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Computer simulation and experimental verification of welding in thin steel sheet containment

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Abstract

Thermal analysis of welding a thin steel sheet containment can around the modular coil winding pack of a Quasi-Poloidal Stellarator was performed. Welding causes distortions and thermal stresses to develop in the coil. Damage to the conductor coil nearest to the welding region would cause distortion of magnetic field produced by it, which would disrupt working of the stellarator. Computer weld models were developed and temperature response normalized with respect to ambient temperature was plotted at predefined locations on the cross-section of the coil. This study predicted that the maximum temperatures reached were less than the insulation melt temperatures. Independent studies using data from this study predicted that there is negligible distortion and stresses in the coil after welding. Experiments were also performed which confirmed no visual damage to conductor coil nearest to the weld zone and served to validate the computational models.
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1. Introduction

Thermonuclear reactions produce large amounts of energy, which could be controlled and used for constructive purposes. Plasma confinement using a toroidal magnetic field has been the main focus of most research. Stellarators have a toroidal magnetic configuration that does not require net plasma current to produce closed magnetic surfaces. The resulting plasma shape is complex, has a periodic geometry and is not axisymmetric. The Quasi-Poloidal Stellarator (QPS) is a low aspect ratio compact stellarator with a non-axisymmetric, near-poloidally symmetric magnetic configuration, being developed at The Oak Ridge National Laboratory [1]. An integral part of the QPS design is the modular coil set that produces the primary magnetic configuration. The design and fabrication of the modular coils is a major engineering challenge due to the complexity, precise geometric accuracy and high current density of the windings.

The modular coil set design uses flexible, copper cable conductor to make it easier to wind into the complex shape. The copper cable is insulated using a nylon cloth and alternate layers of glass cloth and Kapton®. A tee-shaped structural member supports the copper cable conductors. Stainless steel sheets are welded to the tee steel member to completely enclose the windings (see Fig. 1). After enclosing the cable, it is vacuum pressure impregnated with epoxy using a prototypical impregnation and curing cycle to form a monolithic copper–glass–epoxy composite [2].

The welding process required in the containment of the conductor prior to the imposition of vacuum pressure impregnation (VPI) has important features and problems with respect to damage to conductor and residual stresses associated with it [3]. In particular the proximity of welding area to the copper and its insulation wrapping during the welding process, poses a challenge to prevent damage to the windings. In addition high local heat flux and temperature generated during welding can easily cause undesirable deflections and thermal stresses within the winding.

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Nomenclature

F_{1-2} shape factor
g acceleration due to gravity
h convection parameter
I welding current
k thermal conductivity
L length
Nu_L Nusselt number
Pr Prandtl number
$q(r)$ welding heat flux
q heat flux
Q amount of heat input
r effective radius over which heat flux is applied
$\bar{r}$ characteristic radial dimensional distribution parameter for welding
Ra_L Rayleigh number
T dimensional temperature
T_{in} ambient temperature, 297.15 K
T_1 temperature at first-thermocouple location (Figs. 4–8)
T_2 temperature at second-thermocouple location (Figs. 4–8)
T_3 temperature at third-thermocouple location (Figs. 4–8)
T_{1e} temperature at first-thermocouple location obtained during experiment (Fig. 8)
T_{2e} temperature at second-thermocouple location obtained during experiment (Fig. 8)
T_{3e} temperature at third-thermocouple location obtained during experiment (Fig. 8)
T_∞ reference temperature, 300 K
T_{avg} average temperature of surface
T_f film temperature
V arc voltage
x x-axis dimension of weld area
y y-axis dimension of weld area

Greek symbols
α thermal diffusivity
β $1/T_f$
ε emissivity
η efficiency
π pi
σ Stefan Boltzmann's constant
υ kinematic viscosity

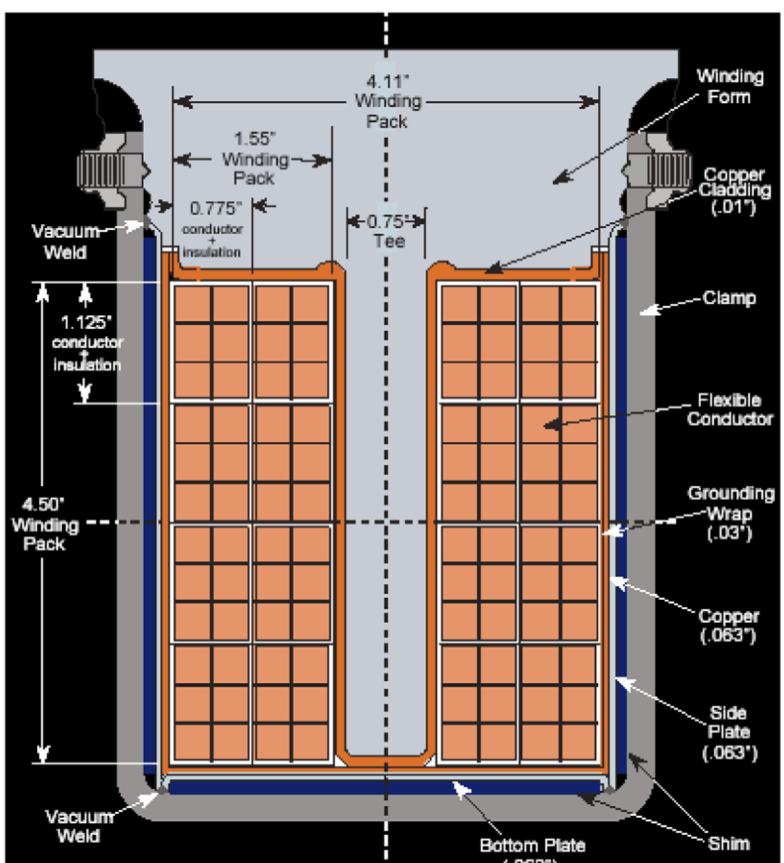

Fig. 1. Modular coil cross-section.

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