Cavitation in High Energy Pumps – Detection and Assessment of Damage Potential

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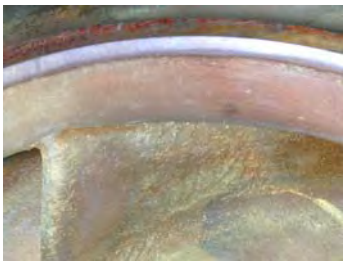
Topics

- Overview
- Cavitation
- NPSH
- Factors Causing Cavitation
- Supplementary Pictures

Cavitation in High Energy Pumps

Detection and Assessment of Damage Potential



Prepared and Presented by Paresh Girdhar and Steve Mackay

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Overview of Topic

Cavitation related erosion damage continues to be a problem in a variety of centrifugal pumps. The methods of detection and assessment of the damage potential are examined in this practical discussion.

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Cavitation

Pump cavitation is a hydraulic disturbance that has a potential to:

- Increase operating noise levels
- Affect the performance of the pump
- Cause damage to the internals of the pump

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Detecting Cavitation

Cavitation is not very difficult to detect:

- Mild cavitation is often heard as passing of sand / gravel through the pump
- Medium and severe cavitation can be heard as passing of pebbles or larger sized rocks through the pump
- Vibration levels especially on the pump casing are high. This is typically a broad band frequency of vibration in the higher range
- Pressure pulsations causing pressure gauge and ammeter oscillations are also indicators of pump cavitation

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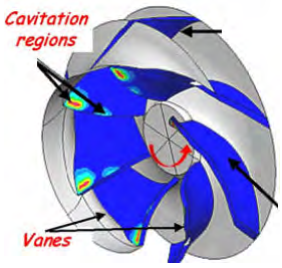
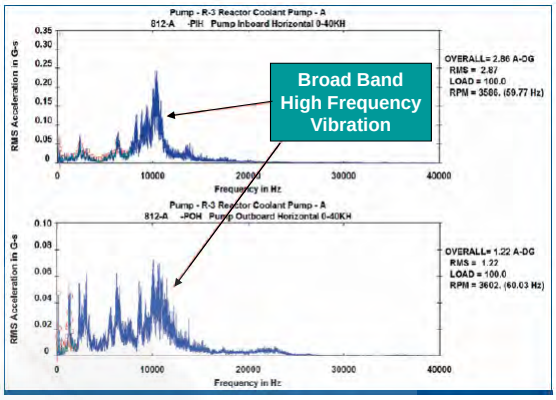
Cavitation Effects





What Causes Cavitation?

- Pumps handle liquids
- When vapor phase is formed in the liquids, the performance of the pump is affected
- Cavitation too is caused due to the formation of the vapor phase in the liquid
- In order to understand the details we need to understand a property of a liquid called Vapor Pressure

Vapour Pressure

- If a quantity of liquid is placed in an evacuated, closed container
- After some period of time, a vapour phase forms in the space above the liquid surface.
- This space consists of molecules that have passed through the liquid surface from liquid to gas.
- The pressure exerted by that vapour phase is called the *vapour (or saturation) pressure*.
- For a pure liquid, this pressure depends only on the temperature.

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Examples of Vapor Pressure

- Vapor pressure is 101 kPa (1 atmosphere) at
  - 100°C for water
  - 78.5°C for ethyl alcohol
  - 125.7°C for octane.
- Similarly, at 20°C
  - Water has a vapor pressure of 2.33 kPa
  - Isopropyl alcohol (rubbing alcohol) has a vapor pressure of 4.4 kPa (33 mm Hg)
- Alcohol has a higher vapor pressure than water at the same temperature.
- Alcohol has a tendency to evaporate more easily (cf water).

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Cavitation

- Very often pumps handle liquids with suction conditions very close to a liquid's vapor pressure.
- When a liquid is drawn into the pump inlet there is a pressure drop resulting from the fluid friction along the pipeline, valves, fitting and flow pattern.

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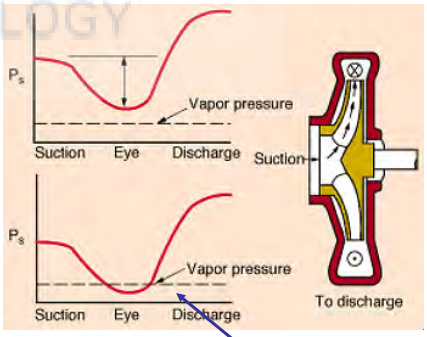
Cavitation

- Under conditions, when the reduced pressure approaches the vapor pressure of the liquid (at that temperature) it causes the liquid to vaporize
- As these vapor bubbles travel further into the impeller, the pressure rises again causing the bubbles to collapse or implode.



Bubble Implosion

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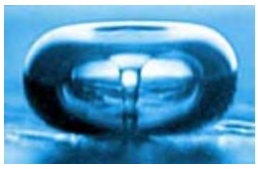
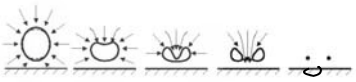
Implosion of Bubbles

- These bubbles collapse rapidly and violently when the local absolute pressure increases
- On implosion, micro jets of liquid rush in with high velocity to fill the imploded space and impinge with energy on the metal
- These implosions cause severe damage to pump internals and can adversely affect pump performance
- This phenomenon is called as cavitation



Micro Jets



Erosion

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Cavitation

- Cavitation damage to a centrifugal pump may range from minor pitting to catastrophic failure and depends on the pumped fluid characteristics, energy levels and duration of cavitation
- Most of the damage usually occurs within the impeller; specifically, on the leading face of the non-pressure side of the vanes.
- The net effect observed on the impeller vane will be a pockmarked, rough surface.

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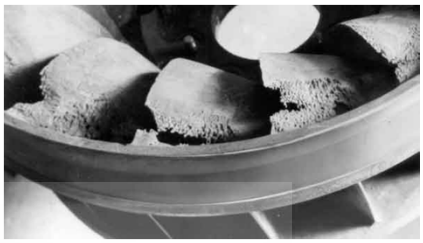
Cavitation Effects



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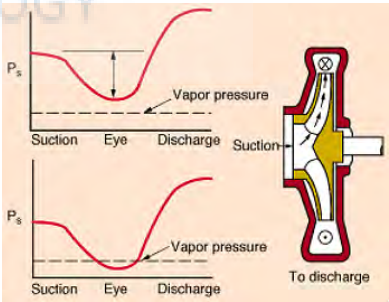
NPSH

- *Thus, the pressure of the liquid as it enters the impeller eye has to be greater than the vaporization pressure.*
- This excess head of liquid column is called the NPSH or net positive suction head.



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NPSH-Available

- Every pump has an associated inlet system comprising vessel, pipes, valves, strainers, and other fittings.
- The liquid, which has a certain suction pressure, experiences losses as it travels through the inlet system.
- Thus the inlet pressure (in absolute terms) net of the pipe and fitting losses and the vapor pressure is what is available at pump inlet and this is called the *Net Positive Suction Head–Available* or NPSH-a.

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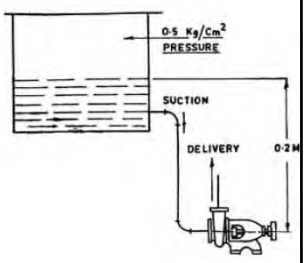
Calculating NPSH-a – Pressurized Suction

- Vapor Pressure = 0.45 kg/cm^2
- Pipe Losses = 1.5 m
- Specific Gravity = 0.8
- Absolute Pressure = 1.02 kg/cm^2 = $(10 \times P_{abs} / \rho) = (10 \times 1.02 / 0.8) = 12.8$ m

- P_s = 0.5 kg/cm^2
  $H_s = (10 \times P_s / \rho) = (10 \times 0.5 / 0.8) = 6.3$ m
- h_s = + 0.2 m
- $H_{vap} = (10 \times P_{vap}/\rho) = (10 \times 0.45 / 0.8) = 5.6$ m



- NPSH-a $= H_{abs} + H_s + h_s - pl - H_{vap}$
- $= 12.8 + 6.3 + 0.2 - 1.5 - 5.6$
- = 12.2 m

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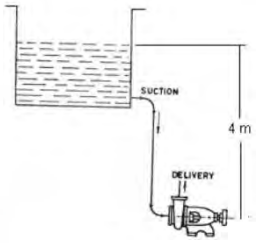
Calculating NPSH-a – Atm. Suction

- Vapor Pressure = 0.45 kg/cm^2
- Pipe Losses = 1.5 m
- Specific Gravity = 0.8
- Absolute Pressure = 1.02 kg/cm^2 = (10 ´ P_{abs} / ρ) = (10 ´ 1.02 / 0.8) =12.8m

- P_s = 0 kg/cm^2 *(open to atmosphere)*
  H_s = 0 m
- h_s = + 4 m
- H_{vap} = (10 ´ P_{vap}/ρ) = (10 ´ 0.45 / 0.8) = 5.6 m

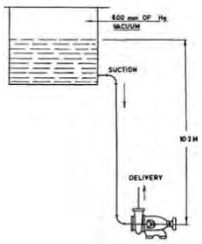


- NPSH-a =H_{abs} + H_s + h_s – pl - H_{vap}
- = 12.8 + 4 – 1.5 – 5.6
- = 9.6 m

Calculating NPSH-a – Vacuum Suction

- Vapor Pressure = 0.45 kg/cm^2
- Pipe Losses = 1.5 m
- Specific Gravity = 0.9
- Absolute Pressure = 1.02 kg/cm^2 = (10 ´ P_{abs} / ρ) = (10 ´ 1.02 / 0.9) =11.3m

- P_s = 600 mm - Hg *(Vacuum)*
  H_s = - (600/1000) ´ 13.6 / 0.9 = – 9.1 m
- h_s = + 10.2 m
- H_{vap} = (10 ´ P_{vap}/ρ) = (10 ´ 0.45 / 0.9) = 5 m

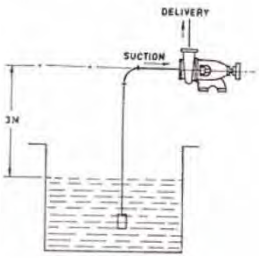


- NPSH-a =H_{abs} + H_s + h_s – pl - H_{vap}
- = 11.3 – 9.1 + 10.2 – 1.5 – 5
- = 5.9 m

Calculating NPSH-a – Negative Lift

- Vapor Pressure = 0.45 kg/cm^2
- Pipe Losses = 1.5 m
- Specific Gravity = 0.8
- Absolute Pressure = 1.02 kg/cm^2 = (10 ´ P_{abs} / ρ) = (10 ´ 1.02 / 0.8)= 12.8m

- P_s = 0 kg/cm^2 *(open to atmosphere)*
  H_s = 0 m
- h_s = – 3 m
- H_{vap} = (10 ´ P_{vap}/ρ) = (10 ´ 0.45 / 0.8) = 5.7 m



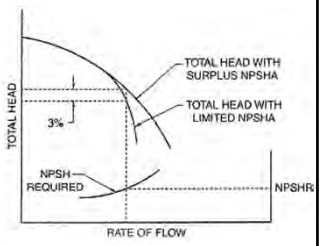
- NPSH-a =H_{abs} + H_s + h_s – pl - H_{vap}
- = 12.8 + 0 – 3 – 1.5 – 5.7
- = 2.6 m

NPSH-Required

- As the liquid in the suction pipe approaches the impeller eye, losses in terms of liquid head occur due to:
  - Velocity and Acceleration of liquid
  - Sharp change in direction to enter the impeller
  - Higher flow rates
  - Recirculation due to higher clearance at wear rings
  - Use of smaller diameter impellers in volutes
- The pump inlet nozzle and impeller inlet vane geometry are designed to minimize the losses but cannot be eliminated entirely.
- The summation of the above losses is termed the *Net Positive Suction Head* as <u>required</u> by the pump or NPSH-r.

NPSH-Required

- The Hydraulic Institute defines NPSH-r of a pump as the NPSH that causes the total head (first stage head of multistage pumps) to be reduced by 3%, due to flow blockage from cavitation vapour in the impeller vanes
- NPSH-r by the above definition <u>does not necessarily imply that this is the point at which cavitation starts; that level is referred to as incipient cavitation.</u>
- The NPSH at incipient cavitation can be from 2 to 20 times the 3% NPSH-r value, depending on pump design especially in case of **high suction energy pumps**.

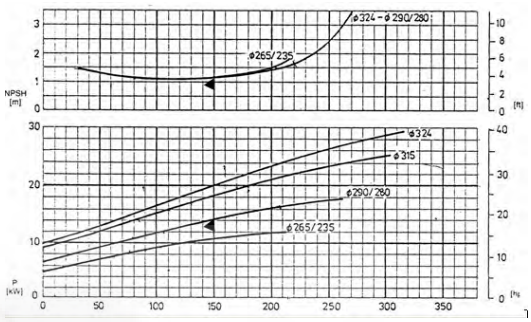


Q vs. NPSH-r Curve

- NPSH-r or Net Positive Suction Head – required by the pump is the minimum pressure or head required at the pump inlet to avoid a damaging phenomenon called cavitation.
- NPSH-r on the characteristic curves is the measured suction head obtained while throttling the suction flow until a 3% drop in the differential head is observed at any particular flow rate
- NPSH-r is dependent on the service liquid but it is known that cavitation resulting from cold water is most damaging as compared with most commonly pumped liquids hence no corrections are made while using it for other liquids

Q vs. NPSH-r Curve

- There is also an effect of Impeller OD on NPSH-r
- It is more pronounced for pumps with higher specific speed than with pumps of lower Specific Speed



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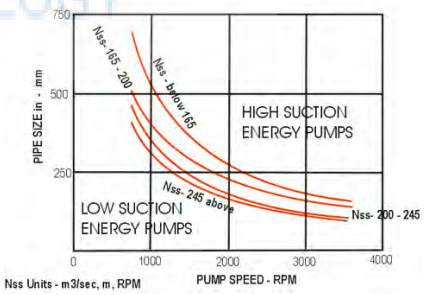
Suction Energy

- The suction energy level of a pump increases with:
  - The casing suction nozzle size / Impeller eye diameter
  - The pump speed
  - The suction specific speed - Nss
  - Specific gravity of the pumped liquid
- Most standard low suction energy pumps can operate with little or no margin above the NPSH-r value, without seriously affecting the service life of the pump.



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Inception of Cavitation

- Thus we see that the NPSH-r as defined by the Hydraulic Institute is not a true indicator of incipient cavitation, though it a practical method
- This necessitates a theoretical evaluation of NPSH-r
- The theoretical derivation of NPSH-r or "Cavitation Free NPSH" is based on factors such as:
  - Head loss due to friction
  - Head drop due to fluid acceleration
  - Head loss due to improper fluid entry into the impeller blade

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NPSH Margin

- As there is ambiguity with regards to the inception of cavitation, a margin is kept between the NPSH-available and NPSH-required
- Most pump specifications quote a margin of not less than 1 to 1.5 m over the entire range of pump operation
- Another approach adopted to define the margin is by taking the ratio of NPSH-a and NPSH-r.

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NPSH Ratio

	Minimum NPSH Margin Ratio Guidelines (NPSH-a / NPSH-r)		
	Suction Energy Levels		
Application	Low	Medium	High
Petroleum	1.1-a	1.3-c	
Chemical	1.1-a	1.3-c	
Electrical Power	1.1-a	1.5-c	2.0-c
Nuclear Power	1.5-b	2.0-c	2.5-c
Cooling Towers	1.3-b	1.5-c	2.0-c
Water / Waste Water	1.1-a	1.3-c	2.0-c

"a" – Or 0.6 m (2 feet) whichever is greater
"b" – Or 0.9 m (3 feet) whichever is greater
"c" – Or 1.5 m (5 feet) whichever is greater

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High Energy Pump Cavitation

- In high energy pumps, NPSH obtained by 3% head drop is not sufficient
- This NPSH-r (3%) value could be 5 to 6 times less than the suction head when bubble formation takes place and can cause impeller blade erosion
- As in other pumps causes the following but with greater consequences:
  - Erosion of impellers at suction
  - Introduces compressible volume in liquid that causes pressure pulsations and affects performance

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Factors Affecting Cavitation in High Energy Pumps

- The factors that intensify cavitation effects in High Energy (HE) pumps are
  - Liquid Properties (vapor pressure, specific gravity…)
  - Hydraulic Design – Most important factor is Impeller tip speed (radius of impeller eye time shaft angular speed), Blade angle, positive and negative pre-swirls
  - Impeller Metallurgy
  - Operating point and conditions (flow rate)

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Assessment of Impeller Life

- Research in this area has come up with a method to assess the life of the impeller due to cavitation based on many parameters indicated in earlier slide
- A simplistic equation estimating life of impeller is as follows

$$\Delta m = U_c^a \times L^b \times t$$

  - Δm = Loss of Material/ Erosion depth (penetration of 75% of vane thickness is considered as end of life)
  - U_c – Impeller tip speed
  - L – Cavity Length (see next slide)
  - t - time of operation
  - a, b - constants

    Thus by knowing thickness the time "t" can be back-calculated

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Cavity Length – HE Pump Impeller

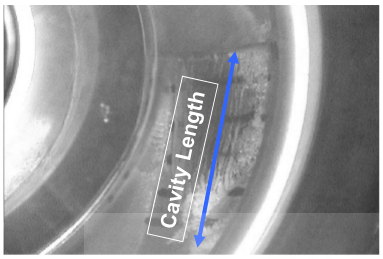

Figure 1. Typical Sheet Cavitation Pattern on High-Energy Feed Pump Impeller Blade.

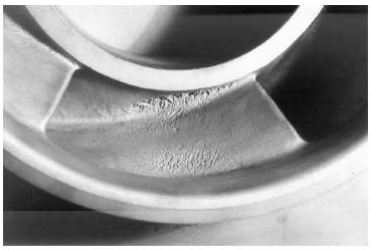

Figure 2. Cavitation Erosion on High-Energy Suction Stage Impeller. (Evidence of sheet cavitation and hub fillet cavitation as seen by the erosion patterns.)

Cavitation Prevention

- Cavitation can be prevented by ensuring a proper margin or ratio of the NPSH-a to the NPSH-r
- However even after careful design and specification it is possible that due to equipment installation issues and revised operating conditions the situation may lead to cavitation
- Often poorly insulated lines result in affecting inlet temperature of the liquid leading to cavitation issues

Cavitation Prevention

- Solutions to improve NPSH margin include
  - Lowering Inlet temperature
  - Increasing suction vessel pressure or head
  - Raising the level of the suction vessel
  - Lowering the pump in a pit
  - Replacing the pump type with a vertical submersible type
  - Increasing suction line size
  - Removal of redundant valves, fittings, strainers from inlet line
  - Installing an inducer to the pump impeller

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Supplementary Slides

Cavitation versus corrosion

Can you distinguish between them ?

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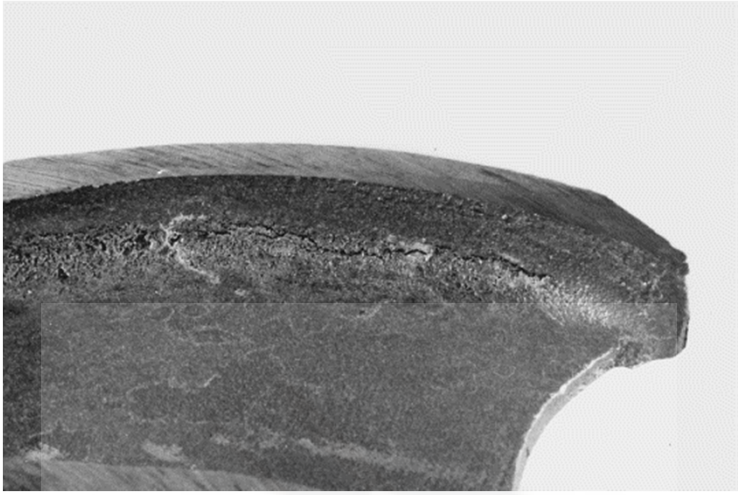
Pitting & cracking



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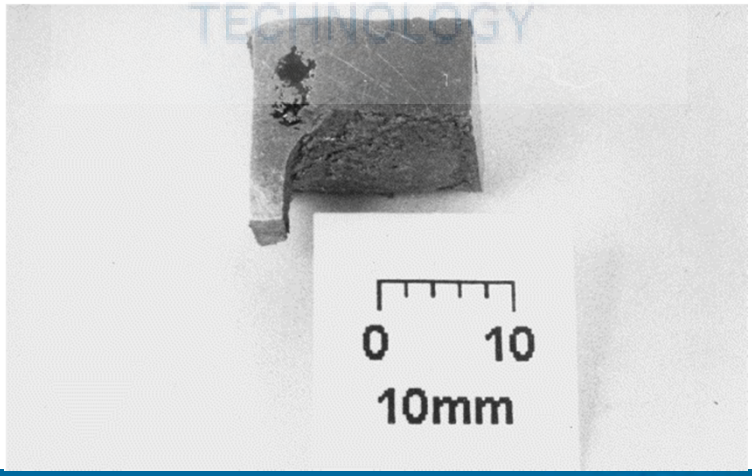
Porosity of cross section



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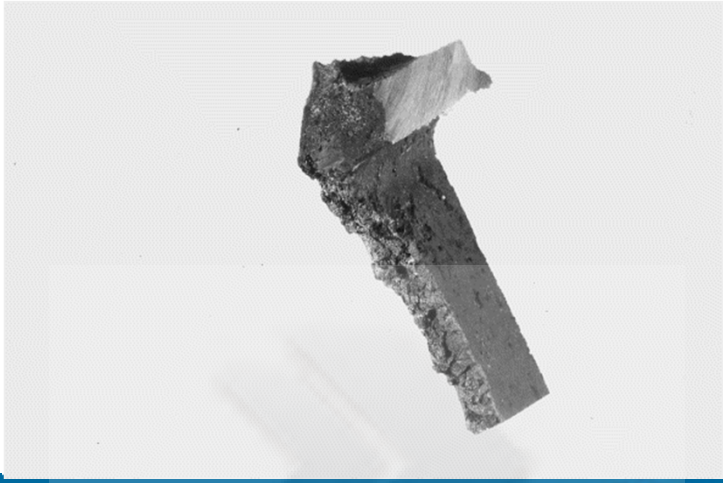
Porosity in failed bronze one



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Cavitation Failure

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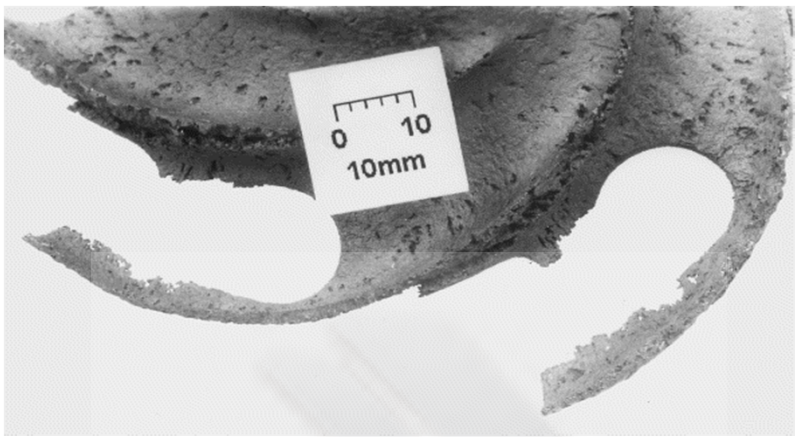
Close up of cavitation failure



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General Corrosion

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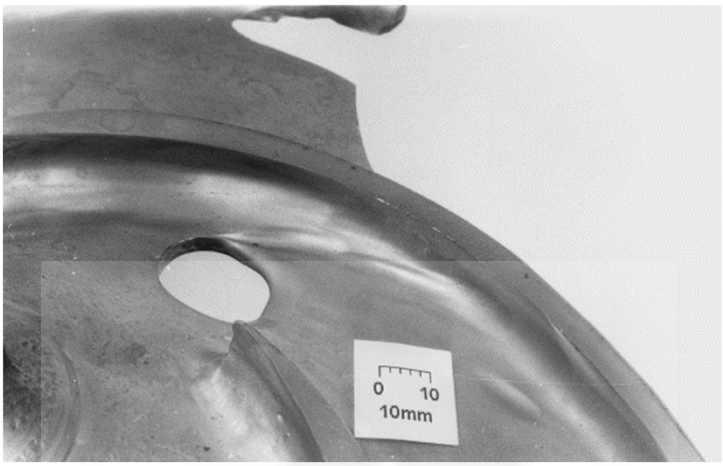
Erosion-corrosion grooves



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