PRAMANA
— journal of
physics

© Indian Academy of Sciences

Vol. 55, Nos 5 & 6
Nov. & Dec. 2000
pp. 941–945

Operation of a capacitor bank for plasma metal forming

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Abstract. Previously metal forming has been done using electromagnet in pulsed power mode, better known as magneform [1]. Here we will be presenting a different technique for metal forming. We are using water as a medium for this process. By discharging the stored electrical energy of the capacitor bank in water, we are getting the desired result i.e. to form (expand or compress) a wide range of workpiece to the desired shapes. The advantage of this method over conventional method is that it uses low power (negligible running cost). It does not require any post assembly cleaning degreasing and is hence environmentally 'friendly'.

Keywords. Metal forming; capacitor bank; spark gap.

PACS Nos 84.60.-h; 84.60.Ve

1. Introduction

Underwater sparks [2,3] have been used in the past to generate pressure pulses for various applications. Here we present one of these applications known as 'metal forming'. There are many methods to form, join or assemble parts, but none provides wider application than metal forming in pulsed power mode. Previously metal forming has been done as magnetic metal forming in pulsed power mode. It has its own disadvantages. Plasma metal forming utilizes pressure pulses that are being generated by underwater sparks. It does not generate any toxic waste, uses low power (negligible running cost) and also cuts the time of operation (split second forming). The major advantage over the magnetic metal forming is its simplicity in design and fabrication. The biggest challenge in magnetic metal forming is the design and fabrication of the coil, since it has to withstand the tremendous pressure that it generates without being damaged.

2. Principle of operation

In the plasma metal forming process, electrical energy is stored in a capacitor bank and suddenly released by a triggered spark gap switch in the liquid to generate the blast. The power is conducted to the work region by a low impedence coaxial cable. Here in this case

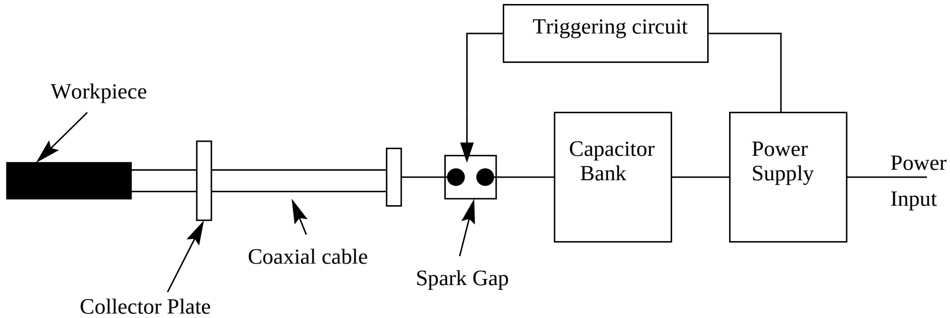

Figure 1. Schematic diagram of the process.

the work piece and a rigid conductor forms the electrode (in a coaxial form) as shown in the figure. We have used only hollow GI pipes as the work piece which forms the ground electrode, one end of which is tamped. Through this tamping, the rigid conductor is inserted to form the high voltage (HV) electrode. Water is poured into the work piece so as to have the discharge between the rigid conductor and work piece, when the stored electrical energy is released from the capacitor. Ordinary tap water can be used as the fluid when the work piece is in vertical or sufficiently inclined position, but suitable additives must be added to increase viscosity when in horizontal position. The schematic of the plasma metal forming is shown in figure 1.

In the first few microseconds of the electrical breakdown in liquid, a conductive channel is formed between the inner and outer conductor. Heat generated as resistive losses in the electric arc vaporizes the surrounding water and brings the steam to high temperature. Since the discharge is very short, a steep pressure rise takes place on the inner walls of the work piece to give it the required shape. The pressure generated depends on the rate of energy dissipated and also on the distance between the two electrodes namely the HV and ground (the work piece). Indirect measurement i.e. from simulation, indicates the pressure ranges to several hundred KPa [4].

3. Experimental arrangement

The experimental arrangement consisted mainly of a capacitor bank, high voltage power supply, trigger generator, coaxial transmission cables, work piece and current diagnostics. The schematic diagram is shown in the figure 1.

3.1 *Capacitor bank*

The capacitor bank consists of 12 Passoni Villa capacitors each of 5.7 kJ at 40 kV charging voltage (total bank energy is 68 kJ). Each capacitor can deliver a peak current of 150 kA and can handle 80% voltage reversal. The capacitors have a built-in three electrode (field distortion) spark gap switch. The total inductance of each switch and capacitor is 110 nH. The capacitor bank was configured for the various experiments. The charging and discharging of the capacitors are done in parallel so as to have maximum current.

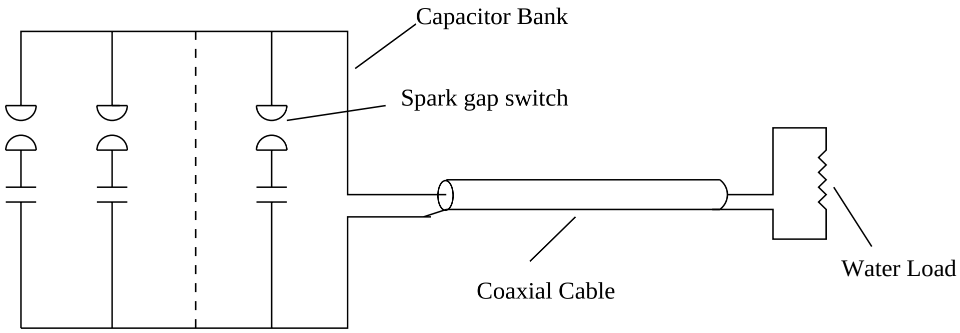

Figure 2. Equivalent circuit representation of the spark discharge load.

3.2 *Trigger generator*

The trigger generator is used to trigger the spark gap switches of the main bank, so as to have a simultaneous triggering. As a result one will get maximum current with lower period of discharge. The trigger generator consists of four charging capacitor of 0.22 μF each, a spark gap switch which is operated by releasing the gas. Blocking capacitors were used to block the return stroke and water resistors to attenuate the amplitude of the return stroke.

3.3 *Transmission cables*

RG 213 coax is being used as the transmission cable. The cables were tested to 35 kV dc (in pulsed mode) and 40 kA peak rigorously. A parallel arrangement of 12 cables (one from each capacitor) are being used to provide the peak current capability. These 12 cables were terminated to a collector plate from where three cables were taken to the work piece.

3.4 *Work piece*

The work piece is a hollow GI pipe with an OD of 6.3 cm ($2\frac{1}{2}$ in). The braid of the coaxial cable is connected to it. One end of the pipe is heavily tamped (with industrial grade M-seal) through which a rigid conductor passes. This rigid conductor is connected to the inner conductor of the coaxial cable. Thus the inner rigid conductor serve as high voltage electrode and the GI pipe itself acts as a ground electrode. Then the work piece is filled with water. The discharge takes place between the inner conductor and the GI pipe.

3.5 *High voltage power supply*

This is a 100 mA, 46 kV constant current power supply. It consists of a HV transformer, a HV diode and charging resistors.

3.6 *Diagnostics*

At this moment only current is being measured on the discharge side. This is being done by a Pearson current transformer, the output of which is recorded on to a Tektronix 540D digital oscilloscope. The charging voltage is being monitored by a micro-ammeter, connected in series with a 1000 MΩ resistor chain.

4. Results

A summary of the experimental result is shown below.

From figure 3 it can been seen that the shape of the first half of the current pulse corresponds to the current resulting from a discharge in a constant low value resistive load. Whatever oscillations are noticed is due to cable inductance.

Shot No.	Charging voltage (kV)	Peak current (kA)
1	21.0	58.0
2	22.0	60.0
3	21.5	58.0
4	24.0	63.0
5	20.0	54.0

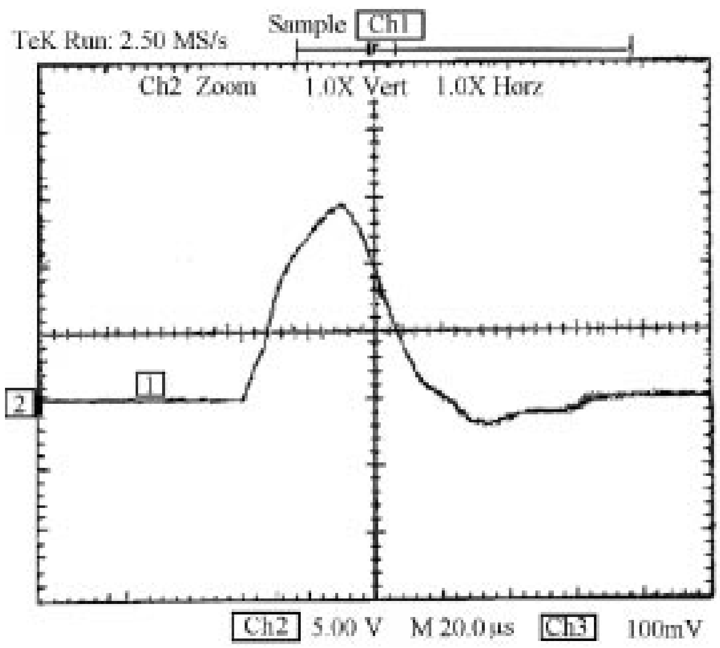

Figure 3. Discharge current vs time.

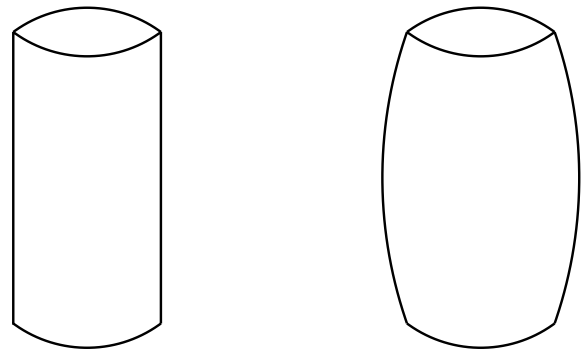

Figure 3. A sample piece (GI pipe) before and after the shot.

5. Conclusion

It has been observed that the expansion (or bulge) of the pipe is uniform along the circumference, if the axis-symmetry is maintained i.e. the inner conductor is perfectly at the center of the pipe. The expansion is like an annular ring. The advantage of this method over magnetic metal forming is its simplicity in design. One just has to tamp the one end of the work piece in order to hold the water and the pressure pulse. If the tampering is not proper then the expansion of the periphery (along the circumference) will be ineffective. From our experience industrial grade M-seal is found to be very good for this purpose. Also in case of magnetic metal forming one has to design various dimensions of magnetic coil according to the sample piece. Until now we have used this method for expanding the hollow pipes only, but this can be used for other shapes of work piece. This method has got all the advantages of the magnetic metal forming (but for bigger jobs one has to go for higher energy and larger discharge area i.e. the spacing between the high voltage electrode and the ground electrode).

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