Available online at www.sciencedirect.com
ScienceDirect
Publishing Services by Elsevier
International Journal of Naval Architecture and Ocean Engineering xx (2017) 1–9
http://www.journals.elsevier.com/international-journal-of-naval-architecture-and-ocean-engineering/

Assessment on shock pressure acquisition from underwater explosion using uncertainty of measurement

Seok-Jun Moon*, Jeong-Il Kwon, Jin-Woo Park, Jung-Hoon Chung

Dept. of System Dynamics Research, Korea Institute of Machinery and Materials, Daejeon, 34103, South Korea

Received 13 December 2016; revised 14 March 2017; accepted 10 April 2017
Available online ■ ■ ■

Abstract

This study aims to verify experimentally the specifications of the data acquisition system required for the precise measurement of signals in an underwater explosion (UNDEX) experiment. The three data acquisition systems with different specifications are applied to compare their precision relatively on maximum shock pressures from UNDEX. In addition, a method of assessing the acquired signals is suggested by introducing the concept of measurement uncertainty. The underwater explosion experiments are repeated five times under same conditions, and assessment is conducted on maximum quantities acquired from underwater pressure sensors. It is confirmed that the concept of measurement uncertainty is very useful method in accrediting the measurement results of UNDEX experiments.

Keywords: Naval ship; Underwater explosion (UNDEX) experiment; Shock pressure; Data acquisition system; Uncertainty of measurement

1. Introduction

Survivability against threat weapons by the enemy is an important factor in designing and constructing naval ships. As part of such considerations, countries with advanced navy such as the United States have consistently been conducting lots of researches, such as design methods for shock hardening, response analysis methods to shock and so on. They have also been accumulating of experiment data through naval ship shock trials and shock tests for shipboard equipment. In Korea, various research studies – such as study on shock response analysis of ship structure by underwater explosion, application research on actual vessels through the development of the relevant programs and introduction/utilization of commercial programs, and shock withstand interpretation and performance test evaluation of equipment and mounting devices – are actively being conducted by Agency for Defense Development (http://www.add.re.kr) and Korea Institute of Machinery and Materials (http://www.kimm.re.kr). The relevant core technologies in this field are also being secured in a continuous manner through such efforts (Korean Register, 2014).

Ship shock trial may be conducted to check comprehensive shock withstand performance for naval vessels with all equipment under complete construction. The navy in some advanced countries require ship shock trials for a guide ship of equivalent class in principle. Ship shock trial is a necessary process for verifying the shock reinforcement measures applied to the target ship and equivalent-class ships, confirming the validity of the applied standards and criteria, drawing improvement points for follow-up of the same class with equivalent quality, and establishing the basis for setting the shock reinforcement requirements for future vessels (Mair and Reese, 1999). In addition, it is necessary to measure various signals such as pressure, acceleration, etc. as data for setting the standards for future designs and constructions as well as other engineering works, and these signals are

* Corresponding author. Korea Institute of Machinery and Materials, 156 Gajeongbuk-Ro, Yuseong-Gu, Daejeon, 34103, South Korea. Fax: +82 42 868 7418.
E-mail address: sjmoon@kimm.re.kr (S.-J. Moon).
Peer review under responsibility of Society of Naval Architects of Korea.

http://dx.doi.org/10.1016/j.ijnaoe.2017.04.002

evaluated as meaningful resources that can be used for analysis of shock response results. Park et al. developed a measurement equipment system for acquiring the shock pressure on the hull from underwater explosion and the response to shock from the hull and its equipment in order to utilize it on the ship shock trial of mine sweeping hunter (Park et al., 2003a; Park et al., 2003b).

Since ship shock trial requires a lot of budget, studies using small-sized model ships are being conducted. Chen et al. (2009) have experimentally investigated the dynamic response of scaled ship model using rubber sandwich with the square honeycomb core coatings subjected to underwater explosion. Wang et al. (2014) have performed experimental tests and numerical analyses in order to investigate the transient dynamics and failure mode of a ship-type box structure (STBS) subjected to non-contact, near-field underwater explosion (UNDEX). The UNDEX experiments are conducted by setting small explosive charge under the floating STBS directly. Kwon et al. conducted a research for performing an underwater explosion trial for small-sized model ships, measuring the response to shock from the model ship, and comparing the result with the M&S (modeling & simulation) results (Kwon et al., 2015; Kwon et al., 2016).

In general, input to the vessel on the underwater explosion experiment is the shock pressure that occurs due to the explosive, and output is the structural response by the vessel (acceleration, velocity, deformation, etc.). Therefore, it is extremely important to measure accurately the shock pressure generated by the explosive. This study aims to verify experimentally the specifications of the data acquisition system (DAQ system) required for the precise measurement of signals in an underwater explosion experiment. The three data acquisition systems with different specifications are applied to compare their precision relatively. In addition, a method of assessing the acquired signals is suggested by introducing the concept of measurement uncertainty (JCGM, 2008; ISO, 2011). The underwater explosion experiments are repeated five times under same conditions, and assessment is conducted on maximum quantities acquired from underwater pressure sensors.

2. Data acquisition system

In order to evaluate the effects of Analog-Digital Converter (ADC) resolution and sampling rate of the data acquisition system (DAQ system) on the measurement results, three DAQ systems were selected. Products of the same manufacturer (National Instruments, NI) were chosen to minimize the effects of the unique characteristics of the DAQ system. The models and major specifications of the three DAQ systems are shown in Table 1.

System No. 1, which has 24-bit ADC resolution, allows 51,200 samplings per second, whereas system No. 2, which has 24-bit ADC resolution, allows 204,800 samplings per second. Thus, system No. 2 has four times' higher sampling rate capacity than that of system No. 1. System No. 3, which has 10-bit resolution, allows 12,500,000 samplings per second.

Table 1
Data acquisition systems.

	System No. 1	System No. 2	System No. 3
Model Name	NI 9234[a]	NI-PXIe-4497[b]	NI PXIe-5160[c]
Sampling Rate	51.2 kS/s	204.8 kS/s	12.5 MS/s
ADC Resolution	24-bit	24-bit	10-bit

[a] Data Sheet NI 9234 (NI, 2016a).
[b] NI 449x Specification (NI, 2016c).
[c] Device Specification NI PXIe-5160 (NI, 2016b).

While the ADC resolution is smaller than others, the sampling rate is much huge over 50 times. Each DAQ system was connected with a computer to collect and save the data.

The sensor used for this experimental research is underwater pressure sensor of PCB (http://www.pcb.com). It is a sensor for measuring shock pressure generated by underwater explosion, and its model name is W138A10 (PCB Piezotronics, 2016). W138A10 is an ICP-type sensor that produces output within ±5 V, and its maximum measurement pressure is 68,950 kPa. The sensitivity of the sensor is 0.073 mV/kPa, and the resolution of the sensor itself is 0.14 kPa (=0.010 mV). The resonant frequency of the sensor itself is known to be more than 1000 kHz, and the rise time is less than 1.5 μs.

The output resolution of the sensor can be expressed by Eq. (1) below.

$$(Max.\ output - Min.\ output)/2^{bit\ \ No.} \quad (1)$$

Thus, a DAQ system with 10-bit resolution has output resolution of (10 V)/2^{10} = 9.77 mV. On the other hand, one with 24-bit resolution has output resolution of (10 V)/2^{24} = 0.60 μV. Therefore, DAQ system No. 3 can secure a precision of 16,000 times or more as compared with the system No. 1. In order to utilize fully the resolution of the sensor, it can be assumed that a DAQ system with a resolution 20-bit or more from (10 V)/2^{x} = 0.010 mV would be appropriate.

In order to meet the rise time of the sensor, the sampling rate must be equal to or greater than (1/rise time). Therefore, it can be predicted that the sampling rate should be 700,000 or more per second. Assuming that more than 20 points per cycle are required in order to clearly represent the signal waveform measured in the time domain, the frequency of the waveform that can be measured in each system can be expected to be around 1/20 of the sampling rate. Therefore, the system No. 3 can be observed up to the frequency of 625 kHz in the time domain. As such, if we examine only the sensor side, the ADC resolution specification of systems No. 1 and No. 2 are assessed to be satisfactory, but the sampling rate is estimated to be insufficient. On the other hand the system No. 3 is evaluated to have unsatisfactory ADC resolution.

3. Underwater explosion experiment and measurement result

As shown in Fig. 1, an underwater explosion experiment was conducted in a water tank with diameter of 22 m and