

Hydro-abrasive erosion: Problems and solutions

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Abstract.

The number of hydro power plants with hydro-abrasive erosion is increasing worldwide.

An overall approach is needed to minimize the impact of this phenomenon. Already at the start of the planning phase an evaluation should be done to quantify the erosion and the impact on the operation. For this, the influencing parameters and their impact on the erosion have to be known. The necessary information for the evaluation comprises among others the future design, the particle parameters of the water, which will pass the turbine, and the power plant owner's framework for the future operation like availability or maximum allowable efficiency loss, before an overhaul needs to be done.

Based on this evaluation of the erosion, an optimised solution can then be found, by analysing all measures in relation to investments, energy production and maintenance costs as decision parameters. Often a more erosion-resistant design, instead of choosing the turbine design with the highest efficiency, will lead to higher revenue.

The paper will discuss the influencing parameters on hydro-abrasive erosion and the problems to acquire this information. There are different optimisation possibilities, which will be shown in different case studies.

One key aspect to reduce the erosion and prolong the operation time of the components is to coat all relevant parts. But it is very important that this decision is taken early in the design stage, as the design has to be adapted to the requirements of the coating process. The quality of coatings and their impact on the operation will be discussed in detail in the paper as due to the non-availability of standards many questions arise in projects.

1. Introduction

The expectation of the owner of a hydro power plant (HPP) is to have high revenue on his investments which is influenced by turbine efficiency, yearly energy production, availability over the year, possibility to operate in certain conditions (e.g. part load or even speed-no-load), down time and costs for inspection and maintenance. In addition the initial investment to achieve this has to be balanced against payback.

For a HPP using water with a high particle concentration and thus having erosion, this is an additional parameter, which influences the revenue and therefore an evaluation needs to be done as early as possible to determine if erosion takes place and how high the erosion will be. The impact of erosion is dependent on the overall design of the HPP and the design of the turbine. Different



scenarios should be looked at to find the best solution between design and corresponding investment and the impact on the operational costs and resulting revenue.

As the number of power plants with erosion is increasing, the following paper will give an overview of hydro-abrasive erosion and the optimisations, which can be done in a HPP. In the last chapter some case studies of HPPs with erosion and feedback from operation will be given.

2. Parameters determining hydro-abrasive erosion [1],[2],[3]

2.1. Overview

Hydro-abrasive erosion is due to suspended particles in the water, which pass through the turbine. The particles, which are harder than the surface material of the turbine parts, damage the surface depending on the impact conditions. The surface material is worn away, resulting in geometrical changes, causing efficiency loss, cavitation and mechanical problems, with consequential higher maintenance costs, less availability and loss in energy production.

In general, rivers with a catchment area in geological young mountains have a high concentration of particles. These are mainly the Andes, Himalaya, Alps and the Pacific Coast ranges. In some locations the erosion damages are so high that after each high particle load season, eroded parts need to be replaced.

The main parameter groups, which need to be looked at for an erosion evaluation, are:

- Future operation frame work, including operation mode (e.g. base load, peak load), availability, governmental regulations
- Particle parameters of the water, which will pass the turbine
- HPP and turbine design (e.g. type and size of turbine), but also the design of the runner (e.g. for accessibility for coating)

2.2. Operational Frame Work

The base for any optimisation is the future operational condition of the HPP. Examples of the necessary information are:

It is important to know with which discharge the turbines will be operated to determine the amount of part load as especially lower part load increases the turbulences and cavitation, which should be minimised in case of erosion.

It is also important to know if the turbines will be stopped in case of very high particle loads. In many HPPs in the Himalaya certain shut-down criteria for the concentration are in place. This criterion is dependent on the number and length of occurrences, the negative impact on the energy production and the positive impact on the turbine life-time if a shut-down is done.

For the decision if such a shut-down criterion should be implemented, the characteristics of the river have to be known (discharge, particle concentration over time).

2.3. HPP and turbine design

From the HPP layout, the design features (reservoir/desander/intake), which will influence the particle parameters, need to be known.

Another influencing parameter in this group is the type and size of the turbines and also if the design is optimised for these conditions. The runner is important, however the design of all other attacked parts needs to be carefully looked at, as the “weakest” part will determine the maintenance interval. When determining the erosion for a HPP and estimating the overhaul frequency it is therefore important to know how erosion resistant the whole design will be.

As one measure to reduce erosion is to coat all necessary parts, the possibility for coating is a further input when making an erosion evaluation.

2.4. Particle parameters

The four particle parameters, which have an influence on the erosion, are:

- Concentration
- Grain size distribution
- Mineral composition
- Shape

The concentration is the parameter with the highest fluctuation over time depending on the location and can vary significantly over the day, the seasons and the years. Therefore, the particle loads of consecutive years can vary by a factor of 3 or more. Especially in fast flowing (mountain) rivers, significant changes occur in a short time, sometimes in less than one hour, and to get reliable data, the frequency of the measurements has to be optimised, in order to include significant changes. It should be noted that even if no reservoir or desander is included, the yearly average particle concentration of the river is different from the average particle concentration of the water passing the turbine. The minimum information needed for an evaluation is monthly values for the particle concentration and the available discharge for the HPP. The origin of the data should be given, so that it is known if these are values from the river or after taking reservoir or desander effects into account.

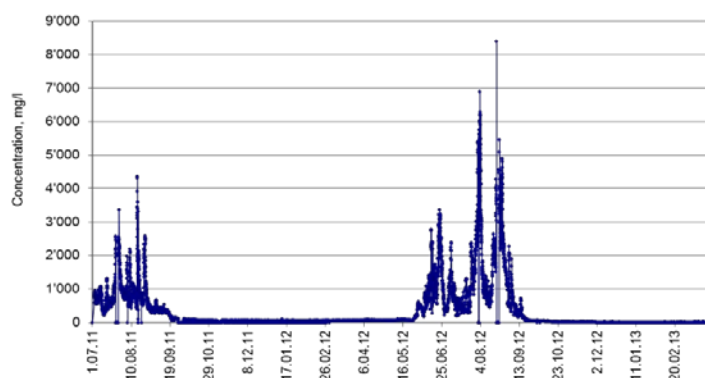


Figure 1 shows the concentration over time after the desander for a HPP in India. Measurements were done during the monsoon season every hour, while in winter with low particle concentration the measurements were done only once a day or even less often. It can be also seen, that there were shut-downs (no values) during the monsoon period due to too high concentrations.

Figure 1: Particle concentration after a desander (Karcham Wangtoo HPP, India)

Due to normal climate differences between years but in addition also due to climate changes the world experiences over the last years, a long term measurement, if possible over at least 2 or more high flood seasons, is necessary to get values on which an evaluation should be based.

The second parameter, the grain size distribution, varies mostly together with the concentration as they are linked to the water movement over the surface in the catchment area. Especially after heavy rainfalls or large snow melts the concentration increases mainly due to the increase of smaller particles [4]. The grain size distribution is important for the evaluation of a desander as especially with a high fraction of larger grains an investment in a desander has a high impact on the turbine's lifetime.

As the influence of the grain size on the erosion damages is not linear, a full grain size distribution is necessary for an erosion evaluation.

The mineralogical composition determines the hardness of the particles. Only particles harder than the surface of the part will lead to significant damages, while particles softer than the surface of the part result more in a polish. The mineral composition should be determined by XRD. The variation of the composition is small compared to the first two parameters and 4 measurements evenly spaced over the high flood season, give in most cases sufficiently good averages.

The fourth particle parameter, the shape of the particles, is determined by the location. In the vicinity of the catchment area the shape is still predominantly sharp edged. Only after a significant

distance from the catchment area, the particles get more rounded. Two samples at different discharges in the high flood season will show the average shape of these particles.

While the first two groups of parameters (frame work and design) are based on human input and a limited number of scenarios for the evaluation can be determined, this last group is the most difficult one to get, and in order to have reliable data, a high effort is needed. Not only a high number of measurements need to be done due to the fluctuation over time but another significant problem is the collection of relevant samples before the HPP is build. The concentration in the river varies over the depth, width and length of its course. Even when the measurement is done at the same location, where the intake of the HPP will be build, it is necessary to take samples at different locations in the cross section of the river to get representative results.

Especially for the measurement of the concentration, different methods are available and it is important when choosing the method to look at the requirements, which need to be fulfilled and are determined by the reason for measuring. Possible reasons for measuring are:

- collecting data for the evaluation during the planning phase,
- determining during operation if a shut-down should be done and
- inspecting the functionality of a desander.

The following parameters have an influence on the measuring method:

- maximum particle concentration
- maximum particle size
- range between finest and coarsest particle grain size distribution
- frequency of measurement
- necessary processing time
- accuracy.

3. Optimisation to reduce the impact of erosion

Reducing the impact of hydro-abrasive erosion can be achieved by different approaches. Depending on the previously discussed factors the measures can be divided into the reduction of the particle load and in the optimisation of the HPP and turbine design.

Different types and designs of turbines are more or less prone to hydro-abrasive erosion as the velocity and the angle of impact are determined by the design. If the problem of erosion is known early enough in the planning phase, the optimal turbine/s can be chosen. And it has to be noted that the turbines with the highest efficiency are not always the best ones for a location with hydro-abrasive erosion.

Some questions, which need to be answered, are:

- Which type of turbine (Francis/Pelton, Francis/Kaplan) is the best, if these possibilities are given by the location?
- Which size and number of the turbines (few large turbines / higher number of small turbines) are best for the future operation?
- What is the main aim of the design (high efficiency or rather more robustness)?

The HPP owner looks for maximum power production and this is especially for hydro power plants with erosion not achieved by high efficiencies, but mainly achieved by high availability, due to longer times between overhauls with short repair times.

To increase the availability of the power plant a solution with more, but smaller units has advantages. Not only is the amount of part load reduced, but a shut-down for overhauling of one turbine - when choosing a larger number of small turbines - has mostly no impact on the power production.

The design of the HPP is also very important in order to give the owner the possibility to replace during an overhaul the parts as quickly as possible. One example for this is the disassembly of the turbine downwards as done by ANDRITZ HYDRO in Karcham Wangtoo (Francis, India).

Once the turbine type and size is decided, the design can be optimized to reduce the velocity and optimise the angle of impact in problematic areas but also to make the design more robust.

For the optimisation, it is also important to know how the minimum maintenance frequency has to be. This is influenced by the number of turbines and also the time for overhaul in the low flood season. A larger number of turbines in an HPP increases the time between maintenances as only few turbines can be overhauled per low flood season. This time between maintenance will limit the allowed amount of damages per season and therefore determine the measures to be implemented to achieve this. If the frequency of maintenance has to be very low, more measures to decrease erosion have to be put into place. As different measures influence each other and no HPP has the same conditions and the investments for certain measures will be significantly different (e.g. building of a desander), the optimisation has to be done for each HPP, as the optimum for one HPP may not be the best solution for another location. As it is not possible for all optimisation steps to be implemented at a later stage the erosion should be discussed in-depth during the planning.

Reduction of particle concentration due to measures at the HPP[5],[6]

The particle concentration will be reduced by a reservoir, but depending on the geometry and size of the reservoir and the amount of particles, it will fill up. The reservoir loses therefore over time this possibility to reduce the concentration. A flushing of a reservoir is in most cases only limited to a certain area in front of the dam as only there the necessary velocity can be achieved in order to bring particles back into suspension. Due to this, the evaluation and optimisation should not only take the first years of operation into account when reservoirs are part of the system, but a much longer period is required.

Depending on the grain size distribution a desander can have a significant impact on the concentration. The investment costs are dependent on the geographical conditions, but also of the necessary cut-off size, which is needed to get a certain reduction.

Another possibility, which is used in some HPP is to change the intake during the high flood season. Due to an increase in the intake height (covering the bottom part of the intake) cleaner water from the top is being used for the operation of the turbine. Turbulences in front of the intake should also be avoided.

Design optimisation to minimize the impact on erosion

HPP layout	Desander	ANDRITZ HYDRO Expertise
	Geometry of intake	
	Turbine type and number of units	
Hydraulic layout	Reduction of relative velocity	
	Minimization of cavitation	
	Design to minimise damages due to h.-a. erosion	
	Better coating suitability (access)	
Mechanic design	Better overhaul possibilities	
	More stable design/construction	
Coating	High quality coating	
	Full robotic if possible	

Table 1: Examples for the HPP optimisation in case of hydro-abrasive erosion

Further improvement can be achieved by optimising the design of the HPP, the turbine and the parts. In Table 1 examples of the optimisation of the design are given. The following will discuss some optimisations.

A very important decision to be taken in the initial planning phase is the type and size of the turbines. The type of turbine has an influence on the efficiency, erosion resistance and maintenance possibilities. Some head ranges allow more than one turbine type and therefore each option should be carefully looked at to determine which solution is the best. As the discharge of many rivers is significantly differs in high and low flood season, it is important to know how the turbines will be operated especially in low flood season, as lower part load should be prevented as it increases erosion. One option to decrease the erosion is to choose the size of the turbine in such a way that no lower part load is necessary for an extended time.

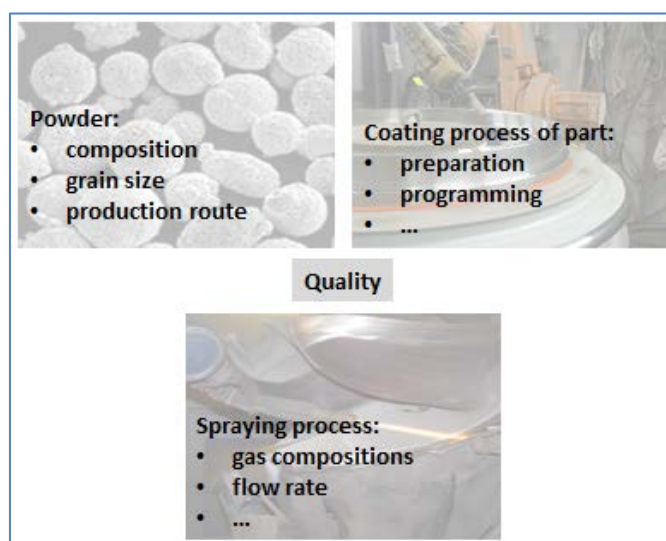
The relative velocity is an important factor when dealing with erosion. The relative velocity for Francis runner depends from the rotational speed. The optimisation has to be done between the advantages of reducing the speed and therefore having less erosion and the disadvantages of increasing size and increasing costs. To be able to coat the water passage of Francis runners sufficient accessibility is needed. Further other design optimisations have to be done to reduce cavitation and optimise the angle of impact for critical areas of all relevant parts.

The mechanical design has also to be optimised to have a more robust design so that erosion damages do not lead to an early necessity for maintenance. The other subject that needs to be looked at is the maintenance friendliness. Easy disassembly and assembly is especially important if parts need to be replaced regularly due to erosion.

One measure is the surface protection of all necessary parts.

The state-of-the-art coating is a hard coating (WC-CoCr), which is applied by a thermal process (high velocity oxy fuel process = HVOF) onto the surface, which needs to be protected. The design of the parts has to be adapted/optimised to have good conditions for coating and therefore the decision to coat parts of the turbine has to be taken already at an early stage in the design of the turbine.

The term of “WC-CoCr-coating” is not describing one specific standardised coating but is an umbrella term for a large number of coatings with a certain basic chemical composition. The coatings under this term have a wide range of properties. Three groups of parameter influence the quality as shown in Figure 2.



The first sub-group is the powder and here not only the chemical composition but also the production route and the grain size distribution play a significant role.

The second sub-group contains all parameters of the spraying process. Different gases with different pressures and flow rates can be used. The relative velocity of the spray jet on the surface as also the distance between the gun and the surface belong into this group.

Figure 2: Parameters, which influence the quality of the coating

The third sub-group contains all the relevant parameters for the application on a part. The surface preparation and the programming are in this group. Coating of non-rotational parts is done either manually or with a robot. Robotic coating improves the quality as it is more homogeneous and very

predictable as all parameters are known, whereas especially for larger parts it is not possible to keep the spray parameter in a constant range, when done manually.

Different coating shops provide coatings with different quality, as the process parameters and the programming are usually in-house developments of the supplier. For a customer it is therefore difficult to differentiate between coatings and their quality. The best way for customers to evaluate suppliers is to compare the know-how and development work in this sector and to look at their references and 7 compare guarantees based in the same framework.

4. Case study

ANDRITZ HYDRO has a long experience in the field of erosion in hydro power plants. The first coatings were applied in the 1980s and have been developed since. Due to this long experience a lot of know-how has been accumulated especially on how to improve the turbine design dealing with erosion. Three HPP will be discussed in the following paragraphs. The first case study is looking at a Swiss HPP with partial coated Francis runners. The second case study is a HPP with fully coated Francis runners in India. The third case study shows the advantages of a coating in a Pelton HPP in Chile.

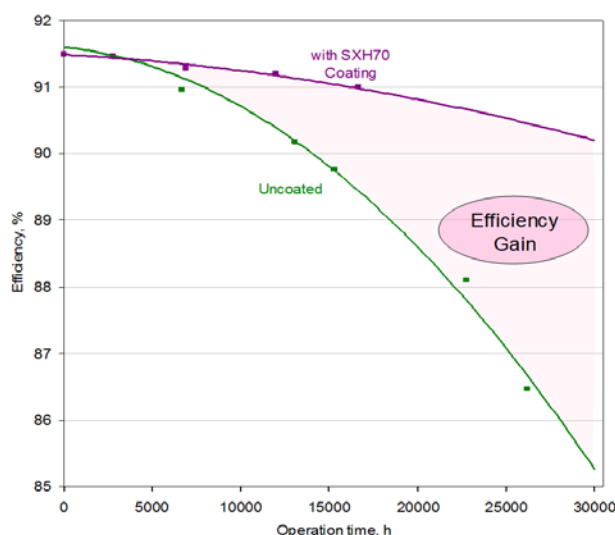
HPP with partial coated Francis runner - Pradella

Pradella is a medium sized, high head Francis HPP and the accessibility to allow full coating is not given. Therefore the runner is only partially coated. The power house is operating since 1987 with coated parts. At the beginning SXHTM48 was used but since 1995 SXHTM70 is applied. This is a WC-CoCr coating developed by ANDRITZ HYDRO. Due to very small dimensional tolerances in this turbine, the coating of the labyrinths, the facing plates and the top and bottom of the guide vanes are polished (Figure 3).



Figure 3: SXHTM70 coated parts, HPP Pradella - Switzerland

Efficiency testing was done with uncoated and coated turbine parts to investigate the advantages of the coating. Figure 4 shows the results of these measuring campaigns. The disadvantage of a coating is a small efficiency decrease at the start of operation compared to an uncoated turbine due to the higher



roughness of the coating. This reduction in efficiency is depending on the size and design of the turbine and the coated area. Due to erosion, the uncoated parts do not retain their geometry for long and the efficiency drops significantly over time, while a partial coated turbine has a much reduced efficiency loss. This resulting efficiency loss is mainly due to the fact that the runner is not fully coated and damages occur especially on the uncoated areas. The operation time in which an efficiency loss occurs is dependant on the location and the particle load, which passes the turbine.

Figure 4: Efficiency loss for uncoated and coated turbine, HPP Pradella Switzerland

HPP with fully coated Francis runner - Karcham Wangtoo [7]

For Karcham Wangtoo (India) the problem of the hydro-abrasive erosion was already known in the planning phase due to the conditions in Nathpa Jhakri HPP, which is located downstream. The main specifications from the customer were:

- Maximum energy production depending on the river discharge; no shutdown for inspection or repair was allowed during the monsoon period
- Short duration for assembly and disassembly: In the winter (non-monsoon period) the exchange of damaged parts had to be possible for 4 turbines; disassembly to the bottom
- Fast repair possibilities of damaged parts
- Coating of all necessary parts

Further actions done by the customer [8]:

- Installation of a desander
- Intake design optimisation to reduce turbulences
- Shut-down of the turbines if the particle concentration is above a certain limit.

ANDRITZ HYDRO implemented the following:

- Design of a high-efficiency, fully coatable runner based on the coating process for Francis runner, developed for Nathpa Jhakri
- Optimisation of the hydraulic design to minimise the relative velocity of the particles on the surface of the parts and a high safety margin for cavitation.
- Replaceable facing plates (in segments), with no screws from the water passage to assure that the whole surface can be coated with no disturbances from screws.
- Replaceable and fully coated labyrinths. When having a fully coated Francis runner the damages on the runner can be repaired more easily on-site, when done early enough. This is not possible for damages on the labyrinths due to necessary tight tolerances.
- Disassembly to the bottom, including a draft tube in two parts for disassembly and also bearings which can be disassembled fast.
- Coating of all necessary parts and providing additionally a spare set for each turbine

Figure 5 shows a cross section through the turbine and shows all the parts which were coated with SXHTM70.

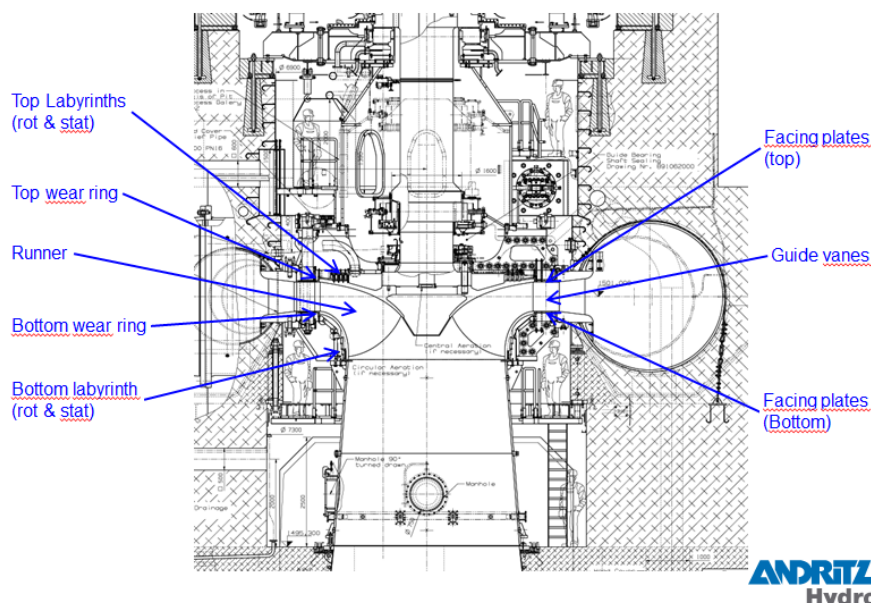


Figure 5: Cross-section through the Karcham Wangtoo turbine with all SXH-coated parts

The first coated turbine was put into operation in July 2011. To determine the particle load the customer made regular particle concentration measurements of the water passing the turbine and in the high flood season these were done on an hourly basis. The turbines operated with up to 6000 mg/l for some days and once for a short period even up to 8000mg/l.

Twice the damages in the coating were inspected. The damages, which were found, can be divided into the following 4 main groups:

- Damages at the inlet on the suction side of the blades
- Damages on the crown
- Damages at the transition of the blades to the band
- Damages near or at the outlet of the blades

The damages were in all 4 turbines similar and as expected in location and area. A coating is not stopping the erosion but shifts the occurrence of damages to a later date and slows the progression. Especially in areas with cavitation and turbulences due to a high amount of low part load, the first damages of the coating occur. The estimation of damaged area is smaller than 5% after nearly 3 monsoon seasons.

Pelton runner - Alfalfal

Alfalfal is a HPP with Pelton turbines (head 690m) in Chile with a very high particle load during each high flood season. While the first runners were operated uncoated, the runners are now operating with a coating. The erosion is so high that even the coated runners generally could not be operated through one high flood season.

Coating with SXHTM70 decreased the damages significantly. The time between overhauls increased by a factor of about 3 and damages at the overhaul were significantly lower. Only about a quarter of the welding material was used for repair of the coated runner compared the uncoated runner.

The last runners put into operation were coated with SXHTM8X. The power decrease was slowed down even more and the particle amount allowed to pass the turbine increased to above 200'000t. Figure 6 shows the damages of three different runners with the corresponding particle load.

Figure 7 shows the progression of the erosion damages by decrease of the maximum power output comparing this to the particle load passing the turbine.

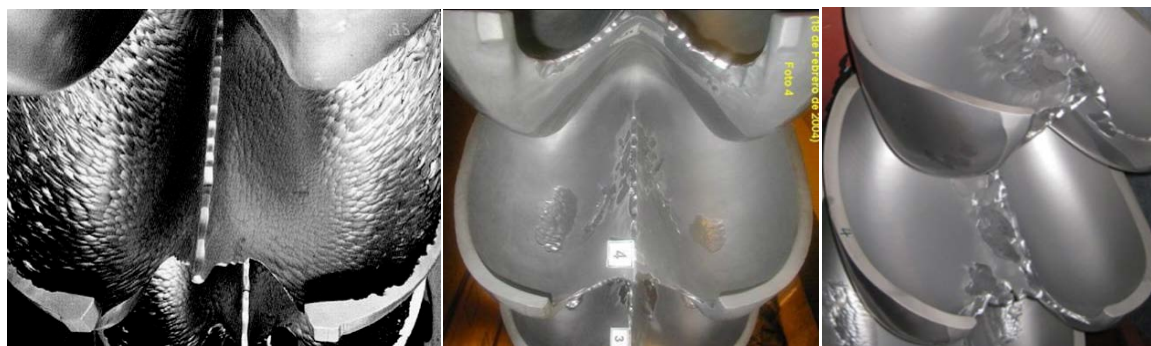


Figure 6: Erosion damages; Left: uncoated runner after 38'000t; middle: SXHTM70 after 120'000t; right: SXHTM8X after 183'000t; Alfalfal – Chile

5. Conclusions

An increasing number of hydro power plants are built in locations with a high concentration of particles in the water and this has to be evaluated in the planning phase. It is therefore important to have enough reliable data regarding the particles in the water in order to determine the impact of erosion on the HPP.

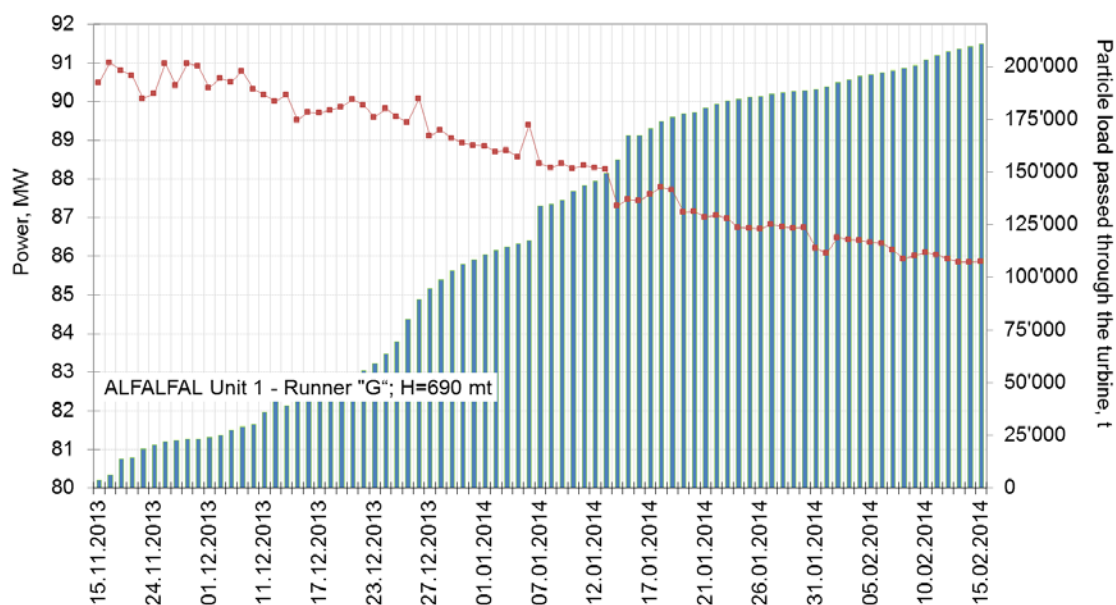


Figure 7: Dependency of particle load and reduction of maximum achievable power

In case of erosion, optimisation has to be done taking the energy production, availability, maintenance costs and overhaul frequency into account. The optimisation has to include all areas to minimize the impact and get the best return on investment. As every location has different framework conditions (e.g. geological conditions, head, discharge, particle parameters) the erosion evaluation and optimisation has to be done afresh for each location.

If this is not done early enough and the erosion problematic only found out at a later stage not all measures can be implemented or only with increasing costs, so that the end result is neither the best solution nor lowest costs.

With an early planning and implementation of all necessary measures even in locations with problematic water a successful operation of an HPP can be done.

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