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Research article :

About a possibility for a tabletop fusion device

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Abstract:

Energy is more and more a concern because the needs increase and the resources are going to rarefy. We propose a new idea for a fusion device which could be a solution to afford for energy supply. The proposed device has not been tested but, if working, it could be a cheap, safe and distributed energy source. Over the last few years, many ways to reach the conditions of nuclear fusion were explored, and amongst them, the x-pinch experiments and the Single Bubble Sono Luminescence. We propose here a new device which uses both of these concepts, each of them enhancing the other.

I- Introduction

The Increasing need of energy and predicable rarefaction of oil cause economic stress all over the world and this problematic is going to be more significant. At this time, the alternative energy sources seem to be a poor answer to the world necessities. The solar, thermal and photovoltaic, and wind energies are intermittent and ask for energy storing solutions which are not easily affordable. The fission nuclear energy has a lot of drawbacks as nuclear waste, needs of a cold source which is usually river water causing its ecosystem warming and limited Uranium reserves available only for fifty to two hundred years. The fusion in huge plants as

tokamak seems not to work before a long time and is a very complicated way. It begins with a low pressure gas to be able to ionize it and get a plasma, compress it with high intensity magnetic fields to increase the density, then warm it with micro waves and when the fusion is supposed to be there, at last put all the stuff in a steam machine.

Maybe there is a place for a more simple device which can be made at different scale as the electric motor or the combustion engine whose dimensions can be in millimeters to ten meters range. It is the aim of this paper to humbly propose such a device as a possibility.

II- Quest for sonoluminescence fusion device

Around the end of the last century, the light emission produced by a small cavitation bubble created by an acoustic standing wave was studied mainly on its SBSL form (Single Bubble Sono Luminescence). A chemistry glass balloon filled with a fluid as water vibrates under the excitation of piezoelectric drivers [1,2]. A standing wave induces huge pressure variations at the center of the balloon, and a light emitting bubble can appear.

People got excited by sonoluminescence phenomena because of theorists who published results of calculation (neglecting a lot of parameters) showing temperature inside the cavitation bubble as high as 10^7 K [3], not so far of the 10^8 K temperature threshold for Deuterium-Tritium fusion. Other simulation papers taking into account lost parameters expected temperature in the range of the 10^5 K, and now some 10^4 K [4]. Measurements have shown, by fitting with black body radiation, temperatures from 25 000 to 50 000 K [5]. The temperature elevation reached by the bubble is due to the compression, its size passing from 50 μ m diameter to 5 μ m and even to 0.5 μ m, involving compression factor from one thousand to one million. At those temperatures the gas inside the bubble is certainly a plasma as claimed in [6] where temperature of 15 200 K were measured and very high energy excited states in Argon were seen. In this situation, the gas is an electric conducting medium. In 2002 was published a paper from Rusi Taleyarkhan (and al.) [7] of Oak Ridge National Laboratory who claimed have seen nuclear fusion in a sonoluminescence experiment. Unfortunately, nobody

seems could not have reproduce successfully this experiment. An overview of the field can be found in [8].

III- Z-pinch fusion

Another way to explore nuclear fusion is Z-pinch experiments in every of its representative, from the very large Sandia facility [9], to the more human size ZaP flow Z-pinch [10], Magnetized Liner Inertial Fusion (MagLIF) [11], Sheared Flow Stabilized Z-Pinch [12], and others. Sandia published extremely high temperatures of more than two billion degrees (2×10^9 K !!!) induced by the vaporization of a wire-array where 18 MA flew during 100 ns [13].

The physical principle is the compression of a gas discharge under the force developed by the current inside the discharge under the magnetic field produce by itself. Each charge carrier, electron or ion, is moving under the effect of an electric field and is subject to the magnetic field produced by the motion of all the other charge carriers as shows fig.1. The force developed in this magnetic field causes an electromagnetic pressure counteracted by the increase of the thermodynamic pressure due to the density and temperature augmentation. The resulting equilibrium is described by the Bennet relation [14]. This relation establish the dependence between the current inside the plasma and the density temperature product as $8\pi Nk(ZT_e+T_i)=\mu_0 I^2$ [15]. The resulting increase of density and temperature can allow reaching the fusion conditions stated by the Lawson criterion which joints the density n , temperature T and confinement time t_E in the following relation:

$$n T t_E > 10^{21} \text{ (keV m}^{-3} \text{ s)}.$$

Z-Pinch has been proposed since a long time as a possible way for fusion reactor design [16]. Many tentative of realization exist as Staged Z-Pinch [17], Sheared Flow Stabilized Z-Pinch [18], Gas Puff [19]...

Fusion was witnessed by neutron production measurements [18-21], but it seems the difficulty consists to obtain a stable operation and neutron emission with an interesting energetic yield.

IV- X-Pinch

Instead of making a cylinder discharge, one other way explored is the try to obtain a punctual one. It is the x-pinch where the discharge is made between two crossing wires. It has been used as a high quality X rays source. A review can be found in [22].

V- Pinch triggered by Sonoluminescence

The first goal of these considerations was the quest for a photon source since the sonoluminescence is supposed to produce some light over a large continuous range of wavelengths from IR to hard X ray [23]. Furthermore, the radiation is pulsed, allowing temporal experiments as permitted by synchrotron radiation (but not with the same photon flux). In this perspective, it is necessary to think about an adapted geometry which avoids the photon absorption by the used fluid (usually water, acetone or sulfuric acid). One possibility, depicted fig.2, corresponds to a cut of the classical SBSL balloon and the insertion of two cones. The sound excitation can come from a current in a coil wrapped around the partly spherical vessel where a magnetic field is imposed. When an alternative current is supply to the coil, the vessel vibrates and this move leads to a wave focused at the center of the device. Very high pressure variations are then generated at the center of the sphere. The photons were supposed to be caught through a diamond window (fig.3) for the isolation between the fluid and the vacuum (truly, over a small solid angle...). The excitation frequency, if the dimensions are the same as the usual SBSL device, is close to 25 kHz. It is to note that, starting from the SBSL balloon, it is natural to consider a partly spherical vessel to get a partially spherical wave, may be other shapes should have good performances, as cylinder in [7].

Comparing with z-pinch problematic where people seek for high density and temperature gas in respect to the Lawson criteria, but start with very low gas pressure we considered the complementarities of those two worlds, sonoluminescence and z-pinch (fig.2).

Assuming an electrically insulating fluid, if a high voltage is set between the two cones, a discharge can occur at the apex of the cones when the gas inside the

bubble, which should be Deuterium-Tritium for instance, turns to plasma by effect of cavitation, and so become a conductive media. One problem evocated inside the literature about the z-pinch is the high voltage commutation speed. This problem could be avoided in the proposed configuration because the passage of the insulating state to the conductive one is supposed to be very fast in the bubble, in the sub nanosecond range as the variation speed of temperature let expect [23], commutation speed which is very difficult to obtain by other technical ways. At this time, we can hope to obtain similar effects than in classical z-pinch which were only tested at this time, as we know, starting with a low pressure and temperature gas whereas the bubble offers high temperature and high density. When the discharge is terminated, the switch SW can be set ON to charge the capacitor C for the next cycle. It is to note that the switch SW uses only at the capacitor C charge and can be replaced by a resistor at the cost of more energy dissipation. In the case where the fluid is not a good insulator, to avoid conductive losses the cones must be covered with an insulating layer, except at their apex where the current must flows.

Considering very naïve thermodynamic consideration, supposing that the model is still valid when very high energy density is involved, we can estimate the energy in the bubble at the room pressure and temperature and when the spherical acoustical wave have compressed it at its maximum. For a quite small bubble of 50×10^{-6} m diameter, at $T = 300\text{K}$ and $P = 1\text{atm}$, the number of mole of gas is $n = 2.92 \times 10^{-12}$. The thermal energy stocked in the bubble is

$$U = 3/2 nRT = 1.09 \times 10^{-8} \text{ J.}$$

At $30\,000\text{K}$ the energy rises to $U = 1.09 \times 10^{-6} \text{ J}$ and at $T = 10^8 \text{ K}$ the energy stored reaches $U = 0.00364 \text{ J}$. By comparison with the energy stored inside a capacitor of $1 \mu\text{F}$ under 100V is $U_c = 0.005 \text{ J}$. Since the capacitor can be augmented up to thousands of μF and the applied voltage increased up to kV or more we can see there is a possibility to raise the electric energy communicates to the bubble by a factor of tens to hundreds of thousands, even taking into account all the losses. Considering all those things, we can reasonably hope far exceed the Lawson criteria and get a working tabletop fusion device.

The gas of the bubble can come from the fluid outgasing or by a feeding system installed on the axis of one cone, involving a needle or just a small hole (fig.3) to let in the gas at the low pressure part of the cycle.

If working, the energy released by fusion could induce a pressure wave inside the fluid which propagates to the vessel. If the coil of wire length L around the vessel is forced to move at the speed v inside the space where is the magnetic field B , a voltage $E = v.L.B$ is generated at the ends of the coil. If the system can be set in a resonant mode, may be it can acts as a direct fusion conversion apparatus and the electric energy harvested directly on the vessel coil, which doesn't have to be use any more for the acoustic excitation but for energy extraction. Due to the small volume of gas inside the bubble, such a device could afford energy in the range of kW or tens of kW, instead of tens of MW as in classical z-pinch realizations, which is enough to supply a house or a vehicle.

Such a device, if working, has to include safety protections about a large sound level, possibly fast neutron emission and heat production. A solution could be its installation in a tank, filled with water or any suitable fluid, set at the proper dimensions and shape according to the working wavelength.

An important point to have a spherical wave is the choice of the cones material which must have specific acoustic impedance far higher than the used fluid. This condition excludes the polymers and can allow the use of metal or ceramic parts. At the contrary, mechanical spacers set to hold the cones together should use PMMA or any matter with acoustic impedance close to those of the fluid. At the apex of the cone, it also has to withstand electric sparks, and so, intend to select refractory metal as Tungsten or Tantalum.

If the bubble diameter is small regarding the distance between the cones, the high voltage between them must be just under the disruptive voltage in the fluid, which is for pure water around 130kV/cm for instance [24]. If the gas is in touch of both cones due to a filling system tuning, this voltage should be lower, because when the gas turns to plasma, it can conduct all over the interspaces.

If fusion can be induced by the way describe here, we can imagine other geometries as for instance the push-pull configuration shown fig.4. Anyway, in all

realizable configurations, except for electrical measurements, current and voltage, instrumentation will be quite a challenge and shall require a lot of imagination.

VI- Conclusion

Starting from a state closer to the Lawson criteria, can we hope to reach the fusion conditions more easily? Only the experiments can answer this question.

For the future, we will perform some multiphysic simulation to determine a suitable geometry before trying a realization. In the sake of finding a so desirable energy source, we hope this proposition is realist and other groups can be interested in it. The system should also be investigated as a pulsed X ray source.

References

- [1] Seth J. Putterman, Sonoluminescence: Sound into light, *Scientific American*, Feb. 1995, p. 32-37
- [2] Seth J. Putterman, Sonoluminescence: The Star in a Jar, *Physics World*, May. 1998, p. 38-42
- [3] Vi Q. Vuong, Andrew J. Szeri, David A. Young, Sonoluminescence and diffusive transport, *Phys. Fluids*, vol.8, pp.2354-2364, 1996.
<https://doi.org/10.1063/1.869020>
- [4] Wu and Roberts, Shock-wave propagation in a sonoluminescing gas bubble, *Physical Review Letters* 70, pp.3424-3427, 1993.
<https://doi.org/10.1103/PhysRevLett.70.3424>
- [5] Hiller, R., S. J. Putterman, and B. P. Barber, Spectrum of synchronous picosecond sonoluminescence, *Physical Review Letters* 69, 1182–1184, 1992.
<https://doi.org/10.1103/PhysRevLett.69.1182>
- [6] David J. Flannigan & Kenneth S. Suslick, Plasma formation and temperature measurement during single-bubble cavitation, *NATURE* , VOL 434, 52-55, MARCH 2005. doi:10.1038/nature03361

[7] R. P. Taleyarkhan, C. D. West, J. S. Cho, R. T. Lahey Jr., R. I. Nigmatulin, R. C. Block, Evidence for Nuclear Emissions During Acoustic Cavitation, SCIENCE VOL 295, pp.1868-1873, 8 MARCH 2002.

<https://doi.org/10.1126/science.1067589>

[8] Michael P. Brenner, Sascha Hilgenfeldt and Detlef Lohse, Single-bubble sonoluminescence, REVIEWS OF MODERN PHYSICS, VOLUME 74, APRIL 2002. DOI: <https://doi.org/10.1103/RevModPhys.74.425>

[9] D. B. Sinars & al., Review of pulsed power-driven high energy density physics research on Z at Sandia, Physics of Plasmas 27, 070501 (2020);

<https://doi.org/10.1063/5.0007476>

[10] D. J. Den Hartog, R. P. Golingo, S. L. Jackson, B. A. Nelson & U. Shumlak (2005) The ZaP Flow Z-Pinch: Plasma Flow Shear and Stability, Fusion Science and Technology, 47:1T, 134-137, DOI: [10.13182/FST05-A624](https://doi.org/10.13182/FST05-A624)

[11] M.R. Gomez & al., Performance Scaling in Magnetized Liner Inertial Fusion Experiments, Physical Review Letters 125, 155002 (2020) DOI: 10.1103/PhysRevLett.125.155002

[12] E. G. Forbes & al., Progress Towards a Compact Fusion Reactor using the Sheared-Flow Stabilized Z-Pinch, Fusion Science and Technology, Volume 75, 2019 - Issue 7: Selected papers from the 23rd Topical Meeting on the Technology of Fusion Energy—Advanced Concepts and Materials

<https://doi.org/10.1080/15361055.2019.1622971>

[13] M.G. Haines & al., Ion Viscous Heating in a Magnetohydrodynamically Unstable Z Pinch at Over 2×10^9 Kelvin, Physical Review Letters, PRL 96, 075003 (2006), DOI: 10.1103/PhysRevLett.96.075003

[14] W.H.Bennett, Magnetically Self-Focusing Streams, *Phys. Rev.* **45** 890 (1934), DOI: [10.1103/PhysRev.45.890](https://doi.org/10.1103/PhysRev.45.890)

[15] M.G. Haines, A Review of Dense Z-Pinch, Plasma Physics and Controlled Fusion, 53 (2011) 09300, DOI: <http://dx.doi.org/10.1088/0741-3335/53/9/093001>

- [16] C.W. Hartman, G. Carlson, M. Hoffman, R. Werne, D.Y. Cheng, A conceptual Fusion Reactor Based On The High Plasma Density Z-pinch, Towards a Compact Fusion Reactor using the Sheared-Flow Stabilized Z-Pinch, ion, Nucl. Fus. Progress 17 5 (1977) p.909-918
- [17] Wessel, F. J., Rahman, H. U., Presura, R., and Ney, P., Fusion in a Staged Z-Pinch, IEEE Trans. Plasma Sci. 43(8), 2463(2015) DOI: 10.1109/TPS.2015.2433796
- [18] Y. Zhang & al., Sustained Neutron Production from a Sheared-Flow Stabilized Z Pinch, Phys. Rev. Lett. 122, 135001 (2019), DOI: 10.1103/PhysRevLett.122.135001
- [19] D. Klir & al., Ion acceleration and neutron production in hybrid gas-puff z-pinch on the GIT-12 and HAWK generators, Matter Radiat. Extremes 5, 026401 (2020); doi: 10.1063/1.5132845
- [20] C. L. Ruiz & al., Production of Thermonuclear Neutrons from Deuterium-Filled Capsule Implosions Driven by Z-Pinch Dynamic Hohlräume, Physical Review Letters vol.93, no.1, 2 JULY 2004, p. 015001-1, DOI: 10.1103/PhysRevLett.93.015001
- [21] C. A. Coverdale, C. Deeney, A. L. Velikovich, R. W. Clark, Y. K. Chong et al., Neutron production and implosion characteristics of a deuterium gas-puff Z-pinch, Phys. Plasmas 14, 022706 (2007); doi: 10.1063/1.2446177
- [22] S. A. Pikuz & al., X-Pinch. Part I, PLASMA PHYSICS REPORTS, Vol. 41 No. 4, 291-342 (2015). DOI:[10.1134/S1063780X15040054](https://doi.org/10.1134/S1063780X15040054)
- [23] P.D.S. Burnett et al., Modeling a sonoluminescing bubble as a plasma, Journal of Quantitative Spectroscopy & Radiative Transfer 71 (2001) 215–223. [https://doi.org/10.1016/S0022-4073\(01\)00069-3](https://doi.org/10.1016/S0022-4073(01)00069-3)
- [24] A. I. Gerasimov, Water as an Insulator in Pulsed Facilities, Instruments and Experimental Techniques, Vol. 48 No. 2 (2005), pp. 141–167. <http://dx.doi.org/10.1007/s10786-005-0029-7>

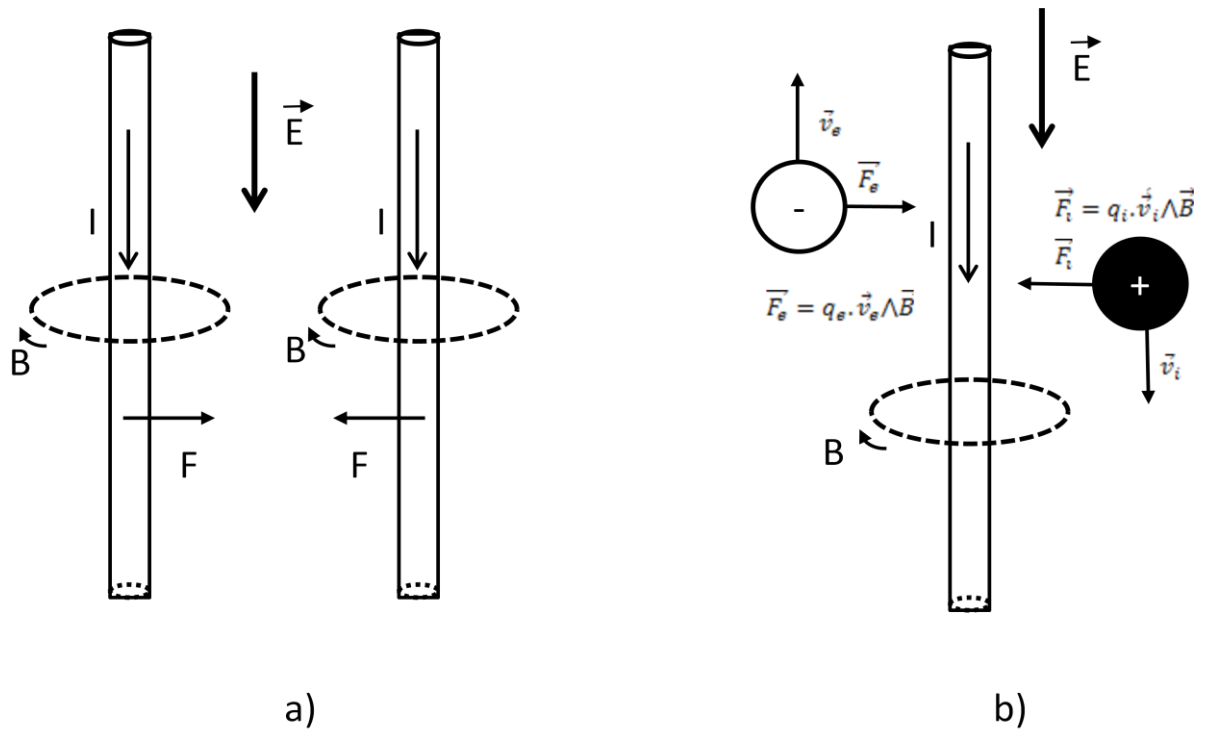


Fig. 1 a) Each of two conductors is subject to a force F due to the magnetic field induced by the current inside the other. b) Each charge carrier, ion or electron, is subject of a force F_i or F_e induced by the magnetic field generated by current of all the other charge carriers.

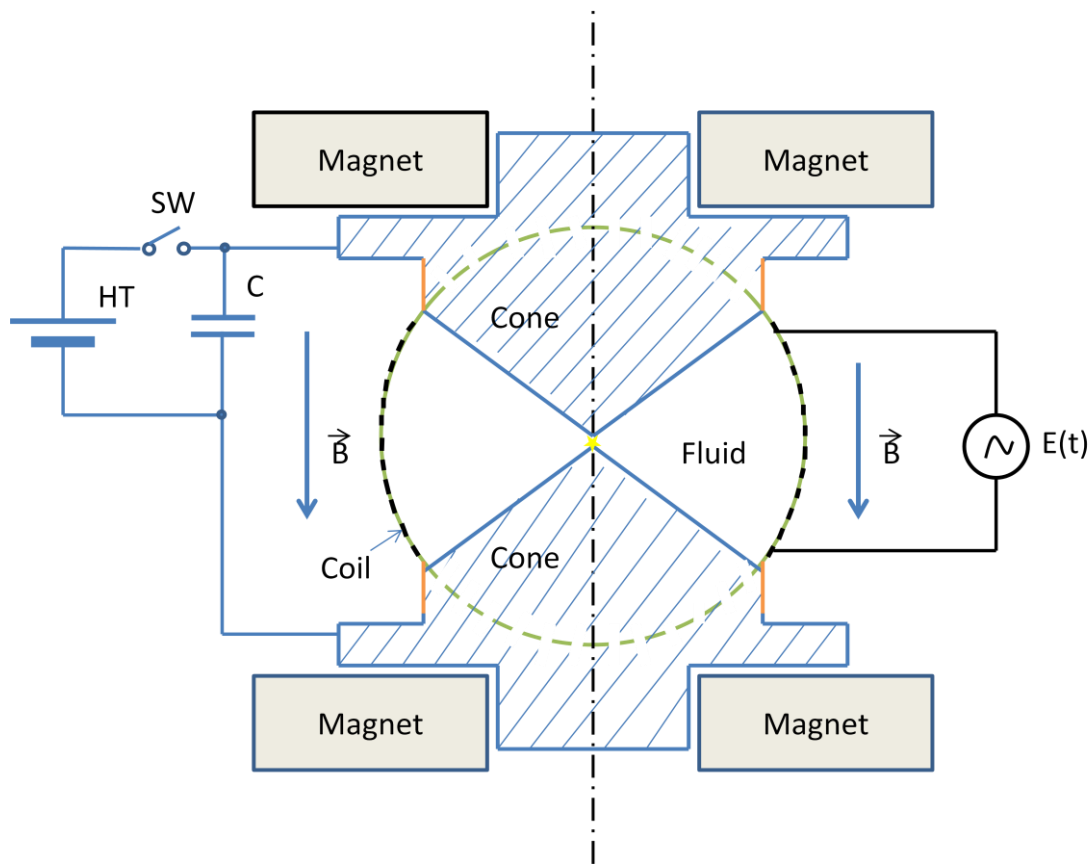


Fig. 2 Sketch of the proposed device

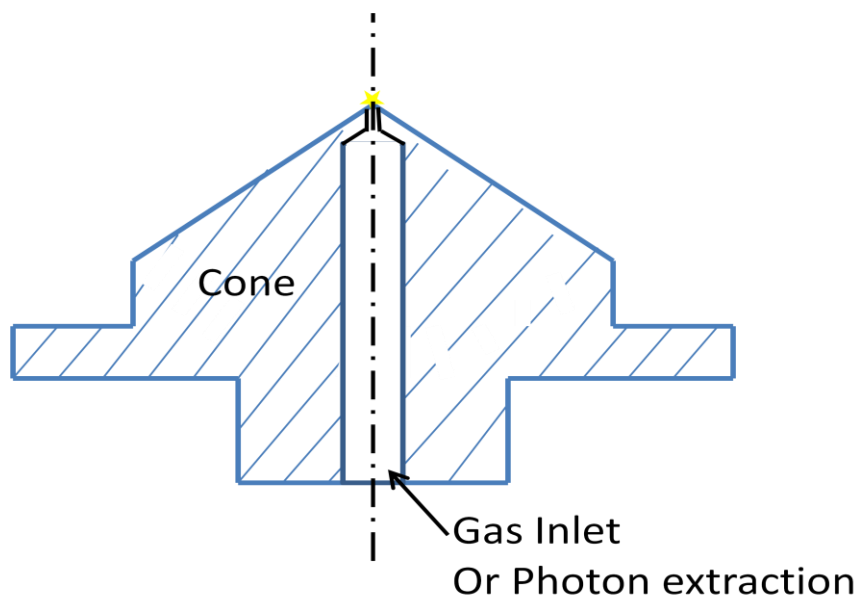


Fig. 3 Detail of the cone structure adapted for gas inlet or photon extraction

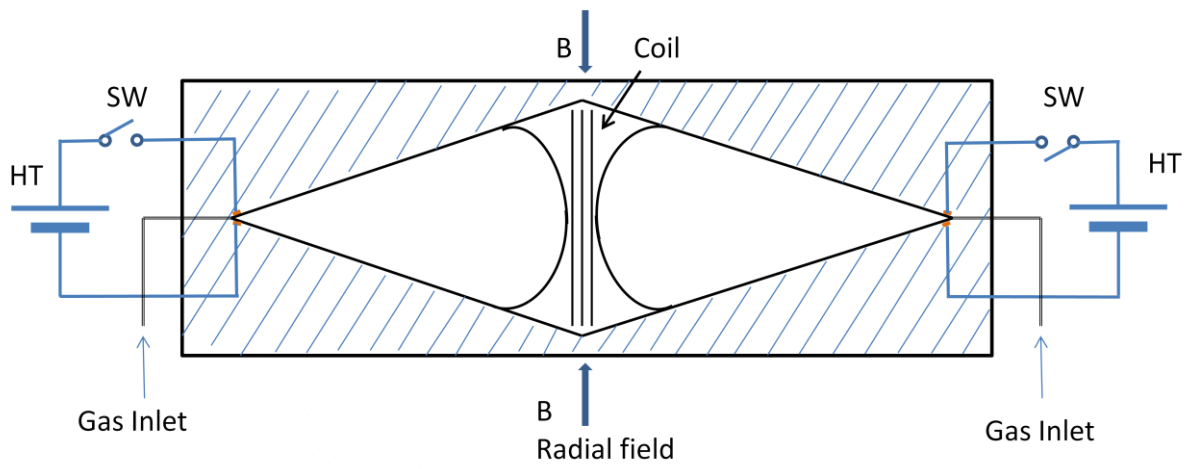


Fig. 4 Example of another geometry as push-pull structure (facultative capacitors omitted)