Suitable Design for Electromagnetic Pulse Processes

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Abstract

Basic conventional production processes, such as arc welding or forming, are more or less thoroughly investigated, reliable process guidelines have been developed and trained engineers are available. This allows them to be put into use usually fast, thus facilitating a wide application.

The usage of electromagnetic pulse processes, on the contrary, still lacks a broad propagation. Despite having a history reaching back several decades, these processes are mostly limited to niche applications. Admittedly, theoretical considerations have been made and various experiments have been carried out. However, when a given joining or forming task needs to be realized with electro-magnetic force, a huge invest is necessary even before the first part is made. This involves the design of the machine, especially of the tool coil, as well as the design of the workpieces to be processed.

In industrial environments this challenge is tackled step by step: After the theoretical product concept in close collaboration with the customer, numerical and experimental trials are carried out. In many cases, iterations are necessary and both geometry and process are optimized. The experimental trials can be conducted with universal sheet welding tool coils or tube compression tool coils with custom field shapers. This procedure allows keeping the prototyping costs low, but at the same time provides valid information on the feasibility in general, the requirements to the workpieces, the design of the tool coil and the properties of the pulse generator. Subsequently, the tool coil is designed and manufactured according to the prior findings. The pulse generator as modular component is assembled and adapted to the customer's requirements.

The iterative product and process design is the most important phase of the whole procedure, which is in accordance with good project management. It significantly lowers the risk of an expensive project cancellation during the late steps.

Keywords

electromagnetic pulse processes, electrical mobility, welding, crimping

1 Introduction

The evolution of an electromagnetic pulse technology (EMPT) project starting with the first idea and ending in a serial pulse system for mass production equals at many stages the state-of-the-art process of conventional custom machines. A regular EMPT project goes through the following stages:

1. Customer request
2. Application analysis
3. Feasibility studies (theoretical and practical)
4. Manufacturing of tools
5. Prototyping
6. Validation by the customer
7. Sale of serial machine

Compared to processes like mechanical pressing or thermal welding the importance and the time spend within the stages differs a lot.

A technology, like the EMP technology, lacks of awareness during the education of the later development engineers and the small number of potential suppliers of this technology and their size inhibit a fast-spreading recognition in the different markets worldwide. The early stages (1 and 2) of the customer journey are much more time consuming due to the fact that the customer has to be taught what EMPT is, how it works and what are the consequences for his products. Some applications, like cable crimping, are already that mature that stage 3 could almost be skipped and you can start right away with the design of the field shaper (customized tool within a tubular coil).

This paper will give a brief overview of the contents of the different stages of the EMPT product development/customer journey.

2 Customer Request

The majority of requests are happening accidently. Like written before the probability for a potential customer to find the electromagnetic pulse technology when searching for a solution of his problem is much lower compared to well-known conventional processes. Assuming that the seeker has heard of EMPT it is quite easy to find out who the major players are in the market. But the possibilities to base the next decisions on references and reputation is much harder. Existing users of the EMPT often keep it secret to not lose their competitive advantage.

The first step is to approach the different suppliers and compare their feedback. To evaluate the potential of a request it is useful to make a standard template asking for design (material, dimensions, etc.), project (annual volumes, start of production (SOP), etc.) and problem (pain points, expected benefit, etc.) related requirements. The standardization speeds up the process, all mandatory information for internal decision making is available and the customer already learns something about the requirements of the EMPT and is building up confidence.

Based on the template the sales department can conduct internal meetings with the special departments and make a first sketch of the future EMPT-system. This sketch includes an evaluation of costs, capacity, risk and reputation. Besides the named characteristics you can separate the requests in two different types which have a big impact on the project overall. On the one hand you will have requests for new developments. Depending on the maturity level you can further distinguish this type between developments with SOP and so-called advanced development. The latter comes often without budget and a timeline. On the other hand, there will be requests of running projects or serial parts which have problems and need solutions very fast but with limited possibilities of changes at their products. Taking all this into consideration a business case is created and is presented internally and externally to get approved. After that the dialog with the customer begins to define the next steps.

3 Feasibility study

A feasibility could never be guaranteed. A feasibility study is always mandatory independent of the number of machines sold for similar or even “identical” applications. That fact is not unique to EMPT but the theoretical prediction accuracy of the result of such a study is still very poor due to the fact that the amount of academic research in the field of high-velocity forming is negligible compared to conventional (slow) manufacturing processes.

These studies comprise four major topics:

- Are the materials suitable for EMPT?
- Is the design suitable for EMPT?
- Is it possible to conduct a numerical simulation?
- Will it work?

Before discussing the questions above two terms will be defined. First the term “flyer”, the component which will be accelerated by the magnetic field and second the term “target”, the component the flyer hits. Between those two components is always a gap for acceleration.

Besides the fundamental rule of a *good* electrical conductivity for the flyer, where silver is set to 100% for this parameter, copper (95%) and aluminium (60%) are considered as “good”, zinc (27%) and nickel (23%) are considered as “ok” and steel (10-15%) and stainless steel (2%) considered as "not suitable without driver[1]", it is also crucial what the target is made of and do I need an atomic bonding or is a form-fit sufficient.

When characterising the material, it is mandatory to know its complete history. How was it manufactured, the exact alloys, yield strength, elongation at break sometimes even the age is important when dealing with annealed metals.

The design of the connection interface is determined by several empirical parameters. Depending on the final type of connection the length of the list of parameters influencing a good result is different. A tubular form fit for example is mainly defined by the requirements before and after the EMP-process. Assuming the electrical conductivity is considered good the initial acceleration gap between flyer and target could be close to zero. Only the tolerances for an easy assembly have to be considered. The actual acceleration gap will be set by the form elements (grooves, edges, knurling, etc.). The mandatory energy to deform the flyer from a design perspective is set by its thickness. The basic requirement on the target is sufficient structural integrity to withstand the impact of the flyer. The residual energy when the flyer touches the target could be as low that even a crimp on glass is possible like shown in Fig. 1.

Figure 1: Medical glass bottle closed with an EMPT crimped cap

An EMPT weld on the other hand has to consider not only the material combination but also the exact acceleration gap, because it is defining the velocity of the point of collision and the angle between flyer and target. Both parameters span the working area II shown in Fig. 2 where an atomic bond could be expected. The surrounding areas are not in the scope of this paper.

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[1] driver: component made out of a material with good electrical conductivity which will be put between tool and flyer. The driver accelerates the flyer

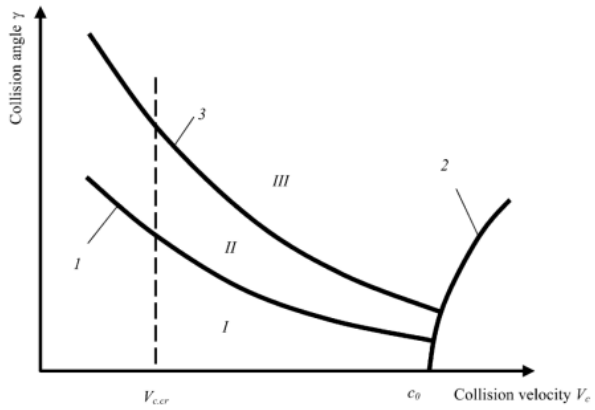

Figure 2: Qualitative process window (Lysak and Kuzmin, 2012)

As known from other manufacturing processes the numerical simulation offers the possibility to accelerate the prototyping phase. The EMPT process is determined by three simultaneously proceeding processes:

- Mechanics
- Thermodynamics
- Electrodynamics

These components are occurring always at the same time and their parameters are changing over time, what makes a detailed simulation of all aspects at once even today very challenging. Depending on the scope and the accuracy demand of the simulation it is possible to couple all three processes or to separate them. The majority of the simulations done in industrial environments are related to the simulation of the efficiency of the tool design and the corresponding deformation of the flyer. A simulation of the connection itself is not effective since there is still a lack of adequate simulation software, material parameters and knowledge about the impact of the periphery e.g., the ambient atmosphere (Pabst, 2019).

4 Tools

EMPT tools can be distinguished between tubular and flat sheet metal coils. Depending on the application the invest in such a tool will be sooner or later in the customer journey.

Simple sheet metal coils for deformation or welding processes are usually not customer specific. The main characteristics of these coils are the length and the cross section of the main conductor. Some serial applications may require several parts per pulse e.g., busbars for batteries like shown in Fig. 3. In these cases, the serial coil is custom-built. But even these applications will start with prototyping at a single-part coil. Typical machine manufacturer could provide the first samples short-term with a minimal invest in tools. This customer-friendly approach is used for feasibility studies of material pairings or final products like shown in Fig. 3 and they are highly appreciated by the customer. The prototyping costs could be minimized leading to more openness to test EMPT for new applications.

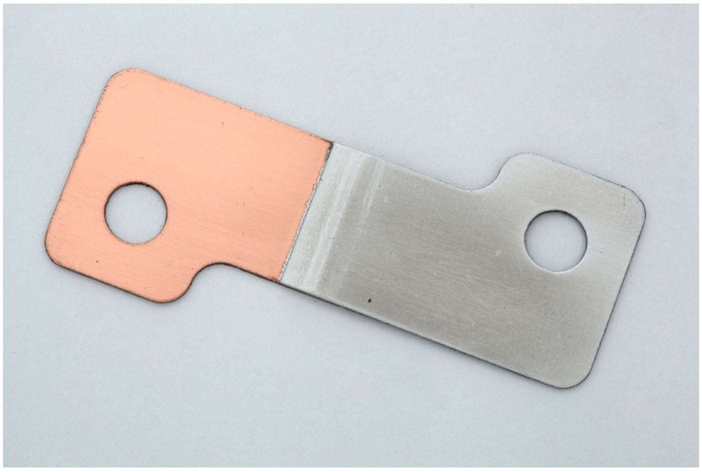

Figure 3: EMPT-welded Cu/Al busbar

Applying EMPT at tubular structures is much more straight forward from a process perspective but it inherits a higher effort in simulation and tools. Therewith the lead time and the invest for tubular applications are 2-3 times higher compared to sheet metal applications. The tubular tool consists of the actual coil and the customer specific field shaper as shown in Fig. 4. It is mandatory to design and manufacture a field shaper for prototyping, the coil itself is a standard tool which is usually available at the supplier.

In addition to the actual tool (flat and tubular) it is necessary to build a customer specific positioning device holding the specimens in place.

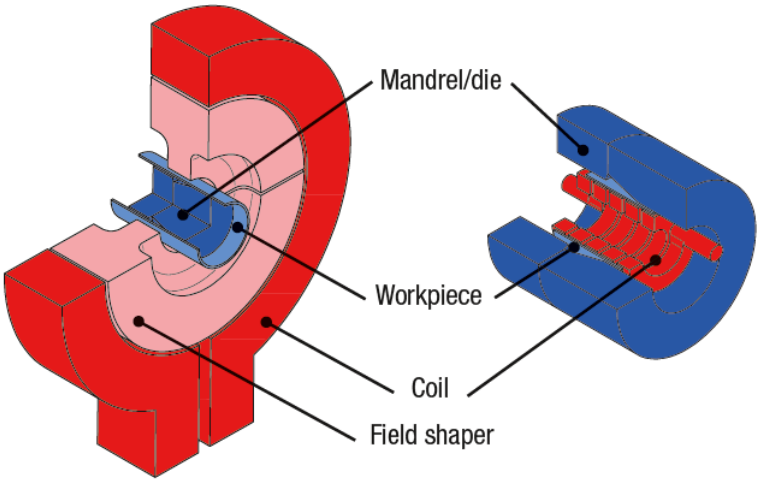

Figure 4: Schematic depiction for the forming of closed cross-sections through compression (left) and expansion (right) (Pasquale, Pabst, Schäfer, 2016)

In some cases, especially when formerly unknown materials or alloys are to be used for tubular welding, the costs for the first trails can be reduced: Flat sheet samples of the tubular parts can be welded tentatively with a standard sheet metal coil, thus avoiding the costs for a custom field shaper if it turns out that the joint does not meet the customer’s requirements.

5 Prototyping and Validation

When planning the prototyping the following topics have to be considered:

1. The customer has to send an *appropriate* number of specimens best *before* the actual test. The number of specimens should include parts for finding the process parameters and for the required number of good prototypes. To spare time it makes sense to send the parts upfront to give the supplier the chance to test the tools and make adaptions if necessary.
2. The customer should consider to perform a parameter study which means to make samples with different parameters. In terms of the EMPT it would imply for example different levels of discharge energy or the position of flyer and target relative to the tool. The reason is the limited possibilities to validate the result directly after the pulse is done. In general, the customer has to conduct product related tests to check if results are fitting the requirements. Fig. 5 show an EMPT-crimped vessel after burst pressure test. The test was conducted by the customer.

Figure 5: EMPT-crimped vessel after burst pressure test

3. Prototyping is an iterative process. Adaptions of the tools are very rare. Due to the numerical simulations the probability of hitting the right design on the first shot is extremely high. If changes are necessary, it includes changes of materials (including coatings, pre-processing, etc.) or the design of the parts (flyer and target).

The complete duration starting with the first prototypes and ending with a validation report could last from month to years depending on the application. Introducing an EMPT-crimped conductor in the automotive industry for example took almost 2 years at the conductor manufacturer and additional 1-2 years at the vehicle manufacturer. Within this period usually the development of the serial handling system for the EMPT process takes place.

6 Definition of the EMPT-system

Based on the empirical experience machine manufacturer are able to theoretically predict the necessary process parameters for an application with a blurring of only some percent. The process parameters (discharge current and frequency) define the size and type of the pulse generator. This provides the possibility to start discussions about the final invest with the customer at the very first stages of the customer journey without having but only one part manufactured.

The prototyping (see chapter 5) proves or disproves the theoretical assumption. Since there are so many influencing parameters on the result of a pulse the assumption stays speculative until the validation of the first hardware test. But the possibility is minimal due to the expert’s judgement and the possibilities of theoretical pre-investigations.

Besides the pulse generator, the tool and the corresponding handling has to be defined. All prototyping test are done manually and based on theoretical automatization concepts a cycle time will be determined. The minimum time between two pulses is set at 5 seconds. Some applications might have annual volumes making a shorter cycle time necessary. These examples might use multi-joining coils (several parts per pulse in one tool) or increase the number of parallel running machines.

Preferably the manufacturer could offer an EMPT-system consisting of pulse generator, tool and handling system because the knowledge and experience of handling these high voltages (16-25kV) is essential. It is not only necessary to avoid contact to electrically conductive parts but also to damp the noise created by the air leaving the gap between flyer and target and to build a shield dampen the electro-magnetic field during the pulse.

Based on a specification aligned between customer and supplier the machine is build up over a period of 6-12 month ending with a commissioning at the customer site.

7 Discussion

There are no hard and fast rules for guiding the customer through the EMPT process but it is necessary to increase the awareness and inform the customer about the requirements of EMPT. This paper recommends to implement standard procedures and guidelines to inform potential and existing customers about the background of EMPT and how this process could be applied to their products. We take their hands on the journey through EMPT to build up confidence for EMPT as innovative but already mature technology and to get all the information from them to maximize the benefits for both sides.

References

Lysak, V.I., Kuzmin, S.V., 2012: Lower boundary in metal explosive welding. Evolution of ideas. In: Journal of Materials Processing Technology, Bd. 212, S. 150-156. doi: 10.1016/j.jmatprotec.2011.08.017.

Pabst, 2019: Ursachen, Beeinflussung, Auswirkungen sowie Quantifizierung der Temperaturentwicklung in der Fügezone beim Kollisionsschweißen, S.33-34

Pasquale, Pabst, Schäfer, 2016: The Electromagnetic Pulse Technology (EMPT), S.36