

Far-field Measurement Program to Extend our NUCLEUS Source Modeling Capabilities



Introduction

The ability to accurately model the output pressure wave-field from a seismic source array is a key requirement in the planning and execution of marine seismic acquisition and processing. The most common applications include source array design, analysis of the effects of gun drop-outs, and signature processing. In addition, firing time delay- and depth stability- analyses are occasionally performed. In survey design, the directivity-dependent signatures from source modeling are used as input to seismic modeling algorithms.

NUCLEUS has been the industry standard for source signature modeling for more than 15 years. The software package is developed continuously and extended with new gun types and increased depth and volume ranges. Since its introduction in 1988, the NUCLEUS modeling has been calibrated and verified against real far-field measurements. In total, more than 20,000 signatures from single air guns, clusters and arrays have been measured by SERES (1985 - 1994), and later by PGS. In addition to the far-field measurements, a large set of laboratory near-field trials have also been conducted to gain an understanding of the physics of bubbles generated by air guns.

In July 2006 PGS conducted a new series of far-field signature measurements of single air guns and two-gun clusters in cooperation with the main vendors of marine seismic air guns; Bolt Technology Corporation and Sercel. The main objective of this project was to perform measurements of new guns for NUCLEUS source signature modelling calibrations. A range of guns was tested, including the new Annular Port Gun (APG) from Bolt Technology, the Mini G. GUN, the Mini GI GUN, and the 380 cu.in. G. GUN, all from Sercel.

Summary

In July 2006 PGS conducted a new series of far-field signature measurements of single air guns and two-gun clusters in cooperation with the main vendors of marine seismic air guns; Bolt Technology Corporation and Sercel. The main objective of this project was to perform measurements of new guns for NUCLEUS source modelling calibrations.

A range of guns were tested, including the new Annular Port Gun (APG) from Bolt Technology, the Mini G. GUN, the Mini GI GUN, and the 380 cu.in. G. GUN, all from Sercel. In addition to measurements of the new air guns, the 150 cu.in. Bolt 1900LLXT and G. GUNS (already included in NUCLEUS) were re-tested, to confirm previous measurements, and to provide a set of reference signatures for future tests.

Based on the measurements from this test the NUCLEUS source modeling has already been extended to include new guns such as the Bolt APG and Sercel Mini G. GUNS. This new version of the software will be available to users early 2007.

In total, more than 2000 shots were recorded for different gun volumes and depths. The test was performed in Salhusfjorden, north of Bergen on the Norwegian west coast, onboard the research vessel Håkon Mosby (Figure 1), owned by the University of Bergen.

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Introduction

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Figure 1: The research vessel *Håkon Mosby*, which is owned by the University of Bergen and operated by the Institute of Marine Research.

The test site was carefully selected to provide optimal conditions for the measurements. Located inside a fjord, it was well protected against bad weather and high waves. The water depth of more than 500 m made it possible to record a signature of sufficient length to be uncontaminated by water bottom reflections, even with a deeply deployed far-field hydrophone.

The PGS personnel and vessel crew were joined by personnel from both Bolt Technology and Sercel in the operations. In addition to measurements of the new air guns, 150 cu.in. Bolt 1900LLXT and G. GUNS (already included in NUCLEUS, and in use by PGS) were re-tested, to confirm previous measurements and to provide a set of reference signatures for future tests. Based on the measurements from this test, the NUCLEUS source modelling has already been extended to include new guns such as the Bolt APG and Sercel Mini G. GUNS. This new version of the software will be available to users early in 2007. As an example, a comparison of the modelled and measured signature for a 40 cu.in Mini G. GUN can be seen in Figure 2.

Test Description

During the tests each airgun or airgun cluster was hung from the ship's cranes, approximately 5-8 m out from the ship's side. Two cranes were normally used, with one gun or gun cluster hanging from each crane, shooting in flip-flop mode. These two cranes were approximately 10 m apart, with the far-field hydrophone deployed in between, at a depth of 170 m. For each combination of chamber volume, pressure and depth, the guns were fired 25 times to ensure that a

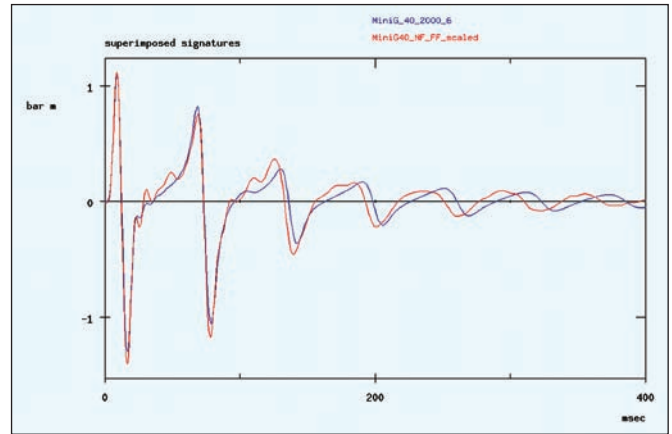


Figure 2: A comparison between the measured and modeled signatures for a 40 cu.in. Mini G. GUN at 6 m depth and a chamber pressure of 2000 psi.



Figure 3: A 2-gun Bolt Annular Port Gun cluster hanging from a gun frame, with the near-field hydrophone and pressure transducer mounted.

stable signature was recorded. The guns were deployed from a special gun frame that allowed accurate positioning of the near-field hydrophone, and also allowed the installation of a pressure transducer in the airline close to the gun (see Figure 3). The shots were typically fired with a 20 second shot interval to simulate a realistic acquisition scenario. For the deepest configurations this was increased to 30 seconds to allow the bubbles from the previous shot to rise to the surface before a new shot was fired (see Figure 4).

Throughout the measurements, the near- and far-field traces were displayed "online" using the PGS geophysical acquisition system (gAS). Any gross errors, such as electrical leakage, were detected using these displays. Immediately after the completion of each test, the SEG-D file was transferred to a laptop together with pressure readings for every shot. These data were loaded into the Viper data QC system, and displayed both in the time and frequency domain

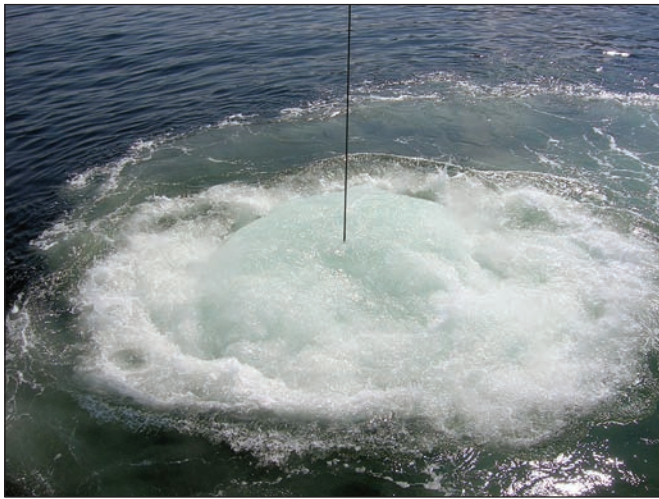


Figure 4: Air bubble rising to the surface during field testing.

to check that the recorded data were of good quality. The spectra were also monitored to check that the notches agreed with the set gun depth for each test. During the tests, the temperature, salinity and the velocity of sound in the water column from the surface to the depth of the far-field hydrophone was measured several times. The velocity was very stable, with a slight increase in the velocity near the surface towards the end of the project. The mean velocity from the surface to the depth of the far-field hydrophone was 1487 m/s, whereas the mean velocity from the surface to the depth of gun was 1493 m/s, increasing to 1495 m/s towards the end of the project, due to rising water temperature. In addition, the atmospheric pressure and the wave height were continuously measured and recorded during the project.

Sources and Range of Parameters Tested

The following single gun and cluster combinations were included in the tests:

Air guns	Chambers (cu.in.)	Second chamber (cu.in.)
Mini G. GUN (Sercel)	12, 20, 24, 40, 60	
Mini GI GUN (Sercel)	Generators: 15, 20, 30	Injectors: 15, 20, 30
G. GUN (Sercel)	150, 380, 2x380	
1900LLXT (Bolt)	40, 90, 150, 250	
APG (Bolt)	50, 100, 200, 300, 2x300	

The Mini G. and Mini GI GUNS were tested at 1.5 and 3 m depth, and at 2000 and 2500 psi. The other guns were tested at 3, 6 and 9 m depth at 2000 psi, and at 6 m depth at 2500 psi. The guns listed above are currently being added to the list of 18 different gun makes and models already available in the latest version of the NUCLEUS software. Graphs presenting peak amplitude, peak-to-bubble ratio, and bubble period, as functions of gun volume can be seen in Figures 5 to 7, respectively. The results correspond well with experimental and theoretical findings presented in (Vaage et al., 1983), and

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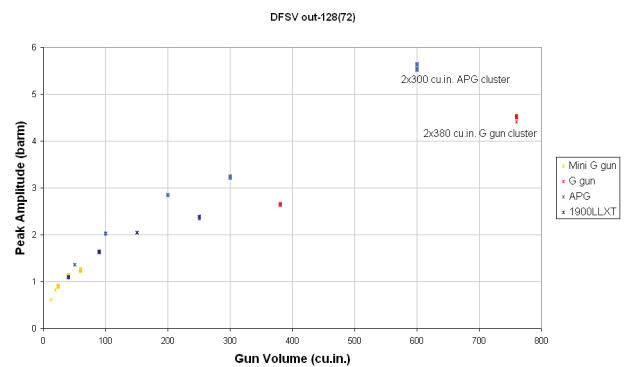
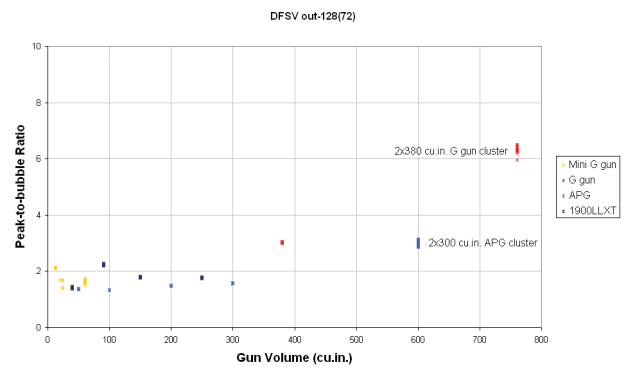


Figure 5: Peak amplitude vs. chamber volume for different gun types.



6: Peak-to-bubble ratio vs. chamber volume for different gun types.

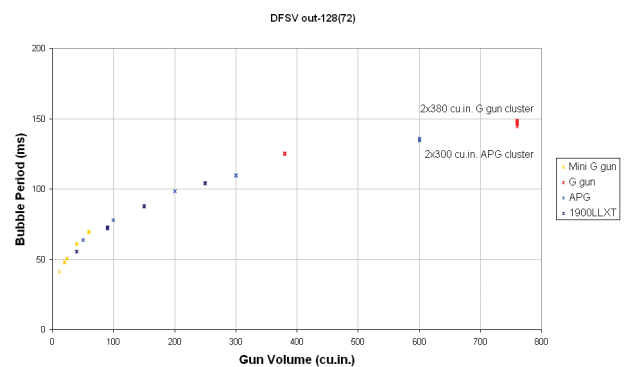


Figure 7: Bubble period vs. chamber volume for different test gun types.

Sources and Range of Parameters Tested

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the references therein. For the cluster configurations, the separation between the guns was 1 m for both Annular Port Guns (Bolt) and the G. GUNS (Sercel). The APG guns were mounted as an inline cluster, and the G. GUNS as a parallel cluster.

Source Modeling Research and Development

The source signature measurement program is part of an ongoing effort within the Geoscience & Engineering division in PGS to extend the capabilities of the NUCLEUS marine source modeling application. The sophisticated modeling algorithms that are implemented in the software have evolved since the pioneering work of Ziolkowski (1970), and incorporate interaction and thermodynamic effects, in addition to the acquisition system responses. The current research includes, amongst other activities, a close cooperation with leading university researchers on developing the theory of bubble interaction in clusters. Significant efforts are also being currently invested in the development of a new generation of the NUCLEUS software application. These new developments are aimed at significantly improving user efficiency by allowing automation of many source modeling related tasks and procedures. As described in a previous edition of TechLink (Vol. 6, No. 10, September 2006), the NUCLEUS source signature modeling has also recently been implemented as a key element in PGS's new Real-Time Source Signature Estimation, built within the onboard Viper data QC system.

The Link to Seismic Modeling and Survey Design

A key capacity of the NUCLEUS software suite is the integration of source signature modeling, with state-of-the-art seismic modeling algorithms, for application within 3D survey design. This unique feature allows the geophysicist to include realistic source directivity effects into modeling studies. The algorithms available include 1D recursive reflectivity modeling, which is an ideal method for addressing the full wave-field interplay between signal and noise upon recorded gathers. It is regularly used for amplitude-based studies such as AVO modeling, fluid substitution and converted wave studies. In addition, the source signature modeling is also integrated with several ray-tracing algorithms and applications, including NORSAR-2D and NORSAR-3D. This means that it is possible to extend the capabilities of these modules beyond kinematic illumination analyses in complex Earth models. It is also possible to combine the effects of source and receiver array directivity with attributes from the dynamic raytracing, such as reflection and transmission losses, and absorption and geometrical spreading, when generating synthetic data. Finally, it is also possible by the use of the visco-elastic finite difference module to generate very realistic synthetic data that includes all effects of the full wave-field in complex 2D and 3D models, combined with the directivity-dependent effects of the source and receiver array.

References

Ziolkowski, A., 1970. A method for calculating the output pressure from an airgun, *Geophys. J.R. Astr. Soc.*, 21, 137-161.

Vaage, S., Haugland, K., and Utheim, T., 1983. Signatures from single airguns, *Geophysical Prospecting*, 31, 87-97.

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