ENGINEERING PRACTICE STUDY

TITLE: USING CIRCUIT BREAKERS AS SWITCHES

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FINAL REPORT

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I. OBJECTIVE

Determine the DoD position on using circuit breakers as switches by soliciting input from our DoD and industry users for their knowledge and experience in the use of these components.

II. BACKGROUND

MIL-HDBK-454, Guideline 37, Para 4.2 prescribes the following guidance on the use of circuit breakers as switches: "Circuit breakers should not be used as ON-OFF switches unless such breakers have been specifically designed and tested for that type of service."

Boeing investigated the use of circuit breakers in this manner independently and found justification for an industry wide study. Boeing's position is: "…the use of circuit breakers as switches is acceptable, and meets the intent of MIL-HDBK-454, so long as the application worst case ON-OFF cycles is significantly lower than the number of endurance cycles the circuit breakers proved in qualification…" This position is based on a lifecycle analysis performed by Boeing on MS24571 type circuit breakers.

Boeing AWACS initially requested the Government Electronics and Information Technology Association (GEIA) G-11 Committee study the origin of the prohibition against using circuit breakers as switches unless they are specifically designed and tested for that purpose, and if technological improvements to circuit breakers have rendered this prohibition obsolete. G-11 assigned a TASK number for this effort. As a result of this tasking, Boeing AWACS requested DSCC conduct this Engineering Practices Study (EP) on the use of circuit breakers as switches (See attachment A, Boeing Study Request).

An EP study was initiated by DSCC-VAT on 24 June 2005. Initially, a review of the internet was done in an attempt to find information on using circuit breakers as switches.

Concurrent with a review of the internet, we initiated a government and industry fact finding effort by distributing an electronic (email) request for definitive information on using circuit breakers as switches. We asked if, with modern manufacturing practices taken into account, circuit breakers should be used in this manner without having been designed and tested for this purpose. Further, we asked what the determining factor is in rating a circuit breaker for this type application and if there is some standard testing which would unequivocally tell us that using a circuit breaker as a switch is acceptable. Using the DSCC military and industrial electronic distribution lists, a request for information was emailed to 204 recipients; 168 industry points of contact (POC) and 36 military activities. DSCC-VAT received 15 replies; 10 from industry and 5 from military activities (See attachment B Information Request, attachment C Industry Responses and attachment D Military Responses).

III. RESULTS

A review of the internet revealed no studies or data from private industry showing the use of circuit breakers as switches in any application they were not specifically designed and tested for. The research did however find two aviation specific reports, one conducted by the Transportation Safety Board of Canada, and the other published by The Federal Aviation Administration, both of which mention the use of circuit breakers as switches in aircraft. These studies are referenced later in this report.

Of the ten industry responders, only one believes that circuit breakers can be used as switches if one employs a good margin in terms of de-rating for the maximum number of expected operations. This manufacturer noted typical concerns with circuit breakers are the vibration environment of the application,

the mechanical operating life, and the electrical operating life for operation under nominal current flow conditions as well as at maximum current flow. The manufacturer also stated that the number of mechanical operations (typically 10,000's) specified is many more than the number of operations specified for the electrical operating life (typically 1000's), and these numbers must not be exceeded in the application. The manufacturer recommended a good margin of possibly 10% in terms of de-rating for the maximum number of expected operations. This manufacturer's position is that if the circuit breakers are able to meet the application environment and there is a margin in the number of operations in service then they believe circuit breakers can be used as switches. The manufacturer did not indicate any specific operating environment or offer any analytical data.

A second manufacturer stated he has seen no technological breakthrough for circuit breakers and would oppose a blanket, across the board lifting of the MIL-HDBK-454 restriction. He feels the restriction could be lifted for single pole breakers in fixed ground or shipboard applications but should remain for multi-pole breakers or any breaker used in mission critical or ground mobile or airborne applications, due to shock, vibration and temperature considerations.

A third manufacturer noted three FAA Advisory Circulars, **AC 23-17B**, April 12, 2005, page 275, **120-80**, 1/8/04, pages 11-12 and **43.13-1B** 9/8/98, pages11-15 to 11-16, and one Airworthiness Directive **AD 2001-16-20**, 9/21/01, pages 2-3, all stating that circuit breakers should not be used as a switch.

The remaining seven manufacturers indicated they would not recommend that a circuit breaker be allowed to act as an ON-OFF switch unless it was designed and tested for that purpose. The main concern of all the manufacturers was twofold. One, the mechanical life expectancy of the override mechanism (10000's cycles for breakers versus 100,000's cycles for switches) and two, the contact materials not being designed to make and break certain types of loads with any reasonable life expectancy (early contact oxidation and pitting).

Five responses were received from military activities, all indicating concurrence with the MIL-HDBK-454 guideline that circuit breakers should not be used as switches.

1. The Navy (NAVSEA) stated they have used circuit breakers as switches in various applications. They cited one particular instance where they used an AQB-A250 as an ON-OFF switch for aircraft servicing power on aircraft carriers. This circuit breaker exhibits a very high rate of failure and, according to the Navy, is most likely due to the circuit breaker being designed for a low number of cycles as apposed to a switch which is designed with high cycle use in mind. This circuit breaker is currently being replaced with a contactor. They are in agreement with the present wording in MIL-HDBK-454.

2. The Army (TARDEC) respondent offered no specific cases where they have used circuit breakers as switches but simply stated that circuit breakers and switches have different functions and therefore they do not recommend the use of circuit breakers as switches unless there is a special requirement.

3. The Air Force's Engineering Data Management Branch (WR-ALC/LGEC) responded by stating it would not be a good idea to mix circuit breakers and switches in terms of application due to the possible initial confusion factor among users. Also, they expressed concern in using circuit breakers as switches since the frequency of operation for breakers is limited compared to that for switches.

4. The Air Force Engineering Standards office at Wright-Patterson AFB had several comments concerning the use of circuit breakers as switches. They cited several pertinent industry documents which state that using circuit breakers as switches is not recommended. These documents and their relevant paragraphs are listed here:

SAE-ARP1199 - DEVICES, ELECTRIC OVERCURRENT PROTECTIVE, SELECTION, APPLICATION, AND INSPECTION OF

"5.7.8 Circuit Breaker Endurance: A typical circuit breaker specification sheet requires a 5000 cycle mechanical life and a 2500 cycle inductive load life. Comparing this to the life expectancy of most switches, it is found that the circuit breaker has a life of 1/10 or less of the life of a switch. In addition, it must be recognized that circuit breakers, both push button and toggle "switch type", usually are not snap-acting devices and should not be considered as substitutes for switches. The push button or toggle may be partially actuated, causing the contacts to "make" without latching the mechanism. This means that the contacts can be "teased" open or closed where the contacts under load are in close physical proximity but not touching, drawing arcs, pitting the contacts and generating EMI."

SAE-AS58091 - CIRCUIT BREAKERS, TRIP-FREE, AIRCRAFT, GENERAL SPECIFICATION FOR

"6.1 Intended use: the trip free circuit breakers defined herein are intended for use in AC and DC circuits. MIL-C-5809 circuit breakers are not generally designed to be used as switches and should not be used as such per MIL-STD-454."

FAA Advisory Circular AC 43.13-1B - ACCEPTABLE METHODS, TECHNIQUES, AND PRACTICES/AIRCRAFT INSPECTION AND REPAIR, Chapter 11, Section 4, Paragraph 11-51:

"Circuit breakers are designed as circuit protection for the wire (see paragraph 11-48 and 11-49), not for protection of black boxes or components. Use of a circuit breaker as a switch is not recommended. Use of a circuit breaker as a switch will decrease the life of the circuit breaker."

This Air Force office also performed research and investigation and found two reports involving circuit breakers in airborne applications. These reports are listed below.

The Transportation Safety Board of Canada (Transportation Safety Board of Canada Report Number A98H003, Aviation Investigation Report, In-Flight Fire Leading to Collision with Water, Swissair Transport Limited, McDonnell Douglas MD-11 HB-IWF, Peggy's Cove, Nova Scotia 5 nm SW, Dated 2 September 1998). The board investigated the crash of Swissair Flight 111. Although circuit beakers were not the primary cause of the crash, the board incorporated in their report a section on circuit breakers which states: "The use of CBs as switches, either by design, or as a consequence of the system's in-service performance, is not recommended." Further, the report makes the following statement: "as there are no regulatory restrictions preventing the use of CBs as switches, it appears that this guidance is provided as a means to enhance system reliability as opposed to establishing the minimum requirements for system safety."

FAA research project report (Federal Aviation Administration Report DOT/FAA/AR-01/118, Aircraft Age-Related Degradation Study on Single- and Three-Phase Circuit Breakers, Authored by Ronnie G. Peterson and Joseph Kurek, Raytheon Technical Service Company, under contract DTFA03-01C-00018, Dated November 2002) which details a study on "aged" circuit breakers removed from two aircraft, a McDonnel-Douglas DC-10 first flown in 1975 and a Boeing 727-232 first flown in 1974. Four hundred circuit breakers were chosen as the sample size with 100 of them as spare. One breaker from the Boeing 727 was found faulted out of the panel and was open on removal. This breaker continued to pop open during routine preparations for their testing. When returned to the manufacturer, they found the latching mechanism excessively worn, possibly caused by excessive cycling of the breaker. This report states the following conclusion: "based on the results and assumption for the HD213 circuit breaker failure, it can be concluded that HD213 was a premature mechanical failure possibly caused by mechanical damage. If the assumption is invalid, an alternate possible conclusion is that the breaker is being used as a switch."

The author's recommendation was: "If the breaker is being routinely cycled on and off, schedule a breaker replacement based on the design requirements of the breaker."

The Air Force Engineering Standards office at Wright-Patterson AFB has been involved in many failure investigations on circuit breakers and switches and maintains documentation on numerous failure modes for a wide range of MIL-C-5809/AS-58091 breakers. Based on their research for this report and their many years of involvement in circuit breaker and switch failure investigations, they offered the following objections to using circuit breakers as switches:

a. In-service circuit breakers can be, and most probably are, mechanically cycled under load any number of times during its service life, even with the advisement against such practice. The current guidance in the Transportation Safety Board of Canada's SR111 report is offered as a way to enhance system reliability rather than system safety. However, it still performs a safety function by attempting to limit abuse of circuit breakers and this idea should not be discounted.

b. Changing the advisement against using circuit breakers as switches will impact not only current and future production breakers, but also those that have been in the field many years, sometimes decades. The effects of aging on older devices is not known since there has not been enough research done on the subject. Anecdotal notes from deficiency reports indicate that time and environment do affect tripping set points for breakers. This can yield nuisance tripping or failure to close.

c. Changing document wording to allow circuit breakers to be used as switches, in any capacity, will allow that usage for all circuit breakers. There is no tracking method to know how many times a breaker is mechanically actuated under load, so there would be no tracking to determine if they have been actuated "… significantly lower than the number of endurance cycles the circuit breaker provided in qualification.".

d. Since circuit breakers are not routinely changed, there is no recorded evidence of how well in-service breakers correlate back to the specifications.

e. Circuit breakers used as switches would most certainly have to become time change items and Weapons Systems Program Offices would frown on making a consumable item a time change item. Implementing this across all platforms would be compounded by not knowing when any given breaker in any given platform was last changed, if ever. This would constitute changing all breakers in all platforms in order to establish a baseline to start from.

f. Circuit Breakers primarily protect aircraft wiring, while switches control circuits. Therefore, the construction of the two devices is different and SAE-ARP1199 recognizes these differences.

The Air Force Engineering Standards office at Wright-Patterson AFB believes that there is not enough information at this time to conclude that using circuit breakers as switches is advisable. Further, they stated that circuit breaker analysis needs to include more than one test parameter since in-service devices experience more than that during service and testing should emulate actual usage as closely as possible. This way, the testing organization would gain knowledge of how environment and time affect the breakers. Finally, they conclude that no documentation should be changed without fully understanding the risks involved. They believe that the requested change to MIL-HDBK-454 is fraught with unintended consequences and will impact military, civil and foreign platforms.

5. The final set of comments came from the Avionics/Electronics Engineering Division of the Warner Robins Air Logistics Center's (WR-ALC) Engineering Directorate, who combined their input with responses from the three Wings at Robins Air Force Base.

The consolidated responses from Robins indicated an apprehension to allow the use of circuit breakers as switches in any aerospace electronic application. Also, in their opinion, there is no one determining factor or standard tests that can be applied to qualify circuit breakers as switches due to the many different types of breakers and switches. They noted there are over thirty switch specifications listed in MIL-HDBK-454. A circuit breaker would have to meet all specifications of switches in the same application. Based upon the application different switches have different requirements, and a circuit breaker would "have a hard time accommodating the many variations without many variants of the circuit breakers and significant circuit breaker standards changes." Further, they mentioned the inherent reliability shortcoming of circuit breakers, which was a concern shared by all survey respondents. The mechanical cycle magnitude of circuit breakers is significantly less than that of switches. Robins AFB had this to say on the subject:

"One reason for this disparity is the lack of need to use a breaker repeatedly. Another reason is that a breaker is made as a "latch" that is tripped by a solenoid or bimetallic strip. The latching operation requires more mechanical interference which results in greater stress and quicker component wear out. This wear out can lead to complete failure or lower current draws being required to trip the breaker which can negatively impact mission performance."

They listed several other factors that would be of concern if a circuit breaker was used in place of a switch. These factors include failure mode, contact bounce, current in-flux, arc reduction and actuation resistance. They stated:

"The ramifications of adding switching requirements to circuit breakers may impair the performance of these items to provide circuit protection. The addition of too many requirements will likely reduce performance and increase cost."

Robins AFB did note that in some cases it is okay to use a circuit breaker as a switch. Here they stated:

"In some instances circuit breakers are already used in a secondary mode as switches. Using breakers as switches is usually done for safety during maintenance but can also be done to extend the life of equipment or as an easy means of turning it off when its use is not needed. But these applications are covered by the design and test criteria of their associated standards (i.e. 2,000 cycles for A-A-55571/1A circuit breakers) and should not be used as justification to approve a circuit breaker in a switching application.

In summary, the engineering community at Robins AFB recommended that the wording restricting circuit breakers from being used as switches unless specifically designed and tested for that type service not be removed from MIL-HDBK-454.

IV. CONCLUSIONS

Lack of available information through research of the topic and with the responses received, although limited, from industry and government activities tells us there are not enough facts to indicate that using circuit breakers as switches, particularly in airborne applications, is prudent. Further, there appears to be no single test or group of tests that can clearly prove that using circuit breakers as switches is acceptable.

V. RECOMMENDATIONS

a. DSCC-VAT recommends keeping MIL-HDBK-454 Paragraph 4.2 as is. The wording restricting circuit breakers from being used as ON-OFF switches unless such breakers have been specifically designed and tested for that type of service should remain. No documents should be changed until the uncertainties of such a change are fully understood.

b. If a program wants to use circuit breakers as switches, they should describe that application in the program documents and not expect a change in higher level guide documents.