⊙ 硏究論文

The Effect of Propeller Skew and Rake on the Fluctuating Pressure

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프로펠러 스큐 및 레이크가 변동압력에 미치는 영향

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Key words : Propeller(프로펠러), Skew(스큐), Cavitation(캐비테이션), Fluctuating pressure(변동압력), Rake(레이크)

요약

프로펠러 캐비테이션은 선체진동 및 수중소음에 악영향을 끼치는 주요한 원인중의 하나로 생각되어 왔다. 그러나 근래 선박의 고속화와 프로펠러 하중의 증가로 캐비테이션이 전혀 없는 프로펠러의 설계개념 적용은 사실상 불가능하다. 고스큐 프로펠러는 기존의 프로펠러와 비교하여 수중소음과 저주파 압력펄스를 약하게 하는데 유리한 것으로 인식되고 있다. 변동압력에 대하여 프로펠러 스큐와 레이크의 영향을 조사하기 위하여 체계적인 실험을 캐비테이션 터널에서 수행하였으며 본 논문에서는 여러 가지 스큐와 레이크분포를 갖는 모형 프로펠러에 대한 캐비테이션 관찰시험과 변동압력 계측결과에 대하여 논의하고 토론하였다. 연구 결과 고스큐는 균일류 및 불균일류에서 공히 변동압력 경감에 효과가 있음이 확인되었는데 이는 아마도 날개에서의 캐비테이션 안정성에 의한 것으로 예측된다. 그러나 레이크는 날개에서의 캐비티 크기나 거동에 큰 영향을 주지 못하였으며, 변동압력이 또한 거의 같은 수준으로 나타나는 결과를 가져왔다.

1. INTRODUCTION

Propeller designer for a high powered container ship is often encountered with series of basic questions concerning the efficiency, vibration, strength and propeller erosion, and how to overcome such kind of formidable requirements. One of the solution for these problems is to give the high skew within certain limit to the propeller geometry[5,6]. The fluctuating hull pressure investigated by Yamasaki et al[10] for highly-skew propellers compared with conventional propeller showed considerable amounts of reduction in the first blade frequency compo-

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nent and indicated that the skew distribution as well as skew angle significantly affected on fluctuating pressure field. Concerning the propeller open water performance, it was found that the variation of skewness had given insignificant influence on efficiency for ahead condition, while large reduction of efficiency was shown on backing condition[5].

The effects of skew were studied in the design of container carrier in order to find the way of reducing pressure fluctuating pulses on stern hull and cavity extent on the propeller blades to prevent blade erosion. From past in experiment and operation of highly-skewed propeller for container vessel, we knew that it was necessary and important to consider propeller strength problem carefully not only in ahead condition but also in backing condition where propeller is frequently suffered from excessive load change. Four model propellers with different skew distributions have been designed and tested in the cavitation tunnel and towing tank to investigate the effects of skew in propeller performance such as efficiency, cavitation characteristics and fluctuating pressure on the hull.

To meet the requirement of high performance propeller in terms of speed and vibration, we reviewed the test results of skew series and decided to study the rake effects. Three model propellers having same skew distribution with different rakes have been designed and tested in the cavitation tunnel to assess rake effects on propeller cavitation behavior and fluctuating pressure pulse level. The second part of this paper will present the propeller rake varied design and model test result focusing on cavity behavior control near propeller tip region and pressure fluctuating pulse reduction.

2. SKEW PROPELLER DESIGN AND TEST

2.1 DESIGN

The design target is to reduce the fluctuating hull pressure level as much as possible and prevent the propeller blade surface from erosion due to cavitation while keeping the propeller efficiency as normal. From the past experiences of design it was clear that the judgement based on a single series of engineering calculation and tests would not lead to optimum design and it would not be sufficient to guide a good design selection with minimum risk. In assessing the design and calculation the systematic experimental database would be a valuable reference. It was decided to design the four propellers to investigate the skew effects on propeller performance including cavitation and fluctuating hull pressure. In order to minimize the other geometrical effects major parameters were fixed and the skew distributions were varied including total skew angle and tip skew angle with reference to existing design propeller[2]. The skew angles along the propeller radius are expressed in the 3rd degree polynomials.

Four model propellers were manufactured of water-resistant aluminum alloy. Blade tip radii and leading edges were finished by hand. The

Table 1 Main Particulars of the Skewed Model Propellers

Model Prop. No		HP284	HP285	HP261	HP289
Diameter(D)	mm	216.34			
Hub Ratio		0.2073			
Pitch Ratio	at 0.7 r/R	1.136			
Exp. Area Ratio	EAR	1.00			
Tip Skew	Degree	0.0	20.0	34.	51.
Rake	i_G	0.	0.	0.	0.
Total Skew	Degree	0.0	25.0	40.	60.
No. of Blades		6			
Material		Aluminum Alloy			
Direc. of Turning		Right Hand			

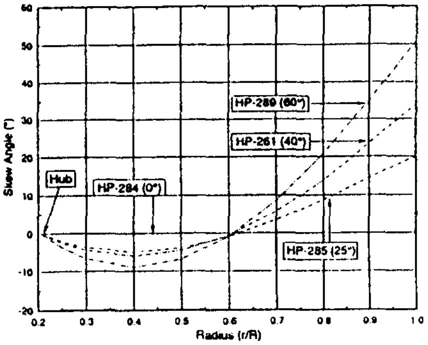


Fig. 1 Skew distributions along propeller radial direction

manufacturing accuracy of the model propeller was estimated to be 0.1mm in diameter. Table 1 lists the main particulars of the model propellers and Fig. 1 shows the skew distribution of the model propellers.

2.2 TEST

Propeller open water tests were performed in the towing tank using propeller dynamometer which is capable of measuring the thrust(T) up to 200N and torque(Q) up to 10N-m in full scale values. The propeller rotation rate(n=15) has been chosen to be sufficiently high to avoid laminar flow effects on the propeller blades and to be low enough to measure the highest propeller loading. To assure the repeatability of the test conditions propellers have been tested successively under identical circumstances. Propeller open water efficiency curves, which are expressed by loading coefficient of K_T/J^2, are represented in Fig. 2

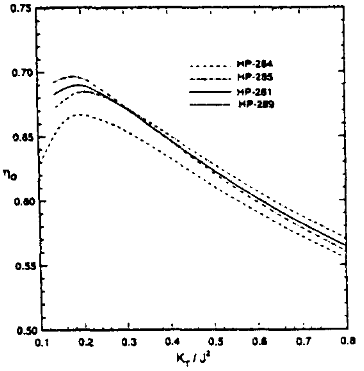


Fig. 2 Propeller open water efficiency

Cavitation tests and pressure fluctuation measurements were conducted in Hyundai maritime research institute(HMRI) cavitation tunnel. This facilities have three exchangeable test sections and a test section of 850mm by 850mm was used for this test. It can accomodate propeller models up to 300mm in diameter and rotation speed of 3500 revolutions per minute. The cavitation observation was made by naked eyes with stroboscope and photographs were taken for every condition. The right-handed propeller rotates counter clockwise when looking downstream. The blade position is indicated in degrees in direction of rotation with respect to vertical top position as zero degree.

The pressure fluctuation measurements were carried out on a flat plate located in the cavitation tunnel. The flat plate was made of bronze and reinforced to prevent the plate vibration. The measuring arrangement is shown in Fig. 3. Three miniature pressure gauges with diaphragms' diameter of 3mm(Pressure range -100kPa to 60kPa, natural frequency 20kHz in water) were fitted to flush with the surface in the flat plate. The pressure measurements were carried out simultaneously with cavitation observation in the tunnel at uniform flow and non-uniform flow. The cavitation number is defined as follows,[2]

$$\sigma_n = \frac{P_C - P_V}{0.5\rho\ n^2 D^2} \tag{1}$$

The numerator contains the pressures from ambient conditions, Pc is the static pressure at submergence depth of propeller 0.7 radius above the shaft center line and Pv is the vapor

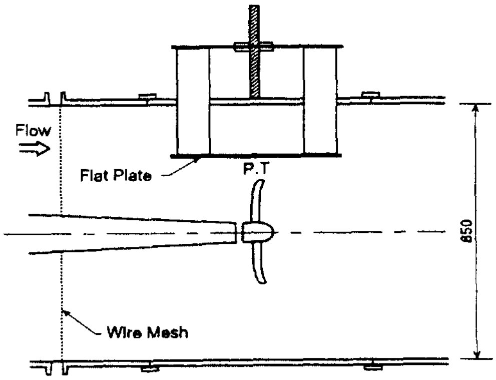


Fig. 3 Arrangement of pressure pick-ups

pressure in cavity. The denominator is a measure for the pressure created by the propeller action.

The pressure signals were fed by a sampling method via analog-digital converter. The sampling was taken for 100 revolutions of the propeller, and the harmonic analysis was performed giving 5% highest pressure amplitudes for up to the 5th order[1]. The sampling rate was determined to be sufficiently high enough for higher harmonic components corresponding to the model propeller revolution. The dissolved gas content in the tunnel was measured by oxygen-probe and maintained around 45% during the test for minimum or no cavity fluctuation.[11] The pressure signal x(t) can be expressed by Fourier expansion as follows[3].

$$X(t)=\sum_{0}^{\infty}\Delta p_i \mathrm{COS}(2\pi f_i t - a_i) \qquad (2)$$

where

ΔP_i : peak to peak amplitude

f_i : frequency

t : time

α_i : phase angle

The pressure coefficient of measured pressure amplitude of harmonic order i, which is the peak to peak values of harmonic amplitude, is defined by

$$K_{P_i}=\frac{\Delta Pi}{\rho n^2 D^2} \qquad (3)$$

The prediction of full scale pressure amplitude is based on the assumption that the pressure coefficients are the same as model and full scale.

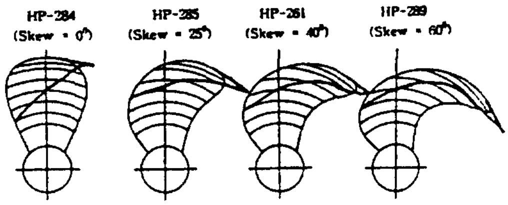
2.3 TEST RESULTS

Uniform flow condition

The cavitation tests and pressure measurements were performed in the cavitation tunnel with freely selected rate of revolution n=25, 27 and 30 revs/sec while keeping $K_T=0.3423$ and $\sigma_n=1.51$. Fig.4 shows the cavitation test results with rate of revolution n=25. It was noticed that cavity extent and behavior seem to be similar in general fashion of all 4 propellers but the tip vortex was decreased in HP261 and HP289 compared with HP284 and HP285. Near the tip region, the skew propellers seem to initiate earlier and smoother detachment of cavity than non-skewed propeller and this kind of detachment could avoid cavitation erosion in the trailing edge region. These phenomena can be found in results of elliptic and swept back foil tests conducted in cavitation tunnel[10]. According to Yamaguchi[10], the sheet cavity on the swept back foil was more stable compared to the elliptic foil and the tip vortex cavity was weaker than that of the elliptic foil. Even if the elliptic wing flow differs from propeller rotating flows, these results are interesting.

The pressure measurements of the first blade frequency are calculated in dimensionless values based on HP284 and represented in Fig. 5 which shows the skew effects. The propeller revolution shows negligible effects in uniform flow. From the observations of uniform flow test, results can be summarized as follows.

- Cavity extent is similar in uniform flow while the tip vortex was decreased in high skew
- The skew seems to initiate early and smooth detachment of cavity near the tip region



n=25 $K_T=0.3423$ $\sigma n=1.51$

Fig. 4 Cavity extent of the skew propellers in uniform flow

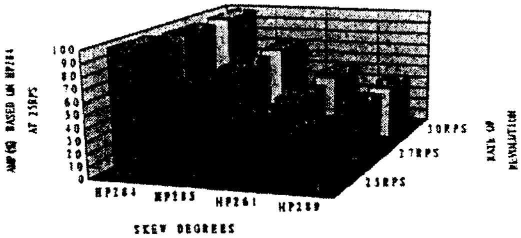


Fig. 5 Pressure amplitudes of skew propellers in uniform flow

- The fluctuating pressure values are decreased with increasing skew angle
- The propeller revolution effects were negligible in fluctuating pressure values at uniform flow

Non-uniform condition

The axial wake field at the propeller plane were reproduced by using a wire mesh screen in accordance with the nominal wake pattern measured behind the ship model at the full load draft. Fig. 6 shows the wake patterns behind simulated wake screens in the cavitation tunnel. The cavitation tests and pressure measurements were also performed at the simulated model wake field in the cavitation tunnel with freely selected rate of revolution n=23, 24 and 25 revs/sec to check propeller revolution effects and test accuracy. Cavitation behavior in this reproduced wake fields at the test condition of $K_T=0.2075$ and $\sigma_n=1.51$ is shown in Fig. 7 which is the sketch of observed mean cavity extent.

The pressure measurements results of the first blade frequency with varying rate of propeller revolution are shown in Fig. 8 in non-dimensionalized values based on HP284. The propeller revolution effects were shown to be negligible which indicates the accuracy of test set-up and measurements. The marked difference of measured pressure values indicates the effectiveness of skew and about 80% of fluctuating pressure pulse reduction was achieved at the first blade frequency in comparison with non-skewed propeller. Fig. 9 gives the harmonics of Fourier analysis of the pressure signal for pressure pick-ups directly located above the propeller. The skew was also effective in the second and third blade frequency. This situation may be due to smooth transition of cavity behavior around propeller blade and relatively

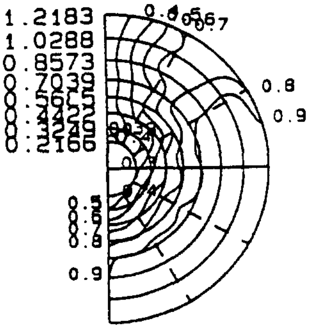
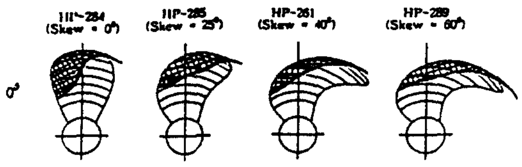


Fig. 6 Simulated wake in the cavitation tunnel



$n=25\ K_T=0.2075\ \sigma_n=1.51$

Fig. 7 Cavity extent of the skew propellers in non-uniform flow

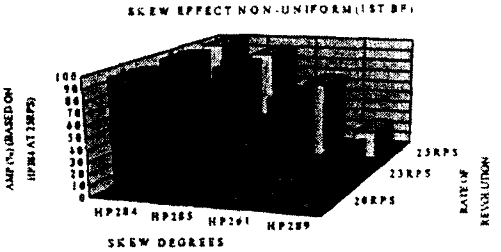


Fig. 8 Pressure amplitudes of skew propellers in non-uniform flow

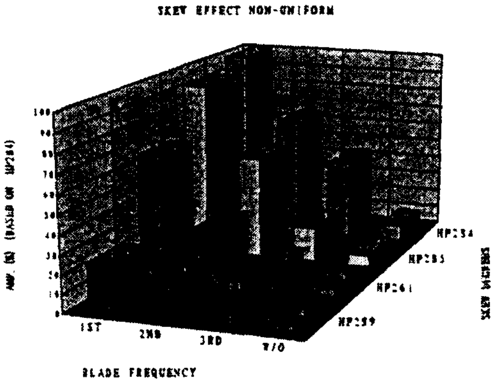


Fig. 9 Harmonic components of pressure amp. for skew propellers in non-uniform flow

stable tip vortex cavity. Hull pressure measurements and observed cavitation phenomena can be summarized as follows.

- Skew helps to stabilize cavity behavior and delays cavitation detachment from blade.
- Reduction of pressure pulse corresponding to increasing skew angle was confirmed

3. RAKE EFFECTS

The five(5) blade propeller was selected as initial study. Three model propellers having same skew distribution with different rake have been designed on the basis of same condition. To support the choice of the basic design variant, the propulsive performance was calculated by a steady and unsteady lifting surface program[7),8)]. The rake distributions applied to three propellers are shown in Fig. 10 in terms of side view of propeller geometry. The model propellers are made of water-resistance aluminum alloy to a diameter of 250mm.

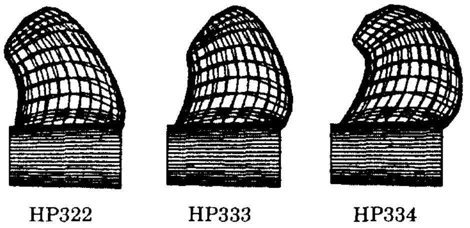
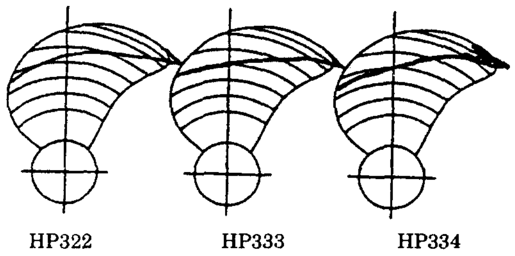


Fig.10 Rake distribution(side projection)

The aim of this study was to investigate the rake effects on propeller cavitation performance and hull pressure with reference to ordinary propeller design in limited range.



$n=25\ K_T=0.35\ \sigma_n=1.43$

Fig.11 Cavity extent of the rake propellers in uniform flow

The cavitation test results at the uniform flow of $K_T=0.35$ and $\sigma_n=1.43$ are shown in Fig. 11. The extent of cavity was observed almost same and hard to distinguish the differ-

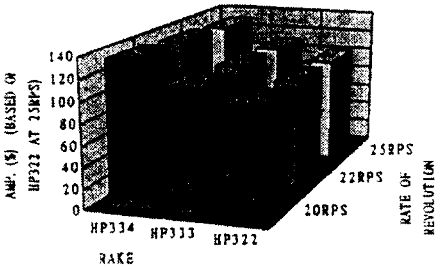
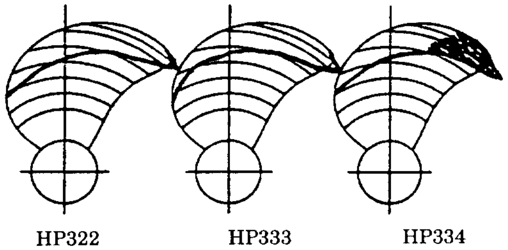


Fig.12 Amplitudes of the rake propellers in uniform flow

ences for all three(3) propellers. This trend was also found in pressure measurements indicated in Fig. 12.

Fig. 13 shows the cavitation pattern observed at the test condition of $K_T=0.212$ and $\sigma_n=1.43$ for non-uniform model wake field, and cavity extent and behavior in whole are similar and no marked difference was seen. The cavity volume and extent of HP334 seem to be a little smaller than that of HP322 and HP334, while the behavior of cavity on blade of HP334 was observed small disturbances toward trailing edges. Hull pressure measurements were simultaneously performed during the cavitation observation and are shown in Fig. 14 in which the pressure amplitude of each harmonic and the first blade frequency of without-cavitation were divided by amplitude of the first blade frequency of HP322



n=25 $K_T=0.212$ $\sigma_n=1.43$

Fig.13 Cavity extent of the rake propellers in non-uniform flow

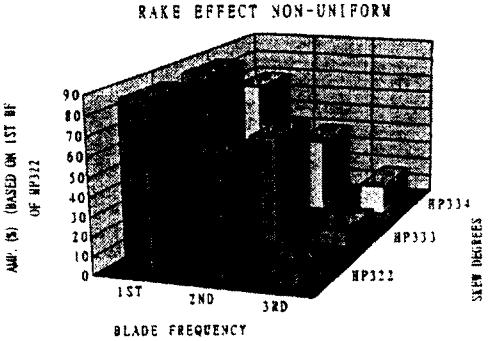


Fig.14 Pressure amplitudes of the rake propellers in non-uniform flow

The first blade frequency amplitude of tip rake propeller HP334 was twice greater than no-rake propeller HP322 and linear-rake propeller HP333, while HP333 and HP322 have similar values in without-cavitation condition in which propeller loading was the prime factor. The first blade frequency amplitude of the pressure pulses of HP334 is 10 to 15 percent less than those of HP333 and HP332, while the 3rd blade frequency amplitudes are similar or higher than those of HP333 and HP332 as in Fig. 14. The reason of higher values at higher frequency of HP334 compared with HP333 and 322 may be come from the violent cavity behavior around 40 to 70 degrees blade position.

4. CONCLUSION

Firstly the four geosim propellers except skew, which are having different skew angles and skew distributions, were designed and tested to investigate the skew effects on propeller performance. To find out another possibility of improving propeller performance, investigations were carried out about the rake. Three model propellers having same geometrical particulars including skew angle and distribution were designed and model-tested. From the theoretical and experimental investigations of above mentioned study major conclusions are summarized as follows

- Increasing skew angle helps to stabilize cavity behavior, lessens cavity collapse and generation, delays cavitation separation from blade, and may help the prevention of blade erosion
- Reduction of pressure pulse corresponding to increasing skew angle was confirmed at both the uniform and the non-uniform conditions.
- Cavity extent and behavior in different rake distributions were similar and no marked differences were observed at both the uniform and the non-uniform conditions.
- The hull pressure measurements result of the rake variant propeller have shown possibility of 10 to 15 percent reduction at the first blade frequency against the linear-rake and no-rake propeller
- Some further works on propeller rake distribution are desired theoretically and experimentally with a particular attention to strength evaluation and design technique.

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