Robot automated EMPT sheet welding

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Abstract

Many industrial applications require sheet to sheet or sheet to tube joints. The electromagnetic pulse technology is capable to produce these kinds of joints. In literature many examples of sheet to sheet solid state welding between similar and dissimilar metals are presented and analyzed in detail. However, the most of the presented welding applications, which are very focussed on the academic level, are simple specimens for example for tensile test. These specimens are usually very small in their dimensions and therewith capable to be welded with the help of stationary EMPT coils. In contrast to this approach the majority of typical industrial applications demand the ability of manufacturing several welds in different positions on the same assembly application comparable to the spot welding process of an automotive car body. Here several spot welds are realised in a variety of positions by a robot mounted spot welding gun. The use of a stationary coil is no option here. A first step in manufacturing complex assemblies by EMPT was done by PSTproducts by welding a car- shaped space frame. Within this project substantial knowledge has been generated with respect to non stationary EMPT coils and the flexibility of the cables connecting the coil with the pulse generator. The results were transferred into the next step, the development of an EMPT robotic welding head. This report details requirements and possibilities of robot automated EMPT sheet welding with respect to complex structures.

Keywords

Automation, Robotic, Welding

1 Introduction

Fusion welding processes are widely adopted within production technology. However, these processes are not capable for joining metals of strongly different melting points. For example Aluminium melts at temperatures above 660°C, whereas iron melts at temperatures 1536°C [1]. Because of this large melting point discrepancy the creation of an aluminum-steel weld puddle is hindered [1]. Moreover, during solidification brittle intermetallic phases will be generated, which will significantly decrease the mechanical properties of the joining area [1,2].

Hence, adhesive joining of Aluminium to steel is best possible, if none or at least only one of the joining partners is melted. In general, there are two ways to accomplish that, solid phase welding (friction/ friction stir welding, explosion welding) and by a combination of welding and brazing, where the Aluminium is melted, but the steel not. The welding/ brazing combination tends to produce some intermetallics phases [2]. Solid phase welding normally does not create intermetallics phases [3]. For joining sheet material friction stir welding is applicable, but the welding velocity is only in the range of 1m/min and the process demands for quite small tolerated gaps between both contact partners [4]. A new possibility to manufacture high quality joints even between steel and Aluminium sheets is given by the electromagnetic pulse technology (EMPT). The process is based on the same principle as explosion welding; only the explosive is replaced by a fully controllable, pulsed electromagnetic field [5,6]. Hence, EMPT sheet welding systems can be operated without any danger for production personal within normal production lines. In literature many possibilities of EMPT sheet welding are shown, see for example [5,6]. However, the samples are commonly small in size. This facilitates the use of a stationary EMPT work coil and therewith a relatively short connection between capacitors and coil. This approach is valid for small assemblies consisting of 2-10 parts to be joined. Favourably the joining lines should not be arbitrary placed in space because of positioning purposes. This is normally true for electric components or simple structural parts. Common structural components however are often quite large and the joining positions are placed on arbitrary positions. Here, the use of a stationary coil is often complex or even impossible, because of handling and positioning tasks of the large structure on the coil. These problems can be classified into three main groups:

- Increased space requirements for large structure handling
- Lack of accessibility for stationary coil
- Distortion of the not fully welded structure during handling

To circumvent these problems a mobile EMPT welding head was developed which can be connected to a robot. Using this coil is beneficial, because now it is possible to reduce the handling operation with respect to the structure to be welded. Accessibility tasks and structure during handling distortion are minimized. Especially in case of big sized and heavy structures, the effort for the handling units is significantly decreased.

2 EMPT sheet welding

2.1 Process principle

The EMPT process is based on two principles: electric induction and the repelling forces generated by counter rotating electrical currents. In case of EMPT sheet welding, a coil, loaded by a fast but high current pulse of several 100 kA induces a voltage surge into a sheet neighbouring the coil. The voltage surge causes eddy currents in the sheet. The amplitude of the induced current is governed by the amplitude of the voltage surge and the electrical conductivity of the sheet. The eddy currents oppose their source- i.e. the coil current- which results in a repelling force between sheet and coil. The sheet loaded by this force ("commonly: magnetic pressure") is called flyer. Figure 1 illustrates the general setup and the eddy currents induced into the work piece.

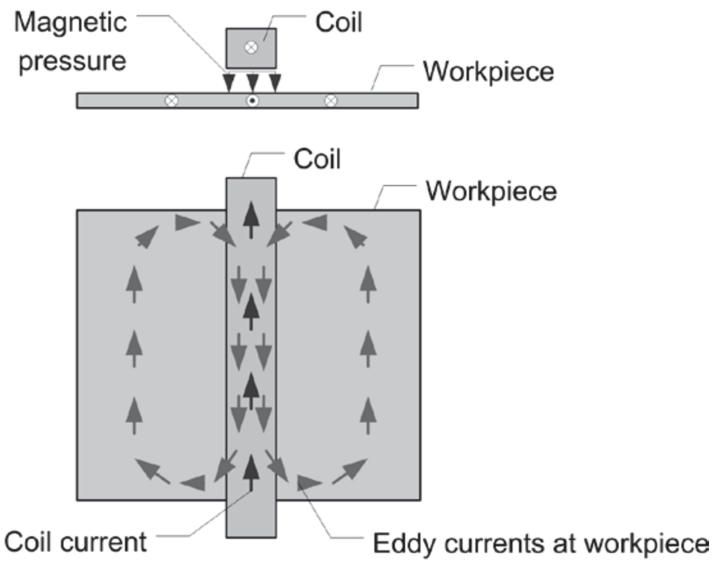

***Figure 1**: Eddy currents induced in work piece*

Accomplishing an EMPT weld requires a specific material flow of the flyer. A flat impact of the flyer on the second work piece – the so called target- will cause a rebound, but not a weld. For welding, the contact area between flyer and target should increase during the process. For accomplishing this, two general options are useful:

- The use of spacers between flyer and target (see figure 2, left)
- The use of a bead imprinted in the flyer before the EMPT process, which is flattened by the coil (see figure 2, right)

The material flow generated by either of the two options causes a superposition of normal and tangential contact stresses in the interfacial zone of both contact partners [6]. The amplitude of the contact stresses is several times beyond the yield strength of the work piece material. Contact stresses and inertia effects cause a high hydrostatic pressure and deviatoric pressure stress combination. Numerical simulation gives evidence, that the hydrostatic pressure' amplitude near the point of first contact is several 1000 N/mm². Because of this, the material behaviour becomes similar to that of a fluid, i.e. metals can suffer straining of 100-200%. It is important to mention, that no melting effects are identifiable. Figure 3 illustrates the stress situation near the point of first contact. The deviatoric stress components cause formation of a wave in front of the first contact point and the hydrostatic stresses increase the material's formability.

The straining of the material in the interfacial zone reaches values of 100-200%, resulting in a chipping of the oxide layers covering the metal surfaces. The high contact normal pressure forces an intimate contact between both work pieces; a metallic bond is accomplished.

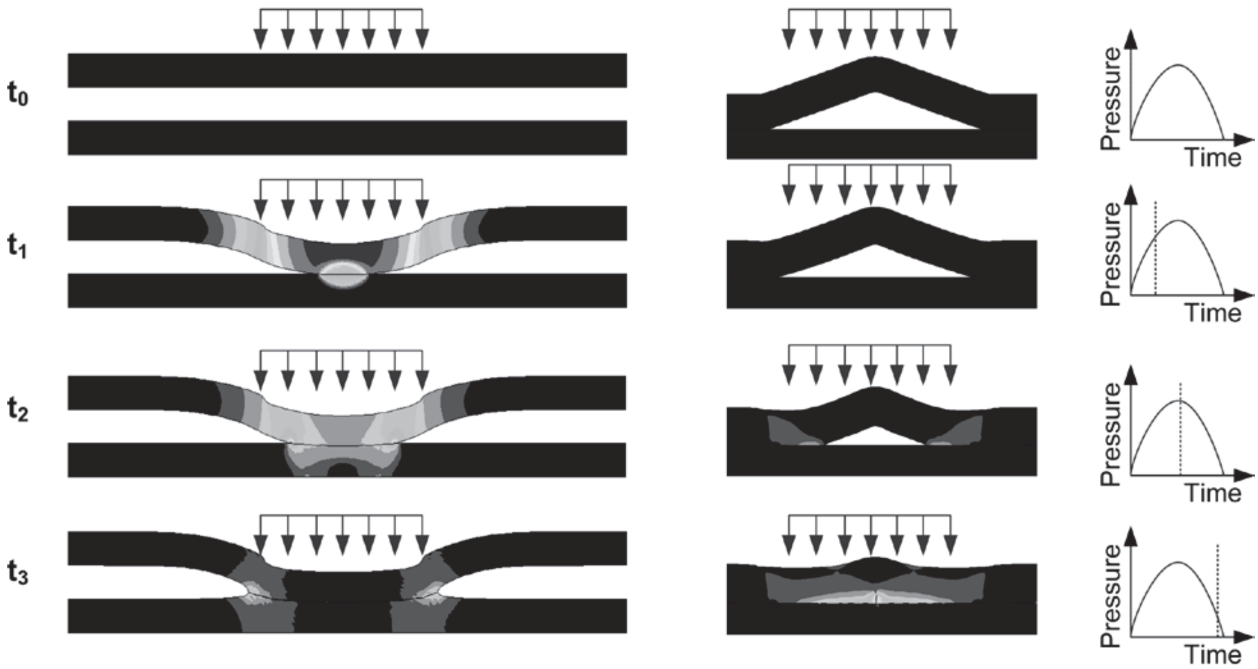

Figure 2*: Material flow within EMPT sheet metal welding*

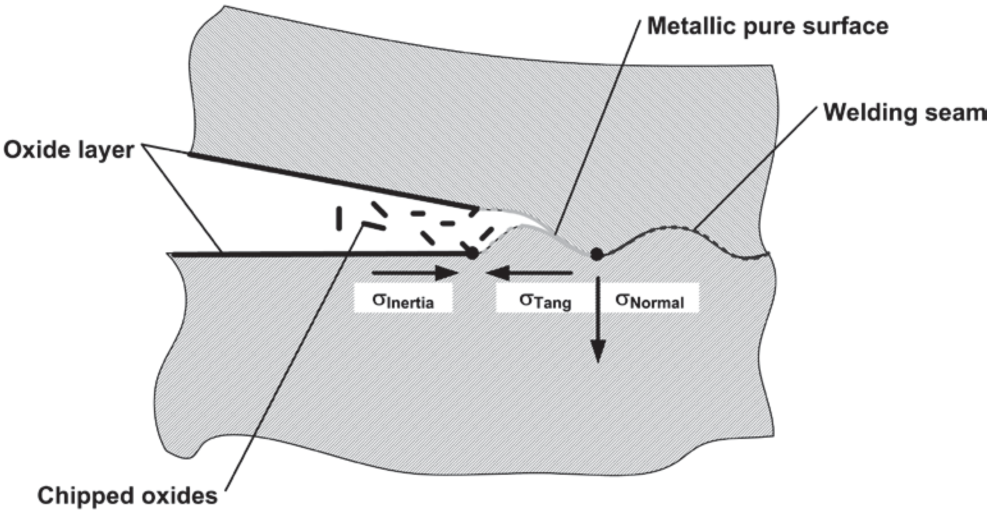

Figure 3*: Stress situation*

A more detailed description of the principle and the stress states can be found in [6]. The strength of an EMPT weld is approximately given by the product of weld area and material strength of the softer bonding partner. Hence, a good EMPT weld is characterized by a weld area which is equal or bigger than the cross-section of the weaker joining partner. Figure 4 depicts for the results of a tensile test at En AW 6016 Aluminium, wall thickness 1mm, weld length 40 mm. Because of the high weld strength, the tensile test specimen fails at the maximum tensile stress of En Aw 6016 approximately 10 mm away from the weld seam.

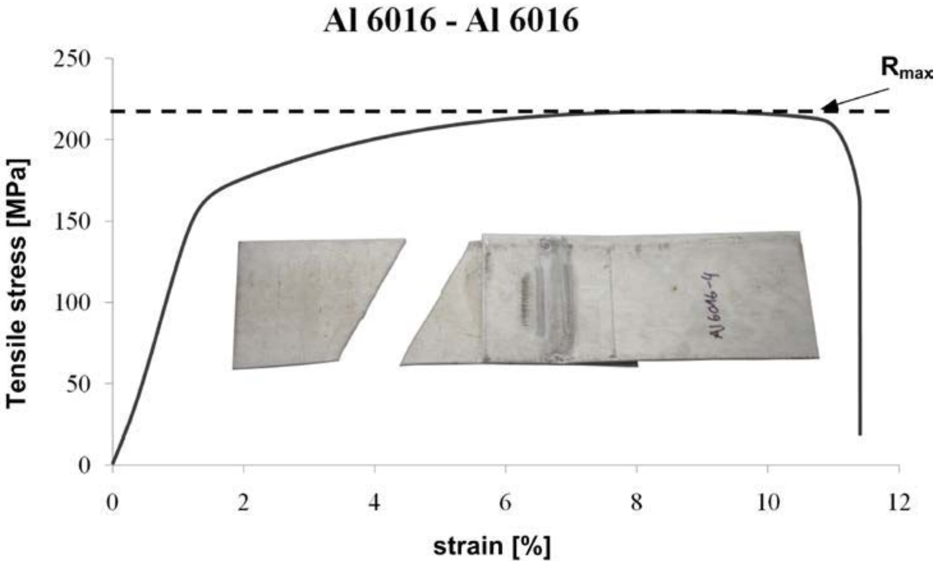

***Figure 4**: Tensile test results with respect to 1mm wall thickness Al 6016 specimen.*

2.2 Stationary EMPT sheet welding coil

Academic and industrial papers present some approaches of EMPT sheet welding samples. Commonly these samples are limited to a size spectrum between some millimetres and 1 meter. Normally only simple subassemblies are welded with the help of those stationary coils. The number of sheet joined within one pulse varies between two and ten layers. Flyer material is normally of a good electrical conductivity, for example Aluminium and Copper. The flyer wall thickness ranges from 10µm to 2.5 mm. Figure 5 illustrates a variety of samples.

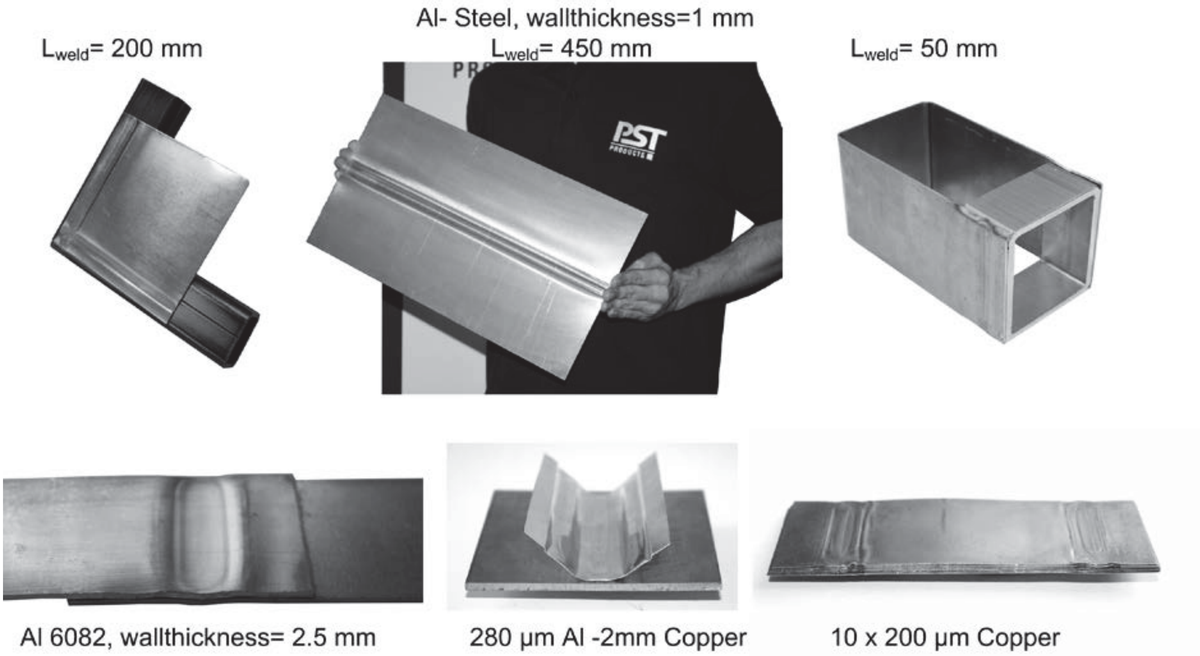

***Figure 5:** EMPT Sheet welding samples accomplished with the help of stationary coils*

Experimental work has shown, that joining of larger subassemblies is possible in case all welding positions are positioned in one plane, see Figure 6. In contrast to other solid state welding techniques there is no need for a support which loads the joining area with static force. For EMPT welding the support can be represented by the inertia of a 10-20 kg mass.

Figure 6: *EMPT welding of larger subassemblies*

2.3 Robotic EMPT sheet welding coil

As mentioned in paragraph 2.2 the use of stationary EMPT sheet welding coils facilitates joining of a broad range of subassemblies. However, complex assemblies like the spaceframe structure shown in Figure 7 are hard to handle for EMPT welding by a stationary coil.

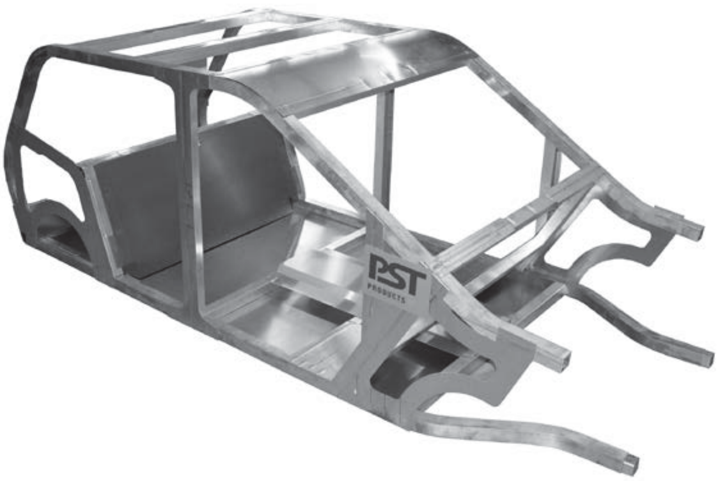

Figure 7: *EMPT welded space frame*

Within the prototyping process of the space frame a special coil has been developed. For first tests, this coil is connected to the structure by C-clamps. Welding trials proofed the industrial feasibility of this coil concept with respect to welding results and handling issues. Based on this experience, the coil concept is upgraded for direct use with a robot. A Reis RV 130-130 robot is used to position the coil above the welding area. A hybrid plate ensures on the one hand electric isolation of the coil via the robot, and on the other hand absorption of mechanical impulses generated by the coil.

The PSTproducts specific cables allow a curvature radius of ~500mm under cyclic loading. Due to that, a cable duct directly fixed at the robot boom would limit the mobility of the system. Hence, an auxiliary cable jack is used to ensure relatively big curvature radius of the cables and therewith small cable bending forces.

Figure 8 illustrates a robot pulse generator configuration. The reaction forces of the welding process are absorbed by the mass of the coil adaptation plate of the robot. The Reaction forces on the work piece are absorbed by the work piece. Figure 9 details the robotic assembly of a subassembly. Here, the components are fixed with the help of a positioning unit. The impact forces acting on the components during welding are absorbed by the mass of the positioning unit (see figure 9)

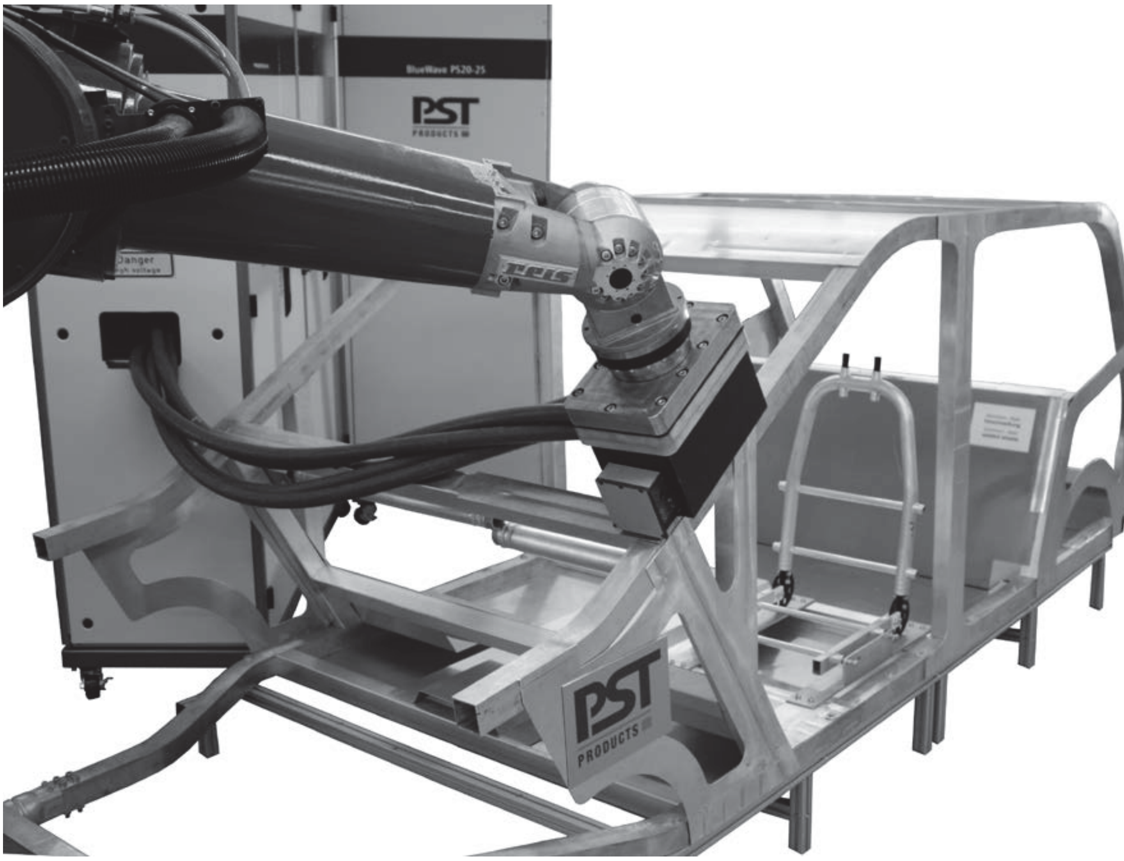

Figure 8: *Robotic EMPT sheet welding coil for large assembly manufacturing*

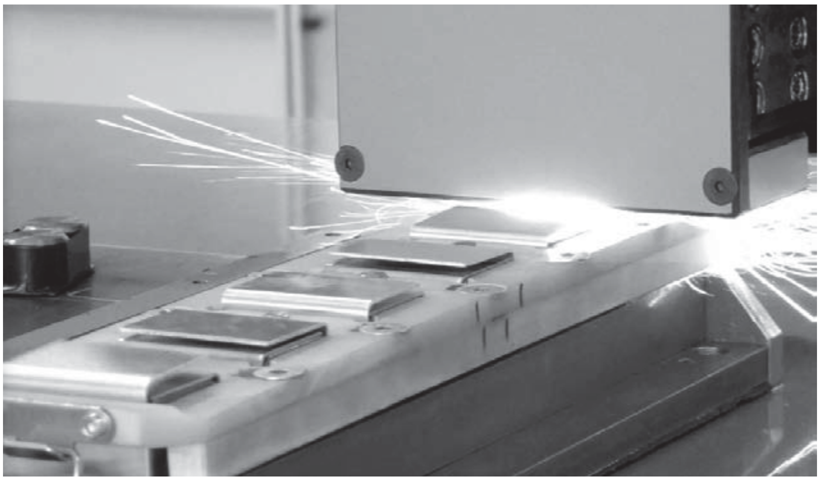

Figure 9: *Robotic EMPT sheet welding coil for subassembly manufacturing (Picture shows the "JET-Effect")*

3 Conclusion

EMPT sheet welding is a solid state welding process, capable to join metals of different melting points without generation of brittle intermetallic phases. Tensile test proof a superior weld quality, i.e. the strength of the weld is equal the maximum tensile strength of the softer joint partner. Small subassemblies and test specimen are commonly manufactured with the help of stationary EMPT sheet welding coils. Large scale assemblies however are problematic to position at a stationary coil. Because of this, a special coil is developed which can be fixed at the tip of a robot boom. Hence, easy and automated positioning of the coil on the welding area is facilitated. This coil is used for welding of space frame structures.

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