Comprehensive Checklist for Ultrasonic flow meter applications

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Abstract

Long experience with ultrasonic flow measurement installations for hydropower and irrigation plants based on the transit time method, reveals interesting findings. Next to many successful installations, the experience showed also shortcomings, complications in the project handling, underperformance and liability questions during the whole installation process of a measurement unit. Therefore, a systematic procedure is highly recommended by building a comprehensive checklist. The whole installation process is a complex course of actions involving many players and resources at different instants of time. The here presented checklist is an attempt to structure all actions in two dimensions. One axis is the time axis, the other is the resource (in manpower and material) axis. The goal of the checklist is to assist people and organizations in such a way that the measurements with low uncertainty can be guaranteed with a high probability. Clamp-on applications of ultrasonic meters are not covered by the checklist, although many aspects are similar and could easily be adapted. However, other aspects, not present in the checklist, will come into play.

1 Introduction

The experience from hundreds of installations of wetted multipath ultrasonic flow meter showed that it is important for the quality assurance of a proper operation that a detailed list of tasks and actions has to be followed thoroughly. This includes actions of different people from different partners at different instants of time during the overall installation project. Figure 1 shows an overview of tasks and people involved in matrix arrangement.

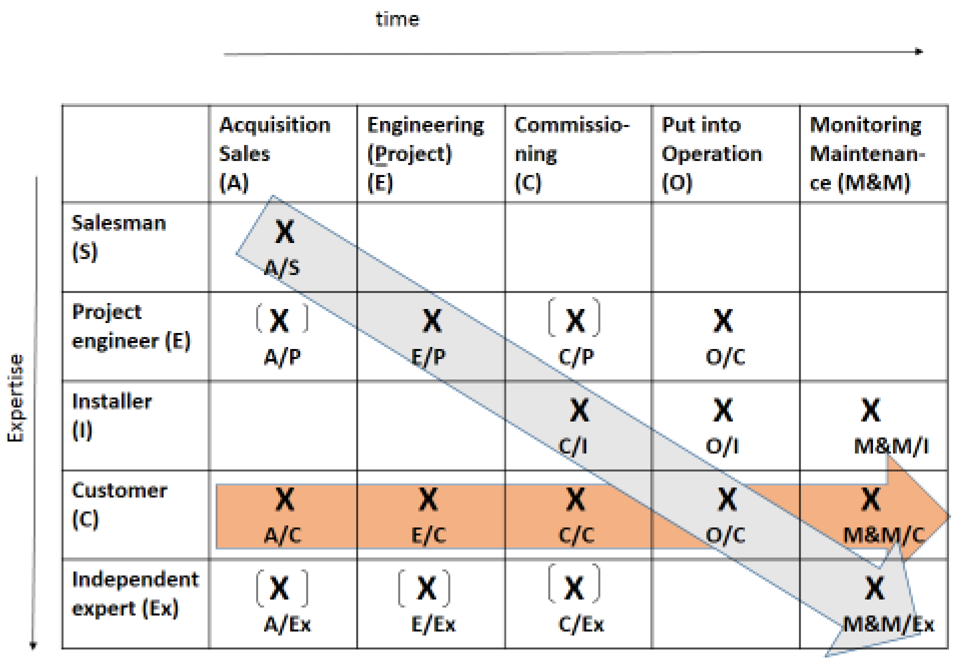

Fig. 1: Checklist matrix for all tasks and people involved in a flow measurement project

The matrix has a horizontal time axis, which is split into the following processes and/or phases:

1) **Acquisition & Sales (A)**
   Promotion of the product and acquisition of the customer including the final contract order
2) **Engineering (E)**
   Engineering is the creative application of scientific principles to design or develop structures, machines, apparatus, or manufacturing processes, or works utilizing them singly or in combination; or to construct or operate the same with full knowledge of their design; or to forecast their behavior under specific operating conditions; all with respect to the following goals: an intended function, economics of operation and safety to life and property.(https://en.wikipedia.org/wiki/Engineering, American Engineers' Council for Professional Development)
3) **Commissioning (C)**
   Commissioning is defined as the process by which an equipment, facility, or plant (which is installed, or is complete or near completion) is **tested to verify** if it functions according to its design objectives or specifications. (http://www.businessdictionary.com/definition/commissioning.html)
4) **Putting into operation (O)**
   Put into operation is the activity that is needed, if something comes or goes **into operation**, it starts to work or become effective. (https://en.oxforddictionaries.com/definition/put_something_into_operation)
5) **Monitoring & Maintenance (M&M)**
   Monitoring is arrangement for observing, detecting, or recording the operation of a machine or system, especially an automatic control system. (http://www.dictionary.com/browse/monitoring)
   Maintenance actions are necessary for retaining or restoring a piece of equipment, machine, or system to the specified operable condition to achieve its maximum useful life.
   (http://www.businessdictionary.com/definition/maintenance.html)
   It includes corrective maintenance and preventive maintenance.

On the vertical axis, the variable is the increased knowledge (from top to bottom) of the overall measurement process. Different people are involved in the various phases with their corresponding expertise. They can be divided into the following group:

Salesman (S), Sales engineer (manufacturer):
Promoter of the overall measurement solution, first contact with the customer, collects first data of the site, checks cost range with options, comparisons with competitors, checks time frame of the overall project

Project engineer (P) (manufacturer):
Is the key figure of the project, coordinates all activities and people involved from the beginning to end, makes the project schedule with deliveries and milestones, organizes the needed data and components for the project, handles the logistic internally and externally like delivery time, shipment, export and customs.

Installer (I) (manufacturer or third party)
Internal or external organizations or personnel (subcontractors) specializing in setting the measurement system in place, has technical knowledge in mechanical and electrical installations, can cope with unpredicted events on site, can improvise

Customer (C)
Owner and/or operator of the plant where the measurement system is in place, is responsible for the infrastructure with the interfaces (electrical power, supervisory control system,…), defines the boundary conditions (legal access to plant, operating conditions of the plant, safety issues,…)

Independent expert (Ex)
Independent experts are needed whenever critical key points are disputed: accuracy, choice of measurement location, choice of path configuration, fault detection and removal, simulation issues, calibration, verification, certificates, etc.

All matrix entries marked with an **X** contain a different list of actions and tasks that the corresponding actor has to do. The main diagonal is occupied by the main actor for each phase. For each phase of the project at least two actors are involved, preferably one taking the lead. **[X]** represents possible additional support if needed. Abbreviations (**A/S**) represents the entry position in the matrix: **A** the first column standing for **A**cquisition, **S** first row standing for **S**alesman.

2. Comprehensive list for installation, commissioning and final test

For installations of an ATT flow measurement, there exist check lists for proper operations in several standards: IEC60041 [1], ASME-PTC18 [2], ISO 6416 [3] Chinese norms [4]. Additionally manufacturers have their own check list for a successful installation. Many of the listed checks require thresholds against which quantities have to compared with. For these thresholds, in most cases no concrete numbers are given in the checklist. They have to be found by detailed analysis for each case. In the following, it is attempted to merge the different lists into one document. The activities listed follow the time axis.

2.1 Acquisition/Sales

During the acquisition phase of the project, precise information about the site/plant must be collected, in order to evaluate a possible measurement solution including associated cost. In order to get the required information, the sales engineer has to contact the customer (owner and/or operator) of the hydraulic plant (power plant or channel) and has to convince him of the necessity of providing the information.

Site information

- Owner, operator and their subcontractors, customer to whom power and/or water is delivered
- Pictorial overview of site, pictures of intake, pipes, hydraulic configuration, possible locations for acoustic flow meter installations
- Accessibility to the site: are there any political restriction, are there time constraints?
- Detailed drawings of hydraulic layout (top/side/front view) including location of possible surge tank, number of pipes and number of possible measurement installations. Old drawings should be digitized with a sufficiently good resolution. This is important for possible flow simulation investigations
- List of all hydraulic elements in the overall course of the water upstream of the planned installation (gates, pumps, valves, change of direction, change of cross section, inclination, trash racks, surge tanks…)
- Geometric dimensions preferably as measured, of pipe/channel and the hydraulic elements (lengths and diameters, wall thickness…)
- Nominal water pressure in the pipe
- Nominal water temperature in the pipe
- Outdoor conditions (pressure, temperature, humidity)
- Possible deformations of pipes due to weight
- Expected particle load (concentration, size distribution), analyzed water samples at various time of a year, worst case assumptions
- Expected air bubble content in the water
- Additional available measurements (pressure, level, position, temperature, supplementary paths for monitoring)
- Inflow water condition
- Special conditions not included in above points (e.g. unsteadiness, surge tank oscillations, intermediate water tank storages in water diversion applications, intake vortex formation)

Operation information

- Number of operating points, range of operation
- Min/max flow and velocity
- Nominal flow and velocity
- Nominal position of gates, valves, bifurcations,…
- Way of operating multiple pipe, turbine and/or pump configurations (bifurcations with different operating topology result in different inflow conditions), pipe rupture monitoring
- Required temporal response of the measurement system to operating point changes

2.2 Engineering

The responsibilities of project engineering is:

- Scheduling the project
- Organizing possible investigations from internal development engineers and external experts
- Organizing and scheduling the acquisition and shipping of materials including customs regulations
- Organization of collaboration of people to work on various phases of the project
- Coordinating all people involved in the project, scheduling time windows for installation, commissioning and put into operation
- Assessing and reducing risk associated with the completion of the project
- Check quality of delivered hard- and software, approval of acceptance test

The project engineer relies on all data obtained during the acquisition phase (section 2.1). If the situation is not sufficiently clear, additional investigations by independent experts including simulations have to be organized. Simulations at the beginning of the project are needed, if estimations of expected accuracies of different flow meter configurations in difficult hydraulic situations must be specified. CFD simulations are also useful after the installation is completed and measured values are compared to simulated values. This can help to improve the installation or the simulation. In the end, the concrete choice of the flow meter installation with the corresponding parameter values has to be specified.

Flow meter information
- Flow meter location
- Cross section shape and area
- Wall material, surface roughness
- Path orientation with respect to the pipe/channel
- Inclination
- Number of paths (crossed – not crossed)
- Choice of integration method
- Determination of theoretical (default) geometrical quantities (path height, transducer positions, angles)
- Expected accuracy
- Sensor type (frequency, inside/outside mount)
- Cable routing and protection, length of cable and type

Customer information
- Pipe/channel access
- Power supply
- Interfaces
- SCADA (supervisory control and data acquisition) system
- Possibility of recording long term data:
  Turbine rotational speed
  Other flow meters readings if available
  Electrical power
  Pressures
  Temperatures
  Maintenance record
  Operating changes
- Electrical grounding (pipe and equipment)
- Safety issues
- Scaffold for mounting the transducers

Manufacturer information
- All transducer pairs must be labelled (location, date of installation, section number, path number)
- All components tested and labelled (retrace-ability must be guaranteed)
- Matched transducer pair test in still water
- Data of transducer available (main lobe characteristics, emission angle…)
- Pressure restriction and water tightness of transducers
- Certificate of verified delta transit time of measurement system (hard- and software)
- Timing System Resolution Check (resolution and accuracy of transit time difference) [3]
- Timing System Delay Check [3]

2.3 Commissioning
The distinction between the two processes of commissioning and putting into operation is often not well defined. It strongly depends on site specific conditions, restrictions, boundary conditions. Additionally, there exist a variety of transducer installations, depending on the accessibility. The two most frequently commissioning processes for the transducer installations are:

1) **No access to the interior of pipe/channel**
   Measuring of reference transducer positions from the outside
   Mounting of the transducers from the outside
   Remeasuring, after mounting, the actual transducer positions from the outside

   The pipe/channel can be filled or be empty. Special care for the mounting procedure has to be taken if the pipe/channel is under pressure.

2) **Access to interior of pipe/channel**
Measuring of reference transducer positions from the inside with empty pipe/channel condition
Mounting of the transducers from the inside only or from both sides
Remeasuring, after mounting, the actual transducer positions from the inside with empty pipe/channel condition

In rare cases of channel applications where empty water conditions cannot be met, the mounting of the transducers can be carried out under filled conditions. One method of installing the transducers is to mount them separately under water by divers, another one is to mount them on a supporting frame, which is then lowered into the water and fixed by divers.

Installations can be carried out by internal personnel of the supplier or by subcontractors. If external subcontractors are involved, scheduling and coordinating the activity on site becomes more complex.

Transducer parametrization and system check for empty pipe/channel
- Measuring the pipe/channel geometry with theodolite, laser or optical methods
- Determination of reference transducer positions and path angles
- Mounting of transducers
- Measuring with theodolite, laser or optical methods after mounting, of actual transducers positions and path angles and comparison with reference data. Checking for deviations (threshold of maximal deviations must be specified)
- Laser check of transducer alignment if possible
- Import of actual data to the signal processing unit and generation of parameter file
- Parameter file check. Wrong parametrization is often the cause of faulty behaviour or bias of the flow rate data
- Sensor and cable check (impedance check), protective shielding check
- Geometric uncertainty analysis

System parametrization and check for filled pipe/channel
This check can be done if possible, first with zero flow, afterwards with different flow rates up to maximal flow
The checks have to be carried out for each path.

Per path:
- Recorded pulses
- Amplitudes: Forward/return signal amplitudes should vary only by a few percent, difference might indicate bad alignment of sensors
- Pulse shape should match → check correlation
- Number of path failures, statistics of lost pulses per path, not only the number of bad measurements.
- Path velocities (check if close to zero for zero flow, otherwise comparison to theoretical values)
- Sound velocities per path (temperature), comparison with independent temperature measurement
- Check for zero flow condition, taking if necessary, thermal convection into account
- Possible adjustment of default processing parameters

The goal of the phase of the commissioning is a preliminary acceptance report

2.4 Putting into operation under nominal flow
This phase can be just an extension of the commissioning phase. Due to logistic reasons, it is often the case that the commissioning and put into operation cannot be done at the same time. Sometimes the filling up of the pipe/channel (zero flow conditions) is just preliminary to the nominal flow operating conditions. Then the system parametrization and check for filled pipe/channel can be done at the same time. For plausibility check, the nominal flow rate and velocities, obtained from the pump/turbine characteristics, and water temperature at the time of the installation should be known, also an estimation of the particle load.

Per path:
- Recorded pulses Forward/return
- Amplitudes: Forward/return signal amplitudes should vary only by a few percent, difference might indicate bad alignment of sensors
- Pulse shape should match → check correlation
- Number of path failures, statistics of lost pulses per path, not only the number of bad measurements.
- Path velocities (comparison to simulations or empirical data of velocity distributions)
- Sound velocities per path (temperature), comparison with independent temperature measurement
- Possible adjustment of default processing parameters

Per layer:

- Cross flow magnitude check

Overall

- Area flow function check [7]
  The obtained velocity (axial and transversal) and area flow function profile must be checked against some predefined profile (Gauss-Jacobi, OWICS, Gauss-Legendre, simulated section,…).
- Short time logging (1 second interval) after put into operation for different operating points if possible [4]
- Check of temporal response of the measurement system to operating point changes

The goal after this phase is the signing of the final acceptance report by supplier and customer.

2.5 Monitoring & Maintenance

After an installation is completed, it is recommended to verify the proper functioning of the measurement system over a longer period of time by logging all relevant data [8]. The goal of this monitoring process is to identify changing environmental or flow conditions, and also to detect wear of material. This could lead to a strategy of predictive maintenance. Therefore, it is important that the customer has the means to monitor the long term data and take actions if necessary. This assumes that the customer has persons which are familiar with the measurement system. If not the supplier of the system must offer training sessions for the proper handling.

Customer on-line and long term monitoring

- Operation report (change of operating points, maintenance, ,…)
- Long term logging of ambient conditions (temperature, rainfall)
- Long term logging of operating equipment (pumps, valves, gates, control inputs, pressure, power, ,..)
- Long term logging (amplitudes, velocities, flow)
- Particle load samples

Expert knowhow

- Calibration
- Independent verification of geometrical quantities
- Providing reference measurements
- Trouble shooting in difficult cases
- Guidance for operator and/or customer for an effective monitoring process
- Verification of accuracy analysis
- Certificates

3 Examples

3.1 Wrong parametrization & transducer installation errors

The geometry of the measurement section is quadratic with a given length of 1.4m. The reference path angles are chosen as 45° and the height according to Gauss-Legendre at

Upper path: $0.7m + 0.7m \cdot 0.57735 = 1.1014m \cong 1.10m$
Lower path: $0.7m - 0.7m \cdot 0.57735 = 0.2986m \cong 0.3m$

as shown in Figure 2. The ideal path length L_W is 1.98m.

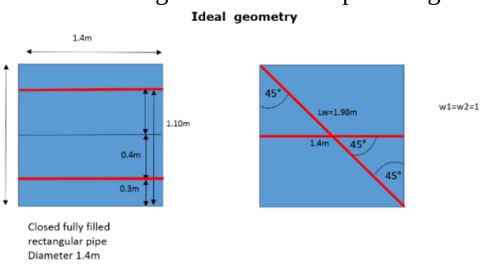

Fig. 2: reference geometry of 2-path in rectangular measurement section

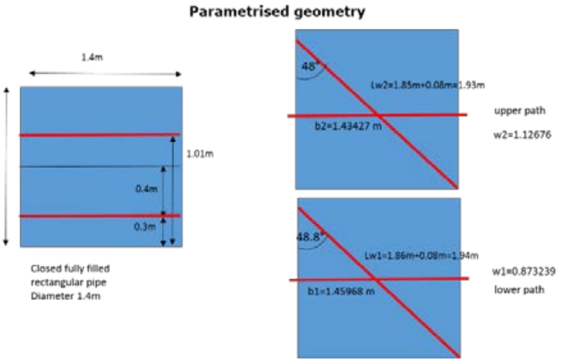

Fig. 3: actual parametrization of the path geometry

From Figure 3, which shows the actual parametrization of the paths, one can conclude:

- The upper path is parametrized at a height of 1.01m, which is obviously wrong. This leads to wrong weights for both paths, if the weights are calculated with the actual positions, Three possibilities exist:
  1) The path is installed correctly, but the parametrization has a misprint 1.01m instead of 1.10m
  2) The path is installed at 1.01m without any obvious reason. By checking the difference to the reference positions (larger than 5% for instance) a warning should show up
  3) The path is installed at 1.01m because of installing at the reference position is impossible for some reason. By again checking the difference to the reference positions (larger than 5% for instance) a warning should show up, which can be ignored for this case
- The path angles of 48.0° and 48.8° are both wrong with differences larger than 5% to the reference of 45°. This differences to the reference have to be checked and a warning set if necessary. The path lengths pill to pill were measured to 1.85m resp. 1.86m. If the protrusion offset of 0.08m is added, the path length are 1.93m and 1.94m. This is 0.05m off the reference value of 1.98m. If the width of the cross section is calculated from path angle and path length wall to wall, substantial differences are obtained (1.453m and 1.459m compared to 1.45m). Therefore, the width, calculated in the way, is again an indicator of accuracy.
- An uncertainty analysis can be made based on these values.

Similar results were reported in the Kootenay installation flow measurement tests [6], [7].

3.2 Velocity profile check & crossflow

A graphical display of the axial and the transversal path velocities is very helpful. Modern flow meters allow to visualize these values. As an example a circular pipe of 2.6m diameter and a nominal flow of ~10m^3/s is investigated at the outlet of up to 3 pumps. The measurement section is far from the locations of the pumps.

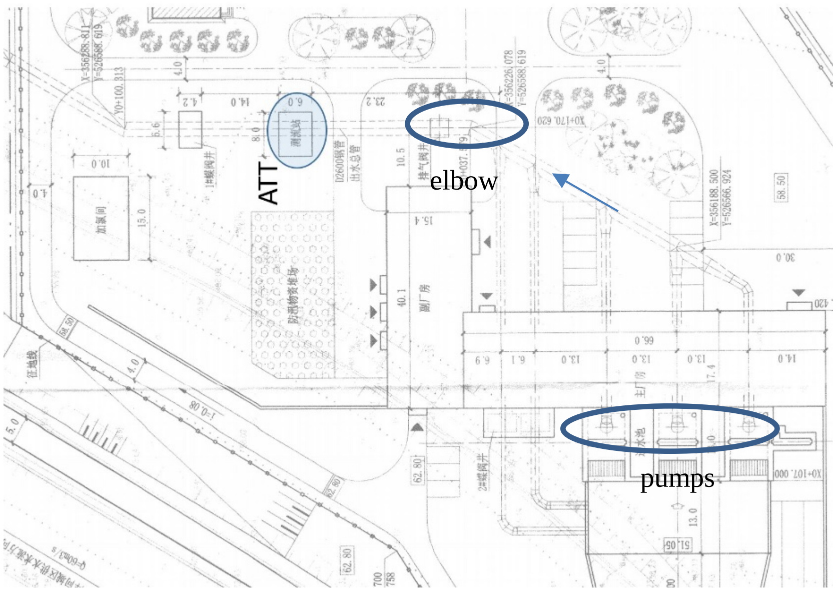

Fig. 4: site map of pump station

About five diameters before the measurement section there is an elbow which causes a distorted flow field.

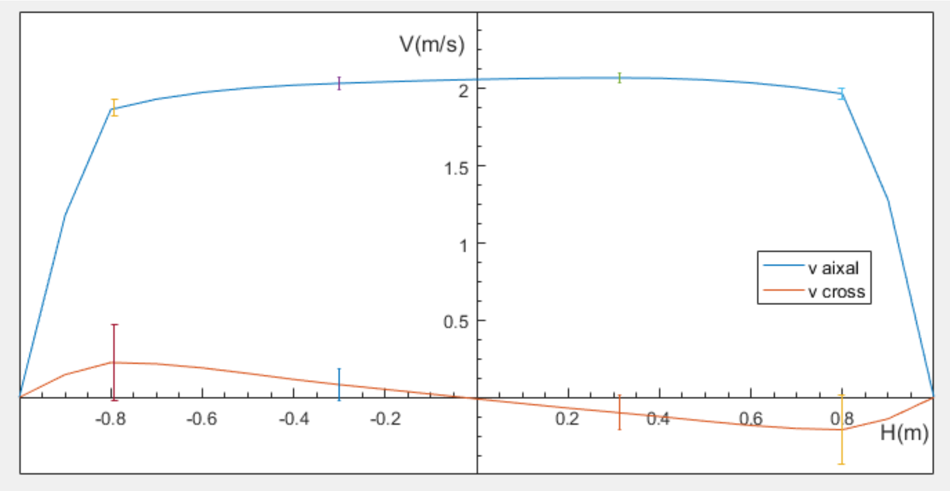

Fig. 5: axial and cross flow components measured by a 8-path configuration (2 planes, 4 paths each)

Figure 5 shows the velocity profile of the 4 axial and cross flow or transverse components. The values at the path positions correspond to an average of the velocity components over a time period of 2 months in 10 minutes intervals. The vertical bars on each data points represent the standard deviation of each measurement. Unusual profiles must be checked for hydraulic plausibility. If the profiles can be explained in this way, then the meter parametrization is okay but maybe not the location. If not, then the path velocity calculation must be investigated. From the velocity profile the area flow function can also easily be displayed [8]. The larger cross flow components on the outer paths and their high standard deviations indicate that the pump or upstream bends induce a non constant cross flow on the measurement section.

3.3 path signal amplitude analysis

To check the path signal quality, the magnitude amplitude of the ultrasonic signal the amplitude is a good indicator. So each forward and return signal of each path is recorded and analyzed. For the same example as in *3.2*, the signal amplitudes are displayed of all amplitudes over a time period of ~1 month in 10min intervals. This time span is a long time after the putting into operation has been completed (2 years). Therefore, this example of monitoring belongs to the maintenance and long term monitoring part of the check list. From Figure 6 it is visible that 6 out of the 8 paths behave stable in an amplitude band of 0.18Volt to 0.25Volt, which is a good level for the quality of the measurement. Path 3 shows a strange behaviour as the amplitude falls 10 to 15% over several longer periods. Additionally several complete amplitudes are recorded. This type of behaviour is hard to explain, is not a serious problem at the moment, but should be analyzed further. It can also be noted, that a slight decrease over time can be observed for the seven paths. Path 5 is a total outlier, having a constant amplitude of only of 25mV, far below the other paths, but still usable for the system. Such a small constant negative deviation is indication for a bad alignment of the transducers of this path.

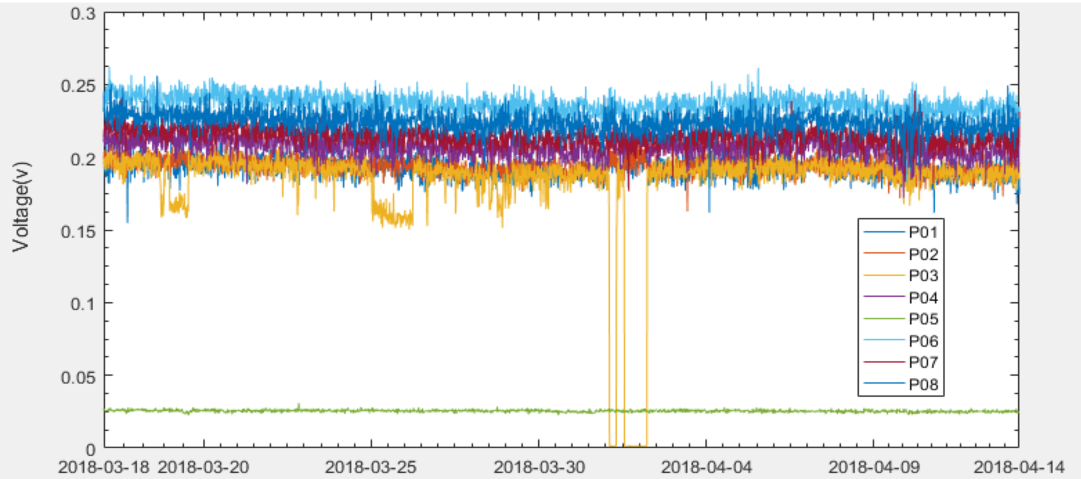

Fig. 6: signal amplitudes over time

4 Conclusions

It cannot be emphasized enough, that a thorough point by point digging through the check list is of great importance. It is clear to the authors that such an intensive procedure is time consuming and expensive for the supplier. The customer however must have confidence into the flow meter and therefore most of the checks are needed. As the flow meters need often only a small portion of the total costs of a pump station or hydraulic power plant, the customer might be willing to spend some money on the increased effort for ensuring the quality of the installations. These check of the installations could be carried out by the manufacturer (supplier himself) itself, by trained personnel of the customer or by a specialized third party.

References

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