Electromagnetic driven selfpiercing riveting of metal & composite sheets

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Company Profile

Since 13 years POYNTING company is equipment manufacturer for diverse applications of Pulsed Power Technologies.

We bring new technologies into industrial application and support research centres with specific equipment developments.

Fields of activity and products:

High Voltage Power Supplies
average power from 3kW to several 100 kW,
output voltage from 1kV to 100kV,
repetition rates from 1Hz to several kHz

Pulse Generators
modules as well as turn-key systems
optimised for the application (adjusted to the “load”)

Engineering Services and Simulation
### Characteristics of EMF Pulse Generators

**Selected pulse generators with different specifications**

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<td>Maximum permitted discharge current</td>
<td>60-100 kA</td>
<td>800 kA</td>
<td>150 kA x no. of modules</td>
<td>up to 1.280 kA</td>
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<td>Short circuit frequency (shorted without coil)</td>
<td>65 kHz</td>
<td>100 kHz</td>
<td>&gt;50 kHz</td>
<td>&gt; 30 kHz up to 50 kHz</td>
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**SMU COMPACT series:**
Compact machine design, which has to be configured in optimum accordance to the forming task.

**SMU MODULAR series:**
Modules (optional 6kJ or 9kJ each) of any number can be connected in serial control chain collecting the power by parallel connection of the HV output.
Electromagnetic Forming (EMF) is a **High Velocity Forming Process** using the energy density of a pulsed magnetic field to form or to accelerate workpieces of good electrical conductivity.

**Process Types**
resulting of the coil-workpiece arrangement

EMF is used for **joining**, **forming**, and **cutting** of thin-walled tubes and sheets, but joining by compression of tubular parts is actually the most important application in series production.
Example of Beneficial Application: Joining of Dissimilar Material

Optimization of joining processes for new automotive metal-composite hybrid parts

Grant Agreement Nr: 609039
Collaborative Project - FP7-2013-NMP-ICT-FOF(RTD)

Application example:
Selfpiercing riveting of carbon fibre composite sheets
Sandwich: DC04 0.5 mm
4 x CFP 0°-90°-0°-90°
DC04 0.5 mm
Rivet H1, 5 x 5
AW5754 1.5 mm

Application example:
multi-material brake pedal

Rivet H1, 5 x 5
Riveting of magnesium sheet at standard setting velocity of ca. 0.01 m/s is not possible at room temperature

Beneficial use of high punch velocity of 10 – 100 m/s for “difficult to form” materials, like magnesium alloy at room temperature

(Source: LWF, University of Paderborn, ICHSF2004, poster session)
Experimental Setup for EM Riveting

- Mass
- Flat coil I
- Driver plate
- Punch
- Sheets to be joined
- Flat coil II (optional)
- Flat coil
- Driver plate
- Punch
- Sheets to be joined
- Die

Mass

Coil winding

Flat coil I

Driver plate

Punch

Sheets to be joined

Flat coil II (optional)

Flat coil

Driver plate

Punch

Sheets to be joined

Die
Experimental Setup for EM Riveting

The energy density of the magnetic field corresponds to a vertical acting pressure on the driver plate.
Experimental Setup for EM Riveting

The energy density of the magnetic field corresponds to a vertical acting pressure on the driver plate.
Parameter Variation – Pulse Shape

Variation of pulse shape and discharge energy efficiency

- Flat coil: F85-20/30
- Upper sheet: AC150, 1.2mm
- Lower sheet: AW5754, 1.5mm
- Rivet: Rivset® H1 5x5 (d x l)
- Energy: 650 J (SMU modular)

- Discharge circuit properties can be changed either by capacitance of energy storage or by change of coil inductance.
- Required pulse shape shall correspond to the weight of the punch.

- Weight of punch: ~ 310 g
Joining Task: Riveting of CFRP Sheet to Aluminium Sheet

CFRP Samples (Ideko):
- thickness 1.5 mm – 1.7 mm
- three biaxial carbon fabrics

<table>
<thead>
<tr>
<th>Aluminium Alloy</th>
<th>thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>AW 5754 H22</td>
<td>1.5 mm</td>
</tr>
<tr>
<td></td>
<td>2.0 mm</td>
</tr>
<tr>
<td>AC 150 T4</td>
<td>1.2 mm</td>
</tr>
<tr>
<td>AW 6082 T6</td>
<td>1.5 mm</td>
</tr>
<tr>
<td></td>
<td>2.0 mm</td>
</tr>
</tbody>
</table>

- Rivets from different types:
  - head diameter Ø k: 7.8 mm
  - shaft diameter Ø n: 5.3 mm

- different shaft length
- different hardness (H0, H1, H2)

Riveting Dies:
- LWF-1
- Boellhoff - C
- Boellhoff - B
- Boellhoff - A

Rivets and dies have been provided by BÖLLHOFF® RIVSET®
quality evaluation by shear test

Sample geometry and test configuration according to EN ISO 14273 (spot welding)

Dimensions for thickness $1.5 < t \leq 3$
Quality Criterion: Cross Tensile Test

Sample geometry and test configuration according to EN ISO 14273 (spot welding)

Dimensions according to shear test samples

clamping bridge with composite sheet

clamping bridge with aluminium sheet
Visual Check of Rivet Setting Quality

**EMR043**
- **Rivet:** RIVSET® SKR 5 x 5 H2
- **Die side sheet:** AW5754; 2.0 mm
- **Punch side sheet:** CFRP (Ideko) 1,7 mm
- **Cover sheet:** -- none --
- **Pulse Energy:** 580 J

**EMR053**
- **Rivet:** RIVSET® FRK 5 x 5 H0
- **Die side sheet:** AW5754; 1.5 mm
- **Punch side sheet:** CFRP (Ideko) 1,6 mm
- **Cover sheet:** -- none --
- **Pulse Energy:** 500 J

**EMR059**
- **Rivet:** RIVSET® SKR 5 x 5 H2
- **Die side sheet:** AW5754; 2.0 mm
- **Punch side sheet:** CFRP (Ideko) 1,6 mm
- **Cover sheet:** -- none --
- **Die:** LWF-1
- **Pulse Energy:** 550 J
Tensile tests with rivet type FKR show better results than the direct SRK rivet

Shear test
- rivet SRK 5x5 H2 (580J)
- rivet FKR 5x5 H0
  - CFRP 0/90, emr082 (550J)
  - CFRP ±45, emr081 (550J)

Rivet stucks in punch-sided sheet, ripped out of the die-sided sheet

Graph:
- CFRP 1.6mm – AW5754 2.0mm, Die „LWF-1“
  - rivet SRK 5x5 H2 (580J, emr044)
- rivet FKR 5x5 H0, different fibre orientation
  - CFRP 0/90, emr075 (550J)
  - CFRP ±45, emr070 (550J)
- change of die shape „C“:
  - CFRP 0/90, emr100 (650J)
  - CFRP ±45, emr095 (650J)
New Process Concept for EMR of Composite-Metal Hybrid Parts

EM riveting of multi-layer fibre reinforced sheet metal or sandwich sheet

hybrid joining partner
(metal-composite-metal)

fastener

metallic joining partner

third metal layer optional

EM riveting of composite sheets using a riveting aid

riveting aid (separate cover sheet or bonded to composite)

composite sheet

fastener

metallic joining partner
Use of Cover Sheet as Riveting Aid

**Punch side sheet:** CFRP (Ideko) 1,7 mm
**Cover sheet:** stainless; 0.15 mm
**Die side sheet:** AW5754; 2.0 mm
**Rivet:** RIVSET® SKR 5 x 5 H2
**Die:** LWF-1
**Pulse Energy:** 600 J

**Punch side sheet:** CFRP (Ideko) 1,7 mm
**Cover sheet:** -- none --
**Die side sheet:** AW5754; 2.0 mm
**Rivet:** RIVSET® SKR 5 x 5 H2
**Die:** LWF-1
**Pulse Energy:** 580 J

**Punch side sheet:** CFRP (Ideko) 1,7 mm
**Cover sheet:** stainless; 0.35 mm
**Die side sheet:** AW5754; 2.0 mm
**Rivet:** RIVSET® SKR 5 x 5 H2
**Die:** LWF-1
**Pulse Energy:** 730 J
**Type of failure 1:**

Rivet stuck in die-sided sheet, but rivet “head” punched the composite

**Influence of cover sheet**

- CFRP 1.7mm (0/90) - AW5754 2.0mm, rivet: SRK 5x5 H2, die: LWF-1
  - no cover sheet (580J, emr078)
  - stainless 0.15mm cover sheet (600J, emr079)
  - stainless 0.35mm cover sheet (730J, emr057)

- Force at first failure:
  - 2130 N
  - 2516 N
  - 2720 N
Type of failure 2:
Rivet stuck in punch-side sheet, ripped out of die-side sheet.

Influence of cover sheet:
- CFRP 1.7mm (0/90) - AW5754 2.0mm, rivet: SRK 5x5 H2, die: LWF-1
  - no cover sheet (580J, emr078)
  - stainless 0.15mm cover sheet (600J, emr079)
  - stainless 0.35mm cover sheet (730J, emr057)
Evaluation by Shear Test Results

**Type of failure 1:**
Rivet stuck in die-side sheet, composite failed along complete drawing length

**Influence of cover sheet**
- CFRP 1.7mm (0/90) - AW5754 2.0mm, rivet: SRK 5x5 H2, die: LWF-1
  - no cover sheet (580J, emr078)
  - stainless 0.15mm cover sheet (600J, emr079)
  - stainless 0.35mm cover sheet (730J, emr057)

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<th>Displacement in mm</th>
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<tbody>
<tr>
<td>4000</td>
<td>12</td>
</tr>
<tr>
<td>3500</td>
<td>11</td>
</tr>
<tr>
<td>3000</td>
<td>10</td>
</tr>
<tr>
<td>2500</td>
<td>9</td>
</tr>
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<td>7</td>
</tr>
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<td>6</td>
</tr>
<tr>
<td>500</td>
<td>5</td>
</tr>
<tr>
<td>0</td>
<td>4</td>
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EMR080
Improvement by Higher Strength of Die Side Sheet (Aluminium Alloy)

The higher strength of die side sheet caused higher cross tension strength

BUT

Rivet sticks in punch-sided sheet, ripped out of the die-sided sheet

Principle correlation between shear strength and cross tension strength
Improvement by Shape of Die & Rivet Length

**Punch side sheet:** CFRP (Ideko) 1.7 mm  
**Cover sheet:** stainless; 0.35 mm  
**Die side sheet:** AW5754; 2.0 mm  
**Rivet:** RIVSET® SKR 5 x 5 H2  
**Die:** LWF-1  
**Pulse Energy:** 730 J

**Punch side sheet:** CFRP (Ideko) 1.8 mm  
**Cover sheet:** stainless; 0.35 mm  
**Die side sheet:** AW5754; 2.0 mm  
**Rivet:** RIVSET® SKR 5 x 6 H2  
**Die:** „C“ (sphere)  
**Pulse Energy:** 950 J
Improvement by Shape of Die & Rivet Length

CFRP 1.7mm – cover sheet 0.35mm - AW5754 2.0mm, Rivet SRK 5x5 H2
Die ‘LWF-1’
Energy 730J
emr057 for shear test
emr051 for cross tension test

CFRP 1.7mm – cover sheet 0.35mm - AW5754 2.0mm, Rivet SRK 5x6 H2
Die ‘C’ (sphere)
Energy 950J
emr118 for shear test
emr116 for cross tension test

Shear strength of > 4kN and cross tension strength of > 3kN are in a comparable range to alu - alu sheet joinings
Equipment for High Velocity Riveting

Pulse Generator, SMU machine

The “Load” (= Coil-Punch-System) does not belong to the pulse generator but is essential part of the discharge circuit.

Most challenging equipment requirements

- Required cycle time for riveting processes: min. 1/sec up to 3/sec
- Life cycle of equipment shall serve an output rate of 20 Mio discharges per year

Consequently, we need:
- Optimum process design aiming at low discharge energy
- New development of pulse generator to provide the repetition rate
- New concepts for tool design with improved durability
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### SMU COMPACT series:
Compact machine design, which has to be configured in optimum accordance to the forming task

### SMU MODULAR series:
Modules (optional 6kJ or 9kJ each) of any number can be connected in serial control chain collecting the power by parallel connection of the HV output
**Typical Discharge Current Curves of EM Pulse Generators**

**SMU MODULAR series:**
Modules (optional 6kJ or 9kJ each) of any number can be connected in serial control chain collecting the power by parallel connection of the HV output.

**SMU COMPACT series:**
Compact machine design, which has to be configured in optimum accordance to the forming task.

- **High current switch:** Thyristors (solid state)
- **High current switch:** Spark gap, tubes etc

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**Graphs:**
- **Coil current in kA** vs. **Time in µs**
- **High current switch:** Thyristors (solid state)

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**METAL MORPHOSIS**

Final Seminar, 24th February 2016
Belgium Welding Institute, Ghent
New Design of High Repetition Pulse Generator: SMU COMPACT 0208 TH – HR60

High repetition rate of 1 Hz by new circuit design with energy recovery

![Diagram of pulse energizing and energy recovery](image)

- Riveting process
- 1 sec (cycle time)
- HVPS
- Tool Coil
- C
- L

- 5 kV
- 2.8 kV
- ≈ 31% energy recovery
- 17 kA

Co-funded by the European Union
New Design of EMR Pulse Generator: SMU COMPACT 0208 TH – HR60

High repetition rate of 1 Hz by new circuit design with energy recovery

- excellent pulse to pulse accuracy
- 8h durability testing @ 1Hz successful component test
- water-cooled test coil, nevertheless recognized temperature problem at the load

High repetition pulse generator
Max. energy: 1.8 kJ @ 7.75 kV
High current switches: Thyristors
Long life pulse capacitors

Cooled test coil
Optimum process design aiming at low discharge energy (improve efficiency, reduce losses)

New development of pulse generator to provide the repetition rate

New concepts for tool design with improved durability

Coil-Punch-System Requirements:

1) Multi-functional punch design
   • carrying the driver plate from material with high electrical conductivity
   • intensifying the pressure by ratio of area facing the coil and area punching the rivet (typically used ratio of 70 - 100)
   • guiding the stroke of about 6 mm

2) Durability of coil and punch
   • strength of punch for pressure intensifying function
   • durability of both components shall be in a promising range for wearing tools (spare parts)

3) Efficiency – electrical, mechanical
   • conductive section (driver plate) shall be close to the coil
   • minimum weight for efficient use of short pulse length

4) Compact design considering accessibility of the joining zone
Optimization of Punch for EMR

Punch 1, light version: 298 g

Manually optimised design (target weight: 150 g)

- High strength steel shaft
- Large diameter Ø 88 low pressure area (coil side)
- Aluminium driver plate
- Titanium structure
- Aluminium driver plate

Topology optimization for SLM manufacturing
performed at DMRC, Paderborn, Germany

Result of third optimization loop
EMR laboratory setup used for feasibility proof of equipment

- high strength, lightweight punch
- pulse generator with energy recovery circuit

Finished punch from titan (360 HV5) & AW6082 (25 MS/m)

- Total weight: 148.3 g
- Surface ratio 1:120

- Energy reduction of again 20% at 50µs, resp.
  reduction of 36% at 25µs current rise time
- Promising punch strength after the first 50 full load pressure pulses
Summary and Outlook

- EMR is a working method to join composite sheet to metal sheet
- A concept using very thin local cover sheets has been introduced and investigated
- Feasibility proof for riveting of thin-walled CFRP sheets and typical aluminium automotive body material
- New circuit design for high repetition pulse generator could be realized and tested, special feature: integrated energy recovery circuit saves about 31-36% of charging energy (essential for rep rate, but for energy consumption as well)
- Improved properties of a coil-punch-system regarding pulse shape and punch weight achieved

- On this basis an industrial scale equipment shall be realized (prototype)
- Open issues still to be solved are related to durability and costs of wear parts (tool components coil and punch) on the one hand and on the other hand to a compact coil-punch-system for best accessibility in complex 3D parts