

Focusing of shock waves in water

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Summary

By means of several examples the present study illustrates the possibilities of shock wave focusing in water by the reflection at different reflectors. Therewith, the theoretical assumptions of shock waves in water are confirmed with respect to propagation and reflection behaviour, whereas up to relatively high pressures of several hundred bar shocks in water can be described with very good approximation by the laws of the geometrical acoustics. Only for pressure values above about 300 bar first linear effects occur. However, the alterations of the reflection behaviour can again be compensated by adapted reflector contours. The example of the parabolic reflector showed that for every shock strength one modified reflector form can be calculated, which reflects all surface normals to one point as long as a Mach reflection is avoided. In the following convergence process further non-linear effects counteract against a high energy concentration. Experiments with 14 different reflectors showed how far they limit the singularities in the focus, which are calculated based on the geometrical acoustics.

The focusing of planar shock waves was investigated by using two parabolic reflectors in a vertical water tunnel. The pressure amplitude of the incident wave could be varied between 4-400 bar. Low shock strengths followed from the coupling with shock waves in air, higher strengths from the loading of the water column by an impinging piston. Schlieren pictures showed no visible deviations from the acoustic propagation. However, the pressure measurements yielded a decreasing focusing degree with increasing focal distance and rising shock strength, which shows a greater influence of the low non-linearities. The focusing process was also influenced by wall effects. Therefore, only a moderate amplification of maximal the triple of the incident shock strength developed.

However, the focusing of spherical shock waves by ellipsoid reflectors was more effective. Their installation into a greater water basin excluded the wall effects. The shock initiation resulted from a short-time spark discharge and for higher initiation energies from detonators. A shadow optic allowed observations of the history of shock focusing, whereas for the measurement of the spherical pressure distribution a miniature pressure probe had especially to be developed based on the piezoelectric, polarizable synthetic PVDF. With a rise time of about 50 ns and an expansion of the sensitive pressure probe of about 0.4 mm time- and

local-resolving measurements of high accuracy are possible even in the focal region.

By means of five planar ellipsoid segments, where the shock initiation takes place at certain a distance from the reflector, and seven deep reflectors, which surround the shock center, the influence of the different reflector parameters, such as diameter, depth, focal distance and material, respectively, on the focusing process were explained.

In consequence to their low convexity by using planar reflectors the pressure distribution on the reflected front is nearly constant. Therefore, they were preferred for the fundamental investigations. It became obvious, that an increase of the reflector surface with identical other reflector values results in a raising of the focusing degree, which is about proportional to the root of the area ratio. In addition to that, the focusing effect could further be improved by increasing the convergence angle. The reflector with the greatest relation of diameter and focus distance of $D/f = 3$ therewith achieved the greatest amplification of more than 100, compared to the incident shock at the reflector position. This corresponds to a pressure in the focus of about 1200 bar. In this case the timely pulse length of the focus amplitude only amounts to several hundred nanoseconds. Its rise time is smaller than 50 ns.

During the whole focusing process deviations from the gradient of the acoustic front were not observed. So the position of the pressure maximum of all five planar ellipsoid segments agree with the geometrical focus. The expansion of the focus is strictly limited. Its lateral width of half intensity, with respect to the focal distance, was nearly constant in all examples and amounts to 2 percent of the focal distance.

One of the planar reflectors was produced from a sound-smooth material. Under inversion of the phases its surface reflected the incident shock waves to expansion waves. Up to tensile stresses of -90 bar they could be focused. A further raising was impeded by the development of numerous cavitation bubbles.

Compared to the planar reflectors, for deep ellipsoids non-linear effects clearly occurred due to the long ways to the focus. They were promoted by the geometrical-conditioned pressure concentration to the region near the axis and by the high pressure niveau of the focusing from the outset. This led to a reducing of the shock curve in the central region and therewith, for this part of the shock front to an early ending of the focusing already before the geometrical focus. With increasing reflector size the outer regions become more important for the focusing, so that by interaction of the different front segments the maximal pressure amplitude can even be moved behind the geometrical focus. In conclusion, for the deep reflectors more expanded focus regions were achieved. Therefore, for the same energies of shock initiation as for the planar ellipsoids only maximum

pressures of about 400 bar could be obtained, although the area utilization of about 90 percent is significantly higher compared to 5 percent for the planar ellipsoids. Also an increase of the initiation energies could hardly raise the focal pressure. In contrary, the increase of the non-linear propagation processes yielded an expansion of the focal region.

A self-developed computer program based on a discretization method by Davies and Guy describes the front and the pressure histories of the focusing in good agreement with the experiments. Comparable results were achieved also with respect to the positions of pressure maximum and front amplitude. However, this method does not consider the region behind the shock front. Nevertheless, it is well suited for parametric studies during the development of a reflector.

Finally, several separate experiments demonstrated the effects of focused water shock waves on different materials. Brittle materials could already be destroyed with only several acoustic irradiations. However, tenacious materials could not hardly be influenced. Though, a loading of physical tissue with a similar acoustic impedance as water yielded a growth deceleration so that a concerted application in medicinal therapy remains possible.

Compared to the deep ellipsoids used until now, the application of planar reflectors with high convergence angles could guarantee a more careful therapy, i.e., in medicine science. Its advantage of a more exact focusing and of limiting the pressure region only to a strictly limited local region allows to avoid undesired loadings of the surrounding physical tissue. At the same time, higher amplitudes are easier to obtain, which allow to shorten the period of the therapy. For example, it would be possible to use a dome-shaped transmitter which, depending on the application form, produces a spherical shock or expansion wave of different size directly on its surface. This could be realized with piezoelectric elements on a spherical surface, where an orthogonal moving of the surface could be obtained with the simultaneous, fast excitation, which causes a low shock or an expansion wave or alternating both. At the same time, this apparatus could also be used as receiver. So, the strong entering ability of the produced shock wave would also allow to locate scopes laying in the depth, which would be very favourable compared to ultrasonic diagnostics. Besides, a pulse exciting into the physical tissue must not result from shock waves of water. A thin-walled transmission pad with a corresponding adapted acoustic impedance could more easily fulfill the task of the energy transport, which would entirely lead to considerable savings with respect to location and equipments of the water conditioning. Besides the simplified handling for the stone therapy, a therapy apparatus modified in this way would also facilitate an application to influence diseased physical tissues. So, a therapy of carcinomic regions, for example, which are inassessible so far, seems to be possible using focused shock waves or concerted produced cavitations.