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Pressure pulsations at Iveland Power Plant

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Abstract. Iveland 2 is a power plant located in the south part of Norway that was commissioned in 2016. Since the start up they have been struggling with loud noise and vibrations when the turbine is running at part load. In order to investigate what causes these vibrations, the pressure pulsations will be measured and analysed. To measure the pressure pulsation, two pressure sensors will be placed at the draft tube, and one at the inlet. In addition there will be done test with reduced air flow to the draft tube, to see if that affect the pressure pulsations. The measurement showed that the pressure pulsation were dominated by the Vortex rope. The reduced air flow at the air intake had little effect on the on amplitude. A spectral analysis of an audio recording showed that the frequency of the noise may lie in the range of 60-70 Hz.

1. Introduction

Iveland Power Plant is located in the Aust-Agder in Norway. It was commissioned in 2016 and has struggled with vibrations and loud noise since the start up. The vibration occur when running at part load and is believed to be caused by the flow in the draft tube. The host, Agder Energi, has asked for help to find out what is the problem. The plan is to measure the pressure pulsations in order to find out what causes them. The turbine is equipped with an air intake into the draft tube. There will also be done tests with different flow rates of air to see how that influence the pressure pulsations.

Table 1: General information about Iveland 2 [1]

Characteristic	Data
Commissioned	2016
Head	50m
Turbine	Francis
Rated power	44 MW
BEP	$\sim$ 39 MW
RPM	176,47

2. Pressure pulsations in a Francis Turbine

When the turbine is operating below or above its design point, the water leaving the blade will have a velocity component that moves in the tangential direction, as shown in Figure 1. This creates a swirl in the draft tube because the angle β and rotational speed u is fixed and the flow rate is off the design point. Experiments have shown that swirling flow in a pipe tend to separate the flow in to two regions, where the movement of water mainly happens at the outer region [2] . When the swirl ratio becomes big enough, a stagnation point forms in the inner region.

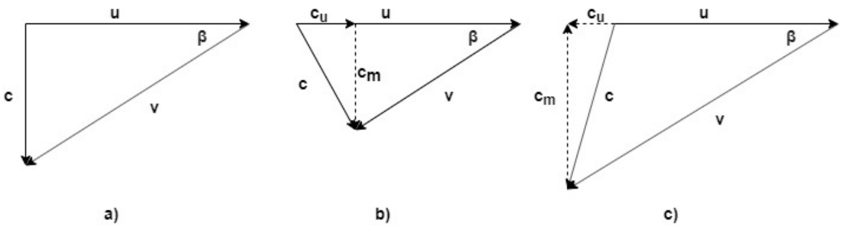

Figure 1: **a)** shows the velocity triangle with the guide vanes at BEP, **b)** shows guide vanes below BEP and **c)** show the guide vanes above BEP

At part load, a helix shaped vortex might appear at the border between the two regions, often referred to as a 'Rotating Vortex Rope'. If the pressure in the draft tube becomes lower than the vapour pressure, the vortex rope becomes visible, as shown in Figure 2. This rope creates a pressure pulsation as it is rotating in the draft tube. The frequency of the pulsation is called the Rheingans frequency, named after W.J. Rheingans, who estimated the relative frequency to be [2]:

$$\frac{f_p}{f_n} \simeq 0.278 \tag{1}$$

where f_p is the frequency at the pressure pulsation created by the vortex rope and f_n is the runner frequency.

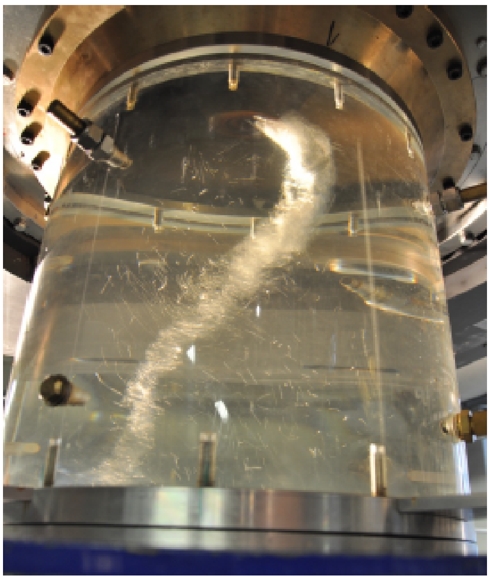

Figure 2: Vortex rope. Photo: Bjørn Winther Solemslie

The vortex rope pulsation consist of two components with the same frequency, an asynchronous and a synchronous component [3]. The synchronous part has equal phase and amplitude in cross section and may be seen as an axisymmetric pressure wave as it propagates through the draft tube. The asynchronous part has a pressure pattern moving around the axis of the draft tube. The components can be calculated using these equations [3]:

$$p_{sync} = \frac{DT1 + DT2}{2} \quad [kPa] \tag{2}$$

$$p_{async} = \frac{DT1 - DT2}{2} \quad [kPa] \tag{3}$$

where $DT1$ and $DT2$ are pressure signals from the same plane but placed 180 degrees apart from each other.

Another source of pressure pulsation can be Von Karman Vortices. These vortices can appear behind a bluff body placed in a fluid with perpendicular flow. The flow will alternate between the sides of the body creating swirls in the wake [2]. This can happen behind the stay vanes, guide vanes and runner blades. If the frequency of the vortex shedding resonates with the natural frequency of the body, it will start to vibrate and may cause cracks and failure of the component.

3. Measurement set up

In order to measure the pressure pulsations, there were placed one pressure sensor at the inlet and two at the draft tube placed opposite of each other. Their placement is shown in figure 3. The plant is also equipped with an air intake that lets air into the draft tube through the shaft. The air is sucked in due to the low pressure in the draft tube hub. The air speed in this pipe were measured in order to estimate how much air was sucked in.

In order to get measurement from the whole operating area, there were taken measurement on eight different operating points from 43 MW to 15 MW listed in Table 2. 23 MW and 43 where measured twice to be able to check repeatability. On 23 MW there were also done measurement with different opening at the air intake to investigate if this will affect the pressure pulsations.

For logging the data a labview program premade at Waterpower laboratory was used. The sample rate was set to 5000 Hz and the logging time was set to 60 seconds. There were done two loggings at each measuring point in case there were some mistake in the reading. Since there were no mistake the logging sequence were added together to improve the frequency resolution. The data was imported in to Matlab and transferred into the frequency domain using Matlabs pwelch function. The hanning window was used as window type with 50 % overlap and the number of windows were eight.

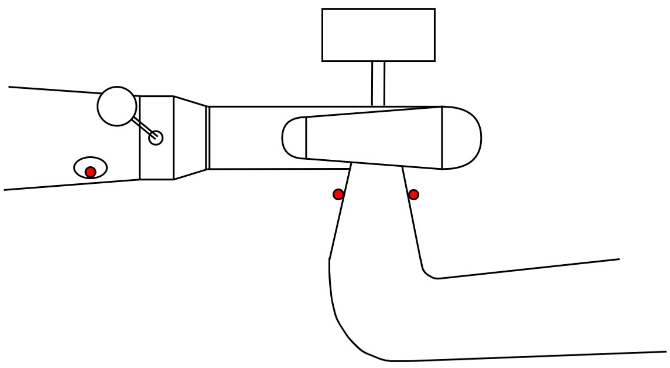

Figure 3: Pressure sensor placement

Table 2: Measuring points

Measurement [#]	Power[MW]	Air intake
1	43	Open
2	39	Open
3	35	Open
4	31	Open
5	27	Open
6	23	Open
7	19	Open
8	15	Open
9	23	Open
10	23	Closed
11	23	Half Closed
12	43	Open

4. Results

The result is presented in Figure 5 and Figure 6. Since the graph from the two sensors are almost identical one sensor is chosen to represent the result. The figures show each measuring point including the ones with varying air flow. The amplitude is normalized with the net head. In Figure 6 the frequency is normalized with the rotational frequency in order to find frequencies that is dependent on the rotational speed. Figure 4 illustrates the difference in pressure pulsations between running on Best Efficiency Point (BEP) at 39 MW and in the problem area at 27 MW.

During the measurement it was observed that the noise started between 31 MW and 27 MW. The noise got significantly worse between 27 MW and 23 MW. During the change in power from 27 MW to 23 MW a video recording was made. There were done a spectral analysis on the audio shown in Figure 7 to determine what frequency that are dominating.

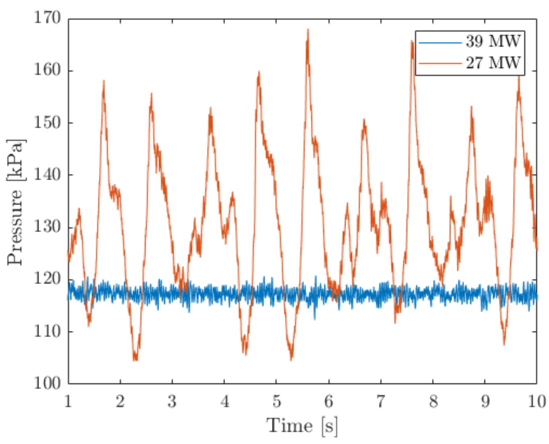

Figure 4: Pressure measurements at 39 and 27 MW in the time domain

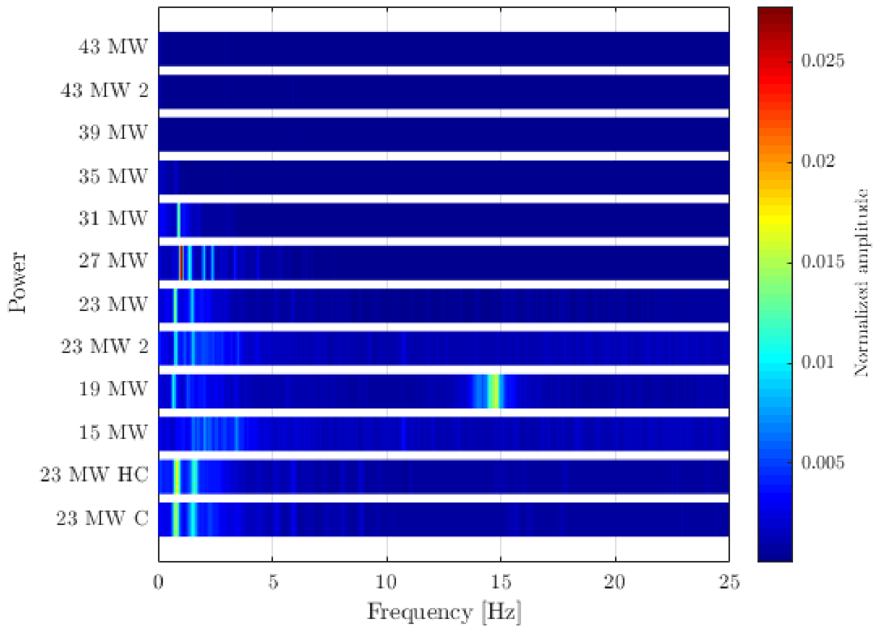

Figure 5: Draft tube sensor 1, showing frequencies from 0 to 25 Hz

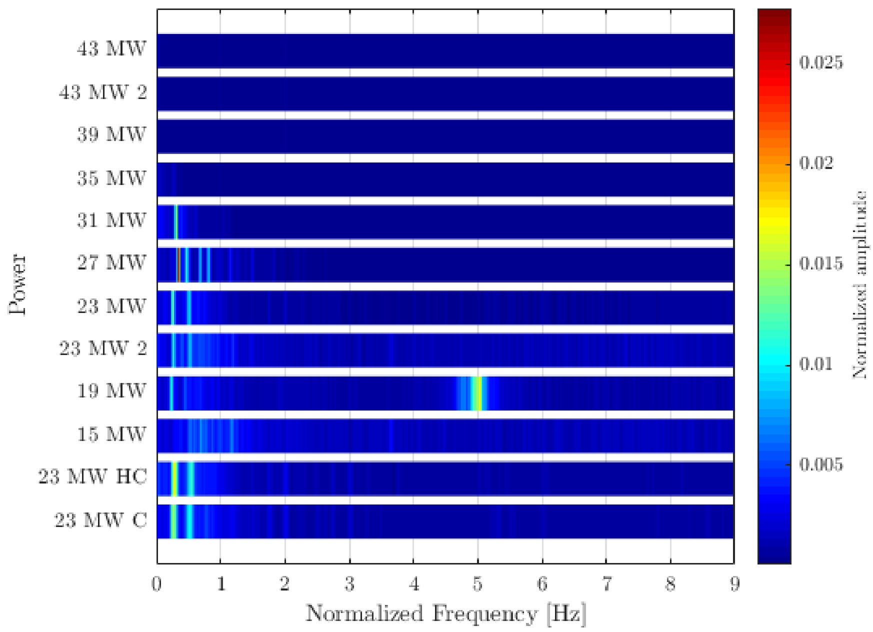

Figure 6: Draft tube sensor 1, with normalized frequencies

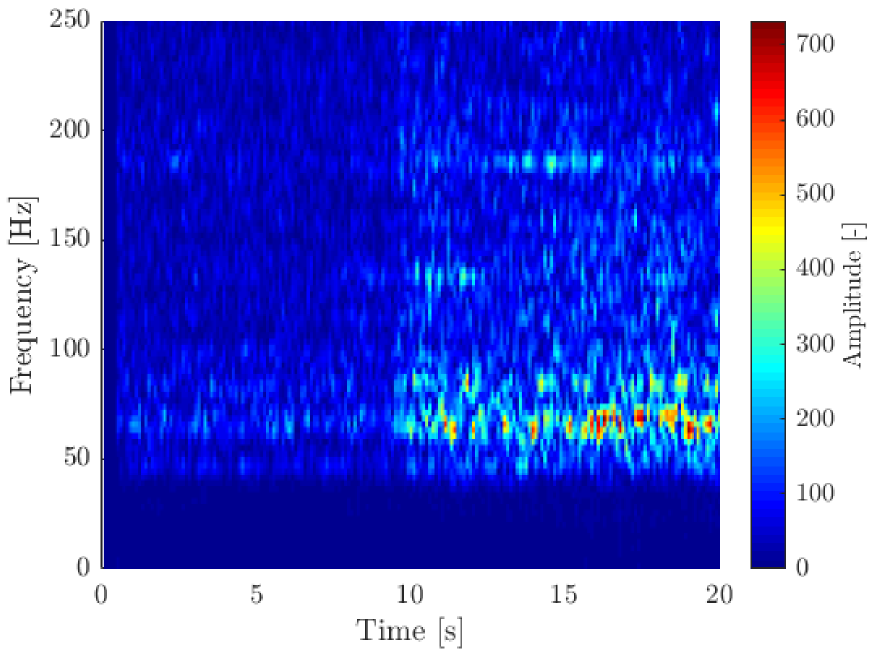

Figure 7: Audio recording of noise when moving from 27MW to 23MW

5. Discussion

Figure 5 show no sign of pressure pulsations at 43 MW and 39 MW. It starts at 35 MW and get worse as the power moves towards 27 MW, before it decreases towards 15 MW. The dominating frequency lies between 0.65 and 0.99. Looking at Figure 6 with the normalized frequency, the dominating frequency lies between 0.33 and 0.22. It matches well with the Rheingans frequency in Equation 1. On both Figure 5 and Figure 6 there can be observed a harmonic after Rheingans frequency.

When running on 23 MW the air flow reduced to see if that would affect the pressure pulsations in any way. 23 MW HC and 23 MW C in Figure 5 show the measurement done with the air intake half closed and closed respectively. There was a small increase in the amplitude when the air flow was reduced.

Since the frequency of the vortex rope is at the most 1 Hz it is suspected that this is not the source of the noise. The audible frequency for humans is 20 Hz and upwards[4]. In figure 7 the change in noise level moving from 27 MW to 23 MW is visible around the ten second mark. It shows a change in amplitude in the range from 60 Hz to 70 Hz. It is possible that this is the source of the loud noise. What phenomena that causes this frequency is not known at the time of writing.

When operating at 19 MW a significant pressure pulsation with a frequency of around 15 Hz appears. The cause of this frequency is not known. Since the frequency is below the audible range for humans, it is believed that this do not contribute to the noise.

6. Further work

In the search for the loud noise the source of the frequency range of 60-70 Hz needs to be investigated further. One possibility that will be pursued is Von Karman Vortices. It difficult to estimate the frequency of vortex shedding but there will done an attempt to see if it can be linked to the stay vanes, guide vanes or the runner blades. Other possibilities apart from Von Karman will also be considered.

The effect of reduced air flow will be looked into in more detail to determine if and how much this effects the pressure pulsations. It could also be interesting to investigate further in the 15 Hz frequency that occurs only at the 19 MW operating point. Another aspect that will be further investigated is the synchronous and asynchronous component of the pressure pulsations.

References

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