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# Impulse Capacitor Discharge Welding of Hollow Structure Made of Nickel-Base Alloy*

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**Abstract:** Future steam turbines will use hollow structures so that the turbine inlet temperature can be increased to improve the thermal efficiency. These hollow structures are made of the nickel-base alloy Nicrofer 6025 HT and consist of a wire mesh between two cover sheets. The cover sheets can be joined to the wire mesh by capacitor discharge welding due to its extremely short welding duration. The goal of this research is to investigate suitable welding parameters so that the weld spots form in an optimum way to increase the tensile shear strength and reduce spattering. Tensile shear tests, three-point bending tests, and micrographs were used to judge the joint quality of structures made with various welding parameters. The results show that the best welds are obtained with a transmission ratio of 1:200, welding energy of 70% to 95%, and electrode force of 7 to 9 MPa.

**Key words:** capacitor discharge welding; nickel-base alloy; hollow structure; tensile shear test; three-point bending test; micrographs

## Introduction

Today, steam turbines are the most widely used means of generating electricity. Hot steam flows through a turbine which rotates a shaft to drive a generator. Higher pressure and higher temperature steam will result in higher turbine efficiencies. However, these two parameters are restricted by the turbine blade material properties. Conventional steam turbine materials, martensitic steels, cannot withstand more than approximately 620℃ in the long run[1,2].

One method allowing increased steam temperatures is to use a composite structure consisting of two cover sheets and an intermediate wire mesh layer in between. These hollow structures can provide coolant flow channels with the fluid cooling the turbine and shaft surfaces which are subjected to high thermal stresses.

Common methods of manufacturing such composite structures include diffusion joining with an active filler metal, friction welding, and TIG welding. These processes often require long exposure times at high temperatures or high pressures, leading to grain coarsening in the microstructure or heavy plastic deformation near the joint[3].

The cover sheets can be joined to the wire mesh by capacitor discharge welding to form lattice segments. The extremely short welding times of this process ensure that the thermal loads on the base material outside the joining zone are quite small. The cooling rate in some condition can be as high as $1\times10^6$ K/s with capacitor discharge welding[4-6]. A more narrow heat affected zone and reduced welding distortion and residual stresses can be obtained with capacitor discharge welding due to its quick welding process[7]. The heat

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input can be controlled by varying the capacitor bank voltage that changes the current pulse amplitude. The condensers ensure that the energy of different pulses is constant, resulting in stability of the welded joint quality[8,9].

To produce high quality composite structures, the process parameters, such as the transmission ratio, the electrode force, and the welding energy, need to be optimized. Since the composite structure will be used in a steam turbine, tensile strength, bending strength, and spattering tendency are also important criteria for producing high quality welded joints.

Conventional martensitic materials are not very corrosion-resistant in a steam atmosphere. Nickel-base alloys exhibit exceptional resistance to oxidation and carburization at higher temperatures. Therefore, a nickel-base alloy is normally used for these hollow structures.

## 1 Experimental Setup

The cost of the energy storage capacitors required by capacitor discharge welding machines makes them considerably more expensive than alternating current machines. However, capacitor discharge welding is still an excellent technology for specific applications in which very large, short duration welding currents are more effective than smaller currents for longer times. Examples of these applications are when a weld must be made in close proximity to a heat-sensitive area such as a glass-to-metal seal or explosive compounds[10].

Impulse capacitor discharge welding is characterized by low thermal impact on the joined parts compared with conventional resistance welding. The welding process duration is extremely short because the capacitor discharges very quickly (8-20 ms) through a pulse transformer that generates a high current and relatively low voltage. The cover sheets and wire mesh are fixed between two copper electrodes at a defined pressing pressure before the capacitor is discharged (Fig. 1). The contact points of the three layers each constitute a resistance for the current. Local heating and complete melting of the material occur at the contact points to bond the plate and the wire mesh together.

In the experiments, two cover sheets with an intermediate wire mesh layer between the sheets were welded with a capacitor discharge welding machine from Manfred Schlemmer GmbH. The operating parameters of the welding machine were as follows: Input

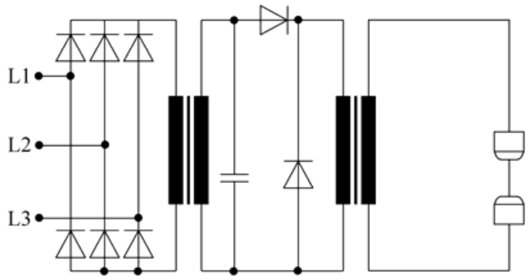


**Fig. 1 Principle of the capacitor discharge welding test set-up**

supply voltage is 400 V/50 Hz; connection power 30 kW; control voltage 230 V (AC)/24 V (DC); valve voltage 24 V (DC); charging voltage 0-3200 V, stepless; energy 0-20 kJ (100%), stepless; electrode force 0-30 kN (10 MPa), stepless.

The switchgear cabinet controlled the equipment and the capacitors. There were altogether six capacitors, each with a capacity of 640 μF, which could be alternatively switched. The hydraulic unit provided a maximum force of 30 kN. The impulse transformer transmission ratio could be changed on the instrument panel.

In a capacitor discharge welding machine, the welding time cannot be changed, only the transmission ratio can be changed, which indicates how quickly the capacitors will discharge into the weld. For a certain energy quantity existing in the capacitors, the maximum welding duration and thus minimum peak current value occur at a transmission ratio of 1:400, while the minimum welding time occurs at a transmission ratio of 1:100.

The two electrodes are key components of the resistance welding machine since they transmit the current and force to the workpiece. Different electrode materials affect the mechanical and electrical characteristics of the welding process, so the electrode material must be selected carefully. The requirement for good electrical and thermal conductivity can be fulfilled most economically with pure copper. However, copper does not adequately resist deformation and distortion in the workpiece, so the electrodes are normally made of copper alloys. These tests used flat 50 mm×50 mm electrodes made of a CuCrZr alloy.

In the wire mesh hollow structure, a so called "sandwich structure", both the cover sheet and the wire mesh were made of the nickel-base alloy Nicrofer 6025 HT (NiCr25FeAlY, designation according to VdTÜV) which is a high-carbon, nickel-chromium-iron alloy with the micro-alloying elements titanium and zirconium together with aluminium and yttrium[11].