RESISTANCE WELDING USING HOMOPOLAR GENERATORS AS POWER SUPPLIES

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Texas Atomic Energy Research Foundation Project Progress Report No. 27
(November 1, 1976, to April 30, 1977)
Fusion Research Center
The University of Texas at Austin

Publication No. PN-31
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ABSTRACT

The University of Texas Center for Electromechanics (CEM) was originally formed to address the pulsed power requirements in the nuclear fusion research areas. It was determined that inertial energy storage using homopolar conversion could effectively meet these requirements. Two homopolar generators have been built and tested by the CEM; one is under construction; and several others are scheduled to begin construction in mid-1977. The machines have been so successful that the CEM is now investigating other areas requiring high energy pulses. Many of these applications have previously been limited by availability of peak power, either by reason of existing technology or economics. One such area is resistance welding where we feel the present generation of homopolar generators offers the potential to significantly extend the limits of cross-sectional areas that can be successfully and economically resistance welded.

Since homopolar generators are used effectively as energy storage devices, storing energy (inertially) slowly and then discharging it very quickly, they are ideal sources for the high power inputs required for resistance welds. This energy storage capability can eliminate demand charges when used in-plant and makes on-site resistance welding possible without requiring excessively large prime movers.

The CEM has done some welding feasibility experiments using the 5 MJ homopolar generator. Thus far, one-inch bars (both 1018 steel and 304 stainless), four-inch Schedule 80 304 SS pipe and four-inch Schedule 40 steel pipe have been welded. The pipe welds were completed in under one second at peak currents of up to 170 kA using less than 30% of the available energy in the 5 MJ machine. The design and construction of larger homopolars that could supply sufficient power and energy to resistance weld cross sections on the order of 100 in^2 on the same time scale is a straightforward extrapolation of the existing technology.

INTRODUCTION

The Center for Electromechanics (CEM) at The University of Texas at Austin (UT-Austin) is developing a technology that could make possible the butt welding of 48-inch pipe in a few seconds. We feel such a development would have significant impact on the pipeline, chemical, and construction industries, as well as the overall economy.

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The CEM has been involved in the design and development of homopolar machines since 1972. Two homopolars, a 0.5 MJ and a 5 MJ (see Figure 1), have been built and tested.[2] Currently under construction is an experimental

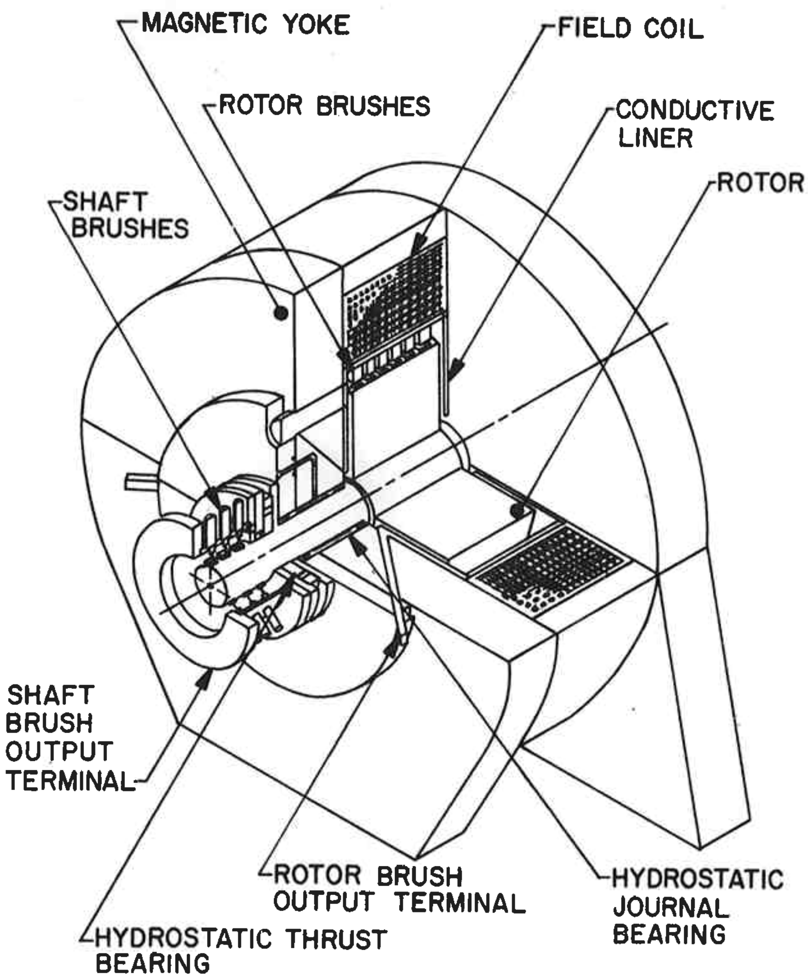

Figure 1: 5 MJ Homopolar Motor Generator

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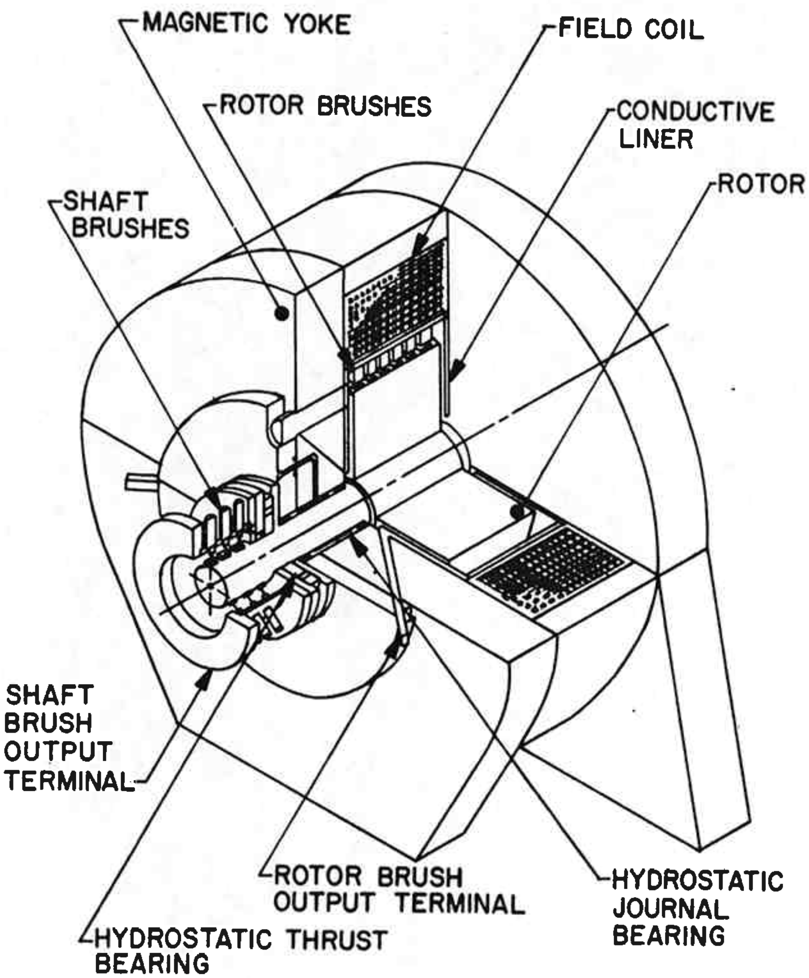

Figure 1: 5 MJ Homopolar Motor Generator

0.36 MJ, 1.88 MA, 208 V fast discharge homopolar[3] and scheduled to begin construction in mid-1977 are four 50 MJ, 125 V homopolar generators ("TEXT" homopolars) that will deliver a 65 MW, two-second pulse every two minutes to the Texas Experimental Tokamak (a fusion plasma research facility) (see Figure 2).[4] Several other homopolar systems are presently being studied for various applications at national labs and for the military. In addition, the CEM is involved in ongoing projects concerned with current pulse-shaping, high current switchgear development and plasma physics.

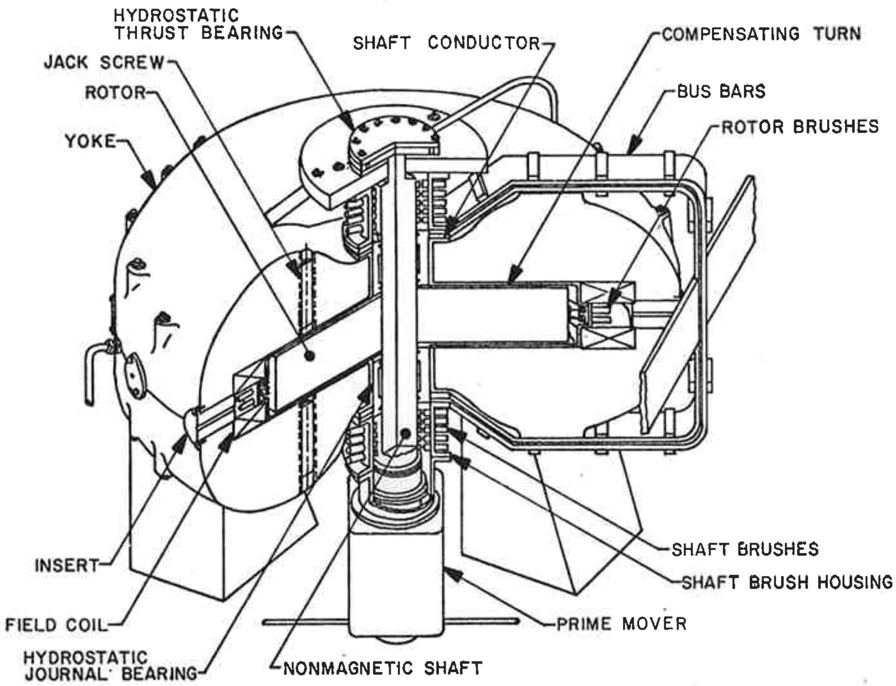

Figure 2: TEXT System Homopolar Generator

A CEM program which involves applying homopolar generators to commercial industrial applications is in its early stages. Resistance welding is one of these applications.

MACHINE CHARACTERISTICS

The Faraday Disc or homopolar machine in the conventional configuration (axial magnetic field and radial current flow, see Figure 3) can conveniently serve as both a motor and direct current generator while the armature of the machine also serves as the inertial store. Thus, the forces which occur during motoring and discharge are generated within the flywheel itself, essentially at the same point where the energy is stored, eliminating coupling and shaft torque limitations. The rotor itself is a right circular

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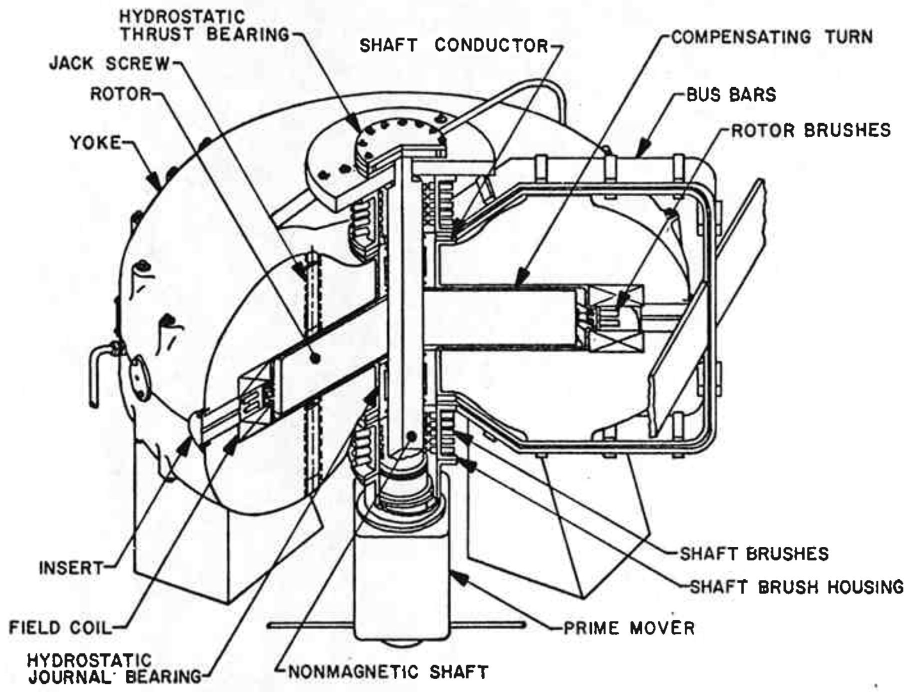

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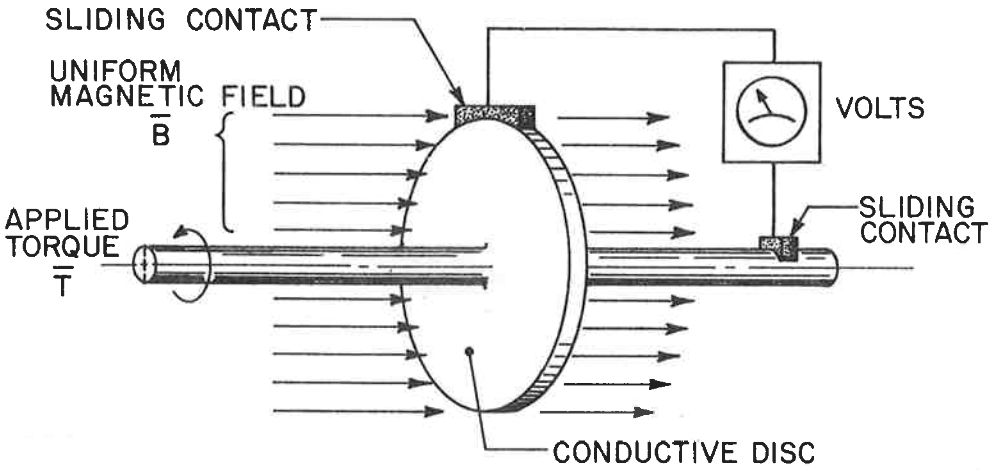


Figure 3: Faraday Disc

cylinder of electrically conductive material, and the magnetic field coil is a simple solenoid. Such units have been built at UT-Austin for less than $0.01 per joule in 0.5 MJ and 5 MJ sizes and several design studies show that larger units can be built for somewhat less than this figure.

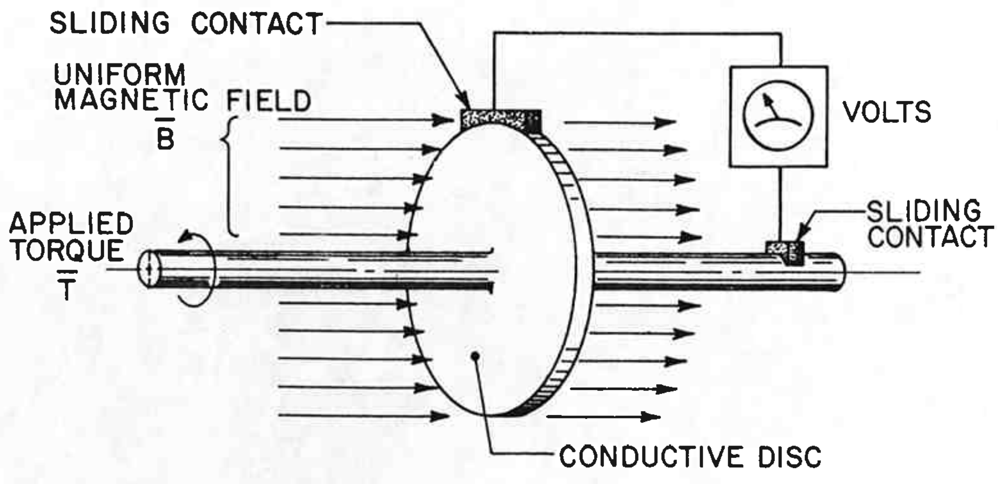
Homopolar generators behave electrically like slow discharge capacitors, delivering pure direct current (no commutation or rectification) at relatively low voltage (an ideal current source for resistance welding). The 5 MJ homopolar machine at UT-Austin stores 5,000,000 W-sec and can discharge this energy in less than 1.0 sec at a peak power level of over 20 MW. Since it is self-motored at less than 200 kW, demand charges are minimized. Also, if motored-up with an external prime mover such as a diesel engine, homopolars may be used on-site for construction welding purposes. The prime mover may be as small as the duty cycle will allow.

A control circuit capable of shaping the discharge current pulse to a desired flat-top, trapezoidal wave-form is now being tested. This control circuit may be modified to provide the current pulse desired for a given weld.

ADVANTAGES

There are many problems inherent with fusion (arc) welding techniques that can be either eliminated entirely or decreased significantly when using a resistance welding process. When expected production is such that the additional equipment cost of many resistance welding systems compares favorably with the slower production and higher labor costs of arc-welding processes, using resistance welding can be easily justified. Since resistance welding generally provides more control over heat input than typical fusion methods, improved weld quality and smaller heat-affected zones can result.

Welding techniques using filler metal involve complex metallurgy due to the interaction of the flux, filler metal and other impurities with the



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Welding techniques using filler metal involve complex metallurgy due to the interaction of the flux, filler metal and other impurities with the work-piece metal during the welding process. Also, when welding larger cross sections, since several passes are required to complete the weld, meticulous cleaning to remove slag after each pass is a necessity. Additionally, the relatively low power inputs and resultant long welding times allow the heat to propagate throughout the weldment causing the temperature-affected zones to be quite large. All of these factors increase susceptibility to hydrogen embrittlement and sensitization.

One promising method for increasing weld quality involves resistance welding at very high power levels. Properly implemented, resistance welding techniques have the potential to decrease these problems significantly and improve the weld in other ways. Since the only materials involved are the parent metals of the two pieces to be joined, the metallurgy of the weld can be very simple, relative to fusion welding processes. Formation of inclusions can be virtually eliminated by proper joint preparation. Using properly sized power supplies and careful current and cooling control, the heat-affected zone can be on the order of a few millimeters, rather than several centimeters as with typical fusion processes. The potential savings of using a resistance welding process are significant. In addition to those inherent with the very fast welding rates (weld times of a few seconds), materials costs would be less since no fluxes or filler metals are required; labor costs would be less since fixtures used in resistance welding are generally automated and lower operator skill is required; and resistance welds are generally more consistent in quality so rejects are fewer and inspection less demanding. However, for large cross sections, few, if any, commercially available power supplies have the power and energy capabilities to accomplish resistance welds in a cost-effective manner. One type power supply which does have the potential to be a cost-effective solution is the homopolar generator.

Resistance welding has not been generally used in the construction industry, primarily due to power supply constraints. Conventional transformer and rectifier resistance welding supplies require some separate source of electrical energy that can supply the instantaneous power required. If access to a utility grid is not available, M-G sets dedicated to welding must be provided. Since for resistance welding of larger cross sections the power required is very large and is required for only short periods, the cost of the M-G set designed to meet these peak demands is generally prohibitive. Even if access to a grid is available for either construction or in-plant welding, the demand charges can become significant and in some cases prohibitive due to the cyclic nature of the power consumption. Homopolar machines are inherently high power, low voltage energy storage devices that can offer major advantages over M-G sets, transformer, and transformer-rectifier type power supplies for both on-site construction and in-plant production resistance welding.[5] Since homopolars are energy storage devices, demand charges and power consumption would be minimized. When used at an isolated construction site and coupled to an external prime mover (such as a diesel engine), the welding supply could be completely self-contained, and again, since the homopolar machine stores energy inertially, the prime mover could be of modest size.

The ideal energy source for many resistance welding applications would supply pure direct current at a low voltage with a very high power rating.

Rectified power can be less desirable for the welding of larger cross sections both for economic and technical reasons. Common dc generators have limitations on brush current densities due to commutation and tend to have surge problems when large loads are switched on and off. Storage batteries can be used but are bulky, inefficient, and require high maintenance. Homopolar generators, the only true dc generators, tend to be low voltage, very high current machines and are ideally suited for resistance welding applications.

5 MJ WELDING EXPERIMENTS

To demonstrate the potential of homopolar generators as resistance welding power supplies, the CEM has done some low budget welding feasibility experiments using the 5 MJ homopolar generator. Thus far, upset butt welds have been produced on one-inch bars (both 1018 steel and 304 stainless) and four-inch Schedule 80 (thick wall) 304 SS pipe. The 1018 steel bars were upset butt welded at a peak current level of 36 kA. Tensile tests indicated weld strength to be equal to that of the base metal. The 304 stainless steel bars were welded at a peak current level of 26 kA and sections showed a very small heat-affected zone.

Using the arrangement shown in Figure 4, samples of 304 SS pipe were welded in less than 4 sec at a peak welding current of 160,000 A, using less than 30% of the available energy in the 5 MJ homopolar generator.

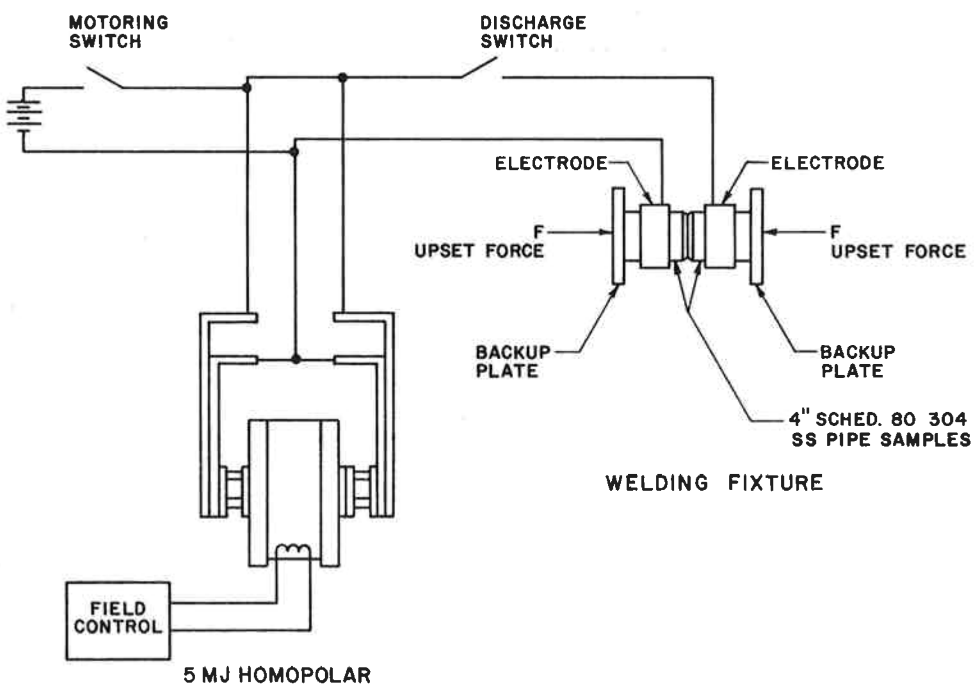

Figure 4: Schematic of Welding Fixture - 5 MJ Interface

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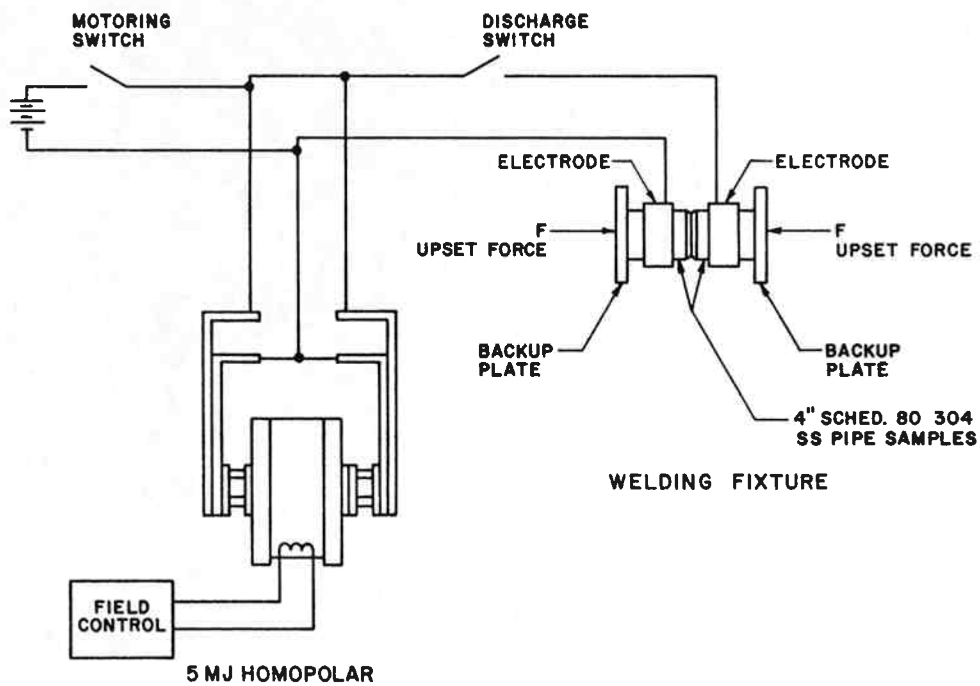

Figure 4: Schematic of Welding Fixture - 5 MJ Interface

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The welded pipe samples are shown in Figures 5 and 6. Only five welding attempts have been made so the welding parameters are by no means optimized; however, the initial results are very encouraging as they illustrate that the power/energy requirements of relatively large welds (up to approximately 10 in^2) are within the capability of the present 5 MJ machine, switchgear and buswork.

Based on projections from the welding experiments performed with the 5 MJ homopolar generator in the CEM lab, a modified version of one of the 50 MJ TEXT homopolar generators should have more than sufficient energy and power to weld 100 in^2 of steel in a matter of seconds. Since this modified 50 MJ would have a maximum voltage of approximately 125 V and a peak current of 4 MA, its instantaneous peak power level would be approximately 500 MW. Since the homopolar must store energy (inertially) after each weld, there must be a finite time interval between weld cycles. Since time is required to remove and replace the work in the fixture anyway, the homopolar rotor can be accelerated during this period. The rate at which the homopolar can recharge itself is based simply on the size of the available prime mover.

Results of initial experiments have generated interest from several areas. The boiling water reactor industry is having problems welding Schedule 80 304 SS pipe satisfactorily using arc welding techniques and are interested in the potential of resistance welding the pipe, on-site, using homopolars as power supplies. We have received inquiries from the rail and pipeline industries for using homopolars as resistance welding power supplies. A government contractor and an industrial manufacturer have expressed interest in upset butt and flash welding cross sections on the order of 100 in. There are also in the aircraft, automotive, ship building, sheetmetal fabrication industries, etc., applications where homopolars as resistance welding power supplies could prove to be cost effective. Of course, there is substantial work to be done, particularly in the area of fixture design, before resistance welding of very large sections will be done commercially. However, the tremendous savings potential of such a process should accelerate transition to commercialization.

We are anxious to transfer this technology to industry. We feel that the welding capabilities that these machines provide could have substantial economic impact on industry.