A proposal for research and development in the area of high-energy sonoluminescence

1. Summary

It is proposed that a research and development project be implemented for large-scale investigation of the mechanism of sonoluminescence.

With conventional sonoluminescence research (with bubble diameters of approximately 50 micron), Mach numbers of 4 have been measured in the walls of imploding gas bubbles, along with plasma temperatures estimated to be at least 100,000K. It is suggested that by increasing the scale by the proposed method, it may be possible to generate Mach numbers in excess of 30. As the peak temperature attained in sonoluminescence is estimated to be a function of the fourth power of the Mach number, on this basis temperatures in the order of at least 100 x 10^6K may be feasible. This is higher than can be attained by any other mechanism.

2. Background

The term sonoluminescence means literally “light from sound.” Sonoluminescence is generated within an air bubble in a liquid such as water which has been exposed to variations in pressure, typically from high frequency sound waves. According to the most commonly accepted theory, the supersonic collapse of the bubble launches an imploding spherical shock wave, the strength and velocity of which varies inversely as the square of the radius. Thus if it were possible to focus the shock wave to a point (or a line), its velocity and intensity would theoretically be infinite. However, limits on the minimum size of volume of the focus are imposed due to the fact that imploding shock waves tend to become unstable as initial irregularities in the sphericity become more significant at smaller scales.

Although bubble sizes measured to date have been relatively small (maximum radii around 50 microns, minimum about 0.5 micron) collapse velocities have been measured by high-speed lasers at over 1 km/sec, or about Mach 4. On this basis, the corresponding acceleration of the bubble at the limit of collapse has been calculated to be at least 10^{11} g. As the maximum temperature realisable within the shock wave is a function of the twice the square of the Mach number (ref. 2), it is very sensitive to scale. The temperature in the liquid pendulum engine will also be raised by shear heating in the interface between the relatively stationary core and the imploding free vortex.

3. Proposed project

The objective of the proposed research would be to scale up the size of the imploding shock wave by means of an oscillating liquid piston as shown.

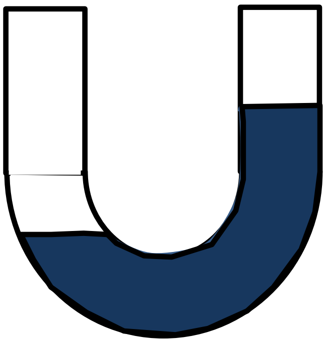
3.1. The principle of the liquid pendulum

In analogy with a simple pendulum, the frequency of oscillation of the liquid pendulum (in a gravitational field) depicted in Fig. 2 is given by:

$$f = \frac{1}{2\pi} * \sqrt{(2 * g)/L}$$

where g = acceleration due to gravity
L = length of the fluid column within the pendulum

Fig. 2



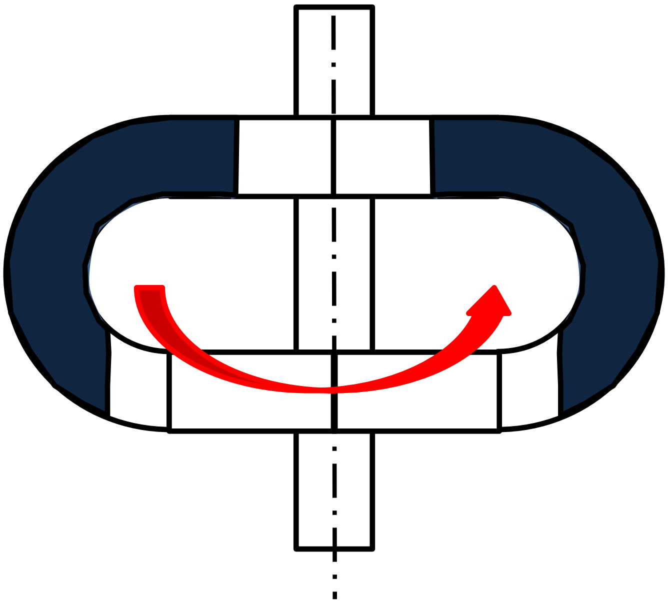


Fig. 3 Principle of rotating liquid piston mechanism

If the liquid pendulum is spun around an axis as shown in Fig. 3, the centrifugal field analogous to the gravitational field g in Fig. 2 is given by $\omega^2.r$, where ω is the angular velocity of rotation and r is the mean radius of rotation. Hence the natural frequency of oscillation will be directly proportional to rotational velocity. By forcing the oscillation of the liquid piston at the natural frequency through the rotating eccentric, a rapidly expanding and collapsing void will be created at the shock chamber.

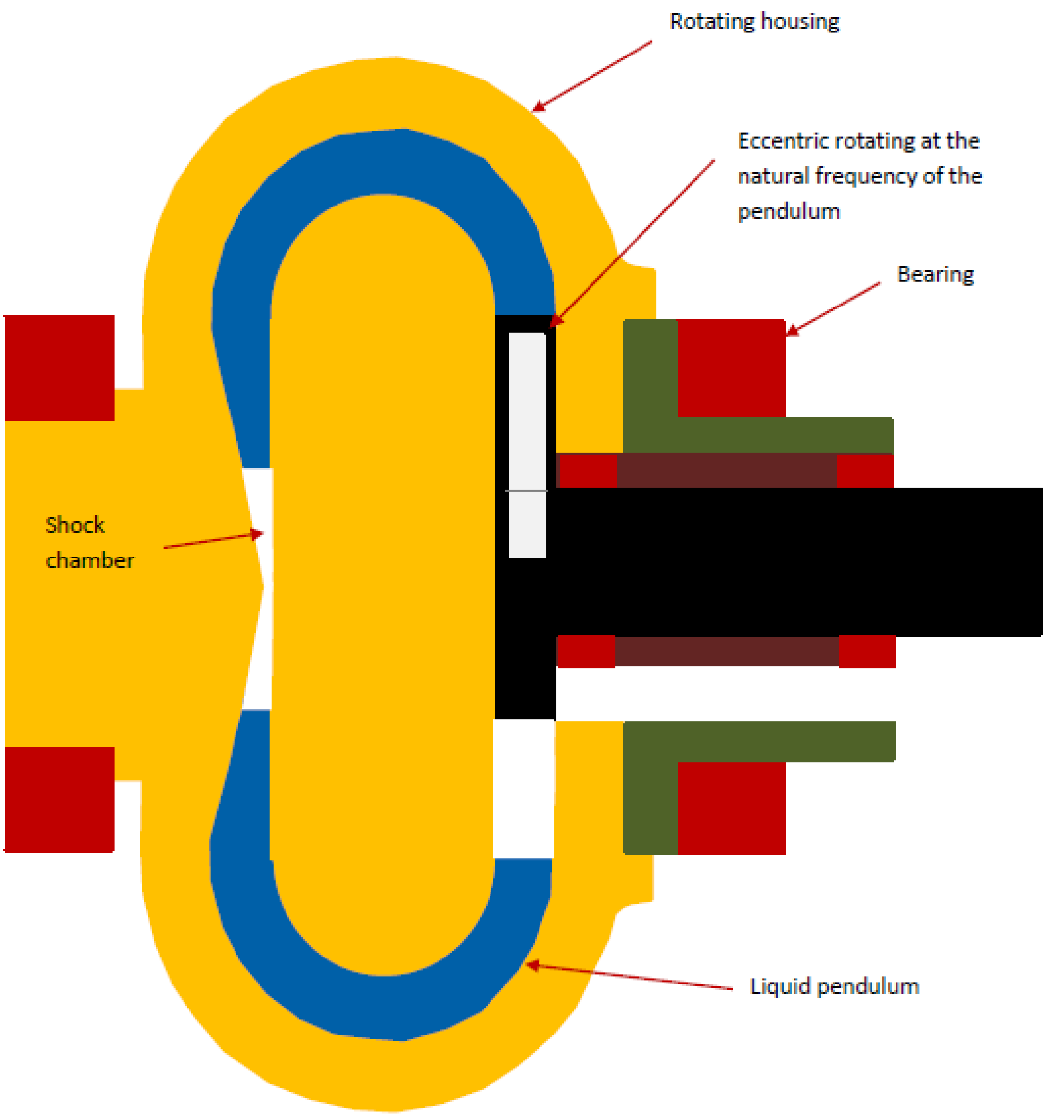


Fig. 4 **Diagrammatic arrangement of liquid piston engine**

3.2. Energy intensification

3.2.1. Sh

3.2.2. ock wave heating

The temperature rise across a shock wave is normally a function of the square of the Mach number, but in an implosion, just after the point of focussing, it is a function of *double* the square power as explained:

> *For an imploding gas bubble, the Mach number approaches infinity as the shock wave moves closer to the focal point, which means that a tremendous amount of heating takes place. Furthermore, when the shock wave hits the centre and explodes outward, the molecules that were behind the shock wave are suddenly in front of it again. The hot molecules are hit a second time and their temperatures go up by another factor of the square of the Mach number. (ref. 3)*

3.2.3. Viscous shear heating

The proposed system would have a mechanism not present within the current sonoluminescence research: as an implosion occurs in a rotating system, the motion of the molecules tend to generate a free vortex. The ramifications of this are that the tangential velocity of the shock front increases inversely with its radius.

The shear force between the relatively stationary core and the shock front would then be extremely high from the relationship

$$F = \mu A \frac{dv}{dx}$$

where dv/dx is large due to the fact that the shock transition occurs over a distance which is of the order of the molecular collision mean free path. At the density which is expected to be generated at the focus of the imploding matter, the thickness of the shear zone would be in the order of one nanometre.

As the power dissipated in shear is a function of the product of the shear force and shear velocity,

Power/Area = $f(F \, . \, v \, . \, r^{-2})$

= $f\text{‘}((r^{2} \, . \, r^{-1}) \, . \, (r^{-1}) \, . \, r^{-2})$

= $f\text{’‘} \, (r^{-2})$

It has been predicted that plasma densities approaching those of typical metals could be generated at the focus (ref. 3). When taking into account this increase in density (which would reduce the thickness of the shear zone and hence increase dv/dx), the power per unit area would be a function of the inverse fifth power of radius. This would bring about a very significant further increase in temperature.

3.3. Limitations

3.3.1. Mechanical

Because the mechanism depends for its effectiveness on focussing the shock wave to a relatively fine point in space, overcoming friction within the mechanism will be important. However it is expected that very significant temperatures can be attained.

The frequency of oscillation of the system is primarily a function of the angular velocity of the liquid pendulum, and hence high rotational speeds are needed. The limitation will be due to centrifugal stresses. Some benefit may be obtained by using a gas-pressurised chamber on the eccentric side of the liquid pendulum to increase the natural frequency of the system.

3.3.2. Scaling Problems

Because the mechanism of sonoluminescence is inherently non-linear, efforts to increase the scale of generation may encounter unforeseen problems.

3.3.3. Material Integrity

With extremely high temperatures possible, damage to components could be a serious obstacle. However there are many potential applications where the temperatures are well within the capacity of existing materials.

3.4. Possible Applications

3.4.1. Sonochemistry

Sonochemistry can arguably use the highly localised pressures and temperatures generated in sonoluminescence to achieve processes not possible with conventional techniques.

Applications include amorphous metal alloys, oxides and nitrides. If molten metal is cooled quickly enough, it can solidify before crystallisation has time to occur. Unlike conventional metals or alloys, the resulting structure is amorphous on a scale greater than a few hundred atoms. They can thus have unique electronic and magnetic properties and can also be more resistant to corrosion. Also “nanophase” metals typically have hardness and tensile strength in the region of five times that of conventional metals, due to the fact that the small crystals do not contain any dislocations (ref.5).

Sonoluminescence has been used to convert iron pentocarbonyl to amorphous iron, which has a very high surface area and is used as a catalyst for several important reactions, such as converting coal to liquid fuel (in the Fischer-Tropsch process). Amorphous iron also has magnetic properties highly desirable for purposes such as electrical transformer cores, magnetic media and magnetic recorder heads.

The production of amorphous metals depends on obtaining high cooling rates. The high turbulence and liquid pressure likely to be associated with the proposed system would give far greater cooling rates than those achievable using conventional methods, such as spraying liquid metal onto a high speed rotating copper disc or drum (ref. 4).

3.4.2. Defence

If the laser action is proven practicable, the energy level and efficiency may be high enough to be of considerable interest for Defence applications.

3.4.3. Energy

Large scale sonoluminescence may be able to generate temperatures high enough for the initiation of nuclear fusion. Several researchers have already reported evidence of non-fusion nuclear processes (and in one case, small but significant amounts of anomalous excess heat) associated with sonoluminescence (refs. 2, 3, 4).

3.5. Conclusion

The use of imploding cavities to focus shock waves is an elegant mechanism for achieving previously unattainable temperatures and densities. It may well be the basis for the “blast furnace” of the future, in that the conditions may support the metallurgical and chemical reactions required for important new classes of solid materials.

The temperatures achieved could support a range of applications including nuclear fusion and lasers.

References

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