

ELECTROMAGNETIC FORMING - A TECHNIQUE WITH POTENTIAL APPLICATIONS IN ACCELERATORS

R.K.Rajawat, S.V.Desai, M.R.Kulkarni, Dolly Rani, K.V.Nagesh and R.C.Sethi
Accelerator & Pulse Power Division, Bhabha Atomic Research Centre, Mumbai-400 085, INDIA.

Abstract

Present day accelerator development requires new technologies for their diverse needs. Accelerator & Pulse Power Division of BARC is working on the development of 'Electromagnetic Forming (EMF) technique' for various industrial applications. This technique utilizes the Lorentz force to achieve the required formation/movement of the job piece. The force is generated when a charged capacitor bank discharges through a forming/displacement coil placed in near proximity of the job piece. The force is developed on account of interaction of induced currents in the job piece with the magnetic field produced by the coil. The technology is a non-contact forming method and has variety of applications in the industry including the nuclear industry. It has distinct advantages like precision, repeatability, automation, no preparatory procedures, etc., over the conventional techniques. Energy storage capacitors are used as primary source of energy. The technique has been used for many of our in-house activities. It was successfully employed for Garter Spring repositioning in Pressurised Heavy Water reactors [1]. The technique stands as a viable alternative for the conventional methods of Fuel Pin fabrication of nuclear reactor. This project at present is in the development stage. Presently, the development of 'Detachment of Rolled Joints' employing EMF implosion has been taken up for Advanced Heavy Water Reactor. This technique has tremendous potential in Accelerators, as well. Presently, we are working on an extremely important development of Metal-Ceramic joints using EMF. Trials on 15mm diameter, ceramic rods and 0.4mm thick copper tubes have qualified Helium leak rate of 10^{-10} Std cc/s and vacuum of 10^{-6} Torr. Further trials for improving the performance are being taken up. This paper highlights the salient features of EMF and suggests some specific areas where it could benefit the accelerator technology.

INTRODUCTION

Modern day accelerator development encompasses a myriad technologies required for their diverse needs. Whereas RF, High Voltage, Vacuum, Cryogenics etc., technologies meet their functional requirements, high finish lapping processes, Ceramic-Metal joining, Oven brazing, Spark erosion or Wire cutting etc., are a must to meet their fabrication requirements. Electromagnetic (EM) forming [2] technique falls in the latter category and is developed at APPD, BARC, as a special technology. It

is currently catering to the development as a nuclear reactor technology, but has the potential to meet accelerator requirements too. This paper highlights the general principle of its working, simple design guidelines, advantages, and suggests some specific areas where this could benefit accelerator technologies.

PRINCIPLE OF OPERATION

The principle of electromagnetic forming is manifested in the very definition of the unit Ampere [3]. Simply told, any two current carrying conductors exert force on each other, this very observation is stated by Lorentz force law as $\mathbf{J} \times \mathbf{B}$, where \mathbf{J} and \mathbf{B} have their usual meaning of current and flux densities, respectively. The ingenuity lies in the generation of the two currents for shaping or joining of metals or metals to plastics or even metal to ceramics. The figure below illustrates the technique.

Depending on the proximity of the two currents and their magnitudes, the force magnitudes can be estimated. As depicted in Figure 1, the primary current in the coil which is generated by discharging energy storage capacitor/s, induces large secondary currents in shorted axis-symmetric tubular job piece. The induced currents in the job piece oppose the very cause (primary current), in accordance with the Lenz's law. In EM forming technique this is manifested as the repulsion between the two currents, thus the two current carrying members physically distance from each other. As one doesn't want to deform the work coil, it should be strong enough to sustain these repulsive stresses. In EM forming technique, mechanical stresses close to 350MPa are routinely generated. Generally above this value, shot life of the coil is the limiting factor for an industrially viable system.

DESIGN GUIDELINES

A simple design guideline, to estimate the energy of capacitor bank and the minimum magnetic flux density requirements for the job coil, can be had by equating the hoop stress required to plastically deform the tubular job piece to the magnetic energy density stored in the volume to be deformed, i.e., $\frac{1}{2} \times \mathbf{B}^2 / \mu_0 = \Sigma_y \times t/r$, where \mathbf{B} is the flux density generated by forming coil, t -the thickness of the job piece, r -the mean radius of job and Σ_y -the yield strength of the material of the job. The criterion to choose the ringing frequency of the damped discharge waveform can be had by equating skin depth for the tube material with the tube thickness.

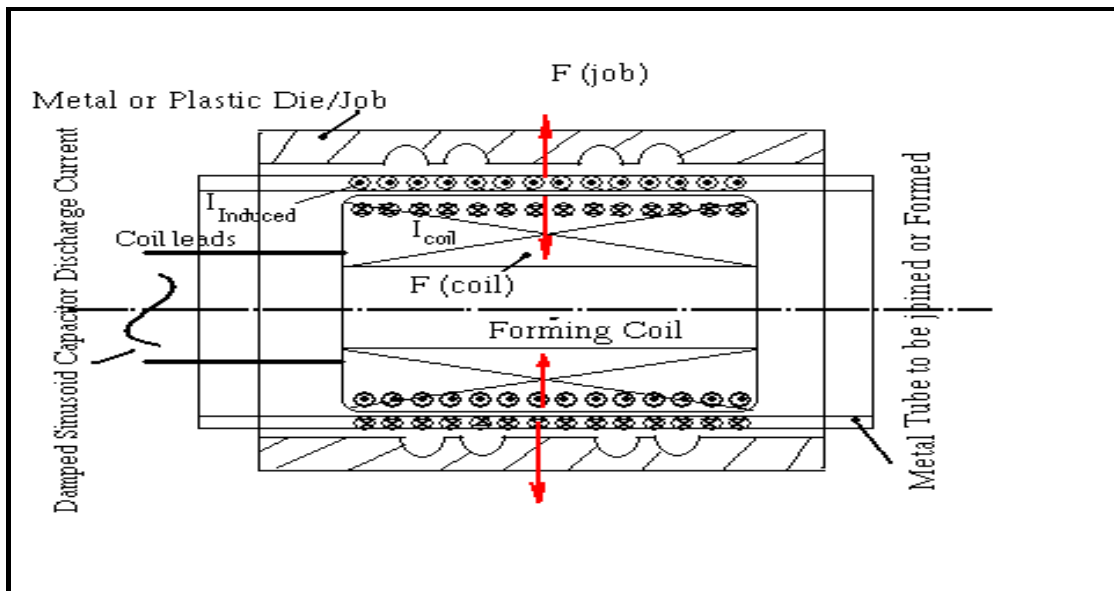


Figure:1 A schematic of EM Forming Process in Axis-symmetric Case

ADVANTAGES

The one unique feature that distinguishes all high energy rate forming (HERF) processes (EM forming is one of them), from the conventional forming techniques, is achieving of high formability of the material. Strains $>100\%$ in plane strain can be achieved without tearing of the material [4]. Other distinguishing feature being - non-contact forming, very low spring back, precision in control, high uniformity and reliability and less prone to operator errors. It is amenable to automation. Invariably, the joint formed is stronger than the parent metal.

POTENTIAL USAGE IN ACCELERATORS

It is envisaged that the metal-ceramic joining, a common technique in modern day accelerators, should certainly be feasible using EM forming. This optimism is based on the recent successful trials we had in typical Alumina-Copper joints. 0.4mm thick, 15mm long Copper sleeves in annealed, as well as in un-annealed conditions, were EM swaged on to 12.5mm diameter Alumina rods. Alumina rods in metallised, as well as in non-metallised conditions, were employed. These joints were tried on Alumina rods having $\sim 0.5\text{mm}$ deep & 1mm wide groove, and the ones having no groove. All the samples (seven in



Photograph 1: EMF joints of Copper Tube to Solid & Tubular forms of Ceramics

all) were subjected to the same amount of EM stress, using a 440 μ F capacitor bank charged to only 2.5kV. The peak current of 57kA was recorded through the forming coil, with <3% variation for each shot. All the samples, thus tried, withstood the vacuum of 10⁻⁶torr level. The leak rate, for all samples, was observed to be <10⁻¹⁰ Std.cc/sec. Vacuum withstand test and leak rate were also performed for these joints after subjecting them to oven temperatures of 200° and 300°C. Every joint successfully passed the test. Atypical photograph for the Copper-Alumina joint is depicted in the photograph below. One can observe in Photograph 1, that the joint has been achieved on solid & tubular forms of Alumina in, with as well as without grooved configurations. Axis-symmetric formation of slow wave structure is another potential area of EM forming application.

THE EQUIPMENT

An exposed view of the EMF equipment is shown in Photograph 2. The unit is portable on wheels and is backed by measurements of coil currents through a pick-up coil, which is recorded on a Tektronix oscilloscope interfaced to a PC through the RS-232 port connectivity. The unit may be operated by a single person with the recording of current measurements in ‘baby-sitting’ mode. Till the date of this reporting, this equipment has been subjected to more than 1500 shots. Except for the changing of stainless steel spark-gap electrodes and its trigger pins, which undergo significant erosion after about 200 shots; equipment has performed remarkably well. Use of ignitron switches should help in improving the shot-life performance of the equipment. The work coil, which needs replacement after every 1000 shots, is undergoing development..



Photograph 2: An exposed view of the EMW-equipment developed for in-house applications.

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