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The RC-Snubber, Redesigned

"C.C. Bates' Snubbers" DO NOT Suppress Arcs!

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The Famous Formula That Fails to Deliver

"Snubber" is a nickname given to a configuration of components, such as a series-RC-network, which are typically used as transient suppressors, noise suppressors, or rise-time limiters. Snubbers are often deployed as spark suppressors, because transient voltages frequently cause sparks. During the 1960s, the belief was born that snubbers are also"arc suppressors" due to the common practice within the electro-mechanical industry of using the terms "arc" and "spark" interchangeably. This deeply embedded belief led to the acceptance of various means to calculate RC values for "arc-suppressing snubbers", especially the "C.C. Bates formulas"(ref. 1, fig. I) and their "nomogram". The C.C. Bates formulae were the result of a transient suppression investigation that preceded Bates by one year, and which do not directly address the following relevant elements:

$$C = \frac{I^2}{10}$$

$$R = \frac{E}{\left\{10 \times I \times \left[1+\left(\frac{50}{E}\right)\right]\right\}}$$

Figure I: RC transient suppression equations popularized by C.C. Bates as "arc suppression" RC calculations

- Breakdown Field Strength (**$E_{(BDN)}$**) of the contact dielectric
- Electric Field Conditions in the narrowing gap promoting Field-Emissions-Initiated-Arcs (**F-Arcs**)
- Minimum Plasma Ignition Voltage (**$V_{(T\text{-}Arc\ min)}$**) of Thermionic-Emissions-Initiated-Arcs (**T-Arcs**)
- Contact Opening Speed (**$v_{(co)}$**), which is materially responsible for determining quench capacitor values

Can an Arc-Suppressing Snubber be Designed?

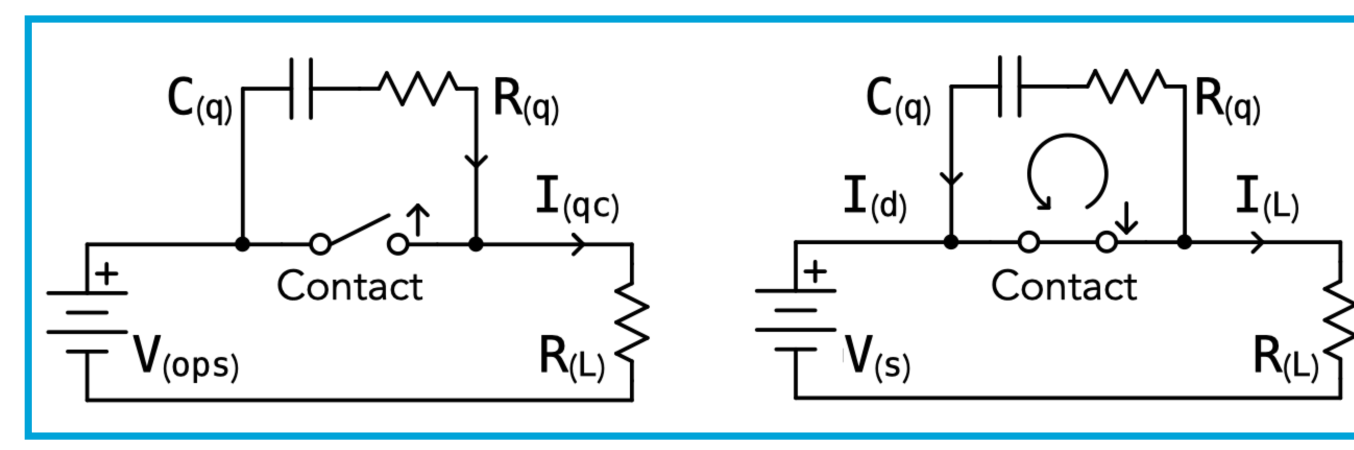

Figure II: Schematic diagram depicting snubber current flow during contact BREAK (above left) and MAKE (above right).

To address this question, we make use of a simplified "(two-frame) animated" schematic diagram of an RC snubber circuit, comprised of what Ragnar Holm calls a "quench resistor" $R_{(q)}$ and "quench capacitor" $C_{(q)}$ (ref. 2, fig. II). We then pursued an iterative process to develop a true arc-suppressor-RC-snubber (**A-RC**) algorithm. We then investigated the various approaches noted above, and found that the $C_{(q)}$ multiplied with the **total** circuit resistance (**$R_{(q)}$+$R_{(L)}$**) determines the charge time constant. A properly sized $C_{(q)}$ charges appropriately during contact BREAK, thereby preventing T-Arc and F-arc plasma ignitions. While the contact is OPEN, $C_{(q)}$ remains charged.

However, because the charged $C_{(q)}$ discharges as soon as the electrodes MAKE contact, a series of high-pressure metallic plasma amplified MAKE-bounce-T-Arcs are initiated. This is the classic arc welding process. While micro-welding of a power contact is required for proper operation, a permanently welded contact is not desired. These considerations led us to develop an A-RC algorithm. Furthermore, our investigations determined that the natural growth and decay laws which govern the charging and discharging voltage across $C_{(q)}$ and the current through $R_{(q)}$, must be used to validate the general applicability of the A-RC algorithm all throughout the BREAK or MAKE transitions. Through this process, we realized that neither inductance nor differential circuit equations are required for A-RC Snubber calculations. Our resulting A-RC algorithm proved useful to calculate the required $R_{(q)}$ and $C_{(q)}$ values along with the resulting initial discharge current $I_{(id)}$ occurring during contact MAKE to determine the thermal stresses on the electrode surfaces. The A-RC algorithm results have been specifically evaluated for three (3) common applications (table I):

#1 "control"— 24V

▶▶ "A-RC SNUBBER" ALGORITHM ◀◀				Exmpl. #1 Control	Exmpl. #2 Consumer	Exmpl. #3 Industrial	Units
	APPLICATION INPUTS	**INPUT PARAMETERS**					
	Dielectric Breakdown Field Strength	$E_{(BDN)}$	*e.g. for air at STP*	3.00	3.00	3.00	MV/m
	Minimum T-Arc Plasma Ignition	$V_{(T\text{-}Arc\ min)}$	*as per contact metal*	12.00	12.00	12.00	V
	Contact Opening Speed	$v_{(co)}$	*as per contact mechanics*	0.12	0.12	0.12	m/s
	Supply Voltage (AC)	$V_{(s)}$	*application dependent*	24.00	120.00	480.00	V
	Load Current (resistive)	$I_{(L)}$	*application dependent*	0.10	10.00	50.00	A
	CALCULATED PARAMETERS	**BREAK EQUATIONS**					
BREAK	Load Resistance	1.	$R_{(L)} = V_{(s)} / I_{(L)}$	240.00	12.00	9.60	Ω
BREAK	Arc Quench Resistance	2.	$R_{(q)} = V_{(T\text{-}Arc\ min)} / I_{(L)}$	120.00	1.20	0.24	Ω
BREAK	Charge Resistance	3.	$R_{(c)} = R_{(L)} + R_{(q)}$	360.00	13.20	9.84	Ω
BREAK	Arc Quench Capacitance	4.	$C_{(q)} = V_{(s)} / (E_{(BDN)} \times v_{(co)} \times R_{(c)})$	0.19	25.25	135.50	µF
BREAK	Charge Time Constant	5.	$\tau_{(c)} = C_{(q)} \times R_{(c)}$	66.67	333.33	1,333.33	µs
		MAKE EQUATIONS					
MAKE	Discharge Time Constant	6.	$\tau_{(d)} = C_{(q)} \times R_{(q)}$	22.22	30.30	32.52	µs
MAKE	Initial Discharge Current	7.	$I_{(id)} = V_{(s)} / R_{(q)}$	0.20	100.00	2,000.00	A
MAKE	Initial Contact MAKE Current	8.	$I_{(icM)} = I_{(id)} + I_{(L)}$	0.30	110.00	2,050.00	A

Table I: The A-RC Algorithm applied to three (3) common resistive AC application examples.

An Algorithm That Works

This A-RC algorithm produces a scalable arc suppressing RC series network that is effective in suppressing arcs. It also explains why above 2A and above 100V the A-RC snubber quench capacitor's initial discharge current $I_{(id)}$ becomes sufficiently large to cause, depending on the specific electrodes, more or less serious contact damage. The higher the voltage, the higher the current, the greater the electrode surface damage.

Considering, the quench capacitor's cost and footprint requirements, our professional opinion is that an A-RC snubber is not an optimal power contact arc suppressor for load currents, much greater than 2A.

References:
1. C.C. Bates, "Contact Protection for Electromagnetic Relays," Electromechanical Design Magazine, August 1966
2. R. Holm, Electric Contacts Handbook, Springer Verlag, 1958 (Third completely rewritten edition of "Die technische Physik der elektrischen Kontakte")