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Unsteady vibration due to cavitation in mixed flow pumps

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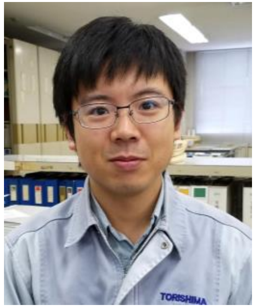
Abstract

In regarding to the large vertical mixed flow pump for seawater supply pump, the authors experienced the strange excessive vibration: the vibration level intermittently changed and the peak frequency was the blade passing frequency as like the vibration due to the submerged vortex in sump.

In order to investigate the real cause, the model test was performed and it was found that the cause was due to the strong tip vortex cavitation on the blade surface of the impeller.

As the countermeasure, the forward swept impeller was designed to suppress the strong tip vortex cavitation. After that, the model test had been performed to estimate the effect of the forward swept impeller on the cavitation condition. As the result, it was confirmed that the cavitation condition was drastically improved. Finally, the strange excessive vibration was disappeared in the actual pump by applying the improved impeller.

Presenter/Author bios



Takuya Nakano is presently the senior engineer of large pump engineering department, engineering division with Torishima Pump Mfg. Co., Ltd. in Osaka, Japan. He joined Torishima in 2012 and had been worked in R&D department until 2016, and mainly researched in regard to the improvement of mixed flow pump performance, and the hydraulically vibration problem.

Hideaki Maeda, Dr. Eng. is presently the general manager of large pump engineering department, engineering division with Torishima Pump Mfg. Co., Ltd. in Osaka, Japan.
He joined Torishima in 1993 and had been worked in R&D department until 2015, and mainly researched in regard to the improvement of pump performance, the vibration issue due to cavitation in mixed flow pump. From 2009 to 2015, He organized R&D department as general manager and developed several the high performance pumps.

1. Problem

The excessive and strange vibration was observed in SWSP(Sea Water Supply Pump) for MSF desalination plant during the plant commissioning

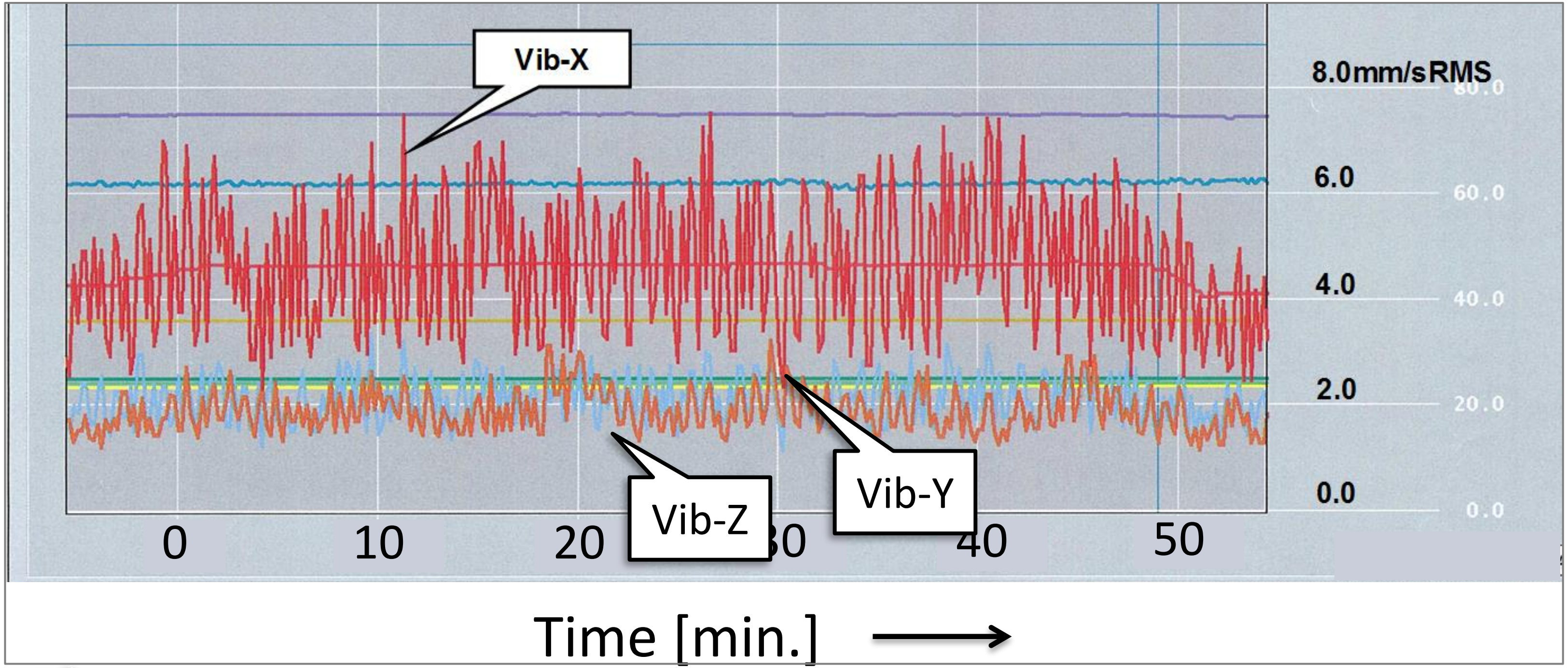
Table Actual pump specification

Type & Size	2,200mm
Rotational Speed: N	295min^{-1}
Rated Capacity: Qr	53,600m^3/h
Rated Head: Hr	27.0m
Motor output	5000kW
NPSHA	15m
NPSH3	9.5m at Qr(nss=1630)
ns (min^{-1}, m^3/min, m)	745

Figure Actual pump structure

1. Problem/Phenomena

As shown in the below, the vibration level was high and intermittent.



POSITION: Pump’s thrust BRG,

X: 90deg from Dis. direction, Y: Dis. direction, Z: Axial

2. Solution/ Site Investigation

The site investigation was carried out and it was found that the dominant frequency was blade pass frequency: Blade number Zr=4 x Rotational frequency : N=4.9Hz ≒ 20Hz).

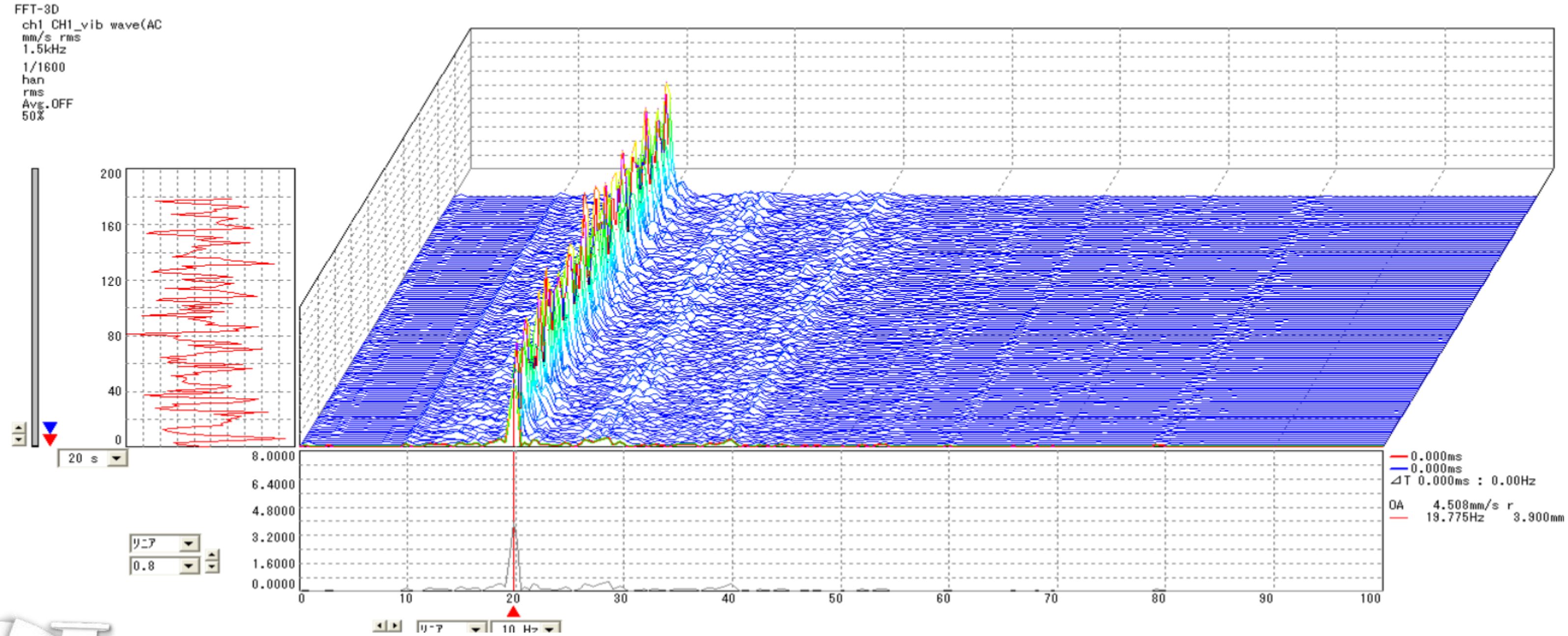


Figure Water fall diagram for vibration at pump thrust bearing and discharge direction

2. Solution/ RCA: What is the cause of vibration?

Possible Causes based on site investigation results:

Several possible causes were considered(listed below), but we couldn't identify the cause which exactly matched to the vibration frequency observed.

But, from the fact that its level intermittently changed, we surmised that this vibration was being induced from internal flow through the pump. Therefore, we decided to carry out a physical model test to confirm the internal flow characteristics of the pump.

Resultant of blade force due to unfavorable combination of impeller and diffuser vane count i.e.

1. Vane interaction forces at Zr x fn
2. Acoustic resonances excited by Zr x fn
3. Resonance with bearing housing natural frequency
4. Uneven flow into the impeller
5. Vortices (Vortex ropes)

AIPS

2. Solution/ Investigation by Physical Model Test

Model Pump:

Physical model test was performed to find the real cause of the vibration by investigating the internal flow of the pump.

Photo. Schematic view of model pump

Table The design specifications of model pump

Design conditions	
Suction and discharge diameter (mm)	300
Design flow rate: Q_d(m^3/min)	16.86
Design total head of pump: H_d(m)	25.3
Rotational speed: n(min^{-1})	2088
Specific speed: ns(min^{-1},m^3/min,m)	760
Cavitation number: σ_3(NPSHA)	0.53(15.0m)

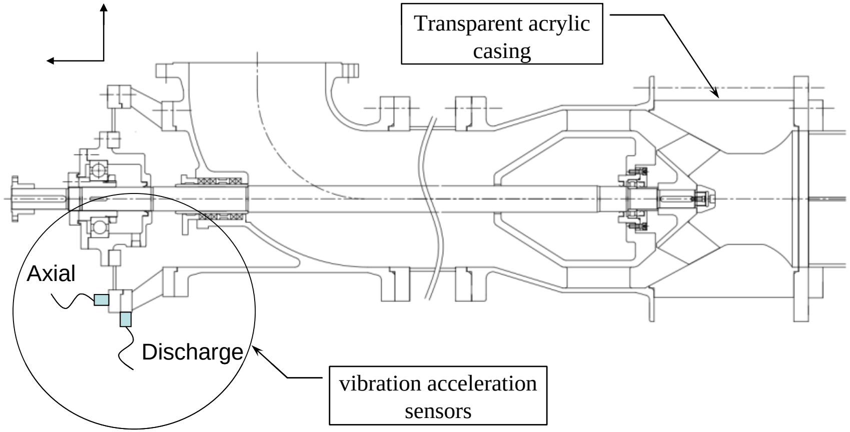


Figure The cross-sectional view of model pump

2. Solution/ Investigation by Physical Model Test

Model specifications

- Dis. dia : 300mm
- Model ratio : 1/7.07
- Rotational speed : 2088min^{-1}

Test conditions

- Eye velocity is 23.5m/s which is identical to the actual.
- NPSHA=15m
- Flow rate : 70% to 110%Qrated

Measurement items

- Vibration level at bearing housing
- Visualization of internal flow

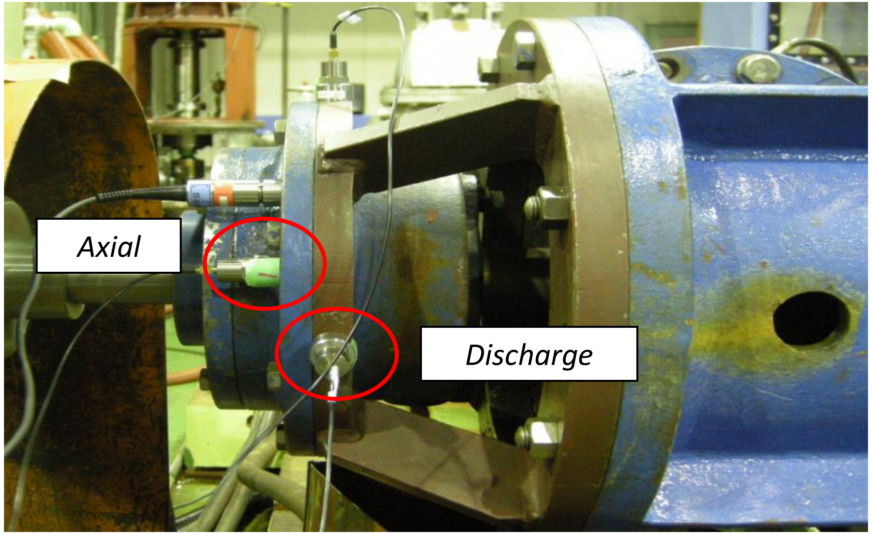


Photo. Locations of vibration measurement

2. Solution/ Investigation by Physical Model Test

Experimental Apparatus

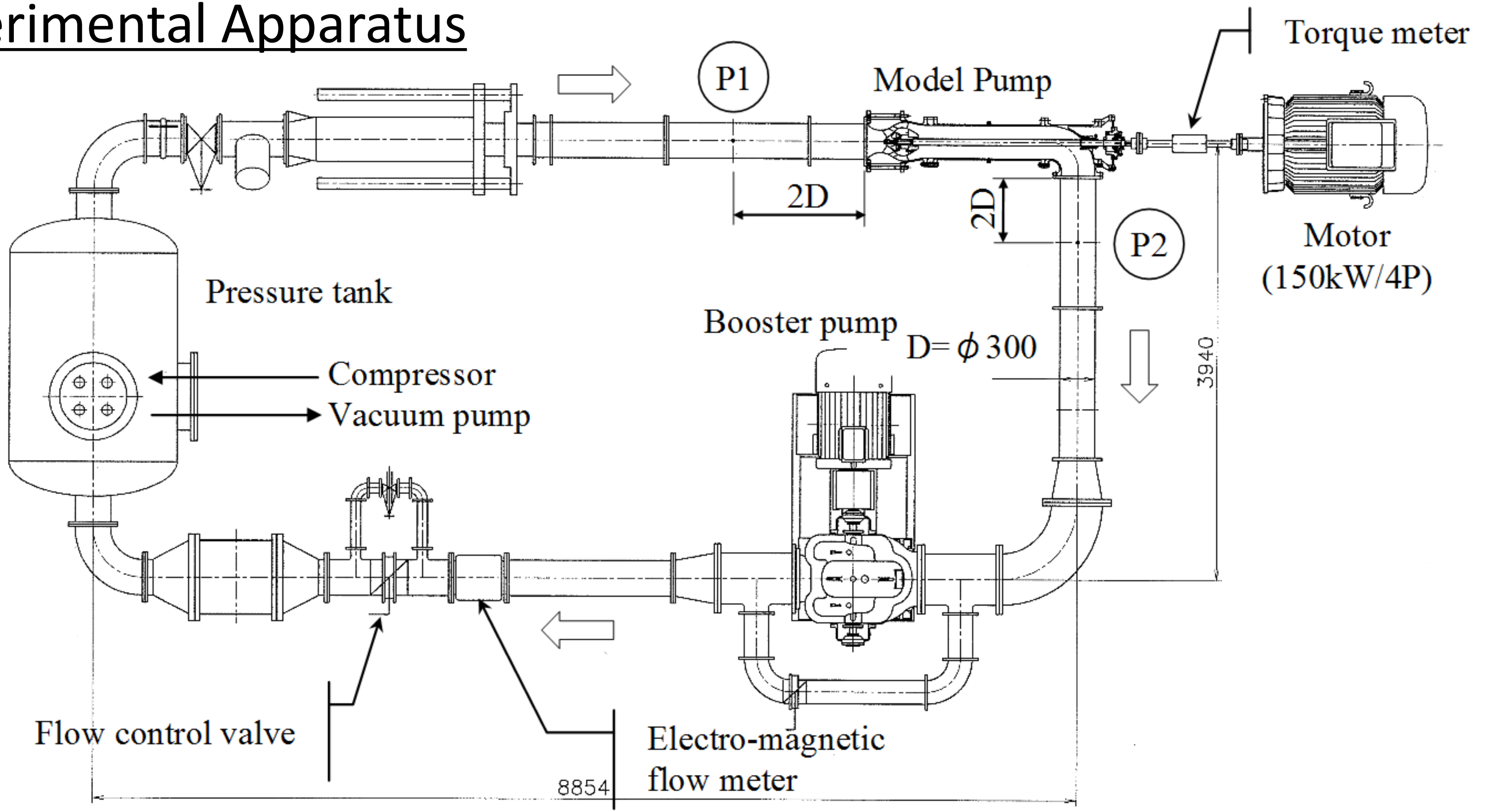


Figure Lay-out of the test loop

2. Solution/ Investigation by Physical Model Test

Flow Visualization : In order to check of impeller flow characteristics, a visualization test was carried out . As the result, strong tip vortex was confirmed. We judged this was the cause of strange vibration.

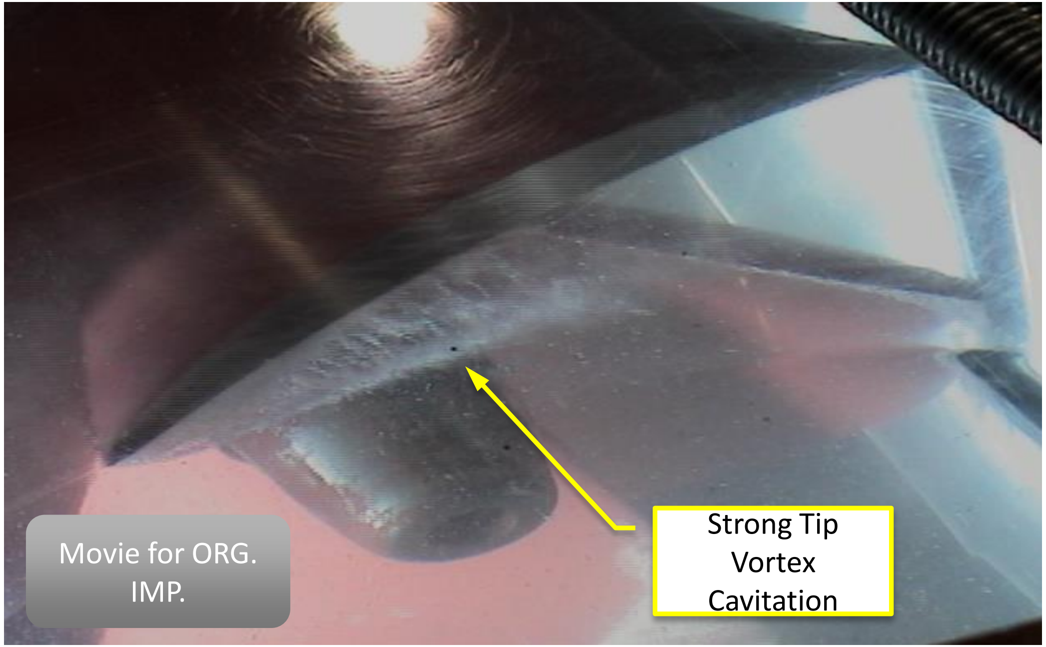


Photo. Cavitation condition in the case of original impellers at Q_r and NPSHA=15m

2. Solution/ Investigation by Physical Model Test

<u>Vibration</u> : The below figure shows the frequency analysis result of vibration at discharge direction and Q_{BEP} in the case of original impeller. It is evident from this that the dominant frequency is the shaft rotating and the blade passing frequencies. Additionally, the level of blade passing frequency changes intermittently. Therefore, the same phenomenon was confirmed in the actual pump.

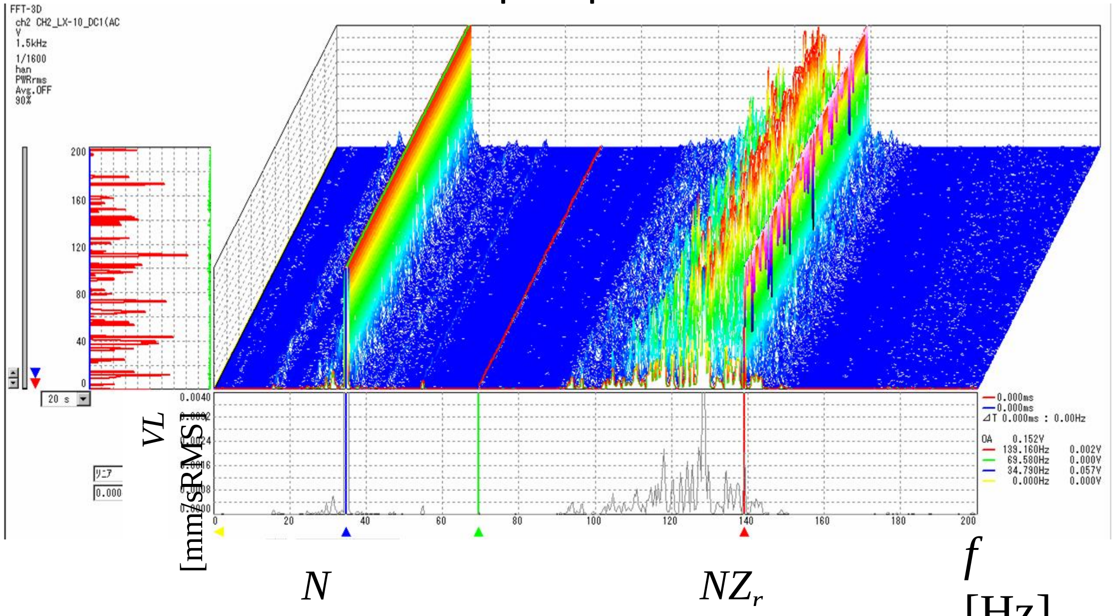


Figure Frequency analysis results for original at Q_{BEP}

2. Solution/ New impeller design

Forward Swept Impeller :

To suppress the cavitation intensity, a forward sweep was designed into a new impeller.

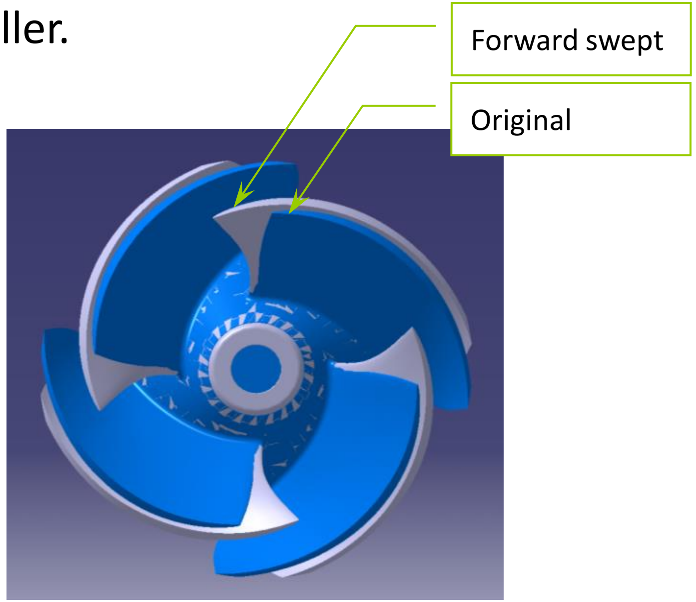


Figure Comparison of the plane view of impellers between the original and the forward swept impellers

Table Main dimensions of the tested pump

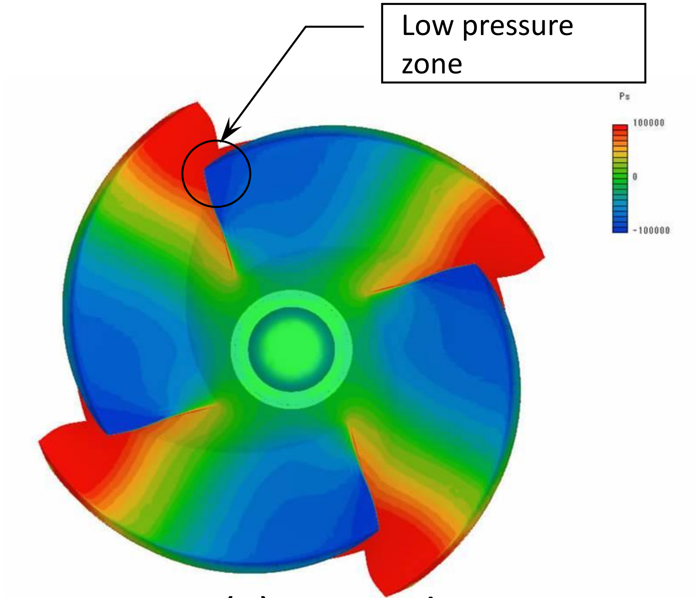
Impeller:		
Sweep	Original	Forward swept
Zr	4	4
D_{1t}/D_{2t}(m)	0.215/0.288	0.215/0.288
D_{1h}/D_{2h}(m)	0.100/0.216	0.100/0.216
$\beta_{1Bt}/\ \beta_{2Bt}$(deg)	22.4/18.3	22.2/19.5
$\beta_{1Bm}/\ \beta_{2Bm}$(deg)	17.2/34.1	17.1/30.3
Diffuser:		
Zg	9	
D_{3t}/D_{4t}(m)	0.392/0.392	
D_{3h}/D_{4h}(m)	0.300/0.300	
$\alpha_{3Bm}/\alpha_{4Bm}$(deg)	45.0/90.0	

Note: All main dimensions and angles between the new and original impellers were designed to be the same. Only the blade stacking was changed.

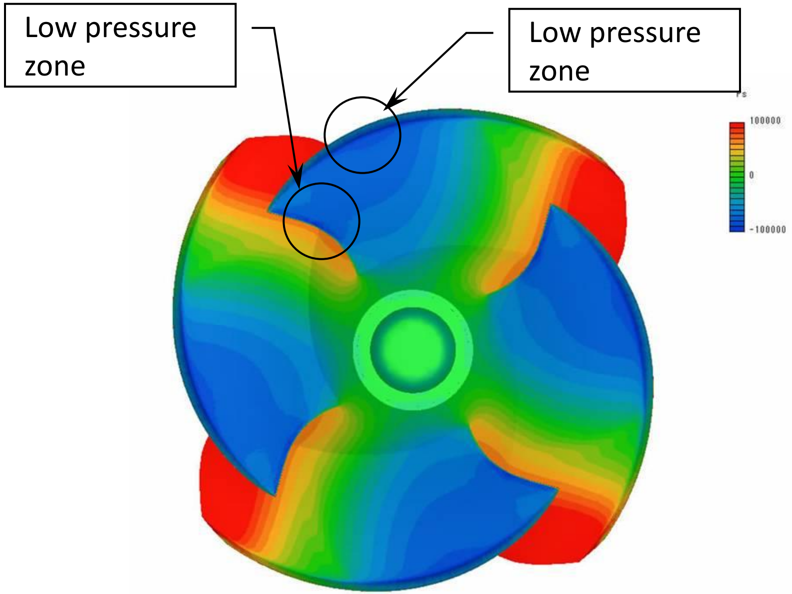
2. Solution/ New impeller design

CFD analysis was performed to estimate the effect of new impeller design on suppressing the cavitation intensity. The summary of the results is as follows:

- Low pressure zone moved inlet tip side to the middle of the leading edge
- The secondary flow at radial direction is suppressed by the forward sweep.
- Consequently, the blade loading decreases around the leading edge at the tip.



(a) Original

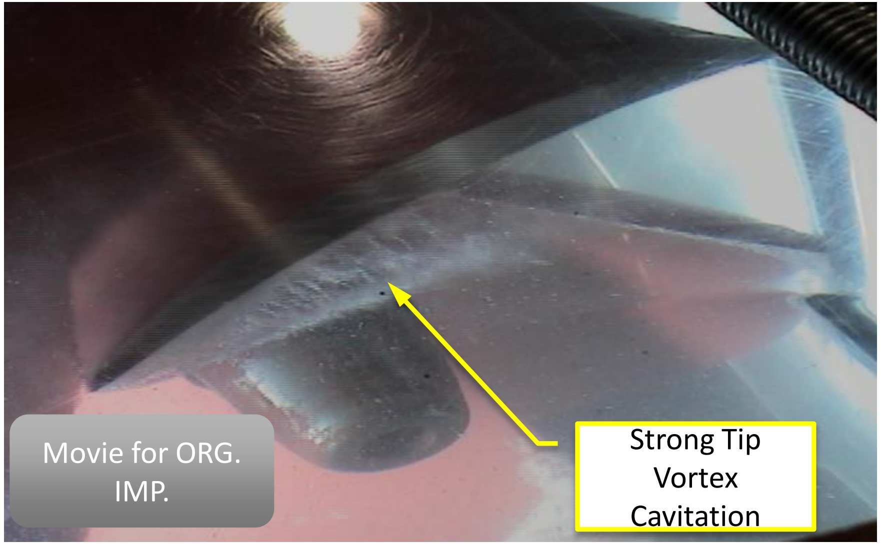


(b) Forward swept

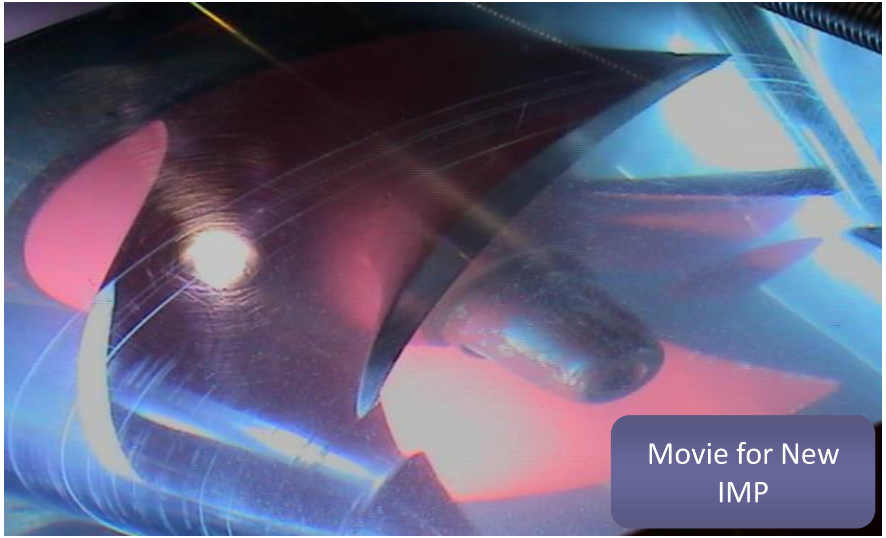
2. Solution/ Investigation by physical model test

Flow visualization : In order to check the cavitation condition on the blade surface of impeller the visualization test was carried out .

NEW impeller : Tip vortex and another cavitation don’t occur.



(a) ORG., at Q_{BEP} and NPSHA=15m



(b) NEW at Q_{BEP} and NPSHA=15m

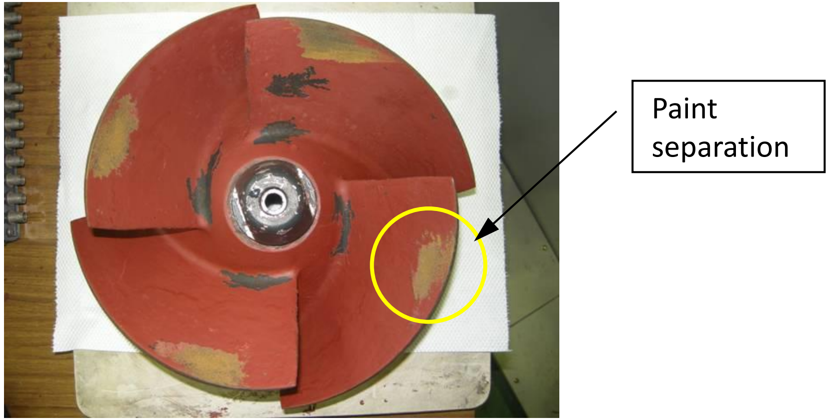
Photo. Comparison of cavitation condition between original and forward swept impellers at BEP

2. Solution/ Investigation by physical model test

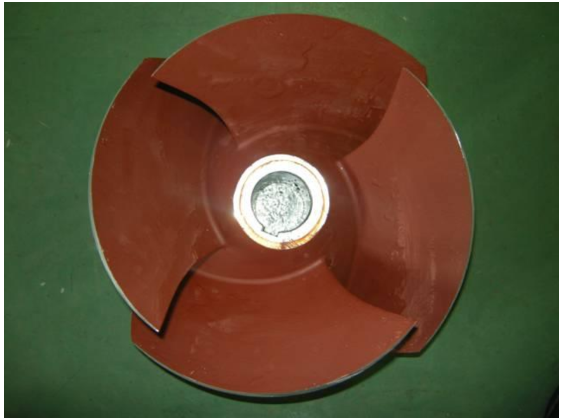
Paint Erosion Test : A paint erosion test had been carried out under the following conditions. As shown in the photos below, paint separation was confirmed in at 80%Qrated for both impellers. From these results, it can be seen that the cavitation intensity decreased significantly with the new style impeller.

TEST CONDITIONS

1. NPSHA (=15.0m), 2. Flow rate : 80%Qrated, 3. Operating time is 3 hours



(a) Original at 80%Qrated

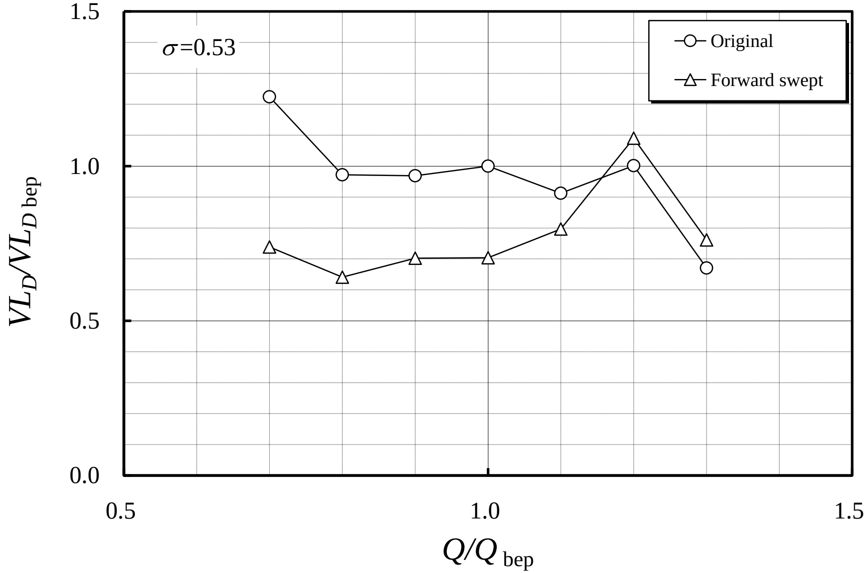


(b) Forward sweep at 80%Qrated

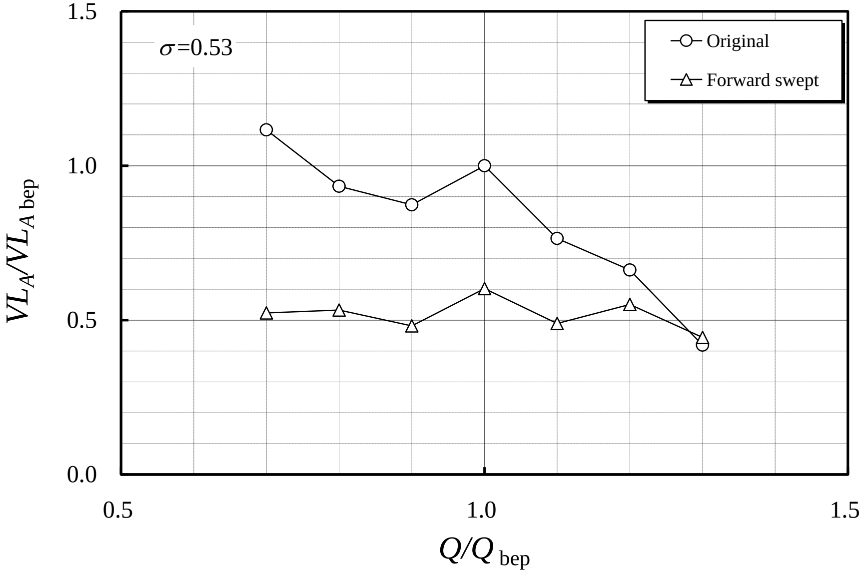
Photo. Comparison of paint erosion test results between original and new impellers

2. Solution/ Investigation by physical model test

<u>Vibration</u>: Below figures show the comparison of the vibration level between the original and the forward swept impellers. From this figure, the vibration level in the forward impeller decreases at both directions compared with the original.



(a) Discharge



(b) axial

Figure Comparison of vibration level between original and forward swept impellers

3. Solution/ Site test results by new impeller

SWSP with new impeller was operated and the vibration level in all of directions had drastically decreased up to 2.0mm/sRMS. This confirmed that the RCA and impeller design improvement was the correct solution for this vibration problem.

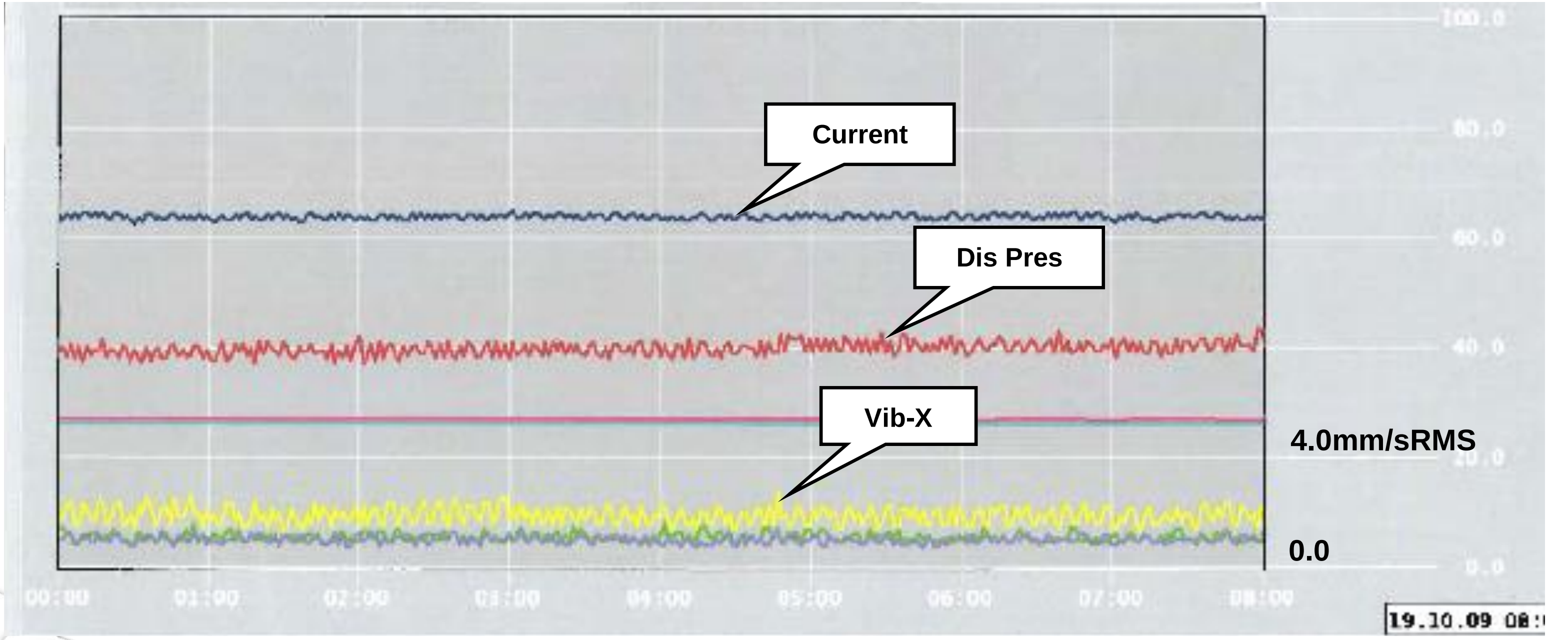


Figure Site test results by new impeller

3. Conclusion and Lesson Learned

The following conclusions were obtained:

1. The strong tip cavitation induces the unsteady excessive vibration.
2. It's mechanism is the following:
   - The tip vortex cavitation on each blade generates the excessive pressure fluctuation at the outlet of the impeller.
   - And then, the excessive hydraulic exciting force with fluctuating in the blade passing frequency is induced.
   - In addition, the intensity of this cavitation changes intermittently. Therefore, the excessive vibration with the intermittently changing and fluctuation in the blade pass frequency occur.
3. In the case of required high suction performance, we have to consider not only NPSH3 but also Cavitation inception performance: NPSHi.
4. The forward sweep is effective as the technique for suppressing the cavitation because it can control the local pressure distribution on the blade surface.

Thank You...

Questions??