On the quality control of Datagun* arrays

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In recent years a considerable interest has been shown by the oil exploration industry in the problem of the quality control of airgun array performance. This is because the acquisition of high-quality seismic data is largely determined by the performance of the seismic source. In this paper we demonstrate that the near field pressure signature radiated by each individual airgun forming the Datagun array can be recorded accurately whilst carrying out production shooting. One important feature of the Datagun array monitoring system is that not only is the near field pressure signature of each gun monitored continuously but also its depth.

Interaction Between Airguns
Before we discuss the proposed monitoring system, we give a very brief review of the concept of interaction between airguns. It is hoped that this will help to clear any confusion that there might be. We assume that the only viable theory is that given by Safar (1976a).

Consider two air bubbles which are produced by two identical airguns placed at the same depth and separated by a distance $D$. When only one airgun is fired, the effective pressure acting on the air bubble is equal to the pressure exerted by the surrounding water and it is given by the product of the air bubble acoustic radiation impedance $Z$, and its volume velocity $V$ (Kinsler and Frey 1962). However, when the two airguns are fired simultaneously the pressure field produced by one air bubble will exert a force on the other air bubble and therefore mutual interaction is said to occur between the two air bubbles. The effective pressure acting on each air bubble then consists of two parts, one exerted by the surrounding water and the other exerted by the other air bubble, and it is given by the product of each air bubble volume velocity and the mutual radiation impedance $Z_{12}$. This means that because of interaction the effective radiation impedance of each air bubble is given by $Z_{1} + Z_{12}$.

Therefore, if we assume that the air bubble produced by an airgun is a slightly non-linear narrow band system, it can be shown (Safar 1976a) that the radiation damping coefficient $\alpha'$ and the period $T'$ of one air bubble when interacting with another identical air bubble are given by:

$$\alpha' = \alpha [1 + \sin(kD)/(kD)][(1 + a_{o}/D)]$$

$$T' = T (1 + a_{o}/D)^{1/2}$$

where $T$, $\alpha$ and $a_{o}$ are the period, the radiation damping coefficient and the equilibrium radius of one air bubble in the absence of interaction and $k$ is the wavenumber. The radiation damping coefficient $\alpha$ is given by the ratio of the acoustic radiation resistance to twice the acoustic radiation mass. We see from (1) and (2) that the effect of interaction between two identical air bubbles is to increase the air bubble radiation damping coefficient and period.

It can be deduced from (1) that the effect of interaction on the air bubble radiation damping coefficient is negligible only if the spacing between the two airguns is considerably greater than the wavelength. In other words, when the spacing between the airguns is considerably less than the wavelength, then the air bubble radiation damping coefficient almost doubles.

The air bubble damping coefficient is given by the sum of the radiation damping coefficient and the damping coefficient due to heat losses. Since the radiation damping coefficient is considerably smaller than that due to heat losses, it follows therefore that the effect of interaction on the air bubble effective damping coefficient is negligible even if the air bubble spacing is less than the wavelength (it also follows, of course, that this conclusion is no longer valid when one takes into account the damping due to heat losses). The effect of interaction on the air bubble damping coefficient is significant only when there are at least 10 small identical airguns with spacing considerably less than the wavelength. This means that in the case of conventional airgun arrays the effect of interaction on the air bubble damping coefficient can be neglected.

It follows from the above discussion that in conventional airgun arrays only the air bubble period is influenced by interaction. Using equation (2) Safar (1976a) proposed that the effect of interaction between two airguns can be neglected if the spacing between the two airguns is about 10 times the air bubble equilibrium radius. This in fact has recently been confirmed experimentally by Vaage, Ursin and Haugland (1982) who carried out a large number of measurements and showed that the criterion proposed by Safar (1976a) differs very slightly from the empirical criterion obtained by Nooteboom (1978). They also showed that Safar's criterion resulted in an increase of the air bubble period and a decrease of the initial pulse amplitude of about 3%.

Datagun Arrays
The main feature of the arrays is that they are distance

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and amplitude weighted to achieve a desired wave-number response. Another important feature is that they differ from other existing airgun arrays in that they are comprised of a number of large single airguns instead of a number of sub-arrays. The minimum spacing between any two adjacent single guns exceeds 6 m and consequently mutual interaction between them is negligible (the equilibrium radius here is less than 60 cm; the exact figure is not quoted for reasons of commercial confidentiality). An important implication of negligible interaction is that the near field pressure signature of each airgun can be monitored accurately in the field.

The arrays consist of two strings separated by a distance of about 25 m. Each string has a number of Bolt 1500C airguns with chamber volumes ranging from 180 in³ to 540 in³, as shown in Fig. 1 for the case of an 80 m array. The guns are fitted with waveshape kits in order to attenuate the pressure bubble pulses. Each gun is suspended as shown in Fig. 2 from the gun plate on which specially designed near field hydrophones are mounted. The distances between the near field hydrophone and the gun ports varies from 0.5 to 0.65 m.

**Field Test Results**

In order to implement and test the method for monitoring the near field pressure signatures radiated by individual guns, three test lines were shot in the North Sea in January 1983. One test line 15 km long was shot over the Dogger Bank using the 48 m Datagun array. The array, placed at a depth of 5 m, has a configuration as shown in Fig. 3. The near field pressure signatures were recorded on the DFS V through the DSS V interface. The data were anti-alias filtered with a 6 dB cut-off frequency of 128 Hz and were sampled at 2 ms.

Figure 4 shows a comparison between the array near field pressure signatures (upper trace in each pair) recorded at a normal production speed of 5 knots and the near field pressure signatures (lower trace) obtained previously from stationary guns when fired separately. For the case of the static measurements, the hydrophone was placed 1.5 m below the guns ports and the anti-alias filter used was the DFS IV with 6 dB cut-off frequency of 248 Hz. The response of this filter was removed from the static measurements and the DFS V anti-alias filter with 6 dB cut-off frequency of 128 Hz was applied.
Four important conclusions emerge from Fig 4. These are:

1. The interaction between the guns forming the 48 m array is negligible.
2. The interference from adjacent guns is insignificant, i.e. the output of the near field hydrophone is mainly due to the gun immediately below the hydrophone.
3. The effect of the ship's speed on the recorded pressure signatures can be neglected.
4. The propagation of the pressure pulses in the region 0.5 to 1.5 m is approximately linear. This tends to confirm the theoretical prediction made by Safar (1977) using Gilmore's theory (1952), namely that for the case of the pressure pulses radiated by airguns, the distortion caused by the non-linearity of the water can be neglected even at distances less than one metre.

Since the interaction between the airguns forming the 48 m array is negligible, it follows therefore that the period of the bubble pulses radiated by each gun is dependent only on the airgun depth, pressure and volume. By knowing the airgun pressure and volume, the depth of the airgun can be accurately determined from the period of the measured pressure bubble pulse. Moreover, the far field pressure signature radiated by the Datagun array can be obtained simply by

Fig. 4. Typical Datagun array near field signatures (top) recorded at a normal production speed of 5 knots and near field signatures (bottom) obtained from stationary guns fired separately. Recording filter: DFS V: OUT – 128 Hz.
superposing the computed far field signatures of the individual guns.

Figure 5 shows a comparison between the computed far field pressure signatures obtained from both near field static measurements and the near field pressure signatures recorded at a speed of 5 knots. It can be seen from Fig. 5 that the computed far field pressure signatures for the case of a ship's speed of 5 knots differs very slightly from that computed for the static case. Figure 6, which displays the amplitude spectra of the computed far field pressure signatures, shows that at the low frequency end of the amplitude spectra the computed far field signatures agree well. The differences between the two computed far field signatures is partly due to the difference in the ghosting effects and partly due to the difference in the low frequency responses of the DFS IV and V recording systems.

**Datagun Array Performance**

A crucial aspect of the operation of any seismic source is its stability, i.e. the extent to which one can detect any variation in its radiated far field pressure signature from shot to shot. We have shown above that trustworthy far field pressure signatures radiated by the 48 m array can be computed accurately from the pressure signatures recorded by the near field hydrophones mounted on the gun plates.

As a test of the 48 m Datagun array stability, the far field pressure signatures were computed for 250 successive shots from 2000 recorded near field pressure signatures. These are shown in Fig. 7. Each far field pressure signature shown in Fig. 7 was obtained by superposing 50 computed far field signatures. We conclude from Fig. 7 that the 48 m Datagun array performance is extremely robust. Clearly Fig. 7 demonstrates that the gun synchronisation is very good and that the variations in gun depth and pressure are very small.

**Conclusion**

We have discussed and attempted to produce empirical support for the theoretical predictions concerning the propagation of the pressure pulse radiated by a single airgun (Safar 1977) and the interaction between airguns forming an array (Safar 1976a, 1976b). These results are exploited in the development of an operational system used for monitoring the performance of the Datagun array. The field test results have shown that the proposed monitoring system proved to be a vital tool in the quality control of the arrays.
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Fig. 7. 48 m Datagun array far field signatures obtained for 250 successive shots from 2000 recorded near field signatures. DFS V filter: OUT–128 Hz.