Project no. 032728

Project acronym: Energy Saving Weld

Project title: New technique for radiation free, energy saving and more versatile High Frequency welding

Instrument: Cooperative Research

Thematic area: Integrating and strengthening the European Research Area

# Publishable Final Activity report

Period covered: from 2006-10-01 to 2008-10-31 Date of preparation: 2008-11-30

Start date of project: 2006-10-01 Duration: 24 + 1 months

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Project coordinator organisation: FIAB HF AB Revision [1]

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# Project Execution

## 1. Summary description of the project objectives

**The overall objective** is to develop a new technique for High Frequency (HF) welding, based on modern technology, giving better energy efficiency and decreasing electromagnetic radiation.
A **secondary objective** is to automate the frequency adjustment. This will enable tuning for new materials / products and welding of materials with varying thickness. Research on polymers in order to find new polymers that can be welded is also an objective.

**The industrial objectives are to:**

- Reduce the electromagnetic radiation with at least 50%
- Enable the use of the outstanding HF welding in products that today are stitched or glued and in new innovative products.
- Safety secured production with lower risk for burn outs.
- Be able to produce smaller and cheaper equipment which will enable more SME:s to invest in the technology.

**The economic objectives are to:**

- Reduce the energy consumption of HF welding equipment with up to 60 %
- Reduce the investment cost for HF welding equipment
- Enhanced productivity of the welding equipment with shorter lead times and more efficient weld cycle.

**The societal objectives are to:**

- Minimize the electromagnetic radiation for the operators

## 2. Contractors involved

| | | |
|---|---|---|
| **SME contractors** | | |
| | FIAB HF AB | Sweden |
| | EBA Plast AB | Sweden |
| | TTF Ltd | England |
| | Stronghold Ltd | England |
| **Other contractors** | | |
| | Thales SA | France |
| | Siemens AG | Germany |
| **Performer contractors** | | |
| | Chalmers Industriteknik | Sweden |
| | Institute für Textil und Verfahrenstechnik | Germany |
| | Innovation Team AB | Sweden |
| | Institute for Product Development | Denmark |
| **Subcontractor** | ETE Ltd | UK |

## 3. Work performed – summaries

**Workpackage 1 Solid State Technology Investigation**

The major work of WP 1 can be divided in the Solid state research and the material research. After some problems in the realization of the solid state generator at Thales, that also led to that much of the project was delayed the project had to cancel some of the tasks in WP1. Instead of these cancelled tasks it was also decided to put more emphasis on the material research, why a subtask called 1.5b Material Manipulation was added.

Solid state research

The other partner Thales developed a technical specification of a basic module of a Solid State Amplifier based on a MOS transistor technology, dedicated to applications at 13.56MHz The research on different types of transistors and configurations gave the following specification:

- Operation in class D ➔ high efficiency
- Series structure ➔ No output transformer
- High voltage MOS

The theoretical results showed that the power and the return are optimal only when the returned load is situated in a self-inductive area. If the phase between U and I is maintained constant in a value included between 4 to 10°, it will operate in the best conditions. It is mandatory not to be in a capacitive load configuration, i.e. below 0°. These conditions will be realized by means of an Auto-matching system (adaptation in phase and in power in real time). The Auto-matching system will have to maintain a constant phase (+10°, for example) during a variation of the output load.

The solid state generator has higher efficiency than the current vacuum tube based generator, which was verified later in the project, even if the operation class of the transistor was not chosen as high as class D when the prototype was built.

ETE Ltd used the technical specification made from Thales to develop a concept of a solid state HF generator and auto matching system. Due to economic factors and also the technical difficulties with very novel technique, it was decided to use a lower class transistor than specified by Thales. The specifications for the generator were also a bit revised from the Thales specification so that instead of working at 13.56MHz and 3kW the system was to be built for 27.12 MHz and 4kW

Material Research

The general objective of the material study was to identify and verify commercially available materials - presently not used for HF welding - that can be processed with HF welding and thereby enable novel applications.

Companies using HF welding as well as materials suppliers were involved in the study. Based on the analysis and on development issues raised by the HF welding companies, polymer materials that are currently not welded were selected for testing.

The materials selected were first characterized with regards to dielectric properties and these data provided indications about weldability and optimum welding parameters. As a second step, the materials were subjected to welding tests. The conclusion is that HF-weldable materials have been identified and verified within the selected target polymer groups Fluor polymers, silicone elastomers and PP-based materials. The best welding results amongst these novel materials was obtained with a 0.25 mm PVDF (Polyvinylidene Fluoride) film.

The material research was then continued with investigations on manipulation and additives of materials for HF welding with special aim at
- Additives,
- Polyolefin materials and
- Fluor polymer materials.

The research concluded that ideal additives have to fulfil the following criteria:
- good dielectric properties (increase of ε“ and tan δ in the changing field),
- support of heat conduction and distribution in the polymer matrix,
- support of a better plastification.

For the further experimental investigations the following substances were used in the additive modification of polyolefin samples:

- fine powder from epoxy resin
- fine powder from unsaturated polyester resin
- barium- and. strontium ferrite
- organic acids and esters (amino acids, aliphatic copolyester)
- phthalic acid dinitrile, phthalocyanine – dye
- different cationic oleic acid – quats
- combinations of cationic oleic acid – quads with alkyl benzene sulfonic acid
- combinations of cationic oleic acid – quads with tri-isobutyl phosphat
- PVDF – fine powder (11008/1001; Fa. Dyneon)
- fine powdered zeolithe
- specific ionic liquid (base: imidazolinum group)

The additives were incorporated in a polyolefin (PE 0.935 HLMI) and a polypropylene (Moplen HF 500 N) (both granulates are delivered by Borealis) in two concentrations (5 % and 10 %) by blending with a twin screw extrusion laboratory unit (Haake/Thermo).

The dielectric measurements and the welding tests show that many additives are not high frequency active after incorporating in polyolefin. There are different reasons for the ineffectiveness of the additives:

- Some additives need humidity to build up active, ionic structures. These additives remain within the polymer inactive because the residual moisture in polyolefin is extreme low.
- The dipole mobility of some additives is strongly hindered in polyolefin with high cristallinity and molecular weight. This is the reason why the high frequency activity of these additives raise up with higher temperatures.
- Ferrite – additives need higher temperatures probably to initiate the vibrations within the crystal lattice.
- The majority of additives do not support the heat conductivity of the polyolefin. So the homogenous plastification will not be possible within the time window of the welding experiment.

To realize HF welding of fabrics two different ways have been tested. Knitted fabrics with different yarn compositions (up to maximal 50 % per weight) were manufactured from high frequency active yarns (polyamide 6,6; polyvinylidene fluoride) and non active yarns (polypropylene). These samples were welded in two different HF welding machines. The results showed that all samples showed no plastification during the test with one of the

machines. With the high frequency welder at Stronghold a continuous melting of the 50 % sample was achieved and a good bonding quality could be demonstrated. The results of the welding experiments demonstrate that sufficient energy for melting is generated and transferred to surrounding yarns only at high content of high frequency active yarns. This high content of HF active yarns however makes the use of polyolefin textiles inefficient today.

The second way to realize bonds with high quality between fabrics is to use so called welding aids. Welding aids can be high frequency active films or coatings. In welding experiments by means of the FIAB welding machine of the firm HUG, 2 cotton woven fabrics were bonded together with a good cohesive strength by using a welding aid film of high frequency active fluorocarbon polymer. This sample as well as PVC coated textile samples from FILK Freiberg (Research institute of leather and plastics) were welded without any problems and with good weld quality.

The research also had a special aim at Fluor polymer research. The group of fluorocarbon polymers covers the following types of polymers:

- Polytetrafluorethylene (PTFE)
- Fluorinated Ethylene Propylene (FEP)
- Perfluoroalkoxy (PFA; MFA)
- Polyvinylidene Fluoride (PVDF)
- Polychlorotrifluoroethylene (PCTFE)
- Ethylene-chlorotrifluoroethylene (ECTFE)
- Ethylene-tetrafluoroethylene (ETFE)
- Polyvinyl fluoride (PVF)

All these materials show excellent properties regarding exposure resistance (UV and weather) but the majority of fluorocarbon polymers cannot be heated by interaction with an external alternating electric field and show therefore typical isolator properties. By contrast PVDF offers very good HF – receptive properties, because the specific molecular structure of the PVDF - backbone show a local separated arrangement of hydrogen atoms on the one side and the fluoric atoms on the other side of the bone. This structural arrangement generates local separated antipodal charges on each side of the backbone (high electro-negativity of the fluoric atoms contra low electro-negativity of the hydrogen atoms) and forms permanent dipole. Formulations of PVDF- and PTFE- powders (PTFE content up to 50 % per weight) were blended with the twin screw extrusion laboratory unit. With increasing PTFE – content the blend formulation showed a softer performance and the process ability was better. Measurements of the dielectric properties showed interesting tan $\delta$ at temperatures > 80 °C. With these electrode temperatures a plastification should be possible. This assessment was confirmed by welding experiments on the Hug machine.

## Workpackage 2 Automated Frequency regulator

Auto-matching system

The transistors in a solid state HF generator have one big disadvantage to the currently used vacuum tubes; they are very sensitive to load variations and especially capacitive load, which will immediately lead to destruction of the output transistor. An Auto-matching system is therefore needed with the objective to maintain a constant phase. The impedance match also ensures optimum power transfer from amplifier to load (application).This system has been developed in association with a partner that was introduced to the project during the second year. The advanced technology required to make this work could not be developed by the

firstly thought of performer, Innovation Team, why the company ETE in UK was introduced instead. The prototype system was made for a machine that welds eyelets, a product that is difficult to weld due to that the machine must be able to both weld single eyelets and double eyelets to a plastic sheet. This means that the load over the High frequency welding tool varies a lot and the auto matching system must therefore be tuned for very different loads.

The matching net achieves the impedance matching by the acquisition of HF voltage and current signals at the input of the matching network, from these signals two bipolar error signals are derived; one phase error and the other magnitude error. These signals are used to drive two vacuum variable capacitors; one that corrects phase error and one magnitude error.

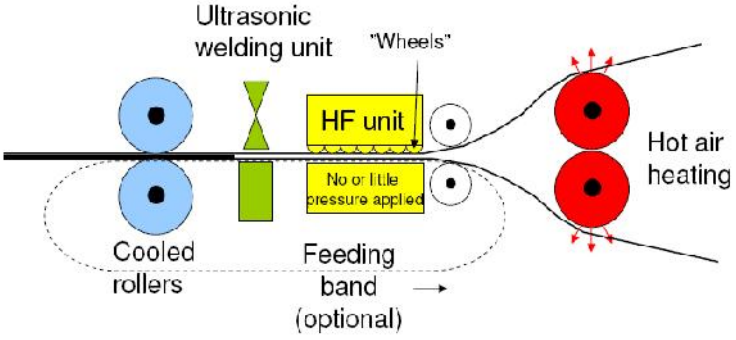
Ultrasonic welding study

The purpose and objective of this task was to investigate the feasibility of combining high-frequency welding technique with mechanical, vibration-induced effects on the welding joint area. This has been carried out as a prestudy with mechanical tests on a FAIB HF welder with a simple test rig for applying vibration. Tests were then made on foils of a quality that is generally hard to HF weld and the tests were made with HF only, with HF and vibration and with vibration only.

The test provided the following general conclusions:

- Adding vibration energy to the HF welding step lead to an improved welding result when the HF welding effect alone was not sufficient for creating a good joint.
- Vibrations of about 100 Hz were not sufficient for creating enough friction energy between the foils for melting to occur. Higher frequencies and different application modes of the vibration energy are required to obtain welding of foils with vibration energy only.

The combination of HF and ultrasonic welding in one machine will require a continuous process design. The suggestion is therefore a hybrid machine with a hot-air wedge, an HF unit and an ultrasonic unit in series, to be applied alternately or sequentially. While making a prototype and testing this, a new problem was discovered. The frequency used is not normal for ultrasonic welding and there was a problem with the sonotrode that broke down. The technique could not be implemented in a final prototype.




Conceptual Design

The prototype machine that was built was made for welding eyelets to for example lorry covers or large advertising posters. In order to realize the early prototype in time it was decided to build it on a more or less standard eyelet machine, but with the generator replaced with the developed solid state system. By doing this it was also easier to compare the prototype with a vacuum tube generator machine. A concept design was instead produced by ITAB for the commercial product, in work package 3.

Energy loss measurements and system improvements

The purposes and objectives of this task were to investigate the energy losses in the current vacuum tube HF welder and suggest improvements other than the solid state generator. One of the main outputs from this investigation was a suggestion to develop a new electrode design. Due to IPR issues we can however not reveal any details on this design. The new electrode system would have the following advantages:

- Better operator access
- Better repeatability
- Less radiated power since the RF power is balanced
- Power loss removed and available for the weld instead
- Better load matching for the triode with 4x higher load impedance
- Much higher output power without power "turn-over".

Disadvantages

- May have design issues with electrode spark-over

A prototype was built and tests were made. The tests indicated that it was very difficult to realise this idea. Some welding results were however really good, why this work will be continued by FIAB and the RTD performer CIT at a later stage.

Software development

A concept for the HSI (Human System Interface) was developed for the commercial eyelet welder. It was unfortunately not possible to get this HSI ready for the early prototype, but it will be implemented in the final product together with software for online measurements of the system performance.


Prototype production

A prototype of the new electrode system was built by FIAB and CIT and also tested at FIAB. A prototype of the Solid state generator and auto matching system was built by the company ETE. This prototype unit was later fitted to a prototype welding machine for welding eyelets, in Work package 3.

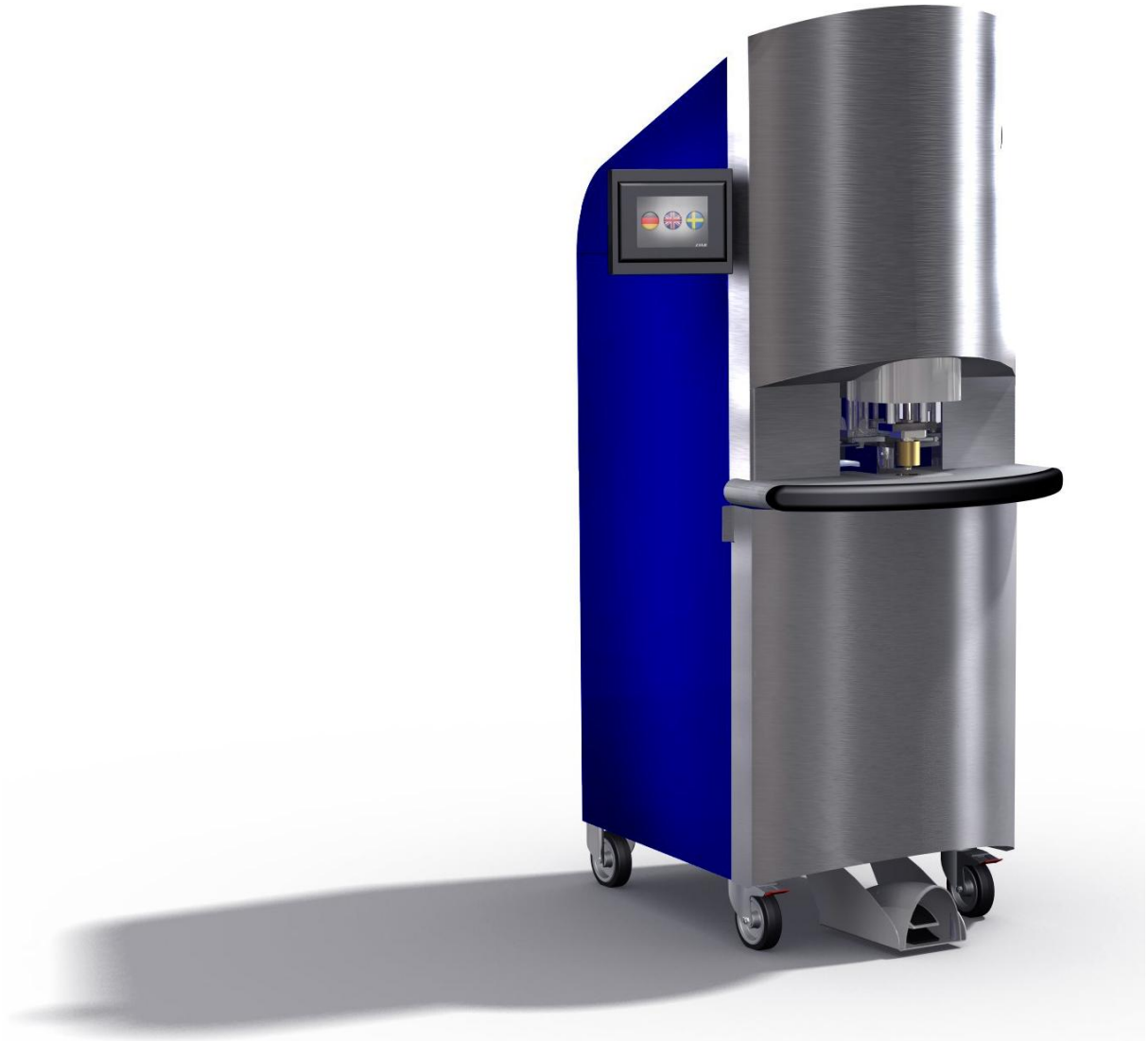
Tests and experiments

The tests performed on the two electrode system prototype showed positive results in weld quality and indicated that the advantages predicted with the new electrode would be possible to realize. Unfortunately the predicted disadvantage of electrode spark-over was very difficult to overcome and it was determined that the work of developing this electrode system would require much more time and resources than were currently available in the project and since this was not one of the main objectives in the project, it was decided to put the work on hold.

*Design concept*

Design concept & CAD Models

A design concept was developed by the performer ITAB for the commercial eyelet machine that was developed in parallel with the early prototype machine used for testing. The design should reflect novelty and futurism to really make the machine stand out towards the line of machines with vacuum tube generators that FIAB also makes. The design is also more thought through from a user's point of view with smooth soft lines and a work table for laying up the sheet material at an ergonomic height. Based on this design concept a 3D CAD model has been developed. Since one of the objectives is to make a machine at lower cost than current machines on the market some of the design features could not be implemented. The final product will look more like the CAD model shown below.



*3D Cad model of the final design*

Prototype

An early test prototype was built together with ETE Ltd. Due to the problems with the illness of Steve Ottaway at ETE, the prototype was however delayed and could not be finalised with all desired functions but with a simpler auto matching network. The generator was developed for a small eyelet machine that was readily available to fit the generator into and this was tested and showed at an exhibition in USA. It was also showed to the FIAB Sales agents on an internal show. The demand from the market proved to be very high for the solid state technology.

The complete and functional generator and auto matching system for the commercial product will be finalized after the end of this CRAFT project and then be funded by FIAB. The machine will be based on the technical concept and CAD models from ITAB and displayed at the Tech Textile Fair in Germany in June 2009.

Material study and new product development

The use of novel materials in HF welding for producing advanced products was identified as one focus of the second part of the subtask. In parallel, the development of HF-weldable polypropylene webbings for less advanced products was decided to be carried out by ITV in collaboration with Stronghold. Several different webbings were produced by ITV with different amounts of HF active yarns in combination with Polypropylene yarns. These test webbings were welded by Stronghold with varying results. It was concluded that a high amount of HF active yarns were needed to get a weldable webbing.

The work carried out by EBA and CIT regarding new product development resulted in the identification of several potential new and existing products for which HF welding could be applied and provide advantages. For several reasons, one of them being lack of resources at EBA-plast, the development of a product prototype was not completed. However, the subtask has initiated work which may lead to the development of specific products within the frame of other projects (e.g. CRAFT projects)

Experiments and tests

TTF was in charge of this task and the tests were made on the prototype machine built for eyelet welding. The energy consumption calculations made when the machine was compared with a conventional vacuum tube generated machine concluded that the energy savings was 67% during welding. Apart from this saving during weld it should also be noticed that the vacuum tube generator has an idling energy consumption of 200W between the weld cycles. This is due to that the tube must be on (glowing) constantly to keep it pre heated, otherwise the weld cycle will be too long if the tube must be heated before every weld and this would also shorten the life of the tube. This is not the case with the transistors in the solid state welder, why the idling energy consumption of this generator is only 10W. The energy savings between the weld cycles is therefore as much as 190/200=95%. Calculating on a duty cycle of 50% (meaning that 50% of the operators time is spent on moving and laying up the material to be welded) the total energy savings is:

0,5x67% + 0,5x95% = **81% energy savings**

The electro magnetic field is measured in two different values, the electric field and the magnetic field. The electric field (called E) is measured in Volts per meter (V/m) and the magnetic field or the H field is measured in Amperes per meter (A/m).

The electric field strength was measured to 1814 V/m during six minutes on the vacuum tube machine and 1282 V/m (E-field) on the solid state machine, meaning a reduction with about 30%. The magnetic field during six minutes was measured to 6,19 A/m on the vacuum tube machine and 3,76 A/m on the solid state machine, giving a reduction of about 39%. Apart from the 6 minute interval that the standards prescribe an instant value is also measured. Summing up the electric and magnetic fields at both instant and 6 minute intervals the total average reduction was about 39%.

## 4. Results achieved

### Workpackage 1 Solid State Technology Investigation

A technical specification of a solid state HF generator has been developed. It describes a generator with an energy efficiency that is theoretically 100%, but with an expected real efficiency of well over 70% and possibly up to 85% compared to the efficiency of today's vacuum tube generators that seldom reach over 50%. Compared to other solid state generators on the market this generator will have the following characteristics.

| Output power | No. of components | Efficiency | Volume | Weight |
|---|---|---|---|---|
| Higher | Lower | Higher | Lower | Higher |

The final product developed will have a lower class transistor than originally specified, but the above characteristics still applies and the energy consumption and radiation is a lot lower than the commonly available vacuum tube generators.

The material research has proved that apart from the known materials PVC and PU it is also theoretically possible to HF weld Fluor polymers, silicone elastomers and PP-based materials. The analysis of known additives shows the possible strategies to manipulate materials for HF activity. For polyolefin and fluoro polymer materials commercial HF-receptive products and additives have been tested with various results. Additives that would theoretically increase the weld ability did in the practical test not always perform as predicted. The potential of the textile technology, coating and finishing processes for manipulation of materials for HF welding were also investigated and in this work it was concluded that so called welding aids can be used. Welding aids can be high frequency active films or coatings.

### Workpackage 2 Automated Frequency regulator

A solid state HF generator and auto-matching system have been developed and a prototype has been built. The prototype has been tested with very good results. A concept was developed for a commercial eyelet welding machine and software with Human System Interface was also designed.

The study on a HF welding and Ultrasonic combination shows that adding vibration to the HF welder gives a better weld result than HF only for materials where the HF activity is low, but this feature have not been implemented in the final design.
A new electrode system called a two electrode has also been tested. It shows good welding results and energy efficiency, but had some problems with spark over, why neither this feature was implemented in the prototype welding machine.

**Workpackage 3 Analyses, tests, adjustments and new product development**

A design concept and a CAD Model of a commercial solid state eyelet welding machine have been produced. A prototype machine of a simpler machine was built and tested. The tests showed excellent results and compared to the state of the art vacuum tube generator the energy savings with a solid state generator was up to 81% and the electro magnetic radiation was lowered with in average about 39%.

Interesting new products have been identified as possible to manufacture with HF if the materials can be developed or manipulated to get the right characteristics.

The final prototype for end user tests was not possible to manufacture during the project but will be built and tested during the first half of 2009 and then displayed at the Tech Textile Fair in Germany in June 2009.

**Summary**

The tests results of energy consumption and radiation on the prototype eyelet welding machine is very promising and much better than the objectives of energy consumption outlined for the project. The radiation did not entirely meet the objective, but almost 40% decrease is still very good.
On the polymer research side it looks very promising with several new materials found to be HF weldable and with manipulation and additives identified for increasing the weld ability of several interesting materials.

**Major achievements**

During the project the following main achievements have been done:

1. A technical specification has been developed for a solid state HF generator that gives a theoretical energy efficiency of 70-85% compared to the about 50% efficiency of the vacuum tube generators.
2. Tests with adding vibration to HF welding shows that a combination of HF and ultrasonic welding can give better weld results at shorter weld cycles and also enable welding of polymer materials that are not weld able with HF only.
3. New polymers have been found that are weld able with HF and with added value due to better performances of these materials they can be used for many interesting applications that are stitched or glued today and also in completely new products.
4. A solid state HF generator has been developed for a small machine for welding eyelets
5. An auto-matching system has been developed for the solid state generator system.
6. The generator and auto matching system is much smaller than the vacuum tube generator and its components. This will enable much smaller welding equipment to be developed.
7. The electro magnetic radiation from the new machine is about 39% less than from a similar vacuum tube generator machine.
8. The energy consumption of a solid state eyelet welding machine has been proven to be up to 81% less than for a similar vacuum tube generated welding machine and with maintained welding results.

# Dissemination and use

Since the final fully functional prototype has not been manufactured and hence the end user tests not been performed the consortium is not ready to publish the results yet. The knowledge arisen from the project and identified as exploitable are:

- The electrical and mechanical configuration of the solid state generator.
- The electrical and mechanical configuration of the auto matching network
- The two electrode system design
- The combination of High Frequency and Ultrasonic welding.

None of these are however at a stage where we can publish the results and the knowledge is not entirely owned by the consortium.

The intensions are that the group of SME will exploit the new product – the complete welding system – on the European market to start with and later on also on other markets. The market demand for the new technique is for example very high in the USA. This exploitation will come at the earliest in mid 2009.

The technical results will be disseminated through

1. Articles / publications / newsletters will be delivered to
    - Technical newspapers
    - The plastic manufacturing industry

2. Fairs – exhibitions
    - The Tech Textil Fair in Frankfurt 16$^{th}$ to 18$^{th}$ of June 2009 is the first exhibition where the new welding machine will be displayed.
    - The MUTA show in France 2010 is a possible second exhibition
    - In the next step the technique will be displayed at several exhibitions in the US.

3. It is planned to produce a CD/DVD and/or brochure with a presentation of the technique and its advantages to vacuum tube generators with emphasis on energy efficiency.

4. A website is also planned or at least the results will be presented on the web pages of FIAB and TTF.