Low Voltage Transient Plasma Arc Deflection

Jeffrey Wolff
MSEE Student
Gannon University
phone: (1) 814-875-3517
e-mail: Jeffrey.Wolff@ge.com

***Abstract*— The paper deals with the simulation, the experimental investigation and the applications of a transiently generated magnetically deflected low voltage plasma arc. Arc is generated by starting flow of current between electrodes then separating the electrodes to sustain the arc in a gas. The arc is transiently extended with the aid of circuit inductors and electrode relative motion.**

I. Introduction

Passing a low current through air at high voltage is tested in such devices as a Jacob's ladder or Tesla coil [1], and calculated by Paschen's Law. These devices utilize high voltage to bring air to breakdown region allowing current to flow. Fig. 1 [2] shows a general curve for voltage current relationship in air. Glow discharge region of curve is the area that high voltage discharges occurs. Arc region is the area that low voltage plasma arcs reside. The minimum voltage resulting in maximum current through air point is labeled as point J, and is the proposed operating point for deflection tests.

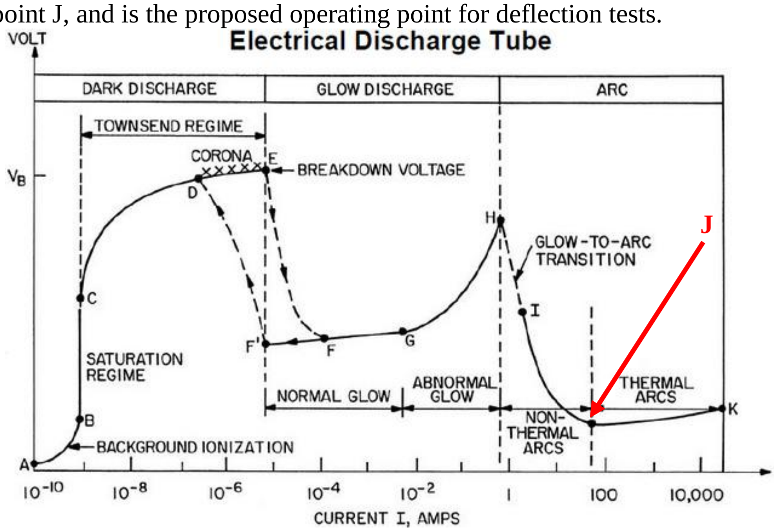

Fig. 1. Voltage to current relation for air tested within an electrical discharge tube. Point J is proposed operating point for testing covered in paper.

By minimizing the required voltage and current for arc generation the power consumed by the arc can be kept to a minimum. Low power in the arc can improve portability of arc generating power supply and open up mobile arc applications. A common AC or DC welder operate at a similar operating point and will provide the power source for arc generation and deflection experiments. Inductance will be added to provide both increased arc stability as well as a voltage source when current is attempting to rapidly change.

II. ARC DEFLECTION EXPERIMENT

A. Test Setup

The test fixture is designed to allow the arc to be extended to a fixed length each time. Fig. 2 shows the fixture for controlling the arc extension. Arc extension fixture is constructed of two insulating supports connected by a hinge. A strap adjusted is used to set max gap after arc has been initiated.

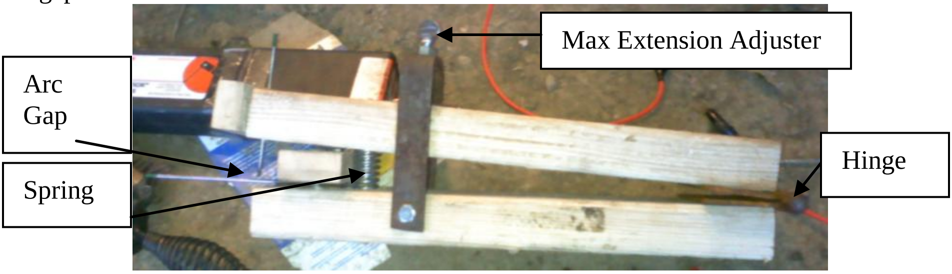

Fig. 2. Fixture for controlling arc extension. The fixture is manually closed to initiate the arc and slowly released to draw arc to desired length.

Fig. 3 shows the basic electrical schematic for arc testing. AC arc welder is used to provide current control and step down isolation from 220 VAC utility power. Inductor 1 and 2 provide the main inductance for smoothing of the rectified output current. Inductor 3 is used for providing the magnetic field for arc deflection. Fig 4 shows the experimental setup, using a welding table for low side electrode. The camera shown in Fig. 4 is modified to have a welding lens with two UV filter lenses.

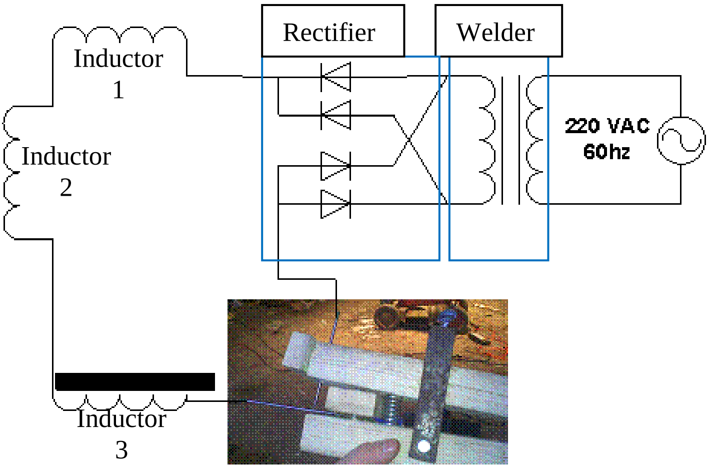

Fig. 3. Basic electrical diagram for testing arc deflection. Provides basic arrangement of inductors and power source.

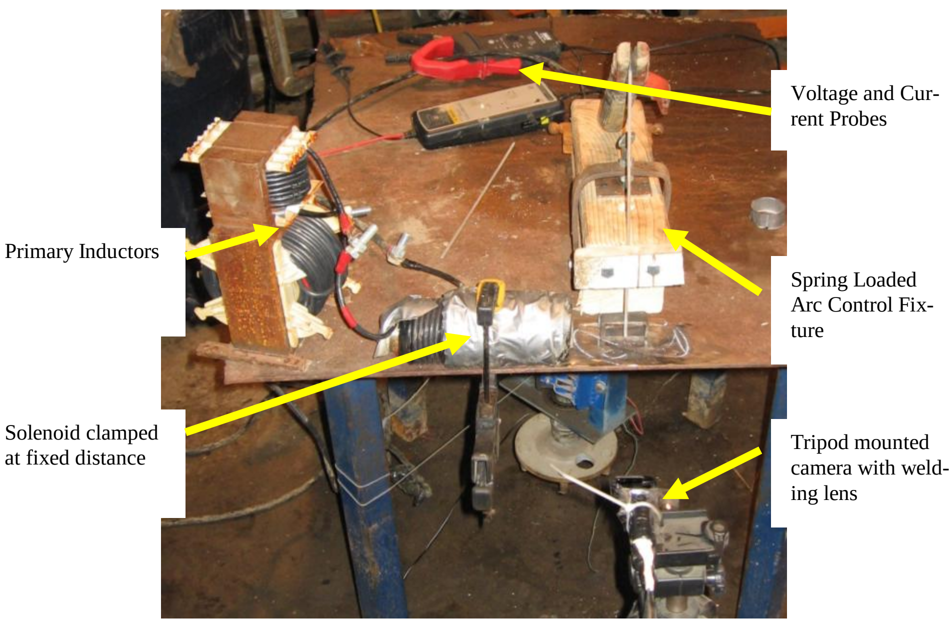

Fig. 4. Photo of actual arc deflection test setup. Shows basic component layout and camera placement

B. Test Results

For each image an associated scope trace including arc current and voltage was recorded. The initiation of the arc trigger current level trigger on scope. Video was reviewed for first observed arc current, and the time from that to time stamp of arc deflected image was used for determining time from trigger in scope trace to correlate to. Fig. 5 shows the scope trace with associated images from the video.

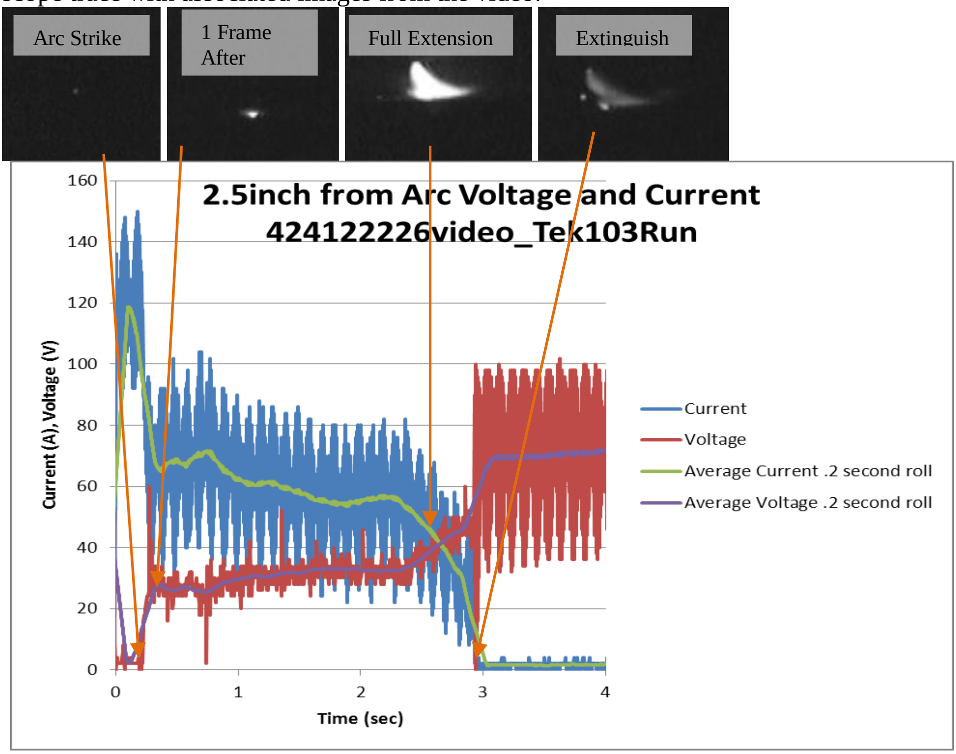

Fig. 5. Scope trace for voltage and current with select frame video detail

The distance the end of the solenoid was from the electrode was varied; Fig. 6 shows a series of coil distance video deflection images. The solenoid magnetic field in the arc gap was later calculated from scope current information.

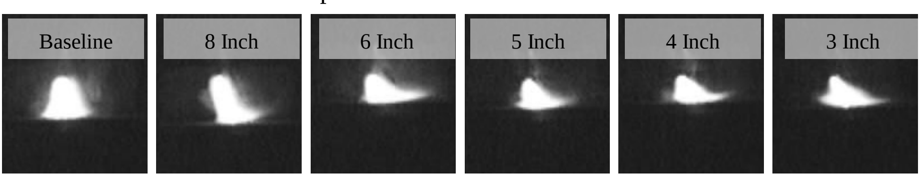

Fig. 6. Video traces for deflection varying solenoid location.

The deflection and magnetic field was calculated for each run. Fig. 7 presents a plot of deflection vs magnetic field strength. Decreasing deflection vs magnetic field strength is explained in conclusion section.

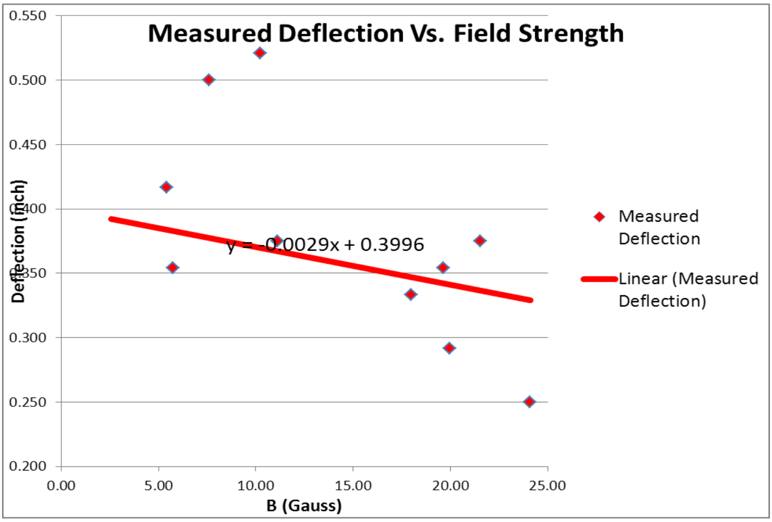

Fig. 7. Test Data for arc deflection vs magnetic field strength.

III. Compare to Calculations

A. Deflection Equation

The detailed calculation for arc deflection was not possible without additional information on the arc behavior in air and at low current levels and large gaps. Information for arc behavior in argon shield gas in high current TIG welding operations was available [3]. A linear regression fit for the relationship of deflection to weld current, arc gap, and magnetic field strength was done to attempt to model air based lower current plasma arc. The relationship for deflection in a low pressure plasma arc in a welding operation is represented in Equation 1 [3]. Equation 1 for calculations shows linearity for magnetic field, arc length and current. Current contributes to E_z and pressure within arc, linearly.

$$\delta = \frac{u_y}{u_z} z = \frac{E_z - \frac{1}{2nq}\frac{dp}{dz}}{-\eta \frac{dp}{dz}} \cdot B_x \cdot z \qquad (1)$$

B. Deflection Test Results Compared to Calculated

Fig. 8 is a plot of test results compared to calculated values for deflection based on a three variable linear regression of argon shield gas deflection tests [3]. As many of the assumptions made in argon shield gas and at very high welding currents can introduce offset in the calculation for conditions of this experiment. A shifted version of the calculated values was generated that subtracts the delta between the measured and calculated data sets.

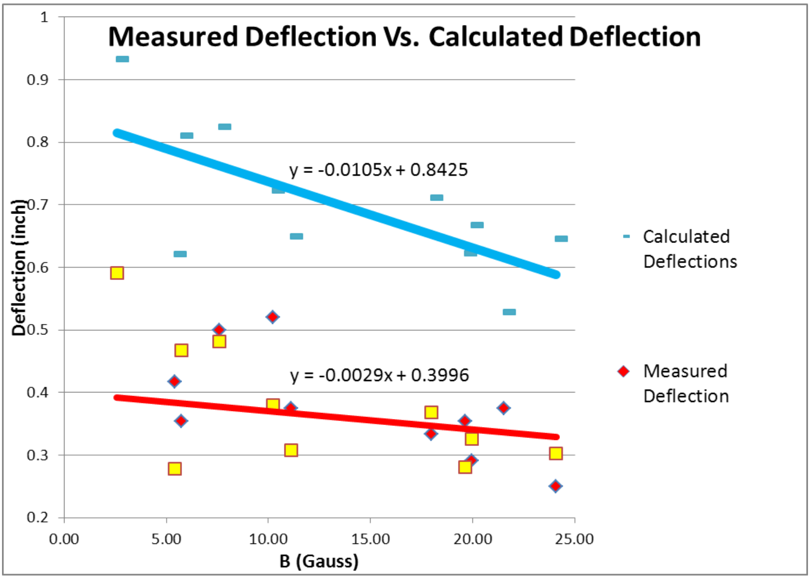

Fig. 8. Test Data for arc deflection compared to calculated values for deflection using fit from argon Tig welding simulations.

General trend down in deflection vs increasing magnetic field was not expected result. The instability introduced from high strength magnetic field caused the arc to clear before steady full length arcs at high deflection levels could be established. The impact on the length of the arc for increased deflection is more significant than the basic increase in magnetic field strength.

IV. CONCLUSION

Increasing the magnetic field caused the arc to be unstable and extinguish before large steady state deflections were possible. Performing additional tests to characterize this delicate balance and determine what max arc length can be obtained is desirable. Next phase of testing would be to determine what max obtainable arc length and generate this arc repeatedly before beginning magnetic field manipulation.

REFERENCES

[1] Jim Lux (2004, 02, 04). Paschen's Law [Online]. Available: http://home.earthlink.net/~jimlux/hv/

[2] J. R. Roth, *Industrial Plasma Engineering*, vol. 3, Bristol UK: Principles. Institute of Physics Press, 1995, Section 12.5.2, Section 9.6.3

[3] Y. H. KANG AND S. J. NA, "A Study on the Modeling of Magnetic Arc Deflection and Dynamic Analysis of Arc Sensor (Journal)," *Welding Journal*, vol. 81 ED-1, pp. 8/S–13/S, 2002.