

Smart Adaptive Relay Triggering (SART[®]) and Electromechanics: A Life-Extending Synergy

Aiming somewhere in between the most “natural” zero-cross switch – the electric arc – and the low-bounce, polarized DE relay, engineers at Panasonic Electric Works are striving to build the ultimate electronic AC power switch: “At current zero crossing, this switch is designed to open its contact so fast – independently of current amplitude, asymmetry, and frequency – that the dielectric stability at the clearance between open contacts always exceeds the instantaneous value of the transient recovery voltage.”^[1]

Hans-Peter Dietrich and Lothar Feige

Engineering the perfect electronic AC power switch is a goal that – in the face of intrinsic limitations to activation, fall, and bounce times – has remained practically impossible to realize. Of the power relays on the market today, one, however, has come impressively close to achieving this ideal: the DE relay designed by Panasonic Electric Works, which can be used for resistive loads up to 16A. In new condition, this relay’s typical activation time is 4.16ms, its typical fall time is 2.91ms, and its typical bounce time is a mere 0.19ms – as shown by the statistical distribution of these parameters in 1000 factory-new DE relays (Fig. 1).

High-precision, reproducible relay manufacturing

Building an optimally bounce-free, latching type relay that is capable of switching kilowatts in a load circuit while keeping intrinsic energy (mWs) consumption low – an important energy savings factor – requires expert design and an infrastructure comparable to Panasonic’s German Factory in Pfaffenhofen, which is equipped for high-precision, reproducible relay manufacturing.

In tests performed on factory-new DE relays, statistics show that a bounce time of 0.00ms can be achieved in a remarkable 1 out of 1000 relays. Under such ideal conditions:

- The bounce-free relay’s energy balance is ideal, because its kinetic energy is equal to zero at the end of the armature travel (see Appendix, Fig. 2).
- The contact gaps occurring here amount to ca. 1 to 10 μ s during the bounce, which can lead to arcing.

In combination, these two conditions guarantee a low arc energy, which is transformed into heat.

By simulating relay switching in a PSpice point-mass model, engineers at Panasonic Electric Works were able to show that bounce characteristics are determined chiefly by the contact spring’s resonance frequency. The pulse response of the linked spring/armature mass system, with its friction-attenuated, exponentially decaying oscillation, can be optimized – in terms of its effect on bouncing – primarily by modifying the spring characteristics [1].

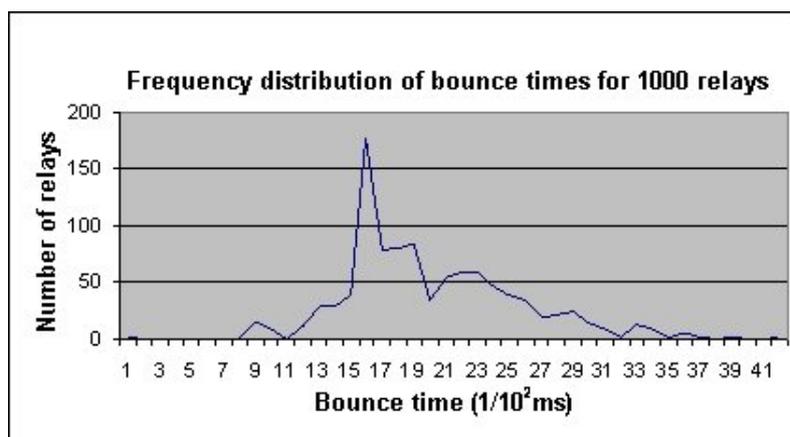


Fig. 1. Frequency distribution of bounce times for 1000 relays

Arc length – and thus the contact gap in relation to current and voltage (see Appendix, Fig. 3 [2, 3]) – depends on the type of contact material. This characteristic does not, however, apply to the smallest gap types, and (in the micrometer range) particularly not to lead arcs.

For any given arc or contact gap length, the intersection point of the arc’s principal voltage-current characteristic with the load circuit’s internal resistance load line marks the point at which the conditions for an arc column buildup and heating-up are no longer given. Assuming that

the DE relay contact closes or opens at zero crossing, a comparison between the current and voltage changes occurring during DE relay bounce time will show a partial probability of these parameters falling below the critical conditions. This example illustrates a $\cos(\Delta\phi) = 0.3$. Contact opening and closing are closely in sync with the load circuit's internal resistance load line during bouncing; the curves can be as close as 1 to 10 μ s apart.

SART[®] technology extends contact life

The following important conditions for a significant extension of contact life have been implemented in the smart adaptive relay triggering (SART[®]) technology developed by pikkerton:

- Continuous measurement of $\cos(\phi)$ in the load circuit; during the first switching cycle, the relay switch is not regulated at voltage zero crossing; thereafter, switching is adjusted to the respective current zero crossing
- Continuous measurement and adjustment of relay triggering to relay switching cycles, contact life (since travel time increases with the degree of contact erosion), and stored phasing information
- Detection of and differentiation between dephased but continuously sinusoidal currents and pulsed loads, for example in switch mode power supplies and phase-controlled modulators (dimmers)
- Detection and use of "low-current windows" for relay operation

Normally, the DE relay is specified for 25,000 switching cycles at 16A, or for 10⁵ switching cycles at 10A resistive load. In practice, this relay has already been tested successfully with up to 300A inrush current (switched with no phase control) in a filament bulb configuration where synchronization with the voltage-current zero cross was implemented [4].

SUMMARY

Promising trials

Figure 2 shows the outcome of initial DE relay testing. The oscillograms of these measurements (Fig. 3) confirmed engineer expectations in that – compared to the unregulated mode – the transient recovery voltage during bouncing and regulated switching was negligible or practically nonexistent.



Fig. 2. (Left) Relay DE1a-L2-5V, which was used to switch a 440- μ F capacity and a 25-W discharge lamp on and off at random time points, welded shut after 1993 switching cycles. (Right) Same as left, but with phase-controlled switching used at current zero crossing; the zero crossing point was determined by adjusting several switch cycles in both directions. In the expectation of a long contact life, switching was terminated after 13,600 cycles.

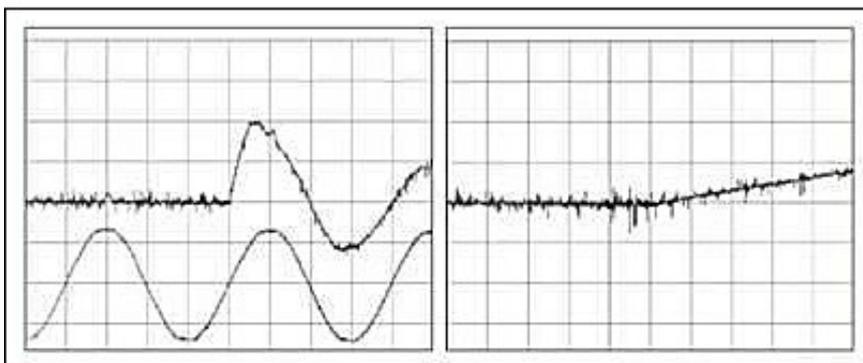


Fig. 3. Switching on at the "right" point in time: (Left) 5 ms/div, (top) current passing through consumer load; (bottom) power voltage. (Right) Zoom, 250 μ s/div.

BACKGROUND

Arc current switching

Arc switching – the safest and most economical current switching method available – is a self-synchronizing mechanism that works under normal atmospheric conditions. The arc loses its conductivity at exactly the desired point in time; it then turns into an isolator and transforms switching energy into heat, which prevents power surges at the contact. An arc forms when a contact opens at the point of constriction resistance, thereby generating heat because of the atmospheric ionization resulting from the contact gap. In this context, the primary engineering goal is to reduce the effects of welding, vaporization, and loss of contact material.

Applications using phase-controlled switching benefit from more advantageous conditions during EMC parameter detection: Due to the contact gap's proximity to the zero crossing, the transient recovery voltage – with its high-frequency oscillations, which are observed without being regulated until the initial peak value has doubled – is likewise held in check after having crossed the abscissa intersection point and after the arc has reignited.

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APPENDIX

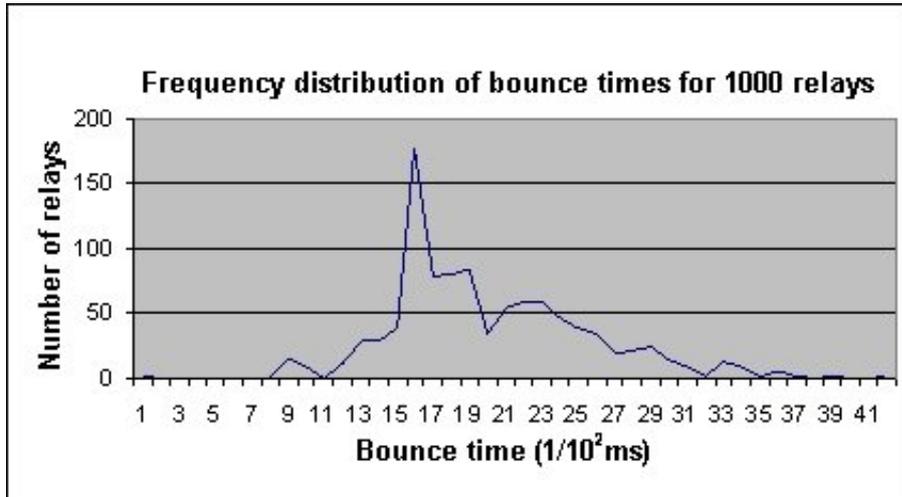


Fig. 1a. Frequency distribution of bounce times for 1000 relays

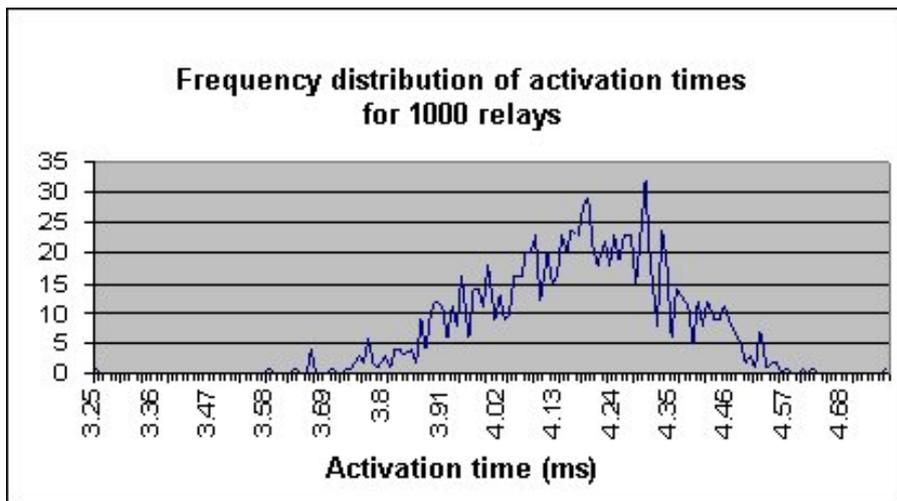


Fig. 1b. Frequency distribution of activation times for 1000 relays

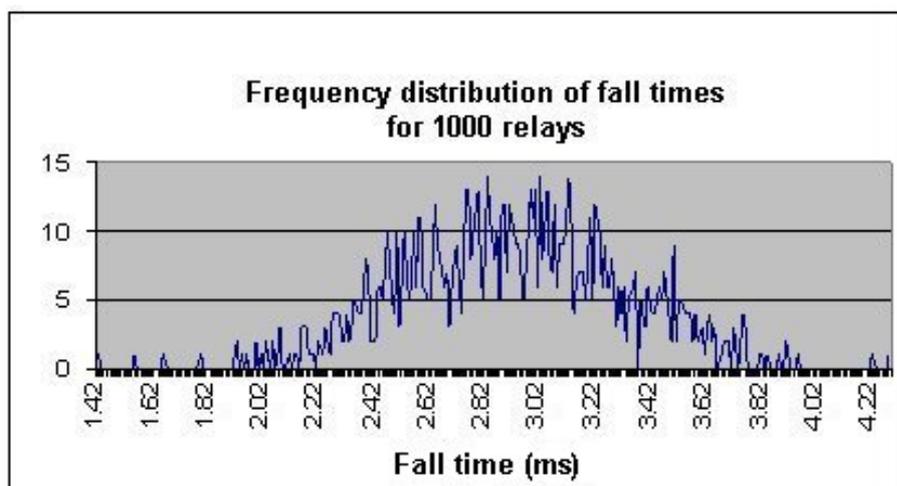


Fig. 1c. Frequency distribution of fall times for 1000 relays

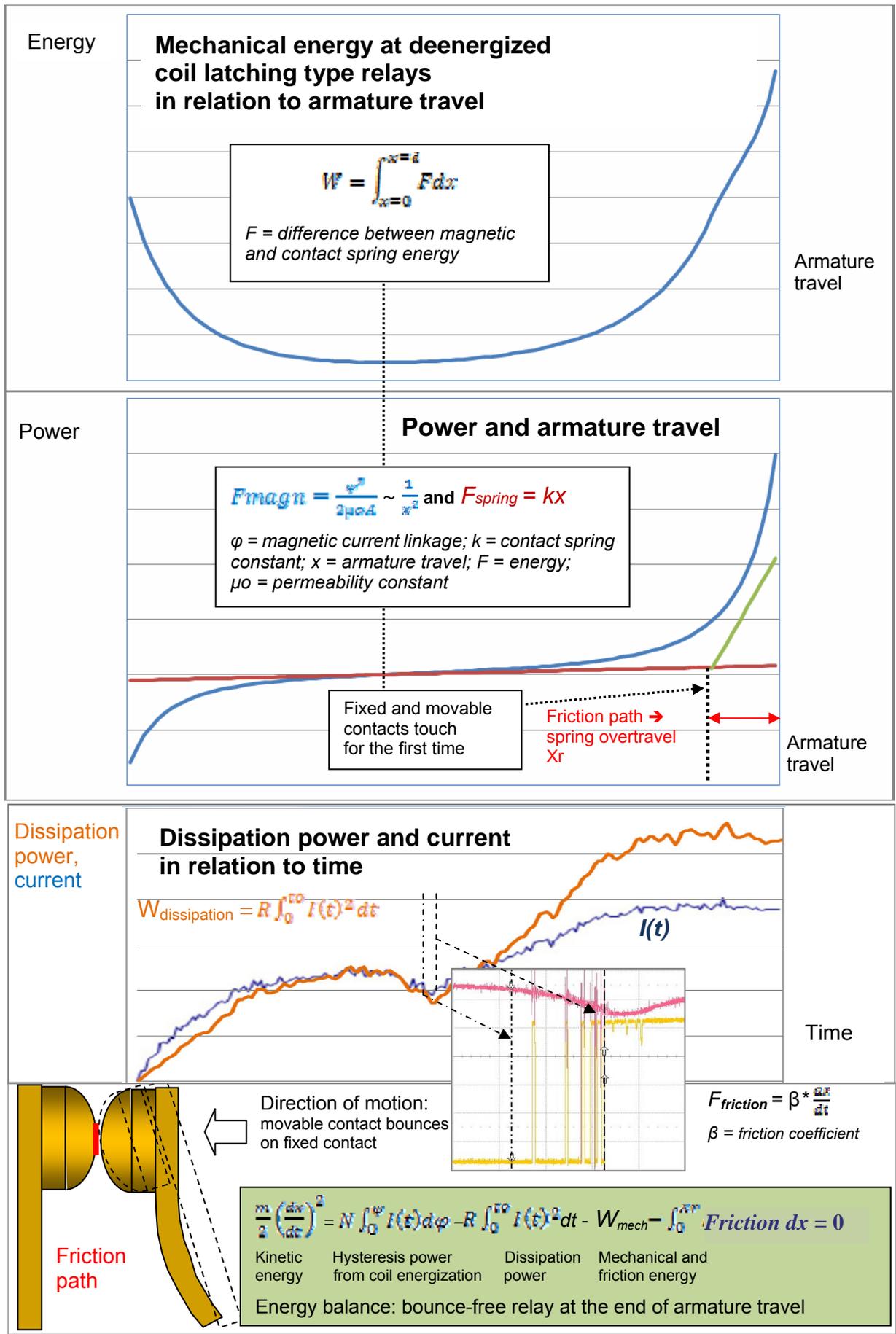


Fig. 2. Energy, power, and travel in the deenergized latching type relay

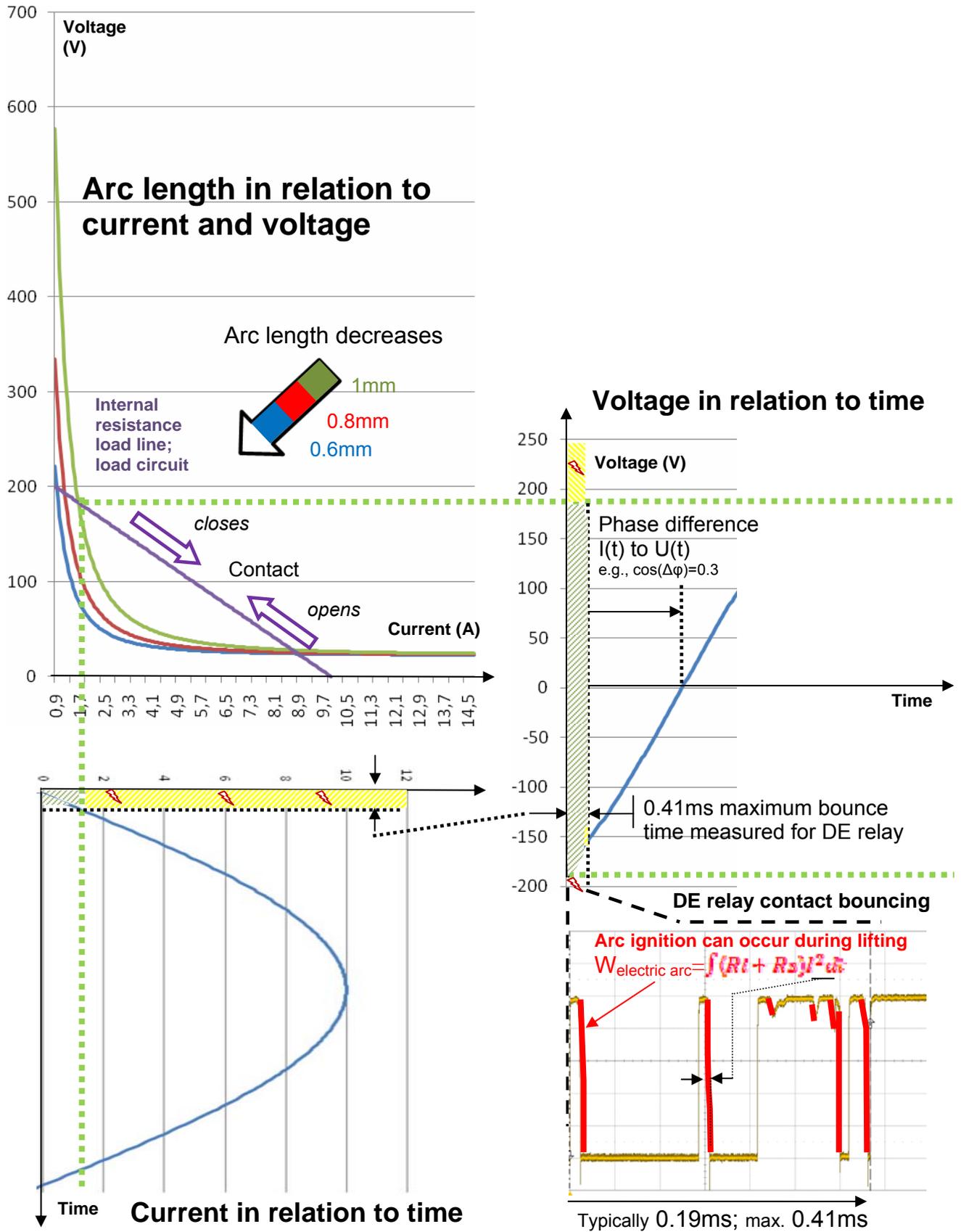


Fig. 3. Electric arc length as a function of current, voltage, and time; voltage and current as a function of time. Based on [2, 3]. (Note: Commas between numbers signify decimal points.)

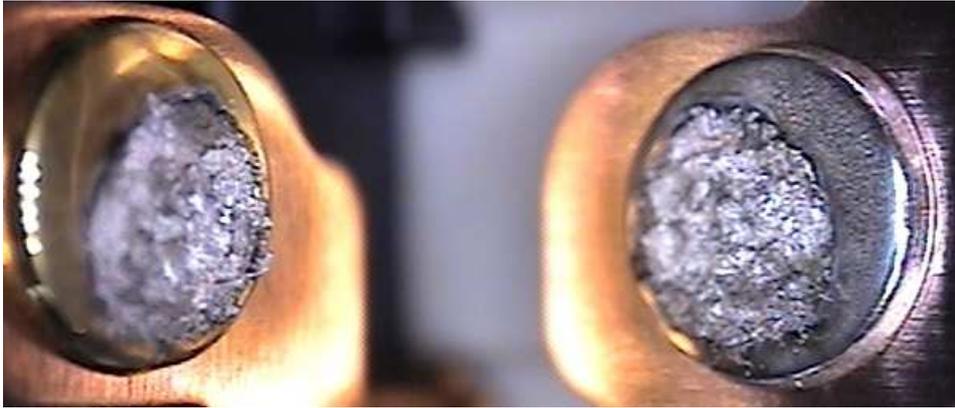


Fig. 4a. Relay DE1a-L2-5V, used to switch a 440- μ F capacity and a 25-W discharge lamp on and off at random time points, welded shut after 1993 switching cycles.



Fig. 4b. Same as Fig. 4a, but with phase-controlled switching used at current zero crossing; the zero crossing point was determined by adjusting several switch cycles in both directions. In the expectation of a long contact life, switching was terminated after 13,600 cycles.

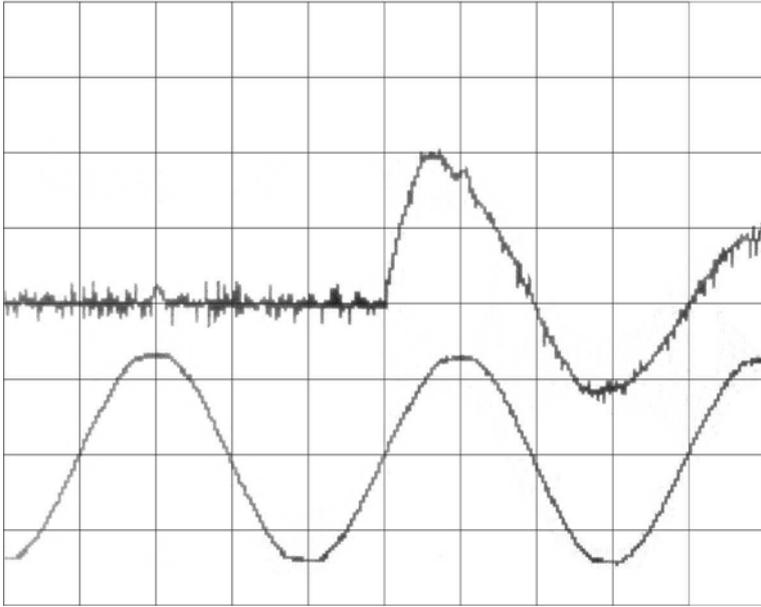


Fig. 5a. Switching on at the “right” point in time; 5 ms/div. (**Top**) current passing through consumer load; (**bottom**) power voltage

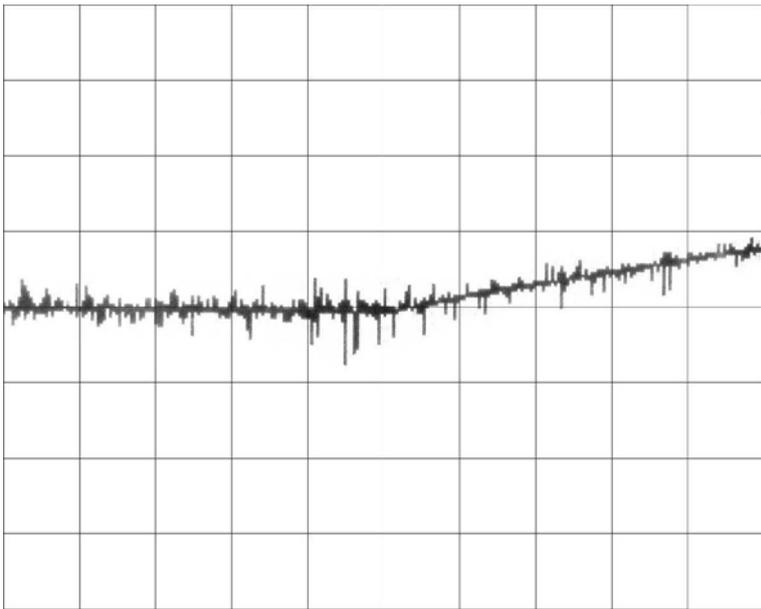


Fig. 5b. Switching on at the “right” point in time (**zoom**); 250 μ s/div

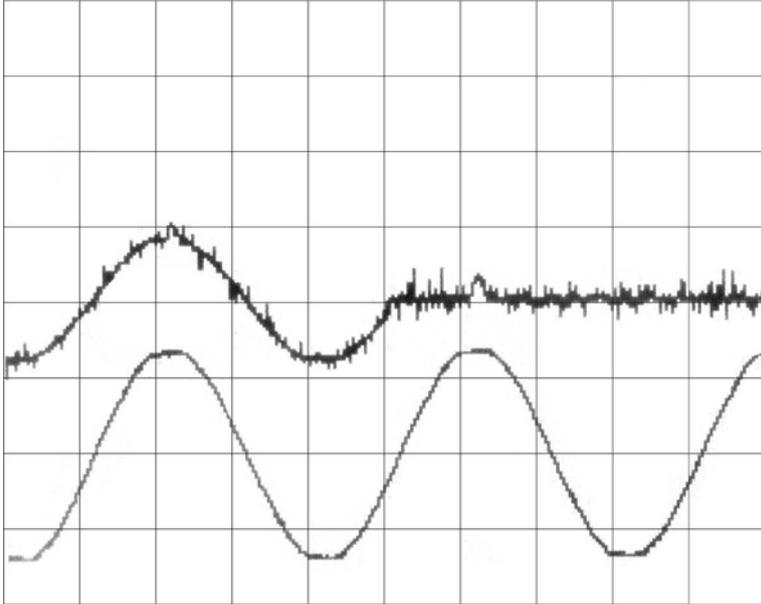


Fig. 6a. Switching on at the "right" point in time; 5 ms/div. (**Top**) current passing through consumer load; (**bottom**) power voltage

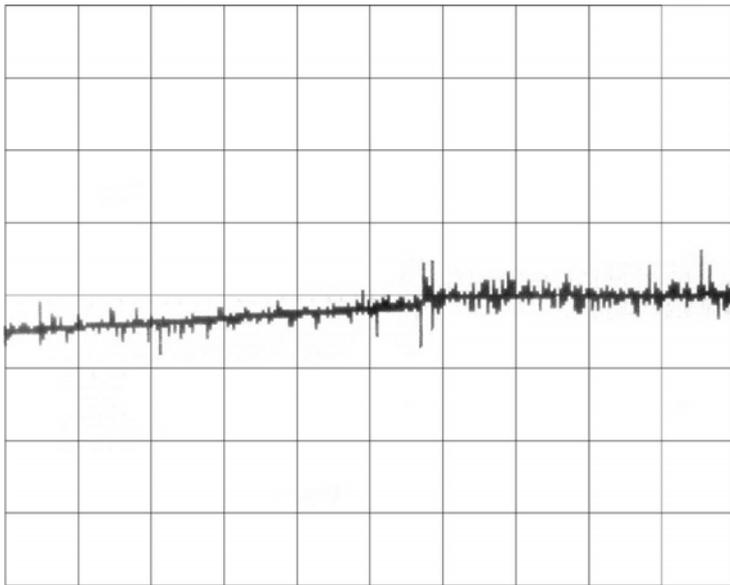


Fig. 6b. Switching off at the „right" point in time (**zoom**); 250 μs/div

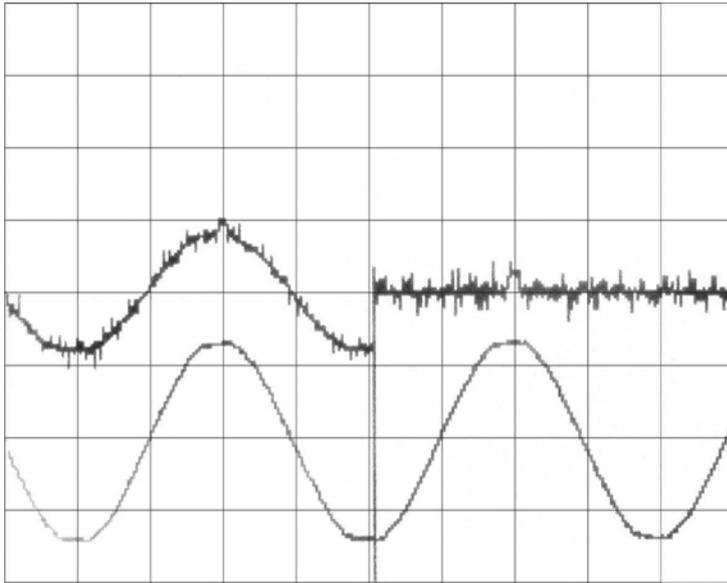


Fig. 7a. Switching off at the "wrong" point in time → current peaks and electric arc; 5ms/div. (**Top**) current passing through consumer load; (**bottom**) power voltage

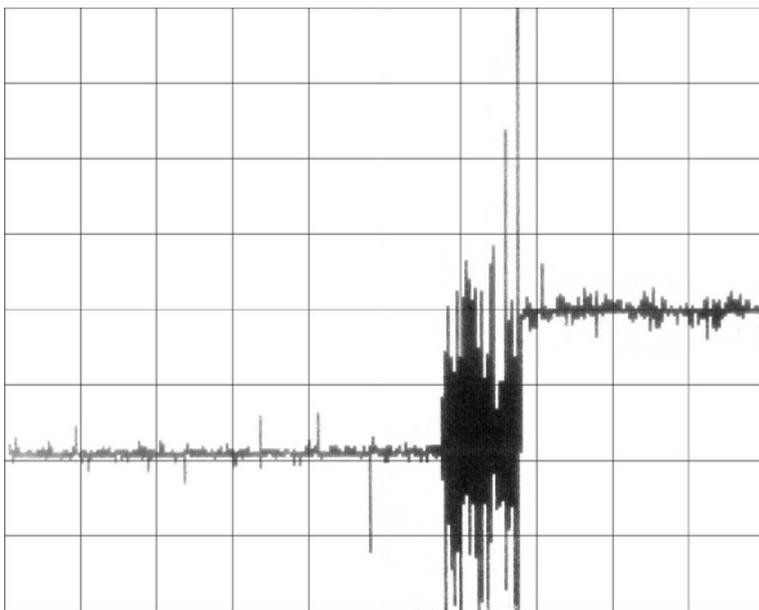


Fig. 7b. Switching off at the "wrong" point in time (**zoom**) → current peaks and electric arc; 250μs/div

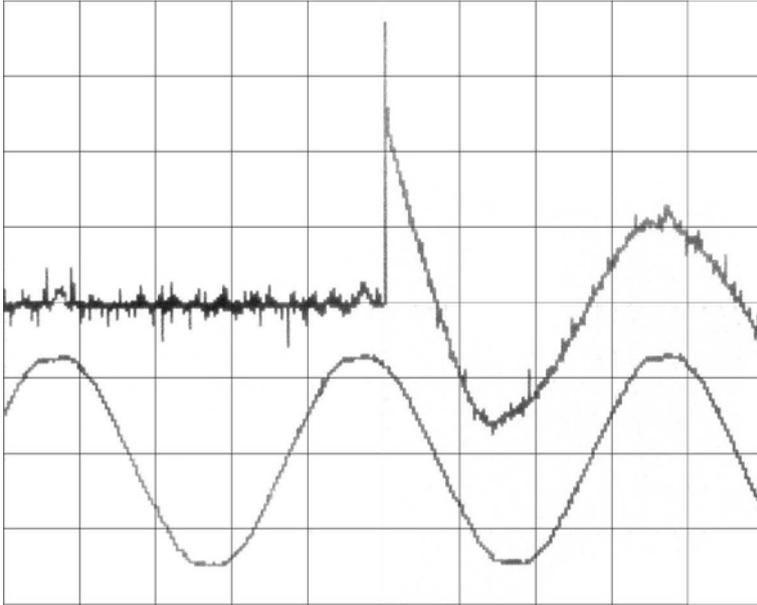


Fig. 8a. Switching on at the "wrong" point in time → current peaks and electric arc due to bouncing; 5ms/div. **(Top)** current passing through consumer load; **(bottom)** power voltage

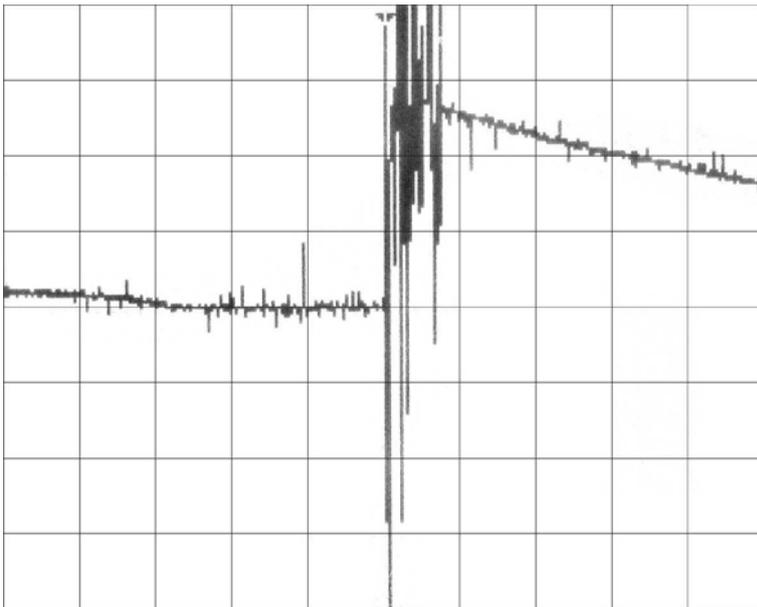


Fig. 8b. Switching on at the "wrong" point in time (**zoom**) → current peaks and electric arc due to bouncing; 250µs/div