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Coupled acoustic–structural response of optimized ring-stiffened hull for scaled down submerged vehicle subject to underwater explosion

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ABSTRACT

One of the major problems confronted by the designer of submersibles is to minimize the weight of the pressure hull for increasing the payload of a crew and necessary equipment and to simultaneously enhance the strength of the pressure hull for withstanding hydrostatical pressure, underwater explosive loading and other environmental loading. Hence, this paper presents the optimal design of a small-scale midget submersible vehicle (MSV) pressure hull with a ring-stiffened cylinder and two hemispherical ends subjected to hydrostatic pressure, using a powerful optimization procedure combined the extended interior penalty function method (EIPF) with the Davidon-Fletcher-Powell (DFP) method. According to the above optimum design results, we built up midget submersible vehicle finite element model. Then, the coupled acoustic–structural arithmetic from the widely used calculation program of the finite element – ABAQUS, was used to simulate and analyze the transient dynamic response of a midget submersible vehicle pressure hull that experiences loading by an acoustic pressure shock wave resulting from an underwater explosion (UNDEX). The analytical results are presented which will be used in designing stiffened optimum submersible vehicle so as to enhance resistance to underwater shock damage.

1. Introduction

An important element of any submersible is the pressure hull, frequently contributing one-fourth to one-half and more of the total vehicle weight. Various pressure hull configurations are being used in small submersibles; representative examples are shown in Fig. 1. The most common types are the single sphere, the connected (intersecting) spheres, and the ring-stiffened cylinder with hemispherical end closures. Selection of the pressure hull configuration depends on a number of considerations: structural efficiency, internal and external arrangements, hydrodynamic form, complexity and cost of fabrication, and the ease with which structural details can be incorporated effectively. From a structural perspective, the predominant one is the stiffened cylinder with hemispherical heads. The stiffened cylinder generally permits superior hydrodynamic form, better internal arrangements, lighter exostructures, and lower fabrication costs. It is also less affected by initial geometric imperfections than shells with compound radii of curvature. Furthermore, to be an efficient source of buoyancy for a submersible, the pressure hull with lowest weight to buoyancy ratio (buoyancy factor) for a given depth is advantageous since the remaining weight can be applied to increase payload, propulsion or life support.

Many countries have invested tremendous capital to develop underwater vehicles for marine resources and national defense requirements. One of the major problems confronted by the designer of submersibles is to minimize the weight of the pressure hull for increasing the payload of a crew and necessary equipment and to simultaneously enhance the strength of the pressure hull for withstanding hydrostatical pressure, underwater explosive loading and other environmental loading. Hence, improving material and configuration design tend to be most important for underwater vehicle. When an explosive is detonated in water, the sudden release of chemical energy generates a high-pressure gas that markedly exceeds hydrostatic pressure. An explosion, therefore, generates shockwaves and gas bubbles. Since explosion pressure exceeds the air shockwave and action time of the resulting underwater shockwave is shorter than the action time of the air shockwave, analyzing underwater explosions is complex and difficult [1–3]. Understanding the behavior of an optimum MSV pressure hull after sustaining an underwater explosion is crucial to determining the threats of different weapons to submarine survival during war operations.

Several studies helped design a submersible stiffened pressure hull. It was observed [4] that the general instability of the stiffened cylindrical shell occurs at structural locations between bulkheads or deep frames. The buckling mode of the stiffened cylindrical shell was investigated [5] using the Rayleigh–Ritz energy method. Also, Kendrick [6] adopted the Rayleigh–Ritz energy method was used to

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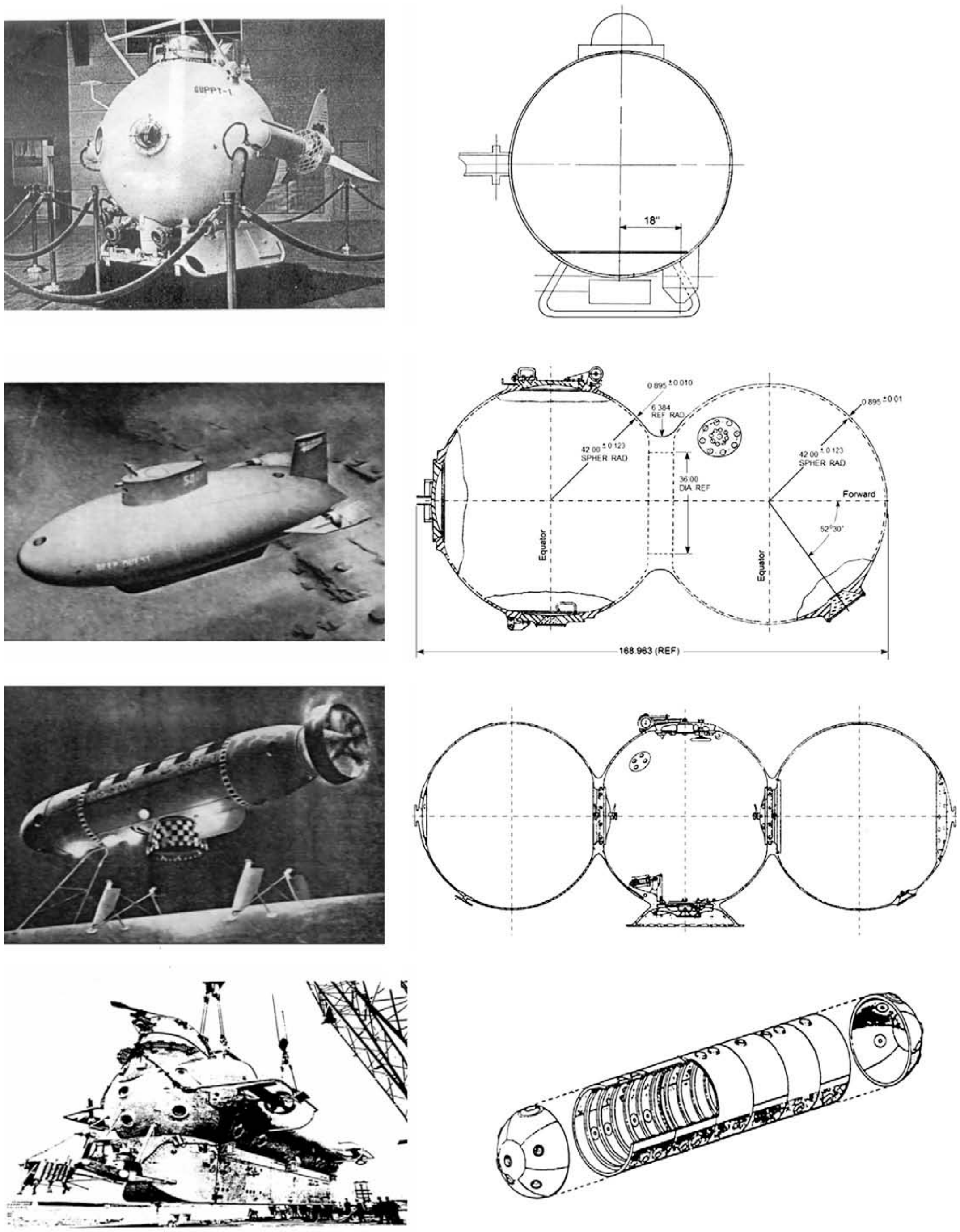

Fig. 1. Typical MSV pressure hull structures.

examine the general instability of the stiffened cylindrical shell. The study revealed that the analytical and experimental results are identical. However, the procedure must solve the third and fifth-order eigenvalue problem, which is extremely complex and inappropriate for design work. The Kendrick's formula was simplified [7] and verified using experimental results. It was also used for submarine design works. A mathematical program [8] was developed for minimum weight structural design to synthesize submersible, circular, cylindrical shells reinforced by equally spaced "T" type frames. Presented in [9] are formulae for evaluating the strength of the pressure hull. These formulae can also be utilized to minimize the weight and improve the design. Gorman and Design rules have been presented [10] for the configuration and material of pressure hull, based on three principal modes of failure, namely shell yielding, shell buckling and general instability failure. Optimal design has been considered [11] for multiple intersecting spheres in a deep-submerged pressure hull. The results indicate that the shell thickness is most important to lobar buckling strength, and that rib-ring width, rib-ring inner radius and spherical shell intersection angle are most important to rib-ring hoop strength.

Fluid–structure interaction has received much attention since the 1950s. Most studies have addressed the dynamic response of the surface, or the submerged structure of the naval vessel. Since the problems of fluid–structure interaction are complex, analytical methodologies such as separation of variables, series expansion,