Ocean Engineering 110 (2015) 314–324

Contents lists available at ScienceDirect

Ocean Engineering

journal homepage: www.elsevier.com/locate/oceaneng

Sea-trial verification of air-filled rubber membrane for mitigation of propeller cavitation induced hull excitation

Jeung-Hoon Lee *, Kyung-Jun Lee, Jin-Hak Kim, Boo-Ki Kim

Samsung Ship Model Basin (SSMB), Marine Research Institute Samsung Heavy Industries Science Town, Daejeon 305-380, South Korea

ARTICLE INFO

Article history:
Received 10 July 2015
Accepted 19 October 2015
Available online 9 November 2015

Keywords:
Propeller cavitation
Rubber balloon
Sea-trial
Full-scale measurement
Destructive interference

ABSTRACT

At a certain frequency, an air-bubble excited by an acoustic wave produces a destructive interference, which plays a vital role in mitigating propeller cavitation induced pressure fluctuations on ship's hulls. By taking advantage of the acoustically transparent nature of rubber material, previous effort proposed employing an inflatable air-balloon so that the destructive interference could be implemented without any energy consumption. For its verification in a full-scale ship, this paper presents sea-trial measurements with the following major contribution. To inflate the balloon to the design size, and to keep the volume constant despite draught changes, a parametric relation is proposed by a semi-analytical method incorporated with the ideal gas law. This scheme is exploited in the full-scale measurements to attain a noticeable hull vibration reduction of 65% at the exciting frequency of interest. Finally, this simple device is expected to be an inexpensive alternative for resolving vibration issues that arise from propeller cavitation.

© 2015 Elsevier Ltd. All rights reserved.

1. Introduction

During operations in a non-uniform wake, a marine propeller is subjected to cyclic occurrences of both cavitation and pressure fluctuation exciting the hull structure at the blade passing frequencies (BPFs) (Carlton, 2007). Although extensive studies on the moderation of cavitation are underway by experimental or numerical approaches (Pereira et al., 2004; Kehr and Kao, 2011; Ji et al., 2012), strict requirements on propulsion efficiency in recent years have caused further increases in cavitation. Modifying propeller geometry often leads to a less than optimal design, sacrificing ship speed or fuel efficiency. Hence, seeking an external device that can alleviate excitation forces without degrading efficiency has long been a subject of great effort for ship designers.

One possible choice to achieve this goal is the air-bubble layer technique (Ukon et al., 2000; Krüger et al., 2004; Ødegaard, 2006; Lee et al., 2014a). During the early developments (Ukon et al., 2000; Krüger et al., 2004; Ødegaard, 2006), compressed air was continuously injected through a system of nozzles located on the hull plate to create the well-known air-cushioning effect (Lee and Kim, 2007, 2009) around the stern-hull wetted surface area (Fig. 1(a)). In another variation, authors' previous work (Lee et al., 2014a) attempted a single-nozzle air-injection (Fig. 1(b)), and discovered the possibility of suppressing hull pressure fluctuations by means of an acoustic phenomenon known as destructive interference (Morse and Ingard, 1987). That is, when a pressure wave generated by a cavitating propeller strikes the injected air, whose acoustical impedance is much less than that of water, reflection occurs at the interface. At a certain frequency, designated as the frequency of destructive interference, the reflected wave is reversed with respect to the incident wave. The two waves in the total field then exactly cancel each other out, naturally leading to a pressure reduction outside the air layer. Compared to the air-carpet system comprising a multiple-nozzle array, significant energy savings in accordance with the simplification of the design were definitely possible with the single-nozzle arrangement. However, the following two issues still hindered its widespread use: (1) fatigue of the air-compressor caused by continuous usage, and (2) fouling accumulations in the protruded nozzle.

To overcome the bottlenecks, the recent work (Lee et al., 2015) was inspired by the similar acoustic impedances of rubber and water. That is, a rubber layer at the water–air interface appears to be transparent to the propagation of acoustic waves.[1] One implication is that a rubber membrane filled with air (hereinafter "the balloon") might play only the role of air packing without influencing the desired acoustic phenomenon, i.e., destructive interference. The underlying principle could

* Corresponding author. Tel.: +82 428654378; fax: +82 428654380.
E-mail address: jhope.lee@samsung.com (J.-H. Lee).

[1] It is not entirely true that a layer of rubber is acoustically transparent. How transparent it is depends on its material stiffness (shear modulus) and the thickness of the layer. The rubber layer will only be transparent if it is sufficiently thin and soft. More discussion on this topic can be found in Church (1995), Calliada et al. (1998) and Lee et al. (2014c).

http://dx.doi.org/10.1016/j.oceaneng.2015.10.030
0029-8018/© 2015 Elsevier Ltd. All rights reserved.

List of symbols (in alphabetical order)

a	Inner radius of spherical balloon [m]
a_{eq}	Equivalent radius of non-spherical balloon [m]
b	Outer radius of spherical balloon [m]
c	Longitudinal speed of sound [m/s]
f	Frequency [Hz]
f_{des}	Frequency of destructive interference [Hz]
f_{res}	Resonance frequency [Hz]
f_{target}	Target frequency [Hz]
g	Relative density, ρ_a/ρ_w
h	Relative sound speed, c_a/c_w
i	$\sqrt{-1}$
k	Wavenumber [rad/m]
λ	Static pressure [Bar]
P	Static pressure [Bar]
P_{ext}	External hydrostatic pressure [Bar]
P_{int}	Internal pressure [Bar]
p	Dynamic pressure [Pa]
p_0	Amplitude of incident plane wave [Pa]
p_r	Reflected wave [Pa]
p_{total}	Total pressure, $p_{inc}+p_r$ [Pa]
R	Specific gas constant (=287.1 J/(kg K))
r	Radial distance from the center of spherical balloon [m]
ρ	Density [kg/m^3]
T	Temperature [K]
t	Time [s]
V	Volume [m^3]
V_{design}	Designed volume of the balloon [m^3]
Ω	Rotational frequency of propeller [Hz]
ω	Angular frequency [rad/s]
Z	Number of propeller blades

Subscripts

$(\ )_a$	Air
$(\ )_{des}$	Destructive interference
$(\ )_{eq}$	Equivalent
$(\ )_{ext}$	External
$(\ )_{inc}$	Incident wave
$(\ )_{int}$	Internal
$(\ )_r$	Rubber membrane
$(\ )_{res}$	Resonance
$(\ )_w$	Seawater

make the previous efforts of air-injection unnecessary by attaching a simple device like an inflatable air-balloon to the stern-hull plate above the propeller, as shown in Fig. 1(c). We also devised a straightforward design strategy, in which the frequency of destructive interference was tuned to the target exciting frequency in order to exploit the benefit of the cancellation effect as much as possible. For implementation, the balloon size would be appropriately chosen as a key design parameter, since it significantly affects the frequency of the destructive interference in an inverse manner.

In spite of confirmative model-scale measurements in a water tunnel, authors' previous study (Lee et al., 2015) would have been much more valuable if it had included full-scale data for further verification. Current investigation presents a sea-trial verification of the balloon with an emphasis on the following unresolved issue. In discussing this item, it is worthwhile to note that the balloon in actual service is exposed to changes in external hydrostatic pressure according to changes in the ship's draught. The balloon has no choice but to expand or to shrink in volume on account of both the compressibility of air and the inherent flexibility of the rubber membrane. Then, the frequency of the destructive interference unquestionably deviates from the tuned state. To prevent this, it is necessary to characterize how much air is required to achieve and maintain the design size. In other words, a parametric relation between the air-charging and the balloon size should be defined for a suitable inflation. An analytical approach, however, would be extremely difficult, not only because the balloon is a complicated shape in itself, but also because a non-linear constitutive equation such as the Mooney–Rivlin or neo-Hookean model needs to be employed to describe the large deformation of the hyperelastic rubber material (Reddy, 2013). If the problem were tackled by experiments, there should be a greater number of test cases so that the entire operating range of the balloon could be covered. We alternatively propose a semi-analytical method that requires only a few measurements. The idea is quite simple. Whilst keeping the external pressure constant (for example, the ambient atmospheric pressure), the balloon increases in volume as it is filled with air. In such circumstances, little effort is required for experimental measurements to characterize the balloon size in terms of either the charging pressure or mass. Once this is done, the charging-size relation for other external pressures can be established by applying the ideal gas law. In this way, the number of measurements would be remarkably reduced while avoiding the use of complicated nonlinear theory.

Section 2 introduces a brief review of the theoretical background of the balloon. Beginning with a description of the test ship, Section 3 deals with the relevant balloon design and the abovementioned inflation method. Section 4 presents the sea-trial measurements, and records a noticeable hull vibration reduction of 65% at the target frequency. Finally, Section 5 gives a summary of the results and concluding remarks.

2. Brief review of theoretical background: principle and design (Lee et al., 2015)

As shown in Fig. 2, we take into account a spherical air-balloon immersed in the water. The inner and outer radii of the balloon are a and b, respectively. Thus, the membrane thickness is b–a. The ratio of acoustic pressure p to particle velocity u, defined as the acoustic impedance, remains a simple product of the medium density ρ and the sound speed c in a plane wave propagation but varies with distance in a spherical wave. Additionally, k $(=\omega/c)$ is the wavenumber, where ω $(=2\pi f)$ is the angular frequency in radians per second. Subscripts w, r, and a denote water, rubber, and air, respectively.

The acoustic modeling for propeller cavitation is often handled by a number of monopoles or, perhaps more accurately, by additional dipoles (Wijngaarden et al., 2006; Kinns and Bloor, 2004; Lee et al., 2014b; Kim et al., 2015). However, the wavelengths λ_w $(=2\pi c_w/\omega)$ at the orders of the blade rates are large enough to compare with the balloon size. For such an acoustically small object, an actual spherical-like wavefront can be approximated as a plane wave across the body's aperture (Section 6.1 of Medwin (2005)). Thus, the pressure fluctuation generated from a cavitating propeller is simplified by an incident plane wave $p_{inc}=p_0\cdot e^{i(\omega t-k_w z)}$ propagating in the positive z direction with a strength p_0. When

Download English Version:

https://daneshyari.com/en/article/1725235

Download Persian Version:

https://daneshyari.com/article/1725235

Daneshyari.com