pH Arc Sensors

Modbus RTU
Programmer’s Manual

Firmware version:

EPHUM034

Rev.	Revision Date	Author	Change Description
01	22.04.2010	PA RD DS	Initial Version 01 for EPHUM011
02	13.08.2012	LW JB	Update to EPHUM014
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04	07.07.2020	CS	Update to EPHUM032
05	22.02.2021	CS	Update to EPHUM034

Table of Content

1 Modbus RTU general information

1.1 Introduction

This document describes in detail the pH Arc Sensors Modbus RTU interface. It is addressed to software programmers.
Chapter 1 is a general description of the Modbus RTU.
The following chapters contain the pH Arc Sensors specific programming.

1.2 Hamilton Arc Sensors: Modbus Command Structure

This definition of the command structure is valid for all members of the Hamilton Arc Sensor family, having the following firmware versions:

- ODOUM0xx (VisiFerm DO / VisiFerm DO Arc Sensor)
- EPHUM0xx (pH Arc Sensors)
- CONUM0xx (Conducell Arc Sensors)
- CPWUM0xx (Conducell PW Arc Sensors)
- EDOUM0xx (EDO Arc Sensors)
- ERXUM0xx (ORP Arc Sensors)

Please check by reading register 1032 (see 2.9.1):
This definition of the command structure is an additional document to the Operating Instructions of the specific sensors. Before reading this manual, the operating instructions of the sensors should be read and understood.

1.2.1 Modbus RTU: Definitions According to Modbus IDA

The definitions in chapter 1.2 are an excerpt from the document:

- "Modbus over serial line - Specification and Implementation Guide V1.02" and
- "Modbus Application Protocol Specification V1.1b"

For more detailed information please consult http://www.modbus.org.

⚠ Attention:

- In this manual the register counting starts per definition at address 1. Some Modbus master protocols operate with register-count starting at address 0. Usually, the Modbus master software translates the addressing. Thus, the register address of 2088 will be translated by Modbus master software to 2087 which is sent to the sensor (Modbus slave). This must be observed during programming. Please check the specifications of the Modbus master that you are using.
- Representation of data formats in this document:
  - decimal values are displayed as numbers without any prefix, for example 256
  - hexadecimal values are displayed as: 0x2A
  - ASCII-characters or ASCII strings are displayed as: "Text"

1.2.2 Command Structure

The Modbus application protocol defines a simple **P**rotocol **D**ata **U**nit (PDU) independent of the underlying communication layers:

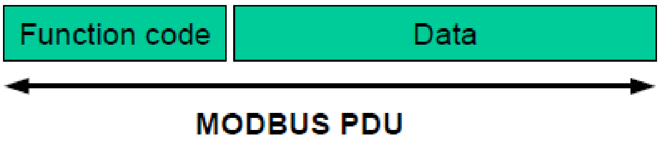


Figure 1.2.2.1: Modbus Protocol Data Unit.

The mapping of Modbus protocol on a specific bus or network introduces some additional fields on the **P**rotocol **D**ata **U**nit. The client that initiates a Modbus transaction builds the Modbus PDU, and then adds fields in order to build the appropriate communication PDU.

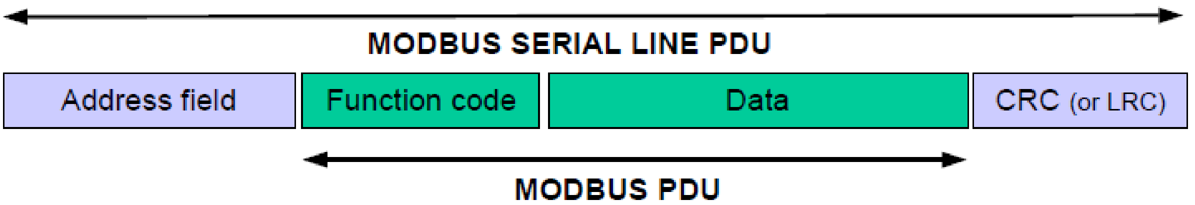


Figure 1.2.2.2: Modbus frame over Serial Line.

- On Modbus Serial Line, the Address field only contains the <u>slave address</u>.

<u>Note:</u>
Arc Sensors support only slave addresses 1 to 32.

A master addresses a slave by placing the slave address in the address field of the message. When the slave returns its response, it places its own address in the response address field to let the master know which slave is responding.

- The function code indicates to the server what kind of action to perform. The function code can be followed by a data field that contains request and response parameters.

- The CRC field is the result of a "Redundancy Checking" calculation that is performed on the message contents.

1.2.3 Modbus RTU Transmission Mode

When devices communicate on a Modbus serial line using the RTU (Remote Terminal Unit) mode, each 8-bit byte in a message contains two 4-bit hexadecimal characters. The main advantage of this mode is that its greater character density allows better data throughput than ASCII mode for the same baud rate. Each message <u>must</u> be transmitted in a continuous stream of characters.

The format (11bits) for each byte in RTU mode is:
Coding System: 8 bit binary
Bits per Byte: 1 start bit
8 data bits, least significant bit sent first
1 bit for parity completion
1 stop bit

Remark: The use of no parity requires 2 stop bits.

How characters are transmitted serially:
Each character or byte is sent in this order (left to right):
Least Significant Bit (LSB)…Most Significant Bit (MSB)

With Parity Checking

Start	1	2	3	4	5	6	7	8	Par	Stop

Figure 1.2.3.1: Bit sequence in RTU mode.

Frame Checking Field:
Cyclical Redundancy Checking (CRC)

Frame description:

Slave Address	Function Code	Data	CRC
1 byte	1 byte	0 up to 252 byte(s)	2 bytes CRC Low, CRC Hi

Figure 1.2.3.2: RTU Message Frame.

=> The maximum size of a Modbus RTU frame is 256 bytes.

1.2.4 Modbus RTU Message Framing

A Modbus message is placed by the transmitting device into a frame that has a known beginning and ending point. This allows devices that receive a new frame to begin at the start of the message, and to know when the message is completed. Partial messages must be detected and errors must be set as a result.

In RTU mode, message frames are separated by a silent interval of at least 3.5 character times.

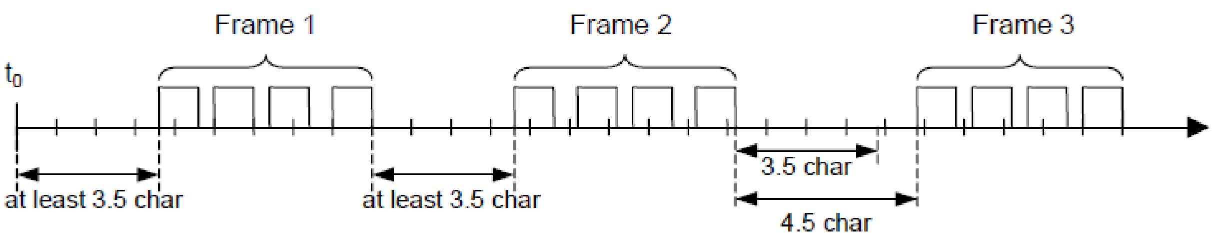


Figure 1.2.4.1: Valid frames with silent intervals.

Start	MODBUS message: Address	Function	Data	CRC Check	End
≥ 3.5 char	8 bits	8 bits	N x 8 bits	16 bits	≥ 3.5 char

Figure 1.2.4.2: RTU Message Frame.

The entire message frame must be transmitted as a continuous stream of characters.

If a silent interval of more than 1.5 character times occurs between two characters, the message frame is declared incomplete and should be discarded by the receiver.

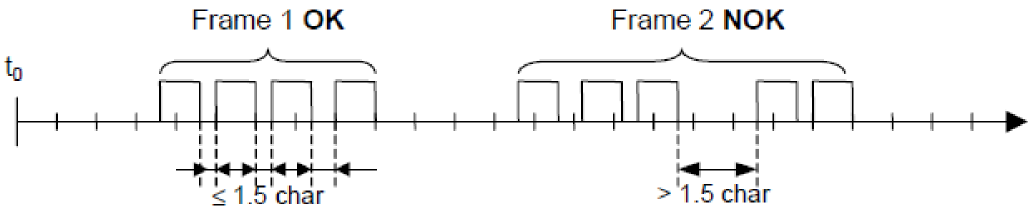


Figure 1.2.4.3: Data transmission of a frame.

1.2.5 Modbus RTU CRC Checking

The RTU mode includes an error-checking field that is based on a Cyclical Redundancy Checking (CRC) method performed on the message contents.

The CRC field checks the contents of the entire message. It is applied regardless of any parity checking method used for the individual characters of the message.

The CRC field contains a 16-bit value implemented as two 8-bit bytes.

The CRC field is appended to the message as the last field in the message. When this is done, the low-order byte of the field is appended first, followed by the high-order byte. The CRC high-order byte is the last byte to be sent in the message.

The CRC value is calculated by the sending device, which appends the CRC to the message. The receiving device recalculates a CRC during receipt of the message, and compares the calculated value to the current value it received in the CRC field. If the two values are not equal, an error results.

The CRC calculation is started by first pre-loading a 16-bit register to all 1's. Then a process begins of applying successive 8-bit bytes of the message to the current contents or the register. Only the eight bits of data in each character are used for generating the CRC. Start and stop bits and the parity bit do not apply to the CRC.

During generation of the CRC, each 8-bit character is exclusive OR-ed with the register contents. Then the result is shifted in the direction of the least significant bit (LSB), with a zero filled into the most significant bit (MSB) position. The LSB is extracted and examined. If the LSB was a 1, the register is then exclusive OR-ed with a preset, fixed value. If the LSB was a 0, no exclusive OR takes place.

This process is repeated until eight shifts have been performed. After the last (eight) shift, the next 8-bit byte is exclusive OR-ed with the register's current value, and the process repeats for eight more shifts as described above. The final content of the register, after all the bytes of the message have been applied, is the CRC value.

When the CRC is appended to the message, the low-order byte is appended first, followed by the high-order byte.

A detailed introduction to CRC generation can be found in the manual
"MODBUS over Serial Line, Specification and Implementation Guide, V1.02"
in chapter 6.2 "Appendix B - LRC/CRC Generation" form http://www.modbus.org.

1.3 Implementation of Modbus RTU in Hamilton Arc Sensors

According to the official Modbus definition, the start of a command is initiated with a pause of ≥ 3.5 characters. Also the end of a command is indicated with a pause of ≥ 3.5 char.
The device address and the Modbus function code have 8 bits.
The data string consists of n*8 bits. The data string contains the starting address of the register and the number of registers to read/write.
The checksum CRC is 16 bits long.

	start	**device address**	**function**	**data**	**Checksum**		**end**
value	no signal during ≥ 3.5 char	1-32	function code according to Modbus specs	data according to Modbus specs	CRC L	CRC H	No signal during ≥ 3.5 char
bytes	≥ 3.5	1	1	n	1	1	≥ 3.5

Figure 1.3.1: Modbus definition for data transmission.

The RS485 interface is configured as follows:

	Modbus RTU implementation in Hamilton Arc Sensors
Start Bits	1
Data Bits	8
Parity	none
Stop Bit	2
String length	11 Bits
Baud Rate	19200 (default), other baud rate can be configured

Figure 1.3.2: RS485 definitions for Arc Sensors.

1.4 Modbus RTU Function Codes Used for Arc Sensors

Arc Sensors use only 3 Modbus function codes:

3: Read Holding Registers
4: Read Input Registers
16: Write Multiple Registers

These three function codes are described below in detail using excerpts from "Modbus Application Protocol Specification V1.1b "(http://www.modbus.org).

1.4.1 Modbus function code #3: Read Holding Registers

This function code is used to read the contents of a contiguous block of holding registers in a remote device. The Request PDU specifies the starting register address and the number or registers. The PDU Registers are addressed starting at zero. Therefore registers numbered 1 – 16 are addressed as 0 – 15.

The register data in the response message are packed as two bytes per register. For each register, the first byte contains the high order bits and the second contains the low order bits.

Request

Function code	1 Byte	**0x03**
Starting Address	2 Bytes	0x0000 to 0xFFFF
Quantity of Registers	2 Bytes	1 to 125 (0x7D)

Response

Function code	1 Byte	**0x03**
Byte count	1 Byte	2 x **N***
Register value	**N*** x 2 Bytes	

***N** = Quantity of Registers

Error

Error code	1 Byte	**0x83**
Exception code	1 Byte	01 or 02 or 03 or 04

Figure 1.4.1.1: Definition of Holding Registers.

Request		**Response**	
Field Name	*(Hex)*	*Field Name*	*(Hex)*
Function	03	Function	03
Starting Address Hi	00	Byte Count	06
Starting Address Lo	6B	Register value Hi (108)	02
No. of Registers Hi	00	Register value Lo (108)	2B
No. of Registers Lo	03	Register value Hi (109)	00
		Register value Lo (109)	00
		Register value Hi (110)	00
		Register value Lo (110)	64

Figure 1.4.1.2: Example of reading holding registers 108 – 110. The contents of register 108 are read as the two byte values 0x022B. The contents of registers 109 – 110 are 0x00 00 and 0x0064.

1.4.2 Modbus function code #4: Read Input Registers

The function code is used to read from 1 to 125 contiguous input registers in a remote device. The Request PDU specifies the starting register address and the number of registers. The PDU Registers are addressed starting at zero. Therefore input registers numbered 1 – 16 are addressed as 0 – 15.

The register data in the response message are packed as two bytes per register. For each register, the first byte contains the high order bits and the second contains the low order bits.

Request

Function code	1 Byte	**0x04**
Starting Address	2 Bytes	0x0000 to 0xFFFF
Quantity of Input Registers	2 Bytes	0x0001 to 0x007D

Response

Function code	1 Byte	**0x04**
Byte count	1 Byte	2 x **N***
Input Registers	**N*** x 2 Bytes	

***N** = Quantity of Input Registers

Error

Error code	1 Byte	**0x84**
Exception code	1 Byte	01 or 02 or 03 or 04

Figure 1.4.2.1: Definition of Input Registers.

Request		Response	
Field Name	*(Hex)*	*Field Name*	*(Hex)*
Function	04	Function	04
Starting Address Hi	00	Byte Count	02
Starting Address Lo	08	Input Reg. 9 Hi	00
Quantity of Input Reg. Hi	00	Input Reg. 9 Lo	0A
Quantity of Input Reg. Lo	01		

Figure 1.4.2.2: Example of reading input register 9. The contents of input register 9 are read as the two byte value 0x000A.

1.4.3 Modbus Function Code #16: Write Multiple Registers

This function code is used to write a block of contiguous registers (1 to 123 registers) in a remote device. The requested values are specified in the request data field. Data is packed as two bytes per register. The response returns the function code, starting address, and quantity of registers written.

Request

Function code	1 Byte	**0x10**
Starting Address	2 Bytes	0x0000 to 0xFFFF
Quantity of Registers	2 Bytes	0x0001 to 0x007B
Byte Count	1 Byte	2 x **N***
Registers Value	**N*** x 2 Bytes	value

***N** = Quantity of Registers

Response

Function code	1 Byte	**0x10**
Starting Address	2 Bytes	0x0000 to 0xFFFF
Quantity of Registers	2 Bytes	1 to 123 (0x7B)

Error

Error code	1 Byte	**0x90**
Exception code	1 Byte	01 or 02 or 03 or 04

Figure 1.4.3.1: Definition of Write Multiple Registers.

Request		Response	
Field Name	*(Hex)*	*Field Name*	*(Hex)*
Function	10	Function	10
Starting Address Hi	00	Starting Address Hi	00
Starting Address Lo	01	Starting Address Lo	01
Quantity of Registers Hi	00	Quantity of Registers Hi	00
Quantity of Registers Lo	02	Quantity of Registers Lo	02
Byte Count	04		
Registers Value Hi	00		
Registers Value Lo	0A		
Registers Value Hi	01		
Registers Value Lo	02		

Figure 1.4.3.2: Example of writing the value 0x000A and 0x0102 to two registers starting at address 2.

1.5 Data Formats Used in Arc Sensors

1.5.1 Float

Definition: Floating point according to IEEE 754 (Single Precision)

Explanation:	sign	exponent	mantissa	total
Bit:	31	30 to 23	22 to 0	32
Exponent bias	127			

Figure 1.5.1.1: Definition Floating point Single Precision (4 bytes resp. 2 Modbus registers).

Example: translate the decimal value 62.85 into binary

Step 1: Conversion of the decimal value into binary fixed-point number

62 / 2	= 31	residue 0	LSB	**0.85** * 2	= 1.70	=> 1	MSB
31 / 2	= 15	residue 1		0.70 * 2	= 1.40	=> 1	
15 / 2	= 7	residue 1		0.40 * 2	= 0.80	=> 0	
7 / 2	= 3	residue 1		0.80 * 2	= 1.60	=> 1	
3 / 2	= 1	residue 1		0.60 * 2	= 1.20	=> 1	
1 / 2	= 0	residue 1	MSB	0.20 * 2	= 0.40	=> 0	
	= **111110**			0.40 * 2	= 0.80	=> 0	LSB
					…		
					= **0.110110011001100110011001100**…		

62.85 = 111110.110110011001100110011001100…

Step 2: Normalizing (in order to obtain 1 bit on the left side of the fraction point)

111110**.**110110011001100110011001100… *2^**0** = 1**.**11110110110011001100110011001100… *2^**5**

Sep 3: Calculation of the dual exponent

2^5 => Exponent **5**
Exponent + Exponent bias = **5** + 127 = **132**

132 / 2	= 66	residue 0	LSB
66 / 2	= 33	residue 0	
33 / 2	= 16	residue 1	
16 / 2	= 8	residue 0	
8 / 2	= 4	residue 0	
4 / 2	= 2	residue 0	
2 / 2	= 1	residue 0	
1 / 2	= 0	residue 1	MSB
	= **10000100**		

Sep 4: Definition of the sign bit

Positive = 0
Negative = 1
= **0**

Step 5: conversion into floating-point

1 Bit Sign + 8 Bit Exponent + 23 Bit Mantissa
0 10000100 11110110110011001100110 (corresponds to 0x427B6666)

One important note for the 23 Bit Mantissa: The first bit (so-called hidden bit) is not represented. The hidden bit is the bit to the left of the fraction point. This bit is per definition always 1 and therefore suppressed.

Example: translate the binary float 0100 0010 0111 1011 0110 0110 0110 0110 to a decimal value

Step 1: Separating the binary value into Sign, Exponent and Mantissa

0 10000100 11110110110011001100110
1 Bit Sign + 8 Bit Exponent + 23 Bit Mantissa

S: **0** $_{binary}$ = **0** (positive sign)
E: **10000100** $_{binary}$ = $1*2^7 + 0*2^6 + 0*2^5 + 0*2^4 + 0*2^3 + 1*2^2 + 0*2^1 + 0*2^0$
= 128 + 0 + 0 + 0 + 0 + 4 + 0 + 0
= **132**
M: **11110110110011001100110** $_{binary}$ = **8087142**

Step 2: Calculate the decimal value

$$D = (-1)^S * (1.0 + M/2^{23}) * 2^{E-127}$$
$$= (-1)^0 * (1.0 + 8087142/2^{23}) * 2^{132-127}$$
$$= 1 * 1.964062452316284 * 32$$
$$= \mathbf{62.85}$$

1.5.2 Character

Definition:

The numerical representation of characters is defined in 8-Bit ASCII-Code-Table (ANSI X3.4-1986). Accordingly, each Modbus register in Arc Sensors can store two ASCII characters.

Example: translate the ASCII-string "2076" to Hex representation

The following interpretation is made according to the ASCII Codes-Table:

"2" => ASCII code table=> 0x32 Low Byte
"**0"** => ASCII code table => 0x30
"**7"** => ASCII code table => 0x37
"**6"** => ASCII code table => 0x36 High Byte

"2076" => **0x36373032**

1.5.3 Decimal

Example: translate Decimal 2227169 to Hex

2227169 / 16	= 139198	residue 1	Low Byte
139198 / 16	= 8699	residue 14 => E	
8699 / 16	= 543	residue 11 => B	
543 / 16	= 33	residue 15 => F	
33/16	= 2	residue 1	
2 / 16	= 0	residue 2	High Byte
	= **0x21FBE1**		

1.6 Modbus RTU Error Messages

Here are listed the Modbus standard error-codes we have implemented in Arc Sensors.

Error-Code Hex	**Status-Text**
0x00	OK
0x01	Illegal function
0x02	Illegal data address
0x03	Illegal data value
0X04	Slave device failure

Figure 1.6.1: implemented Error-Codes (see "Modbus_Application_Protocol_V1.1b" for details)

2 pH Arc Sensor Commands in Modbus RTU

2.1 General

In order to communicate with a pH Arc Sensor over Modbus RTU protocol a Modbus master terminal application software is needed. The Modbus RTU is an open standard and a number of free and commercial application toolkits are available.

This manual contains examples and illustrations from WinTECH Modbus Master ActiveX Control tool: WinTECH (www.win-tech.com) "Modbus Master OCX for Visual Basic". The Modbus Organisation (www.modbus.org/tech.php) provides other links to a wide variety of Modbus terminal software.

In the present manual the addressing of the Modbus registers starts at 1. But the Modbus master protocol operates with register addresses starting at 0. Usually, the Modbus master software translates the addressing. Thus, the register address of 2090 will be translated by the Modbus master software to 2089 which is sent to the sensor (Modbus slave).

Attention:
When configuring and calibrating the sensor, please limit write operations to a reasonable number. More than 100'000 write operations will physically damage the memory of the sensor. Furthermore, for the Free User Memory Space (see chapter 2.9.3), the write operations are limited to 10'000.

2.2 Operator levels and Passwords

2.2.1 Reading / Setting Operator Level

A pH Arc Sensor can be operated in three different operator levels. Each operator level allows a defined access to a specific set of commands.

Abbreviation	Description	Code (hex)	Password (decimal)
U	User (lowest level)	0x03	0
A	Administrator	0x0C	18111978
S	Specialist	0x30	16021966

Figure 2.2.1.1: Definition of operator level and default passwords

At each power up or processor reset, the operator level falls back to the default level U.

The active operator level can be read and written in register 4288.

Start register	Number of registers	Reg1 / Reg2	Reg3 / Reg4	Modbus function code	Read access	Write access
4288	4	Operator Level	Password	3, 4, 16	U/A/S	U/A/S

Figure 2.2.1.2: Definition of register 4288.

Command: Active operator level	Modbus address: **4288**	Length: **4**	Type: **3**	Read
Parameter:	Operator level	Password		
Format:	hex	decimal		
Value:	**0x03**	**0**		

Figure 2.2.1.3: Example to read the active operator level (function code 3, start register address 4288, number of registers 4): The active operator level is 0x03 (User). The sensor does not report the password. The value 0 is returned instead.

Command: Operator level		Modbus address: **4288**	Length: **4**	Type: **3** Read
Parameter:	Operator level	Password		
Format:	Hex	decimal		
Value:	**0x30**	**0**		

Figure 2.2.1.4: Example to read the active operator level: the active level is 0x30 (Specialist). The sensor does not report the password. The value 0 is returned instead.

Command: Operator level		Modbus address: **4288**	Length: **4**	Type: **16** Write
Parameter:	Operator level	Password		
Format:	Hex	decimal		
Value:	**0x03**	**0**		

Figure 2.2.1.5: Example to set the operator level to 0x03 (User). The password 0 has to be sent.

Command: Operator level		Modbus address: **4288**	Length: **4**	Type: **16** Write
Parameter:	Operator level	Password		
Format:	Hex	decimal		
Value:	**0x0C**	**18111978**		

Figure 2.2.1.6: Example to set the active operator level to 0xC (Administrator). The correct password has to be sent.

Command: Operator level		Modbus address: **4288**	Length: **4**	Type: **16** Write
Parameter:	Operator level	Password		
Format:	Hex	decimal		
Value:	**0x0B**	**18111978**		

Figure 2.2.1.7: Example for a Modbus error. If the level or the password is not correct, (Operator level = 0x0B), the sensor answers with a Modbus error message "Slave device exception response" (see chapter 1.6, "VisiFerm DO Modbus RTU Programmer's Manual" (Ref 624179)).

2.2.2 Changing Passwords for Operator Level

The passwords for accessing the operator levels A and S can be modified by S (Specialist) only. U (User) and A (Administrator) have no right to change any password. The new password will remain stored after power down.

Start register	Number of registers	Reg1 / Reg2	Reg3 / Reg4	Modbus function code	Read access	Write access
4292	4	Level	New password	16	None	S

Figure 2.2.2.1: Definition of register 4292.

Command: Password		Modbus address: **4292**	Length: **4**	Type: **16** Write
Parameter:	Operator level	Pass number		
Format:	Hex	Decimal		
Value:	**0x30**	**12345678**		

Figure 2.2.2.2: Example to set the Password of operator level S (code 0x30) to 12345678.

2.3 Configuration of the serial RS485 Interface

Factory settings of the RS485:
Parity is none, 1 start bit, 8 data bits, 2 stop bits (in total: 11 bits).

2.3.1 Device Address

2.3.1.1 Reading and Writing the Device Address

The sensor specific device address can be read and written in register 4096.

Start register	Number of registers	Reg1 / Reg2	Modbus function code	Read access	Write access
4096	2	device address	3, 4, 16	U/A/S	S

Figure 2.3.1.1.1: Definition of register 4096.

Command: Com address		Modbus address: **4096**	Length: **2**	Type: **3** Read
Parameter:	Modbus address			
Format:	Decimal			
Value:	**1**			

Figure 2.3.1.1.2: Example to read the device address.

The device address can be set by S (Specialist), default value is 1.

Command: Com address		Modbus address: **4096**	Length: **2**	Type: **16** Write
Parameter:	Modbus address			
Format:	Decimal			
Value:	**3**			

Figure 2.3.1.1.3: Example to set the device address to 3.

2.3.1.2 Reading the Device Address Limits

The device address limits can be read in register 4098.

Start register	Number of registers	Reg1 / Reg2	Reg3 / Reg4	Modbus function code	Read access	Write access
4098	4	Min. device address	Max. device address	3, 4	U/A/S	none

Figure 2.3.1.2.1: Definition of register 4098.

Command: Com address limits		Modbus address: **4098**	Length: **4**	Type: **3** Read
Parameter:	Min value	Max value		
Format:	Decimal	Decimal		
Value:	**1**	**32**		

Figure 2.3.1.2.2: Example to read the device address limits: Min = 1, Max = 32.

2.3.2 Baud Rate

2.3.2.1 Reading and Writing the Baud Rate

The baud rate can be read and written in register 4102.

Start register	Number of registers	Reg1 / Reg2	Modbus function code	Read access	Write access
4102	2	Baud rate code (definition see below)	3, 4, 16	U/A/S	S

Figure 2.3.2.1.1: Definition of register 4102.

The code for the baud rate is defined as follows:

Baud rate	4800	9600	19200	38400	57600	115200
Code	2	3	4	5	6	7

Figure 2.3.2.1.2: Code for the baud rates.

Command: Com baud rate		Modbus address: **4102**	Length: **2**	Type: **3** Read
Parameter:	Baud rate code			
Format:	Decimal			
Value:	**4**			

Figure 2.3.2.1.3: Example to read the baud rate code, 4 corresponds 19200 baud.

The baud rate can be set by S (Specialist), default is 19200.

Command: Com baud rate		Modbus address: **4102**	Length: **2**	Type: **16** Write
Parameter:	Baud rate code			
Format:	Decimal			
Value:	**5**			

Figure 2.3.2.1.4: Example to set the baud rate to 38400 baud with code 5.

2.3.2.2 Reading the Baud Rate Limits

The baud rate limits can be read in register 4104.

Start register	Number of registers	Reg1 / Reg2	Reg3 / Reg4	Modbus function code	Read access	Write access
4104	4	Min. Baud rate code	Max. Baud rate code	3, 4	U/A/S	none

Figure 2.3.2.2.1: Definition of register 4104.

Command: Com baud limits		Modbus address: **4104**	Length: **4**	Type: **3** Read
Parameter:	Min Baud rate code	Max Baud rate code		
Format:	Decimal	Decimal		
Value:	**2**	**7**		

Figure 2.3.2.2.2: Example to read the baud rate code limits: Min = 2, Max = 7 (see Figure 2.3.2.1.2).

2.4 Configuration of the Analog Interfaces

2.4.1 Available Analog Interfaces

A pH Arc Sensor has two individual physical analog interfaces that have identical functionalities, but can be configured independently from each other.

- Analog Output Interface 1 (AO1)
- Analog Output Interface 2 (AO2)

The number of analog interfaces is defined in register 4320.

Start register	Number of registers	Reg1 / Reg2	Modbus function code	Read access	Write access
4320	2	Available analog interfaces	3, 4	U/A/S	none

Figure 2.4.1.1: Definition of register 4320.

Command: Avail analog interfaces	Modbus address: **4320**	Length: **2**	Type: **3**	Read
Parameter:	Available analog interfaces			
Format:	Hex			
Value:	**0x03**			

Figure 2.4.1.2: Example to read the available analog interfaces. The answer is "0x03" meaning that there exists an Analog Interface 1 (AO1) and an Analog Interface 2 (AO2).

2.4.2 Available Analog Interface Modes

With register 4322, the available analog interface modes for AO1 and AO2 are defined

Start register	Number of registers	Reg1 / Reg2	Reg3 / Reg4	Reg5 / Reg6	Reg7 / Reg8	Modbus function code	Read access	Write access
4322	8	Available Analog Interface Modes for AO1	Available Analog Interface Modes for AO2	reserved	reserved	3,4	U/A/S	none

Figure 2.4.2.1: Definition of register 4322. It defines the analog interface modes available for AO1 and AO2. The analog interface modes are described in Figure 2.4.2.2.

Code (Hex)	Analog Interface Mode	Description
0x00	4-20 mA inactive	Analog interface deactivated
0x01	4-20 mA fixed	Set to a constant output value for current loop testing
0x02	4-20 mA linear	Linear output of measurement (PMC1 / 6)
0x04	4-20 mA bilinear	Bilinear output of measurement (PMC1 / 6)

Figure 2.4.2.2: Definition of the analog interface modes, valid for both AO1 and AO2.

Command: Analog Interface Modes	Modbus address: **4322**	Length: **8**	Type: **3**	Read
Parameter:	Available Analog Interface Modes for AO1	Available Analog Interface Modes for AO2	reserved	reserved
Format:	Hex	Hex	Hex	Hex
Value:	**0x07**	**0x07**	**0x0**	**0x0**

Figure 2.4.2.3: Example to read register 4322: all modes defined in figure 2.4.2.2 are available for both AO1 and AO2.

2.4.3 Description of the Analog Interfaces 1 and 2

Register 4352 / 4480 contain the descriptions of AO1 / AO2 as plain text ASCII:

Start register	Number of registers	Reg1 to Reg8 16 ASCII characters	Modbus function code	Read access	Write access
4352	8	Description of AO1	3, 4	U/A/S	none
4480	8	Description of AO2	3, 4	U/A/S	none

Figure 2.4.3.1: Definition of register 4352 and 4480

Command: Current interface text		Modbus address: **4352**	Length: **8**	Type: **3** Read
Parameter:	Text			
Format:	Character			
Value:	**mA interface #1**			

Figure 2.4.3.2: Example to read the description of AO1. The text is "**mA interface #1**". Accordingly, AO1 is physically configured as a 4-20 mA current output.

Command: Current interface text		Modbus address: **4480**	Length: **8**	Type: **3** Read
Parameter:	Text			
Format:	Character			
Value:	**mA interface #2**			

Figure 2.4.3.3: Example to read the description of AO2. The text is "**mA interface #2**". Accordingly, AO2 is physically configured as a 4-20 mA current output.

Attention:

- pH Arc Sensors do not have an ECS (in contrast to VisiFerm DO)!
- Data structure: register address offset between AO1 and AO2 is always 128.

2.4.4 Selection of an Analog Interface Mode

The analog interface mode of AO1 / AO2 is selected by programming the analog interface mode in register 4360 / 4488.

Start register	Number of registers	Reg1 / Reg2	Modbus function code	Read access	Write access
4360	2	Active analog interface mode for AO1	3, 4, 16	U/A/S	S
4488	2	Active analog interface mode for AO2	3, 4, 16	U/A/S	S

Figure 2.4.4.1: Definition of register 4360 / 4488. Only one bit can be set.

Command: Active interface mode		Modbus address: **4360**	Length: **2**	Type: **16** Write
Parameter:	Mode			
Format:	Hex			
Value:	**0x02**			

Figure 2.4.4.2: Example to set the analog interface mode of AO1 to 0x02 (4-20 mA linear output).

2.4.5 Configuration of the 4-20 mA Interface

Note:
The configuration of AO1 / AO2 is only effective if register 4360 / 4488 (active analog interface mode) is set to the value 0x01, 0x02 or 0x04.

2.4.5.1 Reading the Available Primary Measurement Channels to be Mapped to the Analog Output

Start register	Number of registers	Reg1 / Reg2	Modbus function code	Read access	Write access
4362	2	Available Primary Measurement Channels for AO1	3, 4	U/A/S	none
4490	2	Available Primary Measurement Channels for AO2	3, 4	U/A/S	none

Figure 2.4.5.1.1: Definition of register 4362 / 4490.

For the definition of the Primary Measurement Channels (PMC), see chapter 2.5.

Code (Hex)	Primary Measurement Channel (PMC)
0x01	PMC1 (pH)
	not available
0x20	PMC6 (temperature)

Figure 2.4.5.1.2: Code for selection of the primary measurement channel.

Command: Available PMC AO1		Modbus address: **4362**	Length: **2**	Type: **3** Read
Parameter:	Available PMC 20 mA			
Format:	hex			
Value:	**0x21**			

Figure 2.4.5.1.3: Example to read the available Primary Measurement Channels (PMC) for AO1. The hexadecimal value of “0x21” defines that PMC1 (pH) or PMC6 (temperature) can be mapped to AO1. Register 4490 contains the same value “0x21”. Accordingly, PMC1 or PMC6 can be mapped to AO2 as well.

2.4.5.2 Selecting the Primary Measurement Channel to be Mapped to the Analog Interface

Start register	Number of registers	Reg1 / Reg2	Modbus function code	Read access	Write access
4364	2	Selected PMC for AO1	3, 4, 16	U/A/S	S
4492	2	Selected PMC for AO2	3, 4, 16	U/A/S	S

Figure 2.4.5.2.1: Definition of register 4364 / 4492. Only one bit can be set.

Command: Active PMC AO1		Modbus address: **4364**	Length: **2**	Type: **3** Read
Parameter:	Current PMC 20mA			
Format:	hex			
Value:	**0x01**			

Figure 2.4.5.2.2: Example to read the current primary measurement channel mapped to AO1, defined in register 4364. The value “0x01” is returned, saying that PMC1 is mapped to AO1 (factory setting).
The factory setting for register 4492 is “0x20”, mapping PMC6 to AO2.

2.4.5.3 Reading the Minimum and Maximum Possible Physical Output Current

Start register	Number of registers	Reg1 / Reg2	Reg3 / Reg4	Modbus function code	Read access	Write access
4366	4	Min physical output current for AO1 [mA]	Max physical output current for AO1 [mA]	3, 4	U/A/S	none
4494	4	Min physical output current for AO2 [mA]	Max physical output current for AO2 [mA]	3, 4	U/A/S	none

Figure 2.4.5.3.1: Definition of register 4366 / 4494

Command: Limits AO1		Modbus address: **4366**	Length: **4**	Type: **3** Read
Parameter:	Min limit [mA]	Max limit [mA]		
Format:	Float	Float		
Value:	**3.5**	**22**		

Figure 2.4.5.3.2: Example to read the min and max output current of AO1. Min is fixed to 3.5 and Max is fixed to 22 mA (Currents above 20 and below 4 mA indicate erroneous measurements or errors).
The same values are stored in register 4494 for AO2.

2.4.5.4 Reading the Minimum, Maximum and Mid Current for Measurement Value Output

Start register	Number of registers	Reg1 / Reg2	Reg3 / Reg4	Reg5 / Reg6	Modbus function code	Read access	Write access
4370	6	Min output for measurement value for AO1 [mA]	Max output for measurement values for AO1 [mA]	Mid output (bilinear) for measurement values for AO1 [mA]	3, 4	U/A/S	none
4498	6	Min output for measurement value for AO2 [mA]	Max output for measurement values for AO2 [mA]	Mid output (bilinear) for measurement values for AO2 [mA]	3, 4	U/A/S	none

Figure 2.4.5.4.1: Definition of register 4370 / 4498

Command: MinMaxMid current AO1		Modbus address: **4370**	Length: **6**	Type: **3** Read
Parameter:	Min current [mA]	Max current [mA]	Mid current [mA]	
Format:	Float	Float	Float	
Value:	**4**	**20**	**12**	

Figure 2.4.5.4.2: Example to read the min, max and mid output current for measurement values for AO1. They are fixed to 4, 20 and 12 mA.
The same values are stored in register 4498 for AO2.

<u>Note:</u>
Mid current must always be defined. However, in linear output mode, the mid current value has no physical meaning and will not affect the 4-20 mA output.

2.4.5.5 Reading the Selected Physical Unit for Analog Interface

Start register	Number of registers	Reg1 / Reg2	Modbus function code	Read access	Write access
4376	2	Selected physical unit of AO1 (see chapter 2.5.1)	3, 4	U/A/S	none
4504	2	Selected physical unit of AO2 (see chapter 2.5.1)	3, 4	U/A/S	none

Figure 2.4.5.5.1: Definition of register 4376 / 4504.

Command: Avail unit AO1		Modbus address: **4376**	Length: **2**	Type: **3** Read
Parameter:	Available unit			
Format:	Hex			
Value:	**0x001000**			

Figure 2.4.5.5.2: Example to read the selected unit of the selected PMC of AO1. The value returned is "0x001000", accordingly, the unit is pH. The physical unit for PMC is defined in Reg. 2090 or 2410 and applies automatically for 4-20 mA output.

2.4.5.6 Defining the Measurement Values for 4, 12 and 20 mA Output

Start register	Number of registers	Reg1 / Reg2	Reg3 / Reg4	Reg5 / Reg6	Modbus function code	Read access	Write access
4378	6	Measurement value at Min Output Current (4 mA) for AO1	Measurement value at Max Output Current (20 mA) for AO1	Measurement value at Mid Output Current (12 mA) for AO1	3, 4, 16	U/A/S	S
4506	6	Measurement value at Min Output Current (4 mA) for AO2	Measurement value at Max Output Current (20 mA) for AO2	Measurement value at Mid Output Current (12 mA) for AO2	3, 4, 16	U/A/S	S

Figure 2.4.5.6.1: Definition of register 4378 / 4506.

Command: MinMaxMid value AO1		Modbus address: **4378**	Length: **6**	Type: **16** Write
Parameter:	Min value	Max value	Mid value	
Format:	Float	Float	Float	
Value:	**3**	**10**	**7**	

Figure 2.4.5.6.2: Example to set the min value to 3 (for 4 mA), the max value to 10 (for 20 mA) and the mid value to 7 (for 12 mA). The corresponding physical unit can be read in register 4376 / 4504 and in 2090 / 2410.

Note:
Mid current must always be defined. However, in linear output mode, the mid current value has no physical meaning and will not affect the 4-20 mA output.

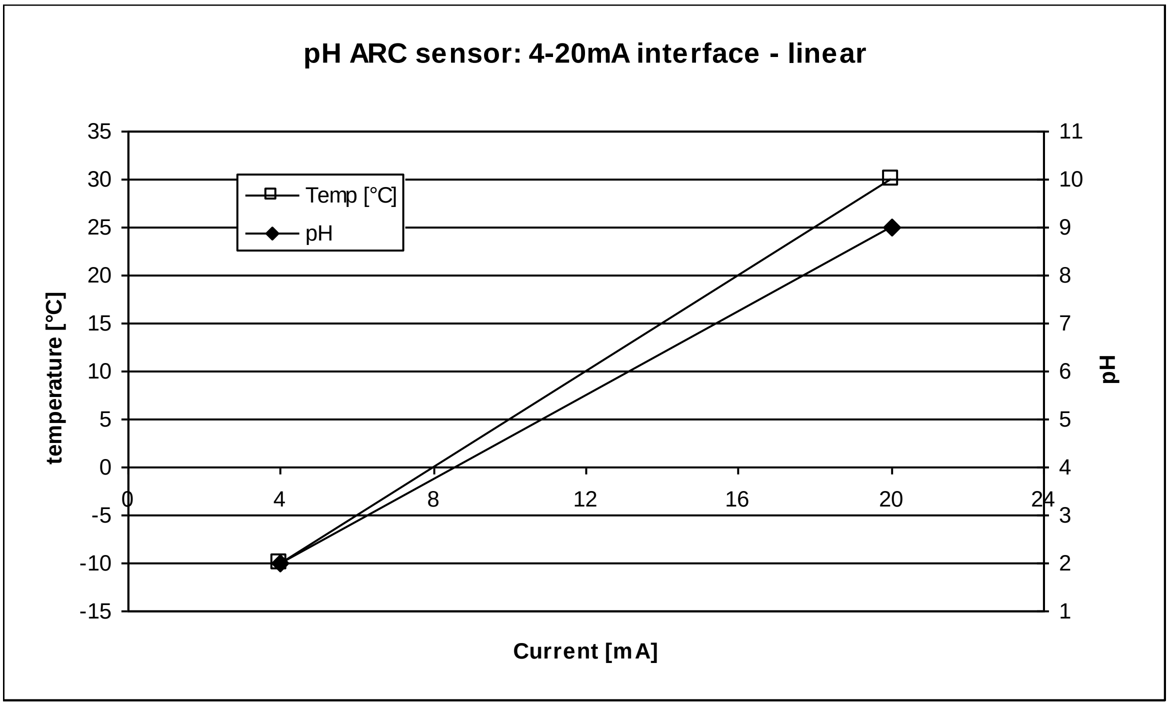


Figure 2.4.5.6.3: Example of linear 4-20 mA output characteristics for pH or temperature.

Current	pH	Temperature	
4 mA	2	-10	°C
20 mA	9	+30	°C

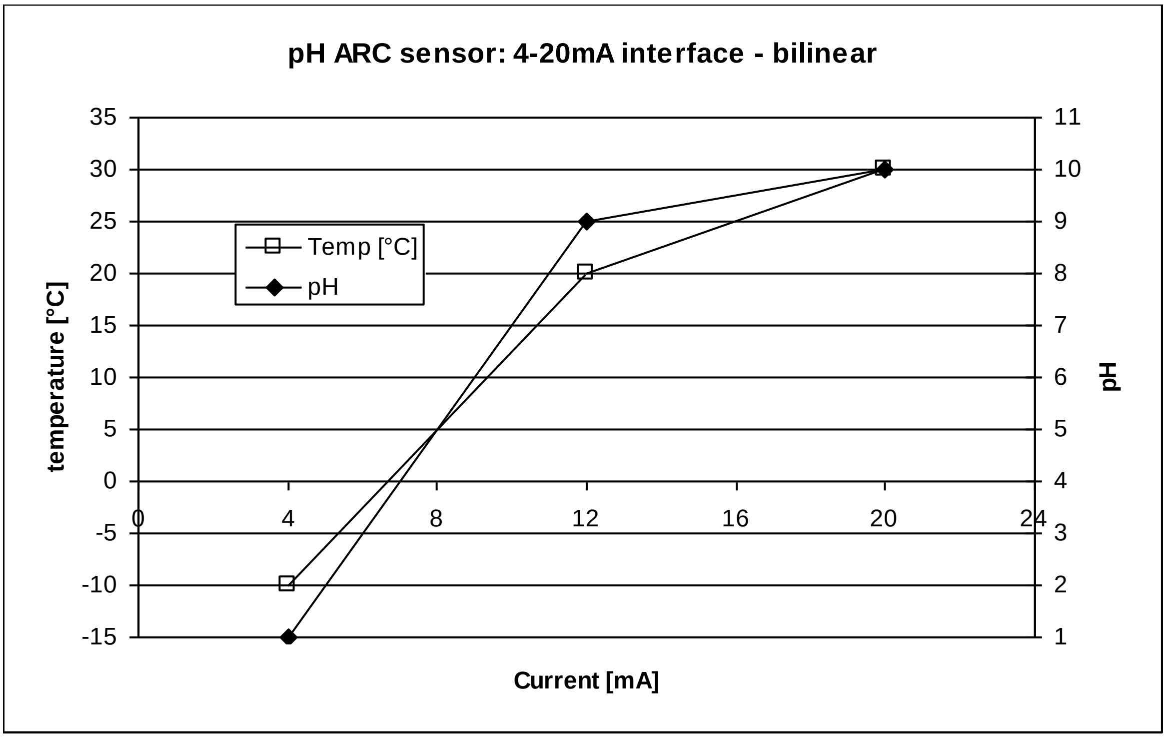


Figure 2.4.5.6.4: Example of bilinear 4-20 mA output characteristics for pH or temperature.

Current	pH	Temperature	
4 mA	2	-10	°C
12 mA	9	+20	°C
20 mA	10	+30	°C

Attention:
When assigning measurement values to 4-20 mA analog output by using register 4378 / 4506, you need to consider the following:

- The PMC you have mapped to AO1 / AO2 (register 4364 / 4492)
- The physical unit currently in use for the selected PMC (register 2090 for PMC1 (pH) and register 2410 for PMC6 (temperature).

Therefore, when the operator redefines one of the register 4364 / 4492, 2090 / 2410, the definitions of the register 4378 / 4506 should be reviewed. If not, the current output at the 4-20 mA interfaces may be wrong.

Note:
The physical unit of the analog output corresponds always to the unit that is set for the selected PMC (register 2090 for PMC1 or register 2410 for PMC6). Accordingly, not only the pH value is selectable at the 4-20 mA interface, but also mV values, degrees centigrade or Kelvin.

Example:
Register 4364 is set to 1 (PMC1 is mapped to AO1).
Register 2090 is set to 0x1000 (the unit "pH" is assigned to PMC1).
Register 4378 is set to 2 and 10 (4 mA = pH 2, 20 mA = pH 10).
The sensor reads currently pH 4, the output at the 4-20 mA is accordingly 8 mA.
The operator now re-assigns register 2090 to the value of 0x200000 (unit = mV), but does not modify all other registers. The sensor is still at pH 4 and reads now +170 mV. At the analog output, as 20 mA is programmed to a value of 10 by register 4378, the current will go to the maximum value of 20 mA. This will generate an interface warning "4-20 mA current set point not met".

2.4.5.7 Defining a Constant Current Output for Testing

Note:
For constant current output, the AO1 / AO2 must be set to analog interface mode 0x01:

Start register	Number of registers	Reg1 / Reg2	Modbus function code	Read access	Write access
4384	2	Constant current output value for AO1 [mA]	3, 4, 16	U/A/S	S
4512	2	Constant current output value for AO2 [mA]	3, 4, 16	U/A/S	S

Figure 2.4.5.7.1: Definition of register 4384 / 4512.

Command: Fixed value AO1		Modbus address: **4384**	Length: **2**	Type: **3** Read
Parameter:	Fixed value [mA]			
Format:	Float			
Value:	**10**			

Figure 2.4.5.7.2: Example to read the constant current output in mode 0x01 for AO1. It is set to 10 mA.

2.4.5.8 Defining the Error and Warning Output of the 4-20 mA Interface

Errors and warnings can be mapped to the AO1 / AO2.

Start register	Number of registers	Reg1 / Reg2	Reg3 / Reg4	Reg5 / Reg6	Reg7 / Reg8	Modbus function code	Read access	Write access
4386	8	Code of warnings and errors (see Figure 2.4.5.8.2) for AO1	Current in case of "warning" [mA] for AO1	Current in case of "error" [mA] for AO1	Current in case of "T exceed" [mA] for AO1	3, 4, 16	U/A/S	S
4514	8	Code of warnings and errors (see Figure 2.4.5.8.2) for AO2	Current in case of "warning" [mA] for AO2	Current in case of "error" [mA] for AO2	Current in case of "T exceed" [mA] for AO2	3, 4, 16	U/A/S	S

Figure 2.4.5.8.1: Definition of register 4386 / 4514.

Bit #	Code (hex)	Behavior of the 4-20 mA interface in case of errors and warnings
0 (LSB)	0x000001	Error continuous output
		not available
16	0x010000	Warning continuous output
		not available

Figure 2.4.5.8.2: Code for the 4-20 mA interface in case of errors and warnings.

If the corresponding bits for the errors and warnings are not set (=0x00), the respective options are inactive.

The default settings are:

- Code 0x01
- current in case of warnings: 3.5 mA
- current in case of errors: 3.5 mA
- current in case of temperature exceed: 3.5 mA

Command: ErrorWarnings AO1	Modbus address: **4386**	Length: **8**	Type: **3**	Read
Parameter:	Warning code	Current in case of warning [mA]	Current in case of error [mA]	Current in case of temperature exceed [mA]
Format:	Hex	Float	Float	Float
Value:	**0x010001**	**3.5**	**3.5**	**3.5**

Figure 2.4.5.8.3: Example: Read the settings for AO1 in case of warnings and errors. Warning code 0x010001 corresponds to the continuous output current in case of warning (0x010000) and continuous output current in case of error (0x01) of 3.5 mA. The output current in case of temperature exceed is 3.5 mA.

2.4.6 Reading the Internally Measured Output Current

Reg. 4414 / 4542 provides internal parameters of AO1 / AO2:

- the setpoint to which the current is regulated in a closed loop control
- the electrical current the sensor is measuring to feed the closed loop control

These values are helpful in order to compare against the externally measured electrical current.

Start register	Number of registers	Reg1 / Reg2	Reg3 / Reg4	Modbus function code	Read access	Write access
4414	4	Set point [mA] AO1	Internally measured [mA] AO1	3, 4	U/A/S	none
4542	4	Set point [mA] AO2	Internally measured [mA] AO2	3, 4	U/A/S	none

Figure 2.4.6.1: Definition of register 4414 / 4542.

Command: Internal values AO1	Modbus address: **4414**	Length: **4**	Type: **3**	Read
Parameter:	Set point [mA]	Internally measured [mA]		
Format:	Float	Float		
Value:	**9.99186**	**9.99742**		

Figure 2.4.6.2: Example to read the internal values of AO1, depending on the analog interface mode.

2.5 Measurement

2.5.1 Definition of Measurement Channels and Physical Units

The pH Arc Sensor Modbus register structure allows the definition of 6 individual Primary Measurement Channels (PMC), and 16 individual Secondary Measurement Channels (SMC).

Bit #	Hex code	Description	Definition
0 (LSB)	**0x000001**	**PMC1**	**pH**
1	0x000002	PMC2	not available
			not available
4	0x000010	PMC5	not available
5	**0x000020**	**PMC6**	**Temperature**
6	**0x000040**	**SMC1**	**R glass**
7	**0x000080**	**SMC2**	**R reference**
8	**0x000100**	**SMC3**	**R auxiliary**
9	**0x000200**	**SMC4**	**E pH vs. ref**
10	**0x000400**	**SMC5**	**E SG vs. ref**
11	**0x000800**	**SMC6**	**E aux vs. ref**
12	**0x001000**	**SMC7**	**E reference**
13	**0x002000**	**SMC8**	**pH act**
14	**0x004000**	**SMC9**	**T act**
15	0x008000	SMC10	not available
		…	
21 (MSB)	0x200000	SMC16	not available

Figure 2.5.1.1: full list of PMC1 to 6 and SMC1 to 16.

In Register 2048, the available PMC and SMC are defined for a specific pH Arc Sensors and a specific operator level.

Start register	Number of registers	Reg1 / Reg2	Modbus function code	Read access	Write access
2048	2	Available measurement channels PMC and SMC (bitwise set)	3, 4	U/A/S	none

Figure 2.5.1.2: Definition of register 2048.

Command: Avail. PMC and SMC		Modbus address: **2048**	Length: **2**	Type: **3** Read
Parameter:	Avail. PMC and SMC			
Format:	Hex			
Value:	0x0261			

Figure 2.5.1.3: Example to read Reg. 2048 for Polilyte Plus Arc.

In case of operator A/U, the value 0x0261 is returned. In other words the following PMC and SMC are available to A/U: PMC1 / PMC6 / SMC1 / SMC4

In case of operator S, the value 0x06261 is returned. In other words the following PMC and SMC are available to S: PMC1 / PMC6 / SMC1 / SMC4 / SMC8 / SMC9

The pH Arc Sensor register structure uses the following physical units used for Primary or Secondary Measurement Channels.

Bit #	Hex code	Physical unit	Start register. (8 ASCII characters, length 4 registers, Type 3, read for U/A/S)
0 (LSB)	0x00000001	none	1920
1	0x00000002	K	1924
2	0x00000004	°C	1928
3	0x00000008	°F	1932
4	0x00000010	%-vol	1936
5	0x00000020	%-sat	1940
6	0x00000040	ug/l ppb	1944
7	0x00000080	mg/l ppm	1948
8	0x00000100	g/l	1952
9	0x00000200	uS/cm	1956
10	0x00000400	mS/cm	1960
11	0x00000800	1/cm	1964
12	0x00001000	pH	1968
13	0x00002000	mV/pH	1972
14	0x00004000	kOhm	1976
15	0x00008000	MOhm	1980
16	0x00010000	pA	1984
17	0x00020000	nA	1988
18	0x00040000	uA	1992
19	0x00080000	mA	1996
20	0x00100000	uV	2000
21	0x00200000	mV	2004
22	0x00400000	V	2008
23	0x00800000	mbar	2012
24	0x01000000	Pa	2016
25	0x02000000	Ohm	2020
26	0x04000000	%/°C	2024
27	0x08000000	°	2028
28	0x10000000	not used	2032
29	0x20000000	not used	2036
30	0x40000000	not used	2040
31 (MSB)	0x80000000	SPECIAL	2044

Figure 2.5.1.4: Definition of physical units used for PMC and SMC.

Command: Unit text		Modbus address: **1968**	Length: **4**	Type: **3** Read
Parameter:	Text			
Format:	Character			
Value:	**pH**			

Figure 2.5.1.5: Example to read the physical unit in plain text ASCII in register 1968

2.5.2 Primary Measurement Channel 1 (pH)

2.5.2.1 Description of PMC1

In register 2080, a plain text ASCII description of PMC1 is given.

Start register	Number of registers	Reg1 to Reg8 16 ASCII characters	Modbus function code	Read access	Write access
2080	8	Description of PMC1	3, 4	U/A/S	none

Figure 2.5.2.1.1: Definition of register 2080.

Command: PMC 1 text		Modbus address: **2080**	Length: **8**	Type: **3** Read
Parameter:	Text			
Format:	Character			
Value:	**pH**			

Figure 2.5.2.1.2: Example to read the description. It is "pH".

2.5.2.2 Selecting the Physical Unit for PMC1

In register 2088, the available physical units for this channel are defined.

Start register	Number of registers	Reg1 / Reg2 (bitwise defined)	Modbus function code	Read access	Write access
2088	2	Available physical units of PMC1	3, 4	U/A/S	none

Figure 2.5.2.2.1: Definition of register 2088.

Command: PMC1 available units		Modbus address: **2088**	Length: **2**	Type: **3** Read
Parameter:	Units			
Format:	Hex			
Value:	**0x201000**			

Figure 2.5.2.2.2: Example to read the available physical units of PMC1: pH (0x001000) + mV (0x200000), total 0x201000.

In register 2090, the active physical unit for this channel can be selected, by choosing one of the physical units that are defined in register 2088.

Start register	Number of registers	Reg1 / Reg2 (bitwise defined)	Modbus function code	Read access	Write access
2090	2	Selected active physical unit for the PMC1	16	none	S

Figure 2.5.2.2.3: Definition of register 2090. Only one bit can be set.

Command: PMC1 set unit		Modbus address: **2090**	Length: **2**	Type: **16** Write
Parameter:	Unit			
Format:	Hex			
Value:	**0x1000**			

Figure 2.5.2.2.4: Example to set the physical unit of PMC1 to pH (0x1000).

⚠ Attention:
Changing the physical unit has also an influence on the output of AO1 / AO2, as the same physical unit is active for the analog outputs. All limits of the 4-20 mA analog output have to be redefined after changing the physical unit!

2.5.2.3 Reading the measurement value of PMC1

Register 2090 is also used to read the measurement values of PMC1.

Start reg.	Num-ber of reg.	Reg1 / Reg2	Reg3 / Reg4	Reg5 / Reg6	Reg7 / Reg8	Reg9 / Reg10	Modbus function code	Read access	Write access
2090	10	Selected physical unit	Measure -ment value of PMC1 (1)	Measure -ment status (2)	Min allowed value (1)	Max allowed value (1)	3, 4	U/A/S	none

Figure 2.5.2.3.1: Definition of register 2090. Measurement value of PMC1.

(1) Value is always in the physical unit defined in register 2090.

(2) Definition of the status see chapter 2.5.4. All bits set to zero means: no problem.

Command: PMC1 read			Modbus address: **2090**	Length: **10**	Type: **3** Read
Parameter:	Unit	Value	Status	Min limit	Max limit
Format:	Hex	Float	Hex	Float	Float
Value:	**0x1000**	**4.02503**	**0x00**	**0**	**14**

Figure 2.5.2.3.2: Example to read register 2090. Physical unit is set to pH (0x1000), PMC1 is pH 4.02503, Status is 0x00, Min allowed value is pH 0, Max allowed value is pH 14.

Command: PMC1 read			Modbus address: **2090**	Length: **10**	Type: **3** Read
Parameter:	Unit	Value	Status	Min limit	Max limit
Format:	Hex	Float	Hex	Float	Float
Value:	**0x200000**	**175.9922**	**0x00**	**0**	**954.6541**

Figure 2.5.2.3.3: Example to read register 2090. Physical unit is set to mV (0x200000), PMC1 is 175.9922 mV, Status is 0x00, Min allowed value is -414.0028 mV, Max allowed value is 414.0028 mV.

For the definition of the measurement status see chapter 2.5.4.

⚠ Attention:

You cannot read selectively the registers 3 and 4 for the measurement value only. You have to read the entire length of the command (10 registers) and extract the desired information.

2.5.3 Primary Measurement Channel 6 (Temperature)

2.5.3.1 Description of PMC6

In register 2400, a plain text ASCII description of PMC6 is given

Start register	Number of registers	Reg1 to Reg8 16 ASCII characters	Modbus function code	Read access	Write access
2400	8	Description of PMC6	3, 4	U/A/S	none

Figure 2.5.3.1.1: Definition of register 2400.

Command: PMC6 text	Modbus address: **2400**	Length: **8**	Type: **3**	Read
Parameter:	Text			
Format:	Character			
Value:	**T**			

Figure 2.5.3.1.2: Example to read the description. It is "T" (Temperature).

2.5.3.2 Selecting the Physical Unit for PMC6

In register 2408, the available physical units of PMC6 are defined.

Start register	Number of registers	Reg1 / Reg2 (bitwise defined)	Modbus function code	Read access	Write access
2408	2	Available physical units of PMC6	3, 4	U/A/S	none

Figure 2.5.3.2.1: Definition of register 2408.

Command: PMC6 available units	Modbus address: **2408**	Length: **2**	Type: **3**	Read
Parameter:	Units			
Format:	Hex			
Value:	**0x0E**			

Figure 2.5.3.2.2: Example to read the available physical unit for PMC6. K (0x02), °C (0x04), °F (0x08), total 0x0E.

In register 2410, the active physical unit of PMC6 can be selected, by choosing one of the physical units that are defined in register 2408.

Start register	Number of registers	Reg1 / Reg2 (bitwise defined)	Modbus function code	Read access	Write access
2410	2	Selected active physical unit of PMC6	16	none	U/A/S

Figure 2.5.3.2.3: Definition of register 2410. Only one bit can be set.

Command: PMC6 set unit	Modbus address: **2410**	Length: **2**	Type: **16**	Write
Parameter:	Unit			
Format:	Hex			
Value:	**0x04**			

Figure 2.5.3.2.4: Example to set the physical unit of PMC6 to °C (0x04).

⚠ Attention:

Changing the physical unit has also an influence on the output of AO1 / AO2, as the same physical unit is active for the analog outputs. All limits of the 4-20 mA analog output have to be redefined after changing the physical unit!

2.5.3.3 Reading the measurement value of PMC6

Register 2410 is also used to read the measurement values of PMC6.

Start reg.	Num-ber of reg.	Reg1 / Reg2	Reg3 / Reg4	Reg5 / Reg6	Reg7 / Reg8	Reg9 / Reg10	Modbus function code	Read access	Write access
2410	10	Selected physical unit	Measure-ment value of PMC6 (1)	Measure-ment status (2)	Min allowed value (1)	Max allowed value (1)	3, 4	U/A/S	none

Figure 2.5.3.3.1: Definition of register 2410. Measurement value of PMC6.

(1) Value is always in the physical unit defined in register 2410.

(2) For definition of the status see chapter 2.5.4. All bits set to zero means: no problem.

Command: PMC6 read		Modbus address: **2410**		Length: **10**	Type: **3** Read
Parameter:	Unit	Value	Status	Min limit	Max limit
Format:	Hex	Float	Hex	Float	Float
Value:	**0x04**	**24.35834**	**0x00**	**-20**	**130**

Figure 2.5.3.3.2: Example to read register 2410. Physical unit is set to °C (0x04), PMC6 is 24.35834 °C, Status is 0x00, Min allowed value is -20 °C, Max allowed value is 130 °C.

For definition of the measurement status see chapter 2.5.4.

Attention:

You cannot read selectively the registers 3 and 4 for the measurement value only. You have to read the entire length of the command (10 registers) and extract the desired information.

2.5.3.4 Input of an Externally Measured Temperature

Unlike to the VisiFerm DO, this feature is not available for pH Arc Sensors.

2.5.4 Definition of the Measurement Status for PMC1 / PMC6

This is the definition of the status registers read in registers 2090 (PMC1) and 2410 (PMC6):

Bit #	Hex code	Description
0 (LSB)	0x01	Temperature out of measurement range (see chapter 2.8.1)
1	0x02	Temperature out of operating range (see chapter 2.8.1)
2	0x04	Calibration status not zero (see chapter 2.7.4)
3	0x08	Warning not zero (see chapter 2.8.3)
4	0x10	Error not zero (see chapter 2.8.4)

Figure 2.5.4.1: Definition of measurement status for Primary Measurement Channels.

2.5.5 Secondary Measurement Channels 1-16

pH Arc Sensors do allow access to secondary measurement values (16 in total). The access to the individual SMC depends on the operator level. The available SMC are defined in register 2048 according to the selected operator level and the sensor type (see chapter 2.5.1).

2.5.5.1 Description of SMC

The registers defined here give a plain text ASCII description of each available SMC.

Start register	Number of registers	Reg1 to Reg8 16 ASCII characters	Modbus function code	Read access	Write access
Address	8	Description of each SMC	3, 4	U/A/S	none

Figure 2.5.5.1.1: Definition of registers at Address

Description	Address	Plain Text (16 ASCII)	Description
SMC1	2464	R glass	Resistance of the pH glass
SMC2	2496	R reference	Resistance of the reference electrode
SMC3	2528	R auxiliary	Resistance of the auxiliary electrode
SMC4	2560	E pH vs. ref	Electrical potential between glass and reference electrode
SMC5	2592	E SG vs. ref	Electrical potential between solution ground and reference electrode
SMC6	2624	E aux vs. ref	Electrical potential between auxiliary electrode and reference electrode
SMC7	2656	E reference	Electrical potential between reference electrode and electrical ground
SMC8	2688	pH act	Current pH value (3-seconds-reading)
SMC9	2720	T act	Current T value (3-seconds-reading)

Figure 2.5.5.1.2: Full list of starting register addresses for the plain text ASCII description of each SMC

Example:

Command: SMC 1 text		Modbus address: **2464**	Length: **8**	Type: **3** Read
Parameter:	Text			
Format:	Character			
Value:	**R glass**			

Figure 2.5.5.1.3: Example to read the description of SMC1 at address 2464. It is "R glass".

2.5.5.2 Reading the measurement value of SMC

The registers defined here are used to read the measurement values of each SMC.

Start reg.	Number of reg.	Reg1 / Reg2	Reg3 / Reg4	Reg5 / Reg6	Modbus function code	Read access	Write access
Address	6	Physical unit	Measurement value of SMC	Standard deviation	3, 4	U/A/S	none

Figure 2.5.5.2.1: Definition of register at Address. Measurement value of each SMC.

Description	Address	Text	Unit	Min value	Max value
SMC1	2472	R glass	MOhm	30	600
SMC2	2504	R reference	kOhm	0.25	100
SMC3	2536	R auxiliary	kOhm	0.25	100
SMC4	2568	E pH vs. ref	mV	-900	900
SMC5	2600	E SG vs. ref	mV	-900	900
SMC6	2632	E aux vs. ref	mV	-50	50
SMC7	2664	E reference	mV	-900	900
SMC8	2696	pH act	pH	-0.5	14
SMC9	2728	T act	K	253	403

Figure 2.5.5.2.2: Full list of register addresses for the measurement values of SMC1 to SMC9

Example:

Command: SMC1 read		Modbus address: **2472**	Length: **6**	Type: **3**	Read
Parameter:	Unit	Value	Standard dev.		
Format:	Hex	Float	Float		
Value:	**0x8000**	**247.56**	**0.02**		

Figure 2.5.5.2.3: Example to read register 2472. Physical unit is MOhm (0x8000), the measurement value of SMC1 is 247.66 MOhm, standard deviation of SMC1 is 0.02 MOhm.

2.6 Configuration of the Measurement

This chapter describes the configuration of PMC1 and PMC6 by means of measurement parameters (PA).

2.6.1 Available Parameters

In register 3072, all available parameters (PA) are given.

Start register	Number of registers	Reg1 / Reg2 (bitwise defined)	Modbus function code	Read access	Write access
3072	2	Available parameters (see Figure 2.6.1.2)	3, 4	U/A/S	none

Figure 2.6.1.1: Definition of register 3072.

Bit #	Hex value	Description	Definition in pH Arc Sensors
0 (LSB)	0x0001	PA1	not available
			not available
7	0x0080	PA8	not available
8	**0x0100**	**PA9**	**Moving average**
9	0x0200	PA10	not available
10	0x0400	PA11	not available
11	**0x0800**	**PA12**	**Moving average R**
			not available
15 (MSB)	0x8000	PA16	not available

Figure 2.6.1.2: Bitwise definition of parameters PA1 to PA16, valid for pH Arc Sensors

Command: Available parameters		Modbus address: **3072**	Length: **2**	Type: **3** Read
Parameter:	Measurement parameters			
Format:	Hex			
Value:	**0x0900**			

Figure 2.6.1.3: Example to read the available parameters. The value 0x0900 corresponds to 0x0100 (PA9) + 0x0800 (PA12). Parameter 9 and 12 are available.

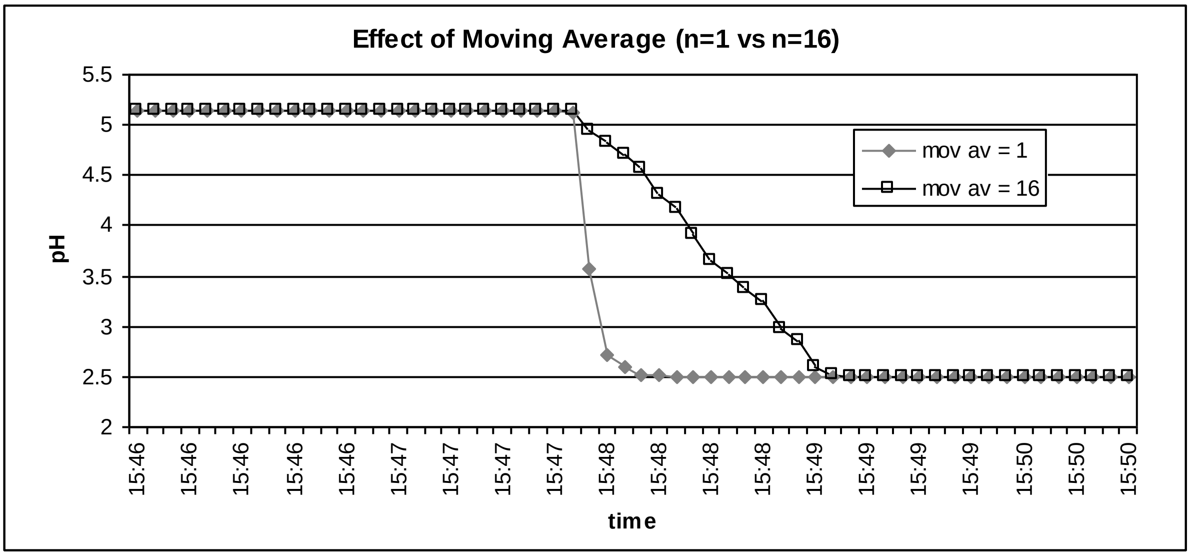
General note:

- PA1 to PA8 use FLOAT as data format for its values
- PA9 to PA16 use UNSIGNED INT as data format for its values.

2.6.2 PA9: Moving Average

The pH Arc Sensor provides new pH readings every 3 seconds. One has the possibility to smoothen the pH reading (PMC1) by means of a moving average applied to the 3-seconds-readings.

PA9 can be applied on 1 to 16 3-seconds-readings. The default value is 2.



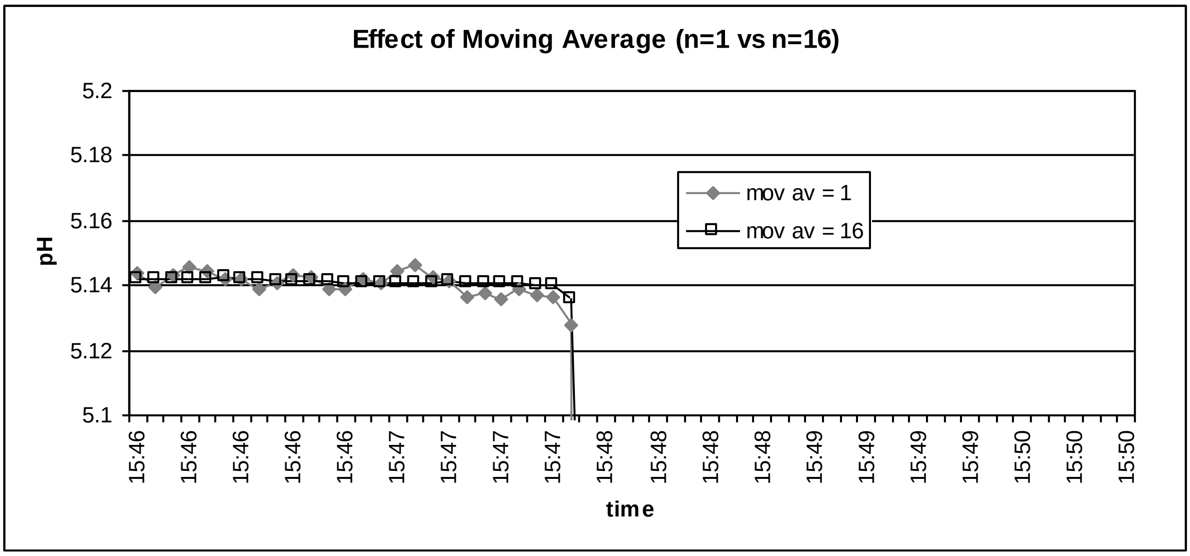


Figure 2.6.2.1: Comparison of the response of a pH Arc Sensor to a change from pH 5.1 to pH 2.5, using no moving average (n=1) or a moving average over 16 3-seconds-readings.

Using moving average, the short term signal stability can be improved; on the other hand, the response time of the sensor increases with increasing moving average. A moving average over 16 samples results in a response time of at least 48 s.

Note:

- PA9 is applied to both PMC1 and PMC6.

2.6.2.1 Description of PA9 (Moving Average)

In register 3360, a plain text ASCII description of PA9 is given.

Start register	Number of registers	Reg1 to Reg8 16 ASCII characters	Modbus function code	Read access	Write access
3360	8	Description of PA9	3, 4	U/A/S	none

Figure 2.6.2.1.1: Definition of register 3360.

Command: Moving average text		Modbus address: **3360**	Length: **8**	Type: **3** Read
Parameter:	Text			
Format:	Character			
Value:	**Moving average**			

Figure 2.6.2.1.2: Example to read the description for "Moving average".

2.6.2.2 Selecting the Physical Unit and Writing the Value for PA9

In register 3368, the available physical units for PA9 are defined.

Start register	Number of registers	Reg1 / Reg2 (bitwise defined)	Modbus function code	Read access	Write access
3368	2	Available physical units for PA9	3, 4	U/A/S	none

Figure 2.6.2.2.1: Definition of register 3368.

Command: Moving average av. units		Modbus address: **3368**	Length: **2**	Type: **3** Read
Parameter:	Units			
Format:	Hex			
Value:	**0x01**			

Figure 2.6.2.2.2: Example to read the available physical units for PA9. The only one available here is "none" (0x01). For the definition of the physical units see chapter 2.5.1.

Start register	Number of registers	Reg1 / Reg2 (bitwise defined)	Reg3 / Reg4	Modbus function code	Read access	Write access
3370	4	Select physical unit for PA9	Value for PA9 (1-16, default: 2)	16	none	S

Figure 2.6.2.2.3: Definition of register 3370. Only one bit for the physical unit can be set. PA9 can be set to the value 1-16. A value of 1 does not influence the response time of the sensor, a value of 16 increases the response time of the sensor to 48 s.

By writing to register 3370 the active physical unit for PA9 can be selected by choosing one of the physical units that are defined in register 3368. The value of the parameter can be set as well.

Command: Moving average		Modbus address: **3370**	Length: **4**	Type: **16** Write
Parameter:	Unit	Value		
Format:	Hex	Decimal		
Value:	**0x01**	**12**		

Figure 2.6.2.2.4: Example to set the physical unit of PA9 to "none" (0x01) and the value of the moving average to 12.

2.6.2.3 Reading all Values for PA9

By reading register 3370, the active physical unit of measurement, the selected value, and the min and max values can be read.

Start register	Number of registers	Reg1 / Reg2	Reg3 / Reg4	Reg5 / Reg6	Reg7 / Reg8	Modbus function code	Read access	Write access
3370	8	Physical unit	Current value	Min value	Max value	3, 4	U/A/S	none

Figure 2.6.2.3.1: Definition of register 3370.

Command: Moving average	Modbus address: **3370**	Length: **8**	Type: **3**	Read
Parameter:	Unit	Value	Min value	Max value
Format:	Hex	Decimal	Decimal	Decimal
Value:	**0x01**	**10**	**1**	**16**

Figure 2.6.2.3.2: Example to read PA9. The physical unit is 0x01 ("none"), the value is 10 and the limit is 1 to 16.

2.6.3 PA12: Moving Average R

pH Arc Sensors allow to have a separate moving average on secondary measurement values:

- Glass resistance
- Reference resistance
- Auxiliary resistance

The moving average can be applied on 1 to 16 3-s measurement values. The default value is 4. Especially if high resistances are measured, it is recommended to choose a higher moving average.

2.6.3.1 Description of PA12 (Moving Average R)

In register 3456, a plain text ASCII description of PA12 is given.

Start register	Number of registers	Reg1 to Reg8 16 ASCII characters	Modbus function code	Read access	Write access
3456	8	Description of PA12	3, 4	U/A/S	none

Figure 2.6.3.1.1: Definition of register 3456.

Command: Moving average text	Modbus address: **3456**	Length: **8**	Type: **3**	Read
Parameter:	Text			
Format:	Character			
Value:	**Moving average R**			

Figure 2.6.3.1.2: Example to read the description for "Moving average R".

2.6.3.2 Selecting the Physical Unit and Writing the Value for PA12

In register 3464, the available physical units for PA12 are defined.

Start register	Number of registers	Reg1 / Reg2 (bitwise defined)	Modbus function code	Read access	Write access
3464	2	Available physical units for PA12	3, 4	U/A/S	none

Figure 2.6.3.2.1: Definition of register 3368.

Command: Moving average av. units	Modbus address: **3464**	Length: **2**	Type: **3**	Read
Parameter:	Units			
Format:	Hex			
Value:	**0x01**			

Figure 2.6.3.2.2: Example to read the available physical units for PA12. The only one available here is "none" (0x01). For the definition of the physical units see chapter 2.5.1.

Start register	Number of registers	Reg1 / Reg2 (bitwise defined)	Reg3 / Reg4	Modbus function code	Read access	Write access
3466	4	Select physical unit for PA12	Value for PA12 (1-16, default: 4)	16	none	S

Figure 2.6.3.2.3: Definition of register 3466. Only one bit for the physical unit can be set. PA12 can be set to the values 1-16.

By writing to register 3466, the active physical unit for PA12 can be selected, by choosing one of the physical units that are defined in register 3464. The value of the parameter can be set as well.

Command: Moving average		Modbus address: **3466** Length: **4**	Type: **16**	Write
Parameter:	Unit	Value		
Format:	Hex	Decimal		
Value:	**0x01**	**7**		

Figure 2.6.3.2.4: Example to set the physical unit of PA12 to "none" (0x01) and the value of the moving average R to 7.

2.6.3.3 Reading all Values for PA12

By reading register 3466, the active physical unit of measurement, the selected value, and the min and max values can be read.

Start register	Number of registers	Reg1 / Reg2	Reg3 / Reg4	Reg5 / Reg6	Reg7 / Reg8	Modbus function code	Read access	Write access
3466	8	Physical unit	Current value	Min value	Max value	3, 4	U/A/S	none

Figure 2.6.3.3.1: Definition of register 3466.

Command: Moving average		Modbus address: **3466** Length: **8**	Type: **3**	Read
Parameter:	Unit	Value	Min value	Max value
Format:	Hex	Decimal	Decimal	Decimal
Value:	**0x01**	**7**	**1**	**16**

Figure 2.6.3.3.2: Example to read PA12. The physical unit is 0x01 ("none"), the value is 7, and the limits are 1 to 16.

2.7 Calibration

2.7.1 Available Calibration Points

In register 5120, the available number of Calibration Points (CP) for Primary Measurement Channel 1 (PMC1) is defined. 8 individual CP are theoretically possible.

Start register	Number of registers	Reg1 / Reg2 (bitwise defined)	Modbus function code	Read access	Write access
5120	2	Available number of CP for PMC1 (see Figure 2.7.1.2)	3, 4	U/A/S	none

Figure 2.7.1.1: Definition of register 5120.

Bit #	Hex value	Description	Definition in Arc Sensors
0 (LSB)	**0x01**	**CP1**	**Calibration Point 1**
1	**0x02**	**CP2**	**Calibration Point 2**
2	0x04	CP3	not available
…	…	…	not available
5	**0x20**	**CP6**	**Product Calibration**
6	0x40	CP7	not available
7 (MSB)	0x80	CP8	not available

Figure 2.7.1.2: Bitwise definition of CP1 to CP8.

Command: Available cali points	Modbus address: **5120**	Length: **2**	Type: **3**	Read
Parameter:	Points			
Format:	Hex			
Value:	**0x23**			

Figure 2.7.1.3: Example to read the available CPs. 0x23 = 0x01 (CP1) + 0x02 (CP2) + 0x20 (CP6).

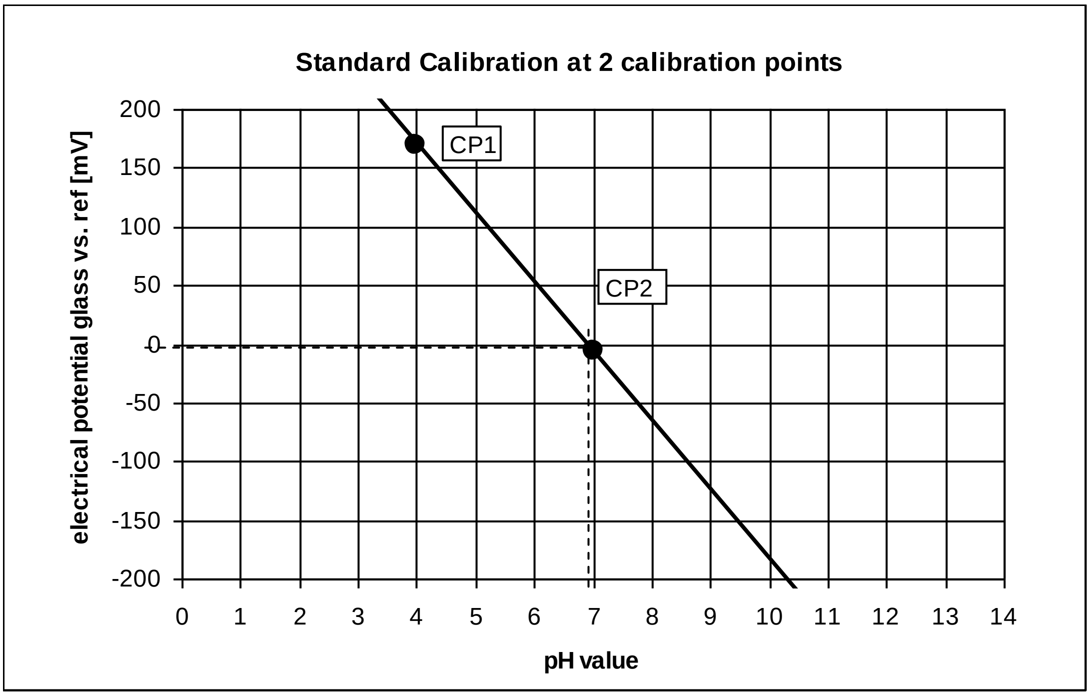


Figure 2.7.1.4: pH Arc Sensors allow 3 calibration points:

CP1 and CP2 are used for standard calibration (shown in this figure).

The product calibration CP6 is used to adjust the standard calibration function to specific process conditions (the effect of CP6 is shown in Figure 2.7.3.2.1).

2.7.2 Definitions of Calibration Points

2.7.2.1 Calibration Points 1 and 2 (Standard Calibration)

The limits for the calibration point 1 are defined in register 5152, for calibration point 2 in register 5184.

Start register	Number of registers	Reg1 / Reg2	Reg3 / Reg4	Reg5 / Reg6	Modbus function code	Read access	Write access
5152	6	Physical unit currently active for CP1	Min value for CP1 (in the physical unit as defined in Reg1 and 2)	Max value for CP1 (in the physical unit as defined in Reg1 and 2)	3, 4	U/A/S	none
5184	6	Physical unit currently active for CP2	Min value for CP2 (in the physical unit as defined in Reg1 and 2)	Max value for CP2 (in the physical unit as defined in Reg1 and 2)	3, 4	U/A/S	none

Figure 2.7.2.1.1: Definition of register 5152 for CP1 and 5184 for CP2.

Attention:
The only physical unit available for calibration is pH ! The physical unit defined in 5152, 5184 and 5312 for CP1, CP2 and CP6 is NOT linked to the physical unit defined for PMC1 in register 2090.
When performing a calibration while having the physical unit set to "mV", the calibration status will report "CP1: incorrect measurement unit" or "CP2: incorrect measurement unit" (see Figure 2.7.4.1.1).

Command: Calibration limits CP1	Modbus address: **5152**	Length: **6**	Type: **3**	Read
Parameter:	Unit	Min value	Max value	
Format:	Hex	Float	Float	
Value:	**0x01000**	**0**	**0**	

Figure 2.7.2.1.2: Example to read the limits of CP1. Currently active physical unit is pH (0x01000). The min and max values are both 0, indicating, that calibration at CP1 can be performed only using defined calibration standards having discrete pH values.

Command: Calibration limits CP2	Modbus address: **5184**	Length: **6**	Type: **3**	Read
Parameter:	Unit	Min value	Max value	
Format:	Hex	Float	Float	
Value:	**0x01000**	**0**	**0**	

Figure 2.7.2.1.3: Example to read the limits of CP2. The active physical unit is pH (0x01000). The min and max values are both 0, indicating, that calibration at CP2 can be performed only using defined calibration standards having discrete pH values.

When initiating the calibration at CP1 and CP2, the measured pH and temperature have to be stable for at least 3 minutes. The stability criteria are defined in register 5128:

Start register	Number of registers	Reg1 / Reg2 (Float)	Reg3 / Reg4 (Float)	Modbus function code	Read access	Write access
5128	4	Max. Drift PMC1 pH [pH/min]	Max. Drift PMC6 Temperature [K/min]	3, 4, 16	U/A/S	S

Figure 2.7.2.1.4: Definition of register 5128.

Command: Read calibration stability		Modbus address: **5128**	Length: **4**	Type: **3** Read
Parameter:	Max drift pH [pH/min]	Max drift Temp [K/min]		
Format:	Float	Float		
Value:	**0.1**	**0.5**		

Figure 2.7.2.1.5: Example to read the calibration stability.

Command: Set calibration stability		Modbus address: **5128**	Length: **4**	Type: **16** Write
Parameter:	Max drift pH [pH/min]	Max drift Temp [K/min]		
Format:	Float	Float		
Value:	**0.2**	**0.5**		

Figure 2.7.2.1.6: Example to set the calibration stability.

Attention:
The stability criteria defined in register 5128 is valid for CP1 and CP2 only, but NOT for CP6.

2.7.2.2 Calibration Point 6 (Product Calibration)

The limits for calibration point 6 are given in register 5312.

Start register	Number of registers	Reg1 / Reg2	Reg3 / Reg4	Reg5 / Reg6	Modbus function code	Read access	Write access
5312	6	Physical unit currently active for CP6	Min value for CP6 (in the physical unit as defined in Reg1 and 2)	Max value for CP6 (in the physical unit as defined in Reg1 and 2)	3, 4	U/A/S	none

Figure 2.7.2.2.1: Definition of register 5312 for CP6.

Command: Calibration limits CP6		Modbus address: **5312**	Length: **6**	Type: **3** Read
Parameter:	Unit	Min value	Max value	
Format:	Hex	Float	Float	
Value:	**0x01000**	**0**	**14**	

Figure 2.7.2.2.2: Example to read the limits of CP6. The active physical unit is pH, the min value is pH 0 and the max value is pH 14.
Note: the definition of min and max is different than the one for CP1 / CP2, because CP6 can be set to any pH value.

2.7.3 Calibration Procedure

2.7.3.1 Calibration at CP1 and CP2 (Standard Calibration)

The Arc Sensor family has a unique calibration routine. When initiating the calibration, the data set of the sensor is automatically traced back within the last 3 minutes and a decision is made immediately if the calibration is successful or not. The operator therefore gets an immediate result. The criteria for a successful calibration are:

- the stability of pH value and temperature over the last 3 minutes (see register 5128)
- the currently measured pH value fits to one of the calibration standards defined in the selected set of calibration standards
- the limits of slope and offset at pH 7 have to be met

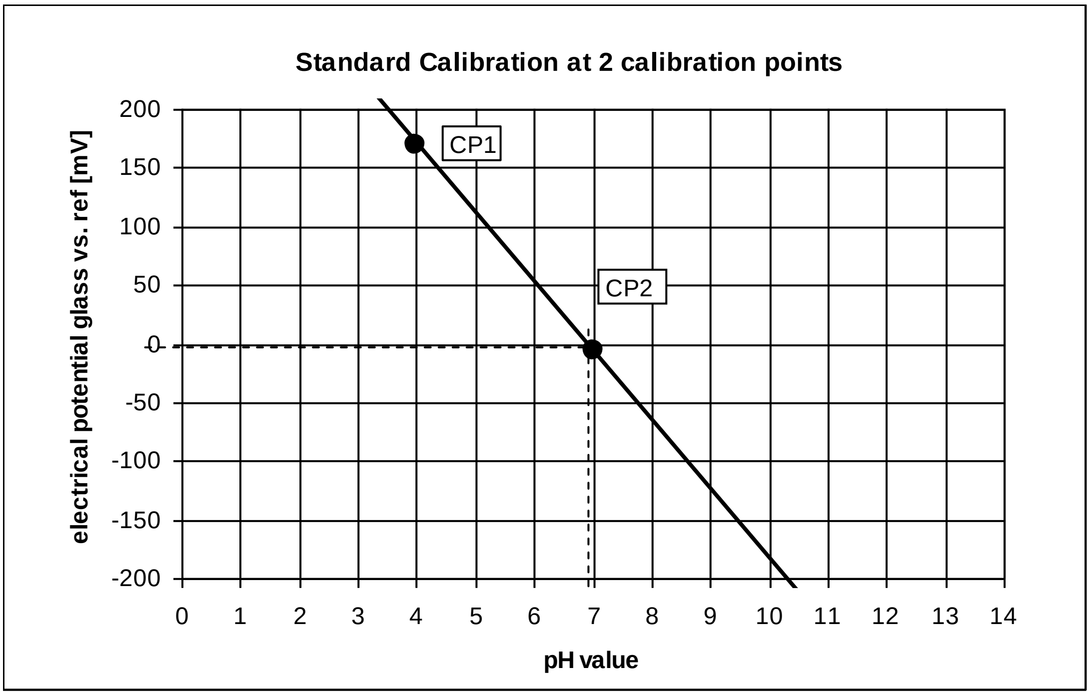


Figure 2.7.3.1.1: Standard Calibration using CP1 and CP2.

CP1 and CP2 define a linear relationship between the electrical potential and the pH value. This linear calibration function is defined by an offset at pH 7 [mV] and a slope [mV/pH]. These two values are stored in register 5448.

Note: the pH value of CP1 can be lower or higher than the pH value of CP2. However, the difference in pH between CP1 and CP2 must always be greater than 1 pH unit.

Notes:

- In order to perform a standard calibration at CP1 and CP2, it is necessary to use commercially available calibration standards. The operator is restricted to use those standards that are defined in the six sets of calibration standards (see chapter 2.7.11).

- There are two ways of performing a standard calibration:

  - standard calibration with **automatic recognition** of the calibration standard:
    in this case, the sensor decides on itself in what calibration standard it is immersed. The criteria to decide on is the electrical potential measured. The sensor checks the list of calibration standards that are available for automatic recognition (see chapter 2.7.11)

  - standard calibration with **manual selection** of the calibration standard:
    the operator is selecting the calibration standard in which the sensor is immersed.

- Factory calibration is pH 4 at CP1 and pH 7 at CP 2.

Standard Calibration with Automatic Recognition of the Standard

Prior to calibration, the specialist selects - for each set of calibration standards - a list of calibration standards allowed for automatic recognition (register 9530).
When the calibration is initiated, the sensor screens this list of allowed calibration standards and checks if the currently measured electrical potential is within the allowed range of electrical potentials, defined for the individual calibration standards in this list.

If the sensor does find a corresponding calibration standard, the nominal pH value of the specific calibration standard is assigned to the currently measured electrical potential. The temperature dependency of the calibration standard is considered during the assignment.

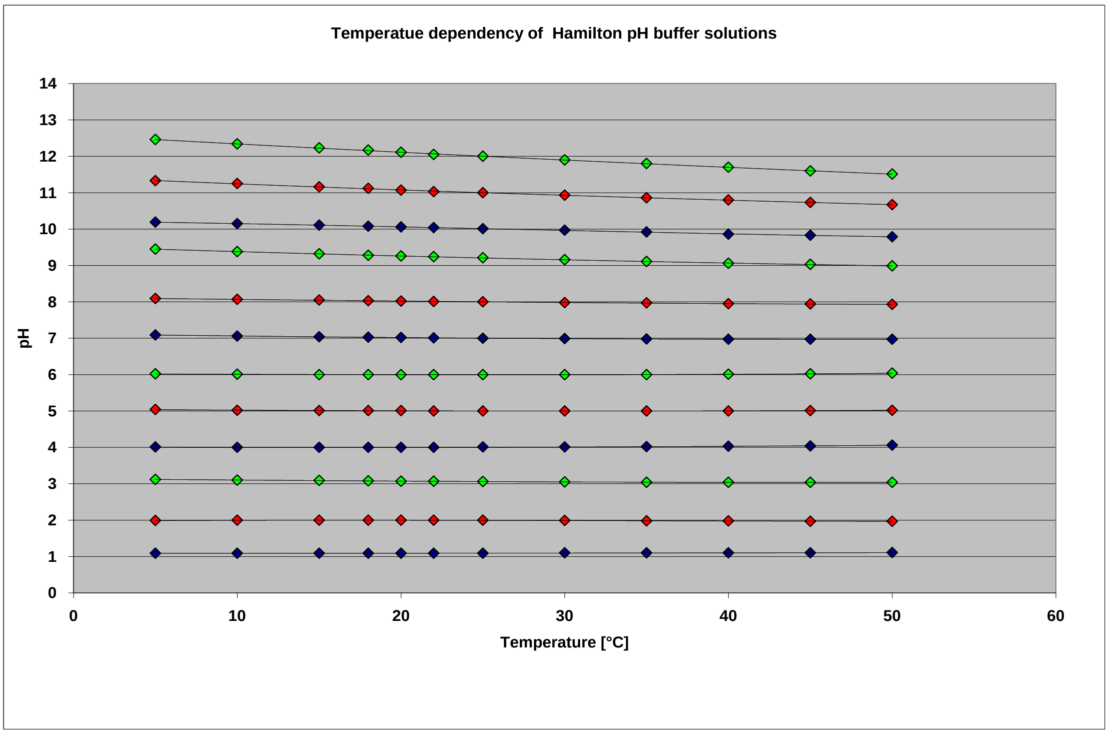


Figure 2.7.3.1.2: Temperature dependency of the pH value of Hamilton DURACAL calibration standards.

If the sensor does not find any corresponding calibration standard, the bit representing the corresponding status "no matching calibration standard" is set in the calibration status register.

Note that only the nominal value of the calibration standard is used for calibration. The actual value of the calibration solution, which may deviate from the nominal value, is not taken into account and cannot be set by the operator.

Standard Calibration with Manual Selection of the Calibration Standard

If the operator knows in what calibration standard the sensor is immersed, he can initiate the calibration procedure by means of setting the pH value to the actual value of the calibration standard. The sensor now screens the list of calibration standards that are allowed for manual selection (register 9530). If the pH value entered by the operator fits in the allowed pH range of one of the allowed calibration standards, the entered pH value is assigned to the currently measured electrical potential. The temperature dependency of the calibration standard is considered during the assignment.

If the sensor does not find any corresponding calibration standard, the bit representing the corresponding status "no matching calibration standard" is set in the calibration status register.

Note: using manual selection only, the actual pH value of the calibration standard can be set. However, the actual value must be within the given tolerance of the standard in use.

Perform the following steps to do a standard calibration at CP1 and CP2:

Step1: Select the desired set of calibration standards (see chapter 2.7.11)

Step 2: Immerse the sensor into one of the calibration standards available in the selected set

⚠ Attention:
It is important that the pH Arc Sensor is immersed in a defined calibration standard at least 3 minutes BEFORE the calibration is started.

Step 3: Choose one of the calibration points CP1 or CP2.

⚠ Attention:
The assignment of both CP1 and CP2 to the same pH value is rejected.

Try to avoid the following situations:
For example, the sensor was calibrated earlier at pH 4 (CP1) and at pH 7 (CP2):

- You want to perform a new calibration at CP1: it is possible to assign CP1 to pH 4 or to pH 10, but not to pH 7 (already used for CP2).
- You want to perform a new calibration at CP2: it is possible to assign CP2 to pH 7 or pH 10, but not to pH 4 (already used for CP1).
- If you calibrate now CP1 at pH 10, pH 4 will later be free for selection at CP2. In this case you can calibrate CP2 at pH 4 or pH 7, but not at pH 10 (CP1).

Step 4: Start the calibration (automatic recognition or manual selection)

The calibration is initiated at CP1 by writing to register 5162 or at CP2 by writing to register 5194.

Start register	Number of registers	Reg1 / Reg2	Modbus function code	Read access	Write access
5162	2	pH value at CP1 (unit is always pH)	16	none	A/S
5194	2	pH value at CP2 (unit is always pH)	16	none	A/S

Figure 2.7.3.1.3: Definition of register 5162 and 5194. You have two options to enter the pH value:
Automatic recognition: pH value=0: the sensor tries to assign the measured electrical potential to one of the calibration standards available for automatic calibration.
Manual selection: enter the actual pH value at 25°C (the value must be within the tolerance range of the nominal value of one of the calibration standards available for manual selection)

Step 5: Read the calibration status (see chapter 2.7.4)

Step 6: Check the pH Arc Sensor's quality indicator

Examples: (Definitions of register 5158 and 5190 used in these examples are given in chapter 2.7.4.1, those for register 4872 in chapter 2.8.6)

Example to calibrate at CP1 with automatic recognition:

Command: Make calibration CP1	Modbus address: **5162**	Length: **2**	Type: **16**	Write
Parameter:	pH value			
Format:	Float			
Value:	**0**			

Figure 2.7.3.1.4: Example to start the calibration at CP1, setting a value of 0 for automatic recognition of the calibration standard.

Example to calibrate at CP2 with automatic recognition:

Command: Make calibration CP2	Modbus address: **5194**	Length: **2**	Type: **16**	Write
Parameter:	pH value			
Format:	Float			
Value:	**0**			

Figure 2.7.3.1.5: Example to start the calibration at CP2, setting a value of 0 for automatic recognition of the calibration standard.

Example to read the calibration status of CP1:

Command: Calibration status CP1	Modbus address: **5158**	Length: **6**	Type: **3**	Read
Parameter:	Status	Unit	Value	
Format:	Hex	Hex	Float	
Value:	**0x00000000**	**0x00001000**	**4.01**	

Figure 2.7.3.1.6: Example to read the calibration status of CP1 after calibration CP1 at 0 = auto. All bits of CP1 are zero (0x000000**00**), indicating that the calibration was successful. The physical unit of the last calibration is pH (0x00001000) and the assigned pH *value is 4.01 at 25°C.*

Example to read the calibration status of CP2:

Command: Calibration status CP2	Modbus address: **5190**	Length: **6**	Type: **3**	Read
Parameter:	Status	Unit	Value	
Format:	Hex	Hex	Float	
Value:	**0x00000000**	**0x00001000**	**7**	

Figure 2.7.3.1.7: Example to read the calibration status of CP2 after calibrating CP2 at 0 = auto. All bits of CP2 are zero (0x0000**00**00), indicating that the calibration was successful. The physical unit of the last calibration is pH (0x00001000) and the pH value is 7.

Example to calibrate at CP1 with manual selection of the calibration standard:

Command: Make calibration CP1	Modbus address: **5162**	Length: **2**	Type: **16**	Write
Parameter:	pH value			
Format:	Float			
Value:	**4.00**			

Figure 2.7.3.1.8: Example to start the calibration at CP1, by means of manually selecting the calibration standard Hamilton DURACAL 4.01 (nominal value 4.01). The operator knows from the certificate of the specific production lot that the actual pH value is 4.00.

Example to read the sensor's quality indicator:

Command: Quality indicator		Modbus address: **4872**	Length: **2**	Type: **3** Read
Parameter:	Quality [%]			
Format:	Float			
Value:	**100**			

Figure 2.7.3.1.9: Example to read the sensor's quality indicator

2.7.3.2 Calibration at CP6 (Product Calibration)

The product calibration is a process in order to adjust the measurement of a correctly calibrated pH Arc Sensor to specific process conditions.
Product calibration is a two stage process:

1. An initial measurement is performed while the operator takes a sample of the process solution. At that time point the pH Arc Sensor stores its raw measurement value, temperature and operating hour in the memory.

   While the operator takes the sample to the analytics lab for reference analysis the pH Arc Sensor is still running on its prior standard calibration (CP1 and CP2) while the initial measurement data for the ongoing product calibration is kept in the sensor's memory.

2. When the result of the reference analysis is available this value is assigned, at a second time point, to the former initial measurement data stored in the pH Arc Sensor.

   The sensor is now, after valid assignment, running on a calibration function which is compensated for the correct process conditions. The product calibration (CP6) is now active.

Performing a Cancel command for the product calibration (CP6) brings the sensor back to its still stored standard calibration (CP1 and CP2).

If a product calibration is still active and a standard calibration (CP1 or CP2) is performed the product calibration (CP6) is cancelled.

If the operator needs to overrun an active product calibration (old CP6) by a new product calibration (new CP6) the above process applies in the same way. After initial measurement the pH Arc Sensor is still running on the first product calibration (old CP6) until a valid assignment has been done (new CP6).

What happens to the pH Arc Sensor's calibration function upon product calibration (CP6)?
A product calibration adds an offset to the linear calibration function defined by the standard calibration at CP1 and CP2.

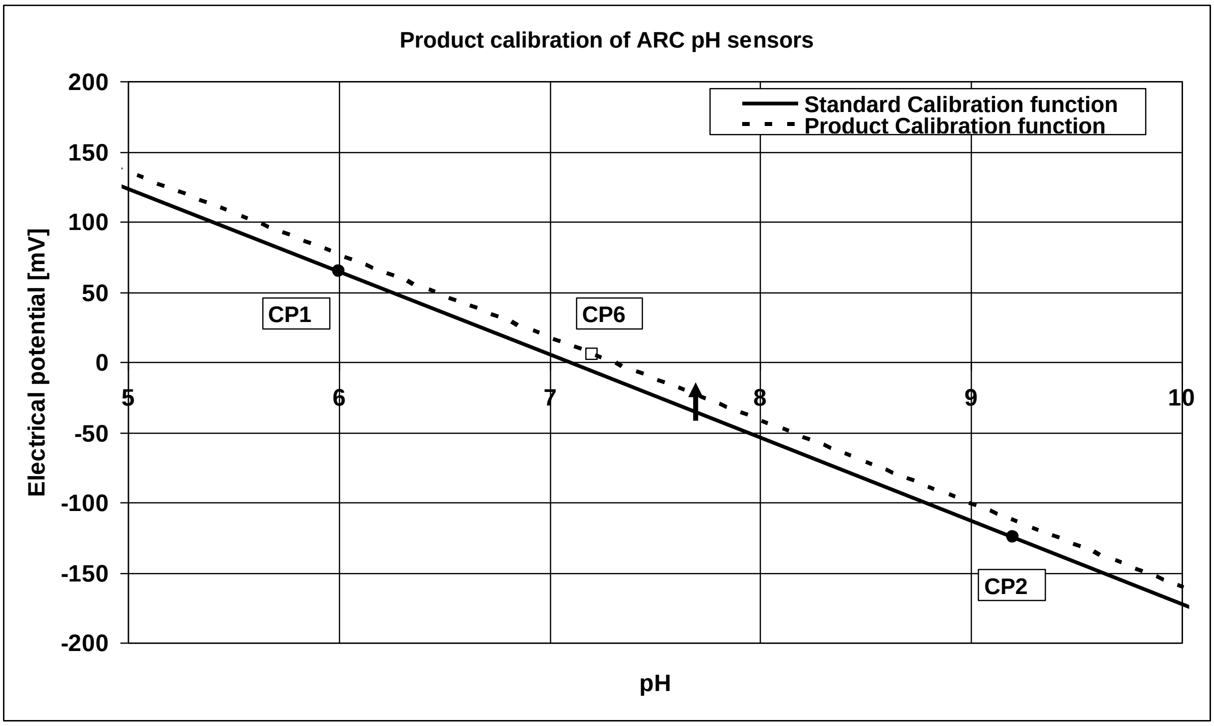


Figure 2.7.3.2.1: Effect of the product calibration CP6 on an existing standard calibration function defined by CP1 and CP2.

The operator starts with a Standard Calibration with calibration points CP1 and CP2:
CP1: pH value of calibration standard: 6 electrical potential: 64.2 mV
CP2: pH value of calibration standard: 9.21 electrical potential: -125.2 mV

The sensor internally calculates the calibration function, using the calibration points **CP1** and **CP2**. The resulting calibration function, compensated to the standard temperature 25°C, is shown as a straight line. The calibration function is described by two parameters: the offset at pH 7 and the slope.

Some weeks later, the operator believes that the Standard Calibration function is not correct anymore. As the process is running and he is not able to perform a standard calibration under defined conditions in the lab, he decides to perform a product calibration CP6, in other words adjusting the standard calibration function to the process conditions:
CP6: pH value of product: 7.2 electrical potential: 5 mV

The sensor internally adds an offset to the calibration curve. The slope remains unchanged.

Another special feature of this calibration point is to switch off and back on again a product calibration. These functions are called “restore standard calibration” and “restore product calibration”.

Note:
The sensor's internal criteria for a successful product calibration are:

- the sensor is currently in an environment corresponding to the pH Arc Sensors measurement range.
- the manually assigned pH value does not deviate more than 2 pH units from the value measured prior the product calibration

The different functionalities of product calibration (CP6) are accessible through the following sensor commands:

- Initial measurement
- Assignment
- Cancel
- Restore standard calibration
- Restore product calibration

All commands are executed by writing a command value to the register 5340 except for assignment where the calibration value is written to register 5322 (see below).

Definition of the commands for product calibration

The commands for register 5340 are defined as follows:

Code Hex	Definition of commands
0x01	Perform initial measurement
0x02	Cancel an active product calibration
0x03	Restore a standard calibration from an active product calibration
0x04	Restore a product calibration from an active standard calibration

Figure 2.7.3.2.2: Definition of the commands related to the product calibration

Start register	Number of registers	Reg1 / Reg2	Modbus function code	Read access	Write access
5340	2	Code as defined in Figure 2.7.3.2.2	3, 4, 16	A/S	A/S

Figure 2.7.3.2.3: Definition of register 5340

2.7.3.2.1 Product calibration: Initial measurement

Upon process sample collection for laboratory analysis the command for initial measurement is sent to the sensor.
This is achieved by writing the command 0x01 to register 5340 which performs the initial measurement and stores the corresponding measurement values in the sensor.

Command: CP6: Initial measurement	Modbus address: **5340**	Length: **2**	Type: **16**	Write
Parameter:	Command			
Format:	Hex			
Value:	**0x01**			

Figure 2.7.3.2.1.1: Example to start the product calibration procedure. Writing the command code 0x01 (initial measurement) to the CP6 command register 5340.

After successful initial measurement the corresponding calibration status (register 5318, Figure 2.7.4.2.1) is "CP6 initial measurement" (0x08000000) (see Figure 2.7.4.1.1).
The sensor continues measuring using the prior standard calibration.

2.7.3.2.2 Product calibration: Assignment

After successful initial measurement a correct value must be assigned to the initially stored measurement data.
This is achieved by writing the correct calibration value to register 5322.

Start register	Number of registers	Reg1 / Reg2	Modbus function code	Read access	Write access
5322	2	pH value [pH]	16	none	A/S

Figure 2.7.3.2.2.1: Definition of register 5322

Command: CP6: Assignment		Modbus address: **5322**	Length: **2**	Type: **16** Write
Parameter:	Value			
Format:	Float			
Value:	**7.2**			

Figure 2.7.3.2.2.2: Example to assign a calibration value to the above performed initial measurement. This is achieved by writing the correct pH value.

From now on the sensor is measuring using the here performed product calibration.

The calibration status (register 5318) is 0x14000000 meaning that a correct value has been assigned and that the product calibration is active (see Figure 2.7.4.1.1).

2.7.3.2.3 Product calibration: Cancel

To cancel an active product calibration or an active initial measurement the command 0x02 is written to register 5340.

Command: CP6: Cancel		Modbus address: **5340**	Length: **2**	Type: **16** Write
Parameter:	Command			
Format:	Hex			
Value:	**0x02**			

Figure 2.7.3.2.3.1: Example to cancel an active product calibration or an initial measurement. Writing the command 0x02 (cancel) to register 5340.

Performing this action the product calibration or any initial measurements are canceled. The values of the prior product calibration are removed from the sensor's memory. From now on the sensor is measuring using its prior CP1 / CP2 standard calibration.

The sensor's calibration status (register 5318) will be reading 0x00 again (see Figure 2.7.4.1.1).

2.7.3.2.4 Product calibration: Restore standard calibration

If a product calibration is active this product calibration can be temporarily switched off by writing the command 0x03 to register 5340.
Performing this action the values of the product calibration remain stored in the sensor's memory.

Command: CP6: Restore standard		Modbus address: **5340**	Length: **2**	Type: **16** Write
Parameter:	Command			
Format:	Hex			
Value:	**0x03**			

Figure 2.7.3.2.4.1: Example to restore a standard calibration from an active product calibration. Writing command 0x03 (restore standard calibration) to register 5340.

From now on the sensor is measuring using its prior CP1 / CP2 standard calibration.
The sensor's calibration status (register 5318) will be reading "CP6 assigned" (0x10000000) meaning that a valid assignment for a product calibration is available in the sensor's memory (see Figure 2.7.4.1.1).

2.7.3.2.5 Product calibration: Restore product calibration

If a valid but inactivated product calibration is available in the sensors memory, the calibration status is reading "CP6 assigned" (corresponding to 0x10000000, see Figure 2.7.4.1.1), this stored product calibration can be restored or reactivated by writing command 0x04 to register 5340.

Command: CP6: Restore product		Modbus address: **5340**	Length: **2**	Type: **16** Write
Parameter:	Command			
Format:	Hex			
Value:	**0x04**			

Figure 2.7.3.2.5.1: Example to restore an available product calibration from an active standard calibration. Writing command 0x04 (restore product calibration) to register 5340.

From now on the sensor is measuring using its prior CP6 product calibration.
The sensors calibration status (register 5318) will be reading 0x14000000 (corresponding to "CP6 assigned" and "CP6 active", see Figure 2.7.4.1.1) again.

If this command is performed without available product calibration in the sensor's memory the sensor will respond with a Modbus exception since this command is not valid.

2.7.4 Reading the Calibration Status

2.7.4.1 Reading the Calibration Status of CP1 and CP2

A standard calibration is not always successful. In order to analyze what has gone wrong, two different calibration status registers can be read:

- Register 5158 for CP1
- Register 5190 for CP2

Note

Registers 5158 and 5190 contain the same information!

Bit #	Hex value	Definition
0 (LSB)	0x00000001	CP1: difference between CP1 and CP2 < pH 1.0
1	0x00000002	CP1: no matching calibration standard
2	0x00000004	CP1: actual temperature reading is too low
3	0x00000008	CP1: actual temperature reading is too high
4	0x00000010	CP1: temperature reading during calibration is not stable
5	0x00000020	CP1: offset a pH 7 is too low or slope is too low (see chapter 2.7.8)
6	0x00000040	CP1: offset a pH 7 is too high or slope is too high (see chapter 2.7.8)
7	0x00000080	CP1: pH reading during calibration is not stable
8	0x00000100	CP2: difference between CP2 and CP1 < pH 1.0
9	0x00000200	CP2: no matching calibration standard
10	0x00000400	CP2: actual temperature reading is too low
11	0x00000800	CP2: actual temperature reading is too high
12	0x00001000	CP2: temperature reading during calibration is not stable
13	0x00002000	CP2: offset a pH 7 is too low or slope is too low (see chapter 2.7.8)
14	0x00004000	CP2: offset a pH 7 is too high or slope is too high (see chapter 2.7.8)
15	0x00008000	CP2: pH reading during calibration is not stable
…		not available
24	0x01000000	CP6: out of calibration range
25	0x02000000	CP6: out of range
26	0x04000000	CP6: active
27	0x08000000	CP6: initial measurement
28	0x10000000	CP6: assigned
		not available
30	0x40000000	CP2: incorrect measurement unit
31	0x80000000	CP1: incorrect measurement unit

Figure 2.7.4.1.1: Definition of the status for register 5158, 5190 and 5318 (see Figure 2.7.4.1.2 and Figure 2.7.4.2.1).

Start register	Number of registers	Reg1 / Reg2	Reg3 / Reg4	Reg5 / Reg6	Modbus function code	Read access	Write access
5158	6	Status CP1 (see Figure 2.7.4.1.1)	Physical unit of the last successful calibration CP1 (always pH)	pH value of the last successful calibration CP1	3, 4	U/A/S	none
5190	6	Status CP2 (see Figure 2.7.4.1.1)	Physical unit of the last successful calibration CP2 (always pH)	pH value of the last successful calibration CP2	3, 4	U/A/S	none

Figure 2.7.4.1.2: Definition of register 5158 for CP1 and register 5190 for CP2.

Command: Calibration status CP1		Modbus address: **5158**	Length: **6**	Type: **3** Read
Parameter:	Status	Unit	Value	
Format:	Hex	Hex	Float	
Value:	**0x00000080**	**0x00001000**	**4.01**	

Figure 2.7.4.1.3: Example to read the calibration status of CP1 after calibration CP1 at 0 = auto. The status message is: "CP1 pH reading during calibration is not stable" (0x000000**80**). The physical unit of the last successful calibration is pH (0x00001000) and the last successful calibration has been performed at pH 4.01.

Command: Calibration status CP2		Modbus address: **5190**	Length: **6**	Type: **3** Read
Parameter:	Status	Unit	Value	
Format:	Hex	Hex	Float	
Value:	**0x00000080**	**0x00001000**	**7**	

Figure 2.7.4.1.4: Example to read the calibration status of CP2 after calibrating CP2 at 0 = auto. All bits of CP2 are zero (0x0000**00**80), indicating that the calibration was successful. The physical unit of the last calibration is pH (0x00001000) and the last successful calibration has been performed at pH 7.

Command: Calibration status CP2		Modbus address: **5190**	Length: **6**	Type: **3** Read
Parameter:	Status	Unit	Value	
Format:	Hex	Hex	Float	
Value:	**0x00000180**	**0x00001000**	**7**	

Figure 2.7.4.1.5: Example to read the calibration status of CP2 after attempt to calibrate CP2 at pH 4.01, which is the same as CP1. The value is 0x00000180 = 0x00000080 + 0x00000100. Shown is still 0x000000**80** of CP1 and new 0x0000**01**00 of CP2, which says: "CP2 space to CP1 < pH 1.0".

2.7.4.2 Reading the Calibration Status of CP6 (Product Calibration)

The calibration status and the current state of the product calibration process (CP6) is read in the calibration status register for CP6 (register 5318).

Start register	Number of registers	Reg1 / Reg2	Reg3 / Reg4	Reg5 / Reg6	Modbus function code	Read access	Write access
5318	6	Status CP6 (see Figure 2.7.4.1.1)	Physical unit of the last successful calibration CP6 (always pH)	pH value of the last successful calibration CP6	3, 4	U/A/S	none

Figure 2.7.4.2.1: Definition of register 5318 for CP6. For examples, see following chapters.

2.7.4.2.1 Product calibration: Initial measurement

Calibration status after initial measurement command under conditions outside the valid calibration range for CP6 (defined in register 5312):

Command: Calibration status CP6	Modbus address: **5318**	Length: **6**	Type: **3**	Read
Parameter:	Status	Unit	Value	
Format:	Hex	Hex	Float	
Value:	**0x01000000**	**0x00001000**	**4.01**	

Figure 2.7.4.2.1.1: Example to read the calibration status of CP6 after having performed an initial measurement at CP6 under measurement conditions outside the calibration range for CP6.
The status says: "CP6: out of calibration range" (0x01000000). The last successful calibration has been performed at pH 4.01.
The initial measurement in this case was **not** successful.
The sensor is still running on its prior standard calibration.

Calibration status after successful initial measurement:

Command: Calibration status CP6	Modbus address: **5318**	Length: **6**	Type: **3**	Read
Parameter:	Status	Unit	Value	
Format:	Hex	Hex	Float	
Value:	**0x08000000**	**0x00001000**	**4.01**	

Figure 2.7.4.2.1.2: Example to read the calibration status of CP6 after having performed an initial measurement at CP6 under correct measurement conditions.
The status says: "CP6: initial measurement" (0x08000000). The last successful calibration has been performed at pH 4.01.
The initial measurement in this case was successful.
The sensor is still running on its prior standard calibration until a valid calibration value has been assigned to this initial measurement values.

2.7.4.2.2 Product calibration: Assignment

Calibration status after invalid assignment:

Command: Calibration status CP6	Modbus address: **5318**	Length: **6**	Type: **3**	Read
Parameter:	Status	Unit	Value	
Format:	Hex	Hex	Float	
Value:	**0x0A000000**	**0x00001000**	**4.01**	

Figure 2.7.4.2.2.1: Example to read the calibration status of CP6 after having performed a valid initial measurement at CP6 and an invalid assignment.
The status says: "CP6: out of range" (0x02000000) and "CP6: initial measurement" (0x08000000). The last successful calibration has been performed at pH 4.01
The initial measurement in this case is still valid and available for further assignment of a product calibration value. The here performed assignment was **not** successful. The sensor remains running on its prior standard calibration.

Calibration status after valid assignment:

Command: Calibration status CP6	Modbus address: **5318**	Length: **6**	Type: **3**	Read
Parameter:	Status	Unit	Value	
Format:	Hex	Hex	Float	
Value:	**0x14000000**	**0x00001000**	**4.5**	

Figure 2.7.4.2.2.2: Example to read the calibration status of CP6 after having performed an initial measurement at CP6 and a valid assignment to pH 4.5.
The status says: "CP6: active" (0x04000000) and "CP6: assigned" (0x10000000). The last successful calibration corresponding to the here performed assignment has been performed at pH 4.5.

The here performed assignment was successful. The sensor is running using a valid product calibration.

2.7.4.2.3 Product calibration: Cancel

Calibration status after cancelling an active product calibration:

Command: Calibration status CP6		Modbus address: **5318**	Length: **6**	Type: **3** Read
Parameter:	Status	Unit	Value	
Format:	Hex	Hex	Float	
Value:	**0x00000000**	**0x00001000**	**4.5**	

Figure 2.7.4.2.3.1: Example to read the calibration status of CP6 after having performed a cancel command at CP6.
The status reports no messages. The last successful calibration at CP6 has been performed at pH 4.5.
The sensor is running on a valid standard calibration and no product calibration is stored.

2.7.4.2.4 Product calibration: Restore standard calibration

Calibration status after restoring a standard calibration from an active product calibration:

Command: Calibration status CP6		Modbus address: **5318**	Length: **6**	Type: **3** Read
Parameter:	Status	Unit	Value	
Format:	Hex	Hex	Float	
Value:	**0x10000000**	**0x00001000**	**4.5**	

Figure 2.7.4.2.4.1: Example to read the calibration status of CP6 after having restored the standard calibration from an active product calibration (CP6).
The status says: “CP6 assigned” (0x10000000). The last successful calibration at CP6 has been performed at pH 4.5.
The sensor is running on a valid standard calibration but a valid product calibration is still available in the sensor.

2.7.4.2.5 Product calibration: Restore product calibration

Calibration status after restoring an available product calibration from an active standard calibration:

Command: Calibration status CP6		Modbus address: **5318**	Length: **6**	Type: **3** Read
Parameter:	Status	Unit	Value	
Format:	Hex	Hex	Float	
Value:	**0x14000000**	**0x00001000**	**4.5**	

Figure 2.7.4.2.5.1: Example to read the calibration status of CP6 after having restored an available product calibration (CP6) from an active standard calibration (CP1 / CP2).
The status says: “CP6: active” (0x04000000) and “CP6: assigned” (0x10000000). The last successful calibration corresponding to the here performed assignment has been performed at pH 4.5.
The sensor is running on a valid product calibration again.

2.7.5 Currently active Calibration Parameters part 1

In registers 5164 (CP1), 5196 (CP2) and 5324 (CP6) the currently active calibration parameters part 1 are stored. These registers contain the values for temperature, number of calibrations and operating hour upon calibration.

Start register	Number of registers	Reg1 / Reg2	Reg3 / Reg4	Reg5 / Reg6	Reg7 / Reg8	Modbus function code	Read access	Write access
5164	8	Unit of temperature for CP1 (bitwise defined)	Value of temperature of CP1	Number of calibrations at CP1	Operating hour for CP1	3, 4	U/A/S	none
5196	8	Unit of temperature for CP2 (bitwise defined)	Value of temperature of CP2	Number of calibrations at CP2	Operating hour for CP2	3, 4	U/A/S	none
5324	8	Unit of temperature for CP6 (bitwise defined)	Value of temperature of CP6	Number of calibrations at CP6	Operating hour for CP6	3, 4	U/A/S	none

Figure 2.7.5.1: Definition of register 5164 for CP1, 5196 for CP2 and 5324 for CP6.

Command: Calibration CP1 values	Modbus address: **5164**	Length: **8**	Type: **3**	Read
Parameter:	Unit of temperature	Temperature	Number of cali	Operating hour
Format:	Hex	Float	Decimal	Float
Value:	**0x00000004**	**24.35184**	**6**	**23.78**

Figure 2.7.5.2: Example to read the calibration values for CP1. The physical unit is °C (0x00000004), the temperature is 24.35184 °C, the number of calibrations at CP1 is 6 and the operating hour is 23.78 h.

Command: Calibration CP2 values	Modbus address: **5196**	Length: **8**	Type: **3**	Read
Parameter:	Unit of temperature	Temperature	Number of cali	Operating hour
Format:	Hex	Float	Decimal	Float
Value:	**0x00000004**	**24.37691**	**5**	**16.45**

Figure 2.7.5.3: Example to read the calibration values for CP2. The physical unit is °C (0x00000004), the temperature is 24.37691 °C, the number of calibrations at CP2 is 5 and the operating hour is 16.45 h.

Command: Calibration CP6 values	Modbus address: **5324**	Length: **8**	Type: **3**	Read
Parameter:	Unit of temperature	Temperature	Number of cali	Operating hour
Format:	Hex	Float	Decimal	Float
Value:	**0x00000004**	**29.93368**	**12**	**379.5167**

Figure 2.7.5.4: Example to read the calibration values 1 for CP6. The physical unit is °C (4), the temperature is 29.93 (°C), the number of calibrations at CP6 is 12 and the operating hour is 379.51 (h).

2.7.6 Currently active Calibration Parameters part 2

Registers 5172 (CP1), 5204 (CP2) and 5332 (CP6) are not defined for pH Arc Sensors, as they document atmospheric pressure and salinity used for dissolved oxygen Arc Sensors only.

2.7.7 Currently active Calibration Parameters part 3

In register 5520, 5528 and 5560 the pH value of the used calibration standards, the electrical potential of the pH sensor and the temperature upon calibration are stored.

Start register	Number of registers	Reg1 / Reg2	Reg3 / Reg4	Reg5 / Reg6	Reg7 / Reg8	Modbus function code	Read access	Write access
5520	8	pH value of calibration standard at CP1 [pH]	Electrical potential at CP1 [mV]	Temp at CP1 [K]	free	3, 4	A/S	none
5528	8	pH value of calibration standard at CP2 [pH]	Electrical potential at CP2 [mV]	Temp at CP2 [K]	free	3, 4	A/S	none
5560	8	pH value of product at CP6 [pH]	Electrical potential at CP6 [mV]	Temp at CP6 [K]	free	3, 4	A/S	none

Figure 2.7.7.1: Definition of register 5520, 5528 and 5560.

Command: Act calibration CP1	Modbus address: **5520**	Length: **8**	Type: **3**	Read
Parameter:	pH CP1 [pH]	Voltage CP1 [mV]	Temp CP1 [K]	free
Format:	Float	Float	Float	Float
Value:	**4.003401**	**179.927**	**297.1378**	**0**

Figure 2.7.7.2: Example to read the actual calibration values of CP1.

Command: Act calibration CP2	Modbus address: **5528**	Length: **8**	Type: **3**	Read
Parameter:	pH CP2 [pH]	Voltage CP2 [mV]	Temp CP2 [K]	free
Format:	Float	Float	Float	Float
Value:	**7.006804**	**3.099747**	**296.6901**	**0**

Figure 2.7.7.3: Example to read the actual calibration values of CP2.

Command: Act calibration CP6	Modbus address: **5560**	Length: **8**	Type: **3**	Read
Parameter:	pH CP6 [pH]	Voltage CP6 [mV]	Temp CP6 [K]	free
Format:	Float	Float	Float	Float
Value:	**7.1**	**5.10469**	**298.3302**	**0**

Figure 2.7.7.4: Example to read the actual calibration values of CP6.

2.7.8 Currently active Calibration Parameters part 4

For standard calibration (CP1 / CP2) register 5448 documents offset at pH 7 and slope:

Start register	Number of registers	Reg1 / Reg2 (Float)	Reg3 / Reg4 (Float)	Reg5 / Reg6 (Float)	Modbus function code	Read access	Write access
5448	6	Offset at pH 7 [mV]	Slope (25 °C) [mV/pH]	Reference temperature [K]	3, 4	U/A/S	none

Figure 2.7.8.1: Definition of register 5448.

Command: Calculated cali values	Modbus address: **5448**	Length: **6**	Type: **3**	Read
Parameter:	Offset at pH 7 [mV]	Slope [mV/pH]	Ref temp [K]	
Format:	Float	Float	Float	
Value:	**3.607782**	**-59.47631**	**298.15**	

Figure 2.7.8.2: Example to read register 5448: offset at pH 7 is 3.6 mV; slope is -59.5 mV/pH; reference temperature is 298.15 K (=25°C)

For standard calibration (CP1 / CP2) register 5480 documents limits of offset at pH 7 and slope: The offset value can be expanded from ±20mV to up to ±40mV.

Start register	Number of registers	Reg1 / Reg2	Reg3 / Reg4	Reg5 / Reg6	Reg7 / Reg8	Modbus function code	Read access	Write access
5480	8	Min value of offset at pH 7 [mV]	Max value of offset at pH 7 [mV]	Min value of slope [mV/pH]	Max value of slope [mV/pH]	3, 4	U/A/S	S

Figure 2.7.8.3: Definition of register 5480.

Command: Limits of calc. cali values	Modbus address: **5480**	Length: **8**	Type: **3**	Read
Parameter:	Min value of offset at pH 7 [mV]	Max value of offset at pH 7 [mV]	Min value of slope [mV/pH]	Max value of slope [mV/pH]
Format:	Float	Float	Float	Float
Value:	**-20**	**20**	**-70**	**-40**

Figure 2.7.8.4: Example to read register 5480: Offset at pH 7 is allowed from -20 to +20 mV; slope is allowed from -70 to -40 mV/pH.

Command: Limits of calc. cali values	Modbus address: **5480**	Length: **8**	Type: 16	Write
Parameter:	Min value of offset at pH 7 [mV]	Max value of offset at pH 7 [mV]	Min value of slope [mV/pH]	Max value of slope [mV/pH]
Format:	Float	Float	Float	Float
Value:	**-40**	**40**	**-70**	**-40**

Figure 2.7.8.5: Example to write register 5480. The offset is set to the maximum allowable (±40mV) and the values entered in the slope are ignored by the sensor. Anyway some values must be transmitted for the slope and the packet must have the length of 8.

2.7.9 Currently active Calibration Parameters part 5

In register 5182, 5214 and 5342 the system time of the calibration is stored. The system time is explained in chapter 2.8.2.
Note: for CP6, the system time is set during the action "initial measurement".

Start register	Number of registers	Reg1 / Reg2	Modbus function code	Read access	Write access
5182	2	System Time CP1	3, 4	U/A/S	none
5214	2	System Time CP2	3, 4	U/A/S	none
5342	2	System Time CP6	3, 4	U/A/S	none

Figure 2.7.9.1: Definition of register 5182 for CP1, 5214 for CP2 and 5342 for CP6.

Command: System Time CP1		Modbus address: **5182**	Length: 2	Type: **3** Read
Parameter:	System Time CP1			
Format:	u-int			
Value:	**1334102400**			

Figure 2.7.9.2: Example to read the system time of CP1. The sensor is calibrated at 1334102400 which is equivalent to the 1st of April 2012 00:00 according to the base date of January 1st 1970.

Command: System Time CP2		Modbus address: **5214**	Length: 2	Type: **3** Read
Parameter:	System Time CP2			
Format:	u-int			
Value:	**1333540800**			

Figure 2.7.9.3: Example to read the system time of CP2. CP2 has been performed on the 4th of April 2012 at 12:00.

Command: System Time CP6		Modbus address: **5342**	Length: 2	Type: **3** Read
Parameter:	System Time CP6			
Format:	u-int			
Value:	**1334131200**			

Figure 2.7.9.4: Example to read the system time of CP6. The initial measurement of the product calibration has been performed on April 11th 2012 at 8:00.

2.7.10 Special Commands for Calibration with VISICAL

The VISICAL calibration device allows calibration of pH Arc Sensors at CP1 or CP2. The pH Arc Sensor's associated calibration parameters for CP1 and CP2 are those predefined and stored in corresponding registers of the sensor.
Register 5164 defines the pH value for CP1 and register 5196 defines the pH value for CP2, which are only valid for use with VISICAL. The same calibration limits for the pH value are used as for standard calibration at CP1 and CP2 (register 5152 and 5184 respectively).

⚠ Attention:

- It is not possible to perform a product calibration using VISICAL.
- Physical unit is fixed to pH by definition.

Start register	Number of registers	Reg1 / Reg2	Modbus function code	Read access	Write access
5180	2	pH value at CP1 (default: pH 4.00)	3, 4, 16	U/A/S	S
5212	2	pH value at CP2 (default: pH 7.00)	3, 4, 16	U/A/S	S

Figure 2.7.10.1: Definition of register 5180 for CP1 and 5212 for CP2.

Command: VISICAL CP1		Modbus address: **5180**	Length: **2**	Type: **3** Read
Parameter:	Value [pH]			
Format:	Float			
Value:	**4.00**			

Figure 2.7.10.2: Example to read the pH value valid for CP1. It is 4.00. Accordingly, the next time when a calibration is started using VISICAL at LOW, a calibration with manual selection is performed, using the calibration standard at pH 4. The operator has to make sure that - within the selected set of calibration standards - a standard at pH 4 is selected for manual selection.

Command: VISICAL CP2		Modbus address: **5212**	Length: **2**	Type: **16** Write
Parameter:	Value [pH]			
Format:	Float			
Value:	**7.00**			

Figure 2.7.10.3: Example to set the pH value valid for CP2.

Command: VISICAL CP2		Modbus address: **5212**	Length: **2**	Type: **3** Read
Parameter:	Value [pH]			
Format:	Float			
Value:	**7.00**			

Figure 2.7.10.4: Example to read the pH value valid for CP2. It is 7.00. Accordingly, the next time when a calibration is started using VISICAL at HIGH, a calibration with manual selection is performed, using the calibration standard at pH 7. The operator has to make sure that - within the selected set of calibration standards - a standard at pH 7 is selected for manual selection.

2.7.11 Calibration Standards

2.7.11.1 Available Sets of Calibration Standards

pH Arc Sensors can store and operate six different sets of calibration standards each having max 12 calibration standards. Before calibration the operator has to select one defined set to operate with. Default setting is the Hamilton set of calibration standards.
The operator can change the selection of sets at any time, without compromising prior calibration data at CP1 / CP2.

In register 9472 the available sets of calibration standards are defined.

Start register	Number of registers	Reg1 / Reg2 (Bit, see Figure 2.7.11.1.2)	Modbus function code	Read access	Write access
9472	2	Available calibration standard sets	3, 4	U/A/S	none

Figure 2.7.11.1.1: Definition of register 9472.

Bit #	Hex value	Description	Definition
0 (LSB)	**0x00000001**	**Set 1**	**HAMILTON**
1	0x00000002	Set 2	MERCK TITRISOL
2	0x00000004	Set 3	DIN 19267
3	0x00000008	Set 4	NIST Standard
4	0x00000010	Set 5	METTLER-TOLEDO
5	0x00000020	Set 6	RADIOMETER

Figure 2.7.11.1.2: Definition of available sets of calibration standards.

Command: Available cali sets		Modbus address: **9472**	Length: **2**	Type: **3** Read
Parameter:	Calibration sets			
Format:	Hex			
Value:	**0x0000003F**			

Figure 2.7.11.1.3: Example to read the available calibration sets: Set 1 (0x00000001) + set 2 (0x00000002) + set 3 (0x00000004) + set 4 (0x00000008) + set 5 (0x00000010) + set 6 (0x00000020), in total 0x0000003F.

In register 9474 the selected set of calibration standards is defined.

Start register	Number of registers	Reg1 / Reg2 (Bit, see Figure 2.7.11.1.2)	Modbus function code	Read access	Write access
9474	2	Selected set of calibration standard	3, 4	U/A/S	S

Figure 2.7.11.1.4: Definition of register 9474. Only one bit can be set.

Command: Selected set of cal stand.		Modbus address: **9474**	Length: **2**	Type: **3** Read
Parameter:	Calibration set			
Format:	Hex			
Value:	**0x00000001**			

Figure 2.7.11.1.5: Example to read the selected set of calibration standards. Set 1 (HAMILTON) (0x00000001) is active.

Command: Select set of cal stand.		Modbus address: **9474**	Length: **2**	Type: **16** Write
Parameter:	Calibration set			
Format:	Hex			
Value:	**0x04**			

Figure 2.7.11.1.6: Example to set the calibration standard set to DIN 19267 (0x04).

2.7.11.2 Definitions for Individual Sets of Calibration Standards

Once the operator has selected a set of calibration standards (register 9474) the register 9504 and following give all information on the selected set of calibration standards.

Start register	Number of registers	Reg1 to Reg8 (16 ASCII characters)	Modbus function code	Read access	Write access
9504	8	Manufacturer of the selected set	3, 4	U/A/S	none
9512	8	Info 1 of the selected set	3, 4	U/A/S	none
9520	8	Info 2 of the selected set	3, 4	U/A/S	none

Figure 2.7.11.2.1: Definition of registers 9504 to 9520.

Command: manufacturer of set	Modbus address: **9504**	Length: **8**	Type: **3**	Read
Parameter:	Text			
Format:	Character			
Value:	**HAMILTON**			

Figure 2.7.11.2.2: Example to read the description (in this case, the set 0x01 is selected)

Within one set of calibration standards, a maximum of 12 calibration standards are available. In the following registers, the details of each calibration standard is given:

Start register	Description
9536	Nominal value and tolerance of calibration standard 1
9552	Nominal value and tolerance of calibration standard 2
9568	Nominal value and tolerance of calibration standard 3
9584	Nominal value and tolerance of calibration standard 4
9600	Nominal value and tolerance of calibration standard 5
9616	Nominal value and tolerance of calibration standard 6
9632	Nominal value and tolerance of calibration standard 7
9648	Nominal value and tolerance of calibration standard 8
9664	Nominal value and tolerance of calibration standard 9
9680	Nominal value and tolerance of calibration standard 10
9696	Nominal value and tolerance of calibration standard 11
9712	Nominal value and tolerance of calibration standard 12

Figure 2.7.11.2.3: Definition for the register range from 9536 until 9720.

Start register	Number of registers	Reg1 / Reg2 (Float)	Reg3 / Reg4 (Float)	Reg5 / Reg6 (Float)	Reg7 / Reg8 (Float)	Modbus function code	Read access	Write access
9536, 9552, …	8	Nominal value (manual) [pH]	Tolerance (manual) (±) [pH]	Nominal value (automatic) [pH]	Tolerance (automatic) (±) [pH]	3, 4	U/A/S	none

Figure 2.7.11.2.4: Definition for registers 9536 until 9720.

Command: Read standard 4	Modbus address: **9584**	Length: **8**	Type: **3**	Read
Parameter:	Nominal value (manual) [pH]	Tolerance (manual) (±) [pH]	Nominal value (automatic) [pH]	Tolerance (automatic) (±) [pH]
Format:	Float	Float	Float	Float
Value:	**4.01**	**0.02**	**4.01**	**0.5**

Figure 2.7.11.2.5: Example to read the values for calibration standard 4 within the "HAMILTON" set. This standard has a nominal value of 4.01 ± 0.02 pH until expiry date as defined by Hamilton.

During standard calibration with automatic recognition the sensor accepts a range of pH readings between 3.51 and 4.51 pH (4.01 ± 0.5 pH) to be assigned to this standard. Of course, the pH reading used for this assignment considers on the currently active offset at pH 7 and slope.

During standard calibration with manual recognition only pH values between 3.99 and 4.03 pH (4.01 ± 0.02 pH) can be assigned to this standard.

Note: The decision, if this standard calibration is valid, is made after calculation of the offset at pH 7 and of the slope. If one of those two parameters is out of limits, the calibration using this standard will be denied.

Note: Make sure that calibration standards selected for automatic calibration do not exhibit overlapping acceptance ranges!

Register 9528 defines for the selected set of calibration standards:

- the available calibration standards for manual selection of the pH value
- the available calibration standards for automatic recognition of the pH value

Start register	Number of registers	Reg1 / Reg2 (Bit, see Figure 2.7.11.2.8)	Modbus function code	Read access	Write access
9528	2	Availability of the 12 cal. standards	3, 4	U/A/S	none

Figure 2.7.11.2.6: Definition of register 9528

Command: Available standards		Modbus address: **9528**	Length: **2**	Type: **3** Read
Parameter:	Standard fields			
Format:	Hex			
Value:	**0x0FFF0FFF**			

Figure 2.7.11.2.7: Example to read the information of register 9528. For the definition of the bits, see Figure 2.7.11.2.8. The value 0x0FFF0FFF says that (for the selected set of calibration standards):

- *all 12 calibration standards are available for manual calibration*
- *all 12 calibration standards are available for automatic recognition.*

Bit	Hex code	Index of Calibration Standard within the selected set	Calibration type
0 (LSB)	0x00000001	1	manual selection
1	0x00000002	2	manual selection
2	0x00000004	3	manual selection
3	0x00000008	4	manual selection
4	0x00000010	5	manual selection
5	0x00000020	6	manual selection
6	0x00000040	7	manual selection
7	0x00000080	8	manual selection
8	0x00000100	9	manual selection
9	0x00000200	10	manual selection
10	0x00000400	11	manual selection
11	0x00000800	12	manual selection
12-15		not available	
16	0x00010000	1	automatic recognition
17	0x00020000	2	automatic recognition
18	0x00040000	3	automatic recognition
19	0x00080000	4	automatic recognition
20	0x00100000	5	automatic recognition
21	0x00200000	6	automatic recognition
22	0x00400000	7	automatic recognition
23	0x00800000	8	automatic recognition
24	0x01000000	9	automatic recognition
25	0x02000000	10	automatic recognition
26	0x04000000	11	automatic recognition
27	0x08000000	12	automatic recognition
28-31		not available	

Figure 2.7.11.2.8: Availability / Selection for the 12 calibration standards within one given set.
Bit 0-11 define availability of standards 1-12 for manual calibration.
Bit 16-27 define availability of standards 1-12 for automatic recognition
Register 9528: the corresponding calibration standard is available if bit is set
Register 9530: the corresponding calibration standard is selected if bit is set

By means of register 9530, the specialist can define for each available calibration standard if the specific standard is available.

Start register	Number of registers	Reg1 / Reg2 (Bit, see Figure 2.7.11.2.8)	Modbus function code	Read access	Write access
9530	2	Selected standard fields	3, 4	U/A/S	S

Figure 2.7.11.2.9: Selected calibration standards within one given set.

Command: Selected standard fields		Modbus address: **9530**	Length: **2**	Type: **3** Read
Parameter:	Standard fields			
Format:	Hex			
Value:	**0x02480FFF**			

Figure 2.7.11.2.10: Example to read the selected calibration standards. The value 0x02480FFF says that:

- *all 12 calibration standards are selected for manual selection*
- *only calibration standards 3, 7 and 10 are selected for automatic recognition*

Command: Selected standard fields		Modbus address: **9530**	Length: **2**	Type: **16** Write
Parameter:	Standard fields			
Format:	Hex			
Value:	**0x05540FFF**			

Figure 2.7.11.2.11: Example to set the standard fields to 12 calibration standards for manual calibration and calibration standard 3 (0x00040000), 5 (0x00100000), 7 (0x00400000), 9 (0x01000000) and 11 (0x04000000) for automatic recognition.

Attention:
The standards selected for automatic recognition must exhibit a difference in pH of at least 2 pH units.

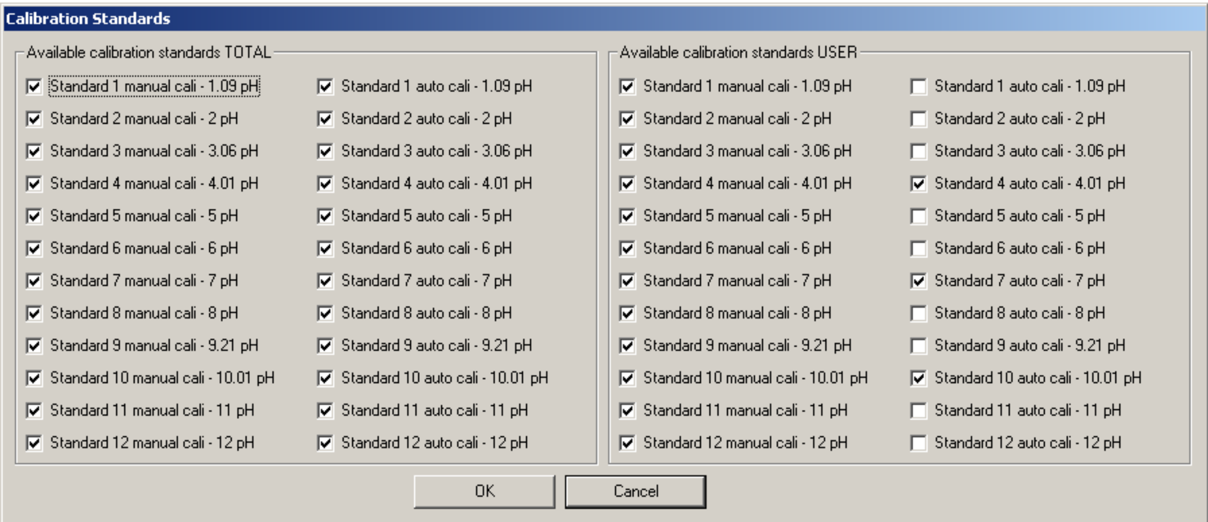


Figure 2.7.11.2.12: Illustration from the Arc Sensor Configurator software tool for registers 9528 and 9530. For this example, the HAMILTON set of calibration standard is selected.
On the left half of the figure, the availability of the calibration standards 1-12 is shown, as defined in register 9528. In the left column, the availability for manual calibration is shown (all standards). In the right column, the availability for automatic recognition is given (all standards as well).
On the right half of the figure, the individual selection defined by the specialist is shown as read from register 9530. In the left column, the selection for manual selection is shown (all standards). In the right column the selection for automatic recognition is given (calibration standards 4, 7 and 10).

Manufacturer	Availability for manual selection (left) and automatic recognition (right)	
HAMILTON	☑ Standard 1 manual cali - 1.09 pH	☑ Standard 1 auto cali - 1.09 pH
	☑ Standard 2 manual cali - 2 pH	☑ Standard 2 auto cali - 2 pH
	☑ Standard 3 manual cali - 3.06 pH	☑ Standard 3 auto cali - 3.06 pH
	☑ Standard 4 manual cali - 4.01 pH	☑ Standard 4 auto cali - 4.01 pH
	☑ Standard 5 manual cali - 5 pH	☑ Standard 5 auto cali - 5 pH
	☑ Standard 6 manual cali - 6 pH	☑ Standard 6 auto cali - 6 pH
	☑ Standard 7 manual cali - 7 pH	☑ Standard 7 auto cali - 7 pH
	☑ Standard 8 manual cali - 8 pH	☑ Standard 8 auto cali - 8 pH
	☑ Standard 9 manual cali - 9.21 pH	☑ Standard 9 auto cali - 9.21 pH
	☑ Standard 10 manual cali - 10.01 pH	☑ Standard 10 auto cali - 10.01 pH
	☑ Standard 11 manual cali - 11 pH	☑ Standard 11 auto cali - 11 pH
	☑ Standard 12 manual cali - 12 pH	☑ Standard 12 auto cali - 12 pH
MERCK TITRISOL	☑ Standard 1 manual cali - 1 pH	☑ Standard 1 auto cali - 1 pH
	☑ Standard 2 manual cali - 2 pH	☑ Standard 2 auto cali - 2 pH
	☑ Standard 3 manual cali - 3 pH	☑ Standard 3 auto cali - 3 pH
	☑ Standard 4 manual cali - 4 pH	☑ Standard 4 auto cali - 4 pH
	☑ Standard 5 manual cali - 5 pH	☑ Standard 5 auto cali - 5 pH
	☑ Standard 6 manual cali - 6 pH	☑ Standard 6 auto cali - 6 pH
	☑ Standard 7 manual cali - 7 pH	☑ Standard 7 auto cali - 7 pH
	☑ Standard 8 manual cali - 8 pH	☑ Standard 8 auto cali - 8 pH
	☑ Standard 9 manual cali - 9 pH	☑ Standard 9 auto cali - 9 pH
	☑ Standard 10 manual cali - 10 pH	☑ Standard 10 auto cali - 10 pH
	☑ Standard 11 manual cali - 11 pH	☑ Standard 11 auto cali - 11 pH
	☑ Standard 12 manual cali - 12 pH	☑ Standard 12 auto cali - 12 pH
DIN 19267	☑ Standard 1 manual cali - 1.09 pH	☑ Standard 1 auto cali - 1.09 pH
	☐ Standard 2 manual cali - 0 pH	☐ Standard 2 auto cali - 0 pH
	☑ Standard 3 manual cali - 3.06 pH	☑ Standard 3 auto cali - 3.06 pH
	☐ Standard 4 manual cali - 0 pH	☐ Standard 4 auto cali - 0 pH
	☑ Standard 5 manual cali - 4.65 pH	☑ Standard 5 auto cali - 4.65 pH
	☐ Standard 6 manual cali - 0 pH	☐ Standard 6 auto cali - 0 pH
	☑ Standard 7 manual cali - 6.79 pH	☑ Standard 7 auto cali - 6.79 pH
	☐ Standard 8 manual cali - 0 pH	☐ Standard 8 auto cali - 0 pH
	☑ Standard 9 manual cali - 9.23 pH	☑ Standard 9 auto cali - 9.23 pH
	☐ Standard 10 manual cali - 0 pH	☐ Standard 10 auto cali - 0 pH
	☐ Standard 11 manual cali - 0 pH	☐ Standard 11 auto cali - 0 pH
	☑ Standard 12 manual cali - 12.75 pH	☑ Standard 12 auto cali - 12.75 pH
NIST STANDARD	☐ Standard 1 manual cali - 0 pH	☐ Standard 1 auto cali - 0 pH
	☑ Standard 2 manual cali - 1.68 pH	☑ Standard 2 auto cali - 1.68 pH
	☐ Standard 3 manual cali - 0 pH	☐ Standard 3 auto cali - 0 pH
	☑ Standard 4 manual cali - 4.01 pH	☑ Standard 4 auto cali - 4.01 pH
	☐ Standard 5 manual cali - 0 pH	☐ Standard 5 auto cali - 0 pH
	☐ Standard 6 manual cali - 0 pH	☐ Standard 6 auto cali - 0 pH
	☑ Standard 7 manual cali - 6.86 pH	☑ Standard 7 auto cali - 6.86 pH
	☐ Standard 8 manual cali - 0 pH	☐ Standard 8 auto cali - 0 pH
	☑ Standard 9 manual cali - 9.18 pH	☑ Standard 9 auto cali - 9.18 pH
	☐ Standard 10 manual cali - 0 pH	☐ Standard 10 auto cali - 0 pH
	☐ Standard 11 manual cali - 0 pH	☐ Standard 11 auto cali - 0 pH
	☑ Standard 12 manual cali - 12.45 pH	☑ Standard 12 auto cali - 12.45 pH

Manufacturer	Availability for manual selection (left) and automatic recognition (right)	
METTLER TOLEDO	☐ Standard 1 manual cali - 0 pH ☑ Standard 2 manual cali - 2 pH ☐ Standard 3 manual cali - 0 pH ☑ Standard 4 manual cali - 4.01 pH ☐ Standard 5 manual cali - 0 pH ☐ Standard 6 manual cali - 0 pH ☑ Standard 7 manual cali - 7 pH ☐ Standard 8 manual cali - 0 pH ☑ Standard 9 manual cali - 9 pH ☐ Standard 10 manual cali - 0 pH ☑ Standard 11 manual cali - 11 pH ☐ Standard 12 manual cali - 0 pH	☐ Standard 1 auto cali - 0 pH ☑ Standard 2 auto cali - 2 pH ☐ Standard 3 auto cali - 0 pH ☑ Standard 4 auto cali - 4.01 pH ☐ Standard 5 auto cali - 0 pH ☐ Standard 6 auto cali - 0 pH ☑ Standard 7 auto cali - 7 pH ☐ Standard 8 auto cali - 0 pH ☑ Standard 9 auto cali - 9 pH ☐ Standard 10 auto cali - 0 pH ☑ Standard 11 auto cali - 11 pH ☐ Standard 12 auto cali - 0 pH
RADIOMETER	☑ Standard 1 manual cali - 1.09 pH ☑ Standard 2 manual cali - 1.68 pH ☐ Standard 3 manual cali - 0 pH ☑ Standard 4 manual cali - 4.01 pH ☐ Standard 5 manual cali - 0 pH ☑ Standard 6 manual cali - 6.84 pH ☑ Standard 7 manual cali - 7 pH ☑ Standard 8 manual cali - 7.38 pH ☑ Standard 9 manual cali - 9.18 pH ☑ Standard 10 manual cali - 10.01 pH ☐ Standard 11 manual cali - 0 pH ☐ Standard 12 manual cali - 0 pH	☑ Standard 1 auto cali - 1.09 pH ☑ Standard 2 auto cali - 1.68 pH ☐ Standard 3 auto cali - 0 pH ☑ Standard 4 auto cali - 4.01 pH ☐ Standard 5 auto cali - 0 pH ☑ Standard 6 auto cali - 6.84 pH ☑ Standard 7 auto cali - 7 pH ☑ Standard 8 auto cali - 7.38 pH ☑ Standard 9 auto cali - 9.18 pH ☑ Standard 10 auto cali - 10.01 pH ☐ Standard 11 auto cali - 0 pH ☐ Standard 12 auto cali - 0 pH

Figure 2.7.11.2.13: Default definitions in register 9528 for all 6 sets of calibration standards available in pH Arc Sensors.

2.8 Sensor Status

2.8.1 Temperature Ranges

In registers 4608, 4612 and 4616 three different temperature ranges are defined:

- Operation – in this range the sensor will work properly (current output, Modbus communication), except the measurement, which is stopped until the temperature is back in the measurement range. In this case the last value of measurement will be frozen and sent to analog interfaces.
- Measurement – in this range the sensor is able to measure.
- Calibration – in this range the sensor can be calibrated.

Start register	Number of registers	Reg1 / Reg2	Reg3 / Reg4	Modbus function code	Read access	Write access
4608	4	Operating temperature min [°C]	Operating temperature max [°C]	3, 4	U/A/S	none
4612	4	Measurement temperature min [°C]	Measurement temperature max [°C]	3, 4	U/A/S	none
4616	4	Calibration temperature min [°C]	Calibration temperature max [°C]	3, 4	U/A/S	none

Figure 2.8.1.1: Definition of register 4608, 4612 and 4616.

Command: Operating T range	Modbus address: **4608**	Length: **4**	Type: **3**	Read
Parameter:	Operating T min [°C]	Operating T max [°C]		
Format:	Float	Float		
Value:	**-20**	**130**		

Figure 2.8.1.2: Example to read the operating temperature values min and max.

Command: Measurement T range	Modbus address: **4612**	Length: **4**	Type: **3**	Read
Parameter:	Measurement T min [°C]	Measurement T max [°C]		
Format:	Float	Float		
Value:	**-20**	**130**		

Figure 2.8.1.3: Example to read the measurement temperature values min and max.

Command: Calibration T range	Modbus address: **4616**	Length: **4**	Type: **3**	Read
Parameter:	Calibration T min [°C]	Calibration T max [°C]		
Format:	Float	Float		
Value:	**5**	**50**		

Figure 2.8.1.4: Example to read the calibration temperature values min and max.

2.8.2 Operating Hours, Counters and System Time

In register 4676 are stored:

- total operating hours
- operating hours above max measurement temperature (see chapter 2.8.1)
- the operating hours above max operating temperature (see chapter 2.8.1)

In register 4682 are stored:

- number of power ups
- number of watchdog resets
- number of writing cycles to the sensor's flash memory

In register 4688 are stored:

- number of sterilizations in place (SIP) (see chapter 2.8.5)
- number of cleanings in place (CIP) (see chapter 2.8.5)

In register 4692 is stored:

- number of autoclavings.

This register has no effect for the sensor and is only for the user to trace the record for himself.

In register 8232 is stored:

- the system time counter:
  When the sensor is powered up, the system time is set to 0. A value between 0 and 2^{32} can be written into this register. From this value, the sensor increments this value every second.
  We recommend to use as base date the so-called UNIX timestamp (hint: www.epochconverter.com) which starts at 1st of January 1970 GMT. When a calibration is performed the system time value will be copied to the register 5182 for CP1, 5214 for CP2 and 5342 for CP6 (after the action "initial measurement"). With this copied value, the absolute time of calibration can be recovered, even if the sensor has powered down in the meantime.
  Be sure to update this register if needed after every power up of the sensor.

Start register	Number of registers	Reg1 / Reg2	Reg3 / Reg4	Reg3 / Reg4	Modbus function code	Read access	Write access
4676	6	Operating hours [h]	Operating hours above max measurement temperature [h]	Operating hours above max operating temperature [h]	3, 4	U/A/S	none
4682	6	Number of Power ups	Number of Watchdog resets	Number of Writing cycles to flash memory	3, 4	U/A/S	none
4688	4	Number of SIP cycles	Number of CIP cycles	-	3, 4	U/A/S	none
4692	2	No. of autoclavings			3, 4, 16	U/A/S	S
8232	2	System Time Counter			3, 4, 16	U/A/S	S

Figure 2.8.2.1: Definition of register 4676, 4682, 4688 4692 and 8232.

Command: Operating hours		Modbus address: **4676**	Length: **6**	Type: **3** Read
Parameter:	Operating hours [h]	Operating hours above max measurement temperature [h]	Operating hours above max operating temperature [h]	
Format:	Float	Float	Float	
Value:	**168.3667**	**0**	**0**	

Figure 2.8.2.2: Example to read the total operating hours, the operating hours above the max measurement temperature and the operating hours above the max operating temperature.

Command: Power & watchdog		Modbus address: **4682**	Length: **6**	Type: **3** Read
Parameter:	Number of Power ups	Number of Watchdog resets	Number of Writing cycles to flash memory	
Format:	Decimal	Decimal	Decimal	
Value:	**34**	**1**	**16**	

Figure 2.8.2.3: Example to read the number of power ups, the number of watchdog resets and the number of writing cycles to flash memory.

Command: SIP & CIP		Modbus address: **4688**	Length: **4**	Type: **3** Read
Parameter:	SIP cycles	CIP cycles		
Format:	Decimal	Decimal		
Value:	**0**	**0**		

Figure 2.8.2.4: Example to read the number of SIP cycles and the number of CIP cycles. For the definition of SIP and CIP cycles see chapter 2.8.5.

Command: Autoclaving		Modbus address: **4692**	Length: **2**	Type: **3** Read
Parameter:	Autoclavings			
Format:	Decimal			
Value:	**7**			

Figure 2.8.2.5: Example to read the number of autoclaving cycles.

Command: Autoclaving		Modbus address: **4692**	Length: **2**	Type: **16** Write
Parameter:	Autoclavings			
Format:	Decimal			
Value:	**14**			

Figure 2.8.2.6: Example to write the number of autoclaving cycles. A number of 14 is written to the sensor.

Command: System Time		Modbus address: **8232**	Length: **2**	Type: **16** Write
Parameter:	System Time			
Format:	Decimal			
Value:	**1334137383**			

Figure 2.8.2.7: Example to write the system time into the sensor. On the basis of January 1st 1970, this value represents the 11th of April 2012 at 09:43:03.

Command: System Time		Modbus address: **8232**	Length: **2**	Type: **16** Read
Parameter:	System Time			
Format:	Decimal			
Value:	**1334150836**			

Figure 2.8.2.8: Example to read the system time into the sensor. On the basis of January 1st 1970, this value represents the 11th of April 2012 at 13:27:16.

Note:

Accuracy of the system time, if not updated by the operator: The deviation of the system time is less than one minute per 24h.

2.8.3 Warnings

A "Warning" is a notification message which still allows further functioning of the system. This message alerts the operator of a possible problem that could lead to uncertain results.

2.8.3.1 Currently Active Warnings

The currently active warnings are stored in register 4736.

Start register	Number of registers	Reg1 / Reg2	Reg3 / Reg4	Reg5 / Reg6	Reg7 / Reg8	Modbus function code	Read access	Write access
4736	8	Active warning measure-ment (bitwise defined)	Active warning calibration (bitwise defined)	Active warning interface (bitwise defined)	Active warning hardware (bitwise defined)	3, 4	U/A/S	none

Figure 2.8.3.1.1: Definition of register 4736 (see chapter 2.8.3.3)

Command: Active warning	Modbus address: **4736**	Length: **8**	Type: **3**	Read
Parameter:	W Measurement	W Calibration	W Interface	W Hardware
Format:	Hex	Hex	Hex	Hex
Value:	**0x00**	**0x00**	**0x00**	**0x00**

Figure 2.8.3.1.2: Example to read the currently active warnings.

2.8.3.2 History of Warnings

The history of warnings is not implemented in pH Arc Sensors.

2.8.3.3 Definition of Warnings

Bit #	Hex	Description
		not available

Figure 2.8.3.3.1: Definition of warnings "measurement". None is defined.

Bit #	Hex	Description
0 (LSB)	0x0001	PMC1 (pH) calibration recommended
1	0x0002	PMC1 (pH) last calibration not successful

Figure 2.8.3.3.2: Definition of warnings "calibration".

Bit #	Hex	Description
		not available

Figure 2.8.3.3.3: Definition of warnings "interface". None is defined.

Bit #	Hex	Description
		not available

Figure 2.8.3.3.4: Definition of warnings "hardware". None is defined.

2.8.4 Errors

An "Error" message indicates a serious problem of the sensor which does not allow further proper functioning of the sensor. This problem must be solved.

2.8.4.1 Currently Active Errors

The currently active errors are stored in register 4800.

Start register	Number of registers	Reg1 / Reg2	Reg3 / Reg4	Reg5 / Reg6	Reg7 / Reg8	Modbus function code	Read access	Write access
4800	8	Active error measure-ment (bitwise defined)	Active error calibration (bitwise defined)	Active error interface (bitwise defined)	Active error hardware (bitwise defined)	3, 4	U/A/S	none

Figure 2.8.4.1.1: Definition of register 4800 (see chapter 2.8.4.3)

Command: Active errors	Modbus address: **4800**	Length: **8**	Type: **3**	Read
Parameter:	E Measurement	E Calibration	E Interface	E Hardware
Format:	Hex	Hex	Hex	Hex
Value:	**0x00**	**0x00**	**0x00**	**0x00**

Figure 2.8.4.1.2: Example to read the currently active errors.

2.8.4.2 History of Errors

The history of errors is not implemented in pH Arc Sensors.

2.8.4.3 Definition of Errors

Bit #	Hex	Description
0	0x0000001	pH reading failure (this error occurs, when any other error is active)
		not available
5	0x0000020	Glass resistance too high
6	0x0000040	Glass resistance too low
7	0x0000080	Reference electrode resistance too high
8	0x0000100	Reference electrode resistance too low
		not available
15	0x0008000	Auxiliary electrode electrical potential too high
16	0x0010000	Auxiliary electrode electrical potential too low
17	0x0020000	Auxiliary electrode resistance too high
18	0x0040000	Auxiliary electrode resistance too low
		not available
25	0x2000000	Temperature sensor defective

Figure 2.8.4.3.1: Definition of errors "measurement".

Bit #	Hex	Description
1	0x0000002	Sensor failure (Quality value < 15%)

Figure 2.8.4.3.2: Definition of errors "calibration".

Bit #	Hex	Description
		not available

Figure 2.8.4.3.3: Definition of errors "interface". None is defined.

Bit #	Hex	Description
		not available
24	0x1000000	Internal communication error (between front-end and user-end)

Figure 2.8.4.3.4: Definition of errors "hardware".

2.8.5 Reading Definition of SIP and CIP

pH Arc Sensor are counting special cleaning events such as sterilizations or cleaning cycles by means of tracking typical temperature profiles (see chapter 2.8.2).

Register 4988 defines a typical temperature profile for SIP (sterilization in place) and register 4996 for CIP (cleaning in place). For the explanation the following values are given:

CIP temperature min: 80 °C   CIP temperature max: 100 °C   CIP time min: 30 minutes
SIP temperature min: 120 °C   SIP temperature max: 130 °C   SIP time min: 30 minutes

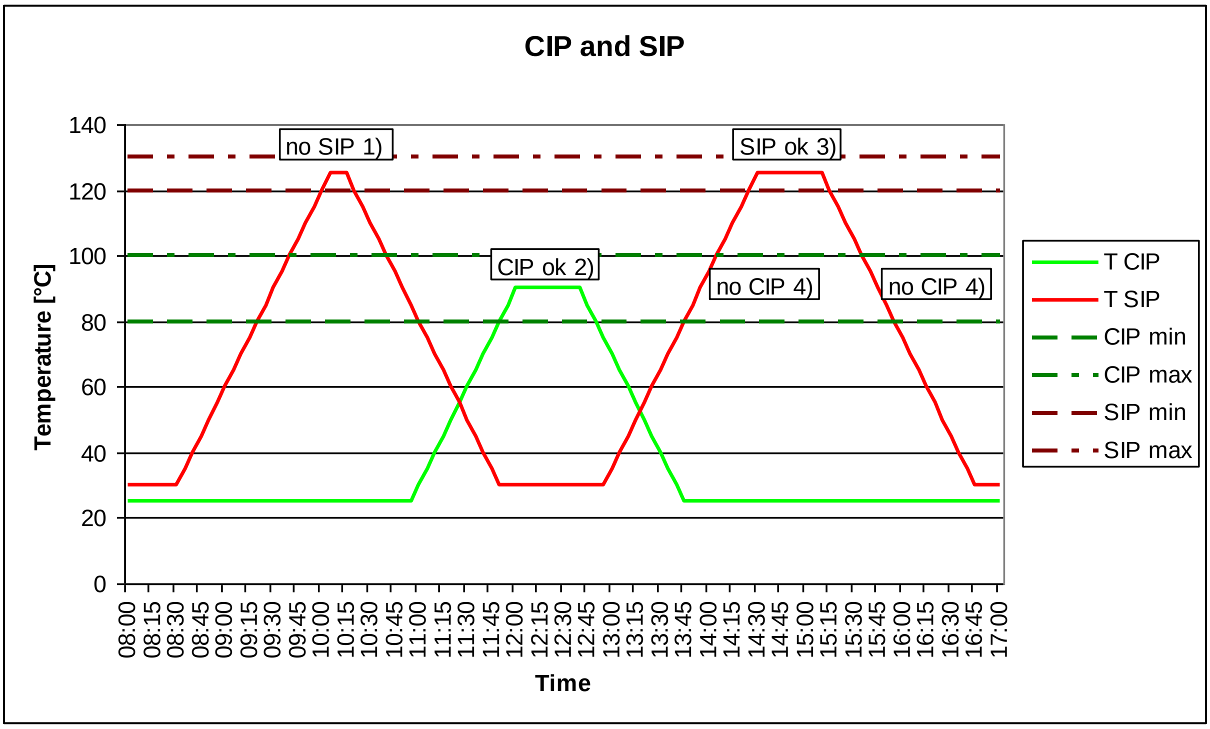


Figure 2.8.5.1: Definition of CIP and SIP cycles.
1) no SIP-cycle counted, because time too short <30 minutes.
2) CIP-cycle counted, because time >30 minutes and in CIP temperature range.
3) SIP-cycle counted, because time >30 minutes and in SIP temperature range.
4) no CIP-cycle counted, because of reaching the SIP-min limit.

Start register	Number of registers	Reg1 / Reg2	Reg3 / Reg4	Reg5 / Reg6	Reg7 / Reg8	Modbus function code	Read access	Write access
4988	8	SIP Tempera-ture min [°C]	SIP Tempera-ture max [°C]	SIP Process time min [min]	Empty	3, 4	U/A/S	S
4996	8	CIP Tempera-ture min [°C]	CIP Tempera--ture max [°C]	CIP Process time min [min]	Empty	3, 4	U/A/S	S

Figure 2.8.5.2: Definition of register 4988 and 4996.

Command: SIP definition		Modbus address: **4988** Length: **8**		Type: **16** Write
Parameter:	T min [°C]	T max [°C]	Time min [min]	Empty
Format:	Float	Float	Float	Float
Value:	**120**	**130**	**30**	**0**

Figure 2.8.5.3: Example to write the SIP definitions.

Command: SIP definition		Modbus address: **4988** Length: **8**		Type: **3** Read
Parameter:	T min [°C]	T max [°C]	Time min [min]	Empty
Format:	Float	Float	Float	Float
Value:	**120**	**130**	**30**	**0**

Figure 2.8.5.4: Example to read the SIP definitions.

Command: CIP definition		Modbus address: **4996** Length: **8**		Type: **16** Write
Parameter:	T min [°C]	T max [°C]	Time min [min]	Empty
Format:	Float	Float	Float	Float
Value:	**80**	**100**	**30**	**0**

Figure 2.8.5.5: Example to write the CIP definitions.

Command: CIP definition		Modbus address: **4996** Length: **8**		Type: **3** Read
Parameter:	T min [°C]	T max [°C]	Time min [min]	Empty
Format:	Float	Float	Float	Float
Value:	**80**	**100**	**30**	**0**

Figure 2.8.5.6: Example to read the CIP definitions.

2.8.6 Reading the Sensor's Quality Indicator

In register 4872 the sensor's quality indicator (0-100%) is given.

Start register	Number of registers	Reg1 / Reg2 (Float)	Modbus function code	Read access	Write access
4872	2	Quality [%]	3, 4	U/A/S	none

Figure 2.8.6.1: Definition of register 4872.

Command: Quality indicator		Modbus address: **4872** Length: **2**		Type: **3** Read
Parameter:	Quality [%]			
Format:	Float			
Value:	**100**			

Figure 2.8.6.2: Example to read the sensor's quality indicator.

The sensor's quality indicator is influenced by:

- Offset a pH 7
- Slope
- Errors

2.9 Sensor Identification and Information

2.9.1 General Information

General information about the sensor is available as shown in the figure below.

Start register	Number of registers	Reg1 to Reg8 (16 ASCII characters)	Example of content	Modbus function code	Read access	Write access
1024	8	Userend FW Date	2020-12-14	3, 4	U/A/S	none
1032	8	Userend FW	EPHUM034	3, 4	U/A/S	none
1040	8	Userend BL Date	2009-09-18	3, 4	U/A/S	none
1048	8	Userend BL	BL4UX001	3, 4	U/A/S	none
1056	8	Userend Ref	242480/00	3, 4	U/A/S	none
1064	8	Userend SN	not available	3, 4	U/A/S	none
1072	8	Userend (space holder)	not available	3, 4	U/A/S	none
1080	8	Userend (space holder)	not available	3, 4	U/A/S	none
1088	8	Frontend FW Date	2009-09-16	3, 4	U/A/S	none
1096	8	Frontend FW	EPHFI010	3, 4	U/A/S	none
1104	8	Frontend BL Date	not available	3, 4	U/A/S	none
1112	8	Frontend BL	not available	3, 4	U/A/S	none
1120	8	Frontend Ref	242828/02	3, 4	U/A/S	none
1128	8	Frontend SN	not available	3, 4	U/A/S	none
1136	8	Frontend (space holder)	not available	3, 4	U/A/S	none
1144	8	Frontend (space holder)	not available	3, 4	U/A/S	none

Figure 2.9.1.1: Definition of registers containing read-only sensor information.

Command: Userend Firmware		Modbus address: **1032**	Length: **8**	Type: **3** Read
Parameter:	Text			
Format:	Character			
Value:	**EPHUM034**			

Figure 2.9.1.2: Example to read register 1032.

2.9.2 Sensor Identification

Start register	Number of registers	Reg1 to Reg8 (16 ASCII characters)	Example of content	Modbus function code	Read access	Write access
1280	8	Sensor Ref	242111/01	3, 4	U/A/S	none
1288	8	Sensor name	Polilyte Plus	3, 4	U/A/S	none
1296	8	Sensor Lot	3214567	3, 4	U/A/S	none
1304	8	Sensor Lot date	22.02.2021	3, 4	U/A/S	none
1312	8	Sensor SN	0001001	3, 4	U/A/S	none
1320	8	Manufacturer part 1	HAMILTON Bonaduz	3, 4	U/A/S	none
1328	8	Manufacturer part 2	AG Switzerland	3, 4	U/A/S	none
1336	8	Sensor type	Arc e. pH Sensor	3, 4	U/A/S	none
1344	8	Power supply	007..030V 0150mW	3, 4	U/A/S	none
1352	8	Pressure range	0 ... 6 bar	3, 4	U/A/S	none
1360	8	Sensor ID	242111-0001001	3, 4	U/A/S	none
1368	8	a-length	120	3, 4	U/A/S	none
1376	8	(space holder)	not available	3, 4	U/A/S	none
1384	8	Electrical connection	VP 8.0	3, 4	U/A/S	none
1392	8	Process connection	PG 13.5	3, 4	U/A/S	none
1400	8	Sensing material	H-Glass	3, 4	U/A/S	none

Figure 2.9.2.1: Definition of registers containing sensor identification.

Command: Serial number		Modbus address: **1312**	Length: **8**	Type: **3** Read
Parameter:	Text			
Format:	Character			
Value:	**0001001**			

Figure 2.9.2.2: Example to read register 1312.

2.9.3 Free User Memory Space

These registers can be used to store any customer specific information in the sensor. There are different registers which can be read by everybody, but only specific operators can write them.

Start register	Number of registers	Reg1 to Reg8 (16 ASCII characters)	Example of content	Modbus function code	Read access	Write access
1536	8	Free user space U/A/S	*FREE_USERSPACE*	3, 4, 16	U/A/S	U/A/S
1544	8	Free user space U/A/S	*FREE_USERSPACE*	3, 4, 16	U/A/S	U/A/S
1552	8	Free user space U/A/S	*FREE_USERSPACE*	3, 4, 16	U/A/S	U/A/S
1560	8	Free user space U/A/S	*FREE_USERSPACE*	3, 4, 16	U/A/S	U/A/S
1568	8	Free user space A/S	*FREE_USERSPACE*	3, 4, 16	U/A/S	A/S
1576	8	Free user space A/S	*FREE_USERSPACE*	3, 4, 16	U/A/S	A/S
1584	8	Free user space A/S	*FREE_USERSPACE*	3, 4, 16	U/A/S	A/S
1592	8	Free user space A/S	*FREE_USERSPACE*	3, 4, 16	U/A/S	A/S
1600	8	Measuring point	242111-0001001	3, 4, 16	U/A/S	S
1608	8	Free user space S	*FREE_USERSPACE*	3, 4, 16	U/A/S	S
1616	8	Free user space S	*FREE_USERSPACE*	3, 4, 16	U/A/S	S
1624	8	Free user space S	*FREE_USERSPACE*	3, 4, 16	U/A/S	S
1632	8	Free user space others	*FREE_USERSPACE*	3, 4	U/A/S	none
1640	8	Free user space others	*FREE_USERSPACE*	3, 4	U/A/S	none
1648	8	Free user space others	*FREE_USERSPACE*	3, 4	U/A/S	none
1656	8	Free user space others	*FREE_USERSPACE*	3, 4	U/A/S	none
1664	8	Free user space others	*FREE_USERSPACE*	3, 4	U/A/S	none
1672	8	Free user space others	*FREE_USERSPACE*	3, 4	U/A/S	none
1680	8	Free user space others	*FREE_USERSPACE*	3, 4	U/A/S	none
1688	8	Free user space others	*FREE_USERSPACE*	3, 4	U/A/S	none
1696	8	Free user space others	*FREE_USERSPACE*	3, 4	U/A/S	none
1704	8	Free user space others	*FREE_USERSPACE*	3, 4	U/A/S	none
1712	8	Free user space others	*FREE_USERSPACE*	3, 4	U/A/S	none
1720	8	Free user space others	*FREE_USERSPACE*	3, 4	U/A/S	none
1728	8	Free user space others	*FREE_USERSPACE*	3, 4	U/A/S	none
1736	8	Free user space others	*FREE_USERSPACE*	3, 4	U/A/S	none
1744	8	Free user space others	*FREE_USERSPACE*	3, 4	U/A/S	none
1752	8	Free user space others	*FREE_USERSPACE*	3, 4	U/A/S	none

Figure 2.9.3.1: Definition of registers containing user information.

An important register is 1600, as it is the description of the measuring point. The information of this register is displayed on the Arc View Handheld in order to identify individual sensors.

Attention:

The Free User Memory Space is located in a memory which allows in total max 10'000 write operations.

Command: Info user		Modbus address: **1568**	Length: **8**	Type: **16** Write
Parameter:	Text			
Format:	Character			
Value:	**Hello World**			

Figure 2.9.3.2: Example to write 16 ASCII characters to register 1568 with operator A or S.

Command: Info user		Modbus address: **1568**	Length: **8**	Type: **3** Read
Parameter:	Text			
Format:	Character			
Value:	**Hello World**			

Figure 2.9.3.3: Example to read the register 1568 (written in Figure 2.9.3.1).

2.10 System Commands

2.10.1 Recall Sensor's Factory Settings

Using register 8192 you can recall the sensor manufacturer values (interfaces, calibration data and passwords), except the SIP and CIP data which remain unchanged. By sending the recall value "911", all configuration values will be set to default.

Start register	Number of registers	Reg1 / Reg2	Modbus function code	Read access	Write access
8192	2	Recall by value 911	16	none	S

Figure 2.10.1.1: Definition of register 8192.

Command: Recall		Modbus address: **8192**	Length: **2**	Type: **16** Write
Parameter:	Recall			
Format:	Decimal			
Value:	**911**			

Figure 2.10.1.2: Example to write the restore command.

3 Abbreviations

AO	Analog Output Interface
CP	Calibration Point
ECS	Electrochemical Sensor Interface
PMC	Primary Measurement Channel
SMC	Secondary Measurement Channel

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