LA-UR- 97-542

CONF-971033--1

~~Abstract~~

RECEIVED
APR 10 1997
OSTI

Design and Testing of High Power, Repetitively Pulsed Solid-State Closing Switches

Heinrich J. Boenig, John W. Schwartzenberg, Lawrence J. Willinger,
Dante E. Piccone, Duane A. Lopez, Howard A. Smolleck

Repetitively pulsed closing switches are often required in high-power physics experiments. Traditionally, ignitrons have been used for these applications. There are reasons why ignitrons have undesirable features, such as the high trigger current which causes electromagnetic interference, the arc instability and environmental concern with the mercury used in the switches. With the development of ever increasing power rating of solid-state switches, in particular thyristors, the designer has the tools to replace ignitrons with solid-state devices. Using as an example a recently designed and tested 10 kV, 80 kA high-power switch, the design philosophy for repetitively pulsed switches is developed. The parameters which impose the greatest challenge on the device, such as di/dt, temperature rise and reverse blocking voltage are investigated with respect to their capability when operating in the pulsed mode. Starting with the available device data sheet information and published results of the dependency of the number of life cycles as a function of the device temperature, it is shown how the overload capability of a device for short term pulsed applications can be exploited. The detailed design of a 2 Hz, 10^8 cycle, 12.5 kV, 80 kA, 3 ms switch, with a short circuit capability of 250 kA, is presented. The paper concludes with a short summary about device limits in voltage, current amplitude and pulse length ratings for repetitively pulsed switches using available thyristors.

Heinrich J. Boenig, Los Alamos National Laboratory, MS E536, Los Alamos, NM 87545, phone 505-667-4404, fax 505-665-4311, e-mail boenig@lanl.gov, corresponding author

John W. Schwartzenberg, Lawrence J. Willinger, Dante E. Piccone, Silicon Power COrporation, 175 Great Valley Parkway, Malvern, PA 19355

Duane A. Lopez, Howard A. Smolleck, New Mexico State University, Department of Electrical and Computer Engineering, Box 3-0, Las Cruces, NM 88003

MASTER

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

Digest

Design and Testing of High Power, Repetitively Pulsed Solid-State Closing Switches

I. Introduction

Physics experiments often require high-power, repetitively pulsed closing switches. Traditionally, ignitrons have been used in these applications. The availability of high power thyristors now provides the designer with the tool to install a switch based on solid-state technology. The solid-state switches show promise for low frequency, repetitively pulsed closing switches in medium voltage systems to a few tens of kV and for currents to a few hundred kA. Close cooperation between the user and the solid-state device manufacturer is mandatory when designing the switches to use the solid-state devices to their full capability without over stressing them.

II. Repetitively Pulsed Switch - A Case Study

The Pulsed Field Facility at the Los Alamos National Laboratory in Los Alamos, NM, is developing a 100 T nondestructive pulsed magnet, to be available for users by the end of 1998. As part of the effort a repetitively pulsed closing switch must be designed for a capacitor bank, which energizes the most inner coils of the 100 T magnet. If an ignitron would be used as a closing switch, electromagnetic interference is generated by the high trigger current of the device. The electromagnetic interference is undesirable, because it occurs at the beginning of the rise in the magnetic field, when reference measurements are being made. To avoid this problem it was decided to build the switch using solid-state devices instead. The switch will be installed in a ringing circuit as shown in Fig. 1. The switch was specified to withstand a voltage of 10 kV.

To reserve some flexibility for future modifications in the experiment, the current rating was specified as given in Fig. 2, assuming a 20 minutes repetition rate. The currents in Fig. 2 are assumed to be equivalent rectangular current pulses with the amplitude I_{peak} and the time length T. An additional current carrying requirement for the switch is the condition of a shorted magnet L_m, when only the protection inductor L_p limits the switch current. Under this condition and with the free-wheeling path disconnected, the current has a nearly half sinusoidal shape with a base time of 5 ms. The detailed design of the switch, using three sets of two parallel connected 77 mm, 4500 V thyristors in series, for a total of six devices, is presented. The temperature rise for different pulsed current shapes has been calculated. Experimental results, as shown in Fig. 3 for two different current shapes, including a 73 kA, 7 ms current pulse, are given.

III. Design Philosophy of Repetitively Pulsed Switches

In the paper a procedure will be derived for designing repetitively pulsed switches. The number of expected life cycles is a very important parameter in the design of repetitively pulsed switches. As has been pointed out in the literature, there is a very close connection between the number of cycles and the allowable maximum junction temperature in the device during a surge[1]. This mostly empirically derived relationship between temperature and life cycles is used to determine the maximum temperature rise during a current pulse. Once the allowable temperature has been determined, the number of parallel devices is selected. The blocking voltage capability determines the number of series connected devices. In contrast to utility applications where a voltage safety factor of 2 to 2.5 is recommended, the voltage safety factor can be reduced to values between 1.3 and 1.5, because the overvoltages are better defined. Because of the shortness of the current pulse, the di/dt limit must be taken into account. While traditionally the device manufacturer gives a di/dt value in the data sheets which is applicable for repetitive 50 to 60 Hz operation, some manufacturer have recently started to give either non repetitive di/dt values[2], which are considerably higher than the repetitive values, or the allowable non repetitive surge current values for shorter current pulses[3]. These higher values allow the design of short, high current pulses.

IV. Design of a 80 kA, 12.5 kV, 2 Hz Switch

Using the design procedure derived in chapter III, a preliminary design for a repetitively pulsed switch with the following parameters is presented. The current has the shape of a half sinusoidal pulse with an amplitude of 80 kA and a base time of 3 ms, the blocking voltage is 12.5 kV, the repetition rate is 2 Hz and the total lifetime is 10^8 cycles. This switch is required in an application in which solid-state physics research is done by bombarding a sample with a neutron beam while the sample is exposed to a 30 T high magnetic field. The switch will be installed in a circuit as shown in Fig. 4. Using the junction temperature versus lifetime relationship of [1] it is easily derived that the short circuit condition for the switch, when the current increases to a peak of 250 kA with a base time of 1 ms, is a more severe requirement than the 10^8 rated 80 kA pulses, although the short circuit is only expected to occur up to 3 times during the lifetime of the experiment. The paper will look at two design options, one using a 5 kV, 125 mm device and the other using a 100 mm, 3.2 kV device. Junction temperature calculations for both devices and allowable di/dt limits as recommended by the manufacturer are presented. Some cost information is given for the two options. The total number of parallel and series devices will be determined and the parameters which restrict the design the most will be mentioned. Considerations for cooling the switch will be evaluated.

V. Outlook

The paper concludes with comments concerning the magnitudes to which voltage levels, current levels and time length of repetitively pulsed closing switches can be reasonably extended by using 100 and 125 mm thyristor devices.

Partial List of References

[1] I. L. Somos, D. E. Piccone, L. J. Willinger, W. H. Tobin, "Power semiconductors -- empirical diagrams expressing life as a function of temperature excursion," IEEE Transactions on Magnetics, Vol. 29, No. 1, pp. 517-522, January 1993.

[2] Powerex, "Rectifier and thyristor -- application and technical data book, " August 1993.

[3] Silicon Power COrporation, "Product catalogue -- high power thyristors, diodes and assemblies," July 1996.

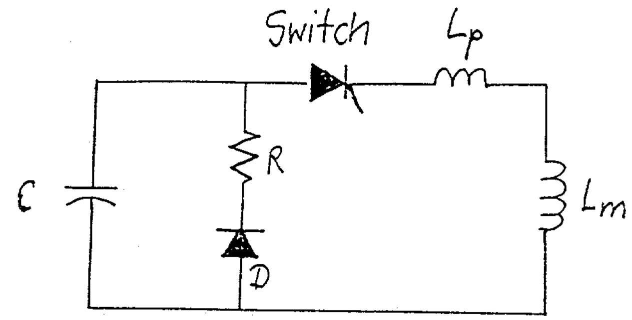
Partial List of Figures

Fig. 1 Electrical circuit for a pulsed magnetic field application, showing the repetitively pulsed closing switch

Fig. 2 Current design specifications for a solid-state closing switch in a pulsed magnet application

Fig. 3 Experimental result for a solid-state closing switch showing (a) a short current pulse with an amplitude of 73 kA and a base time of 7 ms and (b) a longer current pulse with an amplitude of 22 kA

Fig. 4 Electrical circuit for a 2 Hz repetitively pulsed magnet using a solid-state closing switch



C capacitor

R resistor

D diode

L_p protection inductance

L_m magnet inductance

Fig. 1

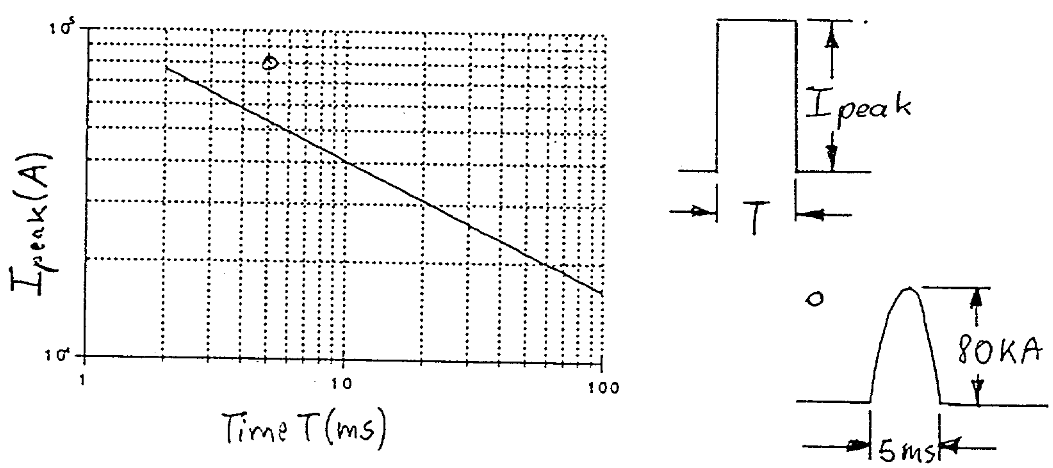
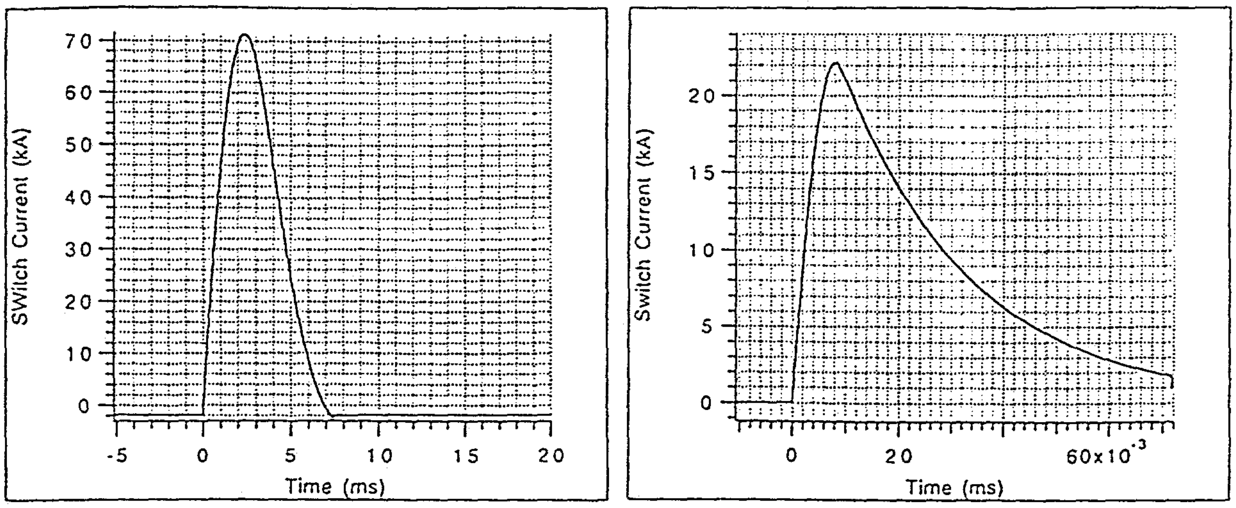
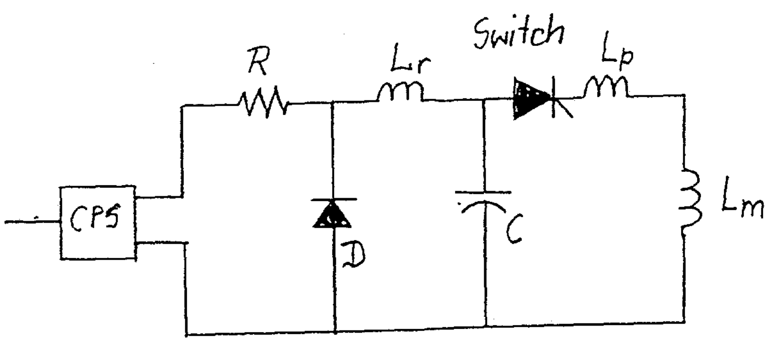


Fig. 2



(a) (b)

Fig. 3



CPS: Charging power supply
R: Resistor
D: Diode
L Resonance inductance
Lp protection inductance
Lm magnet
C Capacitor

Fig. 4