A FAST RISE TIME HIGH VOLTAGE PULSE BURST GENERATOR

by

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Summary

A novel type of pulse generator for kicker magnet excitation is described. Series connected thyatrons and coaxial lines are used to produce a burst of four 20 kV, 800 A, fixed length pulses of fast rise and fall time. Inter-pulse spacing is independently adjustable, typically between 200 ns and 20 μs. The coaxial lines are simultaneously resonantly charged to 60 kV in 1 μs and the subsequent triggered discharge of each Pulse Forming Network (PFN) initiates the pulse bursts which may be produced at a repetition frequency of 100 Hz. This paper presents some of the results obtained with a prototype pulse generator.

Introduction

CERN is currently engaged in the Large Electron-Positron storage ring project (LEP). Electrons and positrons, accelerated in purpose-built linacs, will be accumulated in a new Electron Positron Accumulator ring (EPA), before being transferred to the LEP main ring via the existing Proton Synchrotron (PS) and the Super Proton Synchrotron (SPS).

From EPA, the eight bunches of electrons or positrons, accumulated during periods of about 0.6 and 12 s, must be ejected in succession towards the PS ring. The bunches two circulating in EPA have a spacing of 12 ns and pass the ejection point every 25.4 ns. For synchronisation with the transfer process every fifth bunch must be extracted, giving a bunch to bunch spacing of ~264 ns in the transfer line. These batch transfers take place at regular intervals, the frequency being determined by the PS cycling rate.

In order to extract each bunch without greatly disturbing the two neighbouring bunches, a transmission line type kicker magnet with field rise and fall times of ~25 ns is to be used. To drive this magnet a high voltage pulse generator delivering a 52.4 ns FWHM output pulse of 20 kV, 800 A, with rise and fall times of ~15 ns is required.

The eight bunches of each batch could be extracted by eight such generators pulsing dedicated magnets at intervals of 264 ns. Savings in cost and occupied EPA straight sections can be made, however, if one magnet can be pulsed repeatedly by the same generator. The pulse generator described in this report produces four such pulses of the required quality with no loss of operational flexibility as regards individual pulse amplitude and timing.

Pulse generator design

In the basic high voltage fast pulse generator of Fig. 1, a delay line or PFN of characteristic impedance $Z_0$ and delay $T_1$ is charged to a voltage $V$ and rapidly discharged via a transmission line of transit time $T_2$ into a matched load, producing a pulse of width $2T_1$ and amplitude $V/2Z_0$, delayed by $T_2$.

The switch $S_1$ is normally a hydrogen thyatron and the PFN is charged positively, with the thyatron cathode connected towards the load.

Fig. 1. Basic high voltage pulse generator

Four similar pulse generator cells may be connected in series, as is shown in Fig. 2. However, in order that the pulse furnished by each cell appears in the load with independence of timing and without undue attenuation or distortion, certain fundamental problems must be solved:

Independence of timing

In Fig. 2., $S_1$ is assumed to be triggered at time $t_1 = 0$. At time $t_1 + T_1$ the negative going fast wave front from $S_1$ will double at the cathode of $S_2$, bringing the cathode to zero potential and leaving the $S_2$ trigger grid at positive potential due to its capacitance to ground, thus discharging PFN2 via PFN1 and $S_1$ towards the load. This effect is repeated down the chain, all PFN's discharging sequentially into the load with total loss of control over the triggering of $S_2$, $S_3$ and $S_4$.

This problem can be solved by reversing the connections to the thyatrons, as is shown in Fig. 3., so that the wave front arriving from $S_1$ strikes the $S_2$ anode, rather than the cathode.

Fig. 2. Series connected PFN-switch cells and load pulse voltage +ve polarity

Fig. 3. Series connected PFN-switch cells and load pulse voltage -ve polarity

Fig. 4. Series connected PFN-switch cells and load pulse voltage -ve polarity
With negatively charged PFN's, the wave front is positive going and the capacitive feedthrough from anode to control grid may be prevented by using a screen grid (or pentode) thyratron. If the screen grid is connected via a low inductance link to the cathode, S2 will remain untriggered whilst S1 discharges PFN1 into the load to produce the first pulse. Since the PFN's must now be charged negatively, the pulse generator output pulses are negative. This requires reversal of the usual magnet connections.

**Pulse distortion**

Whilst the first pulse produced by S1 and PFN1 traverses only the transmission line before reaching the load, the fourth pulse produced by S4 and PFN4 must traverse in addition PFN3, PFN2, PFN1, and also S3, S2 and S1. If the fourth pulse is to have low distortion, very low attenuation PFN's are necessary and the pulse transmission performance of the switches, with the thyratron in the post-switched state, must be appropriately good.

Computer modelling of the equivalent circuit of a prototype switch showed that the distributed inductance and capacitance of the various coaxial high voltage connections at the switch input and output of the conducting thyratron do not unduly perturb the transmitted pulse. However, the stray capacitance to ground of the various thyratron heater supply transformers and grid trigger circuits gives rise, on the computer model, to serious distortion of the rise and flat top of the traversing pulse by resonance with the inductance of the connection leads to these circuits. Increasing this connection inductance from 40 nH to 200 nH by means of a ferrite cored inductor makes the parasitic resonant frequency several orders of magnitude lower than those found in the pulse. The distortion then disappears.

Step pulse measurements on a prototype switch have confirmed generally the results of computer modelling. Fig. 4a, shows the incident and reflected parts of a 2 ns incident step at the switch input, with a simulated conducting thyratron (1 cm diameter tube short-circuit) and no thyratron heater and trigger connections. The reflection can be shown, by timing relationship, to come from the coaxial HV plug and socket connections to the switch input and output. Fig. 4b, shows the transmitted waveform.

**Circuit operation**

Fig. 7, shows the final prototype pulse generator circuit including a simplified circuit of the resonant charging power supply for the PFN's. A very important benefit of the architecture of this circuit, which is fundamental to its performance, is the fact that all PFN's are charged simultaneously, and thus S2, S3 and S4 are subjected to forward voltage for only a fraction of a microsecond before being triggered. The normal law relating ionisation time, internal gas pressure and voltage hold-off is thus defeated, and very high gas pressures, giving less than 10 ns ionisation times, are permitted. This does not apply to S1, which has to hold off the full PFN charging voltage of 40 kV for several milliseconds. This thyratron is not of the pentode type, is intrinsically faster and, from the rise time point of view, is placed at the privileged end of the generator.

For the above mentioned reasons, the generator can deliver a fourth pulse which has faster rise and fall times than the first pulse.
Resonant PFN charging

The PFN charge is initiated by the trigger to the thyristor TH1, which partly discharges $C_0$ into the PFN via a 300 to 1 step up transformer TRI. An HT diode chain D1 maintains the HT flat top on the PFN's, whilst the transformer secondary voltage oscillates during core recovery. Components RB and LB have been added to the conventional circuit in order to enable the transformer core to recover within 6 ms.

Fig. 8a shows the TRI primary current and Fig. 8b, the corresponding PFN voltage waveform, while Figs. 9a and 9b show respectively these waveforms for several cycles, when the pulse generator is producing bursts of four pulses at 100 Hz repetition rate.

![Fig. 8a. 50A/div](image)

![Fig. 8b. 20KV/div](image)

![Fig. 9a. 100A/div](image)

![Fig. 9b. 10KV/div](image)

**Fig. 8a.** TRI primary current
**Fig. 8b.** PFN charging voltage at 100 Hz

**Fig. 9a.** TRI primary current
**Fig. 9b.** PFN charging voltage

**Fig. 10. Typical high voltage pulse burst**

**Fig. 11. Details of the four high voltage pulses**

From the computer model a rather smaller pulse tail (25%) was expected, due to oscillations between cathode stray capacitance and the isolating inductor. The higher "tail" after the first pulse is as yet unexplained and requires further investigation.

The maximum pulse to pulse interval required in our application is $\leq 925$ ns. However, it is of interest to know the maximum possible interval between pulses which can be obtained without degradation in pulse shape. This maximum interval is determined mainly by deterioration of the pulse transmission capability of the preceding thyatron due to de-ionisation.

Fig. 12 shows the variation in the quality of the second pulse with a delay between first and second pulses of 0.8 ms (top trace), 20, 40 and 80 ms. The distortion of the pulse from S2 when traversing the partly de-ionised thyatron S1 results in a reflection which appears in the load with a delay of 2(t1+t2) after the incident front of the second pulse, as shown in Fig. 13, lower trace.

![Fig. 12. Waveform of second pulse for various delays](image)

A typical burst of four pulses with pulse to pulse interval set at $\geq 370$ ns is shown in Fig. 10., where the pulse signals are inverted for ease of observation. Fig. 11. shows the same four pulses time shifted and vertically overlaid. The first pulse (top trace) has longer rise and consequently longer fall time and also exhibits a more pronounced "tail" than the following three pulses.
Fig. 13. shows second and third pulses with a delay of 370 ms between first and second pulses (top trace) and with a delay of 40 μs between first and second (lower trace). It may be observed that the passage of the second pulse, distorted by the partly de-ionised Si, has re-established Si ionisation; thus passing the third pulse without noticeable distortion. Little difference could be found between tetrode and pentode thyatrons of types EEV CX1154 and CX1154C, respectively.

From the above observations it is concluded, that a pulse to pulse interval of at least 20 μs does not result in serious degradation of pulse quality.

A second upper limit for pulse separation would be due to the voltage hold-off capability of the screen grid thyatrons. These are required successively to hold off the full PFN voltage after the preceding PFN is discharged. Tests showed this limit to be above 200 μs under the present test condition. The maximum value in this generator could not be determined due to excessive PFN voltage run down during the longer pulse to pulse intervals.

Operational Experience

The four pulse burst generator has run faultlessly at 40 kV PFN voltage for several weeks at 100 times its design repetition rate (1 Hz).

Rise times of individual pulses, the pulse to pulse interval and the PFN charging voltage are easily adjustable from the remote control racks during operation.

Further development

The prototype generator (see Fig. 14.) used four thyatron switch housings taken from existing, larger 80 kV systems. Some improvement in pulse quality may be expected from an optimised switch housing, using input and output high voltage connections of better impedance match.

The cause of the higher than expected post pulse tail is to be investigated, and the level reduced, if possible, to the (2±3)% predicted by computer simulation.

A new trigger pulse amplifier producing a 4 kV peak pulse is under development. The switching jitter of the pentode type thyatrons can thus be further investigated.

The maximum tolerable amplitude difference from pulse to pulse within a burst has yet to be determined. For EPA operation variations up to 8 10% are expected to be acceptable.

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References

1. The chain of LEP injectors, LEP Injector Study Group, CERN/PS/DL 83-23