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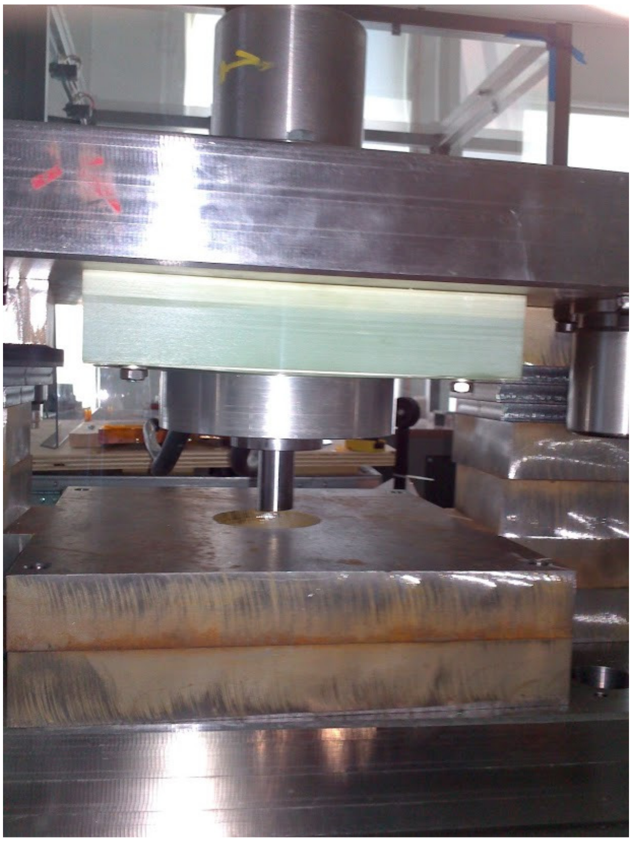
High performance magnetic pulse technology for sheet metal shearing processes



Project within FFI - Sustainable Production Technology

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Content

FFI in short

FFI is a partnership between the Swedish government and automotive industry for joint funding of research, innovation and development concentrating on Climate & Environment and Safety. FFI has R&D activities worth approx. €100 million per year, of which half is governmental funding. The background to the investment is that development within road transportation and Swedish automotive industry has big impact for growth. FFI will contribute to the following main goals: Reducing the environmental impact of transport, reducing the number killed and injured in traffic and Strengthening international competitiveness. Currently there are five collaboration programs: **Vehicle Development, Transport Efficiency, Vehicle and Traffic Safety, Energy & Environment and Sustainable Production Technology.**

For more information: www.vinnova.se/ffi

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1. Executive summary

The use of electromagnetic pulse power for joining and crimping of axisymmetric tubular components has been used in production at the aerospace industry since beginning of 1960´s. The fundamental physical phenomena is to produce a short-duration, high intensity magnetic field. The obtained magnetic field creates a magnetic pressure that can be used for development of new production processes for sheet metals like forming, crimping, welding and cutting/shearing.
This project was using electromagnetic pulse power to develop a new unique innovative production process in the following area:

- Adiabatic cutting/shearing – The major benefit is the ability to create holes in steel sheet materials by single side punching holes

The first experiments were made at Winset Technologies in Long Island, New York due to their long term knowledge of manufacturing high velocity electromagnetic punch presses, former Lourdes Systems. Ultra-high strength sheet materials were used for the experiments and the results were that the obtained holes had tremendous quality. Still, this system had a die as back-up and our attempt were to made a punching device that increase the speed of the punch to a velocity that would create holes without any tool back-up.
This led us to use the capacitor bank (A Pulsar magnetic pulse system) that can be found at Swerea KIMAB and design a flat coil to the inertial data from the system.
We had a lot of failures with burning cables and assembly issues as well of bad design of the first coil. In July 2012 we made some test with a single turn flat coil but the results showed no major movement of the punch device. By consulting a parallel project at Ohio State University, Columbus, USA we did get the information that a multi turn coil with 6-8 windings would improve the energy level with 6 to 8 times for a system like ours. In March 2013 we did some last attempts and we did succeed to invent a high speed punching device. Unfortunately the capacitors bank were too weak to achieve the energy level for creating a hole in a steel sheet material but for a soft sheet of Al alloy sheet a hole did occur.

The conclusion would be that a high speed electromagnetic punching device could be invented for making holes in sheet metals without any back up if the energy level in the capacitors would be higher than in the present set up.

2. Background

At the production line at Volvo Truck´s plant in Umeå several holes should be made of the cabins due to customers order and for subsequently assembling parts. This is made by robot assisted drilling and is a bottle neck today. This method with drilling will also need a robot on the inside of the truck to support the sheet metal.
This project will develop an adiabatic cutting process to make a hole in the sheet without any support from the inside. The advantages should be a significant reduction of robots in Volvo 3P assembly plants around the world and also the possibility to make holes in places that has been impossible today due to the support from the inside.
Another issue in the industry today is shearing of high strength steel sheet material without getting cracks and bad surfaces as well large wear of the punch. These issues could be reduced by an increase in speed of the hole punching tool.
To obtain this high speed device, an electromagnetic pulse was used for the driver of the punch.
The principle with electromagnetic pulse power technology is that electric energy is charged and stored in high performance capacitors. Subsequently, the charge from the capacitors is switched over a coil during a very short period (<100µs) and in the form of a damped sinus wave. This results in a magnetic field which induces eddy currents in any conductive materials nearby. The currents induced in the conductive material will be in opposite direction of the primary current in the coil. The induced eddy current in the conductive material interact with the exciting magnetic field and generates a material body force, the Lorentz force, between the coil and the conductive material. The electromagnetic force can cause the conductive material to accelerate to velocities exceeding 400 m/s[1].
Our idea was to mount a piercing punch on a conductive plate that are assembled close to an electromagnetic coil and let the Lorentz force to accelerate the plate and piercing punch to a speed that could penetrate a sheet metal without any back-up die.

3. Objective

The objective for this project was to develop a high speed adiabatic shearing process, which will solve the problems that the automotive industry has today with punching holes in steel sheet metals.

[1] G. S. Daehn. High Velocity Metal Forming. ASM Handbook (2004)

4. Project realization

The first pre-trials on an electromagnetic punching device were done at Winset (www.winset.net) 72 Bridge Rd., Islandia, NY 11749, US.
Punch & die set-up for the demonstration was a 1-inch square punch with corresponding die for sheet materials of 0.25 mm to 0.39 mm in thickness and for 35-44 mm in width.
The materials the project choose for this pre-trial were these

1. Stainless steel 1.4301 from Outokumpu
    a. Thickness 0.11mm
    b. Typical composition: Cr 18%, Ni 8.3%, C 0.04%
    c. Typical mechanical data:
        i. Rp02 (MPa) =290
        ii. Rm (MPa) = 600
        iii. Elongation A5% = 55
        iv. Hardness HB = 170
2. Stainless steel C20 (AISI 1095) from Sandvik Materials Technology
    a. Thickness 0.38mm
    b. Typical composition: C 1%, Si 0.25%, Mn 0.45%
    c. Typical mechanical data:
        i. Rp02 (MPa) =1650
        ii. Rm (MPa) = 1850
        iii. Elongation A5% = 2-4
        iv. Hardness HB = 495-500

The system are described in the picture 1 and the holes in the sheet specimen in picture 2

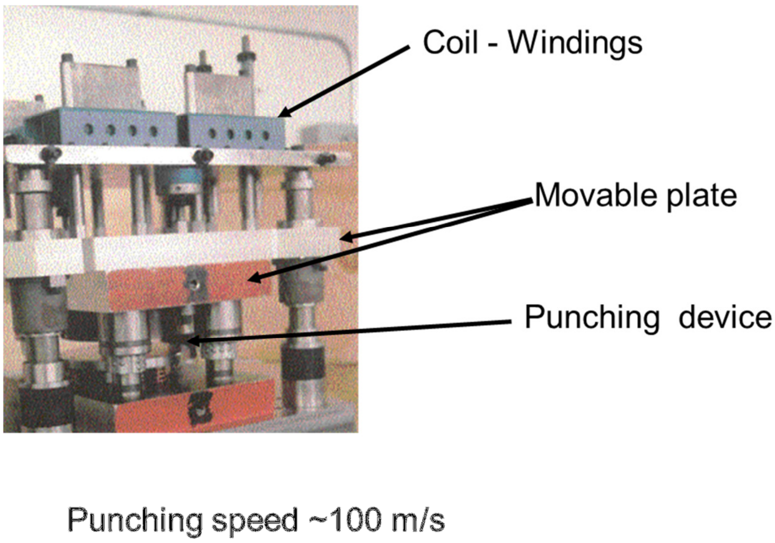


Figure 1 The high speed electromagnetic punch device at Winset Technologies (www.winset.net)

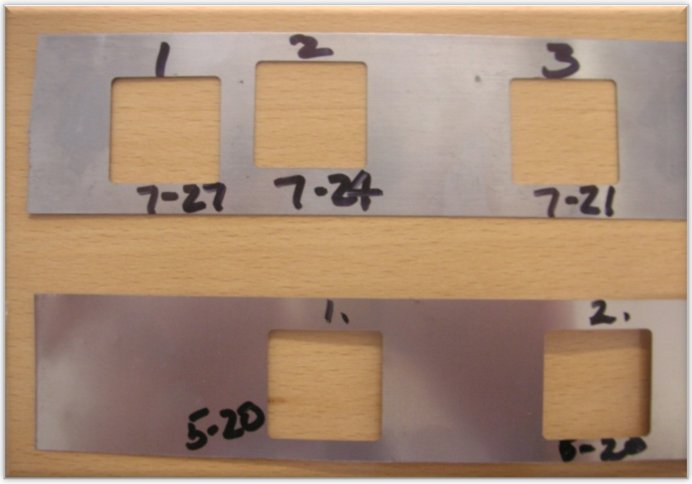


Figure 2 The high speed punched holes.

The rest of the project has been made with the capacitor banks at Swerea KIMAB, see picture 3, and the technical data for this system are tabulated in table 1.

Figure 3 The Magnetic Pulse System at Swerea KIMAB

Table 1 The technical data for the magnetic pulse system at Swerea KIMAB

Detail	Description
Maximal energy storage	12 kJ at 25 kV
Operation energy (for continues production)	6.5 kJ
Discharge peak current (maximal)	100 kA
Operation current	70 kA
Voltage (maximal, *not* for continues production)	20 kV
Working Voltage (maximal, for continues production)	18 kV
Charging time	1 kJ / sec
Capacitance	40 µF
Self inductance (short circuit status)	130 nH ± 10%
Frequency (for short; average)	65 kHz
Voltage-energy ratio	$V = \sqrt{\frac{E}{20}}$ E = Energy [J]; V = Target Voltage [kV].
Repetition time (minimum)	12 sec per pulse

The design was made for implementing in a four pillar die set and the bushing were of non-conductive materials. The contact plates were of pure copper and the wiring to the coil was of traditionally high voltage cables. This set-up was to analyze a punch system without any back-up i.e. a piercing process with only punch and no die. The first attempts were made with a single turn coil and the set-up is described in picture 4 – 5.

Figure 4 show some pictures from the set-up at testing phase 1

Figure 5 show some pictures from the set-up at testing phase 1

The results from the first testing phase were a disappointment due to that the plate with the piercing punch were hardly moving under the obtained magnetic pressure. After

consulting Geoffrey Taber and Professor Glenn Daehn at Ohio State University that work on a similar project[2] we did get the advice to use a multi turn coil, which increases the magnetic pressure between the coil and the die plate. The project did also change the cables to Lits wires to reduce the skin effect between the cables as well to decrease the arcing at the connections.
Pictures from the second testing phase are shown in figure 6.

Figure 6 show some pictures from the set-up at testing phase 2

[2] An Electromagnetically Driven Metalworking Press; G. A. Taber, B. A. Kabert, A. T. Washburn, T. N. Windholtz, C. E. Slone, K. N. Boos and G. S. Daehn ; Department of Materials Science and Engineering, The Ohio State University, Columbus Ohio, USA; 5th International Conference on High Speed Forming (ICHSF 2012) in Dortmund, Germany; April 24th – 26th, 2012

5. Results and deliverables

5.1 Delivery to FFI-goals

The goal was to develop a system that improve quality and increase the productivity for the manufacturing of sheet metal components. This is in line with the information in VINNOVA´s strategic document for manufacturing process systems.

The results from the early pre-trials in Winset Technologies did tell us that we get excellent results with tremendous improved edge qualities. This method would be to prefer for punching holes in high strength metallic materials.

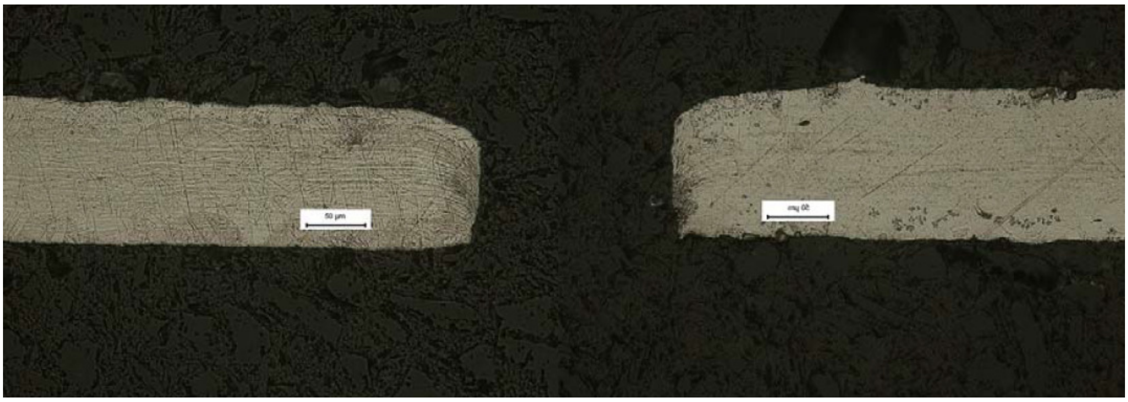


Figure 7 Material 1.4301, 100x

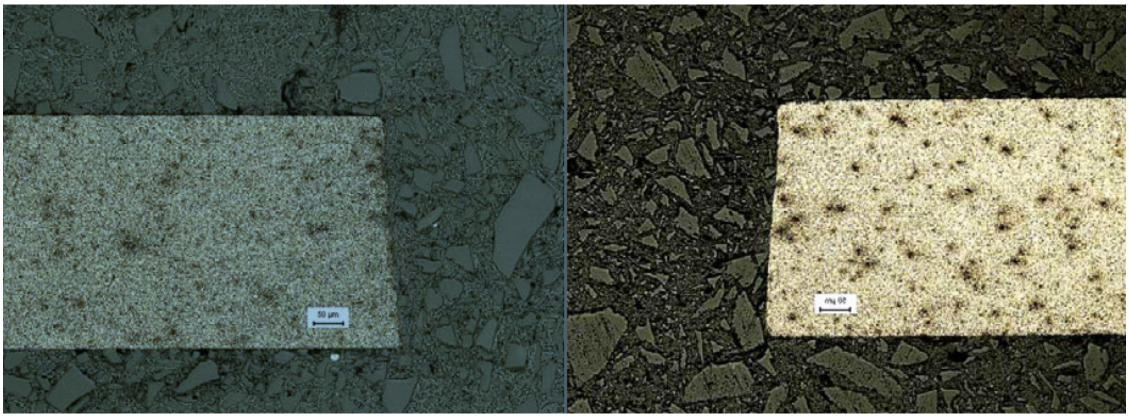
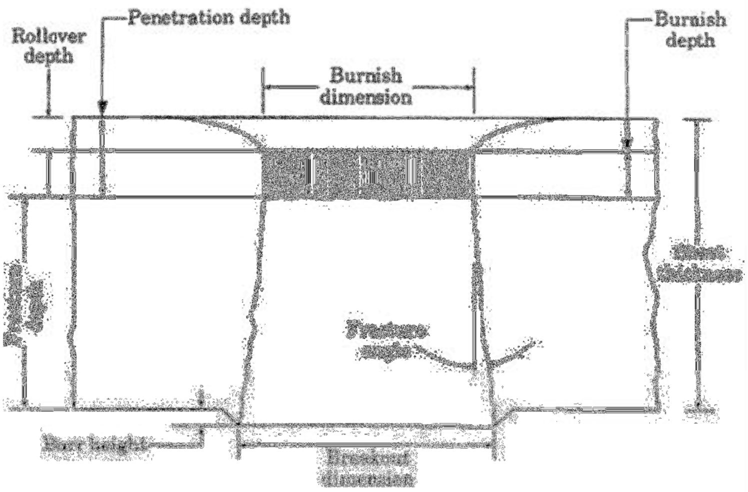


Figure 8 Material C20, 100x,

Table 2 Results from the pre-trials.

	Material 1.4301 - Test 1	Material 1.4301 - Test 5	Material C20 - Test 1	Material C20 - Test 9
	Punched hole, section 1			
Penetration depth (µm)	105	95	30	30
Roll over depth (µm)	30	26	<2	5
Blank zone (µm)	70	70	30	35
Fracture angle (degree)	8	11	-5	-6
Fracture depth (µm)	5	15	350	345
Burr height (µm)	<2	<2	<2	<2
Width of plastic deformation (µm)	10	10	2	3
	Punched hole, section 2			
Penetration depth (µm)	105	90	25	40
Roll over depth (µm)	25	30	<2	3
Blank zone (µm)	75	60	25	37
Fracture angle (degree)	6	12	-5	-4
Fracture depth (µm)	5	15	355	340
Burr height (µm)	<2	<2	<2	<2
Width of plastic deformation (µm)	9	8	2	2
	Section 3			
	Material C20 - Test 1			
	Punched hole, section 3	Blank, section 3		
Penetration depth (µm)	40	30		
Roll over depth (µm)	<2	<2		
Blank zone (µm)	35	35		
Fracture angle (degree)	-3	-4		
Fracture depth (µm)	340	150		
Burr height (µm)	2	3		
Width of plastic deformation (µm)	2	2		



One interesting observation was that the fracture angle for the C20 steel was negative while for steel 1.4301 the angle was positive. The fracture angle is usually positive but this phenomenon can occur at high punching speed.

The results from the first real tests at Swerea KIMAB capacitor bank with single turn flat coil showed on a lot of disappointments. First of all the capacitor energy that flowed through the coil was too low to create any magnetic force field that could accelerate the punch device. The energy level that was passing through the coil was composed by a 10 000 Volt and 250 000 Ampere. All this energy was discharged under a time period of 30µs. Still, it was too low for a single turn coil to accelerate the piercing punch and the initial cables were burnt and the second pair of cables did undergo spark erosion, see figure 11.

Figure 9 show spark erosion at the first trials of magnetic pressure punching tests.

The second attempt with a new redesigned 6 turns winding flat coil and improved electrical cables created an accelerated movement of the piercing punch system. This is shown in a video that could be sent over by the author to whom that might be interested to see the movement. Unfortunately, the obtained kinetic energy of the punch device were not high enough to pierce a hole in a soft steel sheet (t=1mm and tensile strength of 350 N/mm^2) without any die back-up.

But after changing the sheet specimen to Al alloy (t=1mm and tensile strength of 220 N/mm^2) a hole was created after the third stroke. The hole quality were not of the best quality but still a pierced hole was obtained.

Pictures of the results are found in figure 10.

Figure 10 The results for the attempt to punch a hole in a steel sheet with magnetic pulse

Figure 11 The results for the attempt to punch a hole in a Al sheet with magnetic pulse

6. Dissemination and publications

6.1 Knowledge and results dissemination

The results of the project have been disseminated to the consortium members of the project in regular meetings.
The results have also been disseminated with members of the global "International Impulse Forming Group[3]" through informal and annual meetings. By showing the possibility to shear a hole even with a low energy capacitor bank as ours then there is an incitement for the system suppliers of high energy systems to design and produce high velocity punching devices. Unfortunately, most of the system suppliers are based in Germany, France, japan and USA so the industries in these countries will be the first to obtain and implement new production systems based on magnetic pulse technology.

[3] http://i2fg.org

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7. Conclusions and future research

The conclusions after the end of this project are as follows:

- The shearing edge quality become considerably improved with increased punch speed if we have a die as backup
- The fracture angle could change from positive to negative with increased punch speed (with a die)
- It is possible to make a hole in a steel sheet material without any back up but it needs a much higher energy discharged from the capacitor bank than in the system at Swerea KIMAB.
- A new design of the flat coil with more turns could increase the instantaneous magnetic pressure between the coil and the punch plate, which would increase the speed of the device.
- A solenoid (tubular) coil might be a better option due to that a length of the winding would increase by extended number of turns of the coil. This type of coil would also be a better choice if that should be merged to a forming tool or implemented on a robot arm. The reason is the space needed for the coil is less than a flat ("pancake") coil.

8. Participating parties and contact person

Volvo Truck	Håkan Sundberg
Teknoheat	Lars Ullmark
Precomp Solutions AB	Morgan Renström
Former Accra Teknik AB	-
Scania	Rikard Ottosson
Volvo Cars	Lars-Ola Larsson
Former Svensk Verktygsteknik	-
Swerea KIMAB	Arne Melander / Roger Andersson