APPLICATION NOTES

ASSEMBLING 125mm THYRISTORS
FOR
PULSE POWER APPLICATIONS

1. BACKGROUND

1.1 *Defining Pulse Power Applications*

Pulse power involves the storage of energy until it is released at very high power levels. Dethlefsen [1] has bracketed the requirements for suitable solid state power switches as falling within the following envelope:

- blocking voltage, 5 to 60 kV
- peak current, 5 to 200 kA
- pulse widths, 0.1 to 1000 ms

Some of the applications encountered by the authors have di/dt requirement >1000A/ms requiring special considerations on device design and method of gating. Investigations are currently performed in the range of 500 to 1000ms pulse duration and up to 200 kA.

Broad descriptions of the potential market for Pulse Power Switches are given in publications of Dethlefsen [1] and Levy [2]. Most testing activity to date, however, has been to replace triggered spark gaps as closing switches in support of electric gun programs for the U.S. Army and magnet or laser charging circuits used in government laboratories.

1.2 *General Approach to Pulse Power Ratings*

A combination of surge current testing (Fig. 1) and an empirically based computer model [3] are used. The exact current waveform is used in both cases. It is verified based on test that thermal runaway (Fig.2 & Fig.3) does not occur by observing the V_T vs. time or the I_T vs. V_T loop. An internal examination of the device is made to ensure that the mating surfaces are not arcing or spitting as due to insufficient metallization or flatness.

Next, DT_J for the hottest portion next to the gate boundary is determined by computer model, considering the finite expansion rate of the turned-on region in combination with the gate geometry. Finally, life expectancy in terms of the number of shots is determined as in [4], that is:

$$\textbf{\# shots} = (300 / DT)^9 \quad \text{using } {}^oC$$

Special precautions for assembling mating parts needed to ensure predictable life expectancy for the SPT400 series 125mm thyristor under pulse duty.

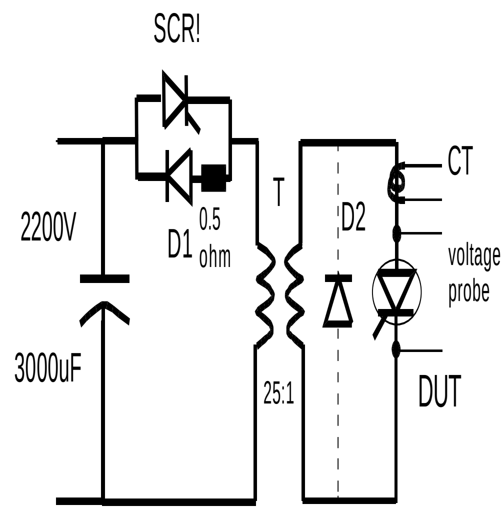

Fig.1 Type of laboratory circuit used to establish pulse power current ratings

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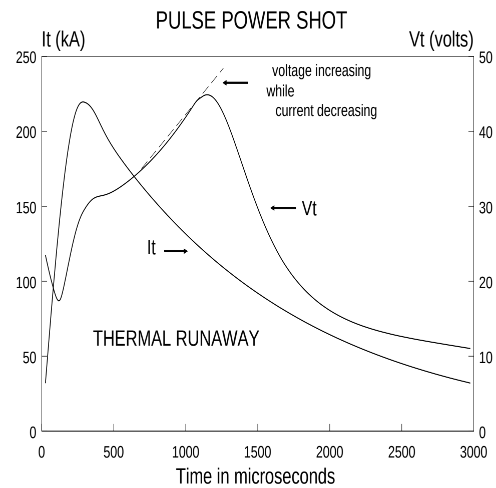


Fig.2 Representation of a pulse power shot showing evidence of thermal runaway. On-state voltage is increasing substantially while the current is decreasing.

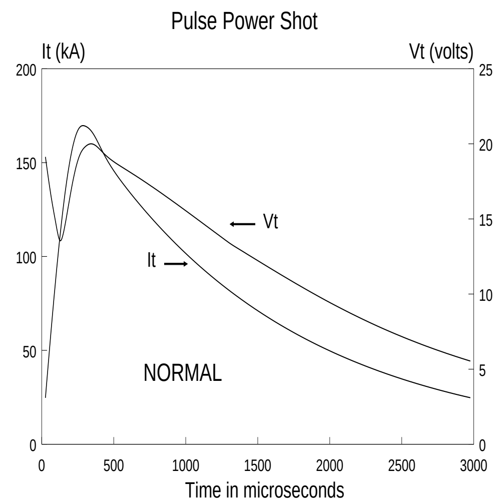
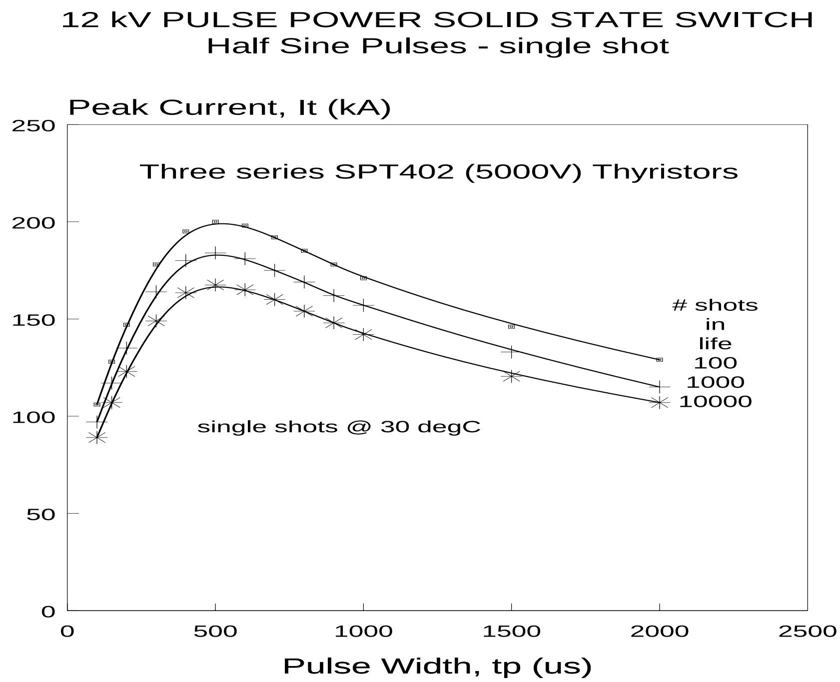


Fig. 3 Representation of a pulse power shot showing <u>no</u> evidence of thermal runaway. On-state voltage is decreasing normally as the current is decreasing.

An example of rating a 12 kV thyristor switch (using three 125mm SPT402 thyristors in series) is shown below. It is presented for half sine pulses at three levels of life expectancy. The pulse waveform will vary for specific cases, varying from job to job.



Overall descriptions and references to these procedures are given in *SPCO Application Notes* [5]. However, achieving this predicted performance and life expectancy is dependent on the attaining the required flatness and assembly of mating parts which is the subject of this application note.

1.3 *Design Concept for the SPT400 Series 125mm Thyristors*

Exploring emerging electrical power systems, military weapons, ship power propulsion & control and commercial ventures led to the development of a light weight low profile plastic disk package shown below:

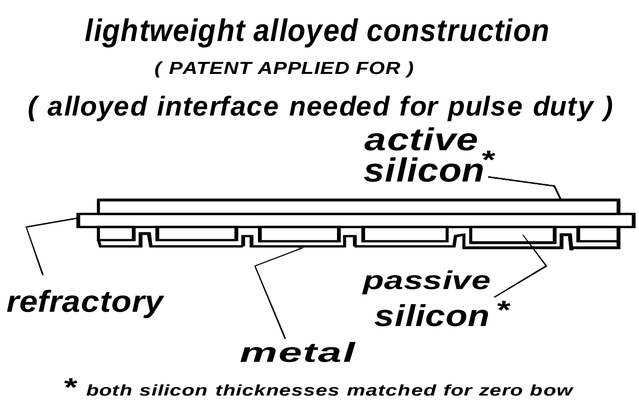
<u>LIGHT WEIGHT - LOW PROFILE</u>
<u>PLASTIC DISK PACKAGE</u>

Dimension	**A**	.250 in	5000V designs
	B	.202	
	A	.220	2500V designs
	B	.232	

Weight: 18 oz Clamping force: 25000-30000 lb

A novel design for the internal junction assembly (silicon to refractory substrate) maintains flatness after being alloyed at very high temperature overcoming the tendency to bow while cooling down. This is accomplished by taking advantage of compensating forces using uniform thicknesses of silicon on both sides of a very thin refractory layer. One side has electrically active silicon; the other has passive or high conductivity silicon.

Bonding the anode to a relatively thick substrate, which causes bowing as used in conventional designs, is not used for SPT400 series. Other off-shore manufacturers have overcome bowing effects by their "free floating" or "alloy free" silicon junctions assemblies eliminating alloying with "dry" interfaces only. The thermal advantage offered by maintaining a bonding interface for the SPT400 type is shown in Fig. 4.



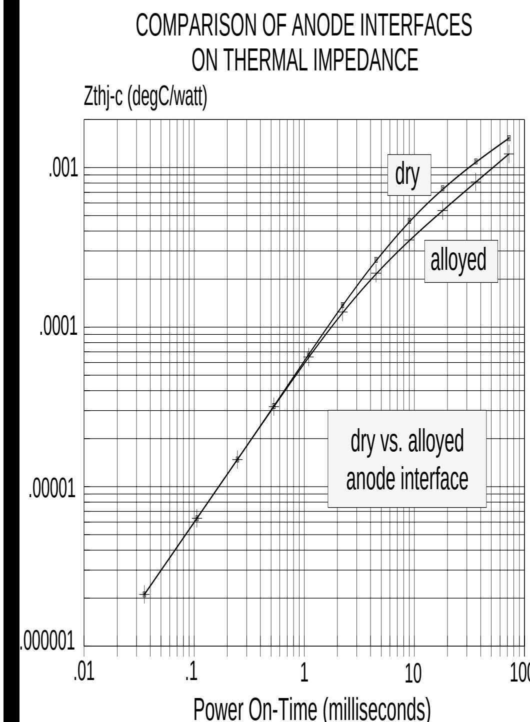


Fig. 4 Thermal impedance of comparable 125mm thyristors with "dry" and bonded (alloyed) anode silicon to substrate interface..

2. MECHANICAL CONSTRAINTS

2.1 *Fundamentals*

Notice that the SPT400 disk package has cups rather than solid poles. Because liquid cooling provides the most advantage for continuous power dissipation, allowance is made for direct insertion of the chiller posts. Otherwise, nickel plated copper posts of uniform thickness (.295 in thick, drw. 0215B8315) are provided to fill these wells.

It is important for achieving the full pulse power rating, performance and life expectancy, to maintain flatness of each mating part throughout the mechanical system beginning with the external anode and cathode posts, continuing with the heat dissipator surfaces butting up against them and still further on to the rigid force spreaders. The mechanical flow of parts can easily be several thousand's of an inch.

After some heat cycling a recheck of clamping force may be necessary if the displacement of the clamping system is on the low side,e.g. for a .030" displacement, a flow of .003' would result in 10% loss in clamping force. Parts likely to "give or flow" are the fiberglass insulators and the pressure points at the force spreader.

2.2 *Mating Surface Specifications*

SPCO maintains inspection of the posts (drw. 0215B8315) to the dimensions and tolerances shown below:

It is essential that any other inserted post such as a water cooled chiller be prepared to these same flatness requirements. Also it must be backed up by a force spreader having the approriate flatness and hardness. SPCO finds that steel spreader of 1.0" thick, 110 Bhn, minimum or equivalent in sturdy heatsink is essential. For one's own system trial experimentation using *Pressure-Recording Film* [see page 6] between contacting surface will exhibit the degree of uniformity being achieved. *[Film having microcapsule within which burst producing color changes and a "topographical" image of pressure variation.]*

2.3 *External Clamping System*

The clamping force specification which is 25000 - 30000 lb [111 - 133 kN] is to be supplied by a mechanical system of spring clamps (leaf or belleville washers) having adequate .030 -.060 " displacement [6] that maintains this force over the intended operating temperature range.

2.3 *Example of an assembly, a pulse power switch for a 12kV bus using three (3) series 125mm thyristors*

Notes:

It is essential for steel (STL) force spreaders as used in an assembly shown here to be at least 1 in thick and of proper hardness, e.g. 110-140 Bhn. For other types of assemblies this function may be absorbed by a rigid heat sink.

Consideration for creep or flow of individual parts would make allowances for possible indentation pressure points of the belleville, that of the fiberglass insulators and possibly the aluminum clamp.

Considerations under very high current surge must also include direction of bus bars for wrenching effects and possible inductively coupled circulating currents and corona effects in the supporting hardware.

2.4 *Mating Surface Preparation*

removal of oxide and cleaning

Plated surfaces are recommended for aluminum and copper heat dissipators. Bare surfaces, however may be used if careful attention is given to cleaning and treating is assured.

- Plated surfaces should be lightly sanded with 3M "Scotchbrite", then oil or compound applied as recommended.
- Unplated aluminum surfaces should be vigorously abraided with a fine wire brush or 3M " Scotchbrite" coated with Alcoa EJC #2 compound. The EJC should be removed and the recommended compound applied or very thin layer of EJC reapplied.

final treatment

Apply silicone oil* or a very thin layer of grease or compound as indicated below. Rotate the disk package so as to distribute the applied agent.

- bare copper use G322L or LS2037
- bare aluminum use EJC #2 or G322L on EJC pretreated surface
- tin plated copper or aluminum
  preferably reapply DC 550 or SF1154
  alternatively use G623 or G322L
- nickel plated aluminum. DC550, G623 G322L
- silver plating is not recommended unless all parts are so plated.
- common white thermal grease or any powder or metal particle filled grease should never be used

.* Recommended silicone oils are SF1154 or DC550
(200 centistoke)

Oils and grease are available from distributors such as:

- oils Eastech Chemical Co. 5700 Tacony St.
  Philadelphia, PA, 19135 (215) 537 8575
- grease Smith of Philadelphia 811 Cayuga Ave.
  Philadelphia, PA 19124-3893 (215) 743-8200
- EJC #2 local electrical supply houses
- Pressure recording film {FUJI Prescale Film]
  McMaster Carr - *part 31705K14*
  P.O. 7690 Chicago, Il 60680 (908) 392 3200

REFERENCES

[1] R. Dethlefsen, *Evolving pulse power industrial market requires better solid state switches*, PCIM Magazine, February, 1996

[2} S. Levy, J. Lai & J. Carter, *Pulsed power for science and industry*, 1991Publication of the Power Electronics Applications Center, Knoxville TN

[3 I.L. Somos, D.E. Piccone, L.J. Willinger & W.H. Tobin, *Power semiconductors - a new method for predicting the on-state characteristic and temperature rise during mult-cycle fault currents*, IEEE Transactions on Industry Applications, Nov.-Dec. 1995

[4] I.L. Somos, D.E. Piccone, L.J. Willinger & W.H. Tobin, *Power semiconductors - empirical diagrams expressing life as function of temperature excursion,* IEEE Transactions on Magnetics, January 1993 and Sixth Symposium on Electromagnetic Launch Technology, Conference Proceeding, 1992

[5] *On surge current, pulse power ratings and SPT400 series 125mm thyristors*, SPCO APPLICATION NOTES, Fall 1997

[6] L.O. Eriksson K.G. Longnecker, *Thermal and electrical interface consideration for high power disk semiconductors*, Conference Record, SATECH '87, Proceedings, September, 1987

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V. TEST RECORD / SPT407 2500V 125mm THYRISTOR

I_{TSM} for 8.3 msec = 100 kA

T_{case}= 125^{o}C ; V_R=0

Test Recordings @ T_{CASE} = 125^{o}C

V_T versus time trace meets the conditions set forth is Section II and Fig. 6 for an acceptable I_{TSM} rating of 100 kA, that is without evidence of thermal runaway as defined by the authors.

Corresponding I_T vs. V_T loop

Silicon Power COrporation

VI. Overall Comments

I_{TSM} ratings must be properly understood. These apply for unusual circuit conditions such as surviving when other components fail and for coordinating with fuses.

I_{TSM} ratings should not be used as criteria for comparing contending vendors as the standards provide only conceptual insight into understanding this rating; consequently it is subjected to broad interpretations. Allowing this, a vendor who provides a conservative rating would be evaluated unfavorably compared to one with an optimistic rating.

Predictability of surviving multi-cycle fault currents requires knowledge of the temperature dependency of the on-state voltage beyond 125^{o}C and well beyond the 25^{o}C. A relationship is needed for on-state voltage representing changes over this very wide temperature range and used with proper thermal representation in a computer model.

Pulse power ratings are usually of sub-cycle duration and very high peak currents: these should be backed up with proper test verification and linked to an empirically based computer model so as to determine DT_J and resulting life expectancy.