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Design of a station for welding parts of a car exhaust system

Making large batches of repeatable components is a challenge for the manual welding process. The solution to these problems is automation using machines with two- or multi-axis systems. The design of a station for welding elements of car mufflers focuses on the automation of one of the processes at Ulter-Sport Sp. z o.o. through the use of a prototype five-axis numerically controlled station. The use of this type of solution provides the operator with the opportunity to quickly develop new welding cycles, which are repeatedly and accurately mapped using a ball system and stepper motors. The spacious working area and large movement capabilities of the torch allow the machine to adapt to perform other welding tasks.

Key words: *welding, exhaust system, automation*

1. INTRODUCTION

The exhaust system is one of the basic components of modern combustion cars. The sound experience it produces depends on the geometry, build quality of the components, and the connections between them. The constant pursuit of innovative shapes has led to significant complexity in the manufactured tips, thus making it difficult to ensure the necessary accuracy of execution.

In the automotive industry, large expenditures of repetitive elements are the basis for broadly used automation, thanks to which the performance of difficult and monotonous tasks is transferred from the operator to the machine.

One of the elements requiring a high degree of accuracy are tailpipes (Fig. 1). The final product, consisting of a perforated tube and two rings, requires the use of six welds arranged circumferentially on the edge connecting the elements.

Fig. 1. Exhaust system parts made at the Welding Station AS-03

The narrow space available to the operator and the small wall thickness significantly hinder the repeatability of welds with the required strength [1].

2. MANUAL WELDING

Manual execution of the tailpipes was carried out at the Programmable Turntable. This device is

equipped with a rotating plate that allows the use of tools positioning components for the time of welding. Programming is carried out by dividing the rotation into "fast passage" and "welding" sections, after starting the device rotates the tool to the position in which the weld should have been made, and then informs the employee, by means of an audible signal, when to start the welding process. After rotation by the programmed angle and at the assigned speed, the cycle repeats around the entire perimeter, resulting in the execution of a given number of welds with the indicated parameters.

Fig. 2. Programmable Turntable (PT)

Maintaining the required quality requires a lot of experience and focus from the operator throughout the entire working time. Due to the large batches of identical elements (reaching up to 600 pieces at a time), such monotonous work leads to a decrease in accuracy and frequent occurrence of welding defects that exclude details from subsequent stages of production.

On the basis of the Programmable Turntable (Fig. 2), the Automatic Torch Pushing System (ATPS) was developed. Operating on the basis of a pneumatic actuator, a set of linear bearings and a valve system. It made it possible to automatically move the welding torch in relation to the welded element, depending on the current work cycle of the station.

The ATPS system allowed automation to be tested on simple details requiring short torch movements in one axis. During testing, many irregularities were noticed, such as:

- difficulties in adjusting the position of the welding torch;
- difficulties in adjusting control of the feed speed;
- vibrations resulting from insufficient number of linear bearings.

These problems had to be solved in subsequent stages of design.

3. CONSTRUCTION REQUIREMENTS

On the basis of the technical documentation of the manufactured elements, as well as the experience resulting from the tests carried out on the ATPS, the following design requirements of the station for welding car muffler elements were determined:

- the number of welds: two, three or four;
- elimination of torch vibrations;
- control of the speed of movement;
- shortening the cycle time;
- weld length in the range of 30–40 mm;
- weld laying speed: 10–15 mm/s;
- welding current voltage within 14–19 V;
- welding current within 80–140 A;
- wire feed speed: 6–9 m/min;
- melting depth: ET1 ≥ 0.2 [2].

4. THE AS-03 WELDING STATION

In order to meet all the design assumptions, as well as the complex shapes of the tailpipes, it was decided to use a machine based on a five-axis (Fig. 3).

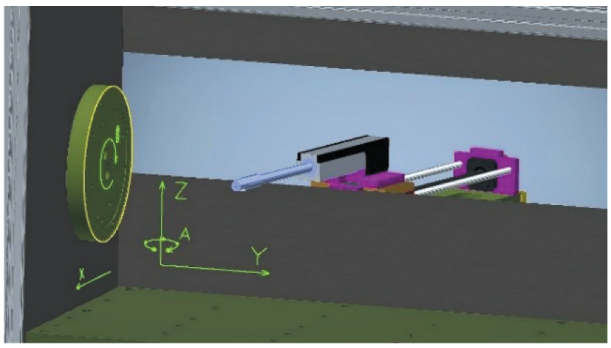


Fig. 3. Workspace model with AS-03 station axis arrangement marked. Model generated with Inventor

The Automatic Welding Machine (AS-03) (Fig. 5) is equipped with a system of three linear axes, the movement of which is carried out through a stepper motor with an encoder [3] connected to a ball screw by the claw clutch [4, 5]. As linear axes, the following are distinguished:

– X axis – responsible for moving the torch to the welded element in the range of 0–255 mm;
– Y axis – responsible for the movement along the welded element in the range of 0–810 mm;
– Z axis – responsible for height adjustment in the range of 0–162 mm.

Additional angular axes are one of the most important elements of the machine design. Those are responsible for controlling the angle between the torch and the welded edge, as well as its positioning and the welding speed. As angular axes, the following are distinguished:

– A axis – responsible for tilting the torch around the Z axis in the range of 0–95°;
– B axis – responsible for the rotation of the welded element in the range of 0–360°.

Due to the design and production capacity of the company's machine park, the AS-03 station uses welding heads of its own design (Fig. 4). It consists of a Teflon housing mounted on a carriage with linear bearings and a brass tube guiding the liner. The end of the head is topped with a gas nozzle holder for use of standardized current tips and gas nozzle.

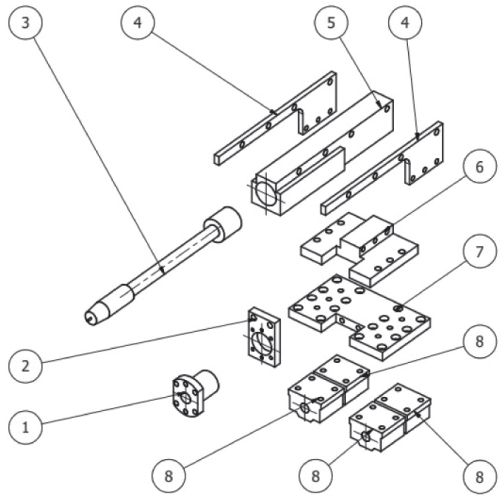


Fig. 4. List of elements included in the welding torch of the AS-03 Welding Station. Drawing generated with Inventor

The most important aspect of working on machines with moving parts is the safety of the operator. Pictograms, covers, ESTOP button, as well as limit switches in combination with the SICK safety module provide hardware protection for the operator against injury.

Fig. 5. Welding Station AS-03

In addition, security systems have been duplicated using a number of macros and scripts written in Python. Those are responsible for such functions as door locking during operation, operation of sensors and other external systems cooperating with the AS-03 station [6, 7].

Additional functions of the station are controlled by a motion controller CSMIO equipped with a number of analog and digital outputs transmitting signals to the station equipment. One such component is the Oerlikon Citowave III welding machine [8], the work of which is controlled by two analog signals that allow a smooth change of wire feed and welding current during a single cycle, and even during the execution of a single weld.

The AS-03 station operates on the basis of G-code with linear accuracies of 0.01 mm and angular accuracies of 30'.

To facilitate the development of programs, the machine is equipped with an MPG remote control (Fig. 6) with an additional button that allows current coordinates to be saved to a file.

Fig. 6. MPG remote control used for development of the G-code

The B angular axis is finished with a rotating plate on which pins and a number of threaded holes are placed, ensuring the uniform installation of positioning tools (Fig. 7) with each retooling of the station.

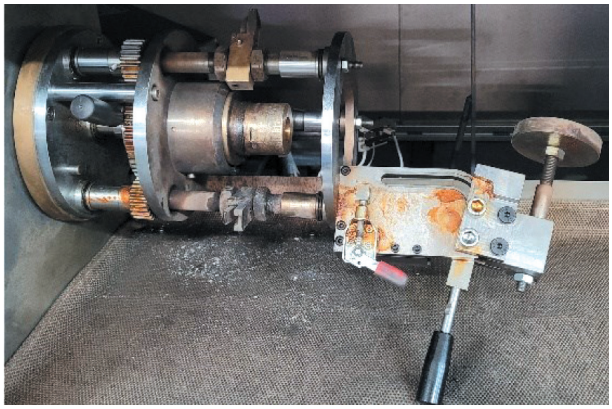


Fig. 7. Tool mounted in the working space of the AS-03 Welding Station

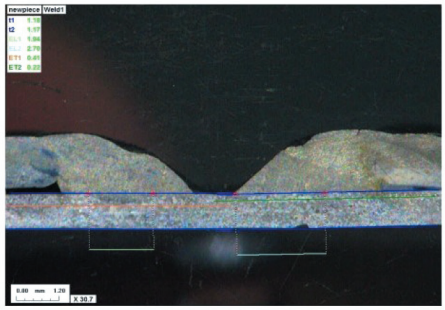
5. USES OF AS-03

The machine has been developed based on all design requirements, and it also provides for the possibility of adapting to welding other elements of the exhaust system such as muffler jackets. Ultimately, the position has the following capabilities:

- compliance with safety rules in accordance with CE directives;
- reduction of the welding cycle time by 144 seconds to 54 seconds (for one of the elements);
- control of wire feed in the range of 2–25 m/min;
- control of welding current in the range of 15–420 A;
- linear accuracy of 0.01 mm;
- an accuracy of the angular axes of 30';
- the operating range of the X-axis in the range of 0–255 mm;
- the operating range of the Y-axis in the range of 0–800 mm;
- the operating range of the Z linear axis in the range of 0–162.5 mm;
- the operating range of the A-axis in the range of 0–95°;
- operating range of the B angular axis in the range of 0–360°;
- the cylinder-shaped working area measuring ∅ 360 mm × 800 mm;
- easy programming using the MPG remote control.

6. METALLOGRAPHIC EXAMINATION

The components made on the AS-03 stand were subjected to metallographic examination (Fig. 8) in the laboratory of the quality control department of Ulter-Sport Sp. z o.o. The test report confirmed the correctness of the ET1, ET2, EL1 and EL2 parameters [2] in the case of 95% of the tested welds.



t1	1,18
t2	1,17
EL1	1,94
EL2	2,7
ET1	0,41
ET2	0,22

Fig. 8. Part of the metallographic examination report (t1, t2 – walls thickness; EL1, EL2 – fusion length in the axis of the cut; ET1, ET2 – fusion penetration

7. SUMMARY

The developed stations for welding car muffler elements were designed, manufactured, tested and put into production at Ulter-Sport Sp. z o.o.

With a working area of ∅ 360 mm × 800 mm, a torch tilting range of ±45°, control of the wire feed, welding current and feed speed all enabled a significant improvement in the repeatability and accuracy of the obtained welds. In combination with a set of positioning tools, it is one of the most important systems ensuring continuity in the production of car exhaust systems.

The AS-03 Welding Machine stand found additional applications in welding other elements such as muffler jackets, and thanks to the system used to support long elements, research on the regeneration of worn machine shafts by means of hardfacing began on it.

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References

[1] Adamiec P., Pilarczyk J.: *Poradnik inżyniera. Spawalnictwo*, t. 1–4. WNT, Warszawa 2003.
[2] TAE13005 Welding Exhaust systems EN 2017-08 [TENNECO standard]. Edenkoben 2017.
[3] *Silniki krokowe i enkodery z oferty WObit.* https://automatykab2b.pl/prezentacje/53098-silniki-krokowe-i-enkodery-z-oferty-wobit [3.12.2020].
[4] Dobrzański T.: *Rysunek techniczny maszynowy*. WNT, Warszawa 2015.
[5] Kurmaz L.: *Podstawy konstrukcji maszyn projektowanie*. Wydawnictwo Naukowe PWN, Warszawa 1999.
[6] *Podstawy Pythona.* https://python101.readthedocs.io/pl/latest/podstawy/index.html [30.11.2020].
[7] *Przewodnik po makrach Python.* https://www.cs-lab.eu/wpcontent/uploads/2019/08/makra-python-przewodnik-simcnc.pdf [30.11.2020].
[8] Instrukcja obsługi spawarki Oerlikon Citowave III. https://www.oerlikon-welding.com/sites/oerlikon/files/2018/06/22/citowave-iii_pl_2018.pdf [3.12.2020].

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