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AN IMPROVED 50-kV PULSER DESIGN

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AN IMPROVED 50-KV PULSER DESIGN*

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Summary

A compact 50 kilovolt pulser has been developed as a gas switch trigger. This unit combines a gounded grid thyratron with a ferrite loaded step-up transformer to provide the required output voltage. A magnetic switch at the output brings the risetime down to the ten nanosecond range. Unit operation is specified into a 25 ohm resisitive load. Integral with the pulser package is the necessary low level support electronics to power the thyratron and to provide trigger and diagnostic functions. Package volume is less than .02 m^3.

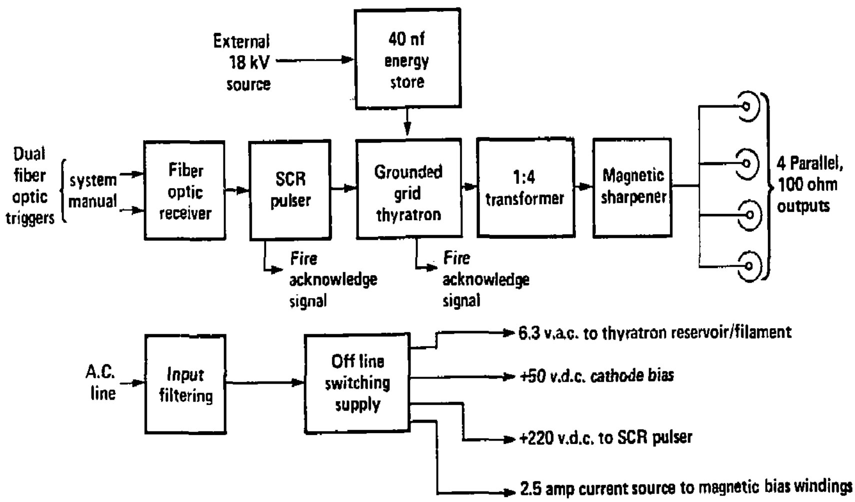
Introduction

Plasma shutters employing electrically exploded foils will prevent retropulse damage to large optics in the Nova laser system. These shutters are presently in an advanced state of development. Switchout of the 3 KJ electrical energy store to the foil is by a four section rail gap gas switch. Triggering the switch is a compact 50 kilovolt thyratron based pulser which has been reported on previously[1]. The following provides an update on this technology at the final design point in the project.

Figure 1 provides an overview of the pulser design. The unit accepts dual fiber optic triggers; one the main system trigger and the other a local, manual trigger for test and maintenance purposes. These triggers are electrically ORed to provide a 50 volt, minimum input to a pulse generator based on small silicon controlled rectifiers. Several changes have recently been made to this circuit resulting in improved noise immunity and lower cost which will be discussed in a future paper. The SCR pulser fires a grounded grid thyratron, which dumps a 40 nf capacitor bank into a fast step-up transformer. New to the design is a simple magnetic switch which compresses the output risetime from the previously attained 22 nanoseconds to the nine nanosecond regime. The resultant output waveform is depicted in Figure 2. Included in the package is a compact regulated power supply to support the unit from the a.c. line, except for the 18 KV high voltage input which is externally supplied from the same source that charges the main plasma shutter energy store.

Output Transformer

We initially used a manganese-zinc ferrite, Ferroxcube 3C8, in the output transformer because of its availability and high saturation flux density. With this ferrite, we obtained a 22 nanosecond output risetime as previously reported. Investigation showed little risetime degradation through the transformer; the output speed was essentially determined by the turn-on time of the tube. Lacking a simple method of measuring thyratron current in this compact device, we hypothesized that this current was very high due to transformer losses, thereby increasing



UNIT BLOCK DIAGRAM

Figure 1

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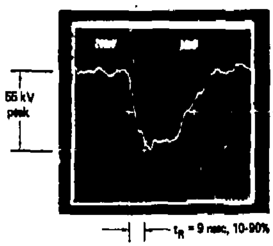


Vertical scale: 15 kV/div.
Horizontal scale: 10 nsec/div.

OUTPUT WAVEFORM

Figure 2

anode fall time. Discussions with A. Faltens at Lawrence Berkeley Laboratory and L. Reginato at LLNL indicated that a high permeability nickel-zinc ferrite would result in lower lossees in this application.

We obtained ferrite from two vendors. The first, which has been tested at this writing, is Ceramic Magnetics CMD5005 material. The second, which has just started test, is TDK PE11B. Also considered, but not purchased, was Stackpole C/7D. The materials are compared in Table 1.

We were somewhat surprised to note that performance with the new ferrite was only marginally better with the 3C8; less than 10 percent improvement in output amplitude was obtained, and a risetime improvement only noticable with a 50 ohm load in place of the required 25 ohm load.

Using a special 1.2 ohm resistive dummy load in place of the transformer, our risetime problems were then traced to the thyratron, as discussed below. Our final design does employ the Ni-Zn material, however, despite the lack of significant performance improvement. The high resisitivity of the material allows it to be used uninsulated in the transformer, providing greater design freedom, fewer parts (a molded silicon insulator was envisioned for the Mn-Zn ferrites), and hence greater reliability. Another problem encountered with this ferrite was a lack of pulse-to-pulse amplitude repeatability. This was traced to the ferrite coming back to a random point on the BH curve. A reset bias current is therefore provided to place the cores in a predetermined state before each shot. Less than five watts of power are required using a d.c. current source from the switching power supply. This same current provides the necessary reset to the magnetic output switch.

Thyratron Limitations

The switching device used is an EG&G HY-1102. It is a hybrid thyratron/spark gap with interesting characteristics for single shot and low repetition rate applications. Despite the existence of a metallic vapor arc internally when switching, the device has a lifetime of approximately 10^8 shots in this lightly loaded (10 kA) application.

We selected the tube at the recommendation of G. KPrausse of Los Alamos National Laboratory, who is using a similar tube, the HY-1313, in a spark chamber application. He is achieving current risetimes of less than 20 nanoseconds to 30 kA with these devices, over a factor of three faster than the LLNL unit. Subsequent discussions revealed several differences to what initially appeared to be a very similar operating situation:

1) The HY-1313 is a special version of the HY-13, a tetrode version of the HY-1102. We have tested the HY-13 and found it comparable to the HY-1102 in di/dt performance. The HY-1313 has a more open grid structure designed to improve risetime, which also appears to degrade holdoff capability. For the plasma shutter application, reliable holdoff is critical.

2) Krausse also obtained an additional 20 percent improvement in risetime by pulsing the auxiliary (simmer) grid positive rather than taking the cathode negative as is normally done to trigger the tube.

3) Los Alamos triggers the tube with a very energetic source; two kilovolts with a three ohm source impedance. According to Krausse, this yields a 15 percent risetime improvement over a 50 ohm drive system.

4) Current rate of rise is load dependent; higher current loads are driven with faster current risetimes. We have also investigated use of the HY-1102 as a Pockels cell driver at the one kiloamp level and risetime under these conditions is only 15 nanoseconds.

Despite the poor risetime, we were reluctant to depart from the simple approach using the HY-1102 with a small SCR trigger. This implementation has been reliable with acceptably low prefire rate and 200 picoseconds peak-to-peak jitter.

TABLE 1

FERRITE COMPARISON

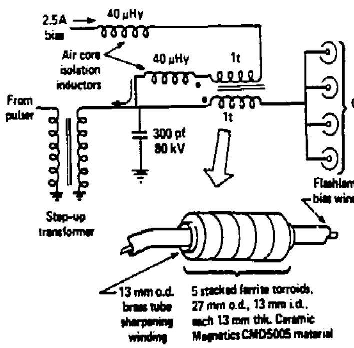
PARAMETER	UNITS	CMD5005	PE11B	C/7D	3C8
Initial Permeability	-----	1200 min	400 min	850 typ	2700 min
Max Flux Density (at 10 Oersteads)	Gauss	3000 min	3000 min	3200 min	4400 min
Coercive Force	Oersted	.23 max	.5 max	.25 typ	.20 TYP
Bulk Resistivity	ohm-cm	10^8 min	10^5 min	10^5	100 approx.

Magnetic Sharpening

A fast risetime in this application is desirable for two reasons. First, in order to maintain the reliability of the 10 unit Nova plasma shutter system, involving ten units, each with redundant triggers, timing of eight different shutter fire events with respect to the input trigger is measured and analyzed with the computer system. Timing discrepancies in excess of five to ten nanoseconds will not degrade system performance but will be an indication that maintenance is required. This threshold discrepancy is short in comparison with a 22 nanosecond trigger. The second factor to consider is the improved performance of the rail gap switches with fast triggers. Multichanneling is enchanced, with resultant lower inductance, lower time jitter and longer life. The rail gap designer has specified a trigger risetime of 10 nanoseconds or less to optimize this effect.

Our improving understanding of the magnetics and of the switch led us to explore a simple magnetic sharpening switch for the unit. Sharpening was added at the secondary side, since the 1.2 ohm impedance at the primary severely restricts the geometry one can use without significantly increasing primary loop inductance. The same Ni-Zn ferrite in the output transformer has good characteristics as a switch, so some smaller cores of CMD5005 material were obtained and tested. The concept was proven in surprisingly short order. Compression to the eight to ten nanosecond regime were attained, along with a ten percent increase in output voltage. The implementation is shown schematically in Figure 3. The series sharpener isolates the main switch from the 25 ohm resistive load, allowing the thyratron to turn on in less than 10 nanoseconds. An initial, high voltage pulse is impressed on the 300 pf capacitor which forms an interim energy store. Saturation of the switch after approximately eight nanoseconds switches out the pulse, with the charged capacitor providing a low impedance source for the leading edge.

Two air core isolation chokes are used to allow the low voltage 2.5 ampere bias source to simulataneously reset both the sharpener and the output transformer as shown in the figure. The effect of bias changes is minimal provided that at least 1.75 amperes is maintained, so this source is unregulated.



MAGNETIC SWITCH SCHEMATIC

Figure 3

Support Electronics

A switching regulator was the logical choice for the low voltage power conditioning in the unit. Both compactness and high efficiency inherent in that approach are important properties since the trigger units are redundant and mount in the compact SF_6 filled pulser housing. The supply design is straightforward, operating directly off the a.c. line and switching at 25 kHz. 6.3 volts at approximately nine amperes are provided for the thyratron filament and reservoir. Remote sensing capability is provided to ensure accurate regulation at the tube. No attempt was made to separately supply filament and reservoir so that optimal operating voltages could be provided for each. It is likely that some performance increase could have been obtained by separately fine tuning filament and reservoir, but this was unnecessary with the addition of magnetic sharpening.

A 220 volt supply is also included for the SCR pulser and optical receiver. A resistive divider from this supply also provides +50 volts of cathode bias. It is interesting to note that the grounded grid thyratron will operate quite well with zero bias between grid and cathode. Occassional prefires do occur under these conditions, however. The filament supply floats on this bias voltage. A high voltage three terminal regulator, the Texas Instruments TL783, provides the 220 volt regulation. A low voltage, unregulated supply provides approximately 2.5 amperes of bias current for the magnetics, with the current limited by the d.c. resistance of the isolation chokes in the high voltage section.

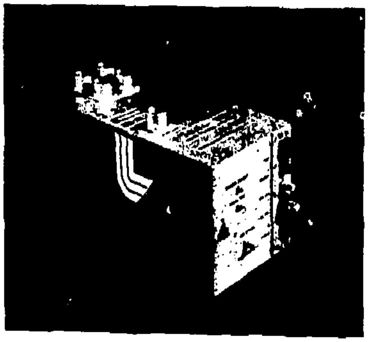
All these supplies must tolerate the noise pulse generated when the trigger unit fires. Various forms of passive isolation filtering, combined with careful packaging attention, ensure that circuit damage does not occur in this severe environment. Two stages of a.c. line filtering are also included to prevent noise conduction to the low level electronics outside the pulser housing.

Packaging

A large effort has gone into the packaging of this unit. A small package was desired, consistent with the liminted space in the pulser housing. High voltage is involved, and a solid dielectric system was selected for compactness and simplicity. A separate low level electronics compartment was created to shield the power supply, and the SCR pulser is provided with a separate enclosure within that compartment for double shielding.

The transformer and magnetic switch are insulated using a system of solid dielectrics. Although yielding the desired compactness and simplicity, this approach requires careful attention to detail so that reliability is not sacrificed. Our confidence in the dielectric integrity is reinforced by the excellent performance of two prototypes and several brassboards, none of which were as conservatively designed or meticulously implemented as the production version. Finally, the solid dielectric system is used only on the pulse side of the unit at low repetition rate; no d.c. high voltage is impressed on the potted unit.

Dow Corning DC-3110 is the encapsulant used. Additional dielectric integrity for the secondary is provided by an acrylic tube and plate system for the transformer secondary, with a compressed silicone gasket between them. The use of compressed elastomer



PROTOTYPE PULSER PACKAGE

Figure 4

gaskets to yield near bulk dielectric strength along material interfaces was extensively investigated[2] and this technique is used throughout the plasma shutter.

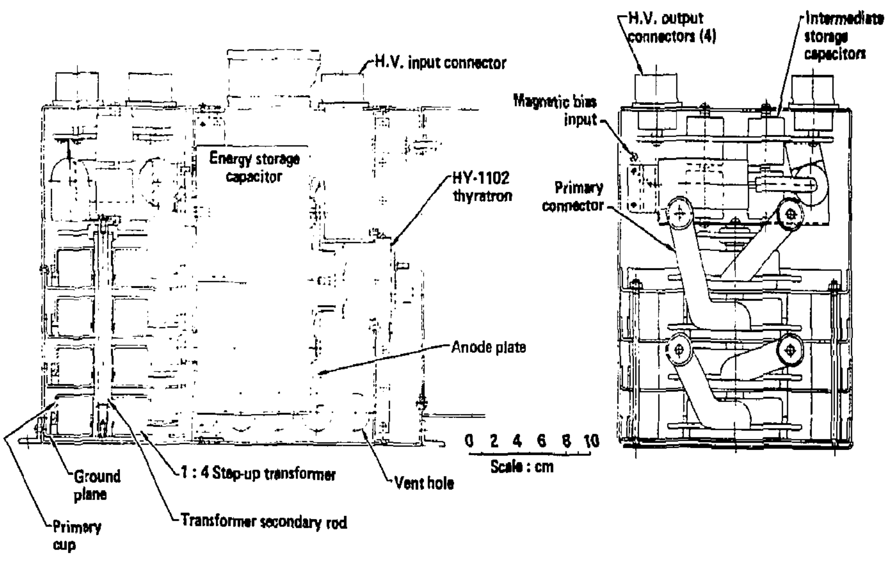
Figure 4 shows the most recent prototype, which is configured similarly to the final unit now in detail design. The prime difference in production chassis will be an increase in height of approximately four cm to accommodate the magnetic switch and to allow additional low level circuit board area. Production dimensions will be 19 cm wide x 23 cm high x 38 cm long. Figure 5 gives two cross sections of this layout.

Conclusions

By combining a grounded grid thyratron, a fast ferrite loaded step-up transformer, and output magnetic sharpening, a high performance pulse generator has been developed suitable for triggering large gas switches. It is apparent that this technology could also be applied elsewhere, with higher repetition rates, opposite polarity output, or use with pulse forming networks in place of the simple capacitive energy store possible. Such a compact device has requried great attention to detail, particularly in terms of solid dielectric integrity, and extensive testing will be carried out on production prototypes as they become available.

1. J. A. Oicles, E. S. Fulkerson, "A Reliable Trigger Unit for Rail Gap Switches" 9th Symposium on Engineering Problems of Fusion Research, Chicago, Illinois, 1981; UCRL Preprint No. UCRL-86028.

2. R. Anderson, "Final Report - Plasma Shutter Pulser Study Contract PSA1111601" American Control Engineering Inc., San Diego, CA, July 1981.



FINAL PACKAGE PARTIAL LAYOUT

Figure 5