could also be designed to allow the system to automatically return to normal operation once the temperature fell back below the threshold value.

With no temperature monitors to prevent the control from operating above T_{DMO}, other types of circuits could disrupt elevator operation as temperature rises above T_{DMO}. One type could be considered performance monitoring circuits. In this case, devices which monitor performance, e.g., velocity, position accuracy, acceleration, etc., can cause the elevator to stop if it runs outside acceptable performance limits. Dead man timers, which monitor the health of micro processors, will trip when the processor begins to fail.

A second type of circuit may be considered component protection monitoring circuits. In higher operating temperatures, current demanded from power supplies tends to increase for the same given load condition. Over current protection devices protect components from damaging high currents and would also be the source of elevator shut down.

Performance or component protection monitoring circuits would normally cause an emergency stop of the elevator. They could be designed reset automatically if conditions permitted or may require manual reset by a service technician. Fuses, which are over current protection devices, usually require manual reset.

ASME A17.1 CODE REQUIREMENTS

As we can see in Table 1, ASME A17.1 code requirements address only some of the causes of elevator control responses in categories 3 and 4[5]. They are explained as follows;

Rule 209.2b, Emergency Terminal Stopping Device (rule 209) requires an emergency stop if the system is not in proper control of the elevator in the terminals areas due to performance degradation or failure (category 3).

Rule 210.2d Motor Field Sensing Means, requires the elevator to make an emergency stop if the motor field sensor does not detect motor field current (category 3 if the motor field power supply tripped on over temperature, category 4 if the supply failed.) In static control (solid state), the rule permits the use of over speed monitoring (category 3) in lieu of motor field monitoring.

Rule 210.9 Control And Operating Circuits, requires the elevator to shut down if a failure (category 4) rendered any of the electrical protective devices in 210.2 to become ineffective or would allow the car to run with the car or hoistway door contacts open.

None of these A17 rules, prescribe manual or automatic restart of the system once the fault has cleared. This alternative is left up to the manufacturer.

V CONCLUSION

Analysis on the Effect on Fire Fighter Services

ASME A17.1 rules in section 211.3, Fire Fighters' Service, Automatic Elevators, do not address the possible response modes of an elevator system to elevating temperatures. Certainly, only a few of the possible causes of category 3 or category 4 response modes are addressed by the code. This would mean that even with the elevator in Firefighters' Service, the response of the elevator system to temperatures above T_{MSO} is, for the most part, left up to the discretion of the manufacturer. Today, firemen can not depend upon consistent elevator control response to rising machine room temperatures from one manufacturer to the next or even from one product to the next.

With machine room ambient temperature specified at 90 deg F, unexpected elevator shutdowns or service disruptions are possible as

TABLE 1

Hardware	Response Mode	Category	A17.1 Requirement
Over temperature devices	Emergency stop or orderly shutdown	3	None
Performance monitors	Emergency stop	3	Rule 209.2b Terminal overspeed
Component protection monitors	Emergency stop	3	Rule 210.2d Lost Motor field
Device failure	Emergency stop	4	Rule 210.9 Ineffective protection device

the temperature rises above this value. A fire below a machine room could easily cause machine room temperatures to exceed T_{MDO}, especially if the machine room cooling system shuts down or is inadequate to handle additional heat brought to the machine room from a fire below. Consider a fire test conducted outside a 10th floor building stairwell. The temperature at the 10th floor stairwell reached 150 deg F in 15 minutes and 240 deg F in 30 minutes. The temperature on the 14th floor stairwell reached 125 deg F and 150 deg F respectively[6].

One could expect similar results if a machine room were at the 14th level and the fire was outside the elevator shaft at the 10th level below. Due to the up draft in an elevator shaft, the machine room temperature could rise correspondingly. Using my previous example for calculating temperature thresholds (1), we can see that a T_{DMO} of 99 °F could easily be exceeded and a T_{MRO} can easily be approached in this case.

Recommendations

Today's complex elevator control can be better utilized to provide safer firefighters' service for the fireman. Several steps can be taken to make the elevator system more predictable and consistent in their response to rising machine room temperatures which may be created from a building fire. Steps can also be taken to provide fireman additional operating temperature margin in case the need arises.

ASME A17.1 rules in section 209, Terminal Stopping Devices, and 210.2, Electrical Protective Devices, could be modified to specify when and how the elevator system will try to automatically reset. This could handle most of the response modes between T_{MDO} and T_{MRO}, since in most cases the response is an emergency stop. Perhaps one possibility would be to give the fireman an easy means to reset the system if an automatic reset is not provided.

Other possible code modifications could be written into A17.1 rules in section 210.9, Control And Operating Circuits, to govern the elevators response to temperatures between T_{MSO} and T_{MDO}. Under firefighters' service, the code could allow the fireman to bypass manufactures performance or thermal protection devices which may have caused the elevator to stop during use. Perhaps the elevator system could also be switched by the fireman to a derated level of performance which would allow the system to attempt to operate in higher machine room temperatures.

Since thermal protection monitoring is not a code requirement, it is possible for some elevator systems to suffer catastrophic failure with no forewarning. For this reason it is also recommended that the code require thermal monitoring by the elevator system. The thermal monitoring system should as a minimum, prevent the system from going beyond T_{MRO} while operating. It would also be desirable that the elevator control system monitor for potential thermal failure and communicate this information to the fireman.

A17.1 rules in section 211.3, Fire Fighters Service, Automatic Elevators would also need to be modified to address such modifications.

Another area which may be addressed is the temperature rise ratings for machine rooms exposed to heat rising up the elevator shaft from a fire below. Such ratings could prolong the service of elevators during a fire.

Since operating temperature can be critical to firefighters' service, (in particular for high rise elevator systems where the elevator is essential), standards should be established which provide for minimum operating temperatures for the various response categories described in this paper. A study will need to be conducted to establish acceptable temperature thresholds and the impact on cost for the elevator system.

NOTES

1 O'Hagan, J. T., 1977, *High Rise/Fire and Life Safety*, Dun Donnelley Publishing Corporation, New York, N.Y., pg. 137.

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4 Coit, D. W. and Priore, M. G., July 1988, *Reliability Prediction Models For Discrete Semiconductor Devices*, Technical Report RDAC-TR-88-97, Rome Air Development Center, Griffiss Air Force Base, NY, pp. 4-8 to 4-24.

5 ASME/ANSI A17.1b—1989, *Safety Code For Elevators and Escalators*, pp. 75-84.1 .

6 O'Hagan, J. T., 1977, *High Rise/Fire and Life Safety*, Dun Donnelley Publishing Corporation, New York, N.Y., Chapter 2, test 4.

ADDITIONAL REFERENCES

1 Anderson, R. T., March 1976, *Reliability Design Handbook*, ITT Research Institute, Chicago, Il., Catalog No. RDH-376.

2 Craney, P. M., March 1983, "Electromechanical vs. Solid-State Relays", *Electronic Products.*

3 MIL-STD-217B, *Reliability Prediction of Electronic Equipment*, September 1974.

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