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The Use of Piezoelectric Materials for the Purpose of Creating Infrasound and Ultrasound Sources for Terrorist Acts

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Abstract: The contemporary security environment has increasingly unpredictable mutations and the international scene seems to be gripped by a conflict that threatens to erupt at any moment, becoming an open conflict, violent and able to spread quickly everywhere. The technological development of the last decades and the so-called revolution in military affairs have not only produced beneficial consequences for human society, but have also opened the possibility of developing new technologies for the benefit of the terrorist organizations. These include infrasound and ultrasound technology, sources with continuous or pulsed operation, capable of acting in a very discreet regime, being very hard to detect, also capable of causing serious harm to human health and even the death. The fact that such devices have the ability to act completely silently amplifies their dangerousness. Due to the authors' research, the present paper aims to present a series of relatively simple technologies for making such weapons which can work with acoustic waves in the non-audible regime. The field is interesting and the rapid technological evolution leaves this chapter open to further debates. With the development of piezoelectric technology, we are witnessing the tendency to develop military applications of this technology briefly presented in our paper, especially in the field of mechanical wavelengths from the ultrasonic regime, but also many other applications.

Keywords: Piezoelectric Materials, Infrasound's, Ultrasounds, Weapons

1. Introduction

At present, both in physics and in the medical field, it is known that in elastic environments (such as, in particular, the terrestrial atmosphere) both low frequency mechanical oscillations (those that have a frequency lower than the lowest audible threshold of 20 Hz), and those of high-frequency, can cause various health problems for people or other creatures. Such as the alteration of the general condition, the appearance of some syncope, in some cases even the serious alteration of internal organs, burns at the exposed skin surface, etc. [1, 3, 5, 8, 10].

With the first findings on the biological effects of low or high frequency mechanical waves, the idea of using these mechanical waves in the armaments industry also appeared. An important aspect is that the oscillations with frequencies below 20 Hz and both those with frequencies above 20 kHz are below the threshold of audibility, so their presence or propagation is not detected by humans, and in the moment when these mechanical waves produce effects on the human body, most often the victims or those close to them, are unable to identify the danger and source of the health problems that have arisen [3, 5, 8].

Thus, armaments based on silent sound technology can be made, either mechanized or portable, based on the use of infrasound or ultrasound sources. Such weapons would have the ability to act effectively but also perfectly silent.

Thus, terrorist attacks can occur, in which the presence and the activity of the terrorists will not be perceived, but only the effects of the mechanical waves will suddenly appear, causing destruction and casualties, panic and confusion. As a result of such attacks, the terrorists will have the opportunity and time to leave the scene without being identified by witnesses or captured by law enforcement.

The contemporary world undergoes a vast process of reconfiguration in all its aspects, the main factors being the rapid technological evolution and globalization process. These factors also have an effect on military thinking, on the panoply of those who plan and perform armed actions. The fastest technological evolution has led, among other things, to the emergence of increasingly compact weapon devices and to the growing of their power. This has led to the development of new weapon models with superior technical and tactical features. At the same time, the contemporary world has seen itself facing new and serious challenges, some of them unprecedented, which puts new light on the issue of national and international security.

With the improvement of weapons technology at the disposal of the armed forces, the means and methods applied by the terrorist organizations have improved, as they have tended to no longer resort to the classic way of organizing and carrying out the attacks, but to actions based on state-of-the-art technologies.

A rather relevant case is represented by the means used during the guerrilla war deployed by Afghan rebel forces during the US military occupation. We can see how the fighting technique of Afghan rebels evolved between 2001 and 2017, adapting to the technological evolution of the world. It is to be expected that soon, terrorist organizations will move to the use of more and more advanced technologies, such as:

1) computer science and cybernetics;
2) bio-nanotechnologies;
3) biochemical hybrid weapons;
4) chemical weapons based on raw materials (precursors) commercially available, also on simple and inexpensive manufacturing techniques;
5) portable weapons, with a new, efficient, silent, modular construction type (such as the electromagnetic weapons, the weapons based on mechanical wave sources, etc.).

In such a new context, in which is often noticed the general adaptation of the terrorist organizations to contemporary technological progress, we will not face a much more dangerous enemy, able to act effectively even against armored cars, using mechanical waves sources of a certain intensity and frequency. They will soon be able to use electromagnetic actuated projectiles, microwave beams, or mechanical waves propagated through elastic environments. With such new means of combat, the terrorist will be able to easily destroy hard solids, also destroying armor and fortifications. This could be achieved by the resonance phenomenon at the molecular level.

The example of the Afghanistan War is interesting from the perspective of analyzing the way in which seemingly rudimentary armed forces, at a general level of development far inferior to the US Army, have managed to adapt quickly to the technological progress and to be a virtually invincible force in front of the foreigner invader. It is known that in 2001 the US Army invaded Afghanistan under controversial legal conditions, which sparked stormy debates in the international relations environment.

This US military assault was initially directly sustained only by the United Kingdom and Canada, later being attracted in a so-called coalition another 40 states, most of them NATO member states. The official purpose of this military intervention was to destroy the terrorist networks in Afghan territory and to impose a democratic regime instead of the Taliban religious regime. Although it seemed to be a relatively easy intervention for the Americans, the disproportion between the armed forces being very high, the Afghanistan War proved to be the longest war involving the US and the most problematic conflict, all the methods attempted by the Americans being led by failures.

On October 7, 2001, the Operation Enduring Freedom was launched in cooperation with the UK. It was not until December 2001 that the so-called International Security Assistance Force (ISAF) was established at the UN level, in order to assist the authorities of the Afghan political regime imposed by the faithful Americans, in an attempt to create a stable political regime. Already in the summer of 2003, NATO came to support ISAF, which also took over the control of this organization. On this occasion, troops from all NATO states, including Romania, were sent to Afghanistan.

It is important to recall these political-military aspects, since the mere passing of them shows that against a weak state which has been deprived of industry, of modern armed forces, of infrastructure, etc., acted some stronger and more developed states on Earth. In theory, the defeat of the Afghans should have taken place as soon as possible.

Using rudimentary but ingenious means of fighting, the Afghans not only resisted during the fight with an international military coalition, but even caused great losses to their enemy. This historical example should allow us to think and focus more and more attention on these seemingly insignificant technologies.

2. New Technologies with Military Applications

The historical example that we have referred shows the manner in which seemingly rudimentary fighters who seem to be detached from the Middle Ages, have managed to quickly and ingeniously adapt the ultramodern technique, making a panoply of artisanal weapons, remarkable through their simplicity and effectiveness. So, we will continue to concern ourselves with the possibility that, in the panoply of the contemporary war, new means of combat would appear, based on new technologies, which although known, have not been applied until now to the execution of armaments.

Returning to the previous historical example, it was possible to see how the American military invasion led to the withdrawal and concealment of the Taliban forces, with a guerilla-specific maneuver, but which gave the impression of a defeat. Mullah Mohammed Omar organized the resistance struggle against the American invader from 2003 until his death in 2013. The Afghan resistance fighters against the American occupant came under the guerrilla warfare: raids,

assaults, ambushes, suicide attacks, etc.

Interesting to note is the fighting technique used by Afghans in this decade (2003-2013), as their resistance struggle has become increasingly organized and effective. During 2003-2006, there was a seeming lull, the guerilla forces seeking to adapt to the situation and to develop the necessary armaments.

The Taliban fighting has become more and more effective in 2007-2009, and battles have gradually expanded to Pakistan. In fact, according to US official statements, the terrorist leader Osama bin Laden was killed in Abbottabad, Pakistan, on May 1st, 2011. However, more than 140,000 NATO troops deployed in Afghanistan, have failed to control the territory of this state and to combat against the Afghan guerrilla forces.

Since May 2012, the issue of withdrawing from Afghanistan has been raised at NATO level. Two years later, in May 2014, the UN officially announced that military operations would end in the winter of that year, so that on 28.12.2014, NATO officially ceased military operations under ISAF. In the summer of 2017 there were still 13,000 NATO troops in Afghanistan. In the guerrilla battles, it is officially announced the death of more than 4,000 ISAF soldiers and over 15,000 Afghan soldiers loyal to the US occupation regime. At the same time, the death of more than 30,000 civilians has been officially reported.

NATO forces (ISAF) largely left the country without achieving its original goals, although a politically correct regime was apparently in place for the US occupation regime. This is just an appearance, because this political regime does not control the situation in the afghan territory and it could be removed at any time by the rebel forces. The remembrance of this episode of contemporary military history is intended to draw the attention to the special capacity of military or terrorist military organizations to adapt to the modern technology and to create, with apparently rudimentary means, some effective armaments and combat techniques capable of putting in great difficulty even the most modern armed forces of the world. Such terrorist organizations will be able to resort to infrasound, ultrasound, ultraviolet laser and X-ray lasers in the coming years.

Let's not forget that, among other things, the Taliban used mobile telephony for remote bomb command devices (they were also able to imagine automatic explosion control devices based on the proximity sensors, motion sensors or heat sensors) and combined in a very ingenious way the most rudimentary and the most modern means of fighting. It is to be expected that in the coming years, these seemingly rudimentary and underdeveloped military forces will become capable of achieving unexpectedly new types of armaments such as:

1) sources of mechanical power high enough to be injurious, operating in the infrasound or ultrasound register [1, 2, 4, 6-8];
2) shock waves that are capable of doing large damage on a limited area around the epicenter, but starting from a very small amount of explosive;
3) ultraviolet radiation sources capable of remote firing the combustible materials as well as to accelerate the chemical fermentation processes in organic materials;
4) lasers in the category of free electrons lasers, but in compacted forms, installations capable of covering a wide range of frequencies and powers of work;
5) hybrid systems based on the above-mentioned technologies.

The use of some physical phenomena not necessarily new, but little used in the fighting technique so far, and which are able to open new possibilities, almost unpredictable, both technically and tactically. It became possible to obtain low-cost combat means capable of ensuring the destruction of the rigid structures corresponding to the metal armor, and even the possibility that the action of the weapon would be achieved beyond the armor, without this layer having any effect (weapons with penetrating radiation waves). The emergence of these new means of fighting, based not on the action of material projectiles but on the action of waves propagated through the fluid and/or solid environment, will make the general organization and execution of combat actions subject to radical changes in the near future.

Through the formation and propagation of mechanical waves in the terrestrial atmosphere, considered sui generis as an elastic medium, such mechanical oscillations produce important influences on a large part of the natural processes at the level of the planetary boundary-level within the troposphere. Among these, we mention the general process of clotting, forming the so-called aggregates that form the water droplets. With the use of these mechanical oscillations (especially those in the ultrasonic spectrum) on dense atmospheric masses (using emissions of high power), effects on local weather phenomena can be obtained, such as the rain, fog or hail.

Some military forces endowed with such ultrasonic power sources (using the energy generated by the explosion of small powder loads or compressed air sources) may under certain conditions, influence the weather regime in a fairly large volume of atmosphere, and almost in the near future, these phenomena can be transmitted to neighboring air masses leading to the propagation or development of mist, rain or other disturbances in the low atmosphere.

The Ultrasound sources have been able to achieve such effects, virtually without the use of any kind of chemical agents, as contained in the classical technologies of induced cloud and/or rain. In addition, such sources constitute means by which the molecular structure of some substances can cause the resonance phenomenon, leading to damage to its integrity and even the destruction of some materials, without any visible material object acting on them [4-6, 10].

Regarding the ultrasonic sources, we are able to generate ultrasound radiation by means quite accessible:

1) the so-called ultrasonic usually driven by the compressed air or other compressed gases having a low temperature; such ultrasonic whistles are efficient and

inexpensive and can work in a wide range of power values, but they assume the existence of sources for compressed air or other compressed gases, such sources being generally bulky and heavy, raising a number of other technological problems, especially since they are consumed relatively quickly and can't be replenished [7-10];

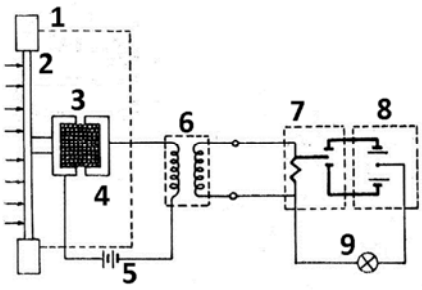

Figure 1. *An example of piezoelectric military application, the scheme of an acoustic fuse for the automatic explosion of marine mines: 1-Hydrophone; 2-membrane; 3-coal dust; 4-electrode; 5-current source; 6-transformer; 7-relay; 8-electric battery; 9-staple. Source: Florin Zăgănescu, Ultrasound in Military Technique, Military Publishing House, Bucharest, 1961.*

2) the high-pressure pyrotechnic loads, in this case the high pressure gases are quickly and easily obtained by burning a very short burst of powder, the flue gases being disposed within a device allowing the mechanical waves to be obtained in the ultrasonic whistle; unfortunately, despite its many advantages over the ultrasonic sources presented in the previous paragraph, that pyrotechnic technology is affected by the general disadvantage that the pressurized gases have too high temperatures and the use of hot gas fired inside the ultrasonic whistles raises complicated technological problems [1, 5, 8-10];
3) the ultrasound sources with piezoelectric materials; these sources are very compact and inexpensive and can be easily done even in improvised workshops; however, this technology presents the great disadvantage of being able to work only at relatively small powers, whereas the ultrasound sources equipped with pyrotechnic cartridges can work with much higher energies (hence the power) [1-3, 8-10].

Having technologies based on the action of mechanical waves and capable of controlling the environmental factors involved in the production and dynamics of weather phenomena, is a very important advantage in the armed confrontations of the near future.

Last but not least, the development of such technologies could pose a serious threat to security, as terrorist organizations would become capable of doing such new means of fighting. We have begun this work by exposing some recent historical episodes (the war in Afghanistan) which we considered relevant, precisely to show how easily the terrorist organizations can adapt to the technological evolution and how ingenuous the members of such networks can adapt the modern technical means so that it can be used in fighting or terrorist attacks.

3. The Piezoelectric Effect for New Combat Means

We know now that the ultrasound technology was applied in the military field even during World War I, at that time the sources of ultrasound are mainly used by the Marine, for the detection systems known as Sound Navigation and Ranging (SONAR). The property of mechanical oscillations in this frequency regime is that the sound movement into the fluid environment (ocean water) is usually greater than those in the atmosphere, this propagation depending mainly on the water temperature and the initial power of the ultrasound. In the post-war period, in addition to the SONAR detection technique, the ultrasounds have begun to be applied quite widely in the medical field, both in medical imaging and treatments.

In the contemporary period, it appears the problem of applying such ultrasonic sources to the manufacture of so-called "non-lethal weapons," such as the LRAD (Long Range Acoustic Device) system.

However, the true use of the ultrasonic sources in military technology would require the use of sources characterized by very high power, or at least by long-lasting action of ultrasonic waves of relatively small powers [3, 6, 8].

However, the ultrasonic sources based on piezoelectric or magneto-astrictive effects may be harmful means used in the event of terrorist attacks. It is true that such ultrasonic sources would not have the ability to produce immediate and spectacular harmful effects, but by prolonged action (minutes or tens of minutes) could cause to the exposed people to present serious health disorders, including perforation eardrums, burns, eye problems, heart arrhythmias or heart attack, etc.

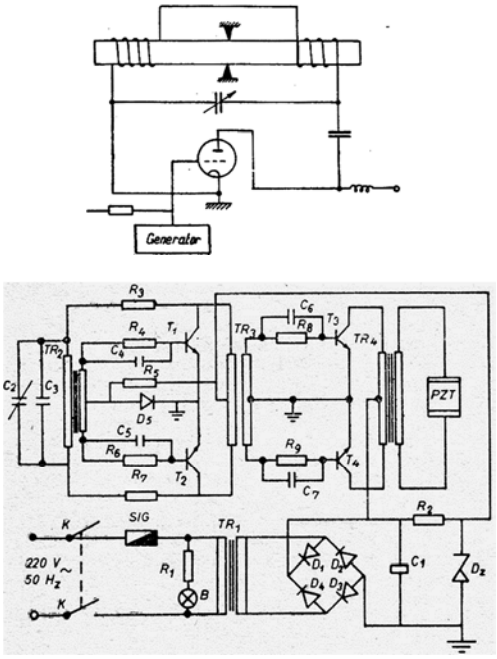

Figure 2. *Ultrasound generator device based on piezoelectric effect (right) and on magneto-striction (left). Source: Eugen Bădărău, Mircea Grumuzescu, Ultra Acustica. Physics and Technique, Technical Publishing House, Bucharest, 1967 (left); Niculae Ion Marinescu, Ultrasound Processing, Technical Publishing House, Bucharest, 1986 (right).*

Practically, terrorists using these new technologies would have a choice between using the sources capable of producing significant effects with phenomenon of great intensity and speed, but on a very small surface. And, respectively, the possibility of achieving relatively small intensity effects, applied on a large surface and relatively during a long time. Despite the need to act for a longer time, the use of low-power ultrasonic sources brings the advantage of constructive simplicity, the low cost that the entire device requires, and especially the fact that it can have effects on a large surface, involving the presence of a great number of people, which is convenient in the case of terrorist attacks. To achieve the relatively low power ultrasonic sources, the piezoelectric method is preferable, and therefore we believe that it will soon represent a new threat to the security of Western states.

It is therefore appropriate to pay more attention to the concrete possibility of using acoustic waves (from certain frequency regimes) in the military, in virtually completely new ways to any military use so far. Especially since such new technologies can reach out to international terrorist organizations.

Last but not least, we draw attention to the possibility of developing hybrid weapons capable of using both classical technology, and the means based on the piezoelectric effect.

A special model of silent hybrid weapon and which can be developed in the near future, is the piston-weapon. In this armament system, the piezoelectric effect can be used to realize the transducer (sensor) designed to disengage the plunger piston when drawing the projectile of such a weapon.

In this field of sonic weapons (the mechanical waves in general) the Romanian inventor George G. Constantinescu had a hard word to say, he invented the piston-weapons even during the First World War. There were heavy armaments (cannons) capable of shooting hundreds of pounds of weight. Of course, the principle used more than a hundred years ago by Constantinescu can also be applied to portable light armaments.

We will present some aspects of the so-called sonic guns invented and made at the beginning of the last century by George G. Constantinescu, in particular with the understanding of their principle of functioning and the general determination of the performances such weapons can reach in the following years. Such a principle of operation is especially suitable for grenade launchers, regardless of their size. But, why not, this principle of operation could also be applied to the ordinary, portable firearms. Practically, G. Constantinescu used some pressure accumulators that release the compressed fluid only at certain (high) pressure values so as to obtain a very strong flash, and this shutter takes place inside the device without the used fluid being practically exhausted in the external environment. Such a hybrid weapon contains the following main elements:

1. the cannon body; made of steel (in classical type) or composite materials; is designed to enable the assembly of all other components and their safety operation at high pressure;
2. cylinder metal (or composite) high-pressure resistant; it is inserted substantially inside the body (1) in order to ensure a better rigidity of the structure but also the sealing of the working gas chamber under pressure;
3. the pyrotechnical staple; it is of a classical type, containing a relatively small amount of explosive powder, the flue gas emanating from its explosion being intended to act on the piston engaging the movable mechanisms of the weapon;

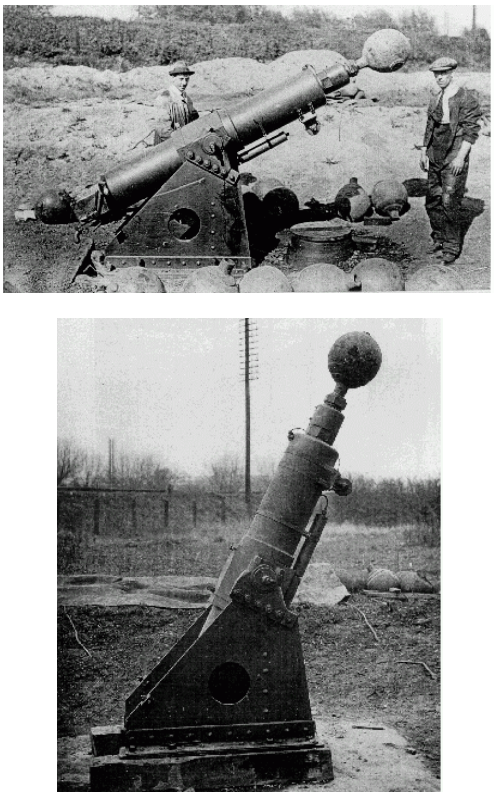

Figure 3. *George Constantinescu's sonic tunnel: using just a trivial pistol cartridge, he was able to throw a 100-kilogram projectile at a distance of 1500 meters, perfectly silent, flame-free, smoke-free! In the contemporary era, the RAW system was proposed by the American company Brunswick Corporation. RAW is a self-propelled ammunition using a small solid-fuel rocket engine, while the device invented and made by George Constantinescu was thrown off by the rapid movement of a piston, which was in turn driven by the expansion of a high-pressure gas. In the case of the RAW system, the 140 mm diameter spherical projectile has a combat load (explosives, etc.) weighing 1.26 kg and a total weight of less than 4.5 kg with a maximum range of 2000 meters, of which the first 300-meter trajectory is straight, so shooting up to 300 meters does not require any shooting corrections. Ammunition total mass 4.27 kg, mass of projectile 3.82 kg, weight of combat load 1.26 kg. RAW Shooting System just looks like the sonic guns invented at the beginning of the second XX century by G. Constantinescu. Constantinescu's sonic gun (in both images) was able to completely silently throw a 100 Kg projectile at a distance of 1500 meters, but the performance limits of this type of weapon were (and are) far higher than what Constantinescu experienced in 1915. Source: Nic. P. Constantinescu, Encyclopedia of Technical Inventions, Royal Carol II Publishing House, 1939, and RAIDS Magazine, no. 82 of March 1993.*

4. compression piston; it consists essentially of a cylindrical piece made of steel or composite material, on which acts directly the flue gas at very high pressures, practically at over 3000 atm;

5. the working agent, in the form of oil (concretely, G. Constantinescu used 10 liters, of oil which by compressing at the pressure of 2500 centimeters reached the volume corresponding to a quantity of only 9 liters under normal conditions); this working agent basically takes up the energy developed by the flue-operated piston, compressing it at great pressures;
6. the automatic valve (using a piezoelectric effect sensor) of the exhaust gas system (11) which is used to ensure the automatic operation of the cannon, and it is discharged only when the pressure is low enough to produce no noise;
7. the latch bolt of the piston, which is set to release the piston only at a pressure greater than 2500 atm; this small device uses a piezoelectric transducer/sensor to measure with great precision the pressure exerted on the inner member which is in direct contact with the piston that act on the projectile (8);
8. the piston which pushes the projectile; it ensures virtually the sealing of the oil enclosure; it does not allow the contact between the oil and the projectile and is direct contact with the projectile to be ejected;
9. the projectile (in 1915, G. Constantinescu used a 100 kg projectile, which he threw at a distance of 2000 meters, using 10 liters of oil compressed to 2500 atm using for that an ordinary pistol blank cartridge); this projectile is basically the combat load that will produce the desired effects on the target;
10. the cannon barrel; it is made of steel or composite material, being ripped or not, according to the nature of the projectile which is used and the general destination of the weapon;
11. the flue gas at high temperature and pressure; it is virtually discharged only after the piston goes to its end position and the projectile has already emerged from the gun barrel;
12. the outlet circuit for the flue gas; it is basically formed from an outlet which is permanently in the outer body of the weapon but in which the flue gases can only reach the moment when the piston has reached the end of its movement.

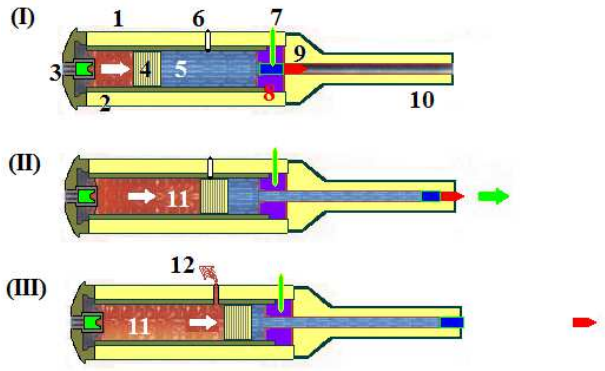

Figure 4. *The cannon of Gogu Constantinescu, its main components. With Roman numerals are presented the three stages of the operation of such an armament system. The description of the notations in the figure is found in the text of this paper. Source: drawing by the authors of the paper.*

The stages of the operation for this hybrid weapon system, imply the operation of a classical pyrotechnic cartridge and the command of a piezoelectric transducer meant to release the piston that acts on the projectile, only when the pressure of oil has reached a certain value. These stages of operation are as follows:

I. The projectile (9) is located on the surface of the piston (8) within the barrel (10); the pusher piston (8) is closed by means of the snap mechanism (7) provided with automatic release; the pyrotechnic stack (3) is percuted and the powder charge is exploded generating the gases (11) at a pressure of 2,500-3,000 atm; under the pressure of the gases (11), the compression piston (4) moves forward by compressing strongly the oil (5) which in a sealed enclosure (2); due to the snap mechanism (7), the pusher piston (8) does not allow the oil (5) to escape from the compression cylinder compartment (2).
II. When a certain pressure is applied (for which the adjustment is made), the locking mechanism (7) allows the pusher piston (8) to move inside the barrel (10), in which case the compressed oil (5) is being released enough to throw a 100 kg projectile (9) to over 2,000 meters, with no noise, no flame, no smoke.
III. After the projectile (9) has been thrown onto the barrel (10), the stroke of the piston (8) is terminated so as to prevent the sealing damage of cylinder (2) in which the oil (5) is discharged in the amount of 10 liters; the exhaust valve (6) is adjusted such that at the end of the stroke of piston (8) it opens to let the flue gas (11) to enter its recirculation system and finally into the exhaust pipe (12).

Such hybrid weapon systems are characterized by: very low consumption of pyrotechnic material (powder), very high power (very good yield) and hence the possibility of throwing a heavy projectile at great distances. An important role in the proper functioning of this weapon is played by the piezoelectric sensor/transducer which must ensure that the piston is released at the precise time so that the weapon operates in good conditions.

4. Conclusions

Today's modern piezoelectric technology allows the creation of some powerful ultra-acoustic sources that could be used for making relatively cheap and easy-to-install installations for ultrasonic aggressions, on some habitacles or even on open surfaces. The role of this exposure to the ultrasounds would be to cause a serious health problem to the people who is in the perimeter, which is to stir up and maintain confusion and panic.

In this way, terrorist acts can be carried out with particularly serious consequences, especially since the action of ultrasound sources can't easily be perceived by humans, ultrasound acting in the non-audible regime.

Last but not least, the piezoelectric technique can also be used to facilitate the production of new types of hybrid

weapons with better performances than those recorded by classic firearms. These are weapons using a pyrotechnic primary source and an oleo-pneumatic piston to throw the projectile toward the target.

With the development of piezoelectric technology, we are witnessing the tendency to develop military applications of this technology, especially in the field of mechanical wavelengths from the ultrasonic regime, but also many other applications.

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