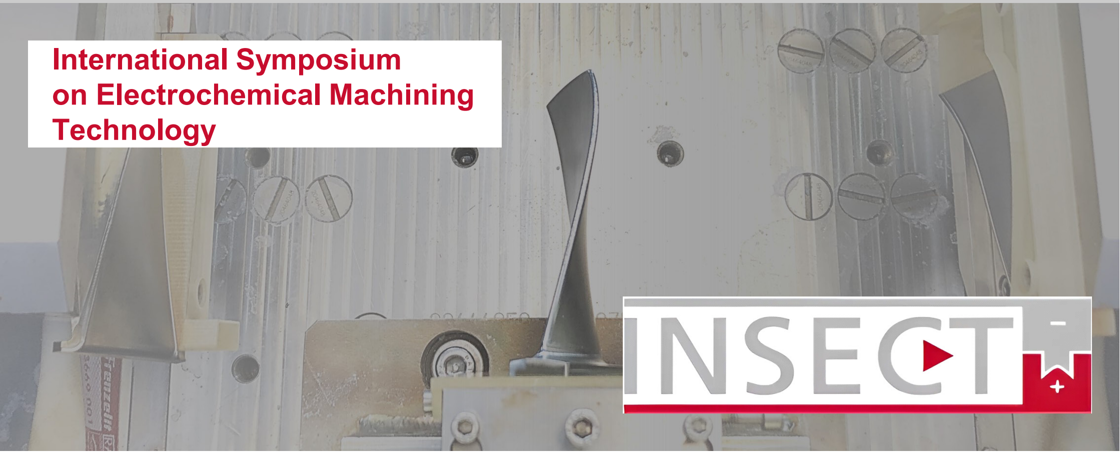

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Aachen, November 18-19, 2024

Thomas Bergs, Elio Tchoupe Sambou, Timm Petersen,
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Editors

Thomas Bergs

Elio Tchoupe Sambou

Timm Petersen

Tim Herrig

Andreas Klink

Manufacturing Technology Institute – MTI, RWTH Aachen University

Campus-Boulevard 30

52074 Aachen

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Setup for flat jet electrochemical cleaning of weld seams

A. Martin[a]*, S. Quitzke[a], M. Krzyzanek[b],

A. Seelke[b], N. Bergmann[c], A. Schubert[a]

[a]Chemnitz University of Technology, Professorship Micromanufacturing Technology, Reichenhainer Str. 70, 09126 Chemnitz, Germany
[b]Elektroanlagenbau Harting, Str. der Jugend 23 A, 03205 Calau, Germany
[c]Friedrich Motorsport, Bamberger Str. 129, 96215 Lichtenfels, Germany

*Corresponding author: andre.martin@mb.tu-chemnitz.de

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Abstract

Weld seams usually require post-machining to remove surficial tempering colors, tinder and rust. Especially in high-end applications such as upmarket exhaust systems, high demands on the surface appearance need to be fulfilled as a sales argument. Hitherto, weld seams are treated individually, e.g. with manual devices using brushes as cathodes for electrochemical cleaning. To reduce human resources and time-consumption, a setup for electrochemical cleaning using a flat jet was developed, which offers the possibility for automated treatment and perspective process chain integration.

Cylindrical tube-shaped workpieces were treated to prove the functionality of the setup. The outer surfaces of metal active gas welded as well as metal inert gas welded tubes were characterized before and after electrochemical cleaning by means of increase in glossiness and reduction of roughness values. Applicable processing parameters such as working distance, voltage and feed speed were analyzed for the design of an industrial setup.

1 Introduction

Upmarket exhaust systems are hand-crafted in individual designs. Especially the manifolds have complicated structures to fulfil special requirements such as pre-defined sound characteristics. For this purpose, constant lengths and cross-sectional areas of the single tubes are required. Hence, the tubes are bended, winded and connected via metal active gas (MAG) or metal inert gas (MIG) welding as can be seen in figure 1.

Figure 1: *Upmarket exhaust manifold and tube parts with weld seams*

Since the manufactured manifolds need to fulfil high demands on their surface appearance as a sales argument, they are treated individually. Especially the regions around weld seams require post-machining treatments to remove surficial tempering colors, tinder and rust. Hence, manual treatments are often unavoidable to treat the complicated tube surfaces. For this purpose, electrochemical cleaning devices with carbon brush cathodes are used. To reduce efforts, minimize human resources and time-consumption, an automated process is aspired offering perspective integration into a process chain.

In this study, an individual laboratory setup was developed to analyze applicable parameters such as voltage, nozzle feed speed and the required machining time. Typical, cylindrically shaped tube-sections were chosen and treated to prove the functionality of the setup and to analyze the polishing results. The focus was on the quality of appearance by means of an increase in glossiness and the removal of tempering colors and tinder. The reduction of roughness values Ra and Rz was analyzed for quantitative comparison before and after polishing. Applicable processing parameters such as working distance, voltage and feed speed were derived from the comparative results.

2 Tube samples

From available upmarket manifolds, a diameter of 63 mm was chosen as one of the most common shapes and hence, the most relevant shape. The wall thickness is approximately 1 mm in this case. Tube sections cut out of exhaust systems with lengths between 60 mm and 120 mm and with MAG as well as MIG weld seams were provided by Friedrich Motorsport GmbH, Germany. Figure 2 shows a benchmark sample in its condition before and after manual polishing, which served as comparative sample.

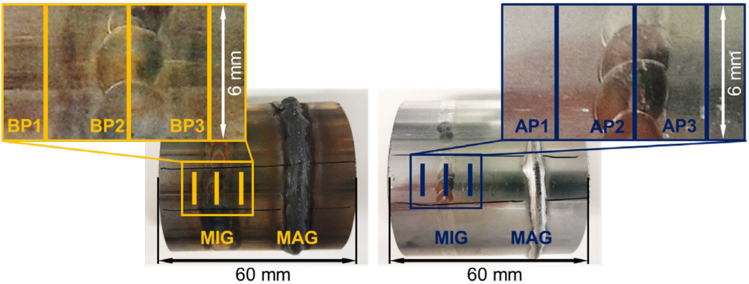

Figure 2: *Benchmark sample before polishing (BP, left) and after manual polishing (AP, right) with details of the respective sections with measurement lines uniform length of 6.0 mm*

The MIG weld seams are characterized by elevations with heights up to 0.5 mm and in some cases also have depressions of approximately - 0.1 mm. This results in working distances with positive and negative deviations. Weld seams from MAG welding have more significant elevations, but were defined as subordinately relevant, since upmarket exhaust systems are usually manufactured via MIG welding. Hence, roughness measurements were carried out on and near the MIG weld seams at the measurement lines indicated in figure 2. For comparison, the roughness was measured before (BP1, BP2 and BP3) and after manual polishing (AP1, AP2 and AP3) over a uniform length of 6 mm. A Keyence VK-9700 confocal laser scanning microscope with an objective magnification of 20 was used. The measured values are shown in Table 1.

Table 1: *Roughness values of the manually polished benchmark sample*

Condition	***Reference position***	***Ra in µm***	***Rz in µm***
Before manual polishing	*BP1*	*0.37*	*4.38*
	BP2	*1.00*	*15.30*
	BP3	*0.45*	*19.00*
After manual polishing	*AP1*	*0.40*	*7.17*
	AP2	*1.57*	*18.50*
	AP3	*0.33*	*4.69*

The central lines BP2 and AP2 were positioned through the center along the respective MIG weld seam, while the other two measuring lines were positioned outside on the left (BP1, AP1) and on the right (BP3, AP3), respectively. The values at the central positions on the wavy weld seams show the highest values. The only exception is Rz at position BP3, which is increased by local remains of tinder. When comparing the values before and after manual polishing, hardly significant changes are recognizable. However, the quality of visual appearance and the gloss are significantly improved after manual polishing.

3 Development of flat jet setup

Electrochemical machining using a cylindrical, free jet of electrolyte (Jet-ECM) is hitherto mainly investigated for micro-machining, e.g. using nozzle diameters of 0.1 mm [1,2,3]. To increase the machining width on the tube component's surface, the laboratory setup was redesigned by means of a flat jet setup, as shown in Figure 3.

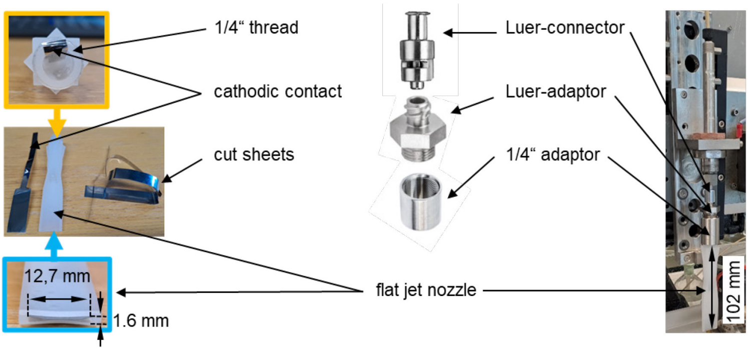

Figure 3: *Flat jet nozzle with cathode contact (left), adaptor and connector components (center) and redesigned nozzle system at the z-axis (right)*

Slotted dispensing nozzles with an outlet cross-section of (1.6 x 12.7) mm² were obtained from VIEWEG GmbH. The resulting cross-sectional area of approx. 20 mm² corresponds to an increase by factor 2500 compared to the previous nozzles for micro-machining. As the flat jet nozzles are available with a 1/4-inch NPT threaded connection, additional adaptors were necessary for the connection with the conical Luer-Lock connection previously used. Due to the long length of the flat jet nozzles of 102 mm, a customized cathode contact sheet made of stainless steel was designed to reduce the electrical resistance over the guided electrolyte and to provide electric current density for sufficient polishing effects. A rotary drive was implemented into the laboratory setup to enable polishing of the entire circumference of the tube's outer surfaces as shown in figure 4.

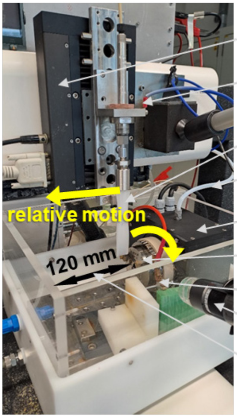

Figure 4: *Photograph of the revised laboratory setup with flat jet nozzle system and integrated rotary drive as well as remaining open length for tube components*

A HarmonicDrive FHA-14C servo drive with hollow shaft was used. The rotary drive was integrated into a plastic housing with sealing air connection to prevent electrolyte solution from entering the sensitive drive components. A DBF55 three-jaw chuck from Koch Maschinenbau GmbH & Co. KG made of stainless steel was selected as a suitable clamping system, which offers sufficient electrical conductivity for anodic contacting and sufficient resistance against corrosion from the electrolyte solution. An individual sliding contact was designed for the anodic contacting of the chuck. The tube components were electrically connected via the clamping jaws. An adapter made of PEEK was placed between the chuck and the drive to ensure galvanic separation of the rotary drive from the electrochemical machining process and to ensure sufficient resistance against chemical influences from the electrolyte solution.

The remaining open length for applicable tubular workpiece components is approximately 120 mm. Considering the travel range of the linear stages, a maximum free length of approximately 100 mm can be reached via relative linear motions between nozzle and workpiece, which is sufficient for polishing experiments on the tube samples.

An alternative electrolyte pump of the type FluSys WADose GEAR was selected and integrated into the setup to provide sufficient flow rates for the formation of a free electrolyte jet without interruptions. The gear pump enables a maximum flow rate of 480 liters per hour, whereas the previous double-piston pump only delivered a maximum of 12 litres per hour. In addition, the gear pump works almost pulsation-free even at high volumetric flow rate and is therefore suitable for forming continuous free jets with the increased cross-sectional area.

4 Functional verification

Three functional tests were carried out with the values charted in Table 2 to verify the applicability of the flat jet setup.

Table 2: *Parameters for functional verification*

Parameter	*Variable*	*Value*	*Unit*
Voltage	*U*	*50, 70, 100*	*V*
Electrolyte pH	*pH*	*0.2*	
Electrolyte conductivity	σ	*202.5*	*mS/cm*
Electrolyte temperature	ϑ	*21.8*	*°C*
Electrolyte supply rate	*V/t*	*49.0*	*l/h*
Nozzle cross-sectional area	*w x l*	*1.6 x 12.7*	*mm²*
Nozzle linear motion speed	*v*	*1.0*	*mm/s*
Workpiece rotational speed	ω	*20.0*	min^{-1}
Working distance	*s*	*≈ 8.0…9.0*	*mm*

A constant nozzle linear motion speed of 1.0 mm/s was chosen from initial experiments. From rough calculations about the required rotational speed considering sufficient overlap of single circumferential machining rotations, a workpiece rotational speed of 20.0 min^{-1} was defined as applicable. From initial tests with the gear pump, a sufficiently delivery rate for the formation of a continuous free jet without interruptions and at the same time sufficiently low for low backscattering effects was investigated and determined 49 l/h. A provisional circular supply was set up to investigate reusability of the electrolyte and reduce its consumption for economic and environmental aspects. A maximum DC voltage of 100 V was selected in accordance with DIN VDE 0100-410.

A commercial electrolyte SuperCleaner from Reuter GmbH & Co. KG was used. The measured pH represents acidic characteristics. The working distance of approx. (8...9) mm is the preset value between the nozzle’s end face and the tube’s surface. The variation of 1 mm results from deviations due non-ideal circular shape, the inclination angle and excentric rotational movements. Additional, irregular deviations at weld seams are not taken into account.

Each experiment was carried out with a polishing time of 20 s, which represents a tube length of 20 mm. Figure 5 shows a tube sample before, during and after three polishing experiments. Cleaning effects are clearly visible with naked eye.

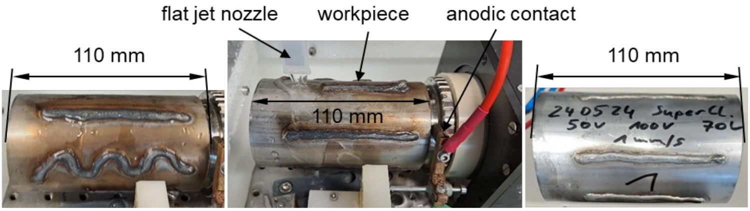

Figure 5: *Tube sample in initial state with residues of tinder and rust and tempering colors (left), experiment with flat jet nozzle and visibly polished area below the jet (center), tube sample after three experiments with voltages of 50 V, 100 V and 70 V (right)*

The experiments were analyzed regarding the electric current over time. Figure 6 shows exemplary measurement results with 70 V.

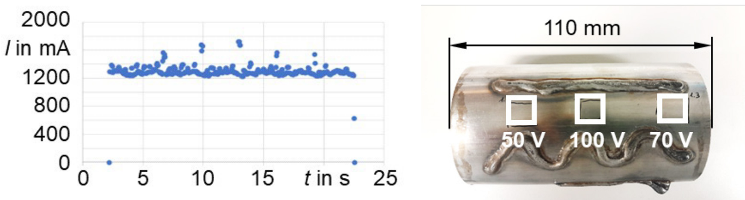

Figure 6: *Electric current over time at U = 70 V (left) and polished tube sample with indicated positions for roughness measurements (right)*

The graph on the left shows an almost constant current of between 1200 mA and 1300 mA with slight increases due to periodic working distance reductions from the recurring weld seams. With 100 V the measured average current values were approx. 2000 mA with similar deviations. The right-handed image shows the polished tube sample with indications of referenced measurement positions. The gloss was significantly increased, as can be seen from light reflections and comparing with the initial state in figure 5. The three polished, circumferential sections were measured for comparison with the same strategy as the benchmark sample. The measurements marked at the reference positions resulted in the values in Table 3. The roughness values are in similar range and partially below the comparative values of the benchmark sample.

***Table 3:** Roughness values of the tube sample polished with the flat jet setup*

Voltage	reference position	Ra in µm	Rz in µm
50 V	Left	0.31	2.61
70 V	Right	0.36	2.98
100 V	Center	0.28	2.49

5 Conclusion

A Setup for flat jet electrochemical cleaning was developed and a proof of its functionality was carried out on weld seams. Comparable results as in manual electrochemical cleaning were achieved with voltages between 50 V and 100 V. Hence, reproducible polishing effects are expected at largely varying working distances. This is one basic prerequisite for sufficient and homogeneous polishing effects of complicated manifolds surfaces in a perspective industrial setup and will be investigated more in detail in future experiments.

Acknowledgement

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