Propeller Cavitation

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A Study on the Propeller Cavitation

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Cavitation 발생기구

CAVITATION (空洞現象)

1. CAVITATION
   1. 유체가 넓은 운도에서 좁은곳으로 고속으로 유입할 때, 또는 벡면을 따라 흐를 때 벡
      면에 요철이 있거나 면공부가 있으면 흐름은 직선적이 못되며 A부는 B부보다 저압이
      되어 여기에 CAVITY(空洞)가 생긴다.
      또 수중에는 압력에 비례하여 공기가 용입되어 있는데, 이공기가 물과 분리되어 기포
      로 나타난다.
   2. 이와같은 현상을 CAVITATION 즉 공동현상 이라고 한다.
      CAVITATION 발생에 의하여 생긴 기포는 고압의 영역에 이르렀을 때 갑자기 파괴되어
      다시 수중으로 말려들어 소멸하고 만다.
   3. 기포가 파괴될때에는 심한충격을 동반하고 소음과 진동을 초래한다.
      이진동은 대체로 600~3,000 사이를 정도로 된다.
      이현상은 흡입관에 공기를 흡입시키므로써 정지시킬수 있다.
      다만, 이조치는 펌프인 경우에는 그렇게 많이 채용되고 있지 않지만 수차에서는 많이
      이용되고 있다.
   4. 또 기포가 파괴될 때, 기포의 전주(全周)에 밀어 물이는 액체의 압력은 기포체적의 급
      격한 축소에 따른 기포 표면적의 급격한 감소에 의하여 그 압력 강도가 매우 커진다.
      실측에 의하면 300 기압이나 될 때도 있다.
      이와같은 극한의 충격 때문에 벡면은 침식하게 된다.
      펌프에서의 CAVITATION은 여러곳에서 발생하는데 가장 문제가 되는곳은 깃잎구
      부근에 발생 하는 것으로서 펌프의 성능을 저하 시키고 또 효율도 나빠진다.
베르누이 원리

\[ p_1 + \frac{1}{2} \rho v_1^2 + \rho g h_1 = p_2 + \frac{1}{2} \rho v_2^2 + \rho g h_2 = \text{일정} \]
물의 상변화
Cavitation 발생기구

Flow around a hydrofoil (blade section)

- Top pressure LOWER than bottom pressure
- Lift increases with $U^2$, Angle of Attack, Camber
- Top pressure DECREASES as Lift (or U) increases

REMEMBER WATER BOILS WHEN....

Pressure = 101 kPa (atmospheric)
Pressure = 1.7 kPa

Temperature = 212 F (100 C)
Temperature = 60 F (15.5 C)

BOILING OF WATER AT NORMAL TEMPERATURES IS CAUSING...
Cavitation 발생순서

- Formation of bubbles inside the liquid
- Growth of bubbles
- Collapse of bubbles

Fig. 2

www.cheresources.com
Cavitation 발생순서

Collapse of a vapor bubble

Fig. 11

Initial bubble
Initiation of bubble collapse
Forming of liquid microjet
Impact & metal extrusion

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Type of Cavitation

- Sheet Cavitation
- Tip Vortex Cavitation (developed)
- Cloud Cavitation
- Bubble Cavitation
- Hub Vortex Cavitation
- Root Cavitation
- Midchord Detachment
- Leading Edge Detachment

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Cavitation Type
Cavitation의 종류

a) Sheet Cavitation
b) PHV and Hub Vortex
c) Tip Vortex with Nodes
d) Bursting Tip Vortex
e) Cloud Cavitation
f) Cloud Cavitation
Cavitation pitting

Fig. 13

Impeller

Diffuser

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Cavitation on Propeller
Cavitation 발생
Damaged Propeller by Cavitation
Propeller Blade Damage
Blade cavitation
프로펠러 공동에 의한 선체 손상

프로펠러 공동에 의한 손상
■ 캐비테이션의 장해

① 캐비테이션의 생성 - 성장 - 붕괴 - 소멸의 과정에서 수증기가 순간적으로 축소하면서 강한 충격력이 추진기 날개면에 가해지고 이는 추진기의 침식을 유발함.
② 주기적인 캐비테이션의 발생과 소멸은 선체 표면에 변동 압력을 가하여 선체 진동 및 소음 유발
③ 추진 효율이 급격히 떨어져 추진 성능이 저하
④ 공회전으로 인한 모터의 소손
⑤ Rudder, Shaft, Hull, Strut 등 선미 구조물에 충격
⑥ 수중 방사 소음 유발로 군함에서 소나 피탐율 증가 야기
Propeller Cavitation

- The formation and collapse of vapor bubbles on propeller blades where the pressure has fallen below the vapor pressure of water

Cavitation occurs on propellers that are heavily loaded, or are experiencing a high thrust loading coefficient

Consequences:
1) Low propeller efficiency (Thrust reduction)
2) Propeller erosion (Mechanical erosion. Severe damage to propeller: up to 180 ton/in²)
3) Vibration due to uneven loading
4) Cavitation noise due to impulsion by the bubble collapse
Cavitation 실험

http://www.youtube.com/watch?feature=player_detailpage&v=SEvxngv-dkY
Eu and Ca

**Euler number (physics)**

\[ Eu = \frac{p_{\text{upstream}} - p_{\text{downstream}}}{\rho V^2} \]

where

- \( \rho \) is the density of the fluid.
- \( p_{\text{upstream}} \) is the upstream pressure.
- \( p_{\text{downstream}} \) is the downstream pressure.
- \( V \) is a characteristic velocity of the flow.

The cavitation number has a similar structure, but a different meaning and use:

The **Cavitation number (Ca)** is a dimensionless number used in flow calculations.

It is defined as

\[ Ca = \frac{p - p_v}{\frac{1}{2} \rho V^2} \]

where

- \( \rho \) is the density of the fluid.
- \( p \) is the local pressure.
- \( p_v \) is the vapor pressure of the fluid.
- \( V \) is a characteristic velocity of the flow.
• Cavitation number

\[ \sigma = \frac{p_0 - p_v}{\frac{1}{2} \rho V_R^2} \]

- \( p_0 \) - pressure at some point of a blade
- \( p_v \) - vapor pressure of water

The cavitation is most likely to occur at the tips of blades where the relative velocity is the largest and the hydrostatic pressure is the lowest when blades rotate to the highest position. It can also occur near the roots where blades join the boss of a propeller because the attack angle is the largest.
• Cavitation on a propeller will
  1. lower the thrust of the propeller, & thus decrease its efficiency,
  2. cause vibration of hull & the propeller and generate uncomfortable noise, &
  3. cause erosion of the propeller blade.

• Criteria for prevention of cavitation

Mean thrust loading coefficient
\[ \tau_c = \frac{T}{\frac{1}{2} \rho V_R^2 A_p} \]
\[ \rho \] - density of water, \( T \) - Thrust,
\[ A_p \] - project blade area,
\[ \frac{A_p}{A_D} = 1.067 - 0.229 \frac{P}{D} \]
\[ V_R \] - the relative velocity at 0.7 \( R \) of a propeller
\[ V_R^2 = V_A^2 + (2\pi \cdot 0.7 R \cdot n)^2 \]
6.7 Cavitation

A typical pressure distribution in a blade element is shown below,

As the pressure on the back of a propeller falls lower and lower with the increase in a propeller’s $n$, the absolute pressure at the back of the propeller will eventually become low enough for the water to vaporize and local cavities form. This phenomenon is known as cavitation. ($P_v$, vapor pressure of water)
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대전에 캐비테이션 터널 준공 세계최대 규모

한국해양연구원은 25일 대덕연구개발특구 내 해양시스템안전연구소

캐비테이션 터널은 선박의 추진기에서 발생하는 캐비테이션 현상(프로펠러 고속회전시 프로펠러 표면에 나타나는 수증기 거품현상으로 추진기 효율을 떨어뜨리거나 추진기 파괴의 원인)을 재현해 고효율, 저진동, 저침적, 저소음 추진기를 설계하기 위한 시설로 규모(본체크기 기준 길이 60m, 높이 22.5m, 폭 6.5m)면에서 미국 해군연구소에 이어 세계 두번째이고 상선용으로는 세계 1위다.

이 시설을 활용하면 함정용 저소음 추진기 핵심기술 개발을 통해 해양방위력 항상기술의 자립과 차세대 수상함정 및 잠수함 개발이 가능하다

2010.5.26
Propeller Cavitation 방지법

1. Jc(트러스트 하중계수)와 σ(케비테이션 넘버)를 적당히 배치
2. Aero foil 단면은 발생이 쉬우므로 익근은 Aero foil형, 선단은 궁형으로
3. 프로펠러와 외판, 선미골재, 축 브라킷 등과 충분한 거리
4. 수면박으로 노출되는 부분은 흐름을 양호하게
5. 날개선단은 움수록 느린속도 3~3.5m/min이하가 되게
6. 날개 전연을 날카롭게, 매끄럽게
7. 강한재료로 두께를 얇게한다.
8. 추력/면적을 적게되도록
9. Wash Back을 설계
Pump에서 Cavitation 방지법

① 펌프의 설치위치를 가능한 한 낮게한다.

② 흡입관의 유체저항을 작게한다. (길이는 짧게, 직은 적게, 관경은 크게 한다)

③ 임펠러의 회전속도를 작게한다.

④ 지나치게 고압정 펌프의 사용을 지양한다.

⑤ 설계 토출량 보다 현저하게 벗어난 운전을 피한다.

⑥ 단흡입 보다는 양흡입 펌프를 사용한다.

⑦ $\text{Av NPSH} > 1.3 \times \text{Re NPSH}$ 가 되도록 한다.

⑧ 흡입수조 내에서 지나친 와류가 생기지 않도록 한다.

⑨ 펌프의 흡입측에는 절대로 유량조절 밸브를 달아서는 안된다.

⑩ 흡상이 불가능한 경우는 흡수면보다 펌프를 낮게 설치하거나 Booster Pump 를 설치하여 흡입조건을 개선한다.
RUDDER CAVITATIONS

Gap Cavitation

Section A-A'

Occurrence of vortex cavitation

Section B-B'

B

B'

A

A'
RUDDER CAVITATIONS

Rudder Cavitation의 종류

1. Side Plate Cavitation
2. Sole Cavitation
3. Gap Cavitation
4. Propeller Hub Vortex Cavitation
5. Propeller Tip Vortex Cavitation
RUDDER CAVITATIONS 방지 방안

• Rudder Sole Cavitation 방지 방안
  - Rudder Sole부를 곡면 형상화 할 것.

• 프로펠러 Hub Cavitation 방지 방안
  - Cutting Type의 Hub Cap 적용 할 것.

• 불균일 표면에 의한 Cavitation 방지 방안
  - 용접부에 Grinding 및 Polishing 작업 정도를 항상 할 것.
  - Rudder Shaft설치를 위한 Rudder 형상 변경은 2% 미만으로 할 것.

• Gap Cavitation 방지 방안
  - Rudder와 Horn 접합부의 꼭 단을 통과해 처리 할 것.
  - Gap의 크기는 표준 간격 50mm 미만으로 할 것.
  - Gap의 위치는 프로펠러 후류의 밖에 위치하도록 설계 할 것.

❖ Rudder의 Cavitation 은

  Rudder의 각도가 큰 경우 발생되는 현상으로 초기 선형 및 프로펠러 설계 단계에서부터 Cavitation 특성이 고려된 Rudder 형상에 대한 설계가 필요하다.
Propeller Clearances

- 선체와 Propeller 사이의 간격 중요
- Propeller는 Baseline 이하로 내려가지 않음

**DNV Guidance**

- Single Screw
  \[ A \geq 0.1D \]
  \[ B \geq (0.03 - 0.02Z_D)D \]
  \[ C \geq (0.24 - 0.01Z_D)D \]

- Twin Screw
  \[ C \geq (0.3 - 0.01Z_D)D \]
  \[ D; Shaft Dia \]
  \[ Z_D; Blade 갯수 \]
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  \[ Z_D; \text{ Blade 갯수} \]
Propeller Cavitation

Preventing Cavitation

- Remove fouling, nicks and scratches
- Operate at speeds below the cavitation inception speed
- Increase or decrease the engine RPM smoothly to avoid an abrupt change in thrust.
- Appropriate pitch setting for controllable pitch propeller
- For submarines, diving to deeper depths will delay or prevent cavitation as hydrostatic pressure increases
Cavitation
Cavitation

- The lift force on a propeller blade is generated by increased pressure on the face and reduced pressure on the back, the latter making the greater contribution.

- If the reduction in pressure on the back is great enough cavities form and fill up with air coming out of solution and by water vapour.

- Thus local pressures in the water are important to the study of propellers.

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Cavitation

- Cavitation can occur if an attempt is made to transmit too much power through the screw, or if the propeller is operating at a very high speed.

- Cavitation can occur in many ways on a propeller. The two most common types of propeller cavitation are:
  - Suction side surface cavitation
  - Tip vortex cavitation.

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Cavitation

- Suction side surface cavitation:
  - Suction side surface cavitation forms when the propeller is operating at high rotational speeds or under heavy load (high blade lift coefficient).
  - The pressure on the upstream surface of the blade (the "suction side") can drop below the vapour pressure of the water, resulting in the formation of a pocket of vapour.

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Cavitation

- Under such conditions, the change in pressure between the downstream surface of the blade (the "pressure side") and the suction side is limited, and eventually reduced as the extent of cavitation is increased.
- When most of the blade surface is covered by cavitation, the pressure difference between the pressure side and suction side of the blade drops considerably, as does the thrust produced by the propeller.

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Cavitation

- This condition is called "thrust breakdown". Operating the propeller under these conditions wastes energy, generates considerable noise, and as the vapour bubbles collapse it rapidly erodes the screw's surface due to localized shock waves against the blade surface.
6.5 Propeller Model Test

A test on a model propeller is run either in a towing tank or a running flow in a water tunnel (cavitation tunnel) without a model hull in front of it, which is called “open water” tests.

![Diagram of a cavitation tunnel](image)

1) $V_A$ – velo. of flow
2) $n$ - rotation of motor
3) $p_o$ - pressure can be controlled

Measure $V_A$, $Q$, $T$, and $n$. 

Fig. 10.25 Diagrammatic arrangement of a cavitation tunnel
Development of cavitations of a propeller in a cavitation tunnel
Location of cavitation

Location on blade

Back cavitation $\alpha > 0$

Back cavitation near L.E.
Location of cavitation

Location on blade

Back cavitation \( \alpha \approx 0 \)

Back cavitation beyond the max thickness \((t_{max})\) point
Location of cavitation

Location on blade

Face cavitation $\alpha < 0$

Face cavitation near L.E.
Trust coeff. $K_T = \frac{T}{\rho n^2 D^4}$,  

Toque coeff. $K_Q = \frac{Q}{\rho n^2 D^5}$,

Open-water efficient $\eta_o = \frac{TV_A}{2\pi nQ} = \frac{K_T}{K_Q} \frac{J}{2\pi}$.

Testing results

Slip ratio $= 1 - \frac{V_A}{nD}$, Pitch ratio $= \frac{P}{D}$, section types & # of blades.
Purpose of open-water tests

• It is usually to carry out open water tests on standard series of propellers. Their features (such as # of blades, blade outline shape, blade area ratio, blade section shape, blade thickness fraction, boss diameter & pitch-diameter ratio) are systematically varied. The result data are summarized in a set of particular diagrams, which can be used for design purposes. We will study how to use these diagrams later for designing a propeller.

• Studying the efficiency of a propeller and find a propeller with better efficiency

• Studying the extent and development of cavitations over a propeller.
Cavitation 방지법

1. **Fouling:** The propeller must be kept unfouled by marine organisms and free of nicks and scratches. Fouling causes a reduction in propeller efficiency as well as the increased chance for cavitation.

2. **Speed:** Every ship has a cavitation inception speed, a speed where tip cavitation begins to form. Unless operationally necessary, ships should be operated at speeds below cavitation inception.

3. **Thrust:** For ships shaft speed and thrust must not be increased too quickly when accelerating the ship. An analysis of the equation for the thrust coefficient ($C_T$) reveals that high propeller thrust ($T$) and low speed through the propeller ($VA$) increases the thrust loading coefficient which may result in cavitation.
Cavitation 방지법

4. **Pitch**: Operators of ships with controllable pitch propellers must take care that propeller pitch is increased or decreased in a smooth manner

5. **Depth**: Since cavitation is a function of hydrostatic pressure, increasing hydrostatic pressure (i.e. depth) will reduce the likelihood of cavitation. Submarines are uniquely susceptible to depth effects and cavitation as the depth of the submarine affects hydrostatic pressure at the propeller blades. When operating at shallow depth, hydrostatic pressure is decreased and the propeller cavitates at lower shaft rpm and low thrust loading. As a submarines depth increases, hydrostatic pressure increases and cavitation inception is delayed. Therefore, a submarine can operate at higher speeds at deeper depths with little worry about cavitation.
Thank You !!!!