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CAVITATION PROCESS IMPROVEMENT FOR EXTRACORPOREAL SHOCK WAVE LITHOTRIPTER (ESWL) SYSTEM

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Abstract

This paper presents a study for the efficiency improvement of a modified extracorporeal shock wave lithotripter (ESWL) system utilized for disintegration of renal calculi. When a shock wave generated by an extracorporeal shock wave lithotripter (ESWL) interacts with a solid, it creates cavitation bubbles at the interface between the solid and the surrounding liquid. The implosion of the cavitation bubbles plays an important role in the disintegration of renal calculi. The stresses generated by the bubble implosions are larger than those generated during incidence of the primary shock wave. Extracorporeal shock wave lithotripter system generates cavitation bubbles that have essential role in the disintegration of renal calculi.

INTRODUCTION

Lithotripsy is the use of high-energy shock waves to fragment and disintegrate kidney stones. The shock wave, created by using a high-voltage spark or an electromagnetic impulse, is focused on the stone. This shock wave shatters the stone and this allows to the fragments to pass through the urinary system. Since the shock wave is generated outside the body, the procedure is termed extracorporeal shock wave lithotripsy, or ESWL.

ESWL is used when a kidney stone is too large to pass on its own, or when a stone becomes stuck in a ureter (a tube which carries urine from the kidney to the bladder) and will not pass. Kidney stones are extremely painful and can cause serious medical complications if not removed.

Lithotripsy uses the technique of focused shock waves to fragment a stone in the kidney or the ureter. The patient is placed in a tub of water or in contact with a water-filled cushion, and a shock wave is created which is focused on the stone. The wave shatters and fragments the stone. The resulting debris, called gravel, then passes through the remainder of the ureter, through the bladder, and through the urethra during urination. There is minimal chance of damage to skin or internal organs because biologic tissues are resilient, not brittle, and because the shock waves are not focused on them.

The extracorporeal shock wave lithotripter (ESWL) is a generator of mechanical shock waves. Such waves are generated outside the human corpus and have the capacity to disintegrate urinary calculi. The most prominent advantage in comparison with other techniques is that no stone contact is necessary in pulverisation the stone. When a shock wave generated by an extracorporeal shock wave lithotripter interacts with a solid, it can produce cavitation bubbles at the interface between the solid and the surrounding liquid. The implosion of the cavitation bubbles plays an important role in the disintegration of renal calculi [1]. Generation of large cavitation bubbles is one of the most important areas of investigation in the search to improve the efficiency of extracorporeal shock wave lithotripsy; therefore the possibility of an enlargement of the induced cavitation size should not be ignored. The stresses generated at large bubble implosion are larger than those generated during incidence of the primary shock wave [2]. The whole process of stress waves and cavitation in stone communition by shock wave lithotripsy has been investigated [3].

ESWL Description

The extracorporeal shock wave lithotripter is a generator of mechanical shock waves. Such waves are generated outside the human corpus and have the capacity to disintegrate urinary calculi. The most prominent advantage in comparison with other techniques is that no stone contact is necessary in pulverisation the stone.

The mechanisms of stone comminution may all be activated to differing degrees by either the lithotripter shock pulse or the subsequent collapse of cavitation bubbles excited by the pulse. Erosion results particularly when bubbles collapse against a surface. Individual bubbles and bubble clusters create jets [4].

A large, plane wave is generated by an ElectroMagnetic Acoustic Source and is focussed, by means of an acoustic lens on the stone position. The high-tension supply charges the high-voltage capacitor to a pre-defined voltage (14 kV to 21 kV). The current pulse in the coil (within the lithotripter) is generated by the discharge of the capacitor. This electrical current produces a rapidly increasing magnetic field, which induces eddy currents inside the homogeneous membrane. The eddy currents produce an inverse magnetic field, and the membrane is repelled, transmitting a shock wave into the water. The acoustic lens focuses the shock wave on the stone position. The shock wave is measured at the stone wave by means of a P.V.D.F. – sensor (Poly-Vinyl Difluoride). This signal is visualised on digital oscilloscope.

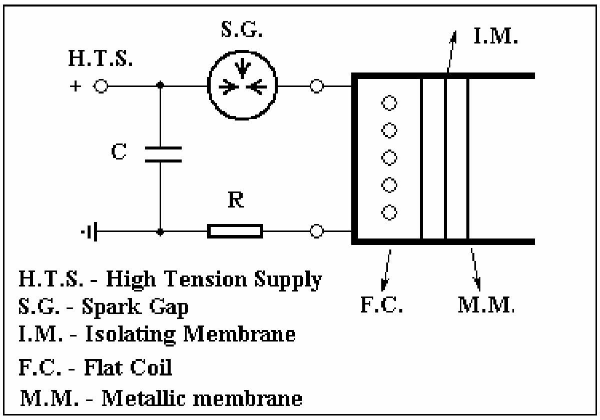

Figure 1 ElectroMagnetic Acoustic Source of ESWL [5]

EXPERIMENTAL RESULTS

Using the ESWL experimental system for stone fragmentation we have investigated the role of the stress waves and cavitation communition in extracorporeal shock wave lithotripsy.

Experiment description

The ElectroMagnetic Acoustic Source of the lithotripter initiates the incident shock waves into the water, and an ultrasound transducer, cantered into the extracorporeal shock wave lithotripter system provides an important role by enhancing the cavitation effects of the bubbles in the target fragmentation. Lithotripter generates transient cavitation bubbles, which grow by the ultrasound waves to their maximum sizes and then collapse violently on the target surface inducing material damage.

The underwater piezoelectric sandwich transducer is supplied by IWATSU SG-4511 Function/Pulse Generator and converts the electrical signals in mechanical vibrations, which are propagated into the water tank towards the Calcium-silicate target. The transducer exhibits low resonance frequency, tunable energy and broad-bandwidth.

The underwater waves, received by the sensor, are converted in electrical signals and displayed by LeCroy 9310 AM oscilloscope.

Experimental results show that the underwater piezoelectric sandwich transducer exhibits low resonance frequency, tuneable energy, broad bandwidth, [6] and low quality factor that means it is optimum for this application. Extracorporeal shock wave lithotripter system generates cavitation bubbles that have essential role in the disintegration of renal calculi.

Using an experimental system that mimics stone fragmentation we have investigated the role of stress waves and cavitation comminution in extracorporeal shock wave lithotripsy (ESWL). The modified ESWL system has an ultrasound piezoelectric transducer, centred into the lithotripter system. The electromagnetic source initiates the incident shock waves, and the ultrasound transducer (delayed in time) improves caviational effects of the bubbles.

The Calcium-silicate material samples, with 10 mm thickness were exposed to 25, 50 and 100 shock waves, at the beam focus lithotripter, in two cases, such as: generated only by the electromagnetic source and by the system ESWL together with ultrasound piezoceramic transducer, respectively. The last equipment showed ability to enhance the cavitational effects of the bubbles collapsed on targets.

Small Calcium-silicate plate samples of 10 mm thickness were exposed to shock waves generated by the modified ESWL system (Figure 2).

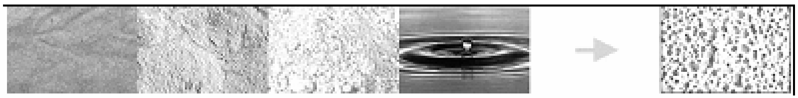

Figure 2 Calcium-silicate (Porous concrete) materials

The piezoelectric transducer powered by IWATSU SG-4511 Function/Pulse Generator converts the electrical signals in mechanical vibrations which propagate into the water. This type of transducer exhibits low resonance frequency, tuneable energy and broad-bandwidth [6], [7]. The underwater shock waves received by the PVDF sensor are displayed by LeCroy 9310 AM oscilloscope.

The set-up from Figure was utilised, heaving the experimental transducer fixed into the ESWL system. The underwater piezoceramic sandwich transducer is supplied by the Pulse/Function Generator, and generates ultrasound field into water creating an increasing cavitation effect on a soft material target surface.

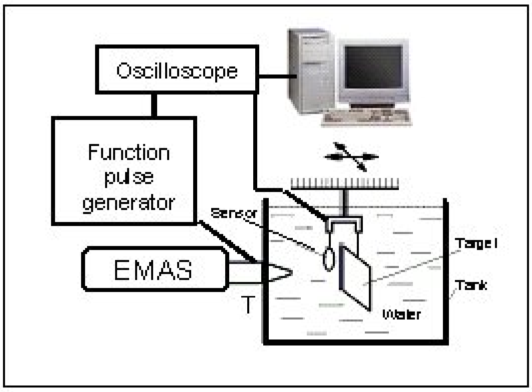

Figure 3 Set-up of ESWL system with piezoceramic sandwich transducer

Experimental Results

The mechanical impulses generated by the ESWL system are propagating into the water. Underwater shock waves received by PVDF sensor (Poly-Vinyl Difluoride) are converted in electrical signals (Figure 4) and displayed by LeCroy 9310 AM oscilloscope.

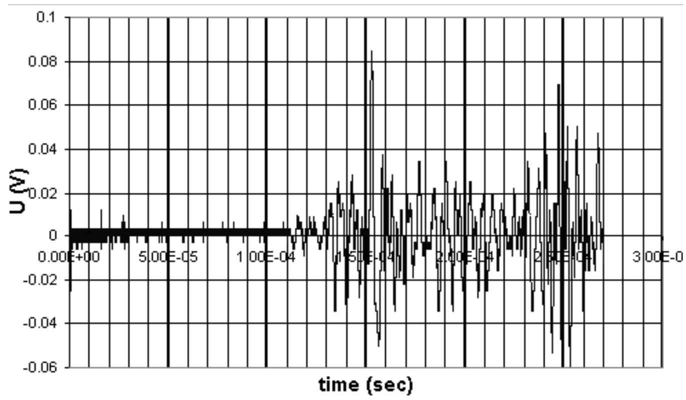

Figure 4 Shock waves generated by the ESWL system

A Hewlett Packard HP 4284A Analyzer, USA, interfaced to a PC was used to obtain the USPT impedance-frequency characteristics. The analyzer has a frequency bandwidth between 20 Hz to 1 MHz, and a LAB VIEW program is implemented to acquire characteristic data in the PC.

The experiments were performed in the same conditions, such as: 200 μsec delay time of photo camera shuts, 50 pulses number of burst signal and 1 sec time period of burst signal. The photos in Figures 5 and 6 illustrate the cavitation bubbles generated by the modified ESWL system, whereas Figure 7 illustrates the cavitation bubbles only by the ESWL.

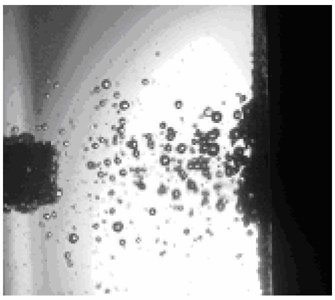

Figure 5 Cavitation bubbles generated modified ESWL system, f = 36 kHz

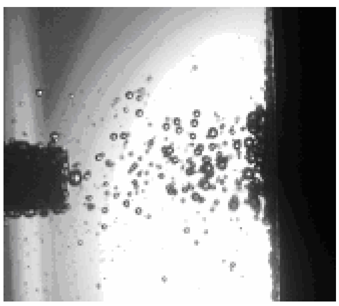

Figure 6 Cavitation bubbles generated modified ESWL system, f = 30 kHz

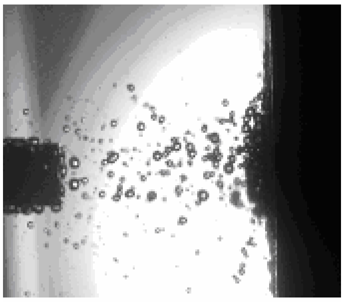

Figure 7 Cavitation bubbles generated by ESWL lithotripter at 14 kV; 200 μs delay time

CONCLUSIONS

The electromagnetic acoustic source lithotripter initiates the incident shock waves into the water, and the ultrasound transducer emphasizes the caviational effects on material fragmentation

Using an experimental modified ESWL system we revealed an improvement of cavitation process, such as: increasing of cavitation size bubbles, better directivity of acoustic field, and shorter period for the material target fragmentation. As result, the Calcium-silicate porous material targets have been destroyed on wider surfaces and deeper. By increasing the number of the burst signals and shocks we could increase the mechanical destroying effects on the samples.

In conclusion, the system ESWL equipment – ultrasound transducer enhances the mechanical efficiency of the lithotripsy process. The experimental results show an improvement of cavitation energy generated by the modified ESWL system.

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