HIGH TEMPERATURE OPERATION OF ELEVATORS

by Nick Marchitto

ABSTRACT

The subject of the operation of elevator in an elevated high ambient machine room temperature is one of concern to elevator manufactures, code writers, enforcing authorities, building owners, and operators, elevator consultants, and fire and safety personnel. Today's solid state design elevator control systems are able to maintain rated performance over a wide rang of normal design operating temperature, but are vulnerable to elevated temperature conditions. In the worst extreme, the elevator system may be called upon to perform under emergency conditions such as Firefighters' Service Phase I Recall, and Phase II operation during which time, because of the very nature of the emergency (a fire), the ambient temperatures in the machine room may often rise above the normal design limits for the solid state controls. Should the elevator be required to continue to operate, and if so, what are the consequences? How can the controls be designed to operate in a high temperature environment? This paper discusses several aspects of this problem, and concludes with some suggestions and recommendations by the author.

SOLID STATE ELECTRONICS

The elevator industry has undergone design revolution over the past 10 to 15 years. The control systems have become almost totally of solid state design. This was inevitable as space age technology filtered down to the commercial industries. solid state technology provides improved performance, higher reliability, space saving miniaturization, flexibility in design changes, and in general, a more effective cost/benefit ration. A properly designed and operating sold state elevator controller may develop only rust cabinet door hinges for lack of use, as compared to the earlier relay control systems which required frequent maintenance such as contact cleaning and/or replacement of relay contacts or coils.

Today's elevator systems use solid state technology for both elevator motion and operation control. Solid state drives are generically variable voltage and/or current and/or frequency. Their prime purpose is to provide controllable electric power to the elevator motor while precisely regulating the speed in both the up and down directions under varying load condition. Both geared and gearless elevator systems may use a DC direct drive which has an SCR (silicon controlled rectifier) bridge. These SCR's are solid state silicon devices which act as both a rectifier (changing input AC power to DC power), and a valve which can control the amount of voltage applied to the DC elevator motor and hence its speed. Another popular geared and gearless system may use the traditional rotating AC to DC power converter; the MG sets. However, unlike older control systems which used relays to insert resistance in the generator field excitation and thus control the generator amplifiers to regulate the generator field excitation and thus control the generator output voltage and the elevator speed. For AC control systems, the older resistance control using relays to cut in and out steps of resistance in series with AC elevator motor windings, has been replaced with a thyristor drive. Here solid state witches control both the amount and direction of power flow to the AC motor to control the elevator speed and direction. The latest AC control system uses a variable frequency drive to vary both the voltage and the frequency of the power applied to the AC elevator motor which in turn controls the elevator speed. These drives use power diodes, SCR's, or even power transistors that provide unity power factor and reduce harmonics from the converter section which changes input AC voltage to DC voltage. Power transistors are used for the invertor section which changes this DC voltage to variable frequency and variable voltage AC. All of the above drives have one common feature: they use solid state devices not only for the actual power handling section, but for the control portion as well. This portion may involve microprocessors to set up and keep track of the intricate timing routines to properly switch the solid state power converting devices "on" and "off" under a variety of elevator operating conditions.

The other portion of an elevator control system is called the *operation and group supervisory controller*. Here the car and hall calls are received and processed to direct the elevators efficiently to answer a call for a waiting passenger. the biggest advancement in this area of design has been the use of microprocessors to replace the older, dedicated relay logic. Besides offering a tremendous reduction in space, the microprocessor provides the speed of operation, the memory storage capability, and the flexibility to be reprogrammed to allow for changes in the buildings' use of elevators. The dispatching routines are software based and reside in PROM's and EEPROM's depending on the system design. The cabinet now contains printed circuit boards filled with chips, and other discrete components such as transistors, diodes, gates, and resistor/capacitor networks. In addition, there are solid state power supplies and solid state input/output (I/O) devices to convey signals to and from the various parts of the elevator system. Again, all of the components and assemblies use solid state technology for the speed, reliability, flexibility, ease of manufacture, and data storage/data processing capability to permit today's elevator systems to operate in a more efficient manner.

ELEVATOR MACHINE ROOM TEMPERATURE LIMITS

The control equipment (drives, motion and operation control), is normally installed in cabinets in the elevator machine room which is typically located above the elevator hoistway at the top if the building either above or below the roof line. Some high rise buildings have machine rooms inside the building, well below the roof line, as in the case of low rise, medium rise, and high rise elevator banks with interior lobbies at both ground level and upper levels. Regardless of the location, all machine rooms have to deal with heat. This is released from the losses in the elevator rotating machinery such as hoist motors and MG sets, and from the controller cabinet transformers, converter, inverters, and power supplies. In addition, other sources of heat may be from non-related elevator equipment such as building distribution transformers and lighting fixtures which are located in or ventilate into the machine room. As a result of this heat, the machine room ambient temperature limit is of concern to designers of elevator equipment. Most elevator manufacturers specify a maximum machine room ambient temperature which must be maintained by the building's ventilating and air handling systems. This is typically in the 85 to 95°F (30 to 35°C) range. This temperature limit is picked by the elevator manufacturer to assure that the actual ambient in the controller cabinets, which is typically 10 to 15°C higher than the ambient room temperature, is not above the design operating limits of the solid state devices used in the control systems. The operating limits are established by the manufacturers of the electronic components to provide stable operation and long life. Elevator manufacturer's temperature requirements usually appear on the machine room layouts and although generally the same, do vary slightly from manufacturer to manufacturer. This is because some elevator suppliers have more test data available to better identify their equipment thermal capabilities, while others use a more conservative approach in recognizing that the actual heat release is a function of elevator duty cycle, which is not easily predictable or assured. Some temperature safety margin is almost always required.

The NEII Vertical Transportation Standard[1] calls for machine room and/or machinery space temperature to be between 55 and 80°F. The A17.1 Safety Code for Elevators and Escalators states in Rule 101.5b, Ventilation for Machinery and Control Equipment,[2] that adequate natural or mechanical ventilation shall be provided "to avoid overheating of the electrical equipment and to ensure safe and normal operation of the elevator." This permits quite a range of possible machine room temperature limits depending on the design of the elevator equipment. The National Electrical Manufacturers Association (NEMA) has established a maximum temperature ambient for elevator rotating equipment (Class DL and DH direct current motors and mg sets) in terms of power rating vs temperature rise.[3] The standard ambient limit is 40°C or 104°F. However, above this temperature a power rating is still available, but at a lower or de-rated value. The National Electrical Code, an NFPA standard, has published 30°C (86°F) as the standard ambient for conductor ampacity ratings, but also includes de-rating factors for ambients up to 80°C or 176°F.[4] Most computer manufacturers recommend an ambient temperature of 60 to 90°F for reliable operation of computer equipment. The various building codes, such as the Standard Building Code, National Building Code, and Uniform Building Code, do not specify a temperature requirement for rooms, but do require that adequate ventilation be provided in buildings. Recommended air volume exchange rates and minimum size of ventilation openings are listed for various types of room usage. The Uniform Building Code does state in Section 3206 2(d) on releasing devices for smoke and heat vents, that 165°F (74°C) is the maximum temperature at which an automatic vent should open.[5] A room under this condition would be unbearable to any occupants and certainly hostile to elevator electrical equipment as presently designed.

TEMPERATURE EFFECT ON SOLID STATE CONTROLS

The effects on solid state components due to temperature may be classified in two areas: operating (reliability) effects, and failure (life) effects. Solid state components have a manufacturers recommended maximum operating temperature limit up to which the parameters and characteristics are guaranteed. This means that the circuit using these devices will operate as designed in a predictable and repeatable fashion. Component ambient limits are determined by the maximum silicon device junction temperature, T_j, typically 125 to 200°C depending on the class of the device: commercial, industrial, or mil spec grade. The junction, where the P and N type materials meet, is the heart of the solid state device, and conducts the current as in the SCR, diode, transistor, or LSI (large scale integrated) chip. This junction is located within a silicon crystal which in turn is enclosed in an out case. This case may or may not be connected to a heat sink for increased heat dissipation.

Modern solid state control designs use high density packaging and high speed of operation. This tend to drive the power density in the devices themselves to higher levels which results in more heat dissipation and a greater need for ambient temperature control to provide the required cooling for the device. Air cooling is still the most popular method for cooling electronic equipment because it is simple and cost effective. The speed of electrical operation (or the electric delay) is inversely proportional to the amount of heat remove from the device. The turn-on/turn-off times are guaranteed for up to the stated junction operating temperature. Operation at above this level will cause a change in component parameters such as turn-on/turn-off voltage levels, switching times, and current carrying capabilities. In analogue control systems, temperature affects the offset voltage levels of operational amplifiers, producing an operating voltage drift which in turn causes the elevator systems to go out of adjustment. At very high ambient temperatures, this drift may have significant effect on the operation of the control system since the original design parameters no longer apply. Prolonged operation at above recommended ambient temperatures will also shorten the expected life of the device and can "set up" the control system for a shutdown. Beside the catastrophic failure mode such as device burnout, irrecoverable damage may occur even if the ambient temperature level returns to normal. The control system may no longer operate as designed due to the unpredictable failure mode of the devices at high ambient temperatures, and could result in erratic operation. this is the primary reason for a conservative approach to component application in circuit design.

CAUSES OF MACHINE ROOM OVER-TEMPERATURE

The main causes of over-temperature in elevator controller cabinets are:

(1) A failure of the machine room ventilation system;

(2) A failure of the cabinet ventilating system such as cooling fan failures or vent restrictions;

(3) An increase in the elevator duty cycle beyond the design criteria;

(4) Sustained operation at low AC input voltage levels;

(5) A fire condition in the building.

The building usually provides the ventilation system in the machine room; the elevator system is only one of the many users of the air provided. No one shuts down the elevator if the building is experiencing a failure of the ventilating system or if the ventilating system is undergoing maintenance. The elevators are expected to continue operating!

A failure of the controller cabinet ventilating system may be monitored by the elevator system through the use of thermal sensors on heat sinks and transformer windings, and/or the use of air flow switches. An increase in the elevator duty cycle or sustained operation at low AC input line voltage, which results in higher current levels in the controller, could also cause thermal sensors to activate.

ELEVATOR MACHINE ROOM TEMPERATURE CONTROL

The present method of controlling elevator machine room ambient temperature depends on two factors:

(1) The amount of heat released from the elevator equipment in the machine room;

(2) The amount of ventilation and/or air conditioning provided in the machine room.

The heat released from the elevator equipment is a function of the efficiencies of the various components including the drive, controller, elevator motor and MG set (if used), elevator machine gearing and bearings, and to some extent, the hoistway losses from rail guide friction if the hoistway heat vents into the machine room. This heat release is also a function of the elevator duty cycle, increasing as the elevator start per hour and traffic loading increase. Elevator manufacturers calculate the expected heat release for their elevator systems as BTU's per hour and provide this information to the customer's building designers. This information, along with the elevator manufacturer's recommended maximum machine room ambient temperature, is used for sizing the ventilation system. If the actual elevator heat release agrees with the predicted, and if the ventilation system is properly sized, the required machine room ambient temperature can be maintained. Conservative approaches by both elevator and ventilation system designers will usually accomplish this. However, there are some unpredictable conditions, such as fire, which can cause the machine room ambient temperature to rise beyond the expected levels.

A fire condition presents some very unusual operating conditions. The temperature level in the machine room cannot be accurately predicted during a fire condition in the building. The building ventilation system may be turned off when a fire is detected which may cause the machine room temperature to rise. The hot gasses from the fire may find their way into the machine room raising the ambient temperatures even further. The elevators may be called upon to operate in a Phase I Firefighters' Service mode[6] in which all hall and car calls are canceled, and the elevator makes a non-stop trip to the designated level where it discharges the passengers and is taken out of service. Elevator controls may be designed such that if, during the Phase I operation, any of the temperature sensors in the elevator control equipment react, the car will attempt to finish its trip to the designated or alternate level where it is taken out of service. Restart is possible only by the elevator service personnel who will examine the system and determine that the operation is back to normal before releasing the car for passenger use. The real question is what course of action should the elevator follow when it has been placed on Phase II Firefighters' Service operation[7] (under the control of trained emergency personnel) and the machine room ambient exceeds the recommended maximum for safe and reliable operation.

OPERATION IN ELEVATED AMBIENT TEMPERATURES

At present, the course of action for the elevator system designer is limited. To comply with the Phase II A17.1 Code requirement, the car is left in service for Phase II operation, but is still subject to the thermal temperature sensors in the drive control system. This means that when the elevator system decides that an operating ambient temperature limit *below* the critical ambient temperature limit has been reached (the critical temperature being that at which the elevator manufacturer has determined to be the electronics failure point), the elevator may revert back to Phase I operation and proceed to the designated or alternate level to discharge the emergency personnel using the car. The elevator would then remain out of service until the elevator service personnel restore the car to operating condition. This means emergency personnel could be without elevator service for the duration of the fire. However, if the ambient temperature in the machine room continued to rise to the critical limit or beyond during the Phase I or Phase II operations, the control system may fail and stop the elevator before the designated or alternate floor is reached, thereby trapping passengers or the emergency personnel. This may create a life threatening hazard if the car stops and shuts down at or near the floor where the fire may be located. It is just as probable that the control system may malfunction and not continue with Phase I or Phase II operation, but go into some unpredictable mode such as inhibiting door operation or failure to respond to car calls. To try and prevent this, the firefighters' service operation must be permitted by the control system only at an ambient temperature *well below* the critical temperature to provide sufficient operating margin.

CONFLICTING REQUIREMENTS

The A17.1 Code is a safety code whose purpose as defined in Section 2, is to "provide for the safety of life and limb and to promote the public welfare."[8] As such, this includes the riding public, the elevator service and maintenance personnel, and the emergency service personnel. However, the requirement to provide Phase II operation during a fire condition which may involve high machine room ambient temperatures, places the building designer and the elevator designer in the position of providing either sufficient ambient temperature stabilizing ventilation in the machine room under these adverse conditions without contributing to the fire spread, or providing a control system which can operate under abnormally high temperature ambients. Remember also that A17.1 Code Rule 105.1b requires machine room ventilation to provide "safe and normal operation" under controlled ambient conditions. Perhaps, Phase II should not be considered a normal operation, just as a fire condition is not normal. What should the elevator industry do to resolve this apparent dilemma?

SUGGESTED OPTIONS AND/OR RECOMMENDATIONS

(1) Over-Temperature Fault Management Strategy

The control system could be designed to use an impending over-temperature fault mode. For example, when the temperature in the controller cabinet exceeds a limit, T_1, which is sufficiently below the maximum allowable temperature, T_0, (the temperature design limit beyond which the equipment cannot be expected to operate properly), the following over-temperature strategy could be implemented:

(a) Car on normal or Phase I operation at the designated or alternate level with the doors open: The doors should not be permitted to close and the car should not be permitted to run.

(b) Car on normal operation and standing at a floor with the doors open, or closing or closed: If the doors are open, they should remain open and not be permitted to close. The car should not be permitted to run. If the doors ore open, they should remain open and not be permitted to close. The car should not be permitted to run. If the doors are closing or are closed, they should be re-opened and not permitted to close. The car should not be permitted to run.

(c) Car on normal operation and traveling away or toward the designated or alternate landing: When the car stops, the doors should open and not be permitted to run.

(d) Car on normal operation and Phase I operation initiated: The car should proceed and complete Phase I operation in the manner prescribed by the code. Upon arrival at the designated or alternate level, the doors should remain open and no further operation (Phase II) of this car should be permitted.

(e) Car on inspection operation: A warning buzzer should sound to alert the operator to exit the car.

(f) Car on Phase II operation and traveling away from or towards the designated or alternate level: The car should revert to Phase I operation and should perform in the manner described in paragraph (d) above.

(g) Car on Phase II operation at a floor other than the designated or alternate level:

(1) If the doors are open, they should not be allowed to close and the car should not be permitted to run.

(2) If the doors are closing, they should continue to close, and the car should return non-stop to the designated or alternate level, and the doors should be opened and not be permitted to re-close. The car should not be permitted to run.

(3) If the doors are opening, but are not fully opened, release of the constant pressure door open button should cause the doors to close, and the car should return non-stop to the designated or alternate level. The doors should be opened and not permitted to re-close. The car should not be permitted to run.

When the temperature reaches T_0, the elevator should stop immediately. The T_0 sensor should cause power to be removed (independent of the microprocessor control equipment) from the driving machine motor and brake. All further operation of the elevator should be inhibited, regardless of the subsequent temperature. The restoration of normal operation should require that the system be manually reset.

For the purposes of this paper, normal operation includes designated attendant operation.

(2) FireFighters' Choice

A mode selection could be offered as part of Firefighters' Service. The keyed switch cold enable the operation with or without a temperature sensing feature. In this way, the emergency service personnel could decide if their use of the elevator is so essential that they will assume the risk and use the elevator under any machine room ambient temperature conditions.

An over-temperature alarm either in the hall at the keyed selector switch, or in the car operating panel, could be provided to indicate the status of the control during Phase II operation. It can be set to trip just below the recommended maximum temperature. This would allow the operator of the elevator to abort the trip or override the sensors and continue on, if willing to take the associated risks.

(3) Certification

Control systems could be certified under some new standard as to their operation in elevated ambient temperatures, and made to comply to a uniform set of requirements under these conditions. The certification tests should simulate the expected high ambient temperature conditions un a non-destructive way so that the operation can be evaluated before and after elevated temperature occurs. It should be demonstrated that the design is such that units returned to service at normal ambient temperature are fully functional.

(4) High Temperature Solid State Materials

Another alternative method could be to design elevators to operate in an elevated machine room ambient temperature. One approach is to consider semiconductor materials other than silicon, such as gallium arsenide (GaAs) or gallium phosphate (GaP). These materials can withstand higher junction temperatures (T_J) and therefore operate in higher ambients; but there are drawbacks. Some of these are:

(a) Difficulty in manufacturing devices with these materials and obtaining the same degree of repeatability of electrical characteristics as with silicon.

(b) Lower breakdown voltage than silicon, therefore requiring different circuit designs.

(c) The thermal stability of these materials is less than that of silicon, therefore making packaging and encapsulation more difficult, and reducing the overall reliability.

(d) Increased cost associated with items (a)—(c) above.

Even though some non-silicon, high temperature devices can function up to 550°C, there are a number of other problems at high temperatures; including wire insulation. The method of connections and terminations, the trace material on printed circuit boards, and the effects on plastics used in other control devices such as relays and transducers. The effects on solder at elevated temperatures (up to the melting point) are increasing the elongation and decreasing yield and tensile strengths. The effect on epoxy glass material used for PC boards is that, above 115°C (239°F), the glass epoxy becomes rubbery and the resulting coefficient of expansion being 20 times that of copper, can lead to PC board connection failures.[9] These effects make using the non-silicon device approach an unlikely choice, at least for now.

(5) Other Alternatives

(a) A temperature activated, emergency cooling unit which could maintain safe operating temperatures inside the control cabinet could also be tried.

(b) The elevator could also be switched to operate at reduced velocity profiles to try to unload the power demand and limit the temperature rise on the solid state power devices if the ambient temperature rises.

(c) A standby controller cabinet could also be provided, in a special protected environment where the ambient temperature could be maintained at a constant level even in a building fire condition. This unit could be automatically switched from elevator to elevator by an "operating decision system" as needed to complete Phase I operation, and to the selected elevator for Phase II. Machine room temperature sensors and each elevator's controller cabinet temperature sensors could be connected to the "operating decision system," also located in this temperature stable area. This system could decide what action to take depending on programmed logic and thermal sensor inputs. This would reduce the possibility of a faulty operation by an elevator controller located in the high ambient temperature machine room environment and experiencing component overheating.

CONCLUSIONS

In conclusion, it is essential that the elevator industry, in conjunction with emergency services, prepare a procedure for operating an elevator during a fire condition when the machine room ambient temperature exceeds normal design limits. My preference is that the elevator code adopt requirements along the lines of the over-temperature fault management strategy in (1) above. The code should provide the required operational actions the elevator system should take at elevated machine room temperatures. Heating, ventilating, and air conditioning (HVAC) systems should be designed to further limit machine room ambient temperature increases under unusual operating conditions such as during a fire. Finally, new technologies in designing for high temperature operation of electronics should continue to be evaluated. In this way, elevators can be made even more useful while maintaining the safety expected of them, even under adverse ambient temperature conditions.

REFERENCES .

1 *NEII Vertical Transportation Standards,* 1983, General NOtes, p. 6.

2 *ASME A17.1-1990 Safety Code for Elevators and Escalators,* Rule 101.5.

3 *NEMA MG-1-1987,* Rev Jan 1989, Part 18.459.2, and 12.43.

4 *ANSI/NFPA 70-1990 National Electrical Code,* Article 310, Tables 310-16 to 310.19.

5 *Uniform Building Code,* 1985 Edition, Smoke and Heat Venting, Section 3206(d), Releasing Devices.

6 *ASME A17.1-1990 Safety Code for Elevators and Escalators,* Rule 211.3.

7 *ASME A17.1-1990 Safety Code for Elevators and Escalators,* Rule 211.3c..

8 *ASME A17.1-1990 Safety Code for Elevators and Escalators,* Rule Section 2.

9 Baker, Earl, "Some Effects of Temperature on Material Properties and Device Reliability," *IEEE Transactions on Parts, Hybrids, and Packaging,* December 1972.

Nick Marchitto received a B.E. from Stevens Institute of Technology in 1964 and an MSEE from Newark College of Engineering in 1970. He joined Otis Elevator Company in 1964 and has worked in the elevator industry for 26 years, 16 of them with Otis. Mr Marchitto has held positions of a design engineer for elevator motors, and generators, test engineer, and control systems engineer. He is presently Senior Design Engineer in the Drives Department at Otis Elevator Company. Mr Marchitto is a member of IEEE and the ASME A17 Electrical and National Interest Review Committees. He is an alternate member of the NFPA National Electrical Code Panel 12 as a representative of the National Elevator Industries, Inc. (NEII). Mr Marchitto is a registered professional engineer with the state of New Jersey.