Quenching Spark Gaps as Trigger Elements in High-Speed Cinematography

PAPER M—1

By FRANK FRÜNGEL and WALTER THORWART

Quenching spark gaps are comparatively simple and reliable devices for precision control of high-voltage pulses with great energy, particularly when operating at extremely high frequencies. Research was carried out into the parameters of pulse energy, pulsing rate, numbers and shapes of discs and gaseous filling. Among others, results showed that one pair of discs can stand a load of approximately 350 v. A quenching spark gap consisting of 25 discs therefore permits triggering of voltages up to 9 kv. The controllable frequency likewise increases with the number of discs. Thus it is possible to control a 50-kc/sec frequency with a 25-disc quenching spark gap.

When operating on the uncontrolled free-run principle, quenching spark gaps can even trigger considerably higher frequencies. A 25-disc gap thus reaches frequencies of up to 300 kc/sec. Even with such uncontrolled discharges a precise start and stop of, say, a flashburst can be ensured by means of heavy-duty thyratrons, one in series with the charging resistor and one short-circuiting the quenching spark gap after a delay. Pure hydrogen or helium proved to be most suitable for the gas filling, and with these gases, copper discs at a spacing of 0.15 to 0.2 mm gave best results.

The life of the discs depends on the degree of surface cratering. However as the quenching spark gap is demountable, one or several redressings of the electrode discs are possible. A cathode is not employed in this system, so there is no limitation of peak current, but only a thermal load limit which is computed according to specific temperature, mass of material and cooling coefficient of the filling gas. Thus, the quenching spark gap has a wide field of application as a trigger element of low resistance for high-frequency, high-energy pulses for feeding spark discharge lamps, air sparks or pulse transformers, etc.

ON MANY OCCASIONS we need to generate high-energy pulses in which both the voltage and the current take high values. Such pulses are needed for the production of "point" light sources such as those required for precise imaging by optical systems, for interferometry, and for Schlieren photography. Such pulses are also needed for energizing the primary of impulse transformers at high pulsing rates and with predetermined energy per pulse, in order to generate at the secondary either high-frequency high-voltage sparks, or x-ray flashes. They may also be used for operating Kerr cells at high-repetition rates, again making use of high-energy impulse transformers.

The present paper describes research into the parameters relating to pulse energy, pulsing rate, number of spark gaps, design of spark gaps and suitable filling gases. These parameters defy calculation since the factors influencing quenching spark gaps are so complex and varied that even approximate methods will not suffice. Some of these parameters may be mentioned: The different breakdown distances in relation to the plasma temperature; the cooling effect of the parallel electrodes; the de-ionization time in a low-pressure discharge zone (the thickness of the discharge zone layer mostly varies between 0.5 and 0.1 mm); the combined effect of a number of such spark gaps in series; and the effect of the impedance of the load on the system.

For these reasons a method of practical experiment was adopted. To begin with, air spark gaps in series with quenching spark gaps were examined. There were two electrode spacings in the quenching gaps, of 0.15 mm and 0.3 mm. The number of quenching spark gaps was between 1 and 4.

Figure 1 shows the experimental circuit, and some of the results obtained. We used two capacitors of 0.03 μf and 0.066 μf. These were discharged through the quenching spark gap into a resistor of 0.2 ohms. The size of this resistor roughly corresponds to the smallest resistance of high-pressure rare gas sparks; and the size of the capacitor corresponds to that of ultra-rapid flasher units.

We tried to determine the smallest value of the charging resistor at which the spark did not transform into a continuous arc. This would clearly set a limit to the system, since the resistance together with the capacitance determines the flashing rate.

The lefthand graph shows that the most effective range for quenching spark gaps lies between 1 and 4 elements, since above that number the curves flatten out. One can further observe that the smaller spacing of 0.15 mm, with 4 spark gaps and 0.066 μf, permits a charging resistor of 570 ohm, compared to 1800 ohm at 0.3 mm. As was to be assumed, the quenching effect increases with decreasing spacing. If, however, one compares the permissible resistance with varying capacitance, one finds that with identical quenching spark gaps (as, for example, in the last line of the lefthand table) the value of the resistance is inversely proportional to the value of the capacitance. Since the RC product gives the time constant of the spark gap circuit, this means that the quenching spark gap itself, and not the size of the capacitance, determines the frequency limit.

This may perhaps be explained by the theory that it may be immaterial for the de-ionization what number

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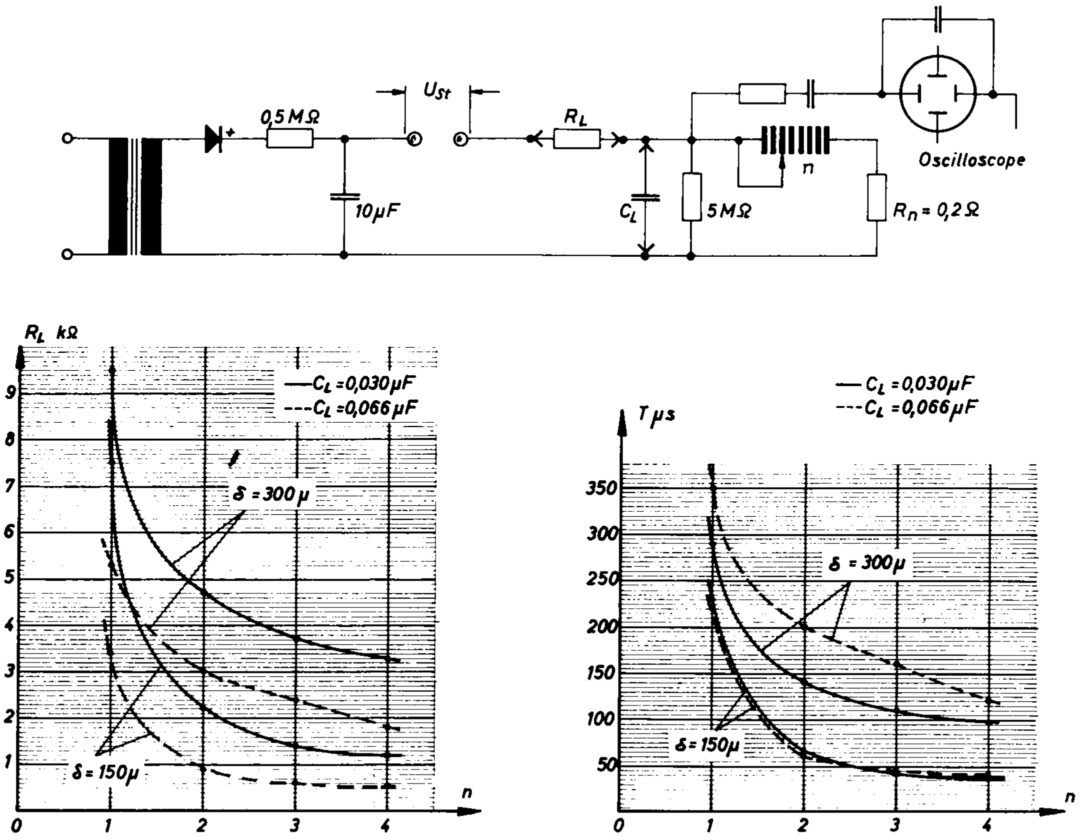
Presented on October 22, 1960, at the Fifth International Congress on High-Speed Photography in Washington, D.C., by Frank Früngel (who read the paper) and Walter Thorwart, Dr.-Ing. Frank Früngel GmbH., Sülldorfer Landstrasse 400, (24a) Hamburg-Rissen, Germany.

electrode spacing 150μ

$U_{St} \cong 7{,}0$ kV				
	$C_L = 0{,}030\mu F$		$C_L = 0{,}066\mu F$	
n	R_L min	T	R_L min	T
1	7,5 kΩ	230 μs	3,4 kΩ	220 μs
2	2,2 kΩ	66 μs	0,92 kΩ	61 μs
3	1,4 kΩ	42 μs	0,65 kΩ	43 μs
4	1,2 kΩ	36 μs	0,57 kΩ	38 μs

electrode spacing 300μ

$U_{St} \cong 7{,}0$ kV				
	$C_L = 0{,}030\mu F$		$C_L = 0{,}066\mu F$	
n	R_L min	T	R_L min	T
1	9,5 kΩ	290 μs	5,3 kΩ	350 μs
2	4,7 kΩ	140 μs	3,0 kΩ	200 μs
3	3,7 kΩ	110 μs	2,4 kΩ	160 μs
4	3,3 kΩ	99 μs	1,8 kΩ	120 μs



smallest charging resistor R_L(kΩ) vs. number of quenching spark gaps n.

smallest intervals (μs) between two pulses vs. number of quenching spark gaps n.

Fig. 1. Influence of number of spark gaps, capacitance and charging resistor on the quenching rate. In series with the quenching spark gaps is a resistor, R_n, to simulate the light-emitting spark resistance.

of spark channels may have been in existence for obtaining sufficient conductivity. The de-ionization may proceed at the same rate. To recapitulate, the quenching spark gap itself determines the RC product.

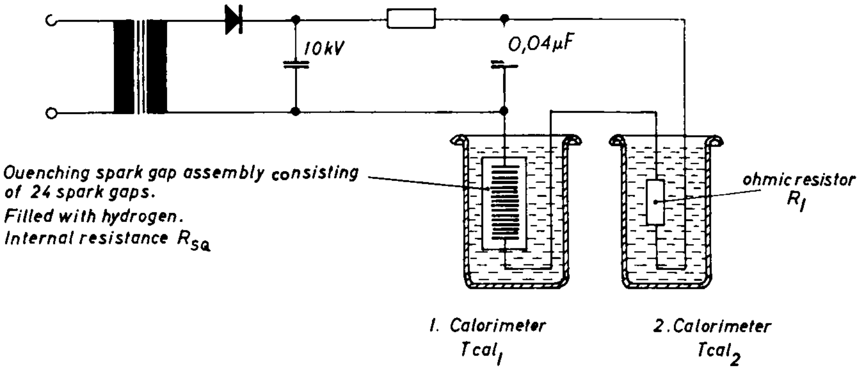
The righthand curves of Fig. 1 show the corresponding time constants. With 4 spark gaps one can already achieve 40 μsec, which would correspond to a possible sparking rate of 25,000/sec.

Figure 2 shows an experimental circuit used to investigate the operation of quenching spark gaps containing a larger number of discs — 25. The results show that the large number of spark gaps, which theoretically would permit a very high flashing rate, becomes impractical when the internal resistance is too high. For measuring power dissipation, resistors of various sizes (corresponding to possible values of spark resistances) were enclosed in a calorimeter; and the quenching spark gap was enclosed in another. In this experiment, the sparking rate as such was of no interest. The measurements, and the curves obtained, show the following:

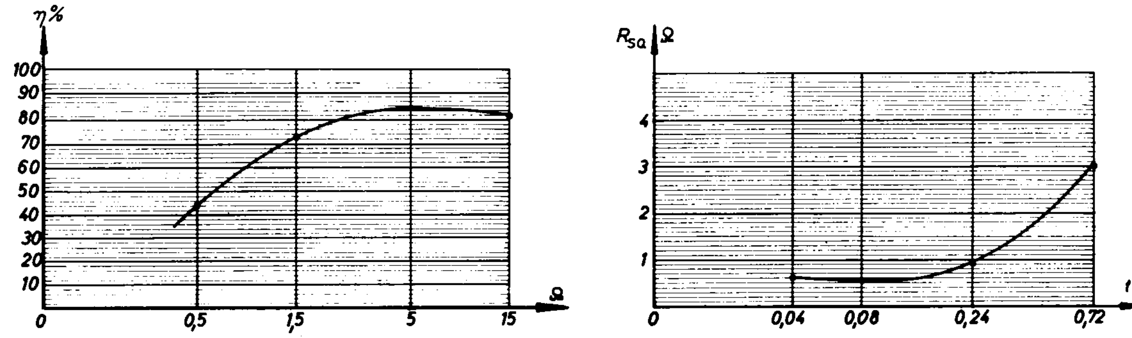
For values of load resistance up to about 1.5 ohms, the efficiency shows a linear increase. It then remains fairly constant at 80%, but shows a tendency to fall a little for values of load resistance over 10 ohms. At such large values of the load resistance, the discharges are of too long duration. The heat losses during the discharge time are significant, and the internal dissipation of the quenching spark gap increases.

The logical conclusion of this is that quenching spark gaps should only be used in such discharge circuits when the resistance of the spark is somewhere between 1 ohm and 10 ohms.

The curve of the righthand graph of Fig. 2 shows the internal resistance of the quenching spark gap as a function of the time constant. From this it is obvious that the resistance shows a steep increase as soon as the discharge continues for more than approximately $\frac{1}{4}$ μsec. The reason for this, as already mentioned, is that the de-ionization starts *during* the discharge. The mean free path of H_2 molecules at 1 atm is very much shorter than



R_1 (Ω)	Δ $T cal_1$ (°C)	Δ$T cal_2$ (°C)	Q = Energy total (kWs)	$\eta\% = \frac{\Delta T cal_1}{\Delta T cal_1 \bullet \Delta\ cal_2} \cdot 100$	$R_{sa} = \frac{T cal_2}{T cal_1} \cdot R_1$ (Ω)	$t = R \cdot C$ (μs)
15	23	5	31	82,0 %	3	0,72
5	50	9	66	85,0 %	0,9	0,24
1,5	27	10	41	73,0 %	0,55	0,08
0,5	25	31	62	44,7 %	0,6	0,04



Efficiency vs. ohmic resistance R_l (Ω). Measured in a discharge circuit consisting of Capacitor C = 0,04 μF, resistor R_l in series with the quenching spark gap which is filled hydrogen (spark width δ = .15mm). Charging potential V = 10 kV.

Internal resistance R_{sa} of the quenching spark gap (24 spark gaps, spark width δ = .15mm, gasfilling hydrogen) vs. time of one impulse $t = (R_{sa} + R_l) \cdot C$

Fig. 2. Efficiency and internal resistance of a 25-disc quenching spark gap as a function of spark resistance and the time constant in the discharge circuit.

the electrode spacing. However, a hydrogen molecule would travel approximately 1,500 m/sec, i.e., 0.15 mm in 0.1 μsec. It is striking that the quenching effect sets in after exactly this time, as can be seen from the curve.

In the case of the Strobokin flashlamp, for which these preliminary measurements were carried out, the current has risen to its maximum at 0.1 μsec. The spark resistance is roughly 1 ohm. It is operating exactly at maximum efficiency.

Basing our work on the experimental results, we endeavored to utilize the quenching effect of the spark gap to design a unit which could achieve the maximum possible flashing rate.

Until now, in the Strobokin equipment, we used an externally controlled quenching spark gap for rates up to 50,000 flashes/sec. The light flashes were emitted from a spark gap in an argon atmosphere. See, for example, the paper presented at the Third Congress.*

Figure 3 shows the circuit of an additional booster unit. In the basic equipment is a capacitor of 65 μf. There are two more in the booster unit. The power-supply charges all three to 9 kv. They are assembled as a Marx Generator, and switched in series by the tube type PL 522 and a spark gap.

These three capacitors, charged now in series to 27 kv, are discharged through any one of four high-voltage resistors into the Strobokin flashlamp, shown on the righthand side of Fig. 3. The basic capacitor for the lamp is 0.02 μf. Four additional capacitors of 0.04 μf can be switched in. There are thus 20 possible combinations of the product RC for presetting the flashing rate. The flash burst is started by the first thyratron type PL 522 (which is equivalent to a 5C 22). It is stopped by the second thyratron which shorts the supply through the resistor R10. Both these thyratrons are controlled by a delay device, or "retarder."

Figure 4 shows the complete setup; the righthand unit contains the cascade booster circuit.

Figure 5 shows a number of flashbursts photographed with the Strobodrum drum camera at 50, 100, 150 and 250 kc/sec. As can be seen, the sparking rate is not very regular, which was to be expected; but for most technical purposes it will be sufficient. If necessary, it is

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* F. Früngel, "High-frequency flash lamp," *Proc. 3rd Int. Congress on High-Speed Photography*, Butterworths Scientific Publications, p. 57, 1957.

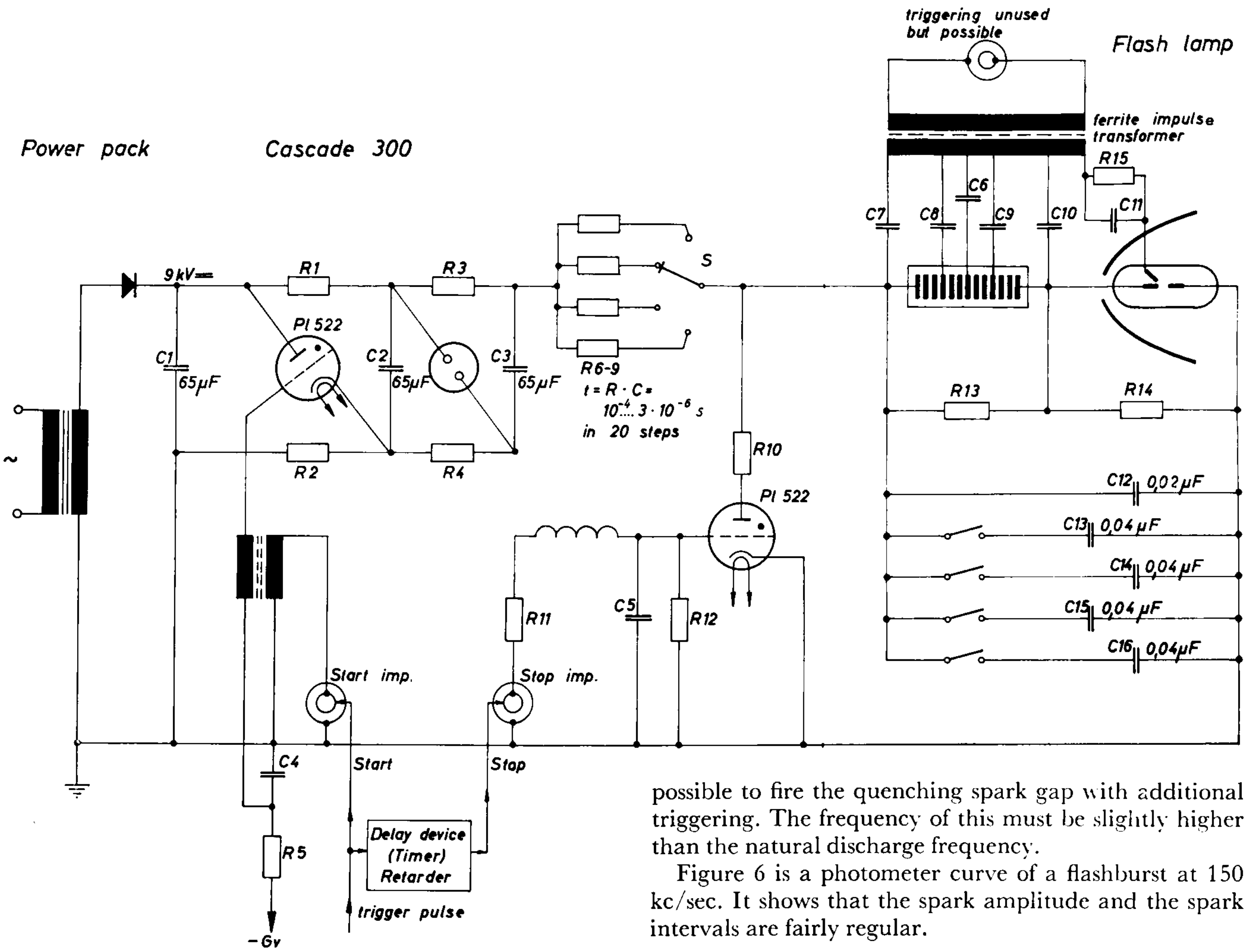

Fig. 3. Circuit of the Strobokin Cascade Booster for rates up to 300,000 flashes/sec.

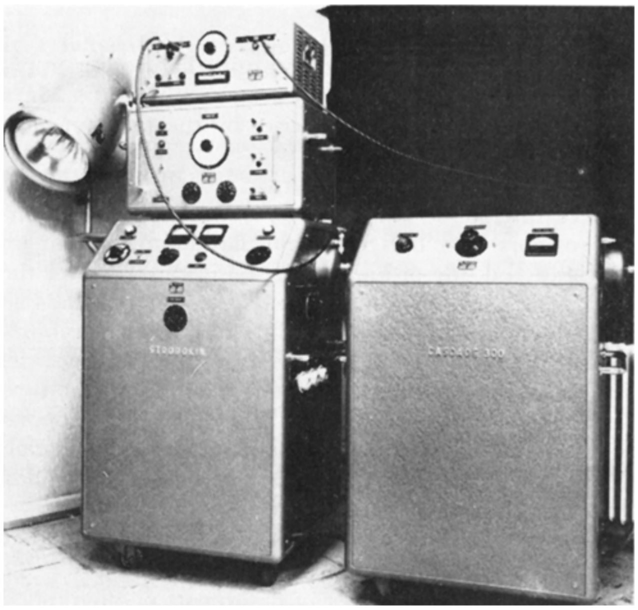

Fig. 4. Complete set of equipment for 300-kc/sec flashing rate. Left: the basic Strobokin unit which ordinarily can give controlled flashes at rates up to 50,000/sec. Right: Cascade Booster unit connected to the delay and timing device.

possible to fire the quenching spark gap with additional triggering. The frequency of this must be slightly higher than the natural discharge frequency.

Figure 6 is a photometer curve of a flashburst at 150 kc/sec. It shows that the spark amplitude and the spark intervals are fairly regular.

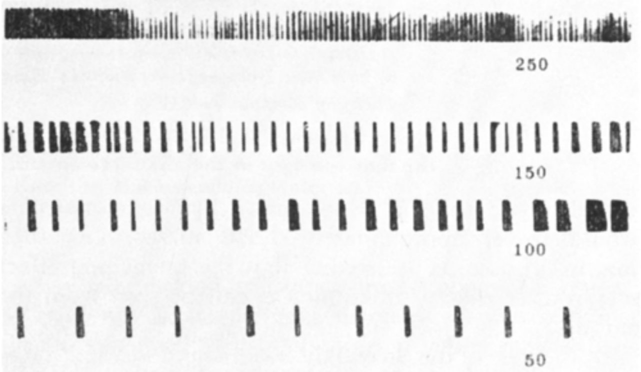

Fig. 5. Four drum camera test films taken at 50, 100, 150 and 250 kc/sec. The object photographed was a thin slot.

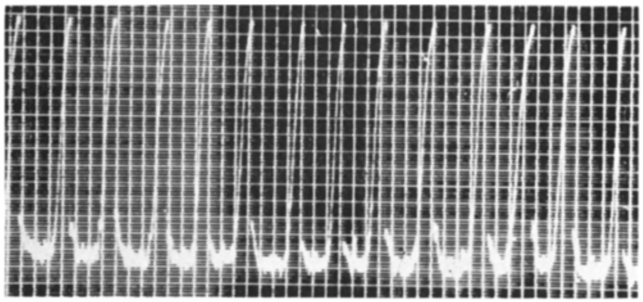

Fig. 6. Photometer curve of a 150-kc/sec flashburst. Spark intervals and amplitudes are sufficiently regular for many technical purposes.