The acoustic signatures of cavitation erosion on grade DH36 steel

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Abstract. Cavitation can cause considerable erosion to adjacent materials. Erosion is accompanied by acoustic emissions, related to crack formation and propagation inside the material. In this study a piezoelectric acoustic sensor mounted on the back of a grade DH36 steel plate is used to identify the acoustic signatures of cavitation. Cavitation is induced near the plate by means of an ultrasonic transducer (sonotrode). Various ‘non-erosive’ and erosive test rig configurations are examined and an acoustic threshold value for the onset of cavitation erosion is identified and presented. The use of a fibre Bragg grating (FBG)-based acoustic sensor developed at City University London for acoustic monitoring purposes is also examined. Acoustic signals from both sensors are analysed, by means of a fast Fourier transform, showing a very good agreement in terms of captured frequencies.

1. Introduction
A series of phenomena are believed to be the cause of cavitation erosion, including bubble collapse and rebound, micro-jet formation, clouds of collapsing micro bubbles and cavitation vortices [1]. Studies with high speed photography have shown high pressure waves emitted from collapsing cavities [2, 3]. Recent studies have suggested that a very high proportion of the collapse energy of a large cavity can be focused into a small region of the solid surface and cause significant erosion, under specific geometries [4]. It has also been suggested that the potential power of macro cavities could be converted into collapsing clouds of micro bubbles, resulting into shock waves that can cause significant erosion on the solid surface [5]. The initiation of erosion can produce acoustic emissions which are essentially high frequency waves related to crack formation and propagation inside the material [6]. The present study is focused on the investigation and design of a monitoring system for cavitation erosion related acoustic emissions from metals, based on piezoelectric acoustic sensors and fibre Bragg grating (FBG) sensors.

2. FBG and piezoelectric acoustic sensors
Fibre Bragg gratings have become an important sensing element for the measurement of strain, temperature, and wide range of other parameters [7]. Their inherent advantages such as immunity to electromagnetic interference ease of multiplexing, small size and typically lightweight have made them suitable to be used in various environments [8]. An FBG is a piece of an optical fibre with its core refractive index being periodically modulated, which creates a narrow band reflection. The principle of operation of an FBG-based sensor system is based on monitoring of the wavelength shift of the reflected Bragg signal, as a function of a measurement, such as strain or temperature applied to
the FBG. On the other hand piezoelectric acoustic sensors are operating on the principle of piezoelectricity, which can be defined as the linear electromechanical interaction between the mechanical and the electric state in crystalline materials [9]. Electrical charge is produced by the sensor in response to applied mechanical stress which can then be captured as an acoustic signal.

3. Experimental setup

Figure 1 shows an experimental setup for the cavitation test of a grade DH36 steel plate. The dimensions of this square shaped steel plate are 50 x 50 x 5 mm. The plastic bridge placed at the bottom of the water tank is used both to support the steel plate and to adjust the distance between the metal plate and the sonotrode. The sonotrode is a Hielsher UIP1000hd ultrasonic transducer, operating at a standard frequency of 19.5 kHz and it is placed above the steel plate surface at a predefined distance. The power output of the sonotrode is also adjustable and directly affects cavitation intensity.

![Fig. 1. Cavitation test rig](image1)

Figure 2 illustrates the detection systems for both the FBG and piezoelectric acoustic sensors. The signal detected by the photodiode is cross-compared with the signal detected by the piezoelectric sensor, placed adjacent to the FBG on the same metal plate. Prior to the recording of the piezoelectric sensor data, both pre-amplification and signal attenuation modules are included to optimize the signal output. Acoustic Signals from both sensors are captured through an Oscilloscope at a sampling rate of 31.3 MHz.

![Fig. 2. Instrumentation of steel plate with both FBG and piezoelectric acoustic sensors](image2)
4. Experimental results

4.1. Acoustic threshold for cavitation erosion (piezoelectric acoustic sensor)

Four different test rig configurations are presented, based on the impact of cavitation on the exposed steel samples in terms of erosion. These configurations were selected by measuring the cavitation erosion related mass loss of the examined steel samples over a period of 2 h. Adjustable parameters of the cavitation test rig include the gap between the sonotrode and the sample as well as the power output of the sonotrode. The distributions of the acoustic emission signals captured through the piezoelectric sensor are presented in Figure 3. Signals are presented in terms of acoustic power, corresponding to different cavitation intensities and consequently erosion of the steel plate. It should be noted that signals were captured under a sampling rate of 31.3 MHz and the average duration of the acoustic samples was 0.4 s containing approximately 1M acoustic data points.

The threshold acoustic value for the ‘non-erosive’ test rig configuration is noticeable and distinct and is of the order of 86 dB. The next ‘slight erosion’ setting, which indicates the onset of cavitation induced erosion has a maximum acoustic power value of 88 dB. Acoustics signals with even higher amplitudes were recorded for the ‘moderate erosion’ and ‘high erosion’ configurations.

4.2. Comparison between FBG and piezoelectric acoustic sensors

The use of fibre Bragg grating (FBG)-based acoustic sensors for cavitation erosion monitoring was investigated through comparison with the piezoelectric sensor. Signals from both FBG and piezoelectric sensors were captured through an oscilloscope at a sampling frequency of 31.3 MHz using a ‘normal erosion’ test rig configuration. The average duration of signals from both sensors was 0.4 s, each one containing approximately 1 M acoustic data points. Signals from both sensors were further processed with the use of a fast Fourier transform (FFT) algorithm in order to investigate the frequency components of which the two signals are composed. Figure 4 shows the frequency-domain data obtained from both sensors for cross-comparison after the use of the fast Fourier transform (FFT). It is noticeable that the same frequency element of 19.5 KHz, which matches with the operating frequency of the sonotrode and is directly related to cavitation activity, has been captured by both sensors. Compared to the piezoelectric sensor, the FBG sensor has shown some additional second harmonic signals as well as some frequencies below 19.5 KHz. It should be noted that cross-comparison between FBG and piezoelectric sensors, in terms of captured frequencies could only be made in the range of 0 to 100 KHz due to the absence of any other resonances above this frequency for the FBG sensor.
5. Conclusion
Acoustic emissions related to cavitation erosion were successfully identified by means of a piezoelectric acoustic sensor-based monitoring system. The acoustic threshold value related to the onset of cavitation erosion was successfully identified by testing various ‘non-erosive’ and erosive test rig configurations. Comparison between FBG and piezoelectric sensors, has shown a common frequency element which matches with the excitation frequency of the sonotrode and is directly related to cavitation activity. The good agreement made between both sensors has demonstrated the potential of FBG-based acoustic sensors that could be possibly used for a variety of industrial applications and has to be further investigated.

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