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This paper describes the underwater noise characteristics of an underwater diamond wire cutting operation during the severance of a 0.76 m diameter conductor at an oil and gas platform in the North Sea. The conductor was cut approximately 10 m above the seabed using a "36-inch" (0.91 m) diamond wire cutting machine, in a water depth of approximately 80 m. The analysis revealed that the sound radiated from the diamond wire cutting of the conductor was not easily discernible above the background noise, which was present during the cutting operation (it should be noted that the cutting process involved the presence of several operational vessels). Increases of between around 4 dB and up to 15 dB were detectable for one-third octave band spectral levels at some frequencies, during the period which broadly corresponded to the cutting operation, with the higher frequencies showing greater increases. There was generally an observable increase in the spectral level for the one-third octave bands at frequencies above 5 kHz. No tonal components in the data could be directly attributed to the diamond wire cutting. These data are the first description of the radiated noise from a diamond wire cutting operation available in the public domain.

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1. INTRODUCTION

The offshore industry employs a range of techniques for the removal and termination of subsea structures, including a number of non-explosive approaches, such as diamond wire cutting (Twachtman et al., 2004). This method generally comprises a diamond beaded wire loop, mounted onto a frame and veered at high speeds by a hydraulically or electrically powered pulley system (Kaiser et al., 2004; Twachtman et al., 2014). The power generation unit can be situated either underwater or be placed above the water on a support vessel. A clamping frame is used to attach the system onto the structure, generally assisted by an underwater remotely operated vehicle (ROV) or scuba divers.

Whilst diamond wire cutting is used for offshore decommissioning in many areas of the world (Twachtman et al., 2004), measurement data of the underwater sound generated by this method is not available in the public domain, which has been noted by previous authors (Nedwell and Howell, 2004). However, manufacturer and technical specifications commonly describe diamond wire cutting as having 'low-noise' emissions (Knecht, 2010; Robore Cuts, 2016), and being a technique that is generally considered safe for the environment (Twachtman et al., 2004). This is a potential advantage over alternative methods, given that efforts are increasingly being made to better understand and reduce the effects of underwater sound on sensitive marine organisms (e.g. MSFD, 2008; NMFS, 2016).

The diamond wire cutting activity does have the potential to radiate underwater sound, and thus the potential to contribute to the local ambient sound conditions. The primary sources of sound radiation from diamond wire cutting can be expected to include the wire (friction), the pulleys and the power mechanism. Furthermore, the support activities such as the presence of an ROV and surface vessel would also contribute to the overall noise, and depending on the actual activity may be noisier, overall, than the cutting process.

This paper provides an analysis of the underwater sound associated with diamond wire cutting, supporting an increased understanding of its effect on the marine environment.

2. METHODOLOGY

A. THE SUBSEA OPERATION, MEASUREMET SET-UP AND DATA ACQUISITION

In May 2014 *Repsol Sinopec Resources UK* commissioned work for the termination of a cylindrical conductor at the Clyde platform, block UK 030/17b, which involved underwater diamond wire cutting. The conductor was a 0.76 m (30-inch) diameter tubular structure. The cutting was carried out underwater, about 10 m above the seabed, where the water depth was approximately 80 m. The cutting tool used to terminate the conductor, described here, was a "36-inch" (0.91 m diameter) diamond wire cutting machine (CUT UK Ltd.), developed by Tecnospamec, which can be powered directly by an ROV or by a surface hydraulic power unit through an umbilical, which was the mode of operation for this study.

The measurement data were obtained using three battery powered autonomous, underwater acoustic recording systems (SM2M, Wildlife Acoustics, Inc). The systems were configured to record continuously, at a sampling rate of 96 kSamples/s, saving batches of 15 minute long datasets to an SD card. The acoustic recorder data were automatically time stamped at the beginning of each recording batch. The SM2M data acquisition system (A/D system) has a dynamic range of ± 1.25 V, and a 16 bit resolution.

The lack of available acoustic measurement data for diamond wire cutting meant that the expected sound levels could not be estimated in advance of the measurements. A spread of measurement distances were selected with the aim of obtaining data such that: i) the underwater sound resulting from the cutting was detectable above the background noise, and ii) clipping of the measurement data did not occur. The autonomous recorders were therefore deployed at distances of 100 m, 250 m and 800 m from the platform. The recorder deployment was carried out by divers, aided by two acoustic positioning systems, a Kongsberg HiPAP 500 USBL and a Sonardyne Ranger LUSBL (Rizza, 2014). The underwater noise recorders were deployed on 5th May at around 17:30 Greenwich Mean Time (GMT) and recovered on 6th May 08:30 GMT, and acquired data throughout this period (the recording was started in advance of deployment and stopped following retrieval). The deployment times, as well as the overall recording start and end times, and the given hydrophone sensitivity and system gain specifications are summarized in Table 1. The diamond wire cutting operation was carried out between 03:22 GMT and 05:19 GMT on 6th May 2014, without pause (Rizza, 2014).

It should be noted that the deployment of the autonomous recorders, and the cutting activity were coordinated from a diving vessel (*Rockwater 1*), equipped with a Class II dynamic positioning (DP) system. The vessel's DP system is supported by various reference systems, including two acoustic positioning systems (HiPAP 500 and Sonardyne Ranger mentioned above). The *Rockwater 1* has two azimuth thrusters, and three bow thrusters to maintain position. During the cutting activity this vessel maintained station alongside the Clyde platform, and its ROV was at 1 m to 2 m distance from the cutting operation. Two other surface vessels, the *Esvagt Celina* (standby vessel) and a Clyde supply vessel/tug *Grampian Sceptre*, were present during the time of the diamond cutting, both holding station outside the 500 m exclusion zone.

B. DATA ANALYSIS

All data (waveform audio file format) were analysed in MATLAB 13a (v8.1, Mathworks, Inc.). For analysis, the time domain data was converted into mean-square sound pressure spectral density (also known as power spectral density (PSD)) using Welch's method (Welch, 1967; Rabiner and Gold, 1975; Robinson et al., 2011) before converting to 'levels' and applying corrections for the hydrophone sensitivity and gain. Only single value data were available for hydrophone sensitivity and gain, and these were assumed to apply across the entire frequency range, to obtain the received acoustic levels. The data were analysed using averaging lengths of one second. The one second analysis was used to obtain good time resolution combined with acceptable frequency resolution (for example, when calculating spectrograms over periods of minutes), and was deemed suitable because the source of interest was considered to be relatively invariant over a period of seconds. It should be noted that this paper follows the terminology set out in the draft ISO standard on underwater acoustic terminology (ISO/DIS 18405.2).

The PSD levels are presented as a function of time (spectrograms – see Figs. 1 to 3), to show the time variant frequency content of the recorded underwater sound. The data are also converted into one-third octave band spectral levels for a selection of frequencies (see Figs. 4 to 6), and the results are presented for nominal center band frequencies up to 40 kHz.

Table 1: Summary of the measurement specifications of the three autonomous recording systems (SM2M Wildlife acoustics, Inc.) deployed to acquire the underwater sound measurement data. The analysis presented in this paper focused on the acoustic data acquired during the cutting activity, and adjacent periods up to approximately 10 to 15 minutes before and after the conductor cutting operation.

Distance from platform [m]	**Hydrophone sensitivity level* [dB re 1V/µPa]**	**Nominal gain setting/ 'actual' gain** [dB]**	**Recording start time: Recording end time (GMT)**	**Recorder deployment : Recorder recovery (GMT)**
100	-164.2	0 / 1.1	3rd May 2014,~ 17 :00: 15th May 2014,~ 08:00	5th May, 2014,~ 19:20: 6th May, 2014 ~ 08 :20
250	-164.8	0 / -1.0	3rd May 2014,~ 17:00: 15th May 2014,~ 07:45	5th May, 2014,~18:50: 6th May, 2014,~ 08:44
800	-164.8	0 / -1.0	3rd May 2014,~ 17:00: 15th May 2014,~ 08:15	5th May, 2014,~ 19:20: 6th May, 2014, ~ 08 :20

** Hydrophone sensitivity level was provided as a single number for an undefined frequency. This was used as a nominal sensitivity and applied across the full measurement bandwidth.*
*** The gain specification was provided as both, nominal and 'actual' overall system gain, and the single value, 'actual' gain data applied across the full measurement bandwidth.*

3. RESULTS

A. SPECTROGRAM ANALYSIS

Figures 1 to 3 show spectrograms of the underwater acoustic measurement data for the period of the diamond cutting operation and the adjacent periods before and after. The adjacent periods are about 10 to 15 minutes long, and were included for comparison purposes to aid acoustic identification of cutting start and stop times, and to establish if the cutting could be associated with acoustic characteristics different from the background noise. The data are shown for all three autonomous recorders positioned 100 m, 250 m and 800 m from the platform.

The spectrogram images indicate a clear rise in the broadband noise shortly after 03:34 GMT and again at about 05:19 GMT, which is broadly consistent with the logged start and end times of the diamond cutting operation. The acoustic signatures that have been identified as associated with the time of cutting are characterized by a rapid overall increase in the received level (PSD level), particularly apparent at frequencies broadly above 5 kHz. This is present in the acoustic recordings obtained at all three recorder locations.

Besides the radiated sound characterized above, contributions from other noise sources were also apparent in the spectrograms, notably the harmonic components across the lower-end frequency bands, and the intermittent tones occurring in the 20 kHz to 30 kHz frequency bands. Figures 1 to 3 also indicate that, in general, the amplitude across the studied bandwidth was generally highest for the recorder at 100 m distance, and lower in the measurement data acquired with the recorders at the 250 m and 800 m distance from the platform. However, there is also an increase in sound level at the 800 m location compared to the data acquired at the 250 m distance from the platform. This is discussed further with the one-third octave band analysis presented in Section 3B.

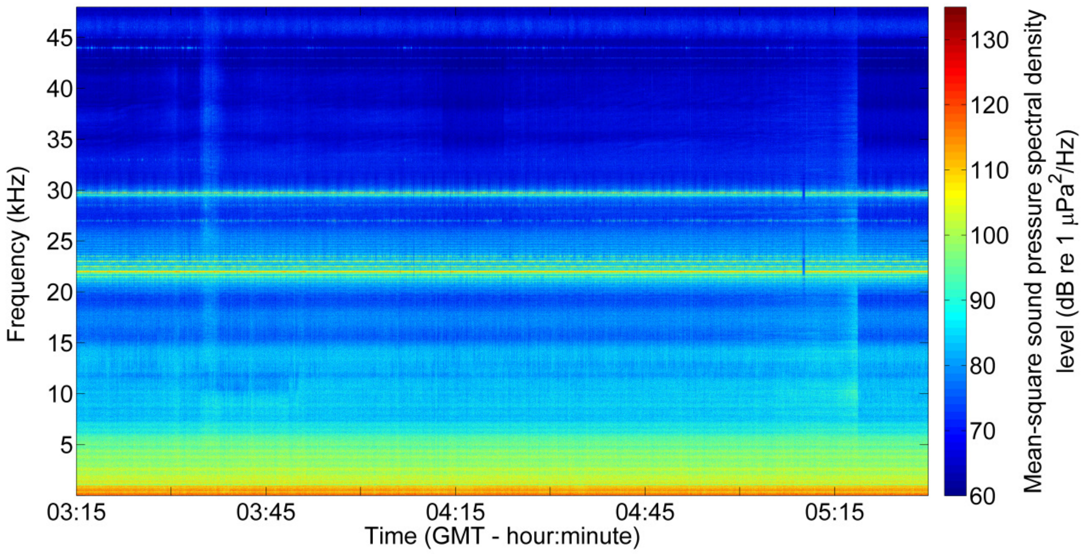

Figure 1: Spectrogram of underwater acoustic data acquired with an autonomous recorder 100 m away from the platform, showing the period of conductor cutting between about 03:34 GMT and 05:19 GMT, and the adjacent period immediately before and after the cutting operation. The spectrogram was produced using 1 s mean-square sound pressure spectral density data, with 1 Hz frequency window.

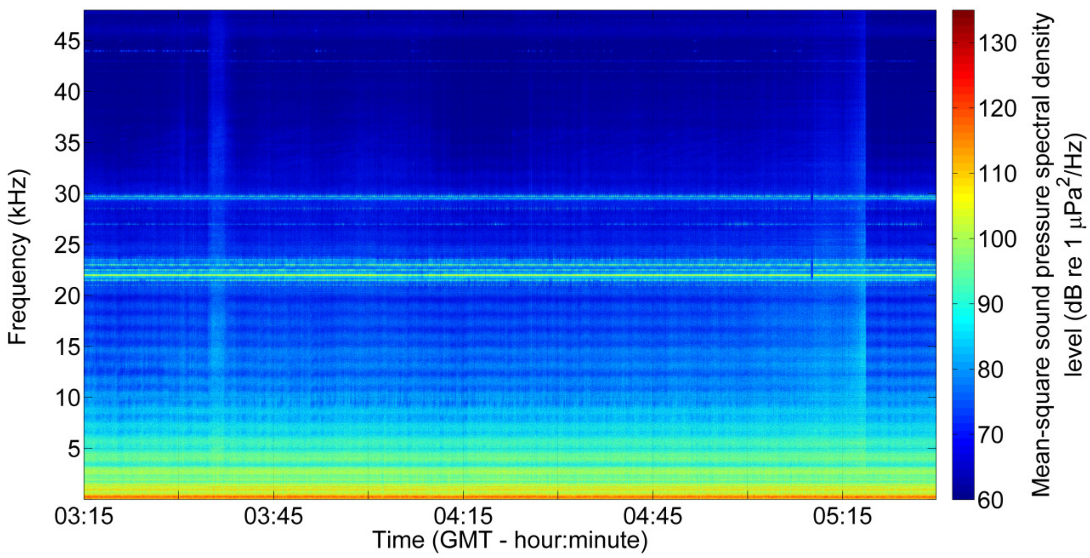

Figure 2: Spectrogram of underwater acoustic data acquired with an autonomous recorder 250 m away from the platform, showing the period of conductor cutting between about 03:34 GMT and 05:19 GMT, and the adjacent period immediately before and after the cutting operation. The spectrogram was produced using 1 s mean-square sound pressure spectral density data, with 1 Hz frequency window.

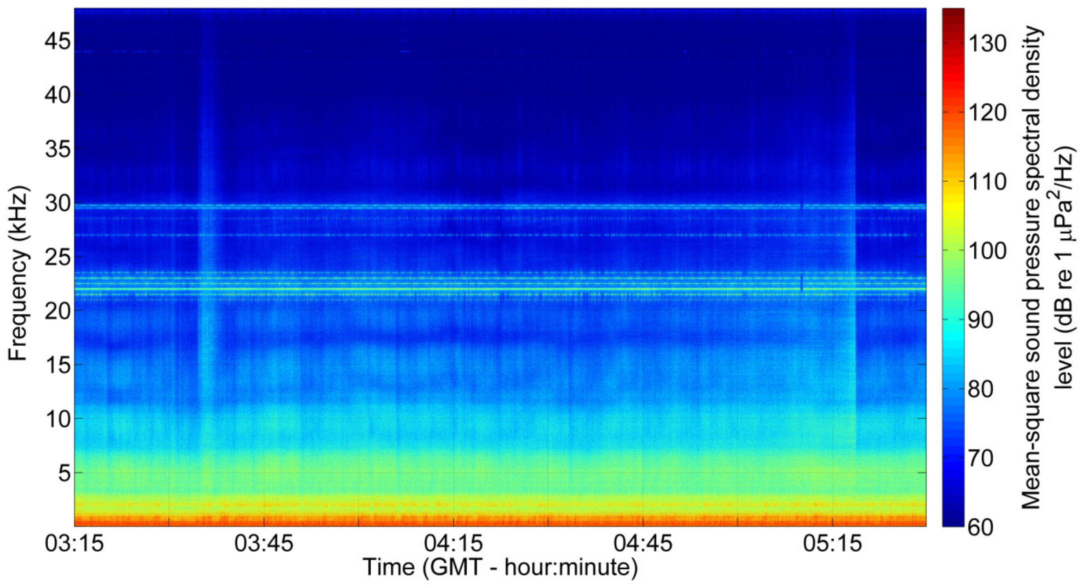

Figure 3: Spectrogram of underwater acoustic data acquired with an autonomous recorder 800 m away from the platform, showing the period of conductor cutting between about 03:34 GMT and 05:19 GMT, and the adjacent period immediately before and after the cutting operation. The spectrogram was produced using 1 s mean-square sound pressure spectral density data, with 1 Hz frequency window.

B. ONE-THIRD OCTAVE BAND ANALYSIS WITH TIME

To help identify temporal variations in the underwater noise that could be attributed to diamond wire cutting across the measurement frequencies, the one-third octave band PSD levels were plotted as a function of time. The spectral level data can be converted to various metrics to facilitate comparison with either ambient noise measurements or receptor sensitivity data. For clarity, the results in Figs. 4 to 6 are shown for the one-third octave band center frequencies where there was an observable increase in amplitude of the acoustic signal, at the times which correspond to the start and the end of the diamond cutting activity. The most notable changes in amplitude of the acoustic signal, with time, were observed for one-third octave bands above 10 kHz, with the largest changes with time at the one-third octave band centered at 40 kHz. At particular frequencies, changes of between around 4 dB and 15 dB were detectable in the one-third octave band spectral levels, with increases corresponding to times when the diamond cutting was underway. It should be noted that at lower frequencies, the operation was generally indistinguishable above the background noise.

The overall one-third octave band levels measured at 800 m might generally be expected to be lower than those measured at 100 m and 250 m. This is not always the case in the measurement data presented in this paper (see Figs. 1 to 3 and Figs. 4 to 6), particularly at lower frequencies. Whilst this could be due to particular local propagation effects, the most likely reason was thought to be the presence of two support vessels beyond the 500 m exclusion zone, closer to the 800 m measurement position.

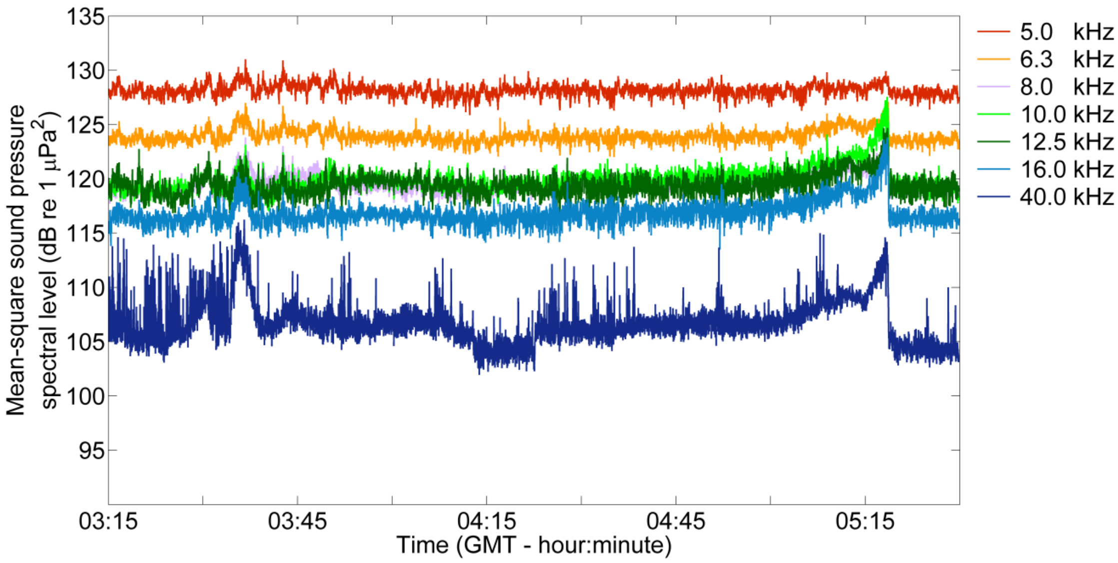

Figure 4: Underwater acoustic data at 100 m distance from the platform, presented as one-third octave band mean-square sound pressure spectral level data, for the period between 03:34 GMT and 05:19 GMT on May 6th 2014. The diamond wire cutting start and end time corresponds to 03:34 and 05:19 GMT.

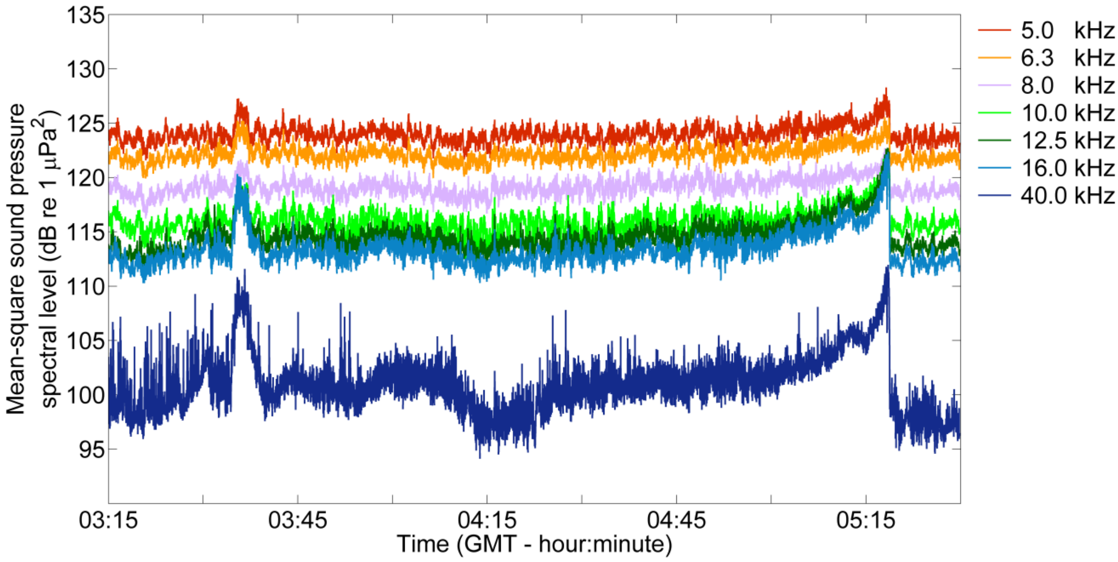

Figure 5: Underwater acoustic data at 250 m distance from the platform, presented as one-third octave band mean-square sound pressure spectral level data, for the period between 03:34 GMT and 05:19 GMT on May 6th 2014. The diamond wire cutting start and end time corresponds to 03:34 and 05:19 GMT.

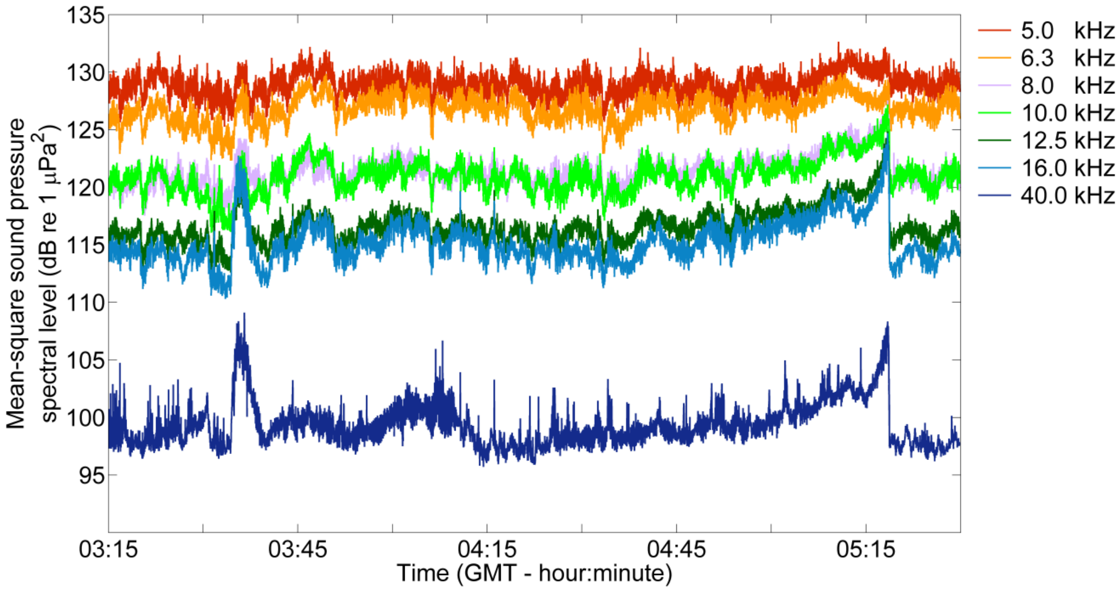

Figure 6: Underwater acoustic data at 800 m distance from the platform, presented as one-third octave band mean-square sound pressure spectral level data, for the period between 03:34 GMT and 05:19 GMT on May 6th 2014. The diamond wire cutting start and end time corresponds to 03:34 and 05:19 GMT.

4. DISCUSSION

In general, the data from this particular cutting operation show signal characteristics, believed to be associated with the sound radiated from the diamond wire cutting, not to be easily discernible above the background noise at the time or in the area in which the measurements were carried out. The sound that could be associated with the diamond wire cutting was primarily detectable above the background noise at the higher acoustic frequencies (above around 5 kHz). It was expected that the noise from diamond wire cutting would be continuous in nature, over a defined period, unlike, for example, the high amplitude, impulsive noise associated with explosive decommissioning. The measured data, presented in this paper, which were associated with diamond wire cutting noise were characterized by a distinct start and end period, however, no tonal components in the data could be directly attributed to the diamond wire cutting.

In general, the sound levels at lower frequencies do not show an increase in amplitude that corresponds to the onset of cutting or to the end of the cutting activity, as seen at higher frequencies. This may be indicative of the cutting noise generating sound that is associated with higher frequencies, or it may be that any sound radiated from the cutting operation was masked by the noise from other sources, such as the noise from the surface vessels or the ROV, for example, which were continuously present throughout the recording period.

Other noise sources were indeed present in the recorded data. Some of these could be attributed to the surface vessel activity, such as the DP acoustic signaling, and other had characteristics which were consistent with vessel noise, although sound radiated from the ROV operation cannot be ruled out. The elevated sound levels at lower frequencies correspond with the characteristic sound signatures which have previously been described as typical of the sound radiated from surface vessels (Carey 2006; Kozaczka and Grelowska, 2011). Furthermore, the sound signals in the 20 to 25 kHz frequency band are consistent with the transmit frequency of the HiPAP acoustic positioning system on *Rockwater 1*, the support vessel present throughout the measurements. The first harmonic of these signals could also be seen, particularly in the measurement data recorded at the recording system closest to the platform (100 m distance), which was also the closest recording location to *Rockwater 1*.

5. CONCLUSION

Measurement data obtained during a diamond wire cutting operation indicate that the sound radiated from the diamond wire cutting of a conductor was not easily discernible above the background noise, which was present in the area during the cutting operation. Increases of between around 4 dB to 15 dB were detectable for one-third octave band PSD levels at some frequencies during the period which corresponded to the cutting operation, with the higher frequencies showing greater increases. There was generally an observable increase in the spectral level for the one-third octave bands at frequencies above 5 kHz. No tonal components in the data could be directly attributed to the diamond wire cutting.

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