**SUDAN UNIVERSITY**
**OF SCIENCE AND TECHNOLOGY**
**COLLEGE OF GRADUATE STUDIES**


# STUDY AND ANALYSIS OF THE CAVITATION PHENOMENON IN ROSEIRES POWER STATION

# دراسة وتحليل ظاهرة التكهف بمحطة توليد الرصيرص

**A Thesis Submitted in Partial Fulfillment of the Degree of M.Sc. in Mechanical Engineering (POWER)**


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*DEDICATION*

*This work is dedicated to my wife and brothers without whose caring support it would not have been possible*

*To the memory of my mother and my father who passed on a love of reading and respect for education.*

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# ABSTRACT


The aim of this thesis is to study and analysis the cavitation phenomenon in Roseires power station.

The research presents the cavitation phenomenon featured by fluid machinery including cavity development related to the turbines operating conditions. The effects of the operating conditions, such as load, head and flow influence the development on machine efficiency, noise, vibration and damage are discussed.

The thesis state the cavitation problem in Roseires power station and the time in which the turbines subjected to cavitation during the intake cleaning process was recorded. The specific speed, cavitation index, and the critical cavitation index are calculated during the mentioned three periods (flood season, water restriction period and blackout) before and after dam heightening.

The results of the calculations indicated that the Cavitation occurred during the three periods since the cavitation index of all periods is less than the critical cavitation index before and after dam heightening.

Some points are recommended for loading units out of cavitation zone to reduce cavitation effect to minimum condition.

## مستخلص البحث

الهـدف مـن هـذاالبحث هـو دراسـة وتحليـل ظـاهرة التكهـف بمحطـة توليـد الروصـيرص. البحـث يعـرض بالمناقشـة والتحليـل ظـاهرة التكهـف فـي آلات السـوائل وارتباطهـا بـالظروف التشـغيلية المحيطـة بالماكينـات . ويناقش المشـروع ايضـا الآثـار المترتبـة علـى ظـروف التشـغيل المختلفـة، مثـل السـمت، القـدرة والتـدفق ، وتـأثيره علـى كفـاءة الماكينـة ، الضوضـاء، الاهتـزاز والضرر الذي يحدث بالتوربينات.

البحـث يعـرض مشـكلة التكهـف فـي محطـة توليـد الروصـيرص وزمـن تعـرض التوربينات للتكهف اثناء عملية نظافة المداخل .

تـم حسـاب السـرعة النوعيـة ، مؤشـر التكهـف ومؤشـر التكهـف الحـرج خـلال ثلاثـة فتـرات فـي محطـة كهربـاء الروصـيرص (موسـم الفيضـان ، ترشـيد الميـاه وفتـرة انقطـاع التيـار الكهربـائي) قبـل وبعـد تعليـة الخـزان. واشـارت نتـائج الحسـابات الـي وجـود تكهـف فـي الفتـرات الثلاثـة حيـث ان مؤشـر التكهـف اقـل مـن مؤشـر التكهـف الحرج في الفترات الثلاثة قبل و بعد تعلية الخزان .

تم تسجيل بعض الملاحظات والتوصيات لتحميل الوحدات خارج نطاق التكهف لتقليل آثاره للحد الادني .


# CHAPTER I

# Introduction

## 1.1 Background

Cavitation is a physical phenomenon unwanted in hydraulic system. It is the phenomenon, of formation and collapse of vapor bubbles in the flow in hydraulic machines (turbines and pumps). [1]

It is results from the fact that real water with its impurities evaporates, when the pressure falls short of critical value and since the density of cold water is about $10^5$ times that of steam at the same pressure and temperature, the sudden condensation of vapor cavity on solid wall causes a severe droplet impact then with consequences of pitting and material destruction. The solid-liquid two-fluid model were adopted in the numerical simulation, and the pressure, velocity and particle concentration distributive regularity on turbine blade surface under different diameter and concentration was revealed. Particle model was used to investigate the region and degree of runner blade abrasion in different conditions. The results showed that serious sand abrasion could be found near the blade head and outlet in large flow rate working condition. Relatively slight abrasion may be found near blade flange in small flow rate working condition. The more sediment concentration and the large sand diameter, the runner is seriously abraded, and the efficiency is greatly decreased. Further analysis of the combined effects of wear and abrasion was performed. The cavitation in silt flow is more serious than in pure water. The runner cavitation performance become worse under high sand concentration and large particle diameter, and the efficiency decrease greatly with the increase of sediment concentration. Cavitation is most likely to occur near the fast moving blades of the turbines and in the exit region of the turbines. The liquid enters hydraulic turbines at high pressure; this pressure is a combination of static and dynamic components. Dynamic pressure of the liquid is by the virtue of flow velocity and the other component, static pressure, is the actual fluid pressure which the fluid applies and which is acted upon it. Static pressure governs the process of vapor bubble formation or boiling. Thus, Cavitation can occur near the fast moving blades of the turbine where local dynamic head increases due to action of blades which causes static pressure to fall. Cavitation also occurs at the exit of the turbine as the liquid has lost major part of its pressure heads and any increase in dynamic head will lead to fall in static pressure causing Cavitation. The formation of vapor bubbles in cavitation is not a major problem in itself but the collapse of these bubbles generates pressure waves, which can be of very high frequencies, causing damage to the machinery. The bubbles collapsing near the machine surface are more damaging and cause erosion on the surfaces called as cavitation erosion.

Cavitation while operating Hydraulic Turbines parameters should be set such that at any point of flow static pressure may not fall below the vapor pressure of the liquid. These parameters to control cavitation are pressure head, flow rate and exit pressure of the liquid.

## 1.2 Aim of research

The aim of this project is to Study and analysis the cavitation phenomenon in Roseires power station.

## 1.3 Objectives

The main objective of this research is to:-

1. Study cavitation in three periods.
2. To determine cavitation index.
3. To compare the cavitation effect in the three periods.
4. To do the above steps before and after dam heightening.

## 1.4 Methodology

In this research cavitation in three periods was studied by studying the effects of the operating conditions, such as load, head and flow which influence the development on machine efficiency, noise, vibration and damage and also by recording the time in which the turbines subjected to cavitation during the intake cleaning process.

Cavitation index and critical cavitation index were determined by using the equations (Bernoulli, continuity, specific speed, cavitation index and critical cavitation index equations).

Comparison was done between the three periods calculated parameters before and after dam heightening by comparing the cavitation index to the critical cavitation index (as a reference value) If the value of $\sigma < б_c$ cavitation will occur in that turbine.

# CHAPTER II

# Cavitation phenomenon

## 2.1 Introduction

The sediment concentration in many rivers in our world is very high, and the Kaplan turbine running in these rivers are usually seriously abraded. Since the existence of sand, the probability of cavitation is greatly enhanced. Under the joint action and mutual promotion of cavitation and sand erosion, serious abrasion could be made, the hydraulic performance of the Kaplan turbine may be descended, and the safety and stability of turbine are greatly threatened. Therefore, it is very important and significant to investigate the cavitation Characteristic of Kaplan turbine under sediment flow conditions. The results from practical experience showed that serious sand abrasion could be found near the blade head and outlet in large flow rate working condition. Relatively slight abrasion may be found near blade flange in small flow rate working condition. The more sediment concentration and the large sand diameter, the runner is seriously abraded, and the efficiency is greatly decreased. Further analysis of the combined effects of wear and abrasion was performed. The result shows that the cavitation in silt flow is more serious than in pure water. The runner cavitation performance become worse under High sand concentration and large particle diameter, and the efficiency decrease greatly with the increase of sediment concentration. When cavitation occurs the liquid changes its phase into vapour at certain flow region where local pressure is very low due to the high local velocities.

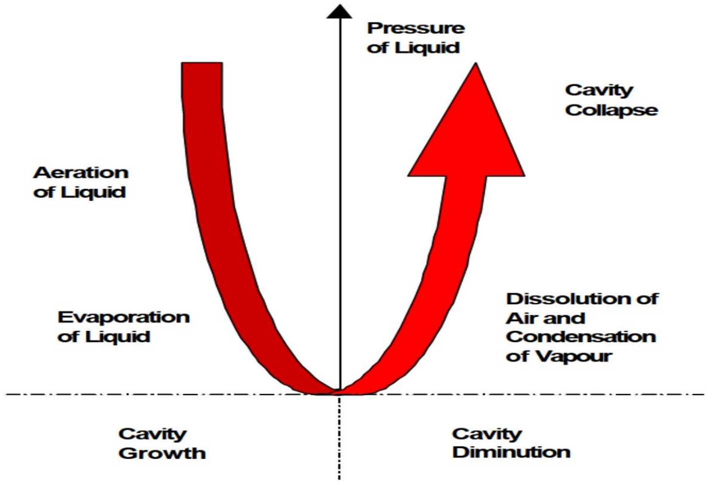


Figure.2.1 Cavitation process [1]

There are two types of vaporization:

1. The first is the well-known process of vaporization by increasing temperature (boiling).

2. Vaporization under nearly constant temperature due to reduced pressure (i.e. cold boiling) as in the case of cavitation.

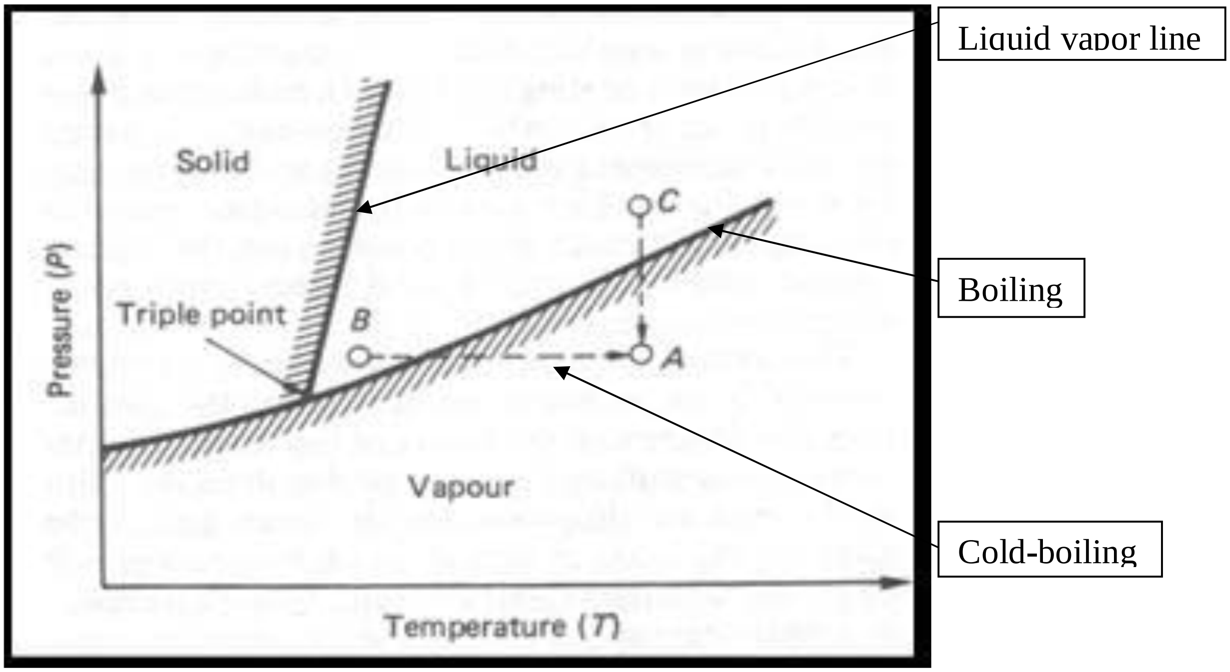


Figure.2.2 Types of boiling [2]

The cold boiling process and hence cavitation depends on the purity of water. If water contains a significant amount of dissolved air, then as the pressure decreases the air comes out of the solution and forms cavities in which the pressure will be greater than the "vapour pressure". This effect applies also when there are no visible bubbles. Submicroscopic gas bubbles can provide suitable nuclei for cavitation purposes. Hence cavitation can either be "vaporous" or "gaseous" perhaps, a combination of both. When cavities are formed in fluid, this violates the homogeneous character of the liquid resulting in practical problems.

Figure.2.2 above explains the types of vaporization and shows clearly the:-

- liquid-vapour line
- cold-boiling
- boiling

Table 2.1 below explains the pressure effect to the boiling point of water:

Table 2.1 pressure effect to the boiling point of water

| Pressure (bar) | Boiling point (deg c˚) |
| --- | --- |

| | |
|---|---|
| 0.02 | 20.0 |
| 0.03 | 26.4 |
| 0.07 | 38.7 |
| 0.14 | 52.2 |
| 0.21 | 60.8 |
| 0.28 | 67.2 |
| 0.34 | 72.3 |
| 0.41 | 76.7 |
| 0.48 | 80.4 |
| 0.55 | 83.8 |
| 0.62 | 86.8 |
| 0.69 | 89.6 |
| 0.76 | 92.1 |
| 0.83 | 94.4 |
| 0.90 | 96.6 |
| 0.97 | 98.7 |
| 1.0 | 100 |

Under atmospheric pressure the water boils at $100^{\circ}$ centigrade. However, if the pressure is reduced to below 0.02 bars, then it boils at temperature 20 centigrade as in shown in figure 2.3

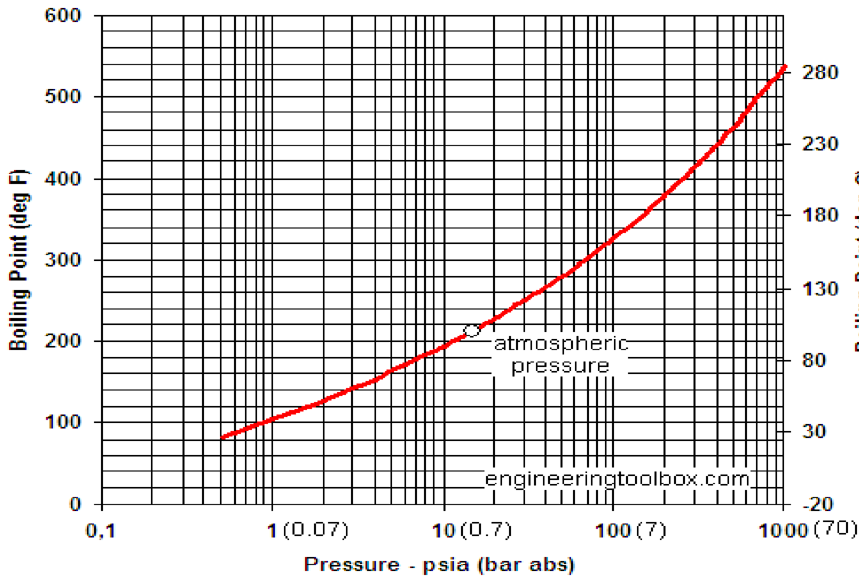


Figure.2.3 relationship between temperature and boiling point [4]

In many hydraulic machines, in some parts the pressure falls to below 0.02 bars (mainly at the runner blades). There vapor bubbles are formed, which are transported by the flow to regions of higher pressure, where they collapse. This phenomenon, the formation and collapse of vapor bubbles in the flow, is called cavitation. In extreme cases these are so severe that the machines may not be allowed to operate. Therefore it is important to know the properties of the cavitation.

## 2.2 Model test loops

There are two main types of the model test loops:

• Closed loop (Figure 2.4a).

• Open loop (Figure 2.4b).

In the closed circuit the service pump generates the head what is consumed by the turbine and it covers also the flow losses of the loop. The model turbine is situated normally at a higher level than the service pump, in order to avoid cavitation in the service pump while the turbine cavitates, perhaps seriously at an extreme test point. The pump is driven by a DC motor, so that by speed regulation the duty point may be adjusted in a wide operating range.

The water is circulated in the open loop. From the suction side vessel of the turbine the water flows through a throttling device into an open channel, and the pump lifts the water from this channel.
The main difference between closed loop and open loop operation is in the quality of the water, what is important in cavitation tests.
In closed loop, testing at low cavitation σ values means that the model turbine seriously cavitates.

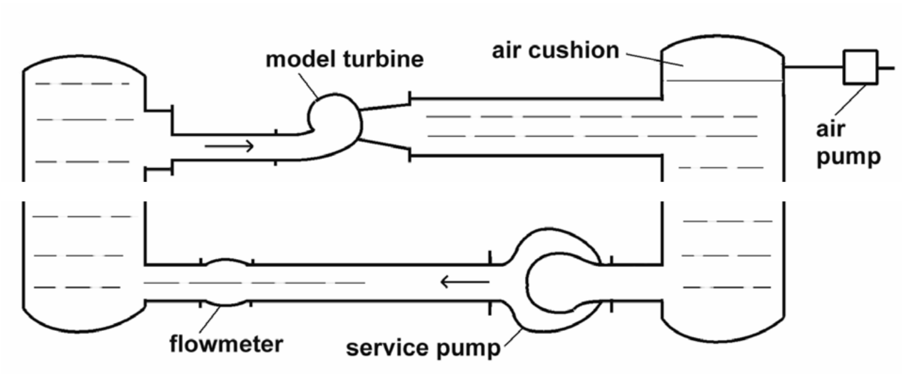


Figure 2.4a Closed loop model test [1]

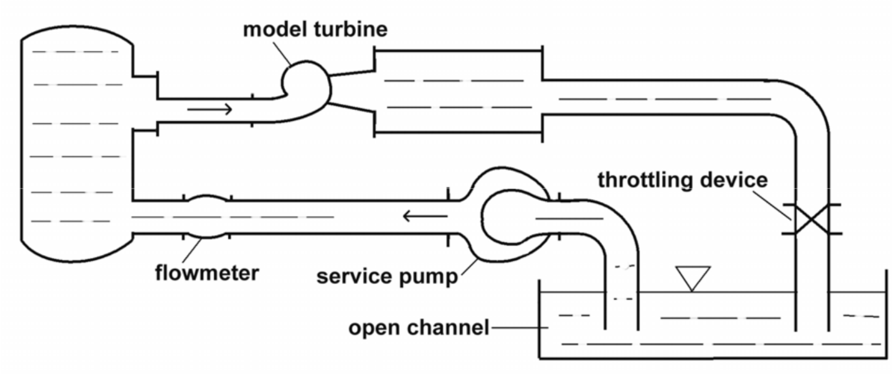


Figure 2.4b Open loop model test [1]

## 2.3 Thomas cavitation coefficient

**Is defined as:-**

$$\sigma = \left( \frac{H_a - H_v - Z}{H} \right) \quad 2.1$$

Where $H_a$ is the atmospheric head, $H_v$ is the vapor pressure head, z is the Height of the runner outlet above tail race and H is the total operating head.

The value of σ depends on Ns (specific speed) of the turbine and for a turbine of given Ns the factor σ can be reduced up-to a certain value up to which its efficiency, ηo remains constant.

The minimum value of σ at which cavitation occurs is defined as critical Cavitation factor $б_c$

$б_c$ is found to be a function of specific speed. In the range of specific speeds For Francis turbine $\sigma_c$ varies from 0.1 to 0.64 and in the range of specific Speeds for Kaplan turbine $б_c$ varies from 0.4 to 1.5. If the value of $\sigma > б_c$ cavitation will not occur in that turbine and cavitation ranges are:

The cavitation sound level peak 1, if σ range is 0.12-0.2 b. The cavitation sound level peak 2 if σ range is 0.05-0.3.

The value of $б_c$ for different turbines may be determined with the help of following relationships:

For Francis turbine: $$\sigma_c = 0.625 \left( \frac{N_S}{380.78} \right)^2 \quad 2.2$$

For Kaplan turbine: $$\sigma_c = 0.28 + \left( \frac{1}{7.5} \left( \frac{N_S}{380.78} \right)^2 \right) \quad 2.3$$

For Kaplan turbine: $$N_s = \frac{N \times (0.76 \times P_w)^{0.5}}{h_{net}} \quad 2.4$$

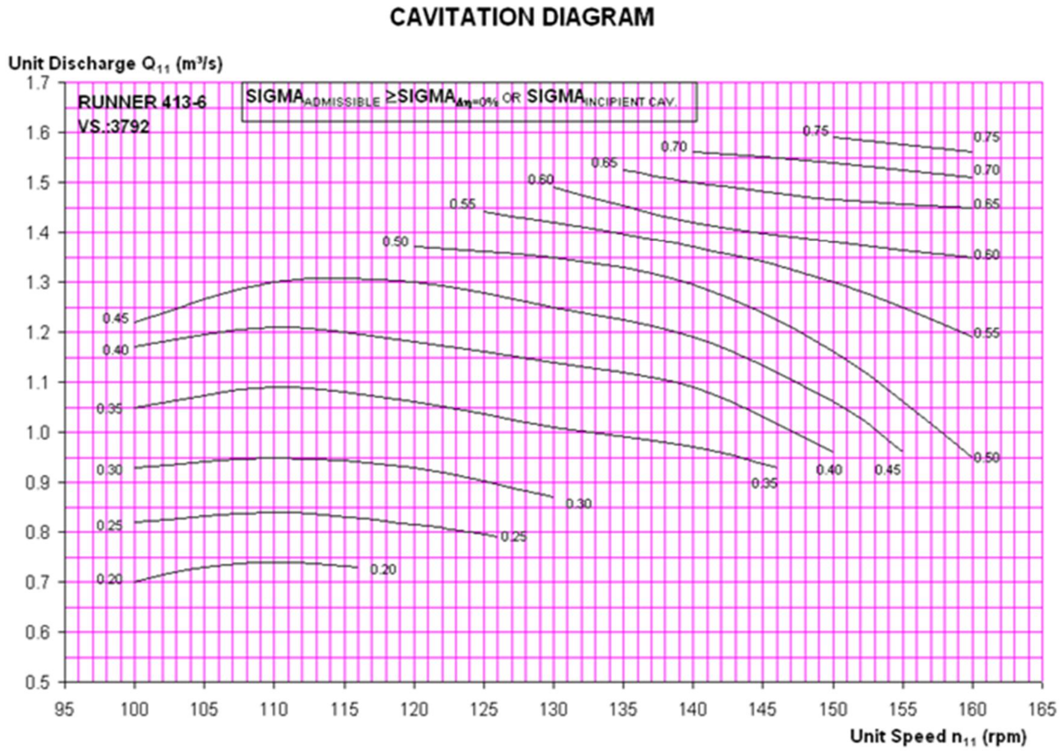


Figure.2.5 Kaplan turbine cavitation diagram [1]

## 2.4 Typical places of cavitation on Kaplan blades

### 2.4.1 Inlet edge cavitation.

This has a glassy surface near the inlet edge but shows severe Turbulence downstream. This occurs when operating with large attack angle. It may arise on the suction side of the blade (at small speed values) and on the pressure side (at large speed values). This may cause damage where the bubbles collapse.

### 2.4.2 Blade cavitation.

This appears on the blade surface far from the inlet edge. No glassy surface is seen but large bubbles form and burst apart. This may also cause damage of the blade.

### 2.4.3 Tip clearance cavitation.

A row of small bubbles are seen along the tip clearance. These are formed mainly in the vortex cores at the tip clearance (see the detail in Figure.2.6). The row of traveling individual bubbles seems to cause no damage. The clearance cavitation may grow however to a bubble cloud, which may be dangerous.

For open runners (without shroud) clearance cavitation cannot be avoided if working in the usual operating range. Cavitation damage seen frequently after a few years operation on axial-flow turbine blades is due mainly to clearance cavitation. The bubbles collapsing downstream of the blades does not damage the blade but they attack the casing.

### 2.4.4 Hub clearance cavitation.

This appears downstream of the clearance between the blade and the hub. Though the area attacked by the collapsing bubbles is small, cavitation pitting and damage is frequently seen on Kaplan blades and on the hub due to this source of cavitation.

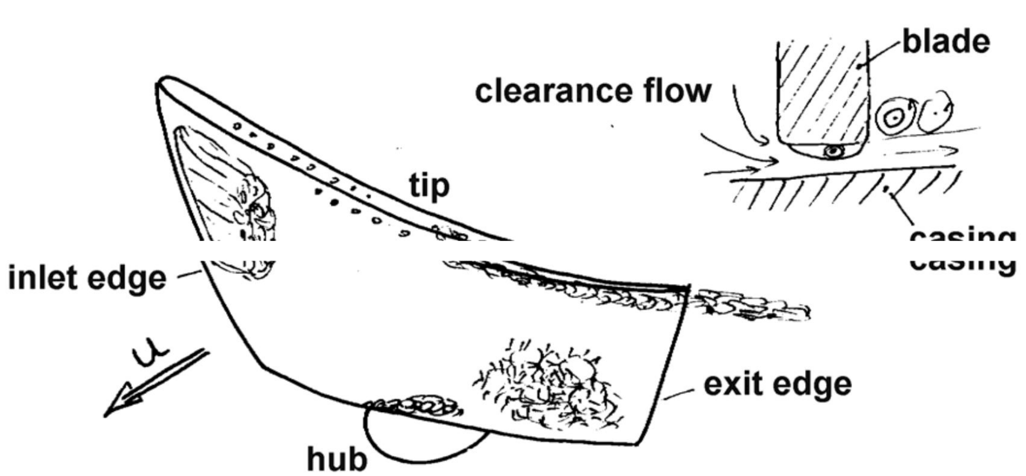


Figure.2.6 Typical places on a Kaplan blade where cavitation occurs[1]

## 2.5The detrimental effects of the cavitation are:-

• Change in efficiency

• Damage

• Noise

• Vibrations

### 2.5.1 Efficiency variation:-

Due to cavitation is seen from the suction curves of the model turbines. These are well described. Conducting the tests with decreasing σ value, sometimes the efficiency first somewhat increases, which is followed by a gradual fall till breakdown occurs.

Efficiency variation can be caused by any type of cavitation listed above, but only in such conditions when an appreciable amount of bubbles is present in the flow which is able to modify the nature of the flow.

There are published some scale effects which somewhat modify this equality, but these are small. It is advised to use some safety margin when the allowable cavitation number is determined.

### 2.5.2Cavitation damage:-

Due to cavitation has been studied for more than hundred years, and it is still not well understood yet. The difficulty is in the very small dimension of the collapsing bubbles. At the last stage of the collapse high pressure appears in the bubble creating a shock wave attacking the nearby wall. Special tests show that individual collapses can cause some small crevices on the wall, called as pitting. After some time, the pitting from the millions of the bubbles causes large crevices. The loss of the blade material may be considerable. Computation of bubble collapse showed large temperatures in the last stage.

Luminescence observed at cavitating regions may perhaps be associated with such high temperatures. Anyway cavitation damage is a fact. Even blades made of high strength steel are damaged usually after a few years of operation.

They are repaired by welding. In extra cases serious damage occurs after a few weeks. The best cavitation resistant material is a steel alloy with chromium content about 14 %, and nickel about 4 %.

### 2.5.3Noise:

Due to cavitation is normally not disturbing. It can however be used to detect the presence of the cavitation.

Fig 2.4a Model test of a Kaplan model, completed with noise measurement Fig2.4b. Shows that the Francis model test started at $\sigma = 0.7$ when no signs of cavitation was observed. The first bubbles were seen at $\sigma = 0.54$ at the runner hub. A microphone placed outside of the draft tube showed increasing sound pressure level (measured at a constant frequency f = 15 kHz) already at $\sigma = 0.6$. This means that cavitation was present in the range $\sigma = 0.54 – 0.6$, but the bubbles were so small that visually were not observable. The appearance of the cavitation is called cavitation inception. In this case the incipient cavitation number is: $\sigma$ incipient = 0.6. With decreasing $\sigma$ the sound pressure level increased, but after a maximum it begun to decrease at about $\sigma = 0.33$. Runner vane cavitation was first seen at a much smaller value, at $\sigma = 0.12$. This means that above this sigma value the increasing-decreasing sound level curve was caused by the cavitation, which developed in the center of the draft tube. The sound level begun to increase again at $\sigma = 0.2$.

This is be attributed to runner cavitation what was present also in the range $\sigma = 0.2 – 0.12$, but the bubbles were so small on the runner vanes that visually were not seen. The runner vane cavitation caused a second peak on the sound level curve at $\sigma = 0.05$. In the measured operating parameters a slight change is seen in n and Q beginning at $\sigma = 0.3$, due to runner vane cavitation. The marked variation of $\eta$ begun at $\sigma = 0.15$. Thus sound level measurement completes visual observations (enabling to determine more correct incipient cavitation numbers). its best efficiency point.

### 2.5.4Vibrations:-

Can also be caused by cavitation When a large amount of bubbles is present in the machine, then this bubble cloud can expand or can be compressed. This can interact with other bubble clouds in the machine or an oscillation can take place along the draft tube being the atmospheric air the other end. Vibrations can also occur in the case of resonance, when the natural frequencies of some parts of the machine are near to each other.

It is well known that Francis turbines are subjected to serious vibrations at part-load operation, so that these operating conditions must be excluded from the allowed operating range. These vibrations occur when a spiral-form vortex cavity is observed in the draft tube.

These vibrations are attributed to the cavitation. This is however an erroneous belief. The experimental fact is that the model turbines operating at a very large σ value, without cavitation, vibrate seriously at part load. The spiraling flow is also present in the draft tube, but without cavitation in the vortex core. At low σ values the cavitation only visualizes the vortex core. The reason of the vibrations is not the cavitation but the spiraling flow.

There is no general agreement on the origin of the spiraling flow. Some basic properties are however known. They occur only when operating away from the best efficiency point. In summing up, the efficiency loss due to cavitation can be avoided by the model tests, and the operating conditions causing serious vibrations can also be recognized. Safe measures against cavitation damage are not known. Therefore in the industrial practice turbine suppliers are forced to give guarantees against the material loss due to cavitation.

This is based on the accumulated experience of the turbine maker. Though this gives comfort to the buyer, one should keep in mind that a material damage larger than the guarantee may occur.

The place of the damage is known. Comparing this to the model visual observations, the corresponding values can be determined. Then a number of

## 2. 6 Actions to avoid cavitation damage:-

Every hydropower plant needs a unique maintenance program what may differ from that of the others.

Each piece of the plant should be inspected regularly.

Cavitation cannot be avoided in hydraulic turbines.

Therefore repair is concentrated mainly to **cavitation damage**.

### 2.6.1 Repair

A repair program for cavitation is:-

- **Inspection**

- **Identify the cause of the pitting**
- **Plan best approach to repairs**
- **Perform repairs**

For new turbines the first inspection may be made after the 1500 hours, then at 4000 and 8000 hours of operation. For units of minimum damage these are followed every 24000 hours of operation or every 4 years whichever is less. For units with considerable damage the maintenance program should be adjusted to the damage.

Inspection of cavitation damage, besides the runner, should be extended to the draft tube area below the runner, and the stay vane/wicket gate area in the spiral. The cause of cavitation damage can be identified using the sketches from the model tests.

Surface irregularities can also cause cavitation, for example in the vortex row Downstream of a small protuberance. Then a smooth streamlined shape of the surface may be produced by grinding.

If all the runner blades show similar cavitation symptoms, then modification of the blades can also be considered. For example leading edge or trailing edge modification can be made but consulted with the designer beforehand.

Excessive damage due to tip clearance cavitation can be reduced by adding anticavitation fins to the blades.

The usual repair is, however, welding with a good cavitation resistant material. In large turbines make the repair by welding only in areas where cavitation damage is 3 mm or deeper. It should be remembered however that after a long initial period (so called

Incubation period), due to cavitation the surface becomes rough and hollows are formed in the material. In reaching this state, cavitation is accelerated. Therefore, in such situation inspect the machine more frequently. For the repair of carbon steel items, even with light damage, use stainless steel weld material. Remove the irregularities caused by cavitation until a clear undamaged surface is seen.

Use at least two weld passes. Adjust the shape of the surface by grinding. After this repair the surface will bear cavitation attack for a much longer time.

Stainless steel should be repaired with a compatible weld.

### 2.6.2 Overhaul

Inspection of the places where wear can occur may be made during every repair. Normally a major overhaul is needed after 25 years of operation.

### 2.6.3 Packing box and shaft sleeve

Many times the packing box will be severely corroded. If the metal loss is significant in the packing box bore, the packing will have to be compressed in order to fill the bore.

This will lead to shortened packing life and excessive wear of the shaft packing sleeve. If the packing box is still structurally sound, the interior bore of the box can be built up with a properly applied epoxy coating. If the corrosion has reached the point that the box has been weakened significantly, some other method of repair or complete replacement may be required. Once the surfaces have been repaired, the packing box should be painted.

The turbine shaft packing sleeve is usually constructed in two pieces so that it can be replaced when worn. In some cases, the sleeve can be built up by welding and machined back to the drawing dimensions. Welding on the packing sleeve must be accomplished with a minimum amount of heat input to prevent inducing stress and distorting the sleeve.

Another alternative is to flame spray the sleeve with a wear-resistant material and machine it back to original dimensions. The coating used in flame spraying must be chosen carefully and the proper procedure followed to ensure proper bonding to the parent material.

### 2.6.4 Alignment of shafts

After the parts of the turbine have been renewed, mounting starts. The most difficult operation is the alignment of the vertical shafts of large hydro units. This is described in details in the manuals. First the design of the unit must be studied.

Small turbines may have their own guide and thrust bearings (like large pumps), and so have the generators as well. In this case the shaft coupling must be of an elastic type, which allows a small misalignment during operation. In this case the coupling is to be aligned as accurately as possible.

Long shafts (or shafts coupled by rigid couplings) may have three guide bearings. The misalignment of these guide bearings results in bending the shaft. This may not be allowed for. Therefore even more accurate alignment is necessary. Normally, vertical shaft hydro units are designed nowadays so that the turbine shaft is joined to the generator shaft by a rigid coupling. The two parts can be considered as one shaft. The unit may have two guide bearings and one thrust bearing.

### 2.6.5 Field balancing

After the shaft has been erected and the motor is turn on, the unit may run with some vibrations. The vibrations are measured near the guide bearings. Sometimes the root mean square of the vibration velocity is measured. Whether a value may be allowed or not, depends on the construction of the machine and many other factors.

After a repair of the runner, comparing to the pre shutdown vibration values, at least these should be achieved. Thus, after repair of the rotor a field balancing of the unit may be required.

Balancing sorts out one the most common vibration source, the unbalance of the rotor. Field balancing is a tedious work, takes time, needs access to the runner, and the unit outage may be costly. Therefore prior to field balancing it is advised to check the possibility of the other vibration sources:

•Bolted connections in the rotating parts should be checked for tightness.

• Check the alignment of the rotor

• Check the bearing positions

• Check bolt tightness at the fixation to the concrete

• Examine the foundation for rigidity

• Check the air gaps in the generator or exciter

• Short-circuited windings may be in the rotor

• The rotor may be not symmetrical enough

• Measure the pressure variation at the outer surfaces of a Francis runner.

Pressure fluctuations may be generated there.

• Obstructions are perhaps in the spiral case

• Debris may be found between vanes or blades

• The runner position may be incorrect relative to the distributor.

### 2.6.6 Causes of refurbishment

An overhaul is due to a turbine after 25 or 30 years of operation. In the overhaul the original conditions of the machine are restored.

During an overhaul a refurbishment is made if the capabilities of the machine are extended. There may be several reasons to do this.

• The technical progress in the efficiency. From 1970 to 2000 the peak Efficiencies of hydraulic turbines increased by about 2, 5 % worldwide. We may assume that also the average efficiency increased by nearly the same amount. Thus exchanging the runner of a turbine after 30 or 60 years of operation may be economical.

•Technical progress in the auxiliary machinery. The regulators, the governing, Monitoring and safety equipment developed in the past decades. Exchanging Those to modern ones (say to computer regulation) may result in more safe, Automatic and more economical operation.

• The price of electricity increased in the past decades. Therefore the optimum of the main operating parameters of the plant has also changed. In many cases Increased plant discharge is desired. This may be done using a new runner. In Most cases also the casing is modified. The increased output has consequences in the electric equipment as well.

• The role of the plant in the electric system may also change. For example the Plant used for generating basic load may be changed for supplying peak load. This involves changes in the governing system.

In a refurbishment, if increased output is required, the feasibility study can follow the calculations of the yearly energy production as for a new plant. The costs and incomes may be compared. Whether the planned change is feasible or not may be assessed in this study.

If the refurbishment includes modifications of hydraulic parts, then model tests are needed.

## 2.7 Actions to be done in the case of excessive cavitation damage:-

First the operating conditions in which the damage occurs should be identified.

• If these points are less important, then these can be disclosed from the allowed operating range.

Thus the operation in the dangerous region will be forbidden.

• In case of a double regulated machine the regulation can be changed.

This means that the machine will not operate on the cam curve, but on one of the propeller curves.

The direction of this change can be determined from the measured noise level curves of the model.

There is experimental evidence that decreasing noise level indicates decreasing damage.

• Air entrainment may also help. The air should be allowed to the vicinity of the damaged region. This somehow softens the damaging attack of the cavitation.

• There are efforts to use cavitation resistant coatings. Experience indicated that in case of severe cavitation each coatings pile off.

• In the case of tip clearance cavitation, changing the clearance geometry can also help. There are patents which promise less cavitation damage.

• The manufacturer may change the runner material if there exists a better one than the original.

• Using suitable welding material may lengthen the time between repairs.

• The ultimate help is making a new runner design, usually with longer blades, which may have smaller damage.

The vibrations of a prototype, due to any reason, may exceed some agreed limits. In this case balancing of the rotor is the first idea. If this does not help, then changing the natural frequencies of some parts of the structure is the second one.

To avoid part-load oscillations of turbines sometimes air entrainment is made through the hub to the center of the daft tube cone. As a result, the diameter of the cavitating funnel will increase (which contains air besides vapor), and having enough air entrained, the flow character changes, it becomes symmetrical, and the spiraling flow is not observed any more.

This means that the vibrations are suppressed by the air entrainment.

### 2.7.1The welding procedure can be made in the following steps:-

- Use brackets or braces to avoid deformations
- Prepare the surface as usual for welding
- Preheat the area
- Make welding (fans around)
- Grind to contour
- Inspect the weld, and clear the surface.

Remember that stainless steel is susceptible to rapid corrosion if it had been Contaminated with carbon from grinding or the weld spatter.

The corrosion resistance of the stainless steel surface can be restored by passivating the surface (using chemicals).

### 2.7.2Blades coating

In new deliveries carbon steel surfaces are painted with red lead priming paint and with at least two layers and good quality paint. These paints protect the piece from corrosion and light cavitation. Some chemical suppliers offer coatings with epoxies or ceramic metals to be used on the damaged area. These are of little use against severe cavitation.

New stainless steel runners are delivered usually without a paint to capitalize on the good quality of the material. However their surfaces have to be protected against contamination (use closed spaces during transport).

# CHAPTER III

# Study and Analysis of Cavitation in roseires Power station

Under the joint action and mutual promotion of cavitation and sand erosion, serious abrasion could be made, the hydraulic performance of the Kaplan turbine may be descended, and the safety and stability of turbine are greatly threatened. In this research, a description of the general features of cavitation phenomenon is given and also discussed about the Cavitation index. Based on the literature survey various aspects related to cavitation in hydro Turbines have been discussed.

Therefore, it is very important and significant to investigate the cavitation characteristic of Kaplan turbine under sediment flow condition.

The runner blades were subjected to the following problems:-

- Serious abrasion could be made.
- The hydraulic performance of the Kaplan turbine may be descended.
- The safety and stability of turbine are greatly threatened.

## 3.1 Cavitation's periods

The study of cavitation in Kaplan turbines in roseires power station during three periods as follows:

### 3.1.1 Flood period

Every unit was subject to be operating with in cavitation zone for different periods (40 min/day approx...)As in shown in tables 3.1.1.A&3.1.1.B

#### 3.1.1. A before heightening

Average time raking (01 of August ----- 30 of September 2012)

Table 3.1 .1.A time subjected to cavitation before heightening

| Unit No. | Total time of raking (min) | Raking load (MW) |
|---|---|---|
| 1 | 240 | 5 |
| 2 | 840 | 5 |

| | | |
|---|---|---|
| 3 | 330 | 5 |
| 4 | 240 | 5 |
| 5 | 1400 | 4 |
| 6 | 950 | 0 |
| 7 | 1100 | 0 |

### 3.1.1. B After heightening

Average time raking (01 of July ----- 31 of August 2014)

Table 3.1.1. B time subjected to cavitation after heightening

| Unit No. | Total time of raking (min) | Raking load (MW) |
|---|---|---|
| 1 | 340 | 10 |
| 2 | 450 | 10 |
| 3 | 330 | 10 |
| 4 | 350 | 10 |
| 5 | 250 | 8 |
| 6 | 140 | 0 |
| 7 | 0 | 0 |

At least to clean the intake by trash – rake (4 times daily) and this is only possible when M/C output 5-10 MW or M/C spinning, due to the high water current at the turbine intake . If the critical time during flood season is 60 days. So the total time that M/C operate under cavitation zone = 40×60/60 = 40 hours. This time is only trash – racking , in addition to that , the pressure drop a cross screen due to blockage also increase possibility of cavitation because some time the maximum out power is less than 10 MW which lead to creates bubbles round runner blades .

### 3.1.2 Water restriction period

This period begin from January up to end of May. The net head during this Period in between 25m to 33 m according to mentioned head the minimum cavitation limits varies between a load of 11 MW and 13 MW respectively, during this period the plant operates daily from early morning hours until the peak hours in minimum load, sometimes reach 26 MW on two units (13MW/unit), so these units were operated within cavitation zone or close to cavitation limit.

### 3.1.3 Blackout period

Beside above mentioned periods, also the blackout increase possibly of operation within cavitation zone, because the line was energized with two units on loads less than cavitation limit (at least 15 min. /blackout).

## 3.2 Cavitation features

The main cavitation features of Roseires power plant are compiled and organized as follows:

### 3.2.1 Areas subjected to cavitation

Areas subjected to cavitation in machine runner chamber are shown in Figure.3.1 are:-

1. Runner hub
2. Blade roots
3. Blade tip

Figure 3.1 Cavitation areas in machine runner chamber [8]

### 3.2.2 Cavitation problem

Rosieres power plant suffers from cavitation, abrasion and erosion phenomena exactly during flood season. The rate of erosion, abrasion by solid particles (debris and sand) and pitting by cavitation is very high. This problem detected during annual maintenance and this lead to low reliability and other problems.

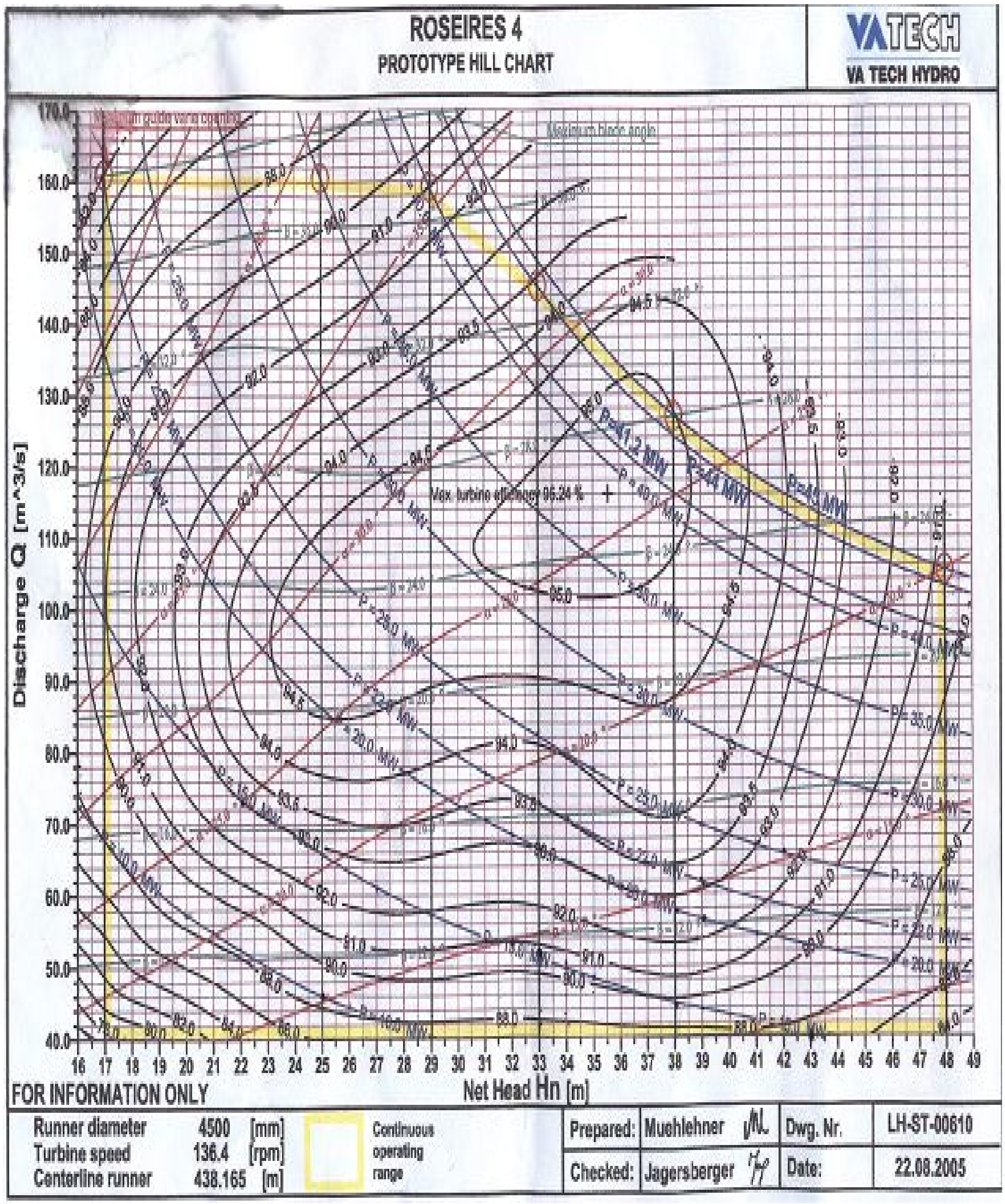


Figure 3.2 Performance curve of cavitation zone [1]

### 3.2.3 Cavitation limits

As in the performance curves as shown in Figure 3.2 there are two cavitation limits:-

1. Upper cavitation limit: this limit is related to:-

- output power
- head
- tail water level

Since the references output power according to a desire head is always below the upper cavitation limit, the power plant always operated out of upper cavitation zone.

2. Lower cavitation limit: this limit is related to:-

- output power
- head

This limit is linear relation (the output power cavitation limit increase as net head). Mainly the plant units are affected by this limit, since most time units are operated within cavitation zone exactly during the mentionable periods.

## 3.3 **Calculation of cavitation index**

Cavitation index is important factor to analysis and evaluate the cavitation phenomena during the flood, water restriction and blackout periods. The index is function of many variables such as density, heads, and discharge, Figure 3.3 below shows the turbine heads and levels.

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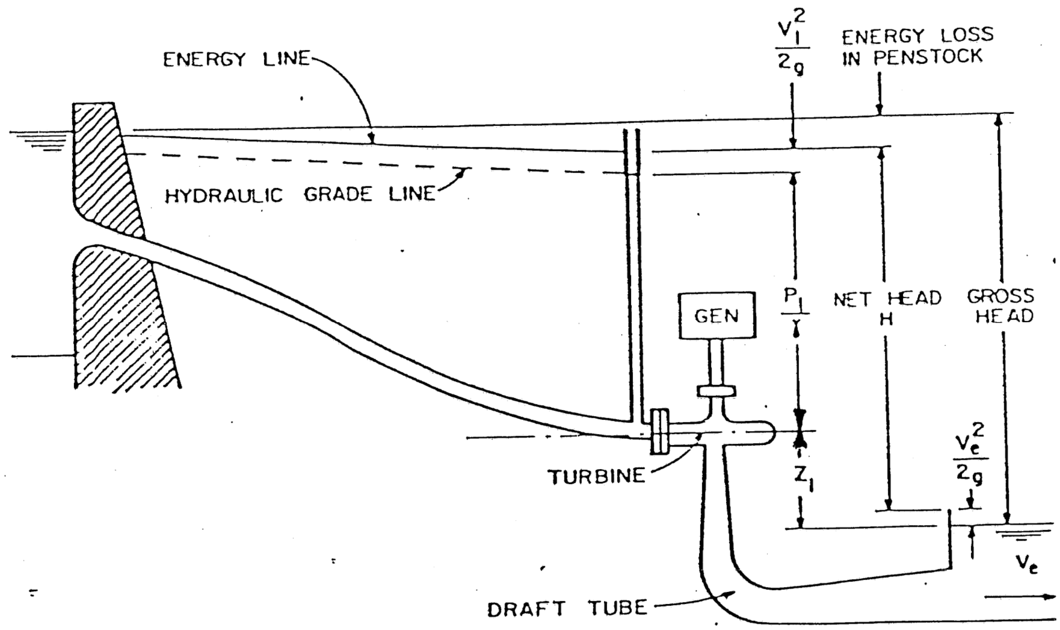


Figure 3.3 turbine heads and levels [10]

Cavitation index can be calculated by using the following equations:

1. Bernoulli equation:

$$\frac{V_1^2}{2g} + \frac{P_1}{\rho g} + Z_1 = \frac{V_2^2}{2g} + \frac{P_2}{2g} + Z_2 + h_f \qquad 1$$

$$h_f = h_{gross} - h_{net} \qquad 2$$

$$h_{gross} = U/S - D/S \qquad 3$$

2. Continuity equation:

$$Q = A \times V \qquad 4$$

3. Cavitation index equation:

$$\sigma = \left( \frac{P_{atm}}{\rho g} - \frac{P_{\min}}{\rho g} - Z \right) \div H \qquad 5$$

$$N_s = \frac{N \times (0.76 \times P_w)^{0.5}}{h_{net}} \qquad 6$$

$$\sigma_c = 0.28 + \left( \frac{1}{7.5} \left( \frac{N_S}{380.78} \right)^2 \right) \qquad 7$$

Table 3.2 Roseires technical data

| | |
|---|---|
| Maximum upstream level before dam heightening | 481.0 m |
| Maximum upstream level after dam heightening | 491.0 m |
| Flood operational level | 467.00 m |
| Maximum downstream level | 455.5 m |
| Minimum downstream level | 440 m |
| Unit Installed capacity | 40 MW |
| Total Installed capacity | 280 MW |
| Maximum head | 48.00 m |
| Rating head | 33.00 m |
| Minimum head | 17.00 m |
| Runner diameter | 4.5m |
| Penstock external diameter | 6.05 m |
| Penstock internal diameter | 5.8 m |
| Runner clearance | 3.5 – 5 mm |
| Runner blades level | 438.165 m |

### 3.3.1Before dam heightening

#### 3.3.1.1 Cavitation index of flood period

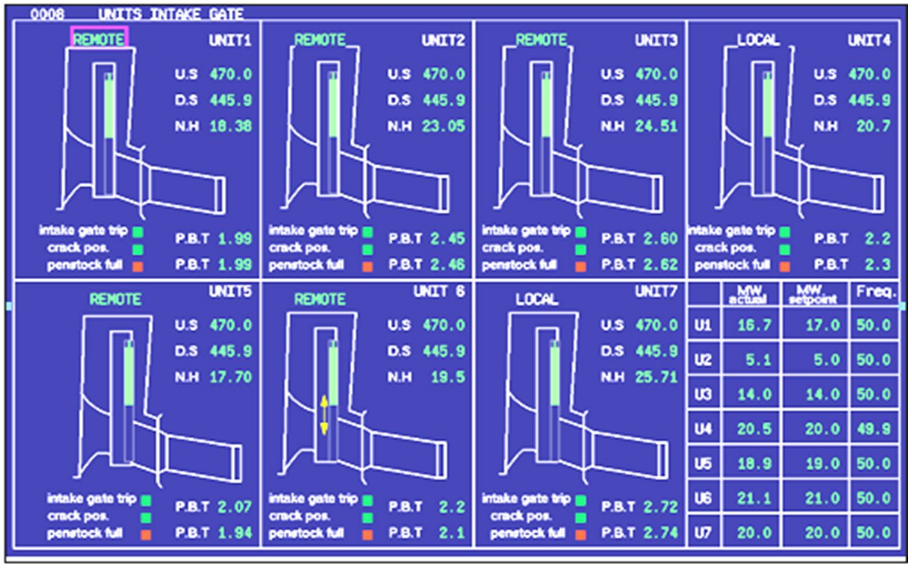


Figure 3.4.A units intake gate [8]

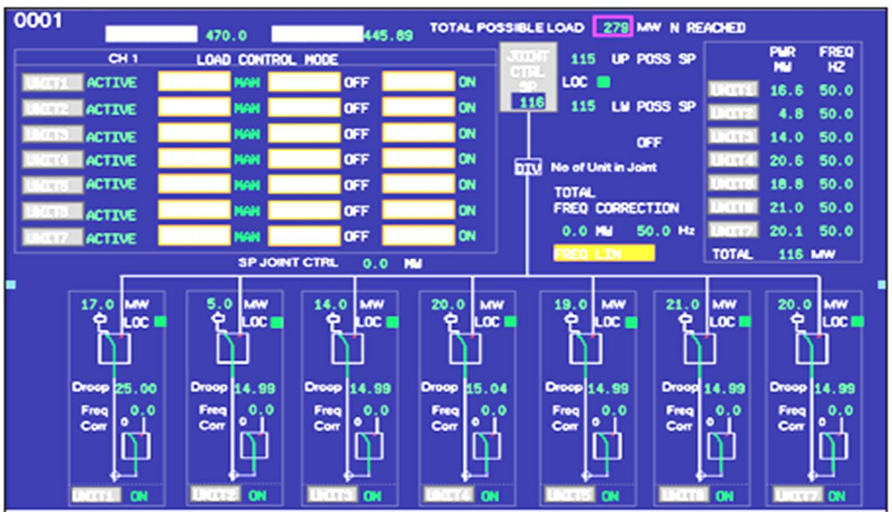


Figure 3.4.B Roseires total possible load [8]

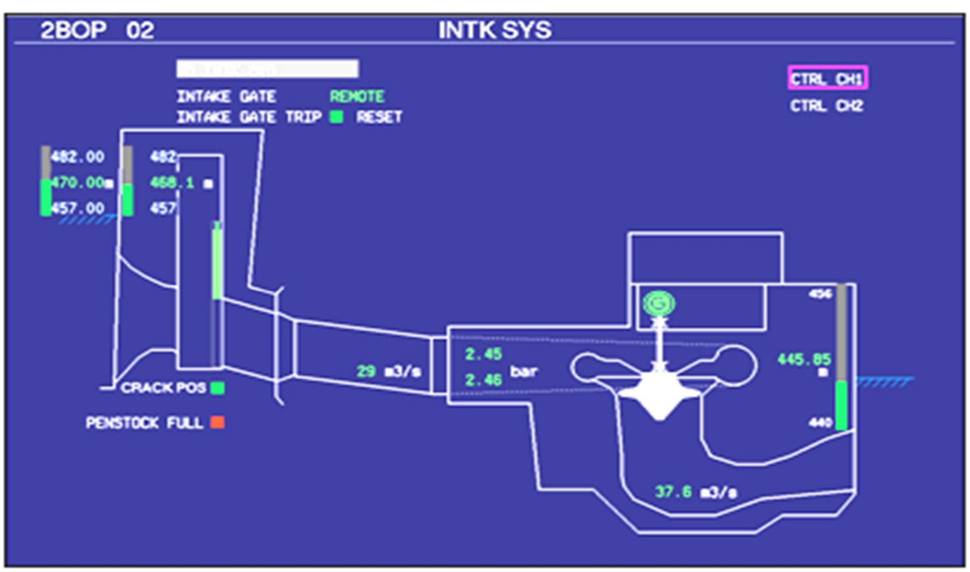

Figure 3.4.C unit 2 intake system [8]

$$h_{gross} = U/S - D/S$$
$$470.00 - 445.90 = 24.10m$$
$$h_{net} = 18.38m \quad (from\ turbine\ monitor\ screen\ in\ Fig.4.3)$$
$$h_f = h_{gross} - h_{net}$$

$$= 21.10 - 18.38 = 2.72m$$
$$\rho = (\rho_s \times x_s + \rho_w \times x_w)$$
$where\ \rho =\ flood\ water\ density$

$\rho_s\ and\ x_s\ are\ silt\ density\ and\ silt\ fraction\ respectively.$

$\rho_w\ and\ x_w\ are\ water\ density\ and\ water\ fraction\ resp.$

$$\rho = (1280 \times 0.10 + 1000 \times 0.90) = 1028 kg/m^3$$
$(A\ sample\ of\ flood\ water\ is\ analyse\ and\ the\ result\ was\ 10\%silt\ and\ 90\%water)$

$$Q = A \times V_f$$
$$Q_2 = 67.6m^3/s \quad (actual\ discharge)$$
$$A_2 = \frac{\pi}{4}(D^2 - d_b^{\ 2}) = \frac{\pi}{4} \times (4.5^2 - 2.5^2) = 11m^2$$
$whwere\ D = runner\ diameter$

$and\ d_b = hub\ diameter$

$$V_f = \left( \frac{67.6}{\frac{\pi}{4} \times (4.5^2 - 2.5^2)} \right) = 3.42m/s$$
$$Z = Z_1 - Z_2$$
$$= 444.80 - 438.165 = 6.635m$$

$$\frac{P_{min}}{\rho g} = \frac{P_2}{\rho g} - \frac{V_2}{2g} - h_f$$

$$P_{min} = \left( \frac{1.013 \times 10^5}{1028 \times 9.81} - \frac{3.42^2}{2 \times 9.81} - 2.72 \right) \times 1028 \times 9.81 = 0.72\ bar$$

$$\sigma = \left( \frac{P_{atm}}{\rho g} - \frac{P_{min}}{\rho g} - Z \right) \div h_{net}$$
$$= (10.045 - 7.14 + 6.635) \div 23 = 0.41$$

$$N_s = \frac{136.4 \times (0.76 \times 10 \times 1000)^{0.5}}{23} = 517 (p = 10MW)$$

$$\sigma_c = 0.28 + \left( \frac{1}{7.5} ( \frac{517}{380.78} )^2 \right) = 0.52$$

#### 3.3.1.2 Cavitation index of water restriction period

$$h_{gross} = U/S - D/S$$

$$469.90 - 441.25 = 28.65m$$

$$h_{net} = 24.2m \quad from\ turbine\ monitor\ screen$$

$$h_f = h_{gross} - h_{net}$$

$$= 28.65 - 24.2 = 4.45m$$

$$Q = A \times V_f$$

$$Q_2 = 45 m^3 / s \quad (actual\ discharge)$$

$$A_2 = \frac{\pi}{4} (D_2{}^2 - d_b{}^2) = \frac{\pi}{4} \times (4.5^2 - 2.5^2)$$

$$V_f = \left( \frac{45}{\frac{\pi}{4} \times (4.5^2 - 2.5^2)} \right) = 3.54 m/s$$

$$Z = Z_1 - Z_2$$

$$= 442.90 - 438.165 = 4.735m$$

$$P_{\min} = \left( \frac{1.013 \times 10^5}{1000 \times 9.81} - \frac{3.54^2}{2 \times 9.81} - 4.45 \right) \times 1000 \times 9.81 = 0.49\ bar$$

$$\sigma = \left( \frac{P_{atm}}{\rho g} - \frac{P_{\min}}{\rho g} - Z \right) \div h_{net}$$

$$= (10.33 - 5.0 + 4.735) \div 24.2 = 0.42$$

$$N_s = \frac{136.4 \times (0.76 \times 15 \times 1000)^{0.5}}{24.2} = 602 (P = 15MW)$$

$$\sigma_c = 0.28 + \left( \frac{1}{7.5} ( \frac{602}{380.78} )^2 \right) = 0.61$$

#### 3.3.1.3 Cavitation index of blackout period

$$h_{gross} = U/S - D/S$$

$$473.40 - 443.00 = 30.4\,m$$

$$h_{net} = 26.2\,m \quad \textit{from turbine monitor screen}$$

$$h_f = h_{gross} - h_{net}$$

$$= 30.4 - 26.2 = 4.2\,m$$

$$Q = A \times V_f$$

$$Q_2 = 39\,m^3/s \quad (\textit{actual discharge})$$

$$A_2 = \frac{\pi}{4}(D^2 - d_b{}^2) = \frac{\pi}{4} \times (4.5^2 - 2.5^2)$$

$$V_f = \left( \frac{39}{\frac{\pi}{4} \times (4.5^2 - 2.5^2)} \right) = 4.08\,m/s$$

$$Z = Z_1 - Z_2$$

$$= 443.00 - 438.165 = 4.835\,m$$

$$P_{\min} = \left( \frac{1.013 \times 10^5}{1000 \times 9.81} - \frac{4.08^2}{2 \times 9.81} - 4.2 \right) \times 1000 \times 9.81 = 0.52\ bar$$

$$\sigma = \left( \frac{P_{atm}}{\rho g} - \frac{P_{\min}}{\rho g} - Z \right) \div h_{net}$$

$$= (10.33 - 5.3 + 4.835) \div 26.2 = 0.37$$

$$N_s = \frac{136.4 \times (0.76 \times 5 \times 1000)^{0.5}}{26.2} = 352 (P = 5MW)$$

$$\sigma_c = 0.28 + \left( \frac{1}{7.5} \left( \frac{352}{380.78} \right)^2 \right) = 0.39$$

### 3.3.2After dam heightening

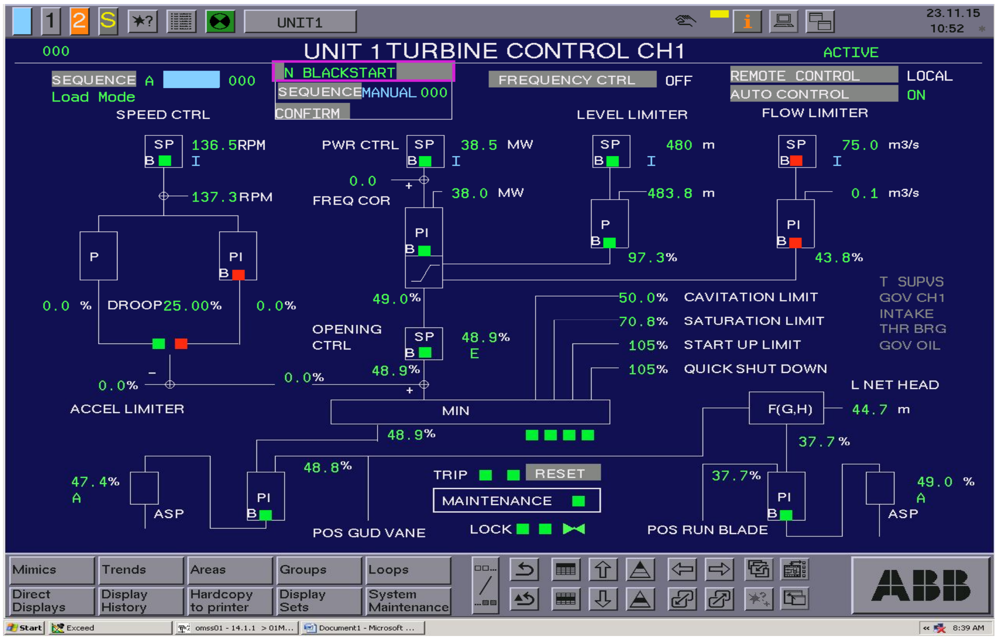


Figure 3.5.A unit 1 turbine control channel [8]

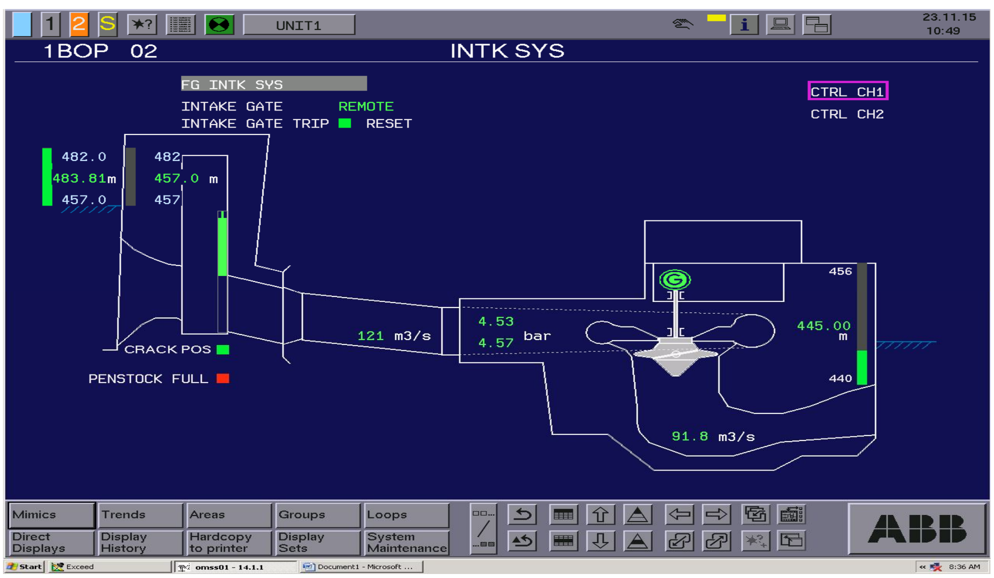


Figure 3.5.B unit 1 intake system [8]

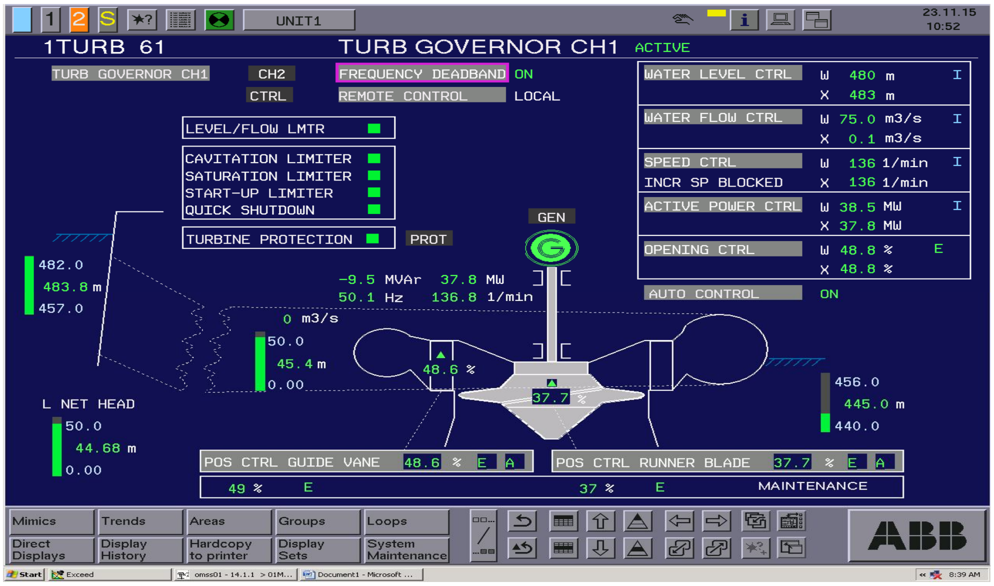


Figure 3.5.C unit 1 turbine governor channel [8]

### 3.3.2.1 Cavitation index of flood period

$$h_{gross} = U/S - D/S$$

$$= 470.00 - 446.20 = 23.80\,m$$

$$h_{net} = 21.5\,m \quad \textit{from turbine monitor screen}$$

$$h_f = h_{gross} - h_{net}$$

$$= 23.80 - 21.5 = 2.30\,m$$

$$Q = A \times V_f$$

$$Q_2 = 91.8\,m^3/s \quad (\textit{actual discharge})$$

$$A_2 = \frac{\pi}{4}(D_2{}^2 - d_b{}^2) = \frac{\pi}{4} \times (4.5^2 - 2.5^2)$$

$$V_f = \left( \frac{91.8}{\frac{\pi}{4} \times (4.5^2 - 2.5^2)} \right) = 8.36\,m/s$$

$$Z = Z_1 - Z_2$$

$$= 446.20 - 438.165 = 8.035\,m$$

$$P_{min} = \left( \frac{1.013 \times 10^5}{1028 \times 9.81} - \frac{8.36^2}{2 \times 9.81} - 2.30 \right) \times 1028 \times 9.81 = 0.70\ bar$$

$$\sigma = \left( \frac{P_{atm}}{\rho g} - \frac{P_{min}}{\rho g} - Z \right) \div h_{net}$$
$$= (10.044 - 7.0 + 8.035) \div 21.5 = 0.51$$

$$N_s = \frac{136.4 \times (0.76 \times 10 \times 1000)^{0.5}}{21.5} = 553 (p = 10MW)$$

$$\sigma_c = 0.28 + \left( \frac{1}{7.5} \left( \frac{553}{380.78} \right)^2 \right) = 0.56$$

## 3.3.2.2 Cavitation index of water restriction period

$$h_{gross} = U/S - D/S$$
$$472.00 - 442.10 = 29.90m$$
$$h_{net} = 27.25m \quad \textit{from turbine monitor screen}$$
$$h_f = h_{gross} - h_{net}$$

$$= 26.90 - 21.40 = 5.50m$$

$$Q = A \times V_f$$
$$Q_2 = 57 m^3/s \quad (actual\ discharge)$$
$$A_2 = \frac{\pi}{4}(D_2^{\ 2} - d_b^{\ 2}) = \frac{\pi}{4} \times (4.5^2 - 2.5^2)$$

$$V_f = \left( \frac{57}{\frac{\pi}{4} \times (4.5^2 - 2.5^2)} \right) = 5.20 m/s$$

$$Z = Z_1 - Z_2$$
$$= 443.80 - 438.165 = 5.635m$$

$$P_{min} = \left( \frac{1.013 \times 10^5}{1000 \times 9.81} - \frac{5.20^2}{2 \times 9.81} - 5.50 \right) \times 1000 \times 9.81 = 0.33\ bar$$

$$\sigma = \left( \frac{P_{atm}}{\rho g} - \frac{P_{\min}}{\rho g} - Z \right) \div h_{net}$$

$$= (10.33 - 3.3 + 5.635) \div 21.40 = 0.59$$

$$N_s = \frac{136.4 \times (0.76 \times 20 \times 1000)^{0.5}}{27.25} = 617$$

$$\sigma_c = 0.28 + \left( \frac{1}{7.5} \left( \frac{617}{380.78} \right)^2 \right) = 0.63$$

### 3.3.2.3 Cavitation index of blackout period

$$h_{gross} = U/S - D/S$$

$$483.81 - 445.00 = 38.81m$$

$h_{net} = 37m$ *from turbine monitor screen*

$$h_f = h_{gross} - h_{net}$$

$$= 38.81 - 37.00 = 1.81m$$

$$Q = A \times V_f$$

$Q_2 = 42\,m^3/s$ (*actual discharge*)

$$A_2 = \frac{\pi}{4}(D_2^{\ 2} - d_b^{\ 2}) = \frac{\pi}{4} \times (4.5^2 - 2.5^2)$$

$$V_f = \left( \frac{42}{\frac{\pi}{4} \times (4.5^2 - 2.5^2)} \right) = 3.82\,m/s$$

$$Z = Z_1 - Z_2$$

$$= 445.00 - 438.165 = 6.835m$$

$$P_{\min} = \left( \frac{1.013 \times 10^5}{1000 \times 9.81} - \frac{3.82^2}{2 \times 9.81} - 1.81 \right) \times 1000 \times 9.81 = 0.488\ bar$$

$$\sigma = \left( \frac{P_{atm}}{\rho g} - \frac{P_{\min}}{\rho g} - Z \right) \div h_{net}$$

$$= (10.33 - 4.97 + 6.835) \div 37.00 = 0.33$$

$$N_s = \frac{N \times (0.76 \times 6 \times 1000)^{0.5}}{37} = 250$$

$$\sigma_c = 0.28 + \left( \frac{1}{7.5} \left( \frac{250}{380.78} \right)^2 \right) = 0.34$$

# CHAPTER IV

# Results and Discussion

## 4.1 Results

### 4.1.1 before dam heightening

Variables that affect the cavitation before dam heightening are shown in table 4.1.1(A), and the calculated parameters affect the cavitation is shown in table 4.1.1(B).

Table 4.1.1(A): Variables affect cavitation before dam heightening

| period | P(bar) | $Q(m^3/s)$ | $P_{atm}$(bar) | $h_{gross}$(m) | $h_{net}$(m) | $h_f$(m) |
|---|---|---|---|---|---|---|
| Flood season | 1.90 | 67.6 | 1.013 | 24.1 | 18.38 | 2.72 |
| Water restriction | 2.50 | 39.00 | 1.013 | 28.65 | 24.20 | 4.45 |
| blackout | 2.30 | 45.00 | 1.013 | 30.40 | 26.20 | 4.20 |

Table 4.1.1(B): Calculated parameters affect cavitation before dam heightening

| period | $A(m^2)$ | V(m/s) | $P_{min}$(bar) | $\rho(m^3/kg)$ | б(-) | $б_C$(-) | $N_s$(-) |
|---|---|---|---|---|---|---|---|
| Flood season | 11 | 3.42 | 0.72 | 1028 | 0.41 | 0.52 | 517 |
| Water restriction | 11 | 41 | 0.49 | 1000 | 0.42 | 0.61 | 602 |
| blackout | 11 | 4.08 | 0.52 | 1000 | 0.37 | 0.39 | 352 |

### 4.1.2After dam heightening

Table 4.1.2(A) variables affect cavitation after dam heightening

| period | P(bar) | Q($m^3$/s) | $P_{atm}$(bar) | $h_{gross}$(m) | $h_{net}$(m) | $h_f$(m) |
|---|---|---|---|---|---|---|
| Flood season | 2.1 | 91.8 | 1.013 | 23.80 | 21.50 | 2.30 |
| Water restriction | 3.5 | 57 | 1.013 | 29.90 | 27.25 | 5.50 |
| blackout | 3.8 | 42 | 1.013 | 38.81 | 37.00 | 1.81 |

Table 4.1.2(B): Calculated parameters affect cavitation after dam heightening

| period | A($m^2$) | V(m/s) | $P_{min}$(bar) | ρ($m^3$/kg) | б(-) | $б_C$(-) | $N_s$(-) |
|---|---|---|---|---|---|---|---|
| Flood season | 11 | 8.36 | 0.70 | 1028 | 0.51 | 0.56 | 553 |
| Water restriction | 11 | 5.2 | 0.33 | 1000 | 0.59 | 0.63 | 617 |
| blackout | 11 | 3.82 | 0.488 | 1000 | 0.33 | 0.34 | 250 |

## 4.2 Discussion

The cavitation sound levels are:

1. The cavitation sound level peak 1 range (0.12-0.2)
2. The cavitation sound level peak 2 range (0.05-0.3)

From tables 4.1.1 (A and B) and tables 4.1.2 (A and B) the following comparisons and observations are listed below:

1. Cavitation occurred during the three periods because the cavitation Periods (0.41<0.52, 0.42<0.61, 0.37<0.39,) before dam heightening And (0.51<0.56, 0.59<0.63, 0.33<0.34,) after dam heightening.
2. The maximum discharge at flood season and minimum at blackout.
3. before heightening the maximum velocity in water restriction while The minimum in flood season, after heightening the maximum Velocity in flood season whiles the minimum in blackout.
4. The maximum minimum pressure in flood season while the minimum Pressure in water restriction period.

5. The maximum density in flood season while the minimum is at black Out and water restriction.
6. Before and after dam heightening the maximum cavitation index in Water restriction period while the minimum at the blackout period.
7. Cavitation effect after dam heightening is less than that before dam Heightening due to additional available head.

# CHAPTER V

# Conclusion and Recommendations

## 5.1 Conclusion

Cavitation is a phenomenon of formation of vapor bubbles in low pressure regions and collapse in high pressure regions, high pressure is produced and metallic surfaces are subjected to high local stresses. Cavitation can present different forms in hydraulic turbines depending on the machine design and the operating condition. As a result, high vibration levels, instabilities and erosion can occur this affect the machine operation and cause damage. It is difficult to avoid cavitation completely in hydraulic turbines but can be reduced to economic acceptable level; this is done by loading unit out of cavitation zone.

Cavitation during three period was studied (flood season, water restriction and black out) before and after dam heightening.

Cavitation index, critical cavitation index and related parameters as specific speed and minimum outlet pressure were calculated.

The results of the calculations indicated that the Cavitation occurred during the three periods since the cavitation index of all periods is less than the critical cavitation index before and after dam heightening.

Comparison of cavitation index during three periods is done and it was found that before and after dam heightening the maximum cavitation index in Water restriction period while the minimum at the blackout period.

Also it found that Cavitation effect after dam heightening is less than that before dam heightening due to additional available head.

## 5.2 Recommendations

### 5.2.1 For minimize cavitation on Roseires turbines

It is impossible to avoid cavitation completely in practices, but it is possible to reduce cavitation effect to minimum condition by loading unit out of cavitation zone, hence the following points are recommended to avoid cavitation zone:

1. Cavitation while operating Hydraulic Turbines parameters should be set such that at any point of flow static pressure may not fall below the vapor pressure of the liquid. These parameters to control cavitation are pressure head, flow rate and exit pressure of the liquid.
2. New trash – racking machines or modify the exist ones to be reliable to clean on load above cavitation zone.
3. Suitable arrangement during water restriction period to load the operating units above cavitation zones.
4. Continuous cleaning of screen to avoid pressure drop across screen.
5. Apply new blackout start procedure to energize the line by one unit and this unit must be quick load to pass cavitation zone.
6. A quick action must be done by K.L.D.C and plant shift engineer to stop M/C running within cavitation zone if no possibility to pass cavitation zone.
7. Fix cavitation tip to the runner blades

### 5.2.2 for research extension

This research can be further extended to include the following:

1. The hardness of blades can be tested
2. The densities of water in three periods can be accurately measured

3. A simulation of cavitation phenomena can done

# REFERENCES


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# APPENDEX 1

## A.1 Material common failure

### A.1.1 Failure Analysis Investigation

Failure of a component indicates it has become completely or partially unusable or has deteriorated to the point that it is undependable or unsafe for normal sustained service.

### A.1.2 Typical Root Cause Failure Mechanisms

- Fatigue failures
- Corrosion failures
- Stress corrosion cracking
- Ductile and brittle fractures
- Hydrogen embrittlement
- Liquid metal embrittlement
- Creep and stress rupture

It is possible for fracture to be a result of multiple failure mechanisms or root causes. A failure analysis can provide the information to identify the appropriate root cause of the failure.

### A.1.3 Common Causes of Failure

- Misuse or Abuse
- Assembly errors
- Manufacturing defects
- Improper maintenance
- Fastener failure
- Design errors
- Improper material
- Improper heat treatments
- Unforeseen operating conditions
- Inadequate quality assurance
- Inadequate environmental protection/control
- Casting discontinuities

### A.1.4 Failure Analysis applications

- boiler and pressure vessels
- Aircraft /Aerospace
- Gas turbine engine components
- Oil and gas transmission pipelines
- Food processing equipment
- Heat exchangers
- Medical supplies
- Automotive components
- Refineries
- Petrochemical plants
- Offshore structures
- Industrial machinery
- Weldments
- Ships

## A.2 Common mechanical failure:-

In many cases of failure the cause is at least partly due to failure to know or realize the potential consequences of seemingly safe practices or decisions. In many of the cases cited failure occurs at the manufacturing stage, either in primary processing, such as injection molding, or in secondary operations. All failures can be traced to the design, the material, or processing, assuming service conditions are not unusually severe. The interdependence of the three main causes of failure is such that often all are contributors. Material and processing are particularly strongly linked. The material contribution to failure may be in the polymer itself or in an additive. Processing imposes on plastics thermal and mechanical stresses that frequently are the most severe a part will experience in its entire lifetime. Failure is often due to lack of realization of how severe the stresses in processing are and of the effect on the material. Examples are given of failures due to part design, mold design, material selection and processing.

## A.3 Measurement of Hardness:-

Hardness is not an intrinsic material property dictated by precise definitions in terms of fundamental units of mass, length and time. A hardness property value is the result of a defined measurement procedure

The above relative hardness tests are limited in practical use and do not provide accurate numeric data or scales particularly for modern day metals and materials. The usual method to achieve a hardness value is to measure the depth or area of an indentation left by an indenter of a specific shape, with a specific force applied for a specific time. There are three principal standard test methods for expressing the relationship between hardness and the size of the impression, these being Brinell, Vickers, and Rockwell. For practical and calibration reasons, each of these methods is divided into a range of scales, defined by a combination of applied load and indenter geometry.

## Hardness Testing Methods:

Rockwell Hardness Test
Brinell Hardness Test
Vickers Hardness Test

## A.3.1 Rockwell Hardness Test

The Rockwell hardness test method consists of indenting the test material with a diamond cone or hardened steel ball indenter. The indenter is forced into the test material under a preliminary minor load usually 10 kg. When equilibrium has been reached, an indicating device, which follows the movements of the indenter and so responds to changes in depth of penetration of the indenter, is set to a datum position. While the preliminary minor load is still applied an additional major load is applied with resulting increase in penetration. When equilibrium has again been reach, the additional major load is removed but the preliminary minor load is still maintained. Removal of the additional major load allows a partial recovery, so reducing the depth of penetration. The permanent increase in depth of penetration, resulting from the application and removal of the additional major load is used to calculate the Rockwell hardness number.

## A.3.2 Brinell hardness Test

The Brinell hardness test method consists of indenting the test material with a 10 mm diameter hardened steel or carbide ball subjected to a load of 3000 kg. For softer materials the load can be reduced to 1500 kg or 500 kg to avoid excessive indentation. The full load is normally applied for 10 to 15 seconds in the case of iron and steel and for at least 30 seconds in the case of other metals. The diameter of the indentation left in the test material is measured with a low powered microscope. The Brinell harness number is calculated by dividing the load applied by the surface area of the indentation.

The diameter of the impression is the average of two readings at right angles and the use of a Brinell hardness number table can simplify the determination of the Brinell hardness. A well-structured Brinell hardness number reveals the test conditions, and looks like this, "75 HB 10/500/30" which means that a Brinell Hardness of 75 was obtained using a 10mm diameter hardened steel with a 500 kilogram load applied for a period of 30 seconds. On tests of extremely hard metals a tungsten carbide ball is substituted for the steel ball. Compared to the other hardness test methods, the Brinell ball makes the deepest and widest indentation, so the test averages the hardness over a wider amount of material, which will more accurately account for multiple grain structures and any irregularities in the uniformity of the material. This method is the best for achieving the bulk or macro-hardness of a material, particularly those materials with heterogeneous structures.

### A3.3 Vickers Hardness Test

The Vickers hardness test method consists of indenting the test material with a diamond indenter, in the form of a right pyramid with a square base and an angle of 136 degrees between opposite faces subjected to a load of 1 to 100 kg. The full load is normally applied for 10 to 15 seconds. The two diagonals of the indentation left in the surface of the material after removal of the load are measured using a microscope and their average calculated. The area of the sloping surface of the indentation is calculated. The Vickers hardness is the quotient obtained by dividing the kg load by the square mm area of indentation.

When the mean diagonal of the indentation has been determined the Vickers hardness may be calculated from the formula, but is more convenient to use conversion tables. The Vickers hardness should be reported like 800 HV/10, which means a Vickers hardness of 800, was obtained using a 10 kg force. Several different loading settings give practically identical hardness numbers on uniform material, which is much better than the arbitrary changing of scale with the other hardness testing methods. The advantages of the Vickers hardness test are that extremely accurate readings can be taken, and just one type of indenter is used for all types of metals and surface treatments. Although thoroughly adaptable and very precise for testing the softest and hardest of materials, under varying loads, the Vickers machine is a floor standing unit that is more expensive than the Brinell or Rockwell machines.

HPP: **ROSEIRES**

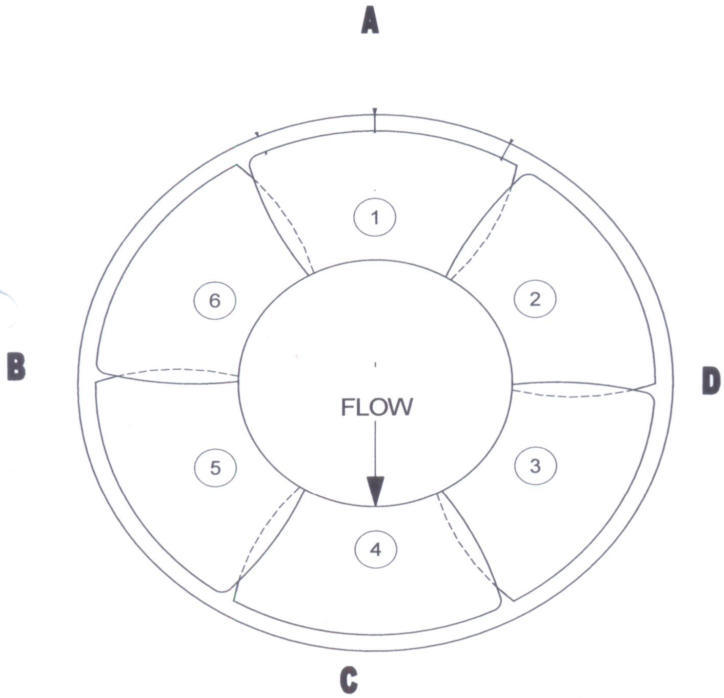
**Unit: 1**

ANDRITZ Hydro

Drawing No. **MB9-** INSTALLATION RECORD

Sheet 1 / 1

## Dimensional check for RUNNER BLADE clearance




Runner blades in close position/ before painting

| **Blades** | Clearance between Runner blades - Runner chamber | | | |
|---|---|---|---|---|
| | **A** | **B** | **C** | **D** |
| **1** | 5,00 | 5,00 | 5,00 | 5,00 |
| **2** | 5,00 | 5,00 | 5,00 | 5,00 |
| **3** | 5,00 | 5,00 | 5,00 | 5,00 |
| **4** | 5,00 | 5,00 | 5,00 | 5,00 |
| **5** | 5,00 | 5,00 | 5,00 | 5,00 |
| **6** | 5,00 | 5,00 | 5,00 | 5,00 |

| **Date** | **RECORDED BY** | **VERIFIED BY** | **APPROVED BY** |
|---|---|---|---|
| 03.12.2009 | | | |
| | Andritz-Hydro | NEC | Andritz-Hydro |

**Figure A.1 dimension test for runner blades**

Table A.1 turbine intake cleaning

| **الزمن المسغرق** | **عدد العمليات** | **الفترة** | | **الوحدة** |
|---|---|---|---|---|
| | | الي :2012/08/31 | من :2012/08/01 | |
| ---- | ---- | | | 1 |
| 00:20 | | | | 2 |
| 01:03 | | | | 3 |
| 01:35 | | | | 4 |
| 18:51 | | | | 5 |
| 02:35 | | | | 6 |
| 08:36 | | | | 7 |
| الزمن المستغرق | عدد العمليات | الفترة | | الوحدة |
| | | الي :2012/09/30 | من :2012/09/01 | |
| 01:39 | ---- | | | 1 |
| 06:50 | | | | 2 |
| 02:46 | | | | 3 |
| 00:27 | | | | 4 |
| 02:10 | | | | 5 |
| 08:50 | | | | 6 |
| 03:17 | | | | 7 |
| الزمن المستغرق | عدد العمليات | الفترة | | الوحدة |
| | | الي :2014/08/31 | من :2014/07/01 | |
| 02:40 | ---- | | | 1 |
| 03:24 | | | | 2 |
| 02:13 | | | | 3 |
| 02:16 | | | | 4 |
| 01:45 | | | | 5 |
| 00:30 | | | | 6 |
| 00:00 | | | | 7 |

Table A.2 Material densities

| Material | Density | |
|---|---|---|
| | (lb/ft3) | (kg/m3) |
| Dirt, loose dry | 76 | 1220 |
| Dirt, loose moist | 78 | 1250 |
| Clay, dry | 100 | 1600 |
| Clay, wet | 110 | 1760 |
| Gravel, dry | 105 | 1680 |
| Gravel, Wet | 125 | 2000 |
| Limestone | 160 | 2560 |
| silt | 80 | 1280 |
| Mud, flowing | 108 | 1730 |
| Mud, steady | 115 | 1840 |
| Rock, well blasted | 155 | 2480 |
| Sand, dry | 97 | 1555 |
| Sand, wet | 119 | 1905 |

Table A.3 Kaplan models

| Group | | - | 0 | 2 | 3 | 5 | 7 |
|---|---|---|---|---|---|---|---|
| Max.head | | m | 12 | 30 | 30 | 48 | 66 |
| Number of runner blades | | - | 4 | 4/5 | 4/5 | 5/6 | 7/8 |
| Runner hub Diameter | max. | m | 0.365 | 0.434 | 0.466 | 0.539 | 0.579 |
| | min. | m | 0.335 | 0.398 | 0.434 | 0.501 | 0.544 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Guide vane height | m | 0.44 | 0.41 | 0.398 | 0.36 | 0.321 |
| Distributer circle diameter | m | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 |
| Number of guide vanes | - | 24 | 24 | 24 | 24 | 24 |
| Spiral case inlet diameter | m | - | - | 1.314 | 1.239 | 1.162 |

## KAPLAN TURBINE
## CAVITATION COEFFICIENT $\sigma_{ADMISSIBLE}$

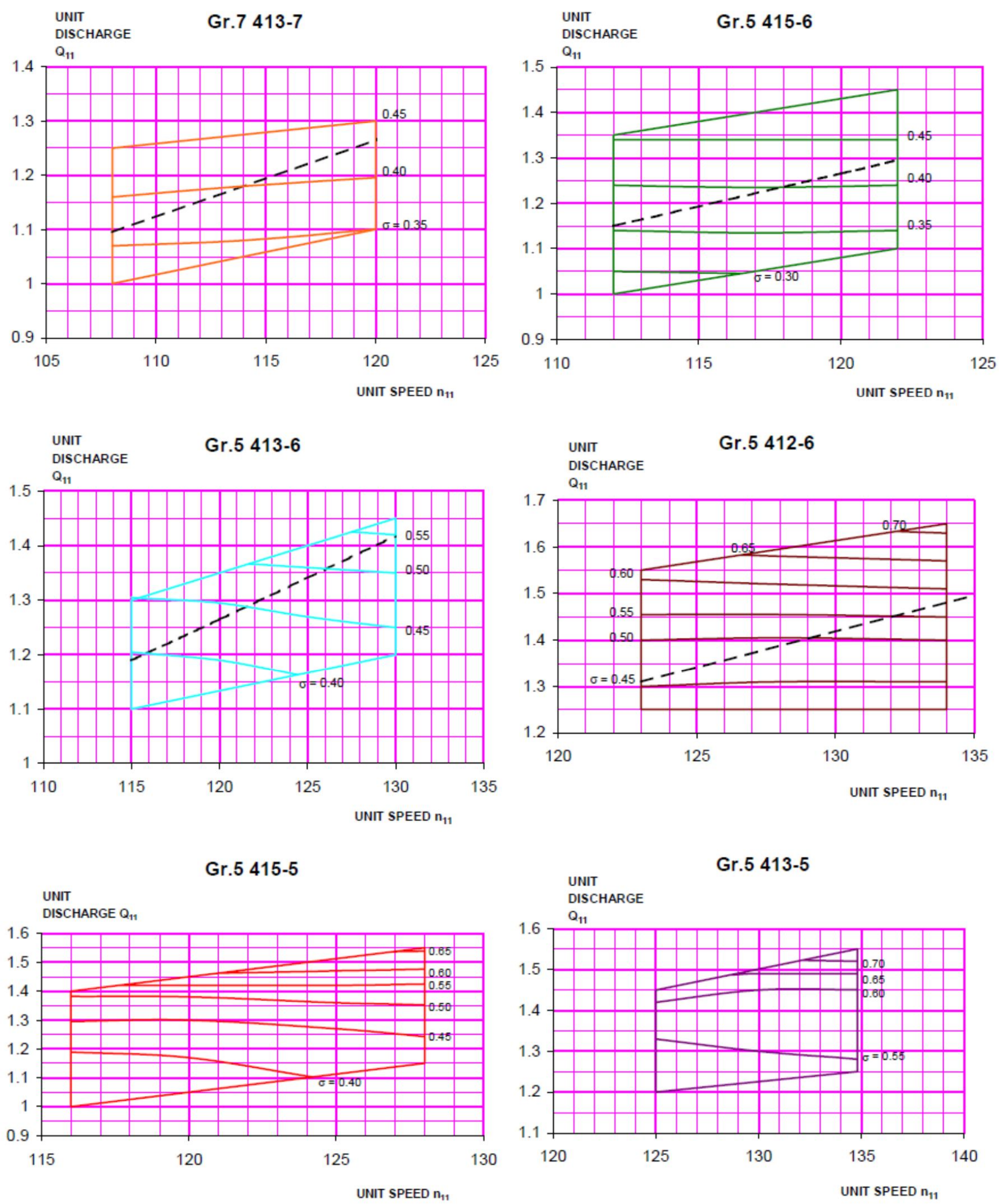
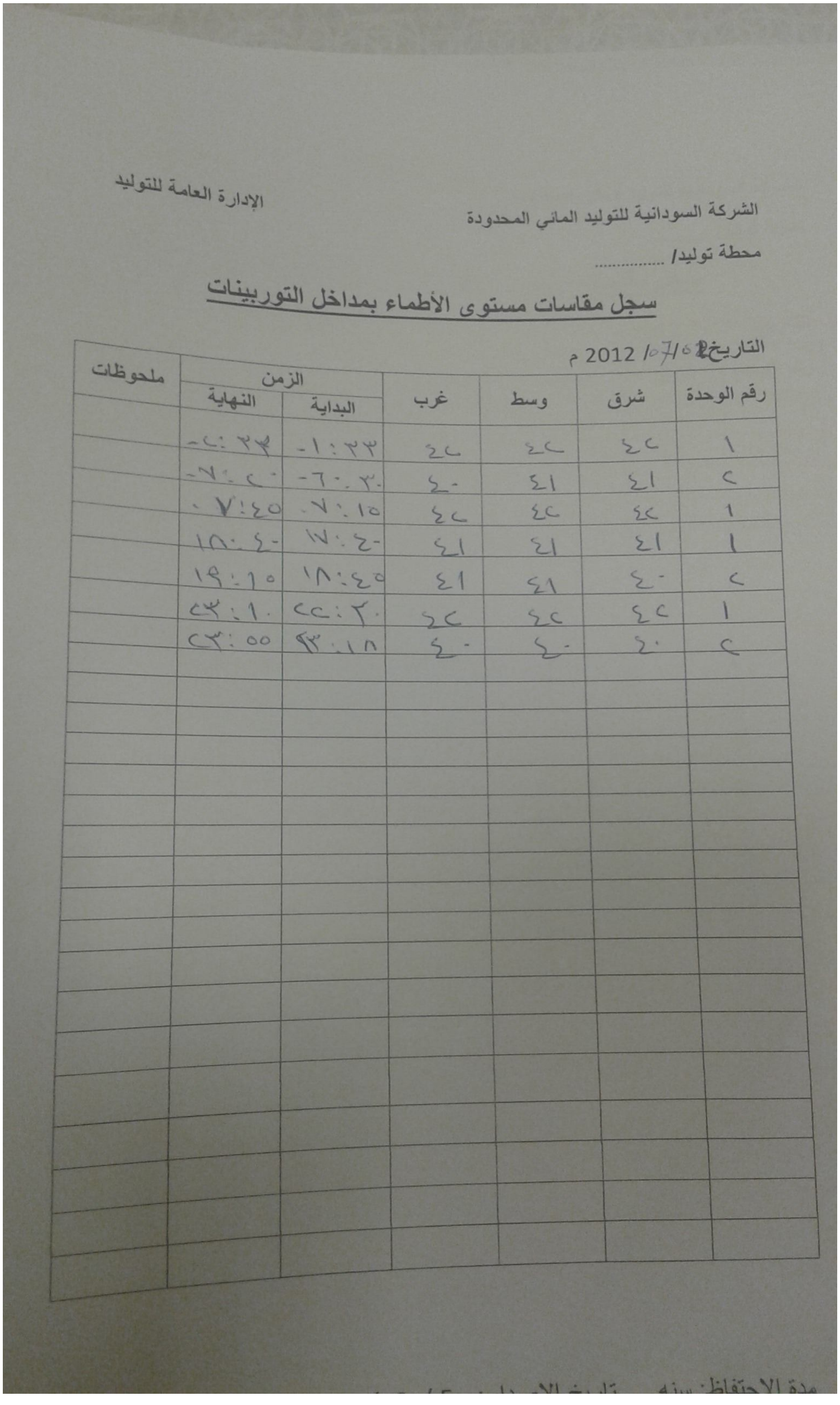


Figure A.2 Cavitation numbers of Kaplan models []



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مدة الاحتفاظ: سنه

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الإدارة العامة للتوليد

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| ٣ | ٤١,٥ | ٤١,٥ | ٤٣,٥ | ٩:٢٦ | ١١:٠٥ | |
| ١ | ٤١ | ٤١ | ٤١ | ١١:٣٠ | ١٢:٠٤ | |
| ٥ | ٤٩ | ٥٠ | تيار | ١٣:٢٥ | ١٣:٤٨ | |
| ٣ | ٤٢ | ٤٢ | ٤٢ | ١٤:٠٠ | ١٤:٣٧ | |
| ٢ | ٤٢,٥ | ٤٢ | ٤٢ | ١٤:٤٣ | ١٥:٥٧ | |
| ١ | ٤١,٥ | ٤١ | ٤١ | ١٦:٠٠ | ١٧:٣٤ | |
| ٢ | ٤٢ | ٤٢ | ٤٢ | ١٧:٤٢ | ١٨:٢٨ | |
| ١ | ٤١,٥ | ٤١,٥ | ٤١,٥ | ١٨:٣١ | ١٩:١٠ | |
| ٢ | ٤٢ | ٤٢ | ٤١ | ١٩:٠٠ | ٢٠:٤٥ | 17.07.12 |

الإدارة العامة للتولي

الشركة السودانية للتوليد المائي المحدودة

محطة توليد/ ...............

# سجل مقاسات مستوى الأطماء بمداخل التوربينات

التاريخ: 16/07/ 2012 م

| رقم الوحدة | شرق | وسط | غرب | الزمن: البداية | الزمن: النهاية | ملحوظ |
|---|---|---|---|---|---|---|
| ٢ | ٤٢ | ٤٢ | | ٣٠ | ١.٠٥ | |
| ٣ | ٤٢ | ٤١ | ٤٢ | ١ ٥٠ | ٢:٤٠ | |
| ١ | ٤٢ | ٤١ | ٤٢ | ٢:٥٠ | ٤:٣٥ | |
| ٢ | ٤٢ | ٤٢ | ٤٢ | ٤.٤٠ | ٥:٢٠ | |
| ٣ | ٤٢ | ٤٢ | ٤٢ | ٥ ٣٠ | ٦:٠٠ | |
| ٥ | تيار | تيار | ٥٠ | ٦.١٠ | ٦.٤٠ | |
| ٤ | ٤٢ | ٤١ | ٤٢ | ١:١٥ | ١:٤٠ | * |
| ٢ | ٤٢ | ٤٢ | ٤٢ | ٢٢:٠٥ | ٢٢:٥٢ | |
| ٤ | ٤٢ | ٤٢ | تيار | ٢٤:٠٠ | ٢٤:٢٧ | |
| ٢ | ٤٢ | ٤٢ | ٤٢ | ١:٢٠ | ١:٤٥ | |
| ٢ | ٤٢ | ٤٢ | ٤٢ | ٢:٤٦ | ٢:١٨ | |
| ١ | ٤٢ | ٤٢ | تيار | ٢:٢٥ | ٤:١٨ | |

الشركة السودانية للتوليد المائي المحدودة — الإدارة العامة للتوليد

محطة توليد الروصيرص. — 15.07.12

## سجل مقاسات مستوى الأطماء بمداخل التوربينات

التاريخ: 15/07/2012 م

| رقم الوحدة | شرق | وسط | غرب | الزمن | | ملحوظات |
|---|---|---|---|---|---|---|
| | | | | البداية | النهاية | |
| ٣ | ٤٢ | ٤٢ | ٤٢ | ٠٥:٢٠ | ٠٦:٠٥ | [signature] |
| ١ | ٤١ | ٤٠,٥ | ٤١ | ٠٧: ١٦ | ٠٨ :١٠ | |
| ٢ | ٤٢ | ٤٢ | ٤٧ | ٨:٢٤ | ٩:١٢ | |
| ٣ | ٤٢ | ٤٢ | ٤٢ | ١٦ ٤١ | ١٦ ٣ | |
| ٢ | ٤٢ | ٤٢ | ٤٢ | ١٧:٤٥ | ١٧:٥٨ | |
| ١ | ٤٢ | ٤ | ٤٢ | ٢٢:١٥ | -- ٣ - | |
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الشركة السودانية للتوليد المائي المحدودة — الإدارة العامة للتوليد

محطة توليد/ ...الروصيرص

## سجل مقاسات مستوى الأطماء بمداخل التوربينات

التاريخ: 4/07/2012 م

| رقم الوحدة | شرق | وسط | غرب | الزمن البداية | الزمن النهاية | ملحوظات |
|---|---|---|---|---|---|---|
| ① | ٤٠ | ٤٠ | ٣٩ | ٩:٢٨ | ١٠:٣٨ | [illegible] |
| ① | ٤٢ | ٣٩ | ٤٢ | ١٤:٠٥ | ١٤:٥٦ | |
| ٢ | ٤٠ | ٤٠ | ٤٠ | ١٦:٣٩ | ١٧:٣٣ | |
| ١ | ٤١ | ٤١ | ٤١ | ١٨:١٠ | ١٩:١٥ | |
| ٣ | ٤٠ | ٤٠ | [illegible] | ١٥:٣٥ | ١٦:٢٠ | |
| ٢ | ٤٠ | ٤٠ | ٤٠ | ١٦:٢٩ | ١٧:٣٣ | |
| ١ | ٤١ | ٤١ | ٤١ | ١٣:١٠ | ١٩:١٥ | |
| ١ | ٤٠ | ٤١ | ٤١ | ٢٢:٠١ | ٢٢:٥٨ | |
| ٤ | ٤٥ | ٤٢ | ٤٢ | ٢٣:١٥ | ٢٣:٤٢ | |

الشركة السودانية للتوليد المائي المحدودة

الإدارة العامة للتوليد

محطة توليد/ الروصيرص

# سجل مقاسات مستوى الأطماء بمداخل التوربينات

التاريخ: 13/07/ 2012 م

| رقم الوحدة | شرق | وسط | غرب | الزمن | | ملحوظات |
|---|---|---|---|---|---|---|
| | | | | البداية | النهاية | |
| ١ | ٤٤ | ٤٢ | ٤٢ | ٠١:١٥ | ٠٢:١٠ | |
| ٢ | ٤٢ | ٤٢ | ٤٢ | ٠٢:١٥ | ٠٢:٥٠ | |
| ٣ | ٤٢ | ٤٢ | ٤٢ | ٠٥:٤٠ | ٠٦:١٥ | |
| ٤ | ٤٣ | ٣٨ | ٤١ | ٠٨:٠٠ | ٠٨:٣٠ | |
| ١ | ٤١ | ٤١ | ٤١ | ٠٨:٤٠ | ٠٩:٣٠ | |
| ٢ | ٤٠ | ٤٠ | ٤٠ | ٩:٣٥ | ١٠:١٥ | |
| ٣ | ٤١ | ٤١ | — | ١٠:٢٠ | ١٠:٥٠ | |
| ٢ | ٤٠ | ٤٠ | ٤٠ | ١٠:٥٥ | ١١:٣٥ | |
| ١ | ٤٠ | ٤٠ | ٤٠ | ١٢:٢٠ | ١٣:٠٠ | |
| ٣ | ٤١ | ٤١ | ٤١ | ١٣:١٠ | ١٣:٤٤ | |
| ٥ | ٤٥ | ٤٥ | — | ١٤:١٠ | ١٤:٣٠ | 13.07.12 |
| ١ | ٤٠ | ٤٠ | ٤٠ | ١٦:٢٠ | ١٦:٤٥ | |
| ٢ | ٤١ | ٤٠ | ٤٠ | ١٧:٤٢ | ١٨:٥٢ | |
| ٣ | ٤١ | ٤٠ | ٤٠ | ١٨:٥٨ | ١٩:٢٦ | |

الإدارة العامة للتوليد

الشركة السودانية للتوليد المائي المحدودة

محطة توليد/ الروصيرص

## سجل مقاسات مستوى الأطماء بمداخل التوربينات

التاريخ: ١٢/٧/2012 م

| رقم الوحدة | شرق | وسط | غرب | الزمن البداية | الزمن النهاية | ملحوظات |
|---|---|---|---|---|---|---|
| ١ | ٤٢ | ٤٢ | ٤٢ | ١:١٥ | ٢:١٠ | |
| ٢ | ٤٢ | ٤٢ | ٤٢ | ٢:١٥ | ٢:٥٠ | |
| ١ | ٤٢ | ٤٢ | ٤٢ | ٥:٤٠ | ٦:١٥ | |
| ٢ | ٤١ | ٤١ | ٤١ | ٦:٢٥ | ٧:٠٥ | |
| ٣ | ٤٢ | ٤٢ | ٤٢ | ٧:١٥ | ٧:٤٩ | |

دة الاحتفاظ: سنه

الشركة السودانية للتوليد المائي المحدودة — الإدارة العامة للتوليد

محطة توليد/ الروصيرص

## سجل مقاسات مستوى الأطماء بمداخل التوربينات

التاريخ: ١١/٧/ 2012 م

| رقم الوحدة | شرق | وسط | غرب | الزمن: البداية | الزمن: النهاية | ملحوظات |
|---|---|---|---|---|---|---|
| ٢ | ٤٠ | ٤٠ | ٤٠ | ٢٢:٠٠ | ٢٢:٥٧ | |
| ١ | ٤٠ | ٤٠ | ٤٠ | ٢٣:٣٥ | ٠٠:٢٥ | |
| ٣ | ٤١ | ٣٩,٥ | ٤٠ | ٠٠:٤٥ | ٠١:٢٨ | |
| ٤ | ٤٠ | ٤٠ | ٤٠ | ٠١:٤٠ | ٠٢:٥٠ | |
| ٣ | ٤١ | ٣٩ | ٤١ | ٠٧:٤٥ | ٠٨:٢٧ | |
| ٢ | ٤٣ | ٤٣ | ٤٢ | ٨:٤ | ٩:٢٥ | |
| ١ | ٤٢ | ٤٢ | ٤٢ | ٩:٤٢ | ١١:٠٢ | |
| ٧ | ٤١ | ٤١ | ٤١ | ١١:٢٨ | ١٢:٢٠ | |
| ١ | ٤٢ | ٤٢ | ٤٢ | ١٦:٤٢ | ١٧:٤١ | |
| ٢ | ٤٢,٥ | ٤٢ | ٤٢ | ١٨:٠٦ | ١٨:٤٠ | |
| ٤ | ٤٥ | ٤٤ | ٤٣,٥ | ١٨:٥١ | ١٩:٣٥ | |

الادارة العامة للتوليد

الشركة السودانية للتوليد المائي المحدودة

محطة توليد/ ................

## سجل مقاسات مستوى الأطماء بمداخل التوربينات

التاريخ ١٥/ ٧/ 2012 م

| رقم الوحدة | شرق | وسط | غرب | الزمن: البداية | الزمن: النهاية | ملحوظات |
|---|---|---|---|---|---|---|
| ١ | -٤٠ | -٤٠ | ٤١ | ٢٤:٧ | ١:٠٨ | |
| ٢ | -٤٠ | -٤٠ | -٤٠ | ١:١٨ | ١:٥٢ | |
| ٣ | ٤١ | ٤١ | ٤١ | ٢:٠٧ | ٢:٤٥ | |
| ٤ | — | — | — | — | — | |
| ٥ | ٥ | ٥ | ٥ | ٥ | ٥ | |
| ٦ | ٤٧ | ٤٧ | | ٢:٠٩ | ٢:٠٥ | |
| ٧ | — | — | — | — | — | |
| ١ | -٤٠ | -٤٠ | -٤٠ | ٠٦:٢٩ | ٠٨:٢٠ | |
| ٤ | -٤٠ | -٤٠ | -٤٠ | ٠٨:٤٥ | ٠٩:١٥ | |
| ٢ | ٤١ | ٤١ | ٤٠ | ٠٩:١٧ | ٠٩:٥٠ | |
| ٣ | ٤٢ | ٤٢ | ٤٢ | ٠٩:٥٢ | ١٠:١٢ | |
| ١ | ٤٢ | ٤٢ | ٤٢ | ١٠:١٥ | ١٠:٤٦ | [signature] |

مدة الاحتفاظ

الإدارة العامة للتوليد

الشركة السودانية للتوليد المائي المحدودة

محطة توليد/ الروصيرص

## سجل مقاسات مستوى الأطماء بمداخل التوربينات

التاريخ: ٠٩/٠٧/ 2012 م

| رقم الوحدة | شرق | وسط | غرب | الزمن | | ملحوظات |
|---|---|---|---|---|---|---|
| | | | | البداية | النهاية | |
| ١ | ٤٢ | ٤٢ | ٤٣ | ٠٥:١٥ | ٠٥:٤٦ | |
| ٢ | ٤٢ | ٤٢.٥ | ٤٢/٥ | ٠٦:٤٨ | ٠٧:٣٧ | |
| ٣ | ٤٢ | ٤٢ | ٤١ | ٠٨:٠٥ | ٠٩:١٥ | |
| ٤ | ٤٢ | ٤٢ | ٤٢ | ١٠:١٥ | ١١:٠٧ | |
| ٢ | ٤٠ | ٤٠ | — | ١١:٤٠ | ١١:٥٠ | |
| ٣ | ٣٩ | ٣٩ | ٣٩ | ١٧:١٨ | ١٨:٣٨ | [illegible] |
| ٢ | ٣٩ | ٤٠ | ٣٩ | ١٨:٤٥ | ١٩:٢٠ | |
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مدة الاحتفاظ:

الإدارة العامة للتوليد

الشركة السودانية للتوليد المائي المحدودة

محطة توليد/ ...............

# سجل مقاسات مستوى الأطماء بمداخل التوربينات

التاريخ: 08/07/ 2012 م

| رقم الوحدة | شرق | وسط | غرب | الزمن | | ملحوظات |
|---|---|---|---|---|---|---|
| | | | | البداية | النهاية | |
| ١ | ٤٢ | ٤١,٥ | ٤١ | ٠٠:٥٨ | ٠٨:٤٤ | |
| ١ | ٤٠ | ٤٠ | ٤٠,٥ | ٠٥:٥٥ | ٠٦:٤٠ | |
| ٢ | ٤١ | ٤٢ | ٤١ | ٠٦:٥٠ | ٠٧:٣٨ | |
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الإدارة العامة للتوليد

الشركة السودانية للتوليد المائي المحدودة

محطة توليد/ ................

# سجل مقاسات مستوى الأطماء بمداخل التوربينات

التاريخ: ٠٧/ ٠٧/ 2012 م

| رقم الوحدة | شرق | وسط | غرب | الزمن | | ملحوظات |
|---|---|---|---|---|---|---|
| | | | | البداية | النهاية | |
| ١ | ٤٢ | ٤١ | تيار | ٠٢:٢٠ | ٠٣:٤٤ | |
| ٢ | ٤١ | ٤١ | ٤١ | ٠٢:٤٧ | ٠٤:٠٤ | |
| ٣ | ٤٢ | تيار | تيار | ٠٤:٠٩ | ٠٤:١٦ | |
| ١ | أمطار | أمطار | أمطار | — | — | أمطار |
| ١ | ٤٢ | ٤١ | ٤١ | ٩:٤٩ | ٩:٢٥ | |
| ٢ | ٤٠ | ٤٠ | ٤٠ | ٠٩:٣٠ | ١٠:٠٨ | |
| ٣ | ٤٢ | ٤١٫٥ | ٤١ | ١٠:٢٢ | ١٠:٥٦ | |
| ٤ | ٤٣ | ٣٨ | ٤١٫٥ | ١٢:٢٥ | ١٣:٠٥ | |
| ٦ | ٥٠ | ٥٠ | تيار | ١٦:١٠ | ١٦:٥٦ | |
| ٣ | ٤١ | ٤٠ | ٤١ | ١٧:٠٦ | ١٧:٤٤ | |
| ٢ | ٤٠ | ٣٩ | ٤٠ | ١٨:٠٦ | ١٨:٢٥ | |
| ١ | ٤٠ | ٤٠ | تيار | ١٨:٤٧ | ١٩:٠٥ | |
| ٢ | ٤٠٫٥ | ٤٠ | ٤٠ | ٠٠:١٥ | ٠٠:٤٥ | |

الإدارة العامة للتوليد

الشركة السودانية للتوليد المائي المحدودة

محطة توليد/ الروصيرص

# سجل مقاسات مستوى الأطماء بمداخل التوربينات

التاريخ: 6/ 7/ 2012 م

| رقم الوحدة | شرق | وسط | غرب | الزمن البداية | الزمن النهاية | ملحوظات |
|---|---|---|---|---|---|---|
| ٢ | ٤١ | ٤١ | ٤٠ | ١٧:٣٥ | ١٨:٢٣ | |
| ١ | ٤٢ | ٤١½ | ٤١ | ١٨:٣٠ | ١٩:٢٣ | S/D |
| ٣ | ٤٢ | ٤٢ | ٤٢ | ٢١:٢٥ | ٢١:٥٣ | |
| ٢ | ٤٠ | ٤٠ | ٤٢ | ١٠ ق | ٥٥ ق | |
| ٤ | ٤٢ | ٤٢ | ٤٢ | ١٠ س | ٥٠ س | |
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الإدارة العامة للتوليد

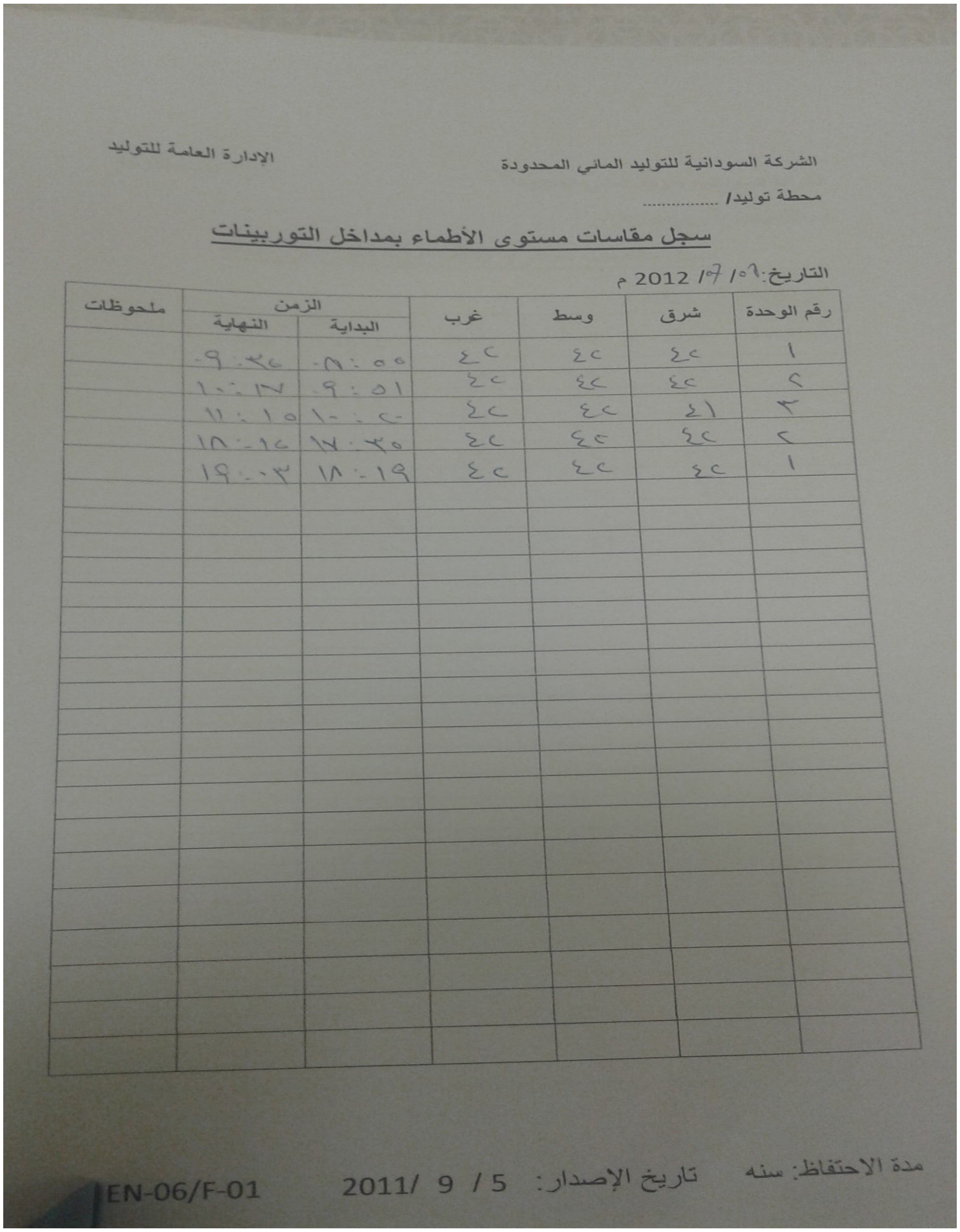
الشركة السودانية للتوليد المائي المحدودة

محطة توليد/ ................

## سجل مقاسات مستوى الأطماء بمداخل التوربينات

التاريخ: 03/07/ 2012 م

| رقم الوحدة | شرق | وسط | غرب | الزمن - البداية | الزمن - النهاية | ملحوظات |
|---|---|---|---|---|---|---|
| ٢ | ٢٩ | ٢٩ | ٣٩ | ٠٠:٠٥ | ٠٠:٣٠ | |
| ٤ | ٤٣ | ٤١½ | ٤١½ | ٠٠:٣٥ | ٠١:١٧ | |
| ٣ | ٣٨ | ٣٨ | ٣٨ | ٠٧:٠٨ | ٠٨:٢٠ | |
| ٢ | ٤١ | ٤١ | ٤٢ | ٠٩:٠٠ | ٠٩:٣٠ | |
| ١ | ٤٢ | ٤٢ | ٤٢ | ١٠:٠٠ | ١٠:٤٠ | |
| ١ | ٤١½ | ٤١ | ٤٠½ | ٢٢:٣٥ | ٢٢:٢٩ | |
| ٢ | ٤١ | ٤٠ | ٤٠ | ٢٢:٣٧ | ٢٣:٠٥ | |
| ٦ | ٥٠ | ٥٠ | ٥٠ | ٠٩:١٠ | ١٠:٠١ | |



الإدارة العامة للتوليد

الشركة السودانية للتوليد المائي المحدودة

محطة توليد/ ................

## سجل مقاسات مستوى الأطماء بمداخل التوربينات

التاريخ: ٠٦/ ٠٧/ 2012 م

| رقم الوحدة | شرق | وسط | غرب | الزمن: البداية | الزمن: النهاية | ملحوظات |
|---|---|---|---|---|---|---|
| ١ | ٤٢ | ٤٢ | ٤٢ | ٠٨:٥٥ | ٠٩:٣٦ | |
| ٢ | ٤٢ | ٤٢ | ٤٢ | ٠٩:٥١ | ١٠:١٧ | |
| ٣ | ٤١ | ٤٢ | ٤٢ | ١٠:٢٠ | ١١:١٥ | |
| ٢ | ٤٢ | ٤٢ | ٤٢ | ١٧:٣٥ | ١٨:١٦ | |
| ١ | ٤٢ | ٤٢ | ٤٢ | ١٨:١٩ | ١٩:٠٣ | |

مدة الاحتفاظ: سنه تاريخ الإصدار: 5/ 9 /2011 EN-06/F-01

Figures.A.3 (1-21) Turbine Depth measurements and cleaning records