Seam tracking with arc sensors using welding power sources for Gas Metal Arc Welding (GMAW) with consumable electrodes

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Tolerances of the work piece, of receptacles and clamping devices and of mechanisation or automation devices up to the wire exit at the current contact pipe of the welding torch make it harder to reproduce the spatial orientation of a welding seam. This technical documentation describes the support provided by Lorch welding current sources in the signal preparation for seam tracking.

1 Basic principle of the arc sensor

The values of current i(t) and voltage u(t) at a specific time of the MIG welding process result from the interaction of:

- Settings and properties of the welding current source;
- Wire feed speed;
- Electrical properties of the wire stick-out;
- Electrical properties of the arc.

Stable welding work points are derived by using suitable current characteristics as well as overlaid control strategies.

Two basic types are discriminated:

- Fast horizontal or flatly decreasing characteristics (constant voltage CV);
- Steeply decreasing characteristics (constant current CC).

Conventional transformer welding power sources for GMAW welding show flatly decreasing characteristics. A change in the arc length and/or the length of the wire electrode stick-out will affect the welding current more strongly than the welding voltage, see **Figure 1.** A shorter arc ($L_1>L_2$) increases the welding current so that the wire electrode melts faster and the arc is extended ($L_2<L_3$). This is called "internal compensation" or "internal control".

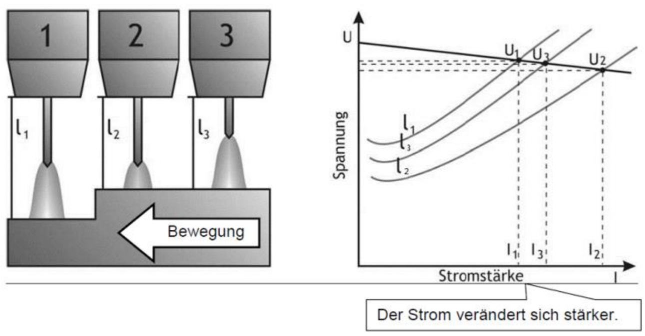

Figure 1: Interdependence of current, voltage and arc length for a flatly decreasing characteristic according to [1]

Modern, controlled welding power sources allow steeply descending characteristics for GMAW welding in special cases. In the past, conventional welding power sources only used this effect for metal manual arc welding (MMA) and TIG (GTAW) welding. A change in the arc length changes the arc voltage more than the welding current, see **Figure 2.** The arc voltage decreases when the arc is shortened ($L_1>L_2>L_3$).

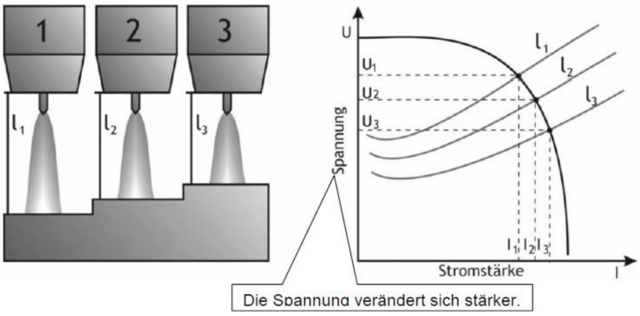

Figure 2: Interdependence of current, voltage and arc length for a strongly decreasing characteristic according to [1]

The light arc in combination with the free wire electrode stick-out end can therefore be used as a sensor for geometrical or spatial changes, as these changes are reflected by measurable current and/or voltage signals.

Either voltage or current or, in specific situations, even both variables together may provide the optimal information regarding the arc length and the length of the free wire electrode stick-out, see **Figure 3**.

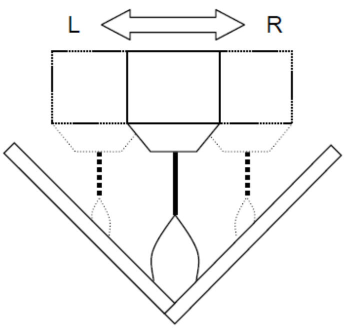

Figure 3: Different lengths of light arcs and the free rod end at different positions of the welding torch relative to the middle of the welding seam.

2 Basic principle of arc tracking

The term arc tracking is used here to include seam finding.

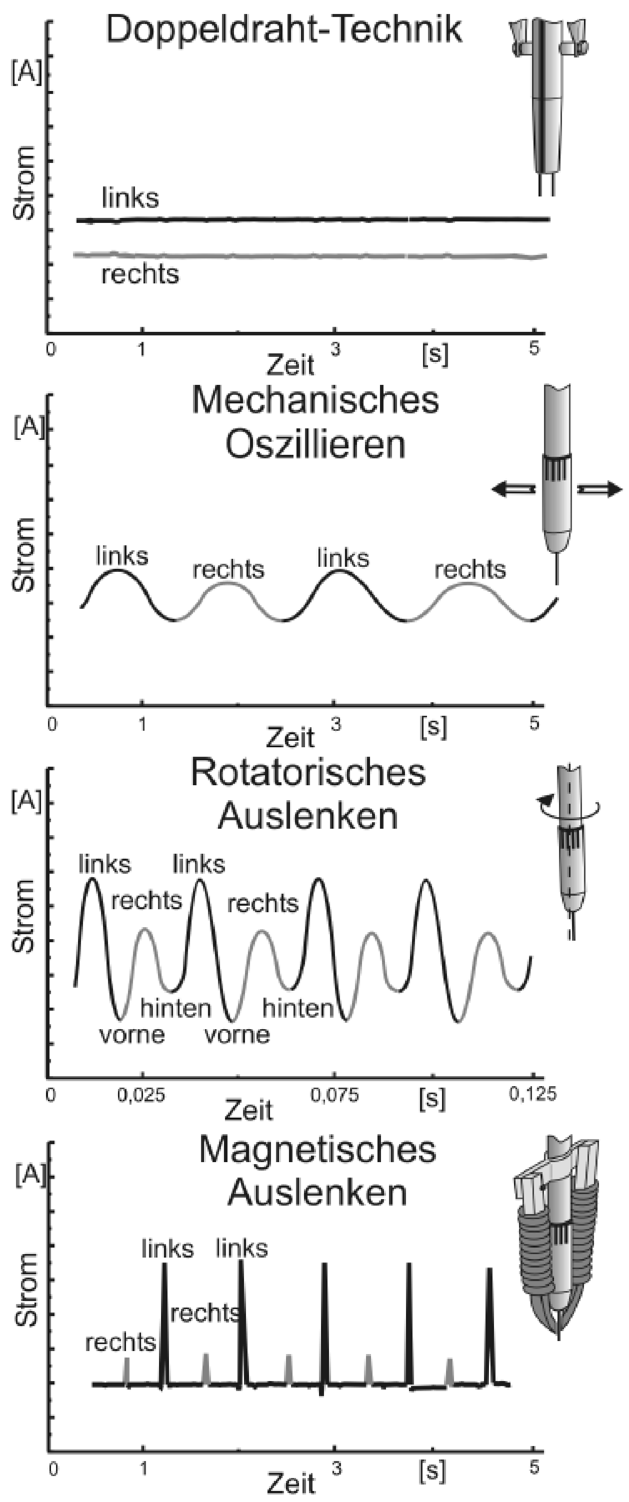

Figure 4: Scanning the groove with arc sensors according to DVS Information Sheet 0927-1 [1]

It is assumed for the purpose of this explanation that the welding power source has a flatly decreasing characteristic (constant voltage characteristic), as most of the images and explanations in the current specialised literature are based on this assumption. It will later be shown how this assumption can be transferred to modern process control.
Figure 4 shows different ways of scanning the groove.

The double wire method makes use of 2 active arcs, one right and the other left of the groove - also see the position of the groove and the arc positions L and R in **Figure 3**. The shorter arc will have the higher current, e.g. the left arc in **Figure 4** is obviously shorter. The difference between the currents (left/right) can be used as a positioning signal that guides the mechanical movement until the seam groove is aligned in the middle.

Normal GMAW welding with only one wire electrode requires movement of the arc in order to track the seam, i.e. varying the arc length over time creates signal patterns that can be used to draw conclusions regarding the relative position of the arc and welding groove.
The most frequently used method is the mechanical oscillation of the entire torch head.
Rotational deflection requires special torches, but it is suitable for use in restricted spaces, e.g. narrow-groove welding.
Magnetic deflection is used in special cases where the arc is moved by electromagnetic forces.

The processing and evaluation of signals that are derived from arcs that are extended and shortened over time provide special challenges that will be discussed below.

3 Signal filtering

The GMAW welding process can be set to be a very dynamic process in which current and voltage change significantly over time.
These continuously changing signals for current and voltage must be filtered in order to derive usable conclusions regarding the arc length.
A further requirement for signal filtering results from the Nyquist-Shannon sampling theorem. It is essential that this basic theorem of communication science, signal processing and information theory should be taken into account, as all modern devices for seam tracking are digital systems that depend on discrete bus cycle times for information exchange. The theorem states that the highest limit frequency used in harmonic signals may at most be half the sampling frequency (which includes the bus frequency in this

contact). A compromise must be made, as no real filter provides a completely ideal performance.
The "smothered" signals derived by filtering must retain sufficient dynamic information to determine changes in the arc length.

The Lorch welding power sources provide signal filtering as a function of the welding process type selected. It mainly consists of the following steps:

- Pre-filtering to suppress the inverter frequency in the signals;
- High-frequency sampling of the current and voltage signals for further signal processing (S, P series with 80 kHz);
- Filtering the signals in a first digital stage to remove process interference signals (low-pass, a few kHz);
- Sampling the signals in a further digital stage at specific times (either continuously or synchronised with the process during impulse welding);
- Filtering the signals in another digital stage to prepare them for cyclical bus communication (compliance with the sampling theorem).

The filtered and transmitted signal will be slightly delayed when compared to the original signal, which is the case with any real-time signal filtering and bus transmission.
The time delay is in the range of several multiples of 10 ms.

4 Signal preparation

In addition to signal filtering, the Lorch welding power sources provide signal preparation as a function of the welding process type selected. The advantages are:

a) Availability of a signal for seam tracking based on the combined signals for current and voltage, which represents the length signal for the arc and free wire electrode stick-out in the way that is most suitable for the welding process type selected;
b) Scaling the signal for seam tracking, i.e. amplification of the information for length of the arc and the free wire electrode stick-out to make better use of the available (numerical or analogue) value range.

The advantages of signal preparation can only be provided in combination with modern welding power sources.
It is important that the user should be aware that prepared signals for seam tracking do NOT directly correspond to filtered welding current, which was generally the case in former times when no signal preparation was used.

5 "Conventional" seam tracking signal

The common, "conventional" approach for normal GMAW welding with welding power sources that had an almost horizontal characteristic was to measure the welding current (e.g. via a shunt) and to use the signal obtained in a seam tracking device.
The strategies for seam tracking by most robot manufacturers are therefore described with reference to the welding current. They may differ in detail, but are very similar in principle, see **Figure 5** and **Figure 6.**

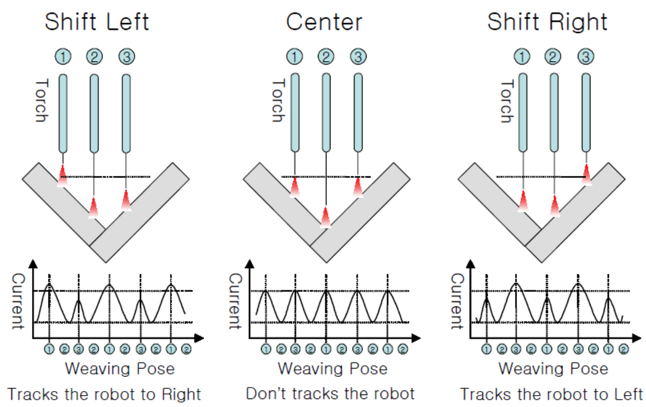

Figure 5: Principle of the evaluation of the "conventional" seam tracking signal for horizontal guidance, image source: Hyundai Hi4 [3]

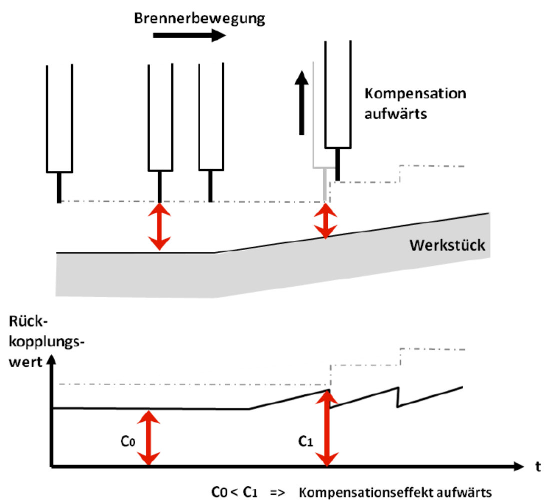

Figure 6: Principle of the evaluation of the "conventional" seam tracking signal for vertical guidance, image source: FANUC [4]

6 The Lorch seam tracking signal

The Lorch seam tracking signal is a specially prepared signal for seam tracking as described in Chapter 3 and 4.

The numerical range of the digital bus signal ranges from 0 to 10000, which corresponds to a signal voltage range between 0V and 10V on the optionally available analogue interface.

The scaling function in **Eq.1** applies to process control versions based on "conventional" common GMAW welding with an almost horizontal characteristic (voltage control, VC).

$$y = Gain_1 \times x_c$$

(Eq.1)

Eq.1: x_c is the filtered current and *Gain* equals 10. A static welding current of 100 A in this case corresponds to a numeric bus signal value of 1000 and an analogue signal of 1 V.
It should be noted that this signal is only intended for seam tracking and that Lorch reserves the right to change the scaling (e.g. in other process versions) to optimise seam tracking.

The scaling function in **Eq.2** applies to process control versions that are mainly based on current control (CC) rather than voltage-control (VC), e.g. to specific characteristics of the S-series for normal or standard GMAW welding or impulse welding.

$$y = Gain_n \times \left(Offset_n - x_v\right) \qquad \text{(Eq.2)}$$

Eq.2: x_v *is a signal derived from the voltage.* $Gain_n$ and $Offset_n$ depend on the process control variable "n". The seam tracking signal according to Eq.2 is arranged so that shortening of the arc and/or the length of the free wire electrode stick-out increases the value of the seam tracking signal. This corresponds to the concept and the direction of the expected, "conventional" pattern, but the value is not related to the welding current value.
The accurate values of $Gain_n$ and $Offset_n$ for the individual process control versions are not specified, as the issue is too complex for this description.

The seam tracking signal is separately accessible according to the description of the options, bus interfaces and the Lorch automation interface.

The "conventional" signal of the filtered welding current value is also accessible according to the descriptions. It is not recommend to use the "conventional" type of seam tracking, although it could be used with suitable, voltage-based process control versions, as it has not been optimised for seam tracking by Lorch.

7 Limits and problems of seam tracking

Various peripheral conditions make seam tracking with an arc sensor difficult or even impossible.

The following peripheral conditions prevent seam tracking with an arc sensor:

- No significant changes of the length of the arc and/or the length of the free wire electrode stick-out;
- Disturbances in the process that interfere too strongly with the length change signals;
- De-adjustment of the process during welding (e.g. ramps);
- Inappropriate settings for the welding process.

A typical example for inappropriate settings for a welding process is the current-controlled standard GMAW process (S-series, specific characteristics) when it is operated within the stable spray arc range at 1 mm G3Si1. Hardly any changes of the welding current take place in this range, even when the light arc length changes. The standard GMAW process is based on Eq.1, which provides no signal sequence that could be used for seam tracking, either in the form of a seam tracking signal nor in the form of a "conventional" current-based signal. Seam tracking simply does not work in the spray arc range, even when it works in the short arc area.
The solution would be the use of a voltage-controlled standard GMAW process for the spray arc range.

Well-functioning seam tracking with an arc sensor requires that the welding process should be adjusted to be stable, so that the arc length can be significantly changed for seam tracking purposes without destabilising the process.

8 Notes for robot manufacturers

It should be noted here that a controller used for seam tracking based on mechanical movement combines two signals that have different time delays as compared to real time.
Firstly, the response of the arc as well as the signal preparation and transmission of the seam tracking signal are subject to a certain delay.
Secondly, the mechanical movement and its stabilisation or registration by the robot are also subject to a certain delay.
The delay times are not equal and are often not known. It is therefore necessary to achieve time synchronisation in the tracking system (by delaying the "faster" signal).

Many important clues for the correct adjustment and use of seam tracking are included in the documentation of the robot manufacturers, see [3], [4], [5].

The FANUC documentation for TAST (which is the name of a function) is quoted here as an example [4]:

The way in which TAST works can be influenced by a variety of factors. Most applications do not need further adjustment once these parameters have been set. Factors that could affect TAST are:

- *Changes to the welding rod (e.g. steel or stainless steel) and changes in the welding rod diameter*
- *Extreme changes in the welding parameters*
- *Changes in the welding position relative to the welding grooves*
- *Gas composition*
- *Type of welding rod advance or welding process like short arc, spray arc or pulsed arc*
- *Changes in the weaving parameters (frequency, dwell time)*
- *Surface of the material*
- *Extreme changes at the workplace - external temperature*

The following recommendations are made in [4] regarding work piece and seam sizes:

- *The material thickness should be greater than 2 mm.*
- *Welding seams should consistently have an enclosed angle of 90°.*
- *A fillet weld may have a max. enclosed angle of 90° and the leg length must be greater than 5 mm.*
- *The minimum oscillation width must be 3 times the diameter of the electrode or larger.*
- *Tack welding point leg length should, where possible, be smaller or equal to half the welding point and have a concave profile.*
- *The welding seam placed should not be rotated against the ideal welding seam by more than 15°.*
- *The torch must be positioned near the welding seam centre before the welding process. "Touch sensing" might be useful.*
- *The oscillation width at corner fillet welds and overlapping fillet welds must be 2 mm smaller than the thickness of the base material.*
- *The groove distance between the parts to be welded should be within the normal welding robot tolerance. The groove distance should ideally be constant along the entire welding path.*

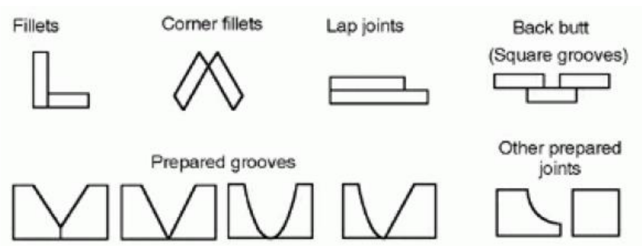

Figure 7: Recommended welding grooves for seam tracking, image source: FANUC [4]

The extensive descriptions of the robot manufacturers are based on the "conventional" GMAW arc sensing method and also describe the signals used by their controllers in conventional terms, e.g. as "reference current", "seam tracking current" or similarly.

The Lorch seam tracking signal can be used as a **direct replacement** for such variables, as the logical direction is the same during arc length changes.

It must again be emphasised that the value of the Lorch seam tracking signal is not equivalent to the value of the current, see Eq.1 and Eq.2 in Chapter 6. Proven "conventional amplification factors" used in seam tracking controllers of robot manufacturer must accordingly be adapted to the scaling of the Lorch seam tracking signal, which has been optimised for seam tracking.

The Lorch seam tracking signal makes it possible also to use current-based process control versions for seam tracking, even though some robot manufacturers exclude this option in their "conventional" analysis of this issue.

9 Presentation of the signal pattern

Suitable measuring devices allow data recordings and presentation of the signal patterns in seam tracking systems.

Figure 8 shows data that were imported by using a spread sheet. They have been recorded via LorchNET (Can Bus) from a Lorch current source during pulse welding by using the PCANVIEW software. The welding process (left side) starts centred in the groove of the fillet weld; the groove is then deliberately left towards the flank (right side) during the course of the welding process. The changing signal pattern can be clearly seen. The outliers towards the bottom represent unwanted process disturbances in the form of short circuits.

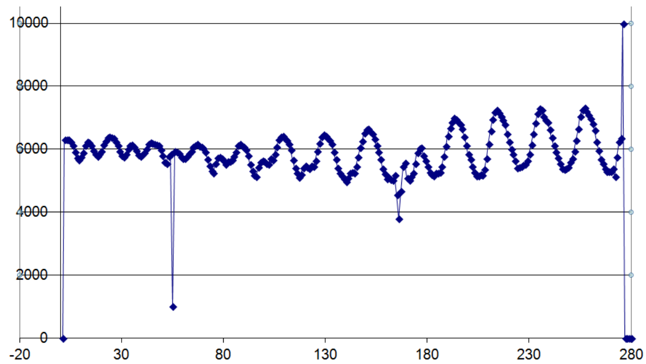

Figure 8: Presentation of a digitally recorded signal pattern of the seam tracking signal.

The signal pattern within a numerical value range between 0 and 10000 can be seen. The value around 6000 does not represent the medium welding current. During current-controlled impulse welding, it corresponds to the seam tracking signal that was specially scaled according to Eq.2. The x-axis of the diagram shows the number of data points over time. Each data point corresponds to a time interval of approx. 20ms.

The recording of an oscillating, current-controlled impulse welding process on an angled sheet is shown in **Figure 9.** The green line shows the movement of the torch while the red line represents the seam tracking signal.
The intense signal pattern at the start does not represent an ignition pulse. It results from the stabilisation of the signal filters after applying Eq.2 and should therefore be ignored.

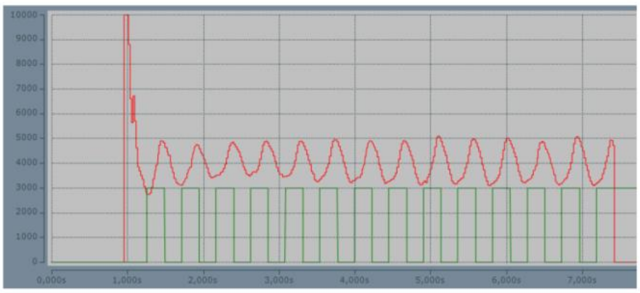

Figure 9: Recording of an oscillating, current-controlled impulse welding process on an angled sheet. Image source: User

A voltage-controlled standard GMAW process is shown in **Figure 10.** In this case the intense signal pattern at the beginning correlates with an ignition pulse, as the filter settles from the bottom and does not cause an irritation as is the case with Eq.2. The effect of the hot start can also be seen in the initial part of the welding diagram. Seam tracking should therefore only start after a few seconds, once the welding process has stabilised and shows the desired welding performance.

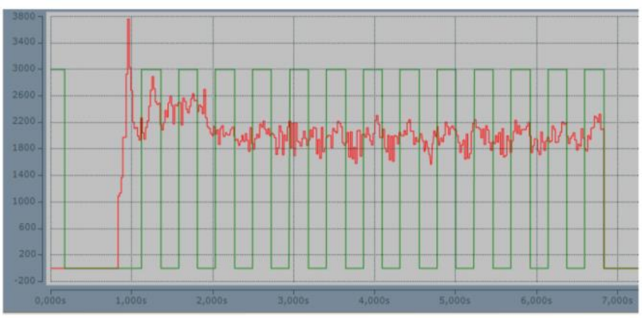

Figure 10: Recording of a voltage-controlled standard GMAW process. Image source: User

This is a voltage-controlled standard GMAW welding process and the feedback value of the seam tracking signal therefore approximately corresponds to the welding current (2000 = 200 A, see Eq.1 in Chapter 6). Current changes caused by the oscillation are noticeable, but the process pattern is rather unsteady and obviously takes place in a transition arc range. However, one can see a trend in the response of the seam tracking signal to the deflection of the torch.

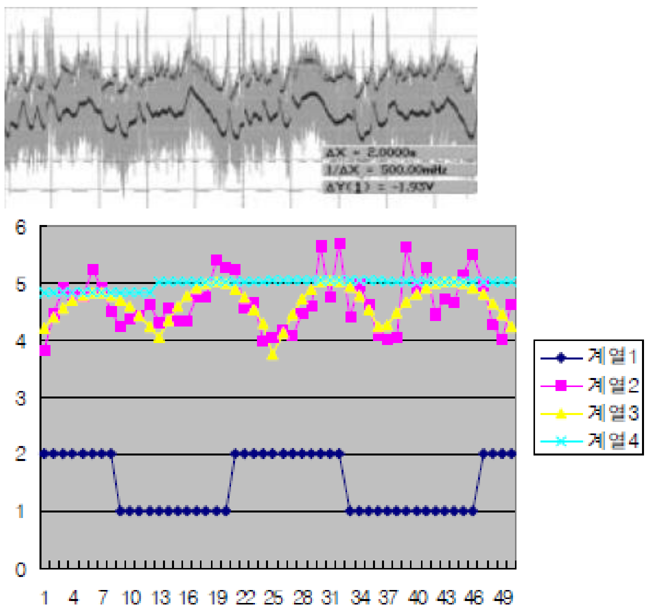

Figure 11: In spite of a turbulent noise process (grey presentation above), an auxiliary track correction signal (4th line, light-blue) could be derived from the filtered evaluation (3rd line, yellow) based on the seam tracking signal (2nd line, pink) and the time-shifted, synchronised oscillation signal (1st line, dark- blue). Image source: Hyundai Hi4 [3].

The seam tracking controller of the robot manufacturer can in many cases use the turbulent process signals and the seam tracking signal derived from them to extract sufficient information for seam tracking, see **Figure 11**.

Data recording and presentation are also possible with a digital storage oscilloscope (DSO) when an interface module with digital/analogue conversion is used to output the seam tracking signal, e.g. the Lorch INT06. It provides the seam tracking signal (state: 09/2014) on channel 4 in the value range between 0V and 10V.

10 Overview of technical data

Seam tracking signal, status 09/2014

Numerical value range	0..10000
Numerical resolution	1
Int06-analogue voltage value range	0V..10V
Resolution of analogue voltage value range	12 Bit
Cycle time (nominal)	20ms
Logical direction of the seam tracking signal	Higher values for shorter arcs
Scaling	Depends on the processor type selected

11 Interfaces

The seam tracking signal is also called seam tracking voltage in older documentation provided by Lorch. This concerns the seam tracking signal.

There are interface protocols for different bus systems and robot types. The documentation for the LorchNet connector [6] can be found in the descriptions, see **Figure 12.**

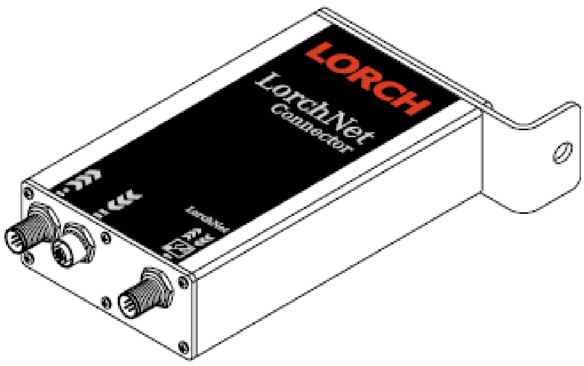

Figure 12: LorchNet connector

The following bus systems are supported (dated 09/2014):

- CAN gateway
- CanOpen
- DeviceNet
- EtherCat
- EtherNet IP
- ProfiPus
- ProfiNet

The parallel analogue/digital interface by Lorch is the INT06, see **Figure 13**. It can also be installed in the machine or the switch cabinet. Extensive documentation is available [7].

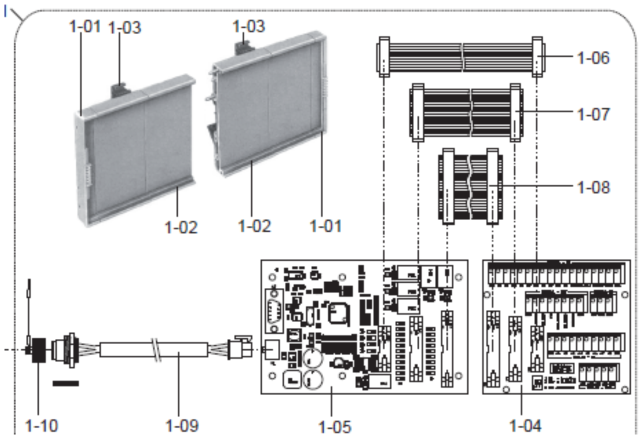

Figure 13: INT06 (1-05) with accessories

12 Recommended literature

[1] DVS Information Sheet 0927-1 "Sensors for fully automated arc welding", DVS-Verlag GmbH, Düsseldorf 2005.

[2] DVS Information Sheet 0927-2 "Sensors for fully automated arc welding, application information“, DVS-Verlag GmbH, Düsseldorf 2008.

[3] The seam tracking with arc sensing, Hi4 Function, HYUNDAI 2002

[4] Arctool Operating Manual B-80944GE-3/01, FANUC Robotics

[5] LIBO Sensor A50 (through-the-arc-sensor), Operating Manual, KUKA 2003

[6] Operating Instructions LorchNet Connector, 909.1550.1, Lorch 2014

[7] Operating Manual for Device Interface Int06-1, 909.0530.1, Lorch 2014