Gas-Triggered Inverse Pinch Switch*

R. G. JAHN, W. VON JASKOWSKY, AND A. J. CASINI

Guggenheim Laboratories for the Aerospace Propulsion Sciences, Aeronautical Engineering Department, Princeton University, Princeton, New Jersey

(Received 6 August 1963)

AN inverse pinch, triggered gap switch developed by Cavalconte[1] has been modified by the addition of a discharge constrictor and an ablating inner column insulator, and has been converted to gas-triggered operation. In this form it provides low inductance, low noise switching of a 15-μF, 10-kV capacitor bank, over extended periods of service. Cavalconte's original design introduced two advantages of coaxial, inverse pinch discharge geometry to high power switching; namely, a low inductance initial discharge current configuration[2] and a minimization of electrode erosion by the outward propagation of the current sheet as the discharge developed. When employed as a switch for a capacitor-driven, large radius pinch machine,[3] however, this device displayed three undesirable characteristics: (1) The electrical trigger pulse applied to initiate the breakdown of the switch gap distorted the early portion of high-gain oscilloscope traces of various diagnostic instrumentation. (2) The initial low inductance discharge pattern rapidly progressed to an excessively high inductance configuration as the current sheet expanded radially all the way to the walls of the switch container. (3) The gap developed a tendency to premature breakdown after some ten or twenty discharges.

The initiation noise has been considerably reduced by converting the switch to gas triggering. Here the gap between the electrodes is evacuated to a pressure substantially below the lower branch of the Paschen curve ($\sim$0.1 mm Hg-mm at 10 kV) where it withstands the full bank voltage. To initiate the discharge, a small puff of argon is admitted through a tiny orifice in the switch chamber, so placed that the gas density in the gap increases symmetrically to a level sufficient to sustain breakdown. This mode of triggering invariably yields the desired low inductance breakdown configuration with a minimum of initiation noise.

The excessive outward excursion of the discharge current sheet, with its attendant inductance increase, can be limited to an acceptable radius by surrounding the electrodes and gap with a cylindrical Plexiglas envelope as shown in Fig. 1. Access for the gas triggering pulse to the gap is then provided by a ring of small holes radially through this constrictor envelope, midway between the electrode surfaces. Fears that the Plexiglas might suffer excessive erosion in the process of containing the discharge have proved unwarranted. The original envelope has survived several hundred discharges without sustaining significant damage. With the addition of such a constrictor, the inductance of a typical 4-cm gap switch is reduced by a factor of about $2\frac{1}{2}$.

The tendency to premature breakdown was associated with a deposition of a conducting layer, presumably aluminum from the electrodes, on the surface of the insulator surrounding the center column. This insulator has conventionally been Pyrex or a refractory dielectric, such as boron nitride. The constrictor envelope described above, which also spans the electrode gap, however, had for convenience been machined from Plexiglas. The latter displays no tendency to accumulate a conducting layer. The speculation is thus that the softer material ablates enough when exposed to the discharge plasma that it keeps itself comparatively clean of foreign deposits. Indeed, if the inner insulator is replaced by Plexiglas, the lifetime of the switch abruptly increases to at least a few hundred discharges.

The present design of the switch is sketched in Fig. 1. The axial gap spacing between the electrodes is a compromise between minimizing the discharge length (and thereby linearly the inductance) and retaining the symmetrical and diffuse discharge structure. Discharges across shorter gaps than the 4 cm currently used at this voltage are found empirically to develop instabilities toward concentrated arcs, with their associated high resistance, high inductance, and electrode surface damage. Similar arc concentrations are found when the switch is triggered across

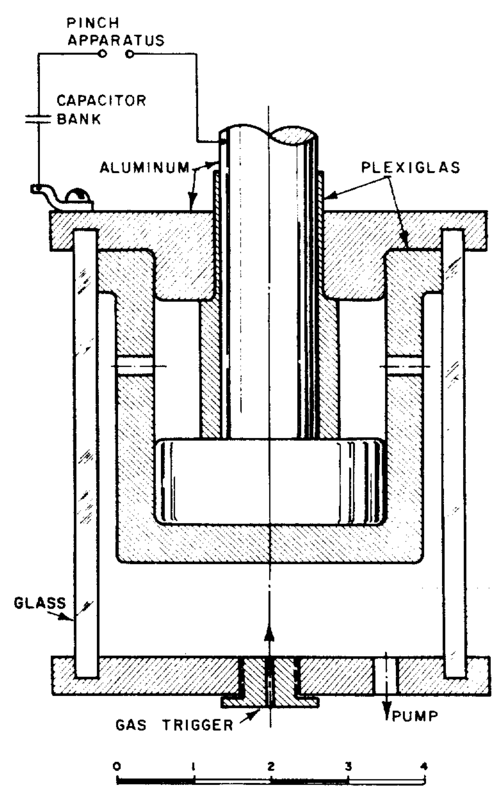


FIG. 1. Schematic diagram of gas-triggered, inverse pinch switch.

the high pressure branch of the Paschen curve ($\approx$500 mm Hg-mm at 10 kV). As sketched, the switch contributes about 4×10^{-9} H to the circuit inductance, and less than 0.005 Ω to the circuit resistance.

Study is currently in progress of the influence of the various radii—inner conductor, column insulator, and constrictor—on the operation of this type of gas-triggered discharge, in an effort further to optimize its performance as a switch.

* Supported by NASA grant NsG-306-63.

[1] C. Cavalconte, "Development of Coaxial Triggered Gap Switch," Republic Aviation Corporation PPL-TN-60-12 (August 1960); "Coaxial Triggered Gap Switch," 4th Symposium of Engineering Aspects of Magnetohydrodynamics, Berkeley, April 1963; U. S. Patent #3,046,436 (July 1962).

[2] O. A. Anderson, Phys. Fluids 1, 489 (1958).

[3] R. G. Jahn and W. F. von Jaskowsky, AIAA J. 1, No. 8 (1963).

Wide Range Current Regulator

Howard H. Rogers

Research Department, Rocketdyne, Division of North American Aviation, Inc., Canoga Park, California

(Received 24 June 1963; and in final form, 2 August 1963)

THIS note describes a simple current regulator which was designed to have low drift over a wide current range as a result of the use of the "complementary Darlington" connection. The basic principles of a current regulator can be described in terms of a common base amplifier[1] or a common emitter amplifier with feedback.[2] Since the explanations in the above references and other literature[3] are adequate, no attempt will be made to repeat them here.

The basic circuit (Fig. 1) is capable of superb performance at low current levels. However, the temperature sensitivity of the base-emitter junction potential, which causes a drift in the regulated current, is an undesirable feature. Specifically, the drift of the base-emitter potential is about 2 mV/°C. If stability is an important consideration, the power dissipated in the transistor must be kept at a low level.

The degree of current regulation obtained in the basic current regulator (Fig. 1), if thermal considerations are neglected, is dependent upon the transconductance ($\Delta I_C/\Delta V_{BE}$) of the transistor. The transconductance is generally increased[2] by the use of the Darlington compound

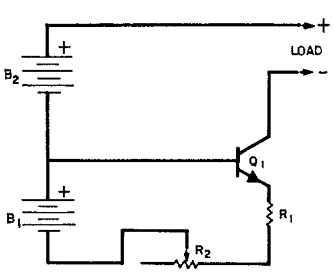
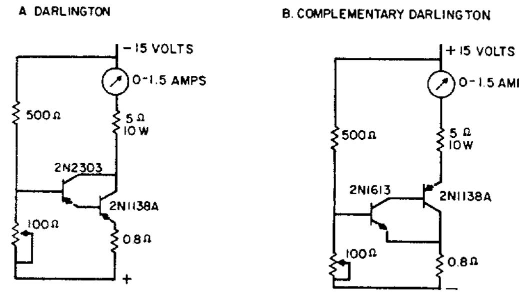


FIG. 1. Basic circuit.



h_{FE} OF 2N1613 AND 2N2303 MATCHED TO ± 5 PERCENT
2N1138A MOUNTED ON 4 3/4 X 4 X 1/16 INCH ALUMINUM

FIG. 2. Circuit configurations.

connection [Fig. 2(a)] which, however, retains the thermal problems associated with the basic circuit. Experimentally, the thermal drift was found to be excessive (Fig. 3). In contrast, it can be seen that the complementary Darlington circuit [Fig. 2(b)] presents an almost ideal solution (Fig. 3). In this complementary configuration, the base-emitter junction of the power transistor, which is subject to heating, is separated from that part of the circuit which determines the magnitude of current flow. The small amount of drift which remained was apparently a result of a trace of heat dissipated by the 2N1613. If an additional transistor is needed to further increase regulator performance and/or current capability, it can be used in a conventional Darlington connection with the power transistor 2N1138A. Their base-emitter junctions would not be in the reference loop and, therefore, would not cause additional drift.

A further advantage of the separation of the main current handling loop from the reference loop is the small change in base-emitter voltage of the control transistor with collector current, compared to the very large change in base-emitter voltage of the power transistor with collector current. The current regulation of this complementary configuration is, therefore, inherently better.

The change in output current caused by a change in ambient temperature has not been considered because this regulator circuit was designed for use in laboratories where only moderate ambient temperature excursions are expected. If large ambient temperature changes are to be a factor in design then a temperature-compensated reference loop would be needed.

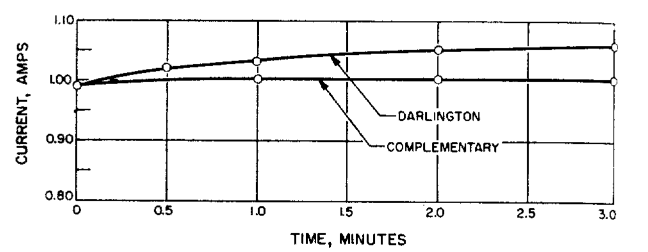


FIG. 3. Effect of circuit configuration on drift.