Study on Fatigue Prediction of Composite Seaplane Float Based on The Porpoising Model Test Data

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ABSTRACT

Amphibious aircraft as an alternative mode of transportation to accelerate connections between small islands without building ground runway infrastructure. Amphibious aircraft floater is one of the important technological components that supports aircraft takeoff at sea. For that reason, the floater must be designed that is strong, effective and safe in the operation of amphibious aircraft. In this paper, the prediction method begins with selecting the heave and pitching data from the model test when float model experienced porpoising. These data is then used to calculate those coupled forces that act on the float structure which made from composite material. By knowing those forces the principal stresses that act on the structure also can be calculated. Therefore the stress time history on the float structure can be obtained. This stress time history is then applied to Palmgren – Miner formula that based on SN-Curve of the composite material to predict the life of the composite float. From this study it is found that the fatigue life of the floats is approximately 11 years with the assumptions of the seaplane experiencing takes off 4 hours daily.

Keywords: Fatigue prediction, model test, porpoising seaplane

1. INTRODUCTION

Many areas in Indonesia are difficult to reach by air transportation facilities, especially in small islands. In order to build infrastructures that are adequate and feasible airports high costs are needed. In general, compared to building an conventional airport it is much easier and cheaper to get a location to build an airport for amphibians that called amphiport. In relation to that the need for amphibious aircraft is very feasible for Indonesia's conditions.

This paper presents a method to predict fatigue failure of composite seaplane float due to the porpoising motion by applying model test data into the strength of material analysis with application of Palmgren – Minner Formula. An Seaplane N – 219A is selected as a case study which presented on Figure 1.

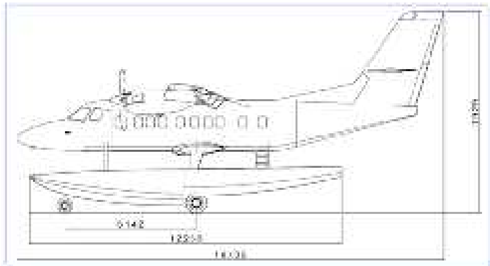

Fig 1. An Seaplane N – 219A is selected as a case study [7]

Application of this formula to the random varying loads is a continuation study of a method used in Nugroho et al [4] on predicting the fatigue life of mooring lines, Nugroho et al [8] also presented a same method to predict the fatigue life for the wooden hull structure of the outboard motor boat. Where the fatigue life of wooden hull structures of the outboard motorboat due impact loads of the porpoising can be predicted by applying cumulative - damage rules. In Mujahid et al [2] used also the Palmgren – Minner Formula to predict a fatigue life of the rudder stock due to the ship roll motion at random sea wave.

2. THEORY

The prediction method begins with selecting the heave and pitching data from the model test when float model experienced porpoising. These data is then used to calculate those coupled forces that act on the float structure which made from composite material.

The heave and pitch coupled motion of a high-speed craft without any excitation can be expressed by following equation [8],

$$\begin{bmatrix} I_3 & I_3 \\ I_5 & I_5 \end{bmatrix} \begin{bmatrix} \ddot{z} \\ \ddot{\theta} \end{bmatrix} + \begin{bmatrix} B_3 & B_3 \\ B_5 & B_5 \end{bmatrix} \begin{bmatrix} \dot{z} \\ \dot{\theta} \end{bmatrix} + \begin{bmatrix} C_3 & C_3 \\ C_5 & C_5 \end{bmatrix} \begin{bmatrix} z \\ \theta \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \end{bmatrix} \quad (1)$$

where z denotes displacement of heave, θ denotes angle of pitch. The coefficient Iij, Bij and Cij are the inertia coefficients included added mass Aij, damping coefficients and restoring force coefficients in direction i due to motion in the direction j, (i,j= 3, 5: 3 and 5 denote direction of heave and pitch motions.

This equation above is used to calculate the forces that act on the floats of the seaplane. Then the maximum principal stress can be calculated using the following formula [3];

$$\sigma_m = \frac{\sigma_x+\sigma_y}{2} \pm \sqrt{\left(\frac{\sigma_x-\sigma_y}{2}\right)^2 + \tau_x^2} \quad (2)$$

Where σ_x, σ_y, and τ_x stress in x , y direction

This stress time history is then applied to Palmgren – Miner formula that based on SN-Curve of the composite material to predict the life of the composite float.

If n_i is the number of cycles corresponding to the ith block of constant stress amplitude σ_{ai} in a sequence of m blocks, and if N_{fi} is the number of cycles to failure at σ_{ai}, then the Palmgren Miner damage rule state that failure occur when,

$$\sum_{i=1}^{m} \frac{n_i}{N_{fi}} = 1 \quad (3)$$

3. EXPERIMENTAL SET - UP

Free-floating test of floater is to know the drag of floater when running at various speed. In addition, the amount of heave at the bow and the stern should be known to see the phenomenon of pitching from the floater and when porpoising effects will begin. For this reason, a measurement system is designed and shown in Figure 3.

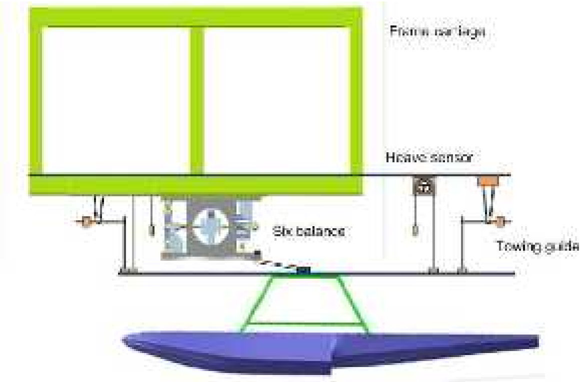

Fig. 3. Design of free-floating test of floater

In Figure 3. The floater is connected to the carriage through a lever that measuresthe resistance through a six-balance transducer. In the front and rear sides, two towing guides are installed to keep the floater moving in one direction but free at vertical axis (heave). Two heave sensors for measuring trim are used potentiometers at a certain distance on the front and rear sides. In Figure 4 shows float model test at Laboratory For Hydrodynamics Technology (BTH), BPPT, Indonesia.

Fig. 4. A float model test at Laboratory For Hydrodynamics Technology (BTH) BPPT. Indonesia.

4. RESULT AND DISCUSSION

This hull bottom of floats frequently object of the cyclic loads resulted from the porpoising motion, and this cyclic stresses can make physical damage to the composite material. When stresses although below the composite ultimate strength, the microscopic damage can accumulate with continued cycling until it develops into a delamination. Delamination is a mode of failure where a material fractures into layers. Palmgren - Miner cumulative damage rule is a simple criterion for predicting the extent of fatigue damage induced by a particular block of constant amplitude cyclic stresses, in a loading sequence consisting of various blocks of different stress amplitudes, and the rule can also be applied on the calculation for composite structures.

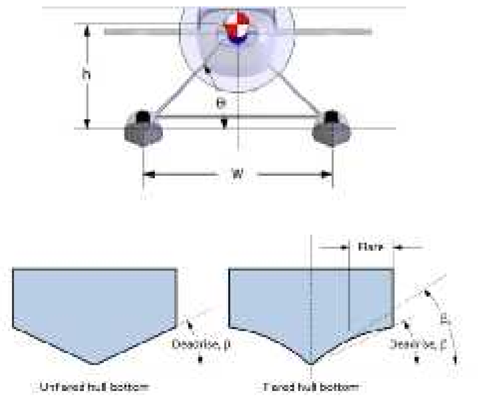

Fig. 5. Two common shapes of hull bottom of float.

To obtain stress time history, equation (2) was applied in combination of equation (1) based on data measurement of heave and pitch from the towing tank. To make the stress calculation simple a cross section type of un-flared hull bottom was selected (see Figure 5).

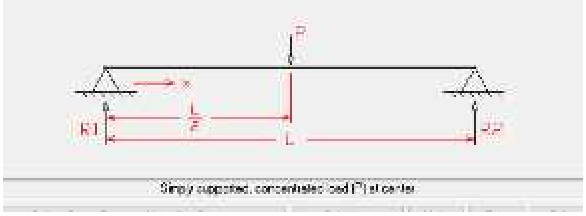

Fig. 5. Simplified Free body diagram force from heave motion.

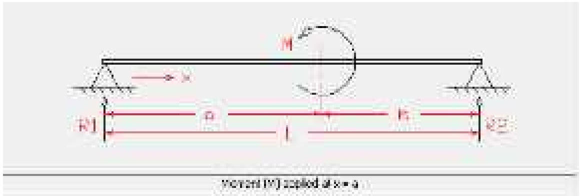

Fig. 6. Simplified Free body diagram moment from pitching motion.

The simplified free body diagram of force and moment acting on the model floater is presented on the Figure 5 and 6 respectively. Based on Euler – Bernoulli beam approximation the stresses that occurred on the floater can be calculated.

A maximum stress σ_{xh} from heave force F is calculated from equation below;

$$\sigma_m = \frac{F_h \quad L}{4} \qquad (4)$$

A maximum stress σ_{xp} from pitch moment M_p is calculated from equation below ;

$$\sigma_m = \frac{M_p \quad h}{Z} \qquad (5)$$

Where Z is section modulus of floats.

An average shear stress τ_x from heave force is calculated from equation below;

$$\tau_A = \frac{F_{he}}{A} \qquad (6)$$

Where A is section area of floats.

The time history of the stress with the marine structure safety factor of 5 [1] that working on the floats are calculated using equation (2) with assumption that σy is zero and the results presented on the Figure 7 below:

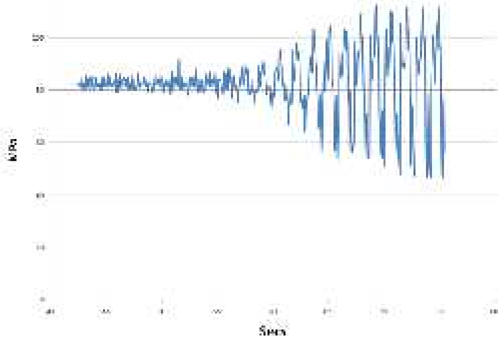

Fig. 7. Time history of principal maximum stress on the float

The fatigue life prediction can be calculated by knowing the fatigue characteristic of the material composite of the floats. The typical S-N Curve of the composite material are presented on Figure 6.

Based on the S- N curve the composite material continue to degrade (no threshold value). The stress limit of the 10^8 cycles can be approximated as a normal threshold for the composite material [10]. From this value a number of occurrence of the higher stress than this limit can be constructed.

To applied the Palgram-Miner rule using the maximum stresses are grouped in to 6 stress blocks. From these blocks of stress amplitude the life of the floats can be calculated. Table 1 shows the fraction of life for the float composite material in every stress block.

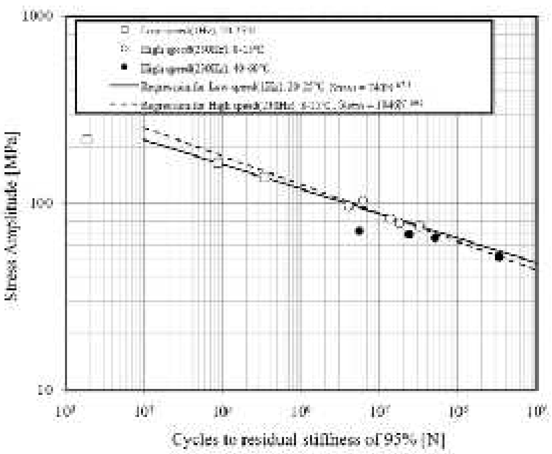

Fig. 6. S-N plot of glass fibre-epoxy laminate obtained from high-speed and low-speed fatigue tests. (Stress ratio: R = -1) [9].

Table1. The fraction of life for the float composite material in every stress block.

No Block Stress	Stress Range (Mpa)	Number of Occurences (ni)	Number of cycles to fatigue (Nf)	Fraction of Life (ni/Nf)
Block 1	61 - 70	20	1281907579	1.56E-08
Block 2	71 - 80	114	2503703240	4.55E-08
Block 3	81 - 90	267	3595014040	7.43E-08
Block 4	91 - 100	68	412990344.6	1.65E-07
Block 5	101 - 110	27	87291029.03	3.09E-07
Block 6	111 - 120	4	8280810.796	4.83E-07
			total	1.08E-06

As presented on Figure 7 the time history as the repeated loading assumed have duration of 33 seconds. The total fraction of life is 1.08 x 10-6 Hz. To make this fraction of life to be unity the 33-second cyclic load time has to be multiplied by 1/(1.08 x 10-6). This corresponds to 11.66139574 years with the assumptions of the seaplane experiencing takes off 4 hours daily.

5. CONCLUSION

From this study it is found that the fatigue life of the floats is approximately 11.5 years with the assumptions of the seaplane experiencing takes off 4 hours daily.

Finally, this simple method of calculation can be used for approximation the strength, lifetime and size of composite seaplane float structural components.

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REFERENCES

[1] American Bureau of Shipping, ”Guide for Fatigue Assesment of Offshore Structures”, April 2003 (Updated March 2018),. All rights reserved. ABS Plaza 16855 Northchase Drive Houston, TX 77060 USA

[2] A.S. Mujahid Prediction Method of Fatigue Life at The Rudder Stock”, Journal of Subsea and Offshore -Science and Engineering-, Vol.9 March 30, 2017

[3] J. P. Vidosic.,” Mechanics of Materials section of 5.2 of Marks’ Standard handbook for Mechanical Engineers, 10th edition,1996

[4] Nugroho Wibowo H, Samudro O, 2004, On The Fatigue Analysis of Mooring Lines in Irregular Wave, 4th Regional Conference of Marine Technology 2004 paper no III. A.14 - 22, on 7 & 8 September 2004 at Johor, Malaysia

[5] Nurhadi, B. Ali ,”Pengujian floater N219A di BTH – BPPT”, Poster Presentation on FGD Kajian Bersama Hasil Uji Hidrodinamika Floater Pesawat N219 AV 10 Desember 2018, BTH BPPT, Surabaya Indonesia, 2018

[6] PT. Dirgantara Indonesia,” N219 Amphibian Version”, Poster Presentation on FGD Kajian Bersama Hasil Uji Hidrodinamika

Floater Pesawat N219 AV 10 Desember 2018, BTH BPPT, Surabaya Indonesia, 2018

[7] R.C. Juvinal and K.M. Marshek," 2nd Fundamentals of Machine Component Design", Chapter 8 pp 257-302 , John Willey & Son(1991)

[8] W.H. Nugroho, Sahlan, and A.S. Mujahid," Prediksi Umur Pakai Struktur Kayu Lambung Motor Tempel di Sungai Musi karena Beban Impak dari Gerakan Porpoising", Proceeding Seminar Nasional Teori dan Aplikasi Teknologi Kelautan, 15 Desember 2011, ITS, Surabaya, Indonesia, ppII_401- 408, 2011

[9] Y. Ikeda and T. Katayama," Porpoising Oscillations of Very-High-Speed Marine Craft", Mathematical, Physical & Engineering Sciences, Philosophical Transactions of The Royal Society, series A, vol.358, no.1771, pp.1905-1915 (2000), The Royal Institution of Naval Architects, UK

[10] Y.Ueki,"High-speed bending-fatigue testing of composite materials", IOP Conf. Series: Materials Science and Engineering 388 (2018) pp 1 – 14, 2018