Pulsed Power Forming

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Abstract

R&D and application work in the sphere of Pulsed Power Forming (PPF) is well known and has been documented since the 1960's, along with its advantages. Pulsed Power Forming applications, which have been developed at Pulsar Ltd over the last decade, are described in this paper.

Special equipment and tools for forming have been designed, developed, and manufactured, utilising pulsed magnetic fields. Theoretical and experimental research has been carried out to determine the magnetic field distribution in certain types of solenoids for diameters up to 600 mm. The software for mechanical pressure simulation and calculation has been carried out.

Research and application of forming by electrical discharge into liquid medium have been carried out with higher deformation than it has been attained by the classic processes.

Flat forming, cutting, and/or perforating of very thin materials (with thicknesses in the range of 0,1 up to 0,3 mm), such as aluminium, steel, stainless steel, nickel alloys, etc., have been made by applying high magnetic field with elastic medium.

In addition, forming and cutting of a steel tube with ~100 mm OD and a wall thickness up to 3 mm have been executed using direct high pulse magnetic field action. Aluminium tubes with OD ~100 mm and a wall thickness less than 0,5 mm have also been similarly processed.

Keywords

Forming, High Energy, Electrical Discharge

1 Introduction

Pulsed Power Forming (PPF) is a new technological application of pulsed power processes based on the use of high pulse current, created by the discharge of a capacitor battery through a load. This load may be a coil, a gap between electrodes, etc. PPF processes have been known for over 40 years and a lot of theoretical and experimental work has been carried out over the years. However, industrial utilisation of the process requires experimental work to determine the best electrical regime data as well as design

of the devices and equipment for each actual application with its accompanying industrial conditions.
Pulsar has performed much R&D work in this direction in order to solve actual problems on the way to industrial utilisation of the Pulsed Power Forming process.

Pulsar has developed a range of Pulse Current Generators (PCG) with parameters to cover a wide range of applications. Table 1 below presents a list of these generators:

Pulsar Model Type	Energy Storage kJ	Working Voltage kV max	Capacitance in microfarad	Self Frequency kHz
7.2/9	7.2	9	184	60
10/10	10	10	200	39
12.5/25	12.5	25	40	120
20	20	9	552	36
20Hf	20	25	64	100
30	30	6	1700	11
40	40	9	1104	22
100	100	25	320	65

Table 1: *Pulsar Pulse Current Generator Data*

Pulsed current generators have been used for many applications, including

- pulse forming by direct pulse magnetic field action,
- pulse forming by pulse magnetic action through an elastic medium.
- pulse forming by using underwater electrical discharge.

The forthcoming sections will define each of these methods.

2 Forming by direct action of pulse magnetic fields

There are two possibilities when using the direct action of pulse magnetic fields, as follows:

a) Forming of tubular shaped components with either/both external and internal pressure.

b) Forming of flat components.

It is well known that distribution of the magnetic field (or magnetic pressure) in the radial direction is very important for forming of flat details. It is a problem to control this distribution, especially for details with large dimensions.Another typical problem is the life time of the working coil. In this, it is well known, too, that single turn coils have an essentially longer lifetime than equivalent multi-turn ones .

Pulsar has developed the system for forming details with diameters up to 600 mm by using multi-turn (see Figure 1) as well as single turn coils. The single turn coils are connected with a PCG through a special matching transformer, which permits control of the magnetic field distribution. An example of magnetic field distribution in the radial direction for multi-turn coils is shown in Figure 2, and for the single turn coil system in

Figure 3. Pulsar has tested tubular as well as flat sheet options for forming by direct action of magnetic fields. Some results of this are illustrated in Figures 4 - 6.

2.1 Advantages and disadvantages for direct action

Advantages of direct magnetic pressure action are as follows:

a) Our experimental work has shown that forming by using direct magnetic field application is preferable for forming tubular shaped details, as it is a well known and documented process, especially for externally applied magnetic fields.

b) Forming of tubular shaped details with diameters less than ~100 mm using internally applied magnetic pressure is very difficult industrially, because of short lifetimes of the working coil for such dimensions.

c) Forming of flat details using the direct action of a magnetic field is a very suitable process for metals and alloys of high and medium electroconductivity, e.g. Cu, Al, and low carbon steels. The best results are obtained by using male rather than female dies. This is dictated by the fact that there is always a pressureless zone at the centre of the coil.

d) A system of single turn coils with matching transformers is the best option for industrial purposes as for control of magnetic field distribution as well as for long working coil lifetime.

Disadvantages of direct magnetic pressure action are as follows:

a) Results depend on the detail's material electroconductivity as well as on the material thickness. These determine the skin depth and process effectiveness in the final analysis.

b) It is very difficult to form flat details with small planar dimensions (less than 100 mm) due to coil's lifetime limitation.

3 Pulsed Power Forming by using magnetic field action through an elastic medium

Pulsed power forming by means of an elastic medium is also well known. Our R&D work has been directed to determine optimal regime data as well as optimal devices design. Here a system was designed with the intention of forming flat details with maximum planar dimensions of 100 mm diameter and material thickness in the range of 0,1 - 0,3 mm. This system consists of a multi-turn flat coil, a mechanical pressure concentrator, an elastomer punch, and a suitable holding device and matrix, etc.

Experimental work has been performed using a wide range of materials, including those suitable for traditional direct pulse forming such as Cu,Al, and low alloy steels as well as stainless steel, nickel alloys, etc. Three types of elastomer materials have been tested as well as the dependance of process effectivity on the type of die. The elastomers' modulus of elasticity (ME) was 38, 70 and 133 N/mm^2 with respective tensile strengths of 34, 38 and 45 MPa. It was determined that an elastomer of higher ME permits the use of an open die (without any constraining outer body).

An elastomer with lower modulus of elasticity can only be effectively used in a closed system due to its higher level of deformation under load. In general, a high ME elastomer is required for cutting processes, while elastomers with lower ME need to be used for forming processes. Devices are shown in Figure 7 and Figure 8.

3.1 Advantages and Disadvantages for the Elastic Medium

a) The elastic medium used permits the forming of materials independent of their electrical properties.

b) The elastic medium requires the use of an essentially lower current oscillation frequency, and therefore permits the use of Pulse Current Generators with low working voltage. Pulse current generators of 6 kV maximum working voltage have been used giving current oscillation frequency of about 5 kHz under load.

c) The industrial disadvantage of using an elastic medium is the medium's lifetime limitation, especially for cutting processes. This process has, for example, cut 1.5 mm diameter holes in the nickel alloy, Inconel 600 material of 0,27 mm thickness. However, elastic medium lifetime was about 500 pulses.

4 Underwater Discharge

Underwater high voltage discharge is an electrical pulsed power process using the liquid medium for transferring the pressure to the formed detail. The principle of high voltage electrical discharge for forming is also well known and a lot of work has been carried out, as well as patents, discribing the process. However, experimental work must be carried out to develop suitable industrial application requirements for the particular application.

Pulsar has passed along a part of this road on the way to forming details of plane dimensions up to 600 mm of materials including alloys of Al, steel, stainless steel, including DP steel etc., with thicknesses from 0,3 up to 1,5 mm.

The pulse maximum pressure in the liquid at the high voltage electrical discharge may be described by formula (1):

$$P_{max} = \rho \cdot \frac{a^2}{\tau^2} \tag{1}$$

Here:

$$a = \left[\frac{(\gamma - 1)}{(\pi \cdot \rho)} \cdot T^2 \cdot \frac{W}{L} \right]^{0.25} \tag{2}$$

W energy introduced into discharge, J

P density of the water at the moment of discharge. It may range from 1,05 up to 1,35 of initial density (this depends on pulse current amplitude), in kg/m3

T discharge duration, sec

γ = 0,26 effective adiabatic index for discharged plasma

L discharged distance, m

Energy introduced into discharge, *W*, depends on time needed for discharge forming and it may be essentially less than energy storage in the capacitor battery, especially at a charging voltage of less than ~10 kV. This means that higher working voltages provide more process effectivity. This is a contradiction because the high voltage battery has a lower capacitance, and thus a shorter discharge time than a low voltage capacitor battery. At the same time, details of greater dimensions (or the same with large mass) need a longer discharge time.

Our experiments show that for details of mass about 1 kg the first quarter of discharge period needs to be about 60 – 80 μsec. This means that discharge current oscillation needs to be about 3-5 kHz at the energy storage of about 30 kJ for steel of yield strength about 400 MPa. Typical formed samples are shown in Figures 9 and 10.

4.1 Advantages and Disadvantages for Underwater Discharge

Underwater electrical discharge is a very useful tool for the forming process which has the advantages inherent in other pulsed forming processes as well as the additional advantages as follows:

a) the possibility of achieving a very high pressure for a wide range of pulse durations.

b) process has a very high flexibility for adjusting the industrial Requirements.

c) process is very useful for forming the details of intricate shapes with or without axial symmetry.

d) disadvantages are that it is nessecary to change the water or to fill up the water after each pulse, which can take some additional time, and that the electrode lifetime is a very important problem. The former may be minimised by clever tooling design, and the latter problem with R&D work.

Figure 1: *Multi-Turn Coil*

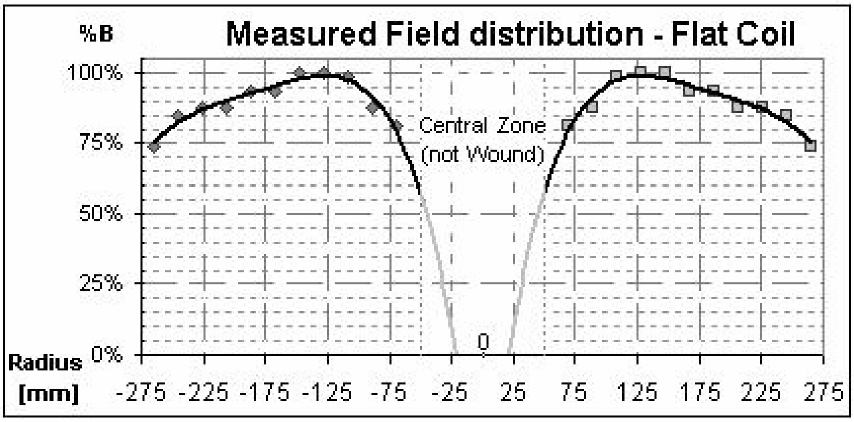

Figure 2: *Magnetic Field Distribution – Multi-Turn Coil*

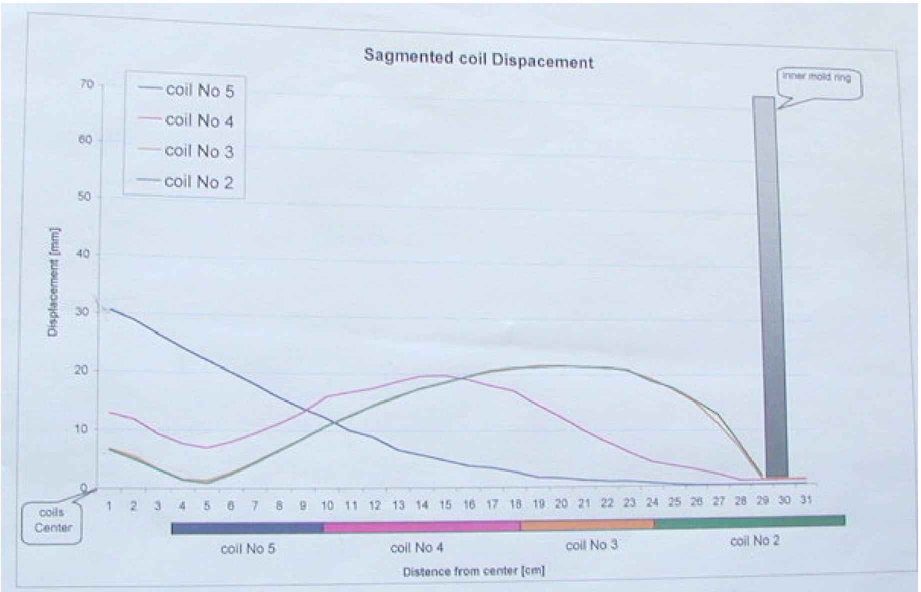

Figure 3: *Magnetic Field Distribution – Single Turn Coil*

Figure 4: *Tubular Forming 3 mm steel*

Figure 5: *Forming of 600 mm Al Antenna Disc*

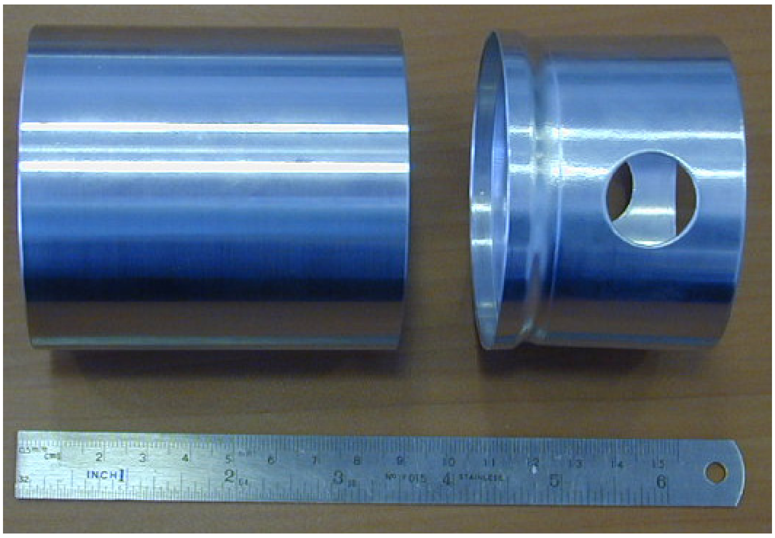

Figure 6: *Formed and Perforated Al Tube*

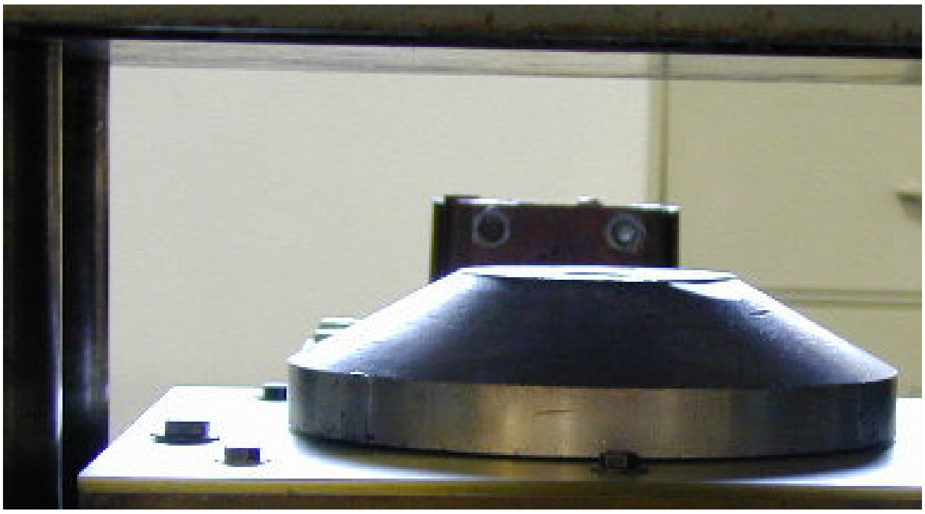

Figure 7: *Forming Device*

Figure 8: *Forming Die Assembly Device*

Figure 9: *Formed Stainless Steel*

Figure 10: *Formed Stainless Steel*