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User Guide

UG000403

TDC-GP30-F01 Calibration Engine

Data Collection and Coefficient Generation

(Former GP30 Vol.5)

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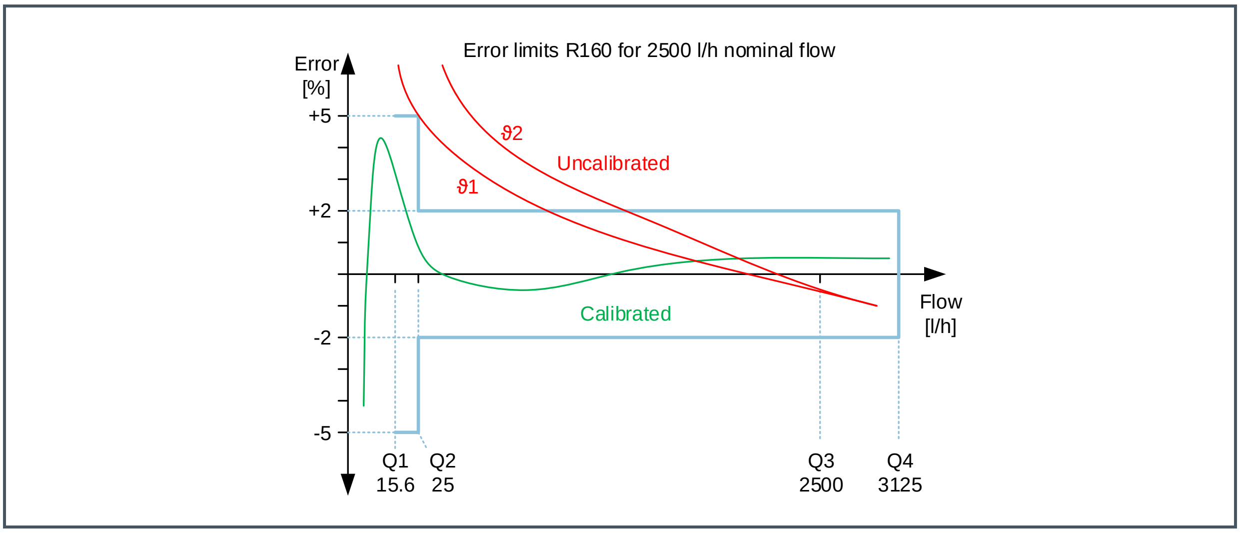
1 Introduction

This document describes the usage of the calibration engine as a separate software module for TDC-GP30-F01. By using the calibration engine, basically a set of coefficients is generated which allows to calibrate the sensor (spool-piece). The set of coefficients is then stored to the TDC-GP30-F01 and is consequently used by the chip's firmware to apply the non-linear correction.

The document is organized like a "cookbook", i.e. it walks the user step by step through the process, from collecting the relevant data to the generation of the set of coefficients.

Water meters intended for the measurement of volumes of clean, cold or heated water in residential, commercial and light industrial use are within the scope of the measuring instruments directive (MID) 2004/22/EC. Annex MI-001. The permissible error limits are regulated across Europe by this MID and correspond with the hitherto familiar values (see appendix 5.2). Standards in other regions of the world give similar limits. This means that water meters may measure with an accuracy of ±5% in the lower flow range and ±2% in the permanent load range. The instruments are classified by the Q3/Q1 ratio. The markings of the flow points are:

Figure 1:
Typical MID Limits



Q1 Minimum flow rate
Q2 Transitional flow rate
Q3 Nominal flow rate
Q4 Maximum flow rate

2 Getting Started

The major task in preparation is an extensive data collection. The more data and the better the data, the better will be the linearization result. The measurement points shall cover the full operating range with respect to flow and temperature. Repeating, randomizing and averaging will give further improvement. A good sample size would be:

- Characterize your devices over the whole parameter space.
  4 temperatures x 10 flows = 40 measurements
- Take care of systematic errors – repeat, randomize and average .
  3 x 4 temperatures x 10 flows = 120 measurements
- Verify and optimize to minimize noise.
  3 x 3 x 4 temperatures x 10 flows = 360 measurements
- Repeat that over a representative sample of spool pieces

It is assumed, that the flow/temperature reflects stable readings within a controlled environment (water flow calibration stand).

Information

This effort is needed only for the characterization, not in series production.

Figure 2:
Ideal Distribution of Measurement Points

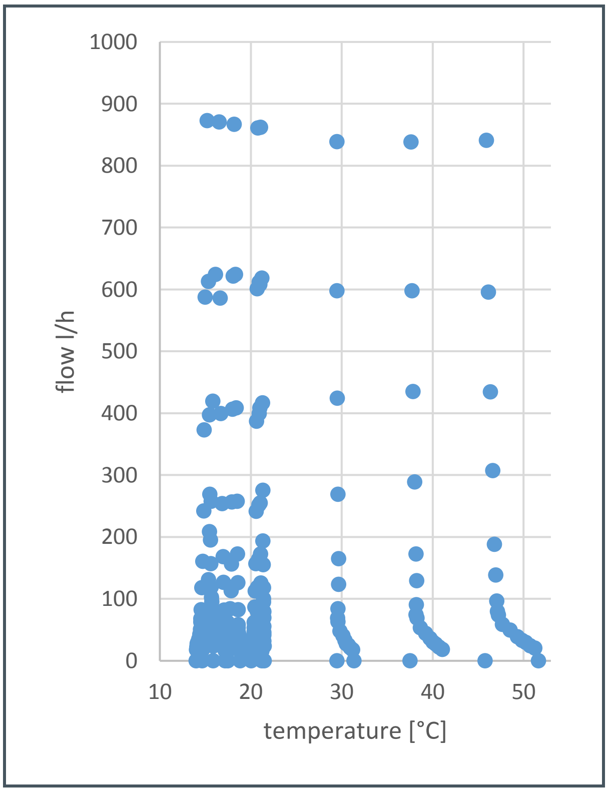
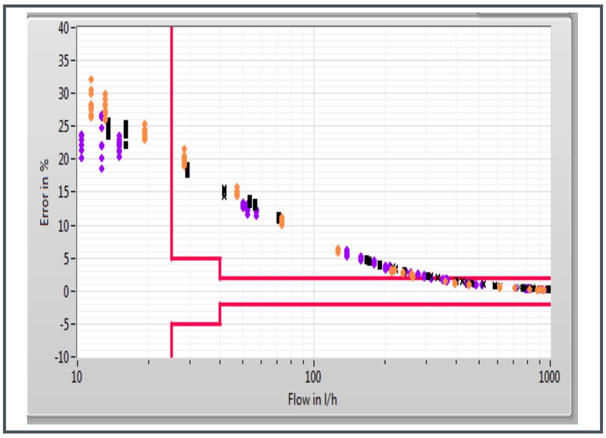


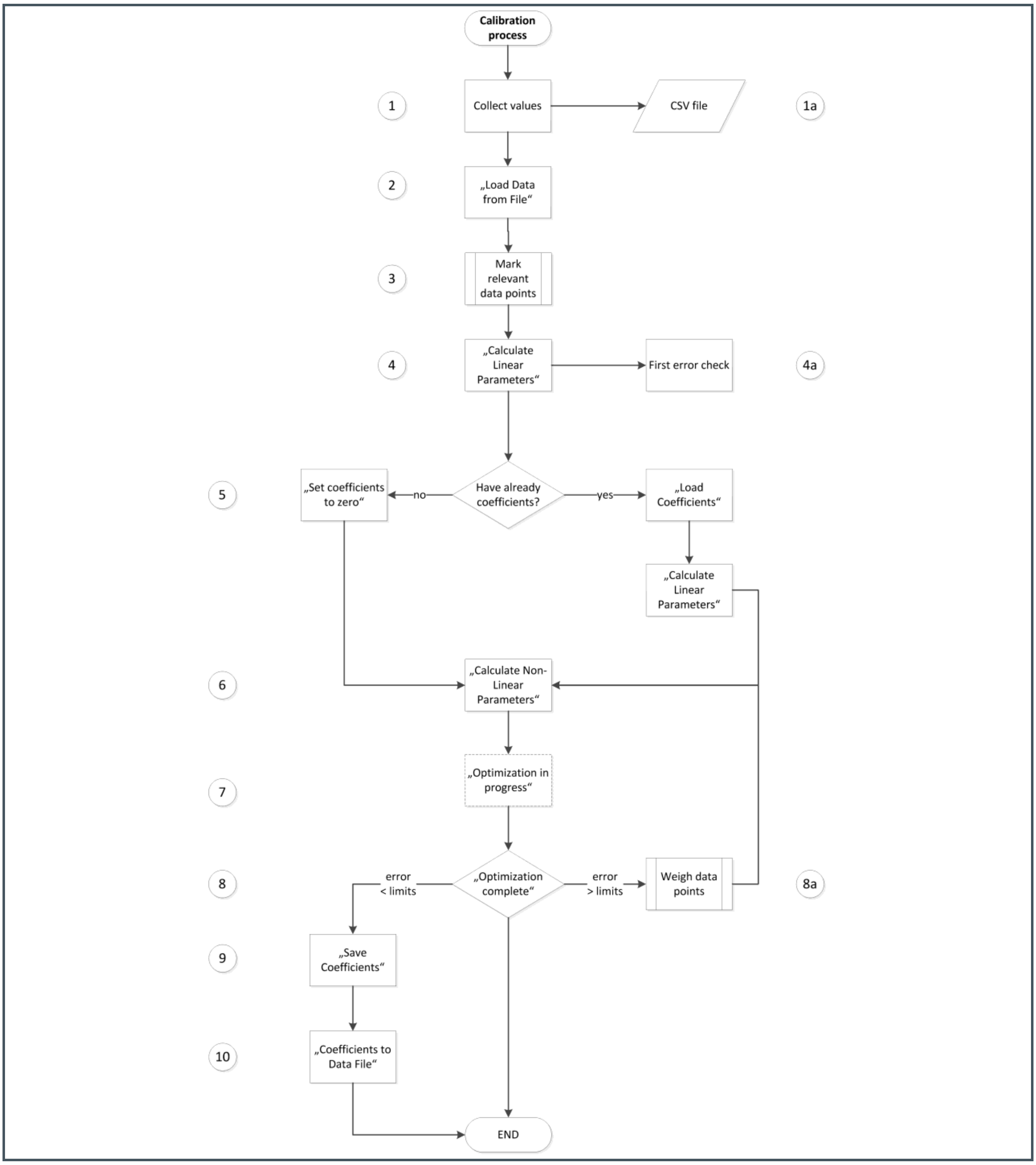
Figure 3:
Typical Results before Calibration



3 Calibration Process

3.1 Calibration Process Flowchart

Figure 4:
Top-Level Flowchart



The flowchart in Figure 4 describes the calibration process on a top level. The major steps are numbered on the left hand side of the flow chart and will be addressed in detail throughout the document. The process steps written in apostrophes, e.g. “Calculate Linear Parameters”, indicate that these refer to a label or button in the software GUI. In the following the individual steps are described in more detail.

3.2 Collect Data (1)

To feed the calibration engine with input, several data points of flow and temperature must be collected. In particular, the following data needs to be acquired:

Line numbering DIFTOF Sum avg SUMTOF Sum avg Flow Temperature

It is recommended to collect several hundred data points for each spool-piece for characterization. Thereby, zero flow measurements and high flow measurements is a must, also minimum two different temperatures (e.g. room temperature and 50 °C). Obviously the more data points, the better, however experience shows that it should be at least 100 data points.

Information

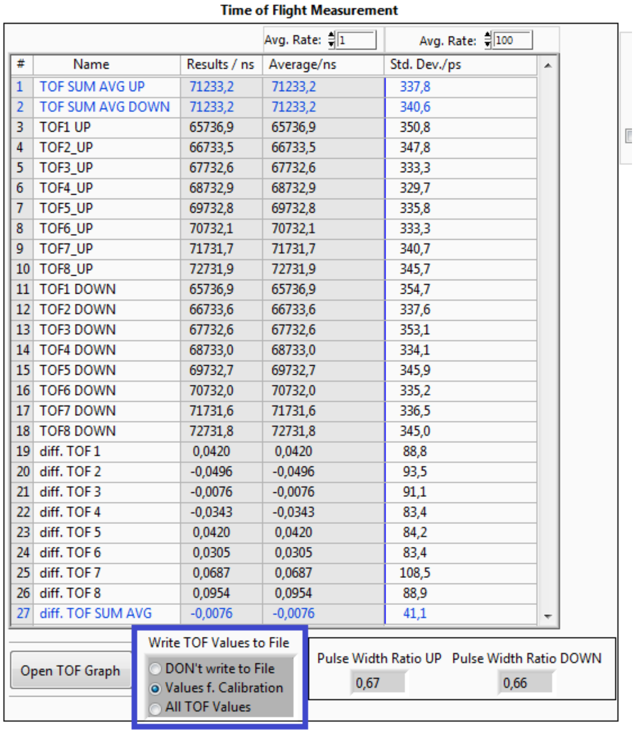
In the process of characterization many data points are usually collected. Later, once the characterization for a representative number of spool-pieces has been done, the individual spool-piece may be calibrated by taking two points only, presuming a stable production.

The data collection of “DIFTOF Sum avg” and “SUMTOF Sum avg” at a certain flow/temperature can be easily collected with the evaluation software of TDC-GP30 (from v1.3.8 on).

Information

For diffTOF and sumTOF use the raw data as shown above. Do not use the values calculated by the firmware, which are stored in RAM addresses 7 and 8 as they are already filtered.

Figure 5:
Evaluation Software - Measurements Tab



#	Name	Results / ns	Average/ns	Std. Dev./ps
1	TOF SUM AVG UP	71233,2	71233,2	337,8
2	TOF SUM AVG DOWN	71233,2	71233,2	340,6
3	TOF1 UP	65736,9	65736,9	350,8
4	TOF2_UP	66733,5	66733,5	347,8
5	TOF3_UP	67732,6	67732,6	333,3
6	TOF4_UP	68732,9	68732,9	329,7
7	TOF5_UP	69732,8	69732,8	335,8
8	TOF6_UP	70732,1	70732,1	333,3
9	TOF7_UP	71731,7	71731,7	340,7
10	TOF8_UP	72731,9	72731,9	345,7
11	TOF1 DOWN	65736,9	65736,9	354,7
12	TOF2 DOWN	66733,6	66733,6	337,6
13	TOF3 DOWN	67732,6	67732,6	353,1
14	TOF4 DOWN	68733,0	68733,0	334,1
15	TOF5 DOWN	69732,7	69732,7	345,9
16	TOF6 DOWN	70732,0	70732,0	335,2
17	TOF7 DOWN	71731,6	71731,6	336,5
18	TOF8 DOWN	72731,8	72731,8	345,0
19	diff. TOF 1	0,0420	0,0420	88,8
20	diff. TOF 2	-0,0496	-0,0496	93,5
21	diff. TOF 3	-0,0076	-0,0076	91,1
22	diff. TOF 4	-0,0343	-0,0343	83,4
23	diff. TOF 5	0,0420	0,0420	84,2
24	diff. TOF 6	0,0305	0,0305	83,4
25	diff. TOF 7	0,0687	0,0687	108,5
26	diff. TOF 8	0,0954	0,0954	88,9
27	diff. TOF SUM AVG	-0,0076	-0,0076	41,1

By activating the bullet point “Values f. Calibration” a text file with the TOF measurements and a corresponding time stamp is generated.

Figure 6:
Data File (German format with “,” for decimal separation)

	A	B	C	D	E	F	G	H	I	J	K
1	19.08.2016 10:01	s Elapsed	diffTOFSum avg	sumTOFSum avg	diffTOF1	sumTOF1	PW UP	PW DOWN	AM UP	AM DOWN	Status Register
2	10:01:21	0	-0,053406	146879,062017	0,076294	135893,630981	0,406250	0,406250	323,977284	323,569383	
3	10:01:31	9,54	-0,043551	146893,688520	0,083923	135908,317566	0,406250	0,406250	324,711111	323,616790	
4	10:01:31	9,69	-0,132243	146893,728892	-0,213623	135908,218384	0,406250	0,406250	324,673196	323,265271	
5	10:01:31	9,84	-0,048319	146893,783569	0,000000	135908,416748	0,406250	0,406250	323,428638	324,368244	
6	10:01:31	9,98	-0,078201	146893,834432	-0,152588	135908,462524	0,406250	0,406250	323,947451	323,306855	
7	10:01:32	10,11	-0,015895	146893,723806	-0,019073	135908,374786	0,406250	0,406250	323,180122	323,674183	
8	10:01:32	10,23	-0,004133	146894,097964	-0,099182	135908,859253	0,406250	0,406250	323,925669	323,941510	

The time stamp can be used to combined these data with the flow and temperature data collected from the reference devices on the test bench.

For noise suppression, averaging over a sufficient amount of data points is crucial. For stability reasons, measurements should be averaged. This includes the flow data from the reference meter and should therefore be done after data collection. It is important that the SUMTOF, DIFTOF and reference flow data are collected during the same period of time. The averaging method should be the same for all, too.

It is not necessary at all that the reference temperature is precise and collected for all measurements. We calculate internally the temperature based on SUMTOF. In fact, for characterization we need only two temperature measurement point, ideally taken at zero flow, to calibrate this temperature calculation. The calibration coefficients will be calculated on base of SUMTOF, and so will be done the flow correction during operation.

Example: During a period of 5 minutes data are collected for SUMTOF and DIFTOF. In parallel, the amount of water that passed during this period is measured by means of a weight scale. Then a simple averaging of the SUMTOF and DIFTOF data is fine.

3.3 Reformatted CSV File (1a)

With the captured (and optionally averaged) data for diffTofSum avg and sumTofSum avg and the corresponding known flow/temperature (coming from your water meter test stand), you can compile the CSV data file for the calibration engine in the following format:

Figure 7:
Reformatted Data File

	A	B	C	D	E	F	G	H
1	No.	Use.	Spool Piece	Weighted	diffTOF	sumTOF	Flow	Temp. File
2	1				0.02	138419.8708	0	15
3	2				0.03	135554.9403	0	30
4	3				0.035	134091.9958	0	42
5	4				0.03	133110.3593	0	55
6	5				440.3514578	138419.8708	5215	15
7	6				412.9017512	135554.9403	5215	30
8	7				397.8488442	134091.9958	5215	42
9	2				387.0196398	133110.3593	5215	55
10	3				1.412693226	138419.8708	13	15
11	4				1.800557904	138419.8708	16.9	15

The data should be marked in the third column with a spool piece number for the device under test, e.g. SP1 in our case.

For convenience, two measurements that will be used for temperature calibration should be marked in the second column entering a “t”. Best are zero flow measurements at a low and high temperature. More details are given in section 3.6. The weight factor for the individual measurements should be set by default to 1.

Figure 8:
Reformatted Data File 2

	A	B	C	D	E	F	G	H
1	No.	Use.	Spool Piece	Weighted	diffTOF	sumTOF	Flow	Temp. File
2	1	t	SP1	1	0.02	138419.8708	0	15
3	2		SP1	1	0.03	135554.9403	0	30
4	3		SP1	1	0.035	134091.9958	0	42
5	4	t	SP1	1	0.03	133110.3593	0	55
6	5		SP1	1	440.3514578	138419.8708	5215	15
7	6		SP1	1	412.9017512	135554.9403	5215	30
8	7		SP1	1	397.8488442	134091.9958	5215	42
9	2		SP1	1	387.0196398	133110.3593	5215	55
10	3		SP1	1	1.412693226	138419.8708	13	15
11	4		SP1	1	1.800557904	138419.8708	16.9	15

Information

- The first column (line numbering) and the three spare columns after that are mandatory to have in the CSV sheet, as well as the order of the data points as illustrated.
- In data sets with multiple spool pieces the data need to be sorted by spool piece. Data for one spool piece should follow each other in one block.

Important: The post decimal notation of the number in the CSV file may vary with your operating system (OS) and/or language settings of your computer. E.g., if you are in a country where the decimal point is represented by a comma instead dot (e.g. Germany), then the CSV needs to be adapted accordingly to match the following format as text (comma "," as delimiter, point "." As decimal separator , no thousands separator):

Text format:

No.,Use.,Spool Piece,Weighted,diffTOF,sumTOF,Flow,Temp. File,Temp. Calc.,Velocity,Prop.Factor,Temp. Range,Onom.,Onon-lin.,Error pre Solver,Error after Solver

1,tz,SP1,1,0.02,138419.8708,0,15,14.67,1466.29,,,,,,,

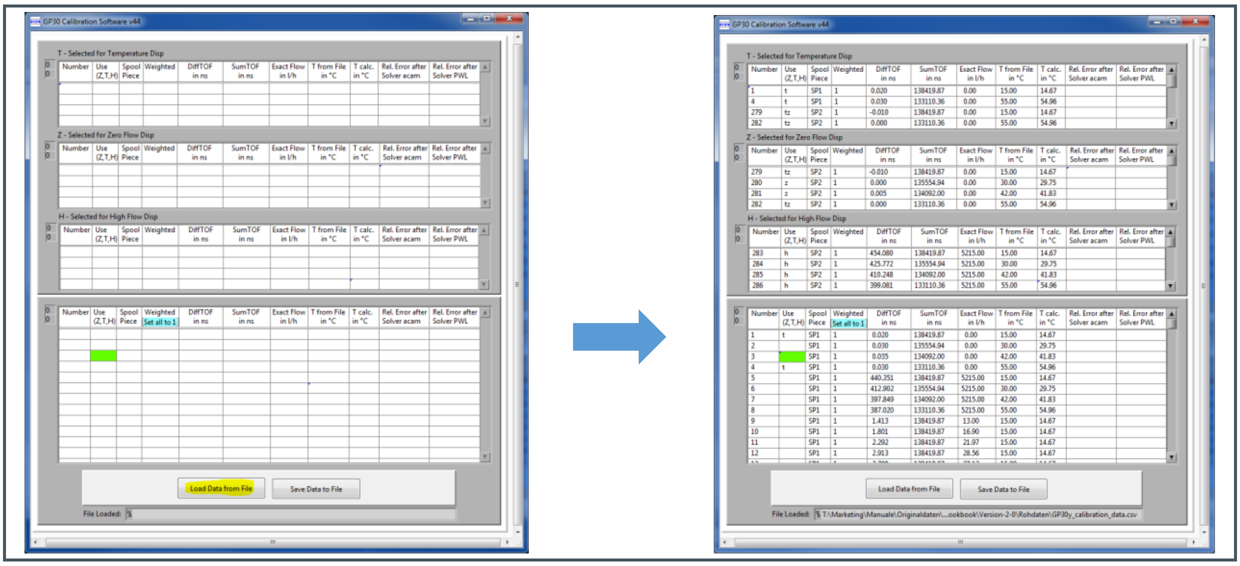
2,z,SP1,1,0.03,135554.9403,0,30,29.75,1509.17,,,,,,,

3,z,SP1,1,0.035,134091.9958,0,42,41.83,1532.04,,,,,,,

3.4 Load Data into Calibration Engine (2)

Once you have gathered your data points in the CSV file, you can load it into the software's GUI. The calibration engine is a separate software module, named GP30y Calibration44, to be started as a stand-alone executable. The calibration software pops up with the following window:

Figure 9:
Load Data from File



3.5 Mark Relevant Data Points (3)

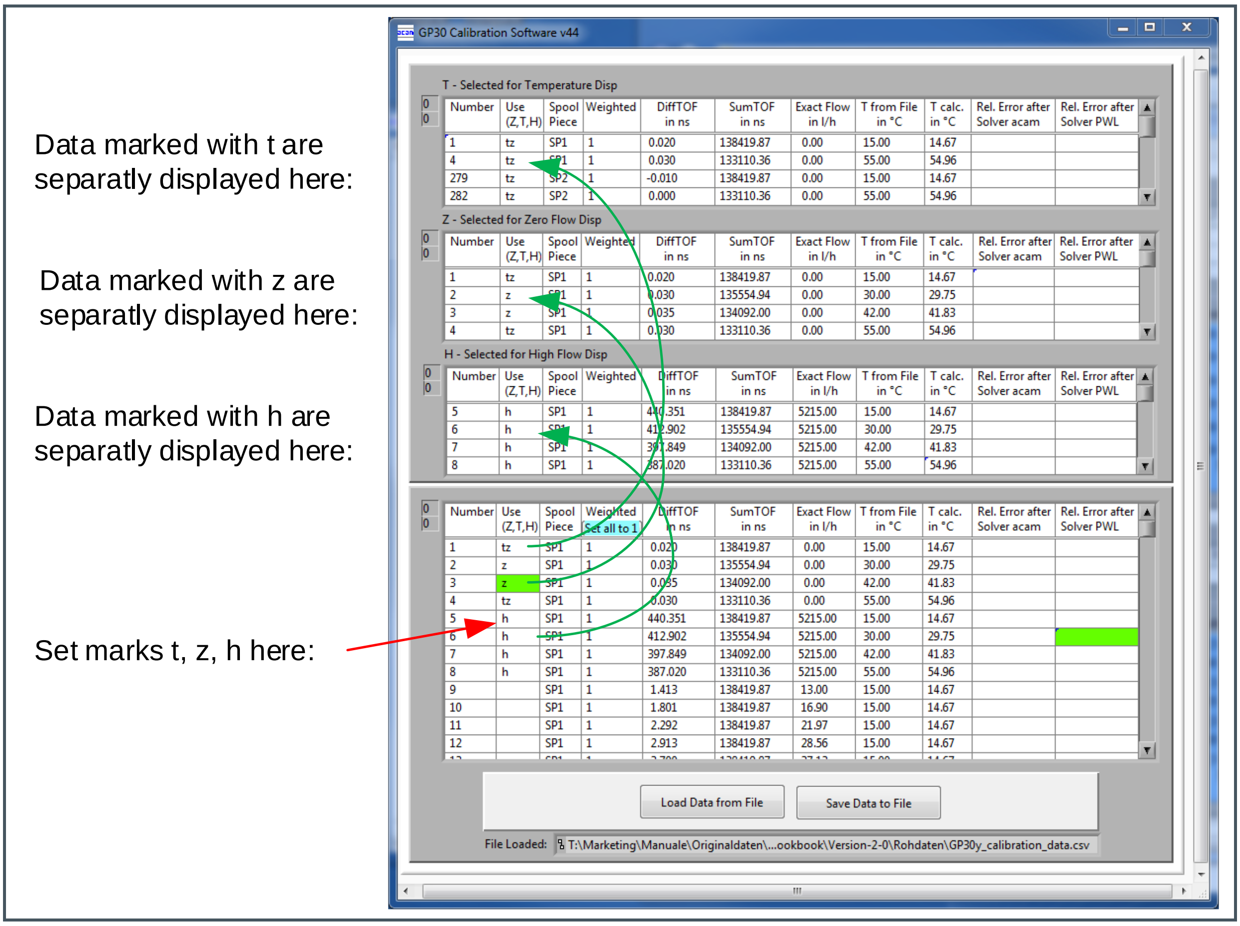
Now you need to mark the relevant data points to tell the software which data points you want to select for e.g. zero flow, high flow (a flow > Qn) and of course the (minimum two) temperatures. There is a letter for each of these three categories (z,t,h), and you can simply mark the data points by putting the corresponding letter into the second column.

Figure 10:
Data Markups

Label	Meaning	Minimum to Mark	Comments
Z, z	Zero flow	1 (4 recommended)	Optimally 4 zero flows at 4 different temperatures
T, t	Temperature	2	
H, h	High flow	1 (4 recommended)	4 high flows at **4 different temperatures**

Example:

**Figure 11:
Marking of Data Points**



As you can see from the example, it is also possible to combine the letters in one line, e.g. z with t by putting, “z,t” or “zt”. The minimum number of data points you need to mark is listed in the table above; and also the recommended number. Of course it is possible to mark more data points than the minimum. The selection of data points should be based on your own estimation of the measurement reliability, i.e. select the data points “you trust in”. For example, if you are sure that a flow was quite stable when capturing high flow, then it is good to mark this one instead of others, which may have not been stabilized to the same degree when captured.

For the very same purpose there is another way to “weigh” different data points stronger than others. For this, there is the column “Weighted”, which allows you to set a numerical value of either 0, 1, or above. 0 means, not to take the data point into consideration, 1 means the “standard weighing”, and any value above that, makes the calibration algorithm considering this value more than others. Usually, in the first round of the non-linear calibration run, the weighing is equal for all data points, except you already want to alter the weighing at this point by e.g. excluding some data points. You can use “(Set all to 1)” as a button to set the whole column to the default of “1”.

Information

Make sure you weighed the data points, otherwise the calibration run will not start!

Once you have the marking of the relevant data points done and weighted them, the data points are transferred to the upper tables and divided into temperature, zero- and high flow.

Information

For the data points where no temperature was given from the user, the temperature is calculated and put into the column “T calc. in °C” on the basis of the speed of sound.

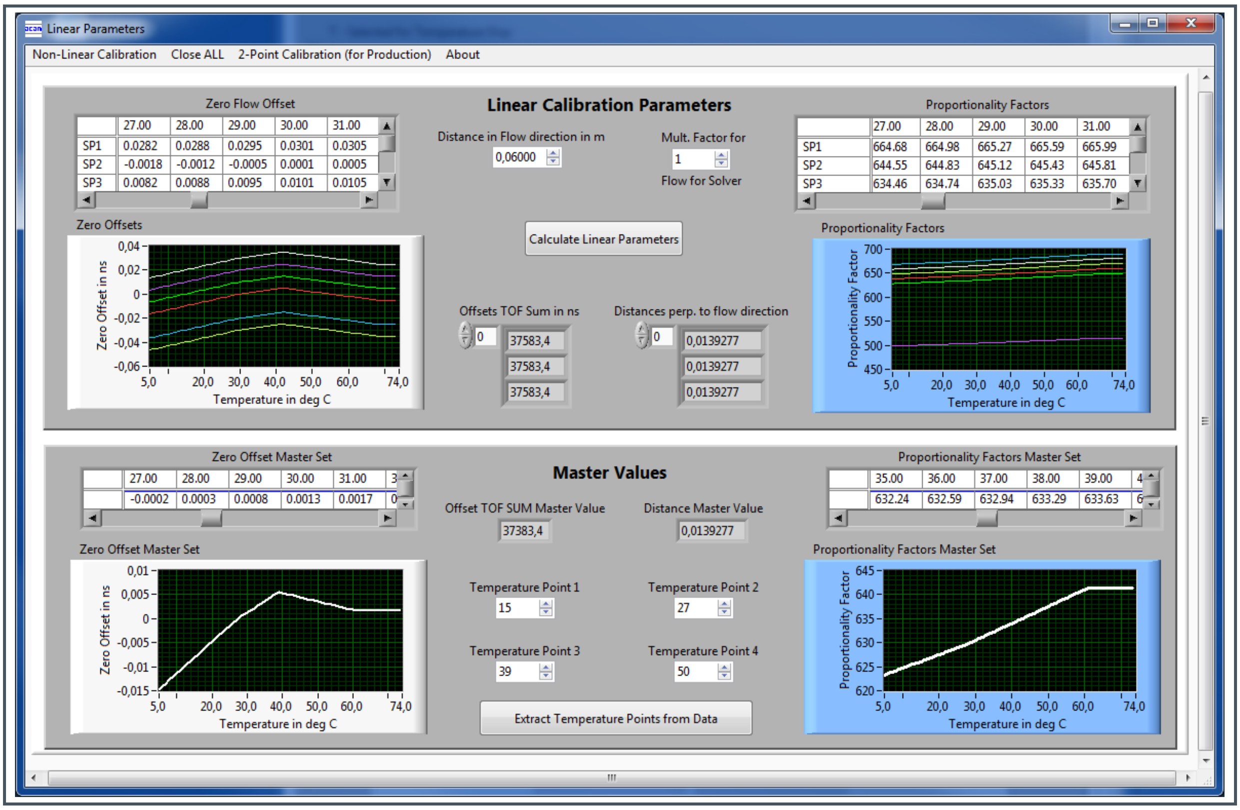
3.6 Linear Parameters (4)

Once the relevant data points are marked, the linear parameters can be calculated. Switch to the “linear Parameters” window.

The parameters for Linear calibration do a first correction over temperature. To have a good quality of results we decided to correct offset and proportionality in three temperature ranges, defined by four temperature points. Those points can be generated by the calibration engine, pressing “Extract temperature points from data”. They can be entered manually, too. Later, during 2-point calibration in production, offset and proportionality factors for all three ranges need to be updated.

Press “Calculate Linear Parameters” button and the calculations are done:

Figure 12:
Linear Calibration Parameters

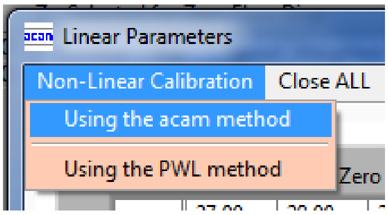


The next step is to do the non-linear calibration. Two methods are available:

- **ams** proprietary method, treating errors at low flow, needs only a low number of coefficients. Not applicable for all kind of meters.
- Piecewise linear (PWL), applicable for all kinds of meters, may need high number of coefficients and therefore memory

The method is selected under menu item “Non-Linear Calibration” with the label “acam method”:

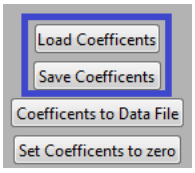
Figure 13:
Non-Linear Calibration



3.7 Using Given Coefficients (5)

In the next step, the user sets the coefficients either to zero by the corresponding button or selects a formerly determined set of coefficients as a basis for the non-linear calibration algorithm.

Figure 14:
Loading Coefficients



Loading and using already existent coefficients can have the purpose of improving the set of coefficients. If it is the initial calibration run, then setting the coefficients to zero is the default option.

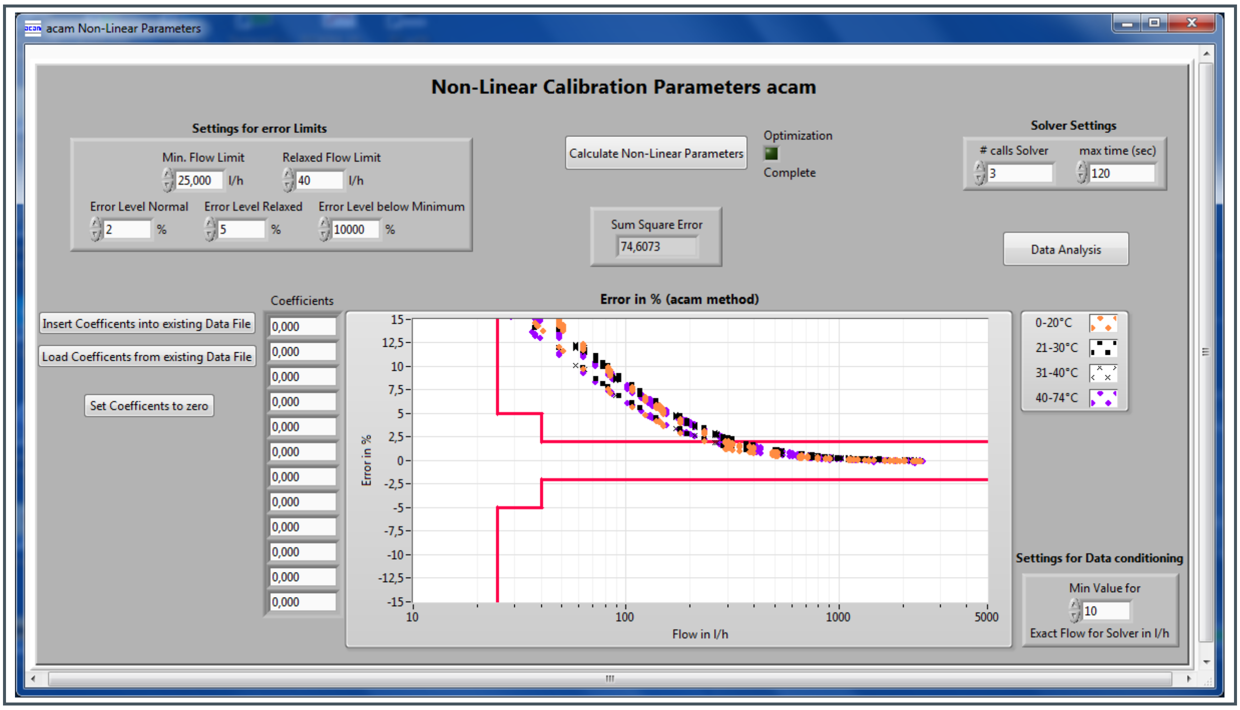
Information

If you choose to load an existing set of coefficients, you need to click on "Calculate Linear Parameters" again to update the data set for the engine.

3.8 Non-Linear Calibration, ams Method (6)

For the **ams** method the following window pops up:

Figure 15:
Linear Calibration Parameters ams

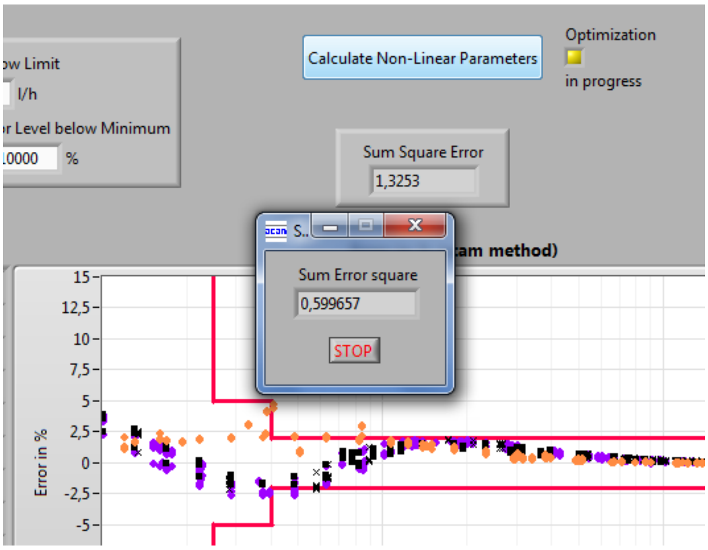


In the field on the top left the error limits according to the customers specification can be set. In this example the limit Q1 is 25 l/h and Q2 = 40 l/h with limits 5% and 2%.

The coefficients are calculated in an iterative manner, reducing the calculated error. The number of solver runs can be set on the right and the current error value is displayed in the middle. The graph shows the distribution of the corrected data. Four temperature ranges have different colors to simplify interpretation.

During Optimization, the current error value is displayed.

Figure 16:
Error Display



The optimization process can be stopped at any time. An error window will pop up and show those data points that exceed the error limits.

Figure 17:
Error Data Exceeding Limits

Display Errors over Limit acam

Sort by Error Size

Ascending

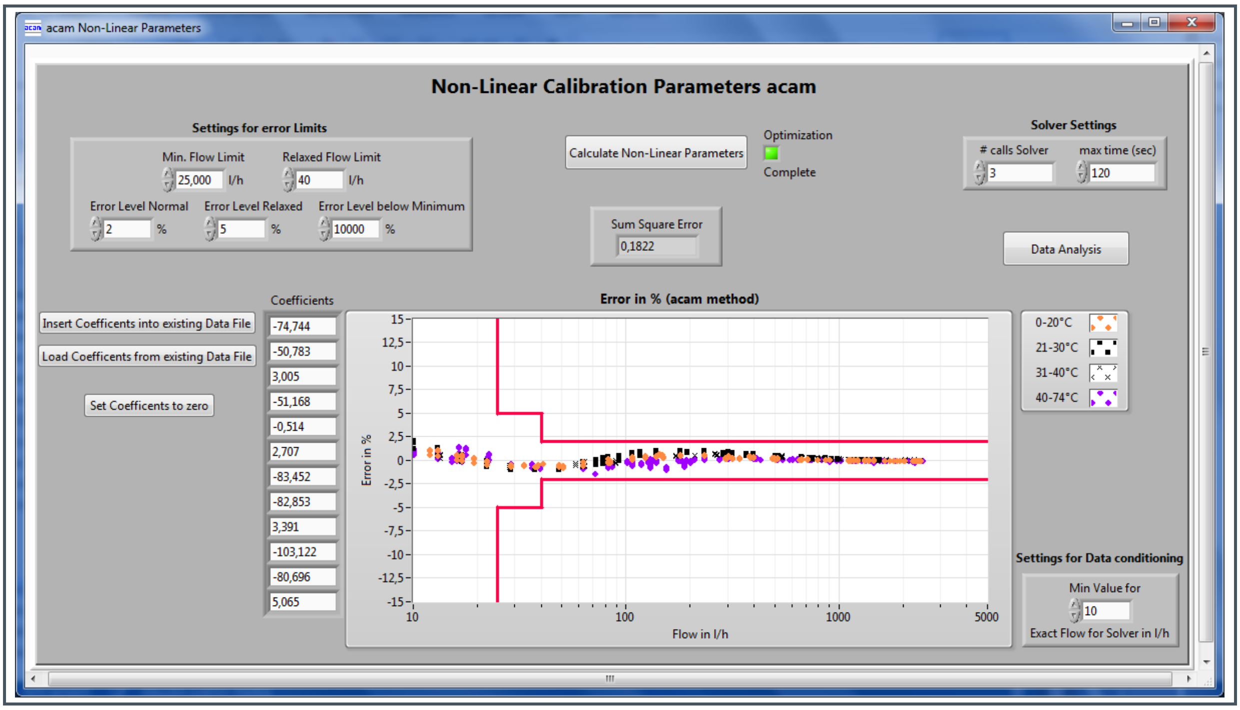
Descending

Errors over the Limit

Number	Use (Z,T,H)	Spool Piece	Weighted	DiffTOF in ns	SumTOF in ns	Exact Flow in l/h	T from File in °C	T calc. in °C	Rel. Error after Solver
14		SP1	1	4.698	138419.87	48.27	15.00	14.67	3.684898
15		SP1	1	5.968	138419.87	62.75	15.00	14.67	4.087980
16		SP1	1	7.589	138419.87	81.57	15.00	14.67	4.116165
17		SP1	1	9.668	138419.87	106.04	15.00	14.67	3.813859
18		SP1	1	12.346	138419.87	137.86	15.00	14.67	3.287911
19		SP1	1	15.808	138419.87	179.22	15.00	14.67	2.660768
20		SP1	1	20.299	138419.87	232.98	15.00	14.67	2.035698
55		SP1	1	5.368	134092.00	62.75	42.00	41.83	-2.330933
56		SP1	1	6.845	134092.00	81.57	42.00	41.83	-2.517694
57		SP1	1	8.738	134092.00	106.04	42.00	41.83	-2.193896
72		SP1	1	2.521	133110.36	28.56	55.00	54.96	5.046237
74		SP1	1	4.100	133110.36	48.27	55.00	54.96	2.267585
89		SP1	1	5.050	134485.78	57.99	38.25	38.05	-6.287069
92		SP1	1	11.932	132740.60	154.02	63.99	64.11	7.450438
94		SP1	1	13.548	139369.58	149.15	11.32	10.98	3.475250
97		SP1	1	13.043	137843.40	148.01	17.48	17.17	2.841997
104		SP1	1	4.209	140815.76	40.45	6.51	6.17	5.891615
105		SP1	1	5.983	138492.91	62.81	14.70	14.37	4.202114
119		SP1	1	10.144	132823.22	129.20	61.39	61.45	6.592687

In the end, with successful optimization all data points should be within the limits:

Figure 18:
Data within Limits



The final coefficients are displayed on the bottom left. Form there they can be inserted into an existing firmware data file.

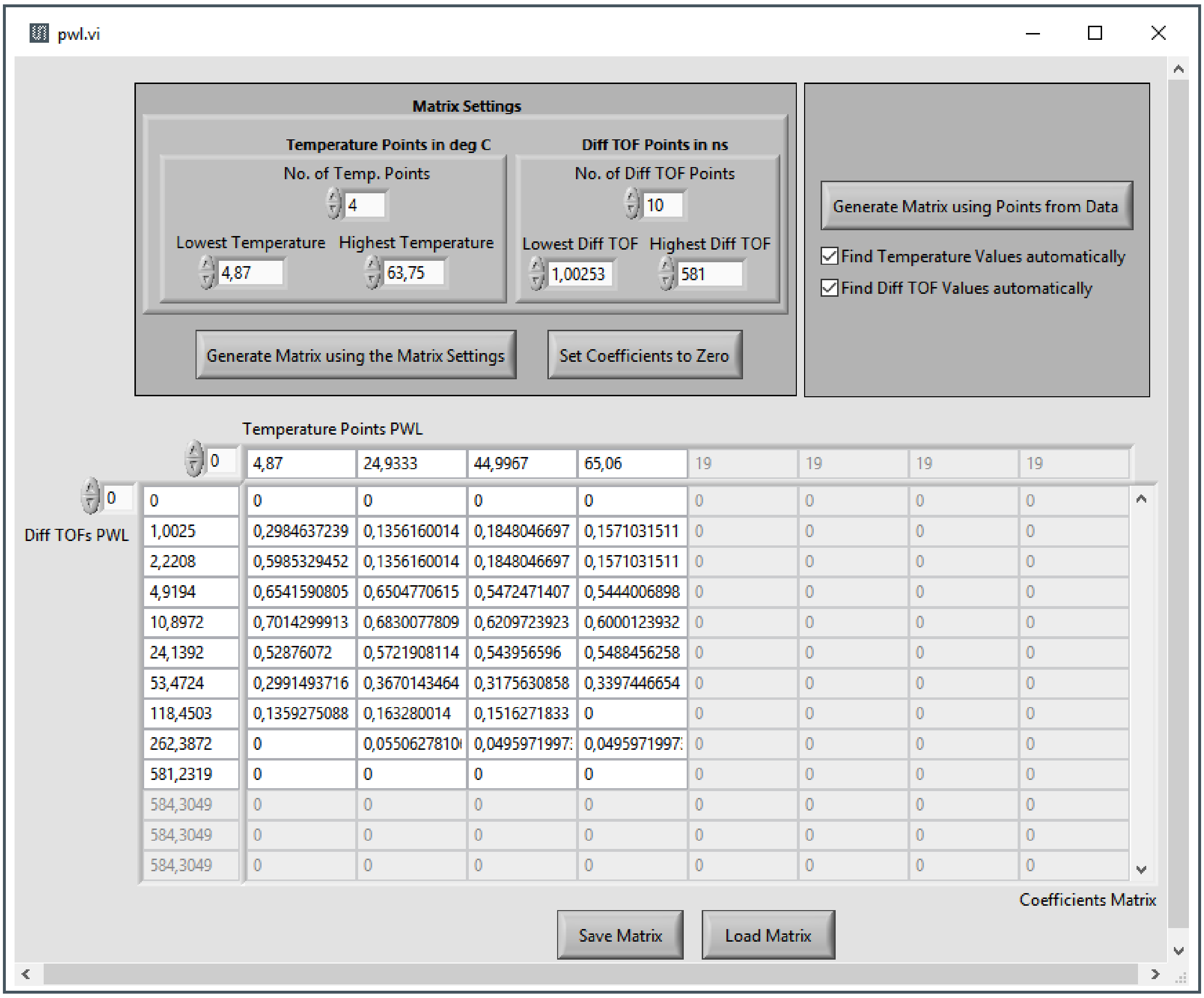
At start of optimization, existing coefficients may be loaded from a file (imported from a data file). Otherwise they should be set to zero to start optimization from the beginning.

3.9 Non-Linear Calibration, PWL Method (6a)

The piecewise linear correction is a well-known method to linearize sensors. Depending on the number of partitions this method allows correction of any shape of non-linearity. The memory size limits the precision.

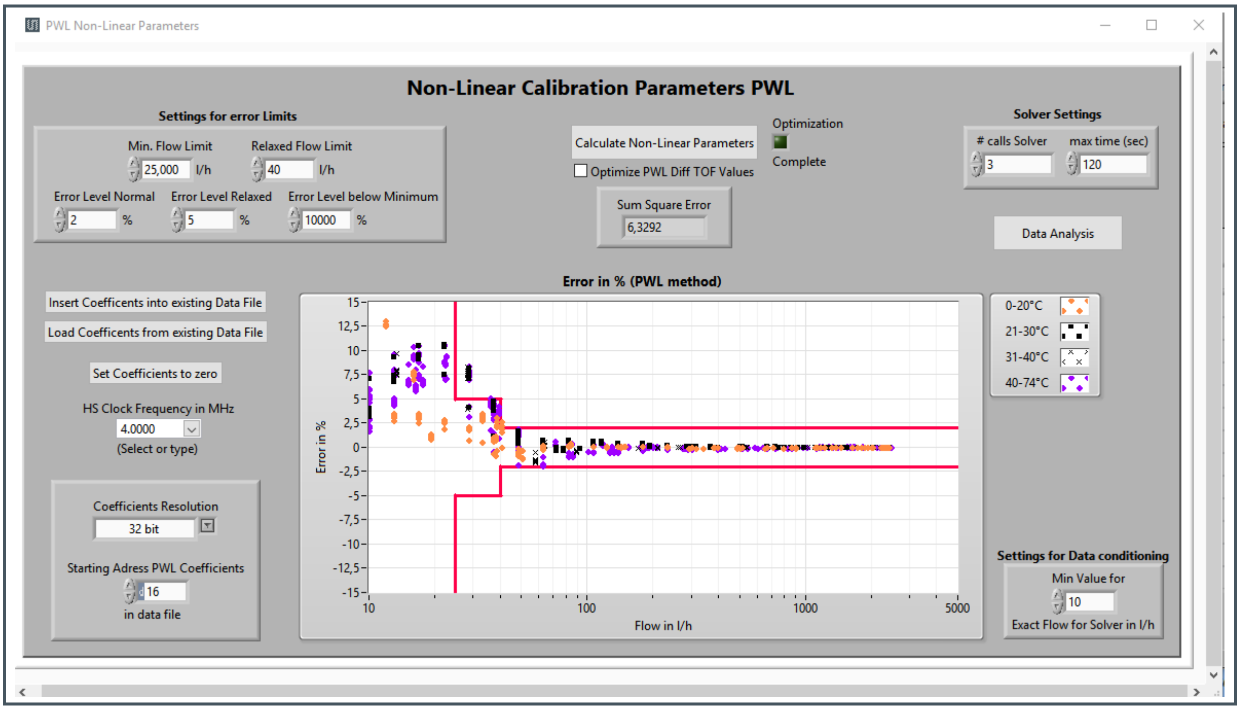
In the calibration engine the user can set the number of temperature and flow points manually of by using the automatic generation of the matrix.

Figure 19:
PWL Partitions



This matrix is the basis for the following run for error-minimization to get the calibration coefficients.

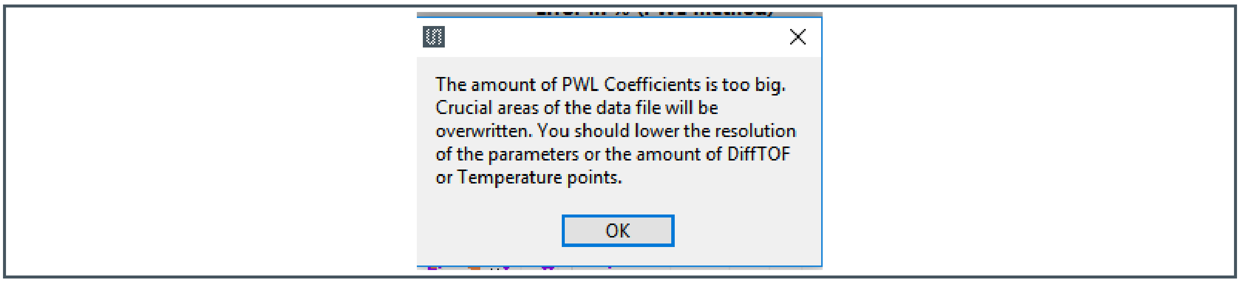
Figure 20:
Coefficient Determination



The coefficients can be inserted directly into a data file. The format and memory allocation in the firmware data is fully managed by the calibration engine.

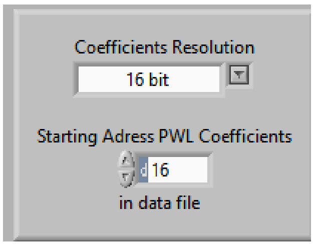
In advance, there will be a check whether there is enough memory in the firmware data with the given coefficient size and number of coefficients. In an error case the following message will pop up:

Figure 21:
Error Message



A first reaction will be to reduce the resolution of the coefficients, e.g. from 32 bit to 16 bit:

Figure 22:
Coefficient Format

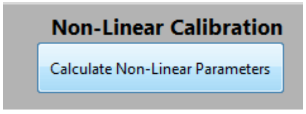


The starting point of the firmware data is by default address 16. It can be reduced to address 5 or even 2 if the error counters are not used.

3.10 Calculate Non-Linear Parameters

The goal of the calibration engine's algorithm is to minimize the error and come into the outlined error band (red lines, which represent ±2% error band) with all data points. To achieve this, **ams** proprietary calibration algorithm is applied and mainly the non-linear correction at low flows is in the main focus. You can start the calibration engine by pressing the corresponding button:

Figure 23:
Non-Linear Parameters

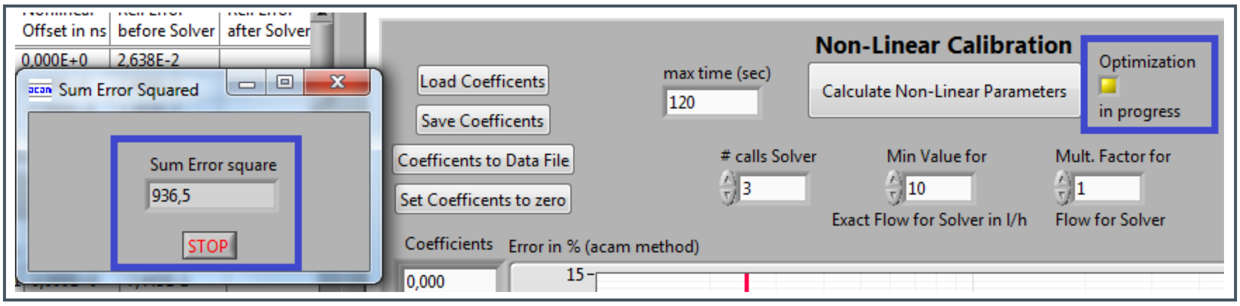


By the field "# calls Solver" you can set the number of runs the calibration engine should run. The maximum time (time-out) for the engine can be configured by adjusting the value in "max time (sec)". By the field "Min Value Exact Flow for Solver" you can set a lower limit for flow values to be ignored by the engine. This can make sense in cases the low flows are hard to measure accurately and hence should be ignored. The "Mult.Factor for Flow for Solver" is an additional scaling factor which may be used in technical support – its default value is "1".

3.11 Optimization in Progress (7)

By pressing the button, the algorithm in the background starts, and the ongoing calculation is shown by a separate window popping up as well as a yellow-lit LED with the label "Optimization in progress".

Figure 24:
Calculation of Non-Linear Parameters in Progress

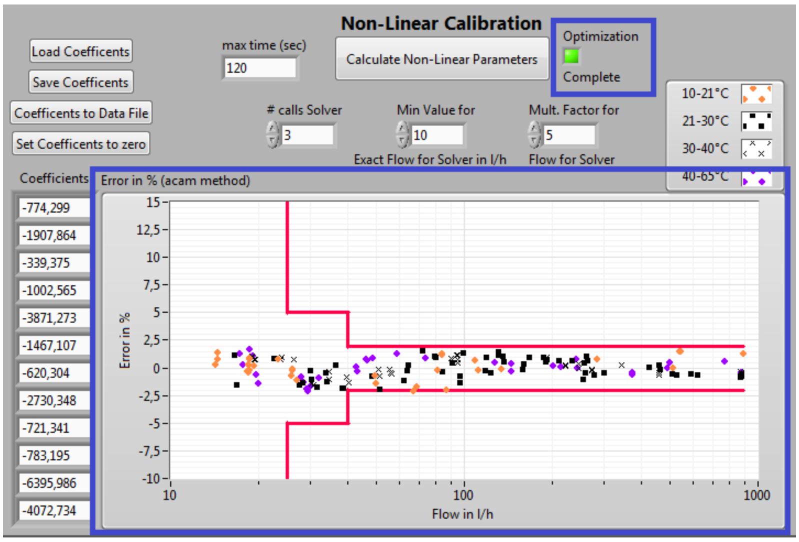


The optimization process can be stopped by clicking on “STOP” in the pop-up window. It will automatically stop after the optimization is done (this can take up to minutes, in dependency on the settings explained in 3.8).

3.12 Optimization Complete (8)

Once the calibration engine run(s) have been finished, this is indicated by the LED being illuminated in green, and of course the updated illustration of the data points relatively to the error band, e.g.:

Figure 25:
Optimization Completed



This graphical illustration of the calibration algorithm’s results allow for a quick evaluation whether the values would be acceptable with this set of coefficients or not.

Please note in this context, that the ±2% error band is only an indication and the requirements for the error tolerance may vary from application to application and/or country to country.

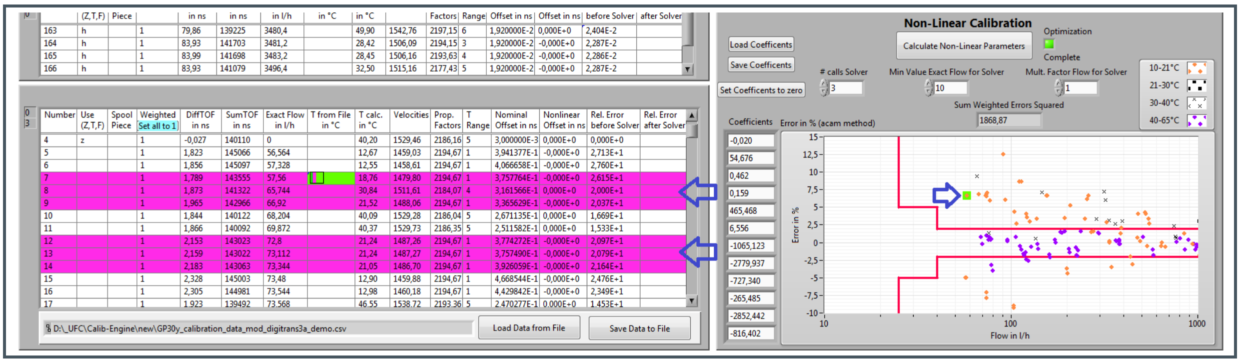
If the data points are entirely or widely within the error band, you may want to use that set of coefficients by saving them into a text file, please refer to section 3.13 for further details.

If the data points are still largely outside the error band or you want to improve the calculated results further, you may weigh certain data points and re-run the engine.

3.12.1 Weigh Data Points

In case there are several “outliers” seen in the graph, you can weigh the corresponding data points with a higher value than “1”, to make them considered more in the calibration algorithm and essentially pull them inside the error band. The software helps you by highlighting the values outside the error band with a purple background back in your data set table:

Figure 26:
Highlighting of Outliers



By clicking to an individual line of the table, the corresponding data point is also highlighted in green color in the graph on the right. According to how important the data point is to be pulled in and how far it is outside the error limits, you set the weighing in the “Weighted” column accordingly. E.g. if it is close, you may set it to 5, if it is far away, to 10 or more.

After making this adjustment for the whole table (purple lines), you re-run the calibration engine by first pressing “Calculate Linear Parameters” (please refer to 3.6) again and then the “Calculate Non-Linear Parameters” button (please refer to 3.10).

An optimization run may yield better results like in the illustrations Figure 27 and Figure 28:

Figure 27:
Before Optimization

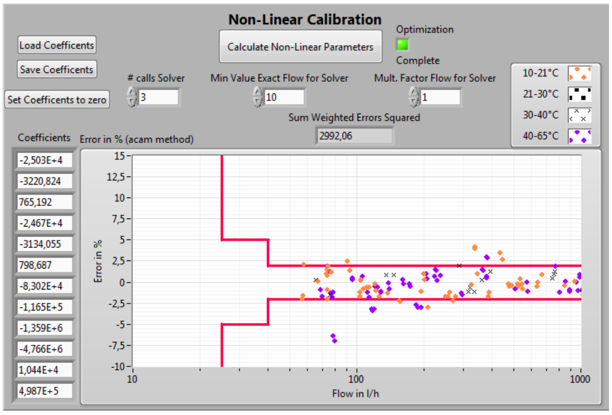
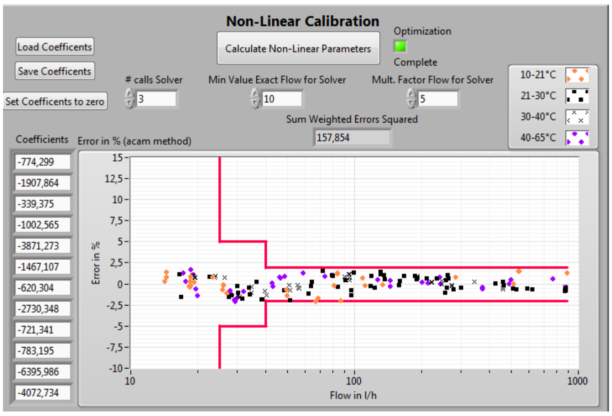


Figure 28:
After Optimization

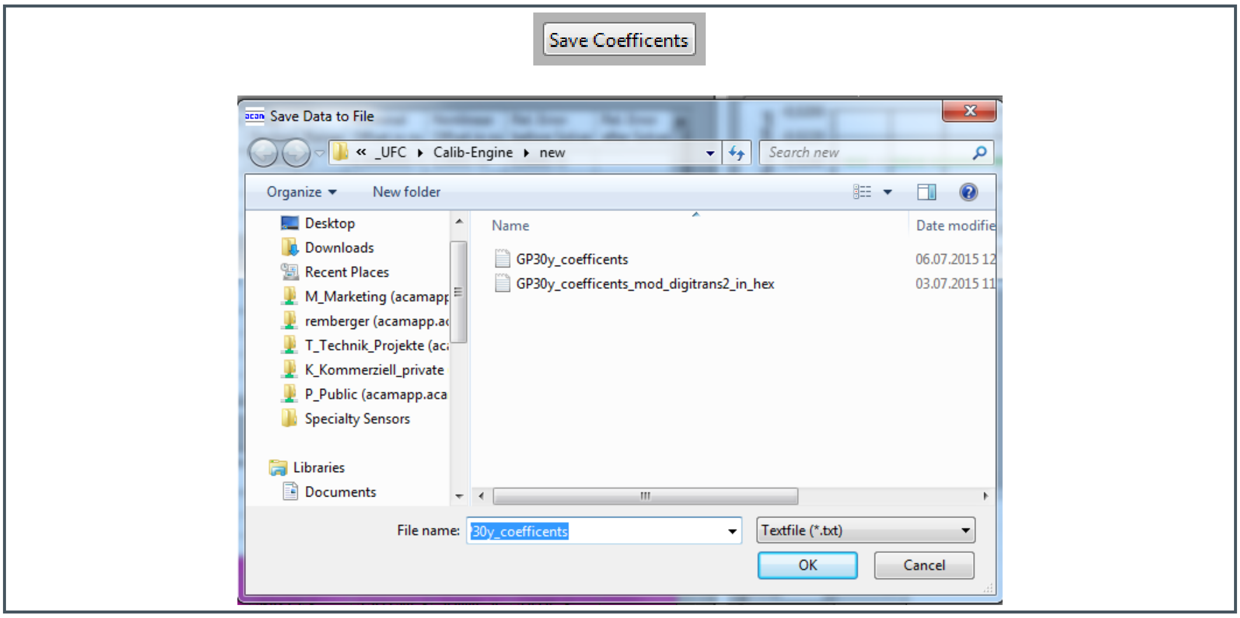


This process of optimization can be performed several times, if desired. Once you have the desired result after re-running the engine, you can save the set of coefficients as described in 3.13.

3.13 Save Coefficients (9)

To save the set of coefficients please press the corresponding button (“Save Coefficients”) and give the name of a txt-file to store the data.

Figure 29:
Save Coefficients



This option to save the coefficients is mainly for the case you want to re-load the coefficients within the calibration software tool at a later point in time (e.g. for further optimization). In case you want to download the coefficients to the TDC-GP30 to apply the calibration, please refer to 3.14“Coefficients to Data File”.

3.14 Copy Coefficients into Data File (10)

The coefficients are part of the firmware data (FWD), which is then to be downloaded to the TDC-GP30. With this, the chip applies the coefficients in the firmware and as a result you get a calibrated spool-piece. In order to get the set of coefficients directly inserted to the firmware data file that can be downloaded to GP30, you can use the button “Coefficients to Data File”:

IMPORTANT: With this action, the original data file may be overwritten with new data! The software warns and permits to choose a different file name. Make sure you work on a copy of your data file in order not to lose or overwrite data accidentally.

Figure 30:
Coefficients to Data File

The set of coefficients will then be inserted directly to the *.dat file – you will see some extra spacing in the comments to distinguish the coefficients inserted from the other already existing data:

Figure 31:
Data File

```
equal 0x494B55B4   ; FW data address37          CONST FWD_COEFF_21
equal 0x505B5B84   ; FW data address38          CONST FWD_COEFF_22
equal 0x6B715C7C   ; FW data address39          CONST FWD_COEFF_23
equal 0x71675B73   ; FW data address40          CONST FWD_COEFF_24
equal 0x00000000   ; FW data address41          CONST FWD_COEFF_25       FOU
equal 0xFFA83E19   ;  FW data address42; CONST FWD_COEFF_k1_TC1
equal 0xFFFFAB8A   ;  FW data address43; CONST FWD_COEFF_k2_TC1
equal 0xFFE60408   ;  FW data address44; CONST FWD_COEFF_k3_TC1
equal 0xFF8E5F16   ;  FW data address45; CONST FWD_COEFF_k1_TC2
equal 0xFFFF549D   ;  FW data address46; CONST FWD_COEFF_k2_TC2
equal 0xFF8FABBB   ;  FW data address47; CONST FWD_COEFF_k3_TC2
equal 0xFFB9B22E   ;  FW data address48; CONST FWD_COEFF_k1_TC3
equal 0xFFFF8720   ;  FW data address49; CONST FWD_COEFF_k2_TC3
equal 0xFFC8C53F   ;  FW data address50; CONST FWD_COEFF_k3_TC3
equal 0xFFA73C04   ;  FW data address51; CONST FWD_COEFF_k1_TC4
equal 0xFFFEE4D6   ;  FW data address52; CONST FWD_COEFF_k2_TC4
equal 0xFEC82BB1   ;  FW data address53; CONST FWD_COEFF_k3_TC4
equal 0x00158000   ;  FW data address54; CONST FWD_TEMP_TC1
equal 0x0020570A   ;  FW data address55; CONST FWD_TEMP_TC2
equal 0x0027EB85   ;  FW data address56; CONST FWD_TEMP_TC3
equal 0x0031E666   ;  FW data address57; CONST FWD_TEMP_TC4
equal 0x0095C1D3   ;  FW data address58; CONST FWD_TOF_OFFSET
equal 0x0001BABA   ;  FW data address59; CONST FWD_TOF_DIFF_CAL
equal 0x00000F5C   ;  FW data address60; CONST FWD_DIST_WITH_FLOW
equal 0x000004BD   ;  FW data address61; CONST FWD_DIST_NO_FLOW
equal 0xFFF97248   ;  FW data address62; CONST FWD_ZERO_OFFSET_TC2
equal 0xFFF8EC11   ;  FW data address63; CONST FWD_ZERO_OFFSET_TC3
equal 0xFFF9B564   ;  FW data address64; CONST FWD_ZERO_OFFSET_TC4
equal 0xFFFFED6E   ;  FW data address65; CONST FWD_O_SLOPE_TC12
equal 0xFFFFEE4C   ;  FW data address66; CONST FWD_O_SLOPE_TC23
equal 0x0000142C   ;  FW data address67; CONST FWD_O_SLOPE_TC34
equal 0xFFFF9064   ;  FW data address68; CONST FWD_F_SLOPE_TC12
equal 0xFFFFE78C   ;  FW data address69; CONST FWD_F_SLOPE_TC23
equal 0x00008AAE   ;  FW data address70; CONST FWD_F_SLOPE_TC34
equal 0x02209B35   ;  FW data address71; CONST FWD_F_OFFSET_TC2
equal 0x021FE1D7   ;  FW data address72; CONST FWD_F_OFFSET_TC3
equal 0x022549E1   ;  FW data address73; CONST FWD_F_OFFSET_TC4
equal 0x00061400   ;  FW data address74; CONST FWD_SOUND_VEL_MAX
equal 0x002CA2E2   ;  FW data address75; CONST FWD_1_BY_A
equal 0x000F6C3A   ;  FW data address76; CONST FWD_CONST_C
equal 0x004A0000   ;  FW data address77; CONST FWD_THETA_MAX
equal 0x00000020   ; FW data address78          CONST FWD_LONG_TERM_ERROR
equal 0x00000014   ; FW data address79          CONST FWD_FHL_USER
equal 0x000FFFFF   ; FW data address80          CONST FWD_TOF_SUM_DELTA
```

Please note, that the whole herein described process is on the basis of a single spool-piece calibration. Taking several spool-pieces into account for characterization and generating of coefficients will become available at later stages of the software. The same is true for doing a 2-point calibration with the software once the coefficients have been determined formerly.

Further, of course the now modified raw data table can be saved as a CSV file again, incorporating the marking labels and the weighing, as well as further parameters as calculated by the software. To do so, simply click on "Save Data to File" below the data table and store the CSV file.

4 Summary

This document describes in a cookbook-like style the steps to perform the operation of the calibration engine. The process is shown on a single page flow chart overview and then broken down into detailed step by step descriptions. At the end of the process, a set of coefficients is obtained, which then can be downloaded with the firmware data (FWD) to the TDC-GP30. The chip internal firmware makes then use of these coefficients to apply the non-linearity correction to the device under test (DUT).

Please note, that this version of the software faces limitations such as that the characterization can be done for one spool-piece only at this time.

5 Appendix

5.1 Troubleshooting

5.1.1 Sum Square Error

If the “Sum Error square” is 0 right from the beginning when clicking on “Calculate Non-Linear Parameters”, this is an indication that the engine cannot be run properly.

Please check in this case that the “Weighted” – column on the left bottom table is set properly (see 3.5Mark relevant data points). Then run the calibration engine again.

5.2 MID Limits

Q1: Minimum Flow Q2: Transition flow Q3: Continuous flow Q4: Overload flow

- MID Class 1:
  The MPE for the upper flow rate zone (Q2 ≤ Q ≤ Q4) is ±1 %, for temperatures from 0.1 °C to 30 °C, and ±2 % for temperatures greater than 30 °C.
  The MPE for the lower flow rate zone (Q1 ≤ Q < Q2) is ±3 % regardless of the temperature range.
- MID Class 2:
  The MPE for the upper flow rate zone (Q2 ≤ Q ≤ Q4) is ±2 %, for temperatures from 0.1 °C to 30 °C, and ±3 % for temperatures greater than 30 °C.
  The MPE for the lower flow rate zone (Q1 ≤ Q < Q2) is ±5 % regardless of the temperature range.

Ratio R: Continuous flow / Minimum flow

Figure 32:
Example DN20 Meter

Q3 [m³/h]	Q4 [m³/h]	Q2 [l/h]	Q1 [l/h]	Ratio	Tof [ps] @ Q1 (Q4=300ns)	Tof Error [ps] @ Q1
4	5	80	50	80	3750	187.5
4	5	40	25	160	1875	93.8
4	5	16	10	400	750	37.5
4	5	8	5	800	375	18.8

5.3 Notational Conventions

Throughout the GP30 documentation, the following style formats are used to support efficient reading and understanding of the documents:

- Hexadecimal numbers are denoted by a leading 0x, e.g. 0xAF = 175 as decimal number. Decimal numbers are given as usual.
- Binary numbers are denoted by a leading 0b, e.g. 0b1101 = 13. The length of a binary number can be given in bit (b) or Byte (B), and the four bytes of a 32b word are denoted B0, B1, B2 and B3 where B0 is the lowest and B3 the highest byte.
- Abbreviations and expressions which have a special or uncommon meaning within the context of GP30 application are listed and shortly explained in the list of abbreviations, see following page. They are written in plain text. Whenever the meaning of an abbreviation or expression is unclear, please refer to the glossary at the end of this document.
- **Variable names** for hard coded registers and flags are in bold. Meaning and location of these variables is explained in the datasheet (see registers CR, SRR and SHR).
- Variable names which represent memory or code addresses are in grey. Many of these addresses have a fixed value inside the ROM code, others may be freely defined by software. Their meaning is explained in the firmware and ROM code description, and their physical addresses can be found in the header files. These variable names are defined by the header files and thus known to the assembler as soon as the header files are included in the assembler source code. Note that different variable names may have the same address, especially temporary variables.
- *Physical variables* are in italics (real times, lengths, flows or temperatures).

5.4 Abbreviations

Figure 33:
Abbreviations

Short	Description
AM	Amplitude measurement
CD	Configuration Data
CPU	Central Processing Unit
CR	Configuration Register
DIFTOF, DIFTOF_ALL	Difference of up and down → TOF
FEP	Frontend Processing
FDB	Frontend data buffer
FHL	First hit level (physical value V_{FHL})
FW	Firmware, software stored on the chip
FWC	Firmware Code

Short	Description
FWD	Firmware Data
FWD-RAM	Firmware Data memory
PI	Pulse interface
PP	Post Processing
PWR	Pulse width ratio
SPI	Serial Peripheral Interface
SUMTOF	Sum of up and down TOF
TDC	Time-to-digital-converter
TOF, TOF_ALL	Time of Flight
TM	Temperature measurement
UART	Universal Asynchronous Receiver & Transmitter
USM	Ultrasonic measurement
ZCD	Zero cross detection, physical level V_{ZCD}

6 Revision Information

Changes from previous version to current revision v2-00	Page
Additional information on data collection	6
Additional information on data reformatting	9

- Page and figure numbers for the previous version may differ from page and figure numbers in the current revision.
- Correction of typographical errors is not explicitly mentioned.

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