ABSTRACT

We have developed a propulsion mechanism using a variable stiffness fin with torsional rectangular elastic plates. The stiffness of the fin was changed by the torsional angle of two rectangular elastic plates. The hardened steel bands SK (QSK plates), which have a low temperature dependence and high durability, were used as the elastic plates. The torsion at the trailing edge of the fin was also added. We evaluated the behavior of the fin, propulsion characteristics, and the flow field surrounding the fin.

KEY WORDS: Bio-inspired mechanism; aquatic propulsion mechanism; variable stiffness fin; thrust force; flow visualization

INTRODUCTION

The conventional screw propeller is widely used to propel boats and underwater vehicles. Recently, the use of a bio-inspired oscillating elastic fin has been proposed as an alternative propulsion mechanism. It is thought that the new mechanism will improve efficiency and safety, relative to the screw propeller. The proposed system resembles the caudal or pectoral fin of a fish. A number of studies have documented the development of this system for use in boats or underwater vehicles/robots (Morikawa, 1980; Nakashima, 2000; Watanabe, 2002). The optimum elasticity of a fin is not constant and changes based on swimming speed and task. However, it is very difficult to exchange fins of different stiffness while moving. To address this problem, we developed a variable-stiffness fin with a variable-effective-length spring for the propulsion of aquatic vehicles (Kobayashi, 2006; Nakabayashi, 2009 and 2010). The apparent stiffness of the spring can be changed dynamically. However, this mechanism was simplified to two rigid fins with a variable stiffness joint, more flexible variable stiffness fin was needed. Thus, we have developed a new variable stiffness fin with torsional rectangular elastic plates that provides more flexible bending of the fin. The stiffness of the fin was changed by the torsional angle of two rectangular elastic plates made of polypropylene (kobayashi, 2011 and 2012). However, polypropylene has problems of large temperature dependence and low durability. In this study, hardened steel bands (QSK plates), which have low temperature dependence and high durability, were used as the elastic plates for the variable stiffness fin. Furthermore, the torsion at the trailing edge was also added. We evaluated the behavior of the fin, propulsion characteristics, and the flow field surrounding the fin.

STRUCTURE OF PROPULSION MECHANISM

Figure 1 shows the structure of a fin with torsional rectangular elastic plates. Total length and height of the fin are 290 mm and 60mm, respectively. The fin system consists of an aluminum box, a servomotor, gear unit, and four rectangular elastic QSK plates (two middle plates: thickness = 0.15 mm width = 12.7 mm, other two plates: thickness = 0.1 mm width = 10mm). The middle of two plates is connected with rotational output shaft of gear unit driven by a servomotor. The rotational angle of the output shaft is corresponding to the torsional angle \( \phi \). The trailing edge of the middle of two plates is fixed by a plate with slits. The angle of slits is corresponding to torsional angle \( \phi \). The four rectangular elastic plates are covered with latex sheet. Principle of variable stiffness using the rectangular elastic plates is shown in Fig. 2. Rectangular elastic plates are twisted by rotational output shaft of gear unit, and its second moment of area, bending stiffness is changed by the rotational angles \( \phi \) and \( \phi \).