Acoustics, Speech and Signal Processing (2022)
Clausius Scientific Press, Canada

DOI: 10.23977/assp.2022.020101
ISSN 2522-6827 Vol. 2 Num. 1

Study on the Development of Foreign Military Acoustic Decoys

Wei Huang[1], Xiangtao Zhao[2], Jiajing Wang[2]

[1]Postgraduate Team of Dalian Naval Academy, Dalian, Liaoning 116018, China
[2]Department of Underwater Weaponry and Chemical Defense, Dalian Naval Academy, Dalian, Liaoning, 116018, China

Keywords: Anti-torpedo, underwater acoustic countermeasure (UAC), acoustic decoy, torpedo

Abstract: The continuous progress and breakthroughs of information technology have improved the comprehensive performance of torpedoes, intensifying the competition in the arena of underwater weaponry. As a result, torpedoes have posed an increasingly greater threat to surface ships. A self-propelled acoustic decoy is by far the most effective underwater acoustic countermeasure (UAC) device for deceiving acoustic homing torpedoes and sonars. This paper reviews the development history of UAC technologies for anti-torpedo and analyzes the directions these techniques are advancing in foreign countries, focusing on the research and production of self-propelled acoustic decoys. This paper provides a useful reference for the research on torpedo and UAC technologies in China. Therefore, this paper is of great significance for advancing the research of torpedo defense in China.

1. Introduction

Torpedo attack and torpedo defense have opposite objectives, yet they promote the development of each other. As the hard kill weapons are not sufficiently mature, underwater acoustic countermeasure (UAC) is still the primary method of torpedo defense. An acoustic decoy is a typical UAC device. This paper reviews the development history of acoustic decoys for surface ships and submarines in foreign countries, aiming to identify some common laws and patterns that can aid the development of acoustic decoys in China.

2. Acoustic Decoys for Surface Ships

2.1. Towed Acoustic Decoy

For surface ships, towed acoustic decoy is one of effective methods to neutralize the incoming torpedoes. The idea is to trick the incoming torpedoes to attack the decoy thus saving the ship from destruction. Because surface ships are usually larger, more manoeuvrable and more convenient in using towing equipment compared with submarines, towed acoustic decoy is more suitable for surface ships [1]. An acoustic decoy can mimic the acoustic characteristics of a certain ship,

generate noise similar to that of the ship, and transmit the noise signal through the towed module at a certain distance from the stern of the host ship. In addition, it can also amplify and tweak the active detection signal of the incoming torpedo received by the acoustic transducer installed in the towed module before transmitting the signal, thus mimicking the ship echo [2-3].

As the first country to study UAC technology, USA began to develop the first generation Surface Ship Torpedo Defense equipment in the 1970s. The AN/SLQ-25 series acoustic decoys, the key products of USA's research in the UAC field in the 1970s and 1980s, have been widely deployed on many large and medium-sized surface ships [4]. A decoy system of this series consists of a winch and two towed modules. The two towed modules are towed by a cable in the water about 400 meters away from the stern. The distance between the two towed modules is carefully calculated so that the modules can acoustically mimic the host ship. With this arrangement, the acoustic decoy can effectively interfere with and deceive the incoming acoustic homing torpedoes. In 1985, the USA researchers made major modifications to AN/SLQ-25, aiming to remedy the deficiency that the decoy could only mimic discrete noise sources (such as the roar of the engine and the fluid cavitation noise of the propeller). After the improvement, the standard comprehensive characteristic noise of "virtual ship" generated by the decoy became more realistic, making it more difficult for torpedoes to distinguish true target from false one. The improved AN/SLQ-25A has been deployed on selected aircraft carriers and amphibious assault ships (LHA and LHD) [5]. The second generation of decoy system is equipped with a dedicated AN/SLR-24 passive torpedo alarm sonar, and the countermeasure subsystem consists of two towed modules containing AN/SLQ-25A towed acoustic decoy. The two decoys serve as backup for each other, and can emit false target echoes simultaneously to mimic a large target. The system is also equipped with an AN/SLQ-36 integrated display & control console, which integrates the alarm sonar and the circuit of acoustic decoy to classify and position the incoming torpedoes, send off alarm signal, solve the countermeasure scheme and organize the countermeasure operation.

The AN/SLQ-25 system is still being upgraded and improved. The latest models, namely AN/SLQ-25C/D use towed module TB-14 weighing 23.5kg. It is built on open hardware and software architectures, uses a modular acoustic emission & reception subsystem, and adopts the latest techniques such as conformal towed modules and towed cable array, optical fiber towing, etc, achieving higher level of flexibility and better performance. At present, almost all surface warships of the US Navy are equipped with AN/SLQ-25 system, and a large number of AN/SLQ-25 systems have been exported and deployed on foreign ships. Due to this widespread application, AN/SLQ-25 has become an indispensable "amulet" for surface ships. An American aircraft carrier is normally equipped with four sets of towed acoustic decoys, while an ordinary destroyer is only equipped with two sets. The reason is twofold. On the one hand, more towed acoustic decoys are required to mask the noise of an aircraft carrier; on the other hand, the coordinated operation of multiple acoustic decoys can deceive torpedoes with spatial scale detection capability.

One prominent feature of towed acoustic decoy is that it can be used repeatedly therefore can provide long-term continuous protection for a surface ship. It is usually used for the inner-layer torpedo defense of surface ships, and it can perform countermeasure operation from a long distance. However, this type of acoustic decoy does not have advantages when the distance is short. Moreover, once the torpedo breaks through the defense line, the towed decoy may increase the risk of the host ship being attacked by torpedoes. For this reason, the US Navy still uses rocket-assisted acoustic decoy as a supplement to towed acoustic decoy even though the AN/SLQ-25 system has reached a high level of maturity.

2.2. Rocket-Assisted Acoustic Decoy

By adding a rocket booster to a common acoustic decoy, The rocket-assisted acoustic decoy can be launched to a position farther away from the host ship, thus expanding the operation range of the acoustic decoy. Modern acoustic homing torpedoes usually adopt the active-passive composite acoustic homing mode. During the attack, the torpedo uses the passive acoustic homing mode at first to search the target ship when the distance is long. After the target is found, the torpedo switches to the active acoustic homing mode at a relatively short distance so as to accurately track the target ship and complete the final attack. As the rocket-assisted acoustic decoy can be quickly launched to a position far away from the host ship to perform underwater acoustic interference on the acoustic homing torpedo still working in the passive search mode, the incoming torpedo will be interfered and lured away before capturing the target, which greatly improves the success rate of the torpedo defense operation of the host ship [6].

In the early 1990s, the SLAT system of the French Navy was put into use. Developed jointly by France and Italy, SLAT consists of a torpedo alarm sonar and a rocket-assisted acoustic decoy subsystem. With the aid of the torpedo alarm sonar, the acoustic decoy can detect torpedo from portside and starboard of the host ship, thus adaptively cancelling the noise of the host ship, and can detect torpedoes from a distance over 10km. The decoy is launched through a dedicated launching system and deployed to a designated area with the help of the rocket. The maximum deployment distance of the decoy can reach 3,800m, and the decoy can work continuously in water for 4-8 minutes. A part from countering the salvo launched torpedoes, SLAT can also provide protection to friendly ships [7-8].

Compared with towed acoustic decoy, rocket-assisted acoustic decoy has faster reaction speed, higher flexibility in application. A large number of rocket-assisted acoustic decoys can be launched in one shot. In contrary, towed acoustic decoy is a one-time consumable device with limited operation time. These two types of decoys can complement each other very well, so the combined use of them can achieve the optimal countermeasure effect, which will undoubtedly increase the success rate of the torpedo defense operation of surface ships.

In addition to developing the SLAT system jointly with France, Italy has also developed the C310 system, which is mainly used to counter large-sized wire-guided torpedoes equipped with accurate acoustic homing system. C310 is composed of STRATOS towed sonar detection subsystem, pneumatic emission suspended acoustic jammer, and self-propelled acoustic decoy. The STRATOS towed sonar detection subsystem can actively detect incoming torpedoes in all directions at a speed of 20 kn. The minimum torpedo alarm distance is 1,500m, and the minimum detection depth is 300m. The system can locate the torpedo according to its horizontal orientation and distance, calculate the countermeasure scheme according to the predetermined order, and launch countermeasure equipment to perform countermeasure operation.

In 1985, Japan developed its own rocket-assisted acoustic decoy by modifying the AN/SQL-25 towed decoy provided by the US Navy with the rocket boosting technique developed by France. The towed acoustic decoys were deployed on the Kongo-class and Atago-class missile destroyers. As all Japanese acoustic decoys were modified versions of the US products, Japan lagged behind the US about 5 years in terms of technical level. Therefore, it can be deduced from the time Japan introduced the AN/SLQ-25 acoustic decoy that the Japanese versions of AN/SLQ-25 (the localized or improved versions of AN/SQL-25B and AN/SQL-25C) were on a par with the American products in 2006. Model A uses optical fiber components; model B incorporates a torpedo detection linear array sensor and an active echo responder, capable of detecting and luring away active acoustic homing torpedoes; and model C incorporates a countermeasure method and has a longer detection sensor.

The Japanese model 4 UAC system has been deployed on the Hyuga-class, Murakami-class, Takanami-class and Akitsuki-class surface ships. A part from installing the Japanese model 4 towed decoy at the stern, the Akitsuki-class general-purpose destroyer is equipped with a throwing type suspended noise jammer (Its launching equipment is located at the rear side of No. 1 chimney) and a 4-unit self-propelled decoy (Its launching equipment is located at the rear side of the tube-shaped torpedo launcher).

As can be seen from the application of the torpedo defense equipment on the Akitsuki-class general-purpose destroyer, the Japanese general-purpose destroyers will gradually be equipped home-made torpedo defense system in the future, and the Japanese Navy will upgrade and adapt the existing torpedo defense system for other key surface warships. Torpedo detection of Japanese surface ships can be performed by towed linear array sonar, towed decoy detection line array, hull sonar and other detection devices, and the torpedo defense task can be performed by the new Japanese torpedo defense system [9-13].

3. Acoustic Decoys for Submarines

Differing from surface ships, submarines can only use the on-board detection equipment to detect the incoming torpedoes or the torpedo launch platform and send off alarm. Therefore, the development of submarine UAC devices is constrained by spatial limitation, and a submarine can launch far less torpedo defense modules than a surface ship in a unit time period. Due to the limitations of launching facility and storage space, the types and quantities of UAC devices used by submarines are also limited, making it impossible to use multiple batches of UAC devices to counter the incoming torpedoes and the torpedo launch platform in a continuous manner. Moreover, since the UAC devices of the submarine can only be launched underwater, it is impossible to use high speed acoustic decoys such as rocket-assisted acoustic decoy [14].

UAC devices can be divided into two types: noise jammers and acoustic decoys. An acoustic decoy emits mimic radiated noise while responding to active pulse signals, thus creating a false target that lures the incoming torpedo to deviate away from the maneuvering direction of the target ship. As a development trend, the suspended acoustic decoys are gradually superseded by self-propelled ones. The combined use of these two types of UAC devices can provide effective protection to the host ship [15].

3.1. Suspended Acoustic Decoy

ADC MK2 is the most widely used submersible suspended acoustic decoy in the US Navy. It has a diameter of 76.2 mm and a length of 1003.3 mm, and is launched by an inboard launcher. ADC MK2 includes multiple series designed for different mounting platforms, which improves its adaptability to some extent. For example, ADC MK2 mod0/1 is designed for the Ohio-class strategic missile nuclear submarines, ADC MK2 mod2 is installed on the Virginia-class attack nuclear submarines, and ADC MK2 mod4 serves the Los Angeles-class attack nuclear submarines. ADC MK3 and ADC MK4 are also suspended acoustic decoys, with a caliber of 158.75 mm and a length of 2,692.4 mm and 2,743 mm, respectively. They can be launched by the ADC MK2 outboard launcher and reach the preset depth of suspension quickly. Then, they can emit mimic radiation noise and respond to active pulse signals so as to deceive the torpedo’s acoustic homing device and platform-based sonar.

The submarine UAC devices used by Israeli Navy mainly include Scutter, Substut and Torburster suspended acoustic decoys [16-17]. The Scutter acoustic decoy has a diameter of 101 mm, a length of 1,020 mm, a working frequency range of 17~85 kHz, a sound source level exceeding 180 dB, a maximum working depth of 300 m, and a working period of 10 min. To provide effective

protection against the incoming torpedoes, the submarine needs to launch five acoustic decoys in one shot. Therefore, the diameter of Subscutt is reduced to 75 mm on the premise of maintaining the performances of the Scutter acoustic decoy. This allows more acoustic decoys to be loaded in the same space, which improves the adaptability of the decoy and enhances the multi-batch countermeasure capability. With the development of a new generation of intelligent torpedoes, the anti-countermeasure capability of torpedoes is constantly strengthened. If only soft countermeasure is used, the submarine is vulnerable to the second attack of torpedoes. Therefore, the Israeli Navy signed a contract with Rafael in 2007 to start the development of Torbuster acoustic decoy, the fourth-generation UAC device with physical destruction capability, Torbuster has a diameter of 203 mm and a length of 1,000 mm, its combat module has a mass of 50 kg and a maximum working depth of 370 m. At a short distance, the decoy can detonate its combat module, and the impact pressure generated by the explosion can confuse or even damage the acoustic homing module of the torpedo, thus completely eliminating the threat of the torpedo. At present, this decoy model has been deployed on Israel's Dolphin-class conventional submarine. Each submarine is configured with 10 Torbuster acoustic decoys, which are launched through a pneumatic outboard launcher.

The submarine UAC devices used by the Italian Navy mainly include C303 and C303/S series [18-19]. The C303 series includes suspended noise jammer and acoustic decoy, both of which have a diameter of 76.2mm and a length of 1125mm. The jammer emits strong noise covering the entire frequency band of torpedo acoustic homing signal to mask the submarine radiation noise and echo signal. The decoy responds to torpedo homing signal in real time, and applies Doppler frequency shift and corresponding range change rate information in the echo to mimic a moving target. It is launched by a pneumatic outboard launcher installed outside the submarine pressure hull. Each side is equipped with a certain number of launch tube modules, which can be used to counter 6 batches of torpedoes.

The UAC device used by the France Navy is CANTO-S acoustic decoy [20]. It has a diameter of 150 mm, a length of 600 mm, a working period of 10 min, and a reaction time less than 5s. Differing from the common acoustic decoy focusing on deceiving and luring, CANTO-S gets suspended to a certain depth after being launched out of the tube, and then creates more than 100 short-lived targets by continuously updating the false echoes in all directions. The duration of each echo is sufficient to make the incoming torpedo mistake the decoy as the potential target. Consequently, the signal processing circuit of the torpedo's acoustic homing module is saturated, and the torpedo will use up its travel distance in checking the false echoes one by one. With such design and arrangement, the submarine needs less countermeasure modules to counter a batch of simultaneously launched torpedoes, and the launching system is compact enough to be easily fit to submarines. The CANTO-S acoustic decoy has been deployed on the Rubis-class and Amethyst-class attack nuclear submarines of French Navy as well as the model 214 submarine exported from Germany to Greece.

3.2. Self-Propelled Acoustic Decoy

In 2000, the U.S. Navy Maritime Command issued a competitive bidding document for the ADC MK5 acoustic decoy, officially launching the development of the next generation UAC device. It is reported that its caliber is 76.2 mm and its length is 1003.3 mm. ADC MK5 can maneuver horizontally at a speed faster than 8 kn. When it is launched by a single inboard launch tube, it can supersede the ADC MK2 acoustic decoy. When multiple ADC MK5 acoustic decoys are launched by multiple outboard launch tubes, it can supersede the ADC MK3 and ADC MK4 acoustic decoys (with the same sound source grade). ADC MK5 can work in suspension mode as a jammer to emit strong noise for signal suppression, and can also work in mobile mode to mimic the acoustic and

motion characteristics of the submarine for luring away the incoming torpedoes. Making use of the full-duplex underwater acoustic communication technology, multiple ADC MK5 acoustic decoys can be networked to perform coordinated countermeasure operation against the incoming torpedoes, which can improve the underwater defense capability of submarine, The US Navy is also upgrading the CSA MK2 outboard launcher into the CSA MK3 launcher, with the aim of promoting the application of the ADC MK5 acoustic decoy on submarines [21-23].

The Italian C303/S series was developed by upgrading the C303 acoustic decoy. The caliber was increased from 76.2 mm to 125 mm, and the length was 1,250 mm. The originally suspended acoustic decoy was upgraded into self-propelled one so as to mimic the motion characteristics of the target more realistically. Multiple decoys dispersed in space can work in a coordinated manner to deceive the incoming torpedoes, thus wasting the travel distance of the torpedoes. At present, the C303/S series is been used by the U209, U212 and U214 submarines of Germany.

In 2017, Ultra Electronics Ocean Systems of France released the Deceptor self-propelled acoustic decoy in the international market [24-25]. Deceptor has a caliber of 100 mm and a length of 1,000 mm. Its 10min working period is much longer than those of most light-weight anti-submarine torpedoes therefore can provide protection during repeated torpedo attacks. Deceptor has a mass of 60 kg and a speed of 6~8 kn, and is capable luring the torpedoes to deviate far from the host submarine. Considering that the submarines can only maneuver the decoys in a very limited depth range, this type of decoy is extremely important in torpedo defense. The maximum launching depth of 400m and the maximum launching submarine speed of 25kn indicate that this decoy has strong platform adaptability, though this cannot be verified due to the lack of order information.

4. Inspiration from the Development of Acoustic Decoys in Foreign Countries

UAC devices are important means of underwater defense for surface ships and submarines in the marine warfare, and are likely to remain so in the future. We can summarize some development laws by analyzing the development history and trends of acoustic decoys for surface ships and submarines in some foreign countries.

4.1. Further Enhance Countermeasure Properties, Continuously Improve Mobility and Expand New Functions

By improving the jamming and deceiving capabilities of traditional UAC devices, the space and frequency range of acoustic jamming against enemy sonars and torpedoes can be expanded, which enables more realistic mimicking of ship noise and echo characteristics. The basic principle of UAC devices is to trick the incoming torpedo to deviate from the escape direction of the host ship on the premise of cutting off the acoustic contact between the torpedo and the ship, thus allowing the ship or submarine to get out of the homing range of the torpedo. The final distance between the host ship and the torpedo depends on the sum of the maneuvering distances of the ship and the countermeasure module. Therefore, a part from increasing the platform speed, increasing the maneuvering speed of the UAC device can effectively extend the time to hold the torpedo, maximize the distance between the torpedo and the ship, and reduce the chance of the ship being captured again. In addition, foreign researchers are continuously improving other aspects of UAC devices besides acoustic countermeasure so as to further improve the overall countermeasure effectiveness. For example, the application of fuze induced explosion, wake simulation, explosive sound source and other techniques endows UAC devices the physical destruction capability.

4.2. Gradually Reduce the Size and Weight of UAC Devices

The development of UAC devices in the United States can be used as a typical example to illustrate the importance of miniaturization for UAC devices. At present, the American Virginia-class nuclear submarines use the 2-tube reloadable inboard launcher to launch 76.2mm ADC MK2 acoustic decoys, and use the 14-tube non-relocatable outboard launcher to launch 158.75mm ADC MK3 and ADC MK4 acoustic decoys. Because the load capacities of the launchers are small, a ship can only cope with the attack of a small number of torpedo groups. In recent 10-plus years, the United States has been promoting the development of small-sized high-power emission energy converter, high energy density battery packs and small-sized high-speed aircraft, successfully shrinking the calibers of UAC devices to 76 mm. ADC MK5 is a typical next generation UAC device of the US Navy. It is reported that the US Navy is upgrading the CSA MK2 launcher to CSA MK3 recently in order to promote the use of ADC MK5 on ships. Under the same launch tube caliber, a single tube of CSA MK3 launcher can load up to 6 ADC MK5 acoustic decoys, that is, the total number of acoustic decoys loaded by a US submarine can reach 84~96, which greatly improves the multi-batch countermeasure capability.

4.3. In-Time Adjustment on the Development Priorities on Deeper Operation and Longer Work Period

In order to ensure high platform adaptability of UAC devices, countries all over the world have carried out the design of UAC devices under the strict spatial constraints of underwater UAC launchers. Consequently, a single submarine platforms can be loaded with different types of UAC devices of the same caliber. Most foreign UAC devices have a maximum operation depth of 400m or shorter, which matches the maximum submergence depth of the host platform. The maximum working period of these devices, which is about 10 minutes, exceeds the working period of most anti-submarine weapons. Therefore, researchers across the world strive to develop acoustic decoys with better acoustic performance, faster maneuver speed and more countermeasure capabilities under spatial and mass constraints on the premise that the overall performance meets the requirements of torpedo defense.

5. Conclusion

Torpedoes will remain to be the main threat faced by surface ships and submarines for a long time to come. As UAC devices play a key role in torpedo defense, their performance is of crucial importance to the safety of surface ships and submarines. This paper reviews the development history of the UAC devices used by foreign ships and submarines, focusing on key performance indicators such as size, mass, maneuvering speed, operation depth and acoustic performance. The facts and lessons summarized in this paper can inform the design of UAC devices for Chinese warships and submarines in the aspects of size and mass, function expansion, operation mode and development direction adjustment, and provide reference for developing torpedo defense technologies and equipment in China.

References

[1] Tu L F. (2020) Dark Warfare under water (4). Weapon knowledge, 5, 81-85. DOI: 10.19437/j. cnki. 11-1470/tj.2020 (05): 17-19. (in Chinese).

[2] Liu B G, Zhang X H. (2001) Research on towed acoustic decoy against homing torpedo.. Ship Science and Technology, 6, 35-40. (In Chinese).

[3] He Q H, Hong W, Zhang W Y. (2015) Simulation of effectiveness of towed acoustic decoy against acoustic homing

torpedo//. Underwater Acoustic Credits of Acoustical Society of China2015 Proceedings of underwater Acoustic Credit year academic conference of Acoustical Society of China, 7, 302-303. (In Chinese).
[4] Guo Y P, Xiang O. (2014) Research on development of anti-torpedo underwater acoustic countermeasures technology for surface ships. Key Laboratory of Underwater Information and Control. Proceedings of 2014 Underwater Acoustic Countermeasures Technology Academic Exchange Conference, 9, 5-8. (In Chinese).
[5] Gao Y F. Foreign underwater acoustic countermeasures technology and equipment. Journal of Yancheng Institute of Technology (Natural Science Edition), 2003(02):67-69. (In Chinese).
[6] Tu L F. (2020) Dark Warfare under water, 5, Weapon knowledge, 6, 81-85. DOI: 10.19437/j. cnki. 11-1470/tj.2020 (06):17-20. (In Chinaese).
[7] Zhao L F. (2001) Anti-torpedo defense systems and technologies for surface ships and submarines. Command and control system and simulation technology, 2, 1-14. (In Chinese).
[8] Wang S, Cheng H. (2020) Command and control system and simulation technology and development trend of anti-torpedo underwater acoustic countermeasures abroad are reported. China Plant Engineering, 12, 201-202. (In Chinese).
[9] Jin Y F, Xie Z G. (2017) Technology and development trend of underwater acoustic countermeasures for surface ships abroad. Marine Electric & Electronic Technology Marine Electric & Electronic Engineering, 37,4, 71-73. DOI: 10.13632/j.meee.2017.04.018. (In Chinese).
[10] Yu T. (2018) Explain Japan maritime Self Defense Force, Modern Ships Magazine, 11, 59-64(In Chinese)
[11] He P, (2013) Summary of anti-submarine combat capability of Japan Maritime Self-Defense Force, Modern Mlitary, 7,58-61(In Chinese).
[12] Hartmut Manseck. (2007) Anti torpedo systems survey sensors and effectors. Naval Forces, 4, 92-98.
[13] Ling Yu, (2011) Japan Maritime Self-Defense Force's latest generation of versatile destroyers, Modern Weaponry, 1, 41-43(In Chinese).
[14] Li F;Shan G C, Li H. (2014) Submarine acoustic countermeasures and its development trend. Journal of Sichuan Ordnance, 35, 9, 150-152. (In Chinese).
[15] Tang B, Meng D, Fang W T. (2022) Development status and enlightenment of underwater acoustic countermeasure equipment abroad—Dive with equipment. Journal of Underwater Unmanned Systems, 30, 1, 15-22. (In Chinese).
[16] Yoshida H, Hyakudome T, Ishibashi S, et al. (2010) A Compact High Efficiency PEFC System for Underwater Plat-forms. ECS Transactions, 26, 1, 67-76. (In Chinese).
[17] Otto Kreisher. (2007) Torpedo defence against state of the art torpedoes. Naval Forces, 4, 84-88.
[18] Edward H. Lundquist. (2004) Torpedoes and Torpedo Defense Ensuring Victory Under the sea. Naval Forces, 3, 86-97.
[19] Mark Jones G. (2019) Strike group defender. LincolnLaboratory Journal, 1, 25-44.
[20] Ward, STAFFORD A. (2015) Forged in War: The Naval-Industrial Vomplex and American Submarine Construction, 1940-1961. Defense AR Journal, 4, 53-56.
[21] Atlas Elektronik. (2010) SeaSpider-Torpedo Defense Hardkill. 4, 97-99.
[22] Anon. (2017) Next Generation Countermeasure ADC MK5. Jane's Defence Weekly, 3, 30, 1-5.
[23] Deng Julong. (1982) Control Problems of Grey Systems. Systems and Control Letters, 1, 5, 288-294.
[24] Anon. Pacific, (2017) Ultra Electronics Positions New Torpedo Countermeasures for SEA 1000. Jane's De-fence Weekly, 10, 6, 1-2.
[25] Anon. (2017) Defender/Deceptor Acoustic Countermeasures. Jane's Defence Weekly, 10, 11, 1-4.