Finally, it is proposed that consideration be given use of the wave factors defined herein, to characterize and to specify devices, instruments and systems, not necessarily limited to those employing particular types of rectifiers and/or filters. Wave factors directly relate the input current (peak, rms or average as appropriate) to that which would flow into a purely resistive load consuming the same power. Thus, knowledge of rms wave factor |WF| and peak wave factor $\widehat{\mathrm{WF}}$, can be of material assistance in designing power/current drive capabilities as well as cable sizes and layouts in complex installations.

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Generation of High Magnetic Fields Using Thyristors

S. NAGABHUSHANA, S. KRISHNAN, AND G. SURYAN

Abstract—**This paper describes the use of high-power thyristors in conjunction with a low-voltage supply for generating pulsed magnetic fields. A modular bank of electrolytic capacitors is charged through a programmable solid-state power supply and then rapidly discharged through a bank of thyristors into a magnetizing coil. The modular construction of capacitor banks enables the discrete control of pulse energy and time. Peak fields up to 15 telsa (150 KOe) and a half period of about 200 microseconds are generated through the discharges. Still higher fields are produced by discharging into a precooled coil (77°K). Measurement method for a pulsed field is described.**

INTRODUCTION

PULSED high magnetic fields can be produced by rapidly discharing the charged capacitors into an optimally designed solenoid coil. High-voltage capacitors of comparatively low values have been generally used [1–6] along with ignitrons for this purpose. This paper discusses the use of high-power thyristors and electrolytic capacitors to generate peak fields in excess of 10 telsa (100 KOe). The capacitor banks are modular in construction so that faulty capacitors can be readily replaced and the discharge energy and time can be controlled in steps. There is a need, however, to store more energy than is actually used up in the coil because of inherently large leakage of electrolytic capacitors.

DESCRIPTION

The system consists of a charging voltage source, a bank of capacitors, a high current switching mechanism and an optimal coil into which the capacitor is discharged within a few microseconds. The advantages of pulsed field such as simplified coil design, limited power demand from a power source etc., have been discussed in great detail in the literature [7–9]. One of the major problems in the pulsed field is the design of a high-current switch which has been realized through the use of ignitrons and triggered spark gaps. With the development of high-power thyristors it is feasible to design a high-current switch capable of interrupting pulsed high currents. The thyristor has been used earlier [10] as a switching element to generate fairly low fields, around 60 KOe, lasting several milliseconds. A single thyristor with a surge current rating of 3500 amperes was used to discharge a capacitor bank of 0.05 farad at 450 volts and the peak current was limited to 2/3 the peak one cycle surge current. Detailed analysis (to be published) indicates that a current of the order of surge current can be repetitively passed through the device for durations shorter than a half cycle at power line frequency using the transient thermal impedance concept [11]. In the present design ten high power thyristors (International Rectifier type no. 151IRC50) are used. Each thyristor has a surge current rating of 3000 amperes. Repetitive currents as high as 3000 amperes have been safely passed through this device for a duration lasting 2 to 3 hundred microseconds without exceeding the maximum junction temperature and experiencing any catastrophic failures. Certain precautions are, of course, observed.These include hard driving of the gate and allowing adequate time between discharges for cooling the junction to ambient temperature.

Fig. 1 is a block schematic of the 100 KOe pulsed magnetic field unit. The capacitor bank consists of 10 modules each of 10,000 microfarad rated at 500 V. dc corresponding to a total stored energy of approximately 10,000 joules. A programmable thyristor phase controlled dc power supply [12] charges all the ten banks to a preset voltage. Each module has a thyristor (151RC50) securely mounted on a heavy-duty busbar. The capacitors and

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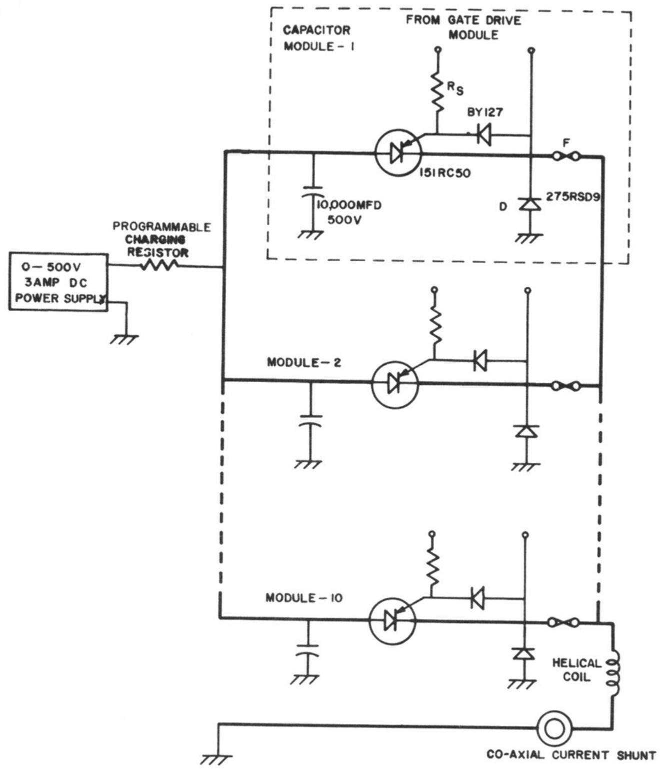

Fig. 1. Block schematic of 100 KOe pulsed field system.

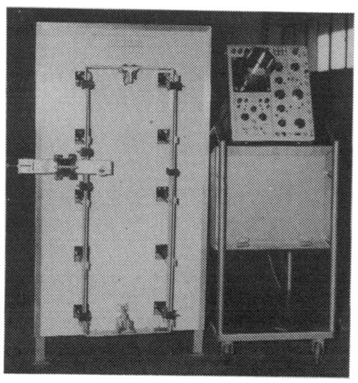

Fig. 2. Photograph of the setup.

thyristor are connected to a strip transmission line consisting of two heavy-duty busbars separated by 1/32 inch fiberglass insulation strip, as indicated by the accentuated line, in order to reduce the bank inductance. Such an arrangement resulted in a modular bank with an effective inductance of 4 microhenries and a resistance of 25 milliohms. A high rupturing capacity fuse F of appropriate rating is included in the discharge path to protect the thyristor in case of excessive current such as might result from a short circuit coil. A freewheeling diode D prevents excessive reverse voltage on the capacitor and extends the effective time during which the mangetic field is available.

The ten modules are interconnected by a low-inductance busbar transmission line with provision to mount the coil and a coaxial current shunt as shown in Fig. 2. The helical coil (Fig. 3) is turned out of solid copper and has

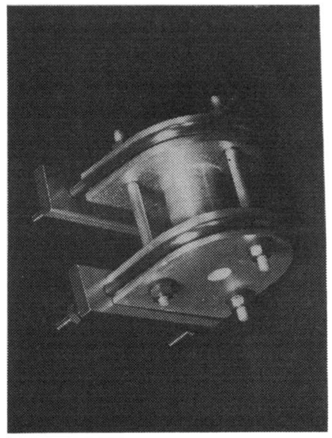

Fig. 3. Photograph of helical copper coil.

the following optimized constants: $N = 40$ turns, $\alpha = 2.5$, $\beta = 3.0$, $a_1 = 0.5$ cm 12 oersted/amp. and is designed for a peak field of 200 KOe. The turns are insulated by a thin polyestyrene sheet and the entire coil is encapsulated in a high grade epoxy resin. The coil is secured to busbars by two high-tensile bolts. The peak field could be substantially increased (40%) by discharging into the precooled coil. Thus a field of 200 KOe has been attained by operating the coil at 77°K.

THYRISTOR TRIGGER CIRCUIT AND PROTECTION

The thyristor gate drive requirements are critical when operating them in high current pulsed discharges. The gates must be driven as hard as possible limited only by gate power considerations. The gates are driven (Fig. 4) by discharging a small bank of capacitors through a fast radar modulator type thyristor (MOTOROLA type MCR-1718). The gate drive pulse consists of a high initial voltage of 18 volts and a maintained low voltage above 3 volts for the entire duration of discharge. Gate current hogging is prevented by a series resistance R_s in the circuit of each thyristor gate. A pulse transformer T_1 provides the triggering for the storage oscilloscope (TEKTRONIX 549).

The thyristor has maximum I^2t rating of 50,000 ampere-sec. In the event of a short circuited coil or excessive current. this rating will be exceeded and the device would fail. A high rupturing capacity fuse with a I^2t rating considerably lower than 50,000 ampere-sec. has been coordinated into the circuit. Over a period of six months the HRC fuse blew off twice during current discharges exceeding 30,000 amperes into precooled coil.

MEASUREMENTS

A coaxial current shunt (0.6 milliohm, low inductance) is included in the discharge path and the current waveform is recorded on the storage scope. Fig. 5 is a typical current waveform. The magnetic field is calculated by using this value of current and the coil geometry dependent parameters. The magnetic field is also independently measured by a carefully designed search coil: 15 turns of 40 gauge

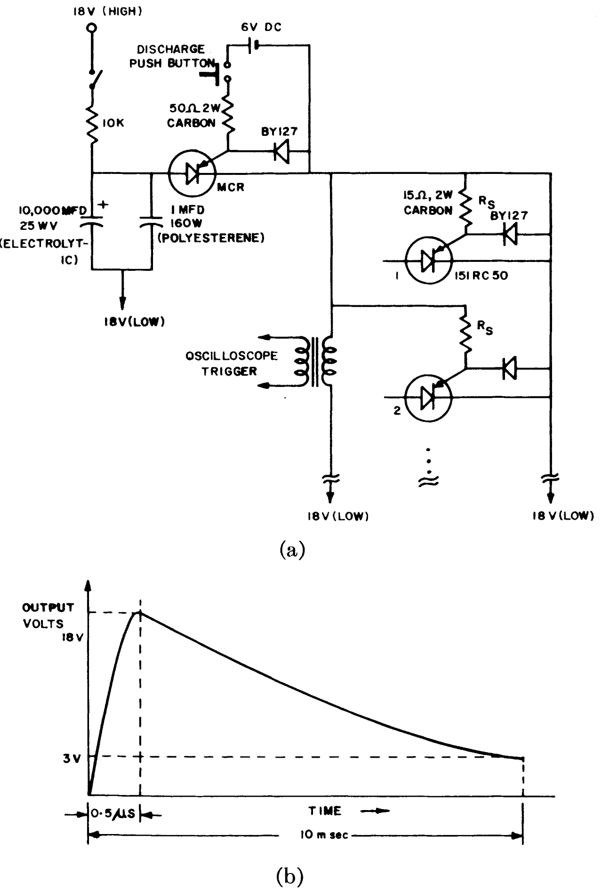

Fig. 4. (a) Gate trigger module, schematic. (b) Gate trigger waveform.

on a 6 mm glass rod whose output voltage is integrated in a simple passive *RC* integrator and stored in the oscilloscope. The output of the integrator is clearly proportional to the field. The fields measured by the above methods were in agreement within 5%. A peak field of 150 KOe has been realized with a duration of 200

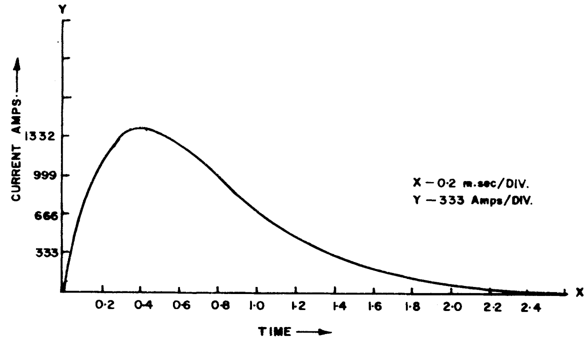

Fig. 5. Current output.

microseconds and is intended for experiments on acceleration of macroparticles, magneto-resistance and certain other experiments of aerodynamic interest.

CONCLUSION

Conventional high-power thyristors are used in pulsed mode to switch very high currents. The low-voltage solid-state capacitor discharge system enables the realization of intense pulsed magnetic fields at reasonable expenditure within the reach of many laboratories.

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