Estimation and Compensation of Hydrofoil Deformations During Operational Season

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One of the restrictions on the use of commercial hydrofoil crafts, which have advantages in comparison with common displacement ships, is the necessity for specialized maintenance of the foil systems. Such work usually requires complicated equipment and experienced specialists. This paper offers a new method effectively restoring of a hydrofoil after foil damage. A simplified method for conservation of the lift coefficient, which greatly influences on ship's performance, is obtained from consideration of the factors defining the lift. The technology of the process is briefly described. This method enables operators to reduce repair expenses and time drastically, which is very important during a season of operation.

Introduction

Peculiarities of the maintenance of hydrofoil crafts are caused by their specific structural elements: light-weight alloy hulls, powerful engines, hydrofoils, complex geometry propellers, inclined shaft lines, etc. In operation, hydrofoil systems can be subjected to impacts with the sea's bed and floating objects, to vibrations from shaft lines and propellers (when they are not in good working state), and to chemical and biological actions of the water environment. Foil-strut and strut-hull connections also sustain sharp wave loads in rough seas. These factors come down to the formation of dents, bends, cracks, breakage, or changes in the geometry of hydrofoil systems. The phenomenon of hydrofoil singing [3] caused by flow-induced oscillations of the foil trailing edge can also lead to the foil damage.

In this paper we consider only distortions of cross-section foil profiles and the installed incidence angles of hydrofoils. The precision of the hydrofoil system geometry is a very important issue, because of the high sensitivity of the lifting force to the profile geometry and to the interaction between fore and aft foil system [4]. These deformations can be treated by the original method given in this paper, which is based on the expression for the lift coefficient. The advantages of this method are simplicity and quickness of the repair, relative to the standard procedures requiring change of hydrofoil installation [2]. The method has been successfully applied to hydrofoil crafts, such as the Katran (Kolhida) shown in the Frontispiece, operating in the Mediterranean basin.

Estimation of Profile Deviations

The profile characteristics, namely the curvature of the mean line and the profile thickness, determine the attack angle a_0 corresponding to zero lift and the correction to this angle a_1 due to the free water surface (Figure 1). The approximate expression for the lift coefficient of an infinite span foil is given at [1]

$$C_y = dC_y/da\ (\ a_{ins} + a_0 - a_1\ )\ , \tag{1}$$

where dC_y/da is the derivative of the lift coefficient with respect to the angle of attack, and a_{ins} is the installed geometrical angle of incidence. Since the derivative remains practically constant, the change of the initial lift coefficient for the deformed cross-section is due to the difference between the current and initial attack angles da given by

$$da = da_{ins} + d\ (\ a_0 - a_1\ )\ . \tag{2}$$

The increment of the angle of incidence is found by the measurements as the difference between the actual and design values. We express the second term in (2) in terms of the distortion of the profile. The characteristic deformations of the cross-sections, which cause the change of the mean line and profile thickness, are combinations of the distortions of the upper and lower surfaces of the profile (Figure 2).

We make use of the empirical dependence for a_0 and a_1 on the relative thickness and immersion, applied at the Central Hydrofoil Design Bureau:

$$a_0 = 2\ n\ f\ /\ b\ , \tag{3}$$

$$a_1 = g\ n\ c\ /\ 2\ b\ , \tag{4}$$

where c is the foil thickness; b is the foil chord; n is the viscous correction which can be taken equal to 0.85; f is the curvature of the mean profile line; and g is the free surface correction,

$$g = exp(\ \text{-}2.5\ h\ /\ b\ )\ /\ (\ 2 - exp(\ -\ 2.5\ h\ /\ b\ )\ )\ , \tag{5}$$

where h is the foil immersion.

The second term in (2) becomes

$$d\ (\ a_0 - a_1\ ) = n\ (\ (\ dC_U + dC_L\ ) - g\ (\ dC_U - dC_L\ )\ /\ 2\ )\ /\ b\ . \tag{6}$$

The distortions dC_U and dC_L are taken with their signs: positive values (upward from nominal) correspond to the increase of the mean profile line. For deeply submerged foils, we can disregard da_1, and the simplified formula is

$$da_0 = 48.7\ (\ dC_U + dC_L\ )\ /\ b\ . \tag{7}$$

In repair processes, it is more convenient to use the dimensions given by the instruments, namely minutes for angular distortions; millimeters for deviations of profile ordinate; and meters for the chord of a foil. Then the increment of zero lift angle of the deformed cross-section is

$$da_0 = 2.9\ (\ dC_U + dC_L\ )\ /\ b\ . \tag{8}$$

The methods for finding deformations of a plate-convex profile by instruments, which are usually used for checking geometrical angle of incidence, are shown in Figure 3. Such measurements are carried out at several stations to find the local deformations.

Compensation of Profile Deformations

In order to keep the lift coefficient constant, the sum of the geometrical incidence angle and the angle of attack for zero lift must be zero. For the local character of the distribution of the deformations considered, it is inconvenient to compensate them by changing the installation of the foil system (or foil sections). In this case, it is effective to apply a correction to the deformed sections by the controllably bending the trailing edge (Figure 4).

For such corrections, not only the curvature of the mean profile line changes, but so also does the geometrical incidence angle. The values of $d'a_{ins}$ and $d'a_0$ obtained in this way have the same sign; that characteristic improves the effectiveness of the bending. Using dimensions considered above (angle in minutes and chord in meters), the desired value of the bending dh (in millimeters) of the segment profile for compensation of the change of the attack angle computed by (2) is

$$dh = 0.16\ b\ da\ . \qquad (9)$$

To bend the trailing "knife" (a massive element with welded upper and lower plating lists) the following technique can be applied (Figure 5). A line is drawn in chalk at a distance ~100 mm from the trailing edge. The flame of a burner heats a foil along the line until the metal acquires a cherry color. The length of the heated area is 0.4-0.5 m. Then fast cooling is carried out from the heated side by a water jet. Shrinkage of the metal takes place, accompanied by smooth curving of the profile (for the case shown in the picture the trailing edge comes down). The same effect is reached by imposing a welded joint on the line. In cooling, the joint pulls the metal to itself. The results of bending are checked by a template. When pouring water, light knocking of the edge through a wood gasket is carried out. The whole area requiring correction is worked up this way. If the bending is not enough, the same procedure is accomplished along a parallel line 2 shown in Figure 5.

Conclusion

Foil theory has specified the development of hydrofoil crafts. Some problems of this type of ship relate to the necessity of keeping high precision of the geometry of the foil system. Applying foil theory again, it is possible to find a fast and simple method allowing changes in the geometry, but preserving the characteristics of hydrofoil performance. The reduction of time and expenses for maintaining hydrofoil crafts makes them stronger competitors in the transportation market.

References

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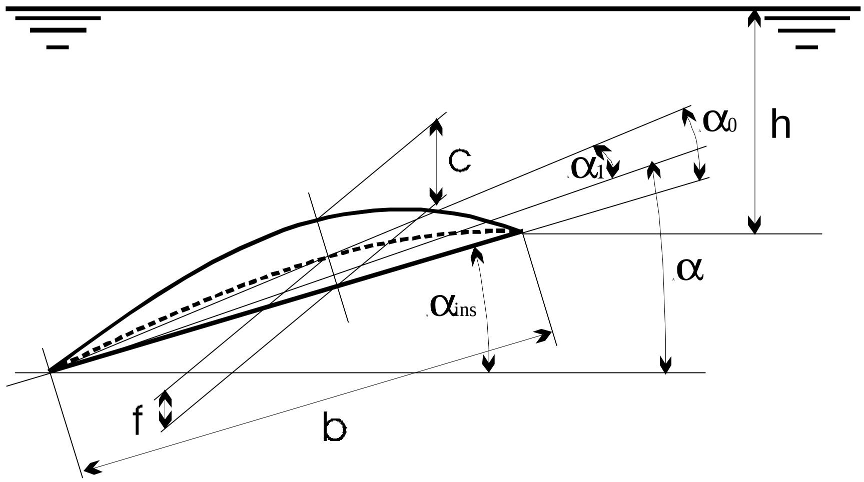

Fig. 1 Hydrofoil view

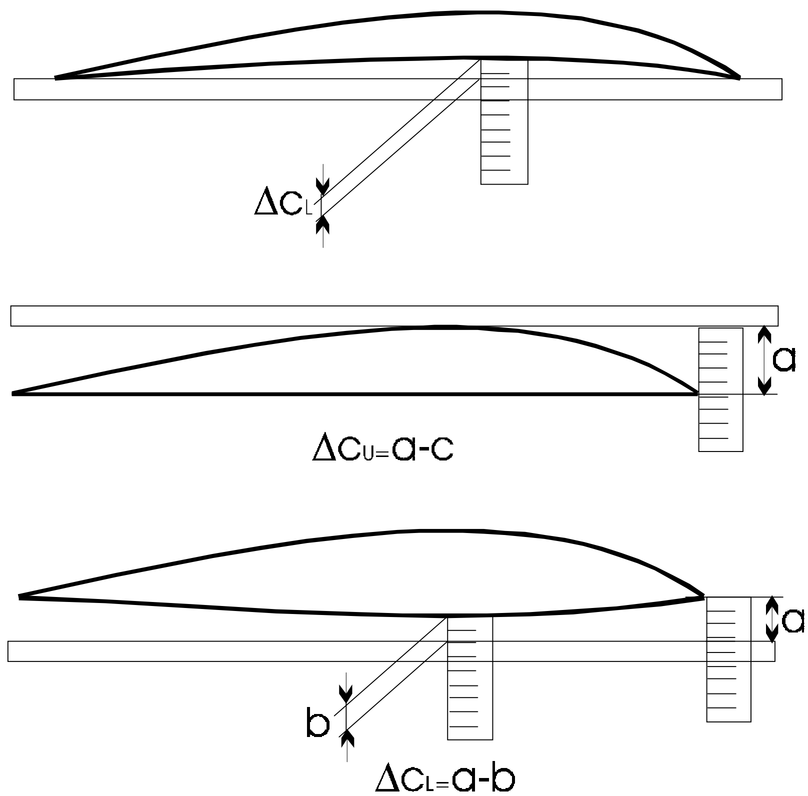

Fig. 2 Distortions of hydrofoil profiles

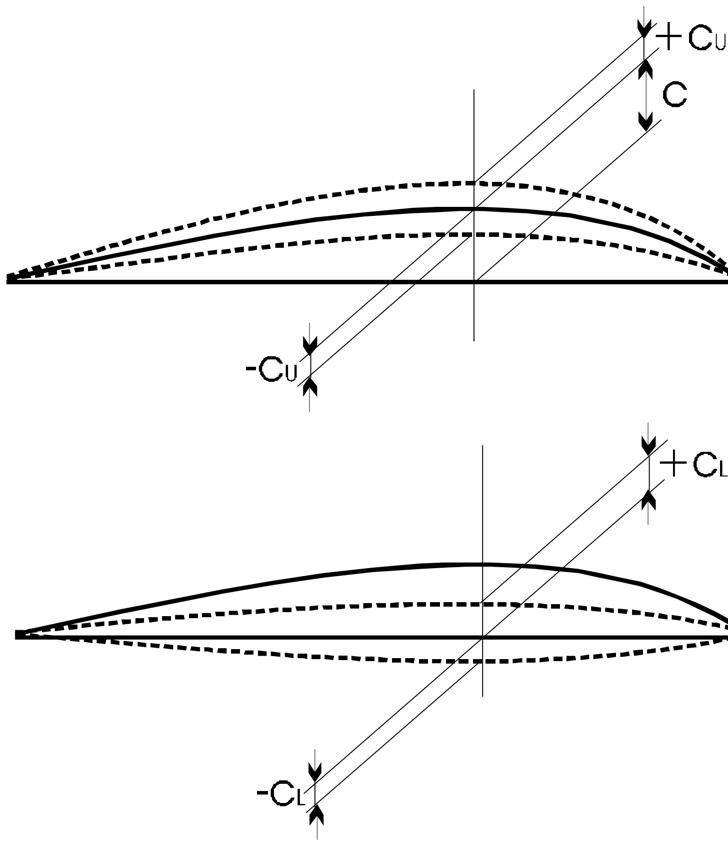

Fig. 3 Measurement technique

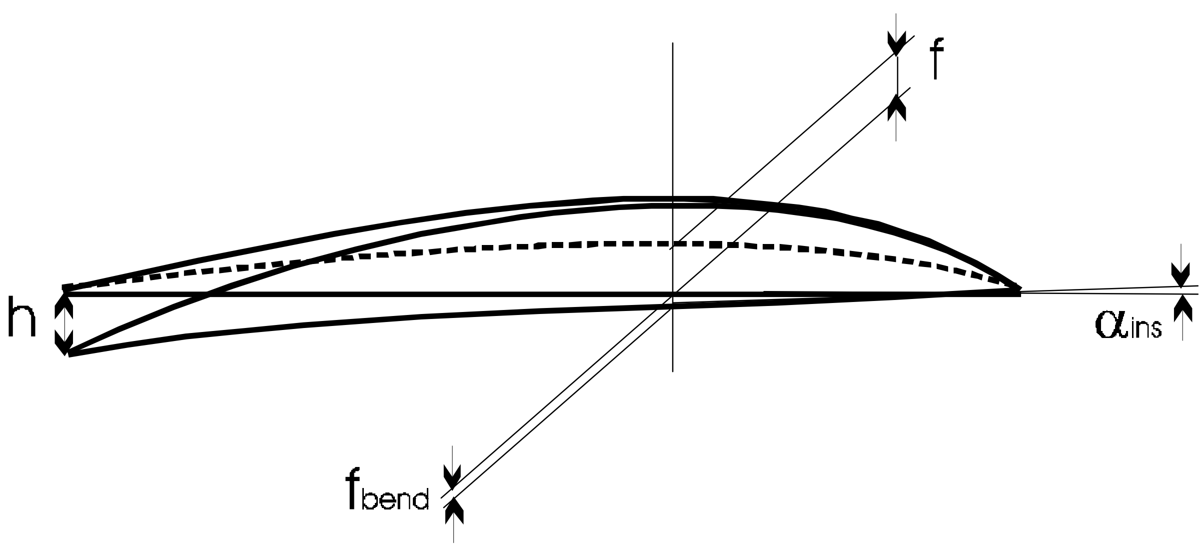

Fig. 4 Influence of bending on the attack angle

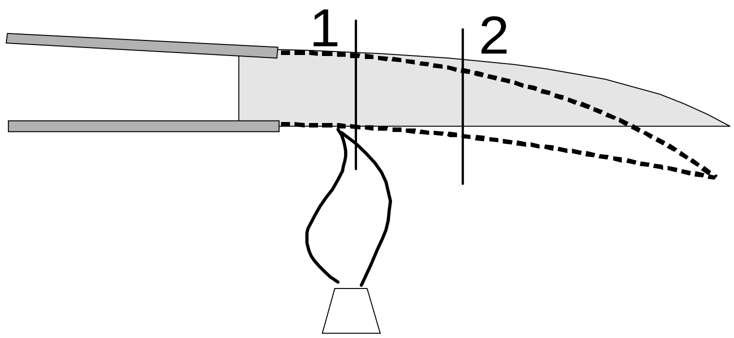

Fig. 5 Thermal bending of a trailing edge