Application report
Turbidity to Reduce Abrasion in Hydro Turbines

Hydropower plants (HPPs) contribute to energy supply from renewable resources. Turbines in HPPs transform the power of flowing water to rotary motion which drives electric generators. The water which flows through HPPs may contain suspended sediment (Fig. 1). Handling these sediments is a major challenge to HPP designers and operators.

Fig. 1: Mountain river and microscope picture of abrasive mineral particles contained in the water (pictures: ETH Zürich)

Typical application
Coarse sediment is excluded in gravel and sand traps at water intakes. Finer sediment particles, typically smaller than 0.3 mm, cannot be excluded completely, since the required facilities would be too expensive. These relatively fine particles can still cause significant abrasive erosion on turbine parts (Fig. 2). This leads to high maintenance costs and production losses. A main reason for production loss is that the turbine efficiency is reduced if the turbine is eroded (Fig. 3).

Fig. 2: Pelton turbine runner affected by abrasive erosion

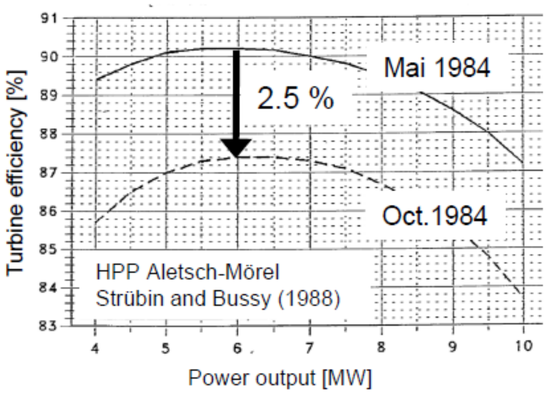

Fig. 3: Turbine efficiency reduction caused by abrasive erosion

Most abrasion problems on hydraulic turbines are known from HPPs in the Himalayas, the South-American Andes and the European Alps. The problem of abrasive erosion is more severe with

- High **difference in elevation** between the intake and the power house (several 100 m), leading to high velocities
- High **suspended sediment concentration (SSC)**, typically in run-of-river HPPs, i.e. HPPs without a storage lake, especially downstream of glaciers
- **Coarse particles** (coarse silt and fine sand, not only clay and fine silt)
- **Hard particles**, e.g. high content of quartz, feldspar etc. (igneous rocks)
- **Angular particles**, as typically found in mountainous regions
- **Turbines without** protective **coating**

Many of these factors are constant over time. The SSC however, may strongly and quickly vary, according to the season, air temperature (glacier and snow melt) and precipitation (floods). High SSCs mean higher production cost per kWh. But in many HPPs the actual SSC is not known since there are no measuring devices for real-time SSC monitoring.
SSC can be determined from bottle samples in the laboratory via the weight of the dried particles (gravimetric method). This method is accurate, but provides results not in real-time, and frequent bottle sampling is generally not affordable. Therefore, surrogate methods are used to get SSC estimates in real-time.
One of these methods is to measure turbidity. Turbidity values are correlated to SSC using a site-specific calibration based on gravimetrical analysis of bottle samples. The conversion from turbidity to SSC depends on particle size, shape and optical properties of the particles. Since particle size may vary in time, SSCs from turbidimeters can be temporarily biased. The use of turbidimeters is quite popular since they are relatively inexpensive.

Benefit
A turbidimeter provides real-time SSC estimates of the water flowing through the turbines. This information is useful for operation decisions. At high SSC, e.g. >2 or >10 g/l during flood events, the generation cost of electricity may be higher than the revenues from power sales. In such periods it is more economic to stop the operation of the turbines for some hours (Fig 4). Knowing the SSC allows thus for a more cost-efficient operation of HPPs and helps to prevent

excessive damages which could lead to production losses.

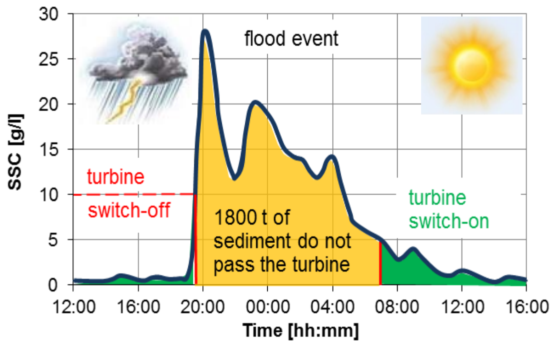

Fig. 4: Time series of suspended sediment concentration (SSC) with turbine switch-off for a few hours (example)

When turbidimeters are used over a long time, their optics may get polluted (fouling), leading to a signal drift. With **AquaScat** (Fig. 5) this is not a problem, since turbidity is measured at a free-falling water jet and the optical parts of the instrument are not in contact with the sediment-laden water.

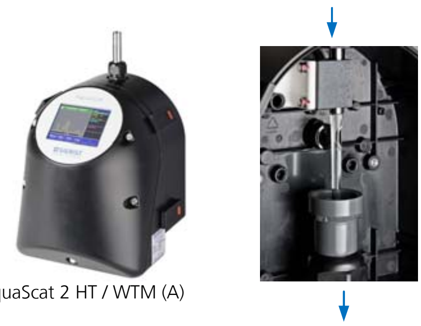
Fig. 5: AquaScat 2 HT / WTM (A)

Typical Applications

An **AquaScat** requires a constant water flow of ≥ 1.3 liters per minute discharging to ambient air pressure. In a HPP it can be installed

- close to the intake, e.g. at the end of the sand trap, fed by a pump, or
- in a valve chamber, at the upper end of the penstock, fed by a small pipe branching off from the penstock.

An installation in the power house is less recommended since there would be no pre-warning time and the water downstream of the turbines may contain small air bubbles which could bias the turbidity measurements.
Special care should be taken to design the feeding pipe, valves and pumps or pressure breaks in such a way that they are not susceptible to blockage by sand grains and that they can be easily flushed.

Cost-Benefit Analysis

The expected benefit from using a turbidimeter to monitor SSC for temporary turbine switch-offs during high SSC depends on many site-specific factors. For larger turbines, a factory overhaul of a turbine runner can cost several 100’000 €. Such an overhaul can become necessary after a single major flood event if a HPP is operated during the event.
For a HPP at which turbine erosion is an economically important issue, the installation of an SSC-monitoring system is expected to be a beneficial investment, which should pay off after a few events. The cost for the measuring device is generally less important than the engineering cost for the following tasks: integrating it into the control system, establishing the conversion from turbidity to SSC and estimating the switch-off SSC.

Products

SIGRIST products and configurations:

- AquaScat 2 HT or AquaScat 2 WTM (A)
- Relevant Control unit for AquaScat 2
- Optional: Flow measurement, level control, de-aeration tube

Parameter adjustments:

- Establish the correlation between turbidity and SSC
- Determination of the alarm values / limits

A combination of several methods may be required to cover the upper part of the relevant SSC range. With silt particles causing a specific turbidity of e.g. 500 FNU per 1 g/l, the **AquaScat** with a measuring range of 4000 FNU is able to measure up to 8 g/l.

Further information

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The PhD-thesis of D. Felix on suspended sediment, abrasive erosion and efficiency of Pelton turbines is planned to be published in autumn 2016. The pdf-file of the thesis will be available from https://www.library.ethz.ch/en/