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Abstract

This paper describes a simple and reliable thyatron circuit capable of generating high energy pulses at repetition rates of 5000 per second or higher. Design considerations and factors limiting the maximum repetition rate are discussed.

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Introduction

The need for a pulse generator capable of operating at high repetition rates has become increasingly evident in the fields of high energy microwave and radar systems, as well as in applications requiring multiple triggering pulses or the generation of staircase voltage functions. The design of high-repetition-rate pulse generators utilizing hydrogen thyratrons has always been limited by the basic difficulties of providing time for deionization of the tube, and yet providing a fast method of recharging the capacitor or pulse-forming network. These difficulties are overcome by utilizing the unique saturation properties of Deltamax magnetic material for the core of a saturable charging reactor. Deltamax is characterized by a hysteresis loop which is almost a perfect rectangle, so that only a small magnetizing force is required to drive it from saturation in one direction to complete saturation in the opposite direction.

Theory

The basic circuit is shown in Fig. 1 and the complete circuit with refinements in Fig. 2.

Tube: 5C22 hydrogen thyratron

C_1 : 0.06 μ F, 16 000 V

C_3 : 0.5 μ F, 5 000 V

Diode: ST-7A, International Rectifier

Load: 4-to-1 transformer, producing 1000 A

through a 2.5-ohm load. Reflected resistance
is 40 ohms.

T_1 : Deltamax tape-wound core (Arnold Engineering Co.,
3T6379-D2);
outside diameter is 5 in.,
core area is 1 in.²,
300 turns #22 enameled wire;
unsaturated inductance is approximately 40 H,
saturated inductance is approximately 1 mH.

Assume that the thyatron has been triggered and that the capacitor C_1 has discharged its energy into the load, leaving the voltage of the thyatron plate and the capacitor close to ground potential. Assume also that the core of the transformer T_1 is saturated in such a direction as to exhibit a high impedance to the flow of current into C_1 or through the tube. The thyatron, used with this load and these circuit parameters, requires 65 μ sec deionization time, during which time the available current through it must be kept below the 50 mA that would maintain ionization. To allow for some safety factor, the transformer was designed to saturate not sooner than 90 μ sec after the capacitor has discharged. The voltage across the transformer primary winding is essentially constant during this time, and the current through it is $i = Vt/L = 11.25$ mA, well below the 50-mA value mentioned previously.

As the core reaches saturation, the value of inductance suddenly drops to its air-core value of 1 mH, and the capacitor becomes charged in 25 μ sec to approximately twice the power supply voltage, in accordance with well-known principles of inductive charging.

When the capacitor has been charged, the transformer sees almost the full power supply voltage impressed across it, but in the reverse

direction, and the core proceeds to saturate in the opposite direction in a time of $110 \mu\text{sec}$. The time is slightly longer because the impressed voltage is less than the full power supply voltage. At the end of this $110\text{-}\mu\text{sec}$ interval, the core is again saturated in the direction to offer a high impedance to the flow of current through the thyatron. This is the optimum time to trigger the tube again.

To operate the thyatron as a free-running relaxation oscillator, a trigger pulse is easily obtained at this time from a 60-turn secondary winding, which produces a voltage at the instant of saturation because of the rapid change of current in the primary winding. This trigger voltage is impressed on the grid through an RC differentiating circuit, whose time constant is short compared with the deionization time of the thyatron, so that the grid is not held in a conducting condition while the gas in the tube is undergoing deionization. The trigger then starts a new cycle of operation. Voltage waveforms are shown in Fig. 3.

This circuit was designed to produce a burst of pulses as triggers for 80 ignitrons, the burst to last 4 msec and to be repeated once every 2 min. A large capacitor ($30 \mu\text{F}$) charged to 5000 V is a convenient power supply in this case, but to prevent damage to the components in case of a misfire, a $100\text{-}\Omega$ 200-W resistor is provided to absorb its energy. The capacitor C3, containing much less energy, completes the fast inductive charging circuit. The diode across the load reduces the negative voltage back-swing at the plate of the tube due to inductance in the load, thus effectively preventing the well-known voltage buildup on the capacitor normally associated with resonance charging.

When the thyatron has been operated as a self-triggered relaxation oscillator or as a burst pulser, the direction of the final core saturation is not known. This difficulty is overcome by applying the power supply voltage suddenly to the capacitor C3 through a high voltage switch or a suitable thyatron. The sudden application of voltage causes the capacitor C1 to go through a complete charging cycle, regardless of the original saturation direction of the core. Therefore, the core direction is always correct when the thyatron receives its trigger pulse from the transformer T1. The timing of any associated circuitry can also be derived from this trigger pulse.

Modifications

The thyatron can be triggered at a fixed or variable repetition rate from an external source by the addition to the circuit of a diode, a capacitor, and a resistor. The secondary winding of the transformer T1 is not used (see Fig. 4).

The circuit operation begins in the same manner as described previously. Ninety μsec after the thyatron has been triggered, the core of the inductor saturates, and the voltage on the capacitor C1 rises rapidly to approximately twice the power supply voltage. It remains there for an indefinite time (neglecting leakage), because the discharge path is blocked by the diode. But the core of the inductor is saturated in the wrong direction for another thyatron operation at this time. However, the saturation direction is easily reversed by the flow of current through the inductor from the capacitor C4, which became charged to the reverse power supply voltage during the charging of C1. The time for core saturation is 110 μsec . The small current flowing during this time produces

negligible change in the voltage across C4 or the resistor R3 compared with the power supply voltage. Therefore, the saturation process takes place virtually as fast as in the burst pulser described above, where these elements are not in the circuit. Upon saturation, C4 quickly discharges through the inductor. Overshoot or ringing is prevented by the 1000- Ω resistor R3, whose resistance is slightly greater than the value for critical damping of the circuit. The inductor is now in a condition to offer a high impedance to current flow through the thyatron, which may again be triggered when desired. In this mode of operation, the final saturation direction of the core is always correct for subsequent triggering of the thyatron. The sudden application of voltage to C3, mentioned above, is therefore unnecessary, and the high voltage switch may be eliminated.

Design Considerations

No serious attempt was made to increase the repetition rate of the circuit or to determine the limitations of the Deltamax core. The number of coil turns was reduced from 300 to 200 with the expectation that the saturation times would be reduced to two-thirds of their original values. The 90- μ sec time was decreased, as expected, but the 110- μ sec time actually was increased, resulting in very little net gain. The decrease in coil turns had resulted in a higher ratio of resistance to inductance, and because of the extra losses the voltage swing of the capacitor C1 above the power supply voltage was less. This resulted in a lower reverse voltage to saturate the core and a corresponding increase in the time. This suggests that the wire size is an important design factor, because the resistance increase due to skin effect is rather high, even at frequencies corresponding to the 25- μ sec charging time. Also, the coil

should occupy as much of the core length as is practical, in order to minimize the air-core inductance.

Conclusions

It seems evident that with careful design the time between pulses can be reduced to a value only slightly greater than twice the deionization time of the thyatron, and that the system described above therefore provides a simple, fast, and reliable method of charging thyatron pulse systems.

Acknowledgment

The author wishes to express his appreciation to Mr. William R. Baker for his encouragement and helpful suggestions, and particularly for his proposal of the method for initiating operation of the burst pulser.

Legends

Fig. 1. The basic circuit.

Fig. 2. The complete circuit with refinements.

Fig. 3. Voltage waveforms.

Fig. 4. A modified circuit.

Fig. 1

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Fig. 2

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Fig. 3 XBL671-324

Fig. 4

XBL671-28

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