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ELECTRIC, MAGNETIC AND ACOUSTIC NOISE GENERATED UNDERWATER DURING OFFSHORE PILING OPERATIONS

R.M. Dunbar

Dept. of Electrical & Electronic Engineering, Heriot-Watt University, Edinburgh, EH1 2HT, Scotland, U.K.

INTRODUCTION

There is an offshore requirement to transmit data underwater without cables over short ranges on offshore platforms, during the installation phase when piles are driven into the sea-bed round the legs of the structure. Very large impulsive forces are involved in the underwater piling operation and the associated pressure waves and structural vibrations contain frequency components over a wide range. Strain and acceleration measurements made on the pile being driven actually contain information that relates to the bearing strength of the foundation [1,2], and these measurements are used to monitor the progress of the pile.

In order to transmit signals by some means in such a difficult environment requires a knowledge of generated noise levels that could cause interference. Electric field, magnetic field, acoustic and optical transmission systems are all possible contenders for the wire-less link and are the subject of a continuing study by the author. It is evident that quantitative data on the amplitude and frequency spectrum of noise generated by piling and other offshore activities is a pre-requisite in the design of a suitable transmitter-receiver link. No such data could be found in the literature and consequently a series of experiments was planned to obtain the raw information required. The first measurements were carried out in 1985, during the piling operation on a North Sea platform, the experiment being sponsored by FUGRO B.V. Geotechnical Engineers, of Leidschendam, Holland. The electronic equipment used was built at Heriot-Watt University to the author's specification and measurements were made to his requirements.

NOISE GENERATED DURING OFFSHORE PILING

It was decided to make wide-band measurements of electric field, magnetic field, and acoustic signal levels, synchronised with the hammer blow of the piling equipment. While it is obvious that very substantial acoustic noise levels are generated, the sources of E-M wave signals from a steel structure are not so evident. No major sources of industrial electrical noise are present on the structure during piling but the steel piles and other structural items carry residual magnetisation which, when moved rapidly, is expected to generate substantial time-changing E-M fields. This is in addition to changes in the local magnetic field due to the movement of material of high relative permeability.

This is very much an unknown area experimentally, as regards systematically recorded data, but an estimate of a possible field can be made. If the earth's magnetic field is taken as 80 AT/m (1 oersted), then the remanent flux density in a sample of steel could rise to 80 x μ_0 x μ_r Wb/m²(T),

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conditions of manufacture and storage permitting. If μ_r is taken as 1000 for example, for steel, then B_{rem} = 0.1 T. Also, in the case of a long steel tube (a typical pile is 50 m in length) it will exhibit the properties of a bar magnet, with strong fringe fields at the ends. Now consider the effect of the piling operation. When the pile is struck by the hydraulic hammer the impulsive force causes the pile to move downwards a short distance during a period of tens of milli-seconds, the downward movement decreasing as the bearing strength increases. In addition, there is a large amount of structural vibration. To obtain an estimate of the time-changing magnetic field a typical velocity profile is assumed, with a maximum velocity of 5 ms^{-1} being reached in around 2 ms. If the change in flux density is taken to be 5% (0.02) of the remanent value (a possible value, for 0.1 m movement, in a fringe field concentrated over ±4 m near the ends) then the rate-of-change of flux density will be

$$(0.1 \text{ T} \times 0.02)/2 \text{ ms} = 1 \text{ T/s}$$

Thus the magnetic field near the ends of the tube will change by approximately 1 T/s as a first estimate. Near the centre portion of the long magnetised tube a very much smaller change in magnetic field is to be expected with respect to longitudinal movement, because of the more uniform flux density in that region.

If a sensing coil is placed near the end of the tube then the induced e.m.f. may be estimated, as follows

$$e = N\frac{d\Phi}{dt} = NA\frac{dB}{dt} \text{ V}$$

$$\Phi = B.A. \text{ Wb}$$

For component and parameter values used in the experimental equipment it was estimated that the induced e.m.f. would be of the order of 0.5 V peak.

It is to be expected that time-changing electric fields will also be caused by the moving permanent magnetic field. From electromagnetic theory

$$\frac{E}{H} = \eta_{sea} = \sqrt{\frac{\omega\mu_0}{\sigma}}$$

The value of ω used here is an equivalent to the physically moving field discussed earlier, and for such conditions E was estimated to be of the order of 0.1 V/m.

It is to be noted that higher frequency components due to vibration and structural resonances can be expected to produce higher values of η_s and correspondingly higher values of E. These order-of-magnitude calculations provide the basis for the design of instrumentation circuits to measure E and H fields.

NOISE INSTRUMENTATION EQUIPMENT

It was decided to design equipment to provide independent measurements of electric and magnetic fields, and acoustic signals. The overall electronic system comprises a remote instrumentation module, designed to be mounted on an offshore structure to a depth of 100 m; a 300 m interconnecting multi-core cable; and a surface data acquisition unit that provides outputs to recording and monitoring equipment, as well as supplying d.c. power to the remote module.

The underwater module contains sensors to measure electric field (E, v/m), magnetic field (B, Wb/m^2 or T), acoustic signals (dB relative to 1 V per μPa), and electrical noise (v) induced in the umbilical cable.

The electric field sensor is a dipole of spacing 0.25 m and the voltage developed across the electrodes is fed to wideband amplifiers with high common mode rejection and a gain of x100 when matched. The output is fed to a balanced line via a matching line driver circuit and the frequency response is flat to 200 kHz. The magnetic field sensor is a ferrite cored 185 turn loop in a Faraday screen. The overall gain of this channel is x100 when matched and the frequency response is flat to 200 kHz. The acoustic sensor was a proprietary wideband hydrophone with a quoted 3 dB passband from 10 kHz to 1 MHz. The hydrophone incorporates a pre-amplifier with a gain of x10 and its output was fed to a balanced line driver stage with a gain of x1 when matched.

The three sensor outputs were fed to the surface over individually screened twisted pairs, of nominal characteristic impedance 70 Ω. The 15 V d.c. power supply to the sensor circuits was fed through a fourth screened pair and this line was also used with a monitor circuit to measure the electrical noise induced in the cable. The intention of this was to provide a signal that could be subtracted from the actual sensor signals, if induced noise proved to be a problem.

The surface unit contained circuits to match the three sensor signal balanced lines, and the noise signal balanced line. Three single-ended outputs were provided on each channel to facilitate connections to paralleled recording/monitoring equipment.

A prototype version of this equipment was installed on the platform while under construction, by clamping the underwater package to an anode near the entry point to one pile sleeve. The directional sensitivities of the sensors were chosen to suit a projected active transmission system as part of the on-going project. The remote package was built to very rugged design standards since it had to withstand the "water slam" that occurs on entry to the water during up-ending and sinking of the platform. The components used also had to be housed to withstand static water pressures to depths of 100 m and the large pressure waves present close to an underwater pile hammer. In the event the equipment survived launch and performed to expectations.

SPECTRAL ANALYSIS OF RECORDED SIGNALS

The raw signals are complex high frequency transients with exponential decay, the overall duration being of the order of 200 mS. There is some similarity to acceleration (force) and strain signals familiar to geotechnical engineers, but the high frequency content is greater. The complex form of the transient presents problems on analysis, since the frequencies generated are not uniformly distributed throughout the transient. Thus a Fast Fourier Transform (FFT) carried out on a narrow "time slice" will indicate frequency components relevant only to the time position. When one considers the frequency content and the length of the transient the problem can be understood. For example, if the highest frequency component is 300 kHz then sampling must taken place at 2 × 300 kHz, say 800 kHz. In 0.2 second 160,000 samples would be required which is well above the capability of most FFT type analysers. However an HP3562A transient analyser with hard disc sample storage is being commissioned to overcome this difficulty, for the continuing study.

To obtain initial results a different although time-consuming technique had to be employed. An HP 3565A swept frequency spectrum analyser was used to examine transients, scanning the same transient many times over until "all" frequency components had been measured and integrated. The resultant spectrum was then plotted via an HP-85 computer over an IEEE interface, under software control.

Sample recordings were analysed and spectra plotted of total signal, environmental noise between transients, and (signal - noise).

Examples are given here of total measured electric, magnetic, and acoustic frequency spectra, in figures 1, 2 and 3 respectively.

In all three figures frequency components above 300 kHz should be disregarded, for the following reasons. Firstly, the analysis was carried out on recordings which had been copied via a machine with a 300 kHz high frequency cut-off. The original recordings were made on wideband (2 MHz) equipment. Secondly, the electric field and magnetic field sensor circuits had upper 3 dB corner frequencies of 200 kHz. The wideband hydrophone line-driver circuit had a high frequency cut-off of 500 kHz. Thirdly, the playback machine produced spurious low level signals above 640 kHz.

Examination of the original wideband recordings relevant to figures 1, 2 and 3, and to many other transients, suggest that the spectra as illustrated are fairly representative of the real situation.

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COMMENT

A large amount of information is contained in electric field, magnetic field, and acoustic signals produced during offshore piling operations, with spectra as illustrated in figures 1, 2 and 3. The detail is contained in the original raw signals, of which analysis is continuing.

This novel experimental method and original measurements point the way towards valuable investigative techniques that may be developed to obtain noise spectra and other correlated data, in an area that has received little attention to date.

ACKNOWLEDEMENTS

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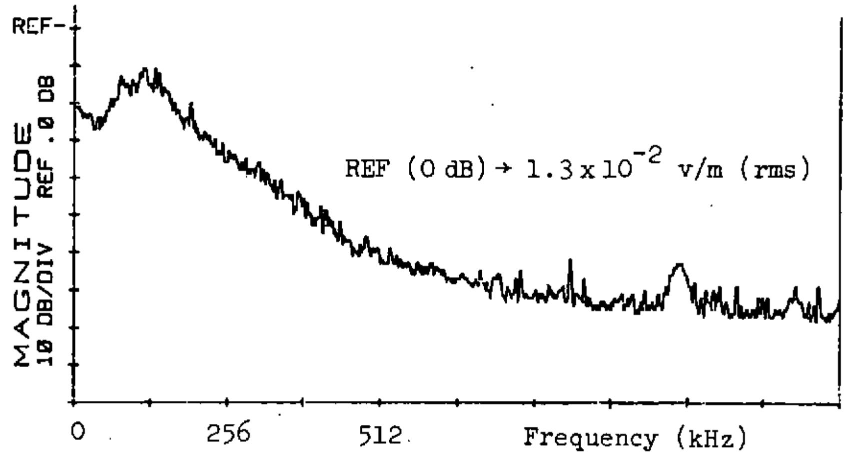

Figure 1 Electric field including all noise

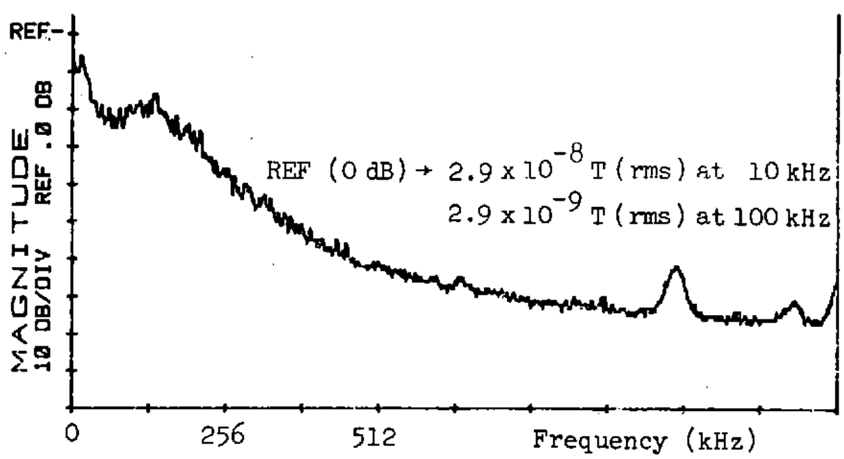

Figure 2 Magnetic field including all noise

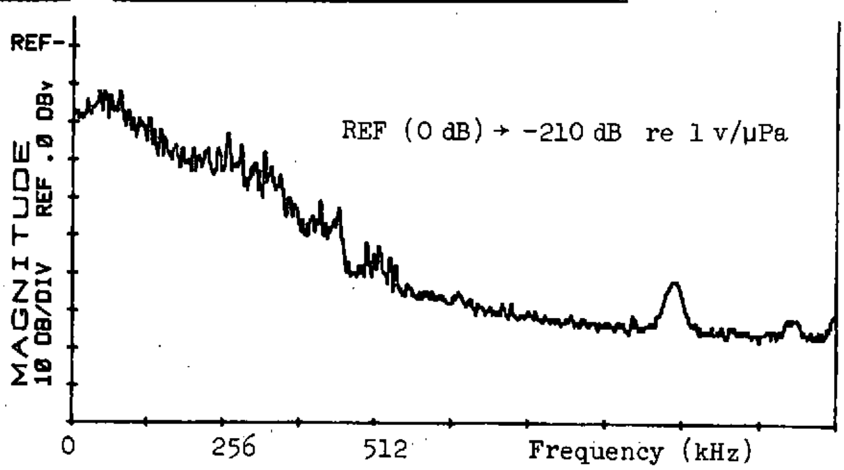

Figure 3 Acoustic signal: Total signal

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