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New capabilities for the Aurora flash X-ray machine

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A series of recent upgrades enable the Aurora flash X-ray machine to provide a wide variety of different radiation pulses. The original design gives a single γ-ray pulse with 50 ns risetime and 135 ns width that irradiates a volume of around 1 m^3 with up to 50 krad (Si). The upgrades allow for two pulses with arbitrary separation in time, each with half the output. The pulse widths can be shortened to around 30 ns (with reduced energy), and the risetime can be reduced to 10 ns. These upgrades are discussed in some detail. Other upgrades are described elsewhere: the moderate energy bremsstrahlung option is described by J.A. Anderson et al. [Nucl. Instr. and Meth. B40/41 (1989) 1189]; the high power microwave option is described by G.A. Huttlin et al. [IEEE Trans. Plasma Sci. PS-18 (1990) 618 and other papers in this series].

1. Introduction

The Harry Diamond Laboratories have operated Aurora for the Defense Nuclear Agency since 1 April 1972. Aurora was intended solely to provide intense high-energy bremsstrahlung over a large volume, about 50 krad (Si) throughout a test volume of roughly 1 m^3 in a pulse with 135 ns width and a risetime of 50 ns.

Now, after four years of upgrading and rebuilding, Aurora has new capabilities while improving on its original specifications. The most extensive upgrade is a new Marx bank that provides a double pulse if desired. The double pulse capability is possible because the machine has four separate Marx generators in one tank, connected in parallel. The two pulses come from a pair of Blumleins, each energized by a pair of Marxes that are electrically separated by a wall.

The second series of upgrades is in the pulse shape itself. A single pulse generated by one of the four Blumleins can now be shortened at the tail end with diverter switches. The risetime can be sharpened with gas erosion cells. The result is a variable pulse shape with a risetime down to 7 ns and a pulse width down to 25 ns from a single line. Excellent synchronization of the four lines allows a four-fold increase in output while keeping the quality of the pulse ideally to better than 10 ns. These different upgrades are now discussed separately.

2. Double pulse capability

Some experimenters at Aurora would like to have two pulses separated by a short time interval. Aurora's design is ideally suited for a multiple pulse capability because Aurora is a four-Marx, four-Blumlein configuration. Aurora becomes two independent flash X-ray generators by splitting the Marx bank into two pairs, and coupling each to two of the Blumleins. In addition, the two generators must be separately triggerable, which implies that they be electrically isolated from each other. Fortunately, the increased energy density available in modern capacitors makes it possible to design a smaller Marx generator that is, in addition, more reliable by virtue of a lower parts count and overrating of components. The new Marx is also more powerful, which gives a design margin for the different modifications as well as more radiation output from Aurora.

The requirements for the new Aurora Marx generator are: a) two pulses with any desired pulse separation; b) 20 krad (Si) in each of the two pulses; c) increased reliability; and d) increased radiation output.

Fig. 1 shows the layout of the new Marx generator, designed by Physics International Co., and installed jointly by PI and HDL. The two independently charged and triggered pairs of Marx generators can be separated by a shield wall in the old Aurora Marx tank. The distance between pairs decreases from over 1 m at the low voltage end to about 40 cm at the high voltage end. Slanting the Marx columns reduces the electric field stress between the capacitors and the ground planes of the Marx tank at the high voltage end.

Table 1 compares the parameters of the old and new Aurora Marx generators. The new Marx generators are designed to operate reliably at a nominal voltage V_{nom} equal to 82% of the maximum voltage $V_{max} = 100$ kV. So far we have had over 500 shots at a Marx capacitor voltage of 73% of V_{max}. During this period we experienced two spark gap failures, while producing the same radiation output as the old Marx generator at 92% of its maximum voltage. At this charging voltage the old Marx generator failed on average after about 10 shots.

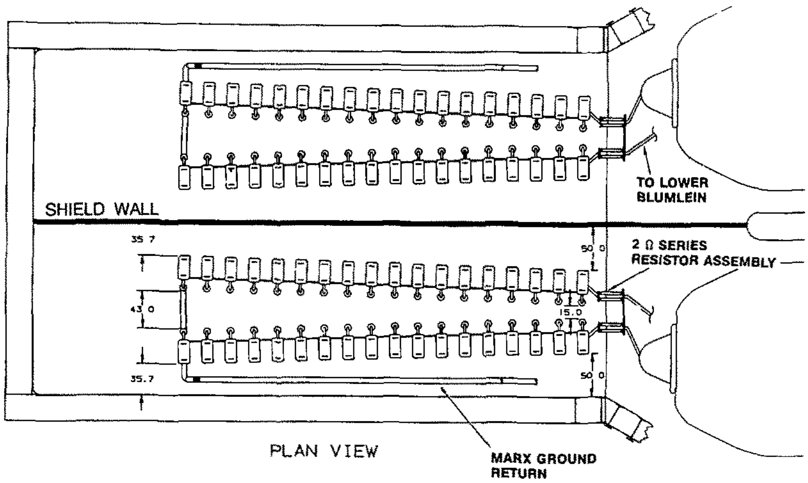

Fig. 1. Top view of new Marx generator. The shield wall is about 20 m long. Note the increasing distance to the side walls toward the high-voltage end of the Marx.

It is evident that the new Marx generator is considerably more reliable.

The radiation output is expected to increase significantly by working with charging voltages around 82% of V_{max}. In the past Marx failures were the primary cause of machine down time, but the higher voltage allowed by the new Marx may change the limiting factor for achieving larger radiation outputs to volume breakdowns in the Blumleins, or failures of the support straps that support the Blumlein electrodes.

Fig. 2 shows typical pulses measured on double-pulse shots. Each panel gives the signal from a scintillator–photodiode detector, with both pulses on the same trace to show pulse separation, and each pulse recorded separately to show individual pulse shape characteristics. Sample pulse separations are 0.1 and 10 μs. The 0.1 μs example shows the overlap of the two pulses, producing a wider pulse. The 10 μs example illustrates the accuracy of the pulse time differences. Fig. 3 shows the silicon equilibrium absorbed dose measured in the Aurora test cell. Note that each of the two pulses gives over 20 krad (Si).

Aurora's double-pulse mode is unique in the flash γ simulator world: no other machine can produce double pulses. Combined with spectral softening [1] Aurora is also the sole operating source for double pulses with lower spectral energy, although in principle the Double-eagle generator at Physics International could be converted to multiple pulse operation.

3. Pulse shape modifications

Other users of Aurora need single pulses with shorter risetimes and pulse widths than originally envisioned. The desired FWHM pulse width is perhaps 25 ns, with a risetime of 10 ns. Fortunately, users of short, fast-rising pulses need an order of magnitude less dose–area product.

Table 1
Comparison between the old and new Marx

	Old		New	
Number of Marx generators	4		4	
Number of stages per Marx	95		90	
Number of capacitors per stage	4		2	
Total number of capacitors	1520		720	
Total number of switches	380		360	
Capacitance of one capacitor [μF]	1.85		2.20	
	at V_{nom}	at V_{max}	at V_{nom}	at V_{max}
Capacitor voltage [kV]	55	60	82	100
Energy stored in one capacitor [kJ]	2.8	3.3	7.4	11.0
Total energy stored in Marx [MJ]	4.3	5.1	5.3	7.9

The modifications implemented to control the pulse shape are: a) diverter switches to shorten the pulse; b) beam front erosion to reduce the pulse risetime; c) Blumlein switch synchronization to achieve desired dose rates by firing the four Aurora diodes simultaneously. These improvements are now discussed in turn.

3.1. Pulse width reduction

Pulse width reduction is achieved by diverting the tail end of the pulse to ground. This is done with diverter switches located in the oil, between the prepulse gap and the oil–vacuum interface. Each of the four energy diverters consists of four negatively enhanced, self-breaking oil switches discharging to a strike plate which is connected to the outer Blumlein cylinder (ground) via a 5-Ω resistor. The oil gap is adjustable from 70 cm, which gives no pulse shortening, to a value around 25 cm when the entire pulse is diverted. Hence it is possible to select any pulse width from 120 ns to 0. All four Blumleins are provided with diverter switches. The energy diverters were designed and installed by Pulse Sciences, Inc.

3.2. Rise time reduction

Aurora achieves a faster rising pulse by using beamfront erosion of an electron beam. This occurs

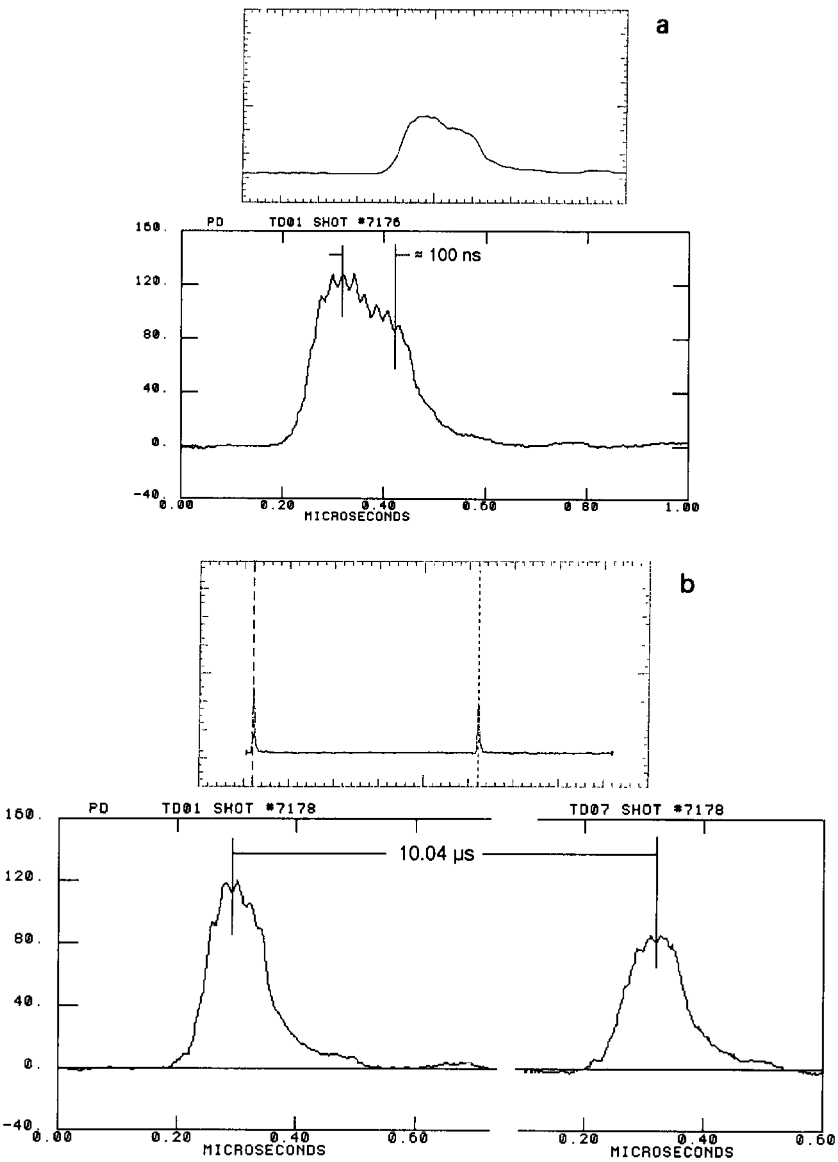

Fig. 2. Dose rate of double pulse shots. (a) Attempted 0.1 μs separation; (b) attempted 10 μs separation.

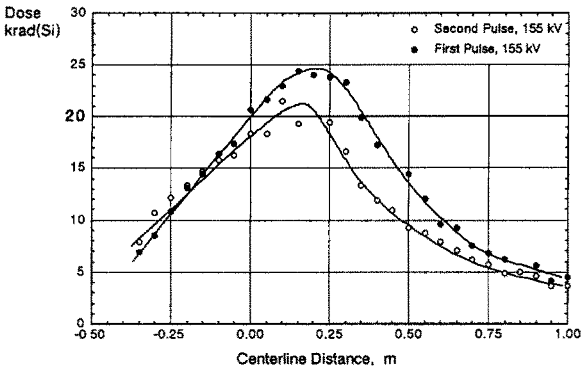

Fig. 3. Dose vs distance from the anodes for the two pulses, measured along the centerline of the machine. The charging voltage (155 kV) is twice 77% of V_{max}.

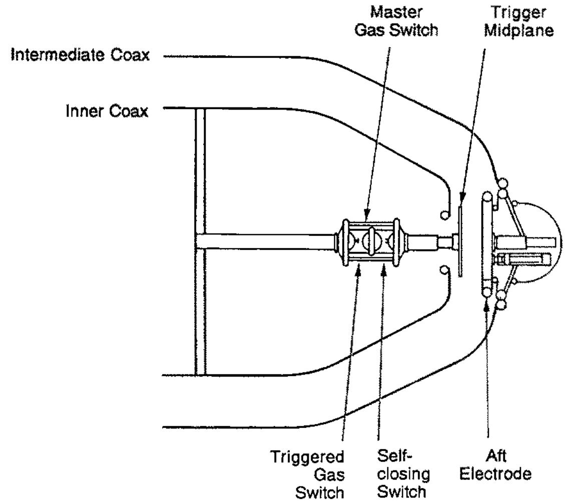

Fig. 4. Layout of the Blumlein switching chain. The distance between gas switch and Blumlein electrode is about 2 m.

when a relativistic electron beam is propagated through a cell containing a low-pressure (~ 10 Pa or 0.1 Torr) neutral gas [2].

The condition for stable beam transport through a neutral gas is that the space charge neutralization fraction, f_e, satisfies the inequality $1/\gamma^2 \leq f_e \leq 1$. The beam electrons in the rising portion of the beam pulse are pushed sideways if the background gas pressure and the drift distance are chosen such that the charge neutralization time is of the order of the beam rise time. Then the initial electrons are lost to the drift chamber walls. The result is that only the electrons after the (relatively slowly) rising part of the beam pulse will propagate to the end of the drift chamber. Therefore, the beam pulse at the end of the drift chamber rises faster. A 3 m long drift chamber on an accelerator tube shortens the Aurora radiation pulse rise time to 7 ns.

3.3. Blumlein output switch synchronization

Fig. 4 shows Aurora's triggered Aurora Blumlein oil switch. The triggering of the oil switch is done by a gas switch, which consists of two stages. The triggered side is a V/N gas switch, the second stage is a self-breaking gas switch. Closure of the gas switch sends a voltage pulse to the trigger (or mid-plane) electrode in the oil. This pulse starts streamers in the oil, which eventually close the oil switch.

Each of the Blumleins has nominally the same type of switch, but small differences between the switches, the voltage on the Blumleins, and other factors cause the four switches to behave slightly differently. As a result, in the original design of fig. 4 the four output pulses arrive within a 40 ns window. However, synchronization must be at least four times better to combine four 25-ns wide, 7-ns rise time pulses into a single 30-ns wide, 10-ns rise time radiation pulse. The effort to improve the synchronization of these switches has been successful. A modified version of the gas switch, with the V/N trigger replaced by a trigatron trigger pin, and the self-break section shorted out closes with less than 1.5 ns jitter. Triggering of the oil switch is then precise. The runtime of the oil switch can be controlled by careful alignment of the trigger blade, and by restricting the breakdown in the oil to 3 points. Presently the four pulses arrive within a 10 ns window on over 75% of the shots. These developments will be described in a future paper on the oil switch [3], and another paper with results of the synchronization effort [4].

4. Conclusion

In the last four years the Aurora simulator has been upgraded in many ways. Besides its original flash γ-ray pulse the machine can now provide two pulses, and a pulse shape tailored to user needs. The upgrades have also improved the reliability and average shot rate. All these advances can be used in conjunction with the Compton backscatter option [1] to make a unique medium energy bremsstrahlung test facility.

References

[1] E.g., J.A. Anderson, J.M. Carroll, K.N. Taylor, J.J. Carroll, M.J. Byrd, T.W. Sinor, C.B. Collins, F.J. Agee, D. Davis, G.A. Huttlin, K.G. Kerris, M.S. Litz, D.A. Whittaker, N.R. Pereira and S.G. Gorbics, Nucl. Instr. and Meth. B40/41 (1989) 1189;
K.G. Kerris, F.J. Agree, D.A. Whittaker, S.G. Gorbics and N.R. Pereira, J. Appl. Phys. 65 (1989) 5;
D.A. Whittaker, K.G. Kerris, F.J. Agee, S.G. Gorbics and N.R. Pereira, J. Appl. Phys 58 (1985) 1034;
N.R. Pereira, J. Appl. Phys. 57 (1984) 1445.

[2] M. Bushell, S. Graybill, M. Litz and G. Merkel, IEEE Trans. Nucl. Sci. NS-31 (1984) 1299;
see also R.B. Miller, Titan/Spectron Technical Report SDL-R-066 (1989).
[3] J. Golden, T. Johnson and N.R. Pereira, in preparation for submission to J. Appl. Phys. (1991).
[4] D. Weidenheimer, T. Johnson, D. Judy, D. Lindsay, and N.R. Pereira, in preparation for the 1991 Pulse Power Conf., San Diego, CA.