TITLE: Overview on the German R&D Programs on ETC Gun Technologies for Main Battletank Weaponization

Overview on the German R&D Programs on ETC Gun Technologies for Main Battletank Weaponization

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Abstract

In order to improve the performance of large calibre guns for main battlefield tank applications a wide range of R&D programs have been performed in Germany on electric and electrically supported barrel guns since 1980. In the beginning pure electric gun technologies were investigated including rail, coil and electrothermal acceleration methods. A large calibre 105mm electrothermal gun demonstrator supplied by a 30 MJ capacitive pulsed power supply system was introduced in 1995. Muzzle velocities up to 2.4 km/s were optained with this set-up resulting in muzzle energies up to 5.8 MJ. The missing perspective on solving the energy density requirements of the pulsed power supply technology for a system realization led to the termination of these programs in the beginning of 1996.

Due to its limited electrical energy requirements the technology of ETC guns has been investigated during the last years with high priority. It is the goal to provide a future main battle tank gun with increased firepower for integration into the next generation of combat fighting vehicles. Current R&D programmes result in a demonstration of the interior ballistic performance of the different ETC concepts. 120mm ETC demonstrators are used to perform this demonstration.

The presentation gives a short briefing on the results of the former investigations on pure electric guns and introduces the background for deciding to terminate these efforts. In the following an overview on the R&D Structure of the German programs on ETC and its related technology fields is presented. Basic investigations led to the definition of different ETC concepts for the realization of electrothermal plasma ignition methods and electrothermal combustion control of ETC tailored propellants and charge designs. Based on the results of 105mm firings and of interior ballistic simulations a 120mm ETC cartridge was designed and investigated experimentally. First 120mm firing results will be given.

The presentation concludes in giving an outlook on the perspectives of the performance of ETC technologies and its power supply technologies in order to provide the access to increased firepower and survivability of existing and succeeding main battle tank systems without leaving the currently introduced boundary conditions of the large calibre weapons.

1 Introduction

Improved protection technologies by active and reactive armor as well as by increased hardeness of armor plating technologies define the requirements of the performance of future tank guns. Improved missile technologies as well as multiple low cost cruise missile attacks will be the challenges for future anti air defence guns. Military operations in urban terrains define new requirements for medium calibre guns for future vehicles.

For the existing conventional guns a high level of lethality has to be provided which can be obtained i.e. from improved temperature insensitive propellants. Future guns have to provide a significantly higher lethality which can be obtained from advanced propulsion and gun technologies. These requirements have been adressed by the R&D programmes on electric and electrically supported guns.

2 Electric Gun Programs

In order to met the requirements of future tank guns and close the gap between gun performance and armor plating technologies electric guns with their potential of realizing very high muzzle velocities were investigated within several R&D programmes in the past. In the US these programmes concentrated on the rail gun technology. Laboratory systems were set-up demonstrating muzzle velocities with 2kg projecties of to up to 3.000 m/s in calibre 90mm [1]. In Germany electrothermal gun technologies were investigated. In 1995 105mm shots were demonstrated firing 2kg projectiles to up to 2.400 m/s [2]. Due to the missing perspective of realising high energy density pulsed power supply technologies for integration into a combat fighting vehicle in the short and mid term time frame several nations including the USA and Germany decided to proceed the investigations with the Electrothermal-Chemical Gun Technology (ETC).

3 R&D Programmes on ETC Technologies

3.1 Goal of the 120mm R&D Program

It was the goal of the German R&D program phase 1 (1995-1999) on ETC guns to demonstrate a muzzle energy of at least 14 MJ out of a 120mm Gun within the boundary conditions of the conventional set-up in terms of maximum breech pressure (670 MPa), volume of the charge chamber (10l), projectile travel length (6m), muzzle pressure (<100MPa) and mass of projectile (8,4 kg). The demonstration of this muzzle energy should be performed by using ETC technologies with available propellants. In addition the results of basic investigations should predict the performance potential of new propellant formulations and charge designs with ETC technology. An evaluation of the results obtained from the investigations on the gun performance and on the pulsed power supply technology should result in the short and medium term availability of ETC technologies within the boundary conditions of existing and future large calibre combat fighting vehicle systems.

3.2 Basic Considerations

ETC technologies opens the opportunity to reconsider the limited success of past conventional investigations under aspects of

- perfect ignition properties
- electrothermal enhancement of propellant conversion
- access to new high energetic propellant formulations
- access to charge designs with increased loading densities.

From these properties a significant improvement of the interior ballistic gun performance can be obtained at limited and realistic electric energy requirements.

The electrothermal energy conversion via approximately massless and volumeless high power plasmas which are arranged in the propellant set-up of the cartridge with a high degree of geometrical flexibility can be used efficiently without time delay for the ignition of the propellant as well as for its combustion control.

The large variety of the properties of the plasma ignition processes which are not given from conventional pyrotechnics enable the development of charge designs with increased performance as well as of new high performance powder formulations based on Nitramin and RDX chemicals. Further advantages are gained from the ETC technologies by the possibility of adjusting the ignition performance directly before or during the development of the shot as well as controlling the combustion during the burning phase of the propellant. These properties can be applied i.e. for a temperature compensation of the propellant.

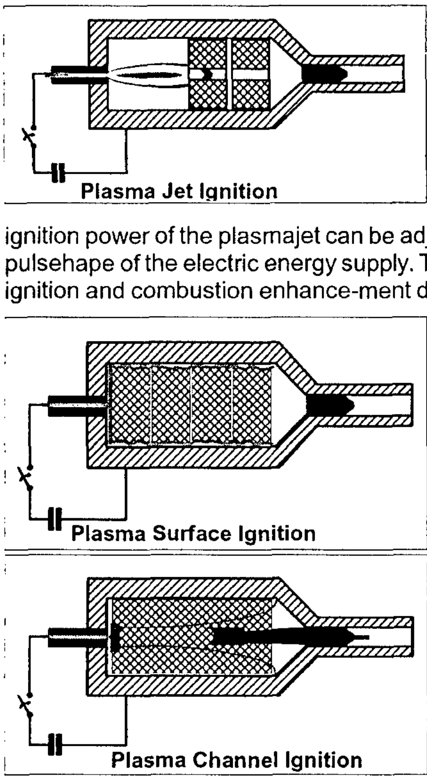


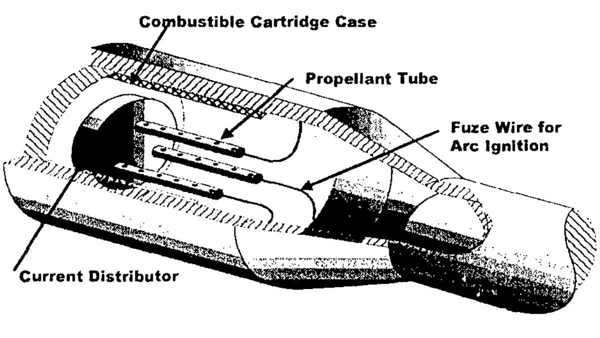
Fig. 1: Electrothermal Plasma Ignition Methods

Fig. 1 gives three different plasma ignition methods schematically. The Plasma Jet Ignition is characterized by a so called plasmaburner which is located in the breech of the charge chamber. Supplying this plasmaburner with electrical energy a high temperature plasmajet is generated and directed into the propellant set-up in the charge chamber. The form and the length as well as the ignition power of the plasmajet can be adjusted by the geometry of the plasmaburner and by the pulsehape of the electric energy supply. The plasmajet interacts with the propellant and results in ignition and combustion enhance-ment during the pressure generation phase. A proper design of the plasmaburner and a good matching of the electrical power pulse can lead to large lengths of the plasmajet. The properties of this method are of interest for solving the ignition of modular charges for artillery guns. The application for large calibre tank gun charges has been investigated with minor success.

The Plasma Surface Ignition realises a plasma coating around the propellant set-up. By this the propellant is ignited from the inner surface of the combustible cartridge case to the inside of the charge set-up over the total lenght of the charge without any time delay in the axial direction. This method opens the access to very compact charge designs i.e. coated propellant discs with very high loading densities.

The last method is given by the Plasma Channel Ignition system. Several plasma channels thin wires which are located within thin walled propellant tubes. The interaction of these plasma channels leads to the ignition of the propellant. By the electrical energy supply the ignition power is adjusted and in addition, a combustion enhancement can be realized over the entire time period of propellant burning.

The application of the plasma ignition methods for improving the interior ballistic performance requires detailled knowledge of the interaction processes between the plasma and the propellant. The energy transfer mechanism from the plasma to the propellant is provided mainly via radiation processes. Therefore the energy is transmitted into a large volume without any significant time delay. Plasmas are of low mass and of low volume requirements. In particular the plasma channel ignition method is characterized by its high degree of geometrical flexibility. By the electrical energy supply ignition power can be adjusted. Furtheron the propellant combustion can be enhanced during the burning period. The application of these properties is the basis for the assessment of charge designs with increased interior ballistic performance due to increased loading density or new propellant formulations or a



combination of both.

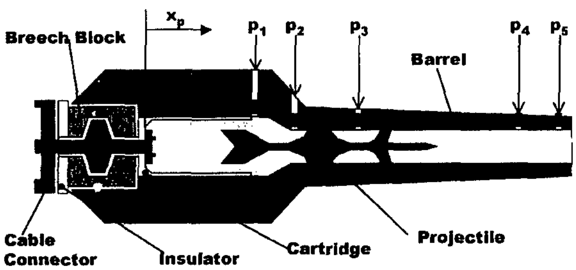
Fig. 2: Large Calibre Cartridge Set-Up with Plasma
Channel Ignition (schematically)

Fig. 2 shows the set-up of a three channel plasma ignition system within a large calibre gun cartridge schematically. The plasma ignition system is installed within a conventional cartridge with combustible cartridge case. The stub case is modified by a high voltage feed through with a current distributing conductor. Exploding wires which are located within thin walled propellant tubes are igniting the plasmas in several channels. By the interaction of these plasma channels with the propellant ignition and combustion enhancement are performed.

3.3 Experimental Results obtained from 105mm ETC Firings

A first validation of the large calibre ETC concepts was performed with a 105mm ETC gun. Fig. 3 gives a view on the gun and on the ETC cartridge set-up with their main parameters.

The gun is characterized by a charge chamber volume of 6.44 l and a projectile travel length of 6.24 m. The maximum operation pressure is 500 MPa. ETC cartridges made from inert plastic material were used in this gun. Several pressure sensors are located in the charge chamber and along the barrel.

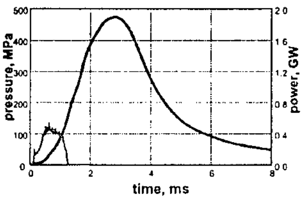


Charge Chamber Volume:	**6.44 l**
Projectile Travel Length:	**6.24 m**
Max. Operating Pressure:	**500 MPa**
x_p Position p_1:	**450 mm**
x_p Position p_2:	**715 mm**
x_p Position p_3:	**3414 mm**
x_p Position p_4:	**6064 mm**
x_p Position p_5:	**6714 mm**

Fig. 3.: Set-Up of the 105mm ETC Gun

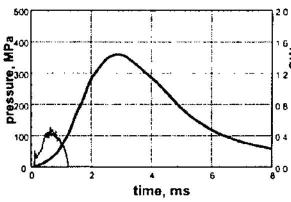
A variety of test firings were performed in the 105mm gun.

Tests with granular propellant made from NENA formulations show the excellent interior ballistic performance of this propellant due to its high impetus. Fig. 4 gives the results of two characteristic experiments conducted with two different web sizes of the propellant grains as well as a summary of all test performed with this concept.



Shot data

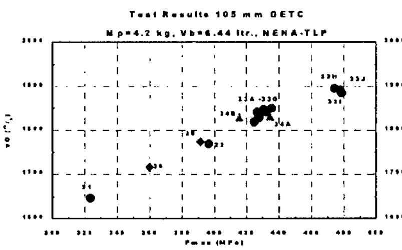
Projectile Mass:	4.2 kg
Mass of Propellant:	5.76 kg
Web Size:	1.3 mm
el. Energy Input:	391 kJ
Muzzle Velocity:	1896 m/s
Muzzle Energy:	7.55 MJ
Overall efficiency:	28.6 %



Shot data

Projectile Mass:	4.2 kg
Mass of Propellant:	5.76 kg
Web Size:	1.5 mm
el. Energy Input:	347 kJ
Muzzle Velocity:	1716 m/s
Muzzle Energy:	6.18 MJ
Overall efficiency:	23.4 %

Summary of results



Standard Deviation t_2:	37.3 µs
Standard Deviation p_{max}:	3.6 MPa

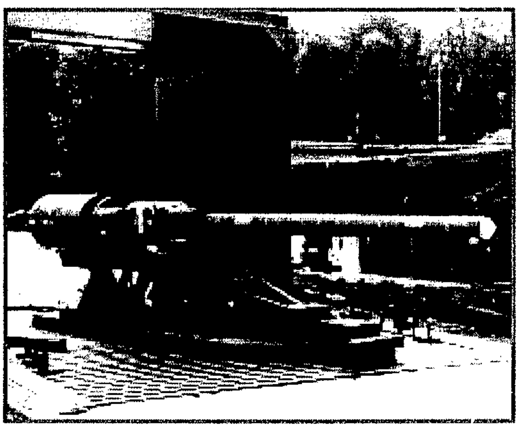
Fig. 4: Characteristic Results of 105mm Test Firings with granular NENA Propellant and single Pulse Plasma Channel Ignition

4.2kg projectiles were accelerated to up to 1.900m/s. A one pulse Plasma Channel Ignition was applied with an electrical energy input of about 400kJ only at a propellant temperature of approximately 21°C. A standard deviation of the ignition delay times of only 37.3µs as well as a standard deviation of 3.6 MPa of the maximum pressure values show the excellant performance of the plasma ignition method even with LOVA type propellants.

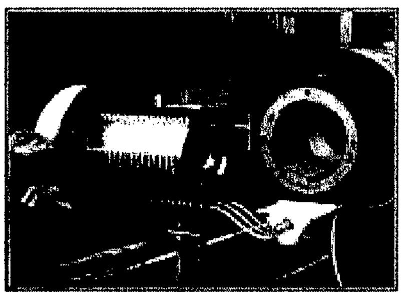
3.4 Experimental Results obtained from 120mm ETC Firings

The 120mm ETC gun being used for the performance demonstration is shown in fig. 5. The gun platform equals those which has already been used for the 105mm firings.

System View



Breech Block System



Technical Data

Calibre Length:	**L55**
Projectile Travel:	**6 m**
Volume Charge Chamber:	**10 l**
max. Operation Pressure:	**700 MPa**
Design Pressure:	**800 MPa**

Fig. 5: Set-Up of the 120mm ETC Gun

A 120mm L55 barrel is assembled in the breech block. The breech block system consists of a bajonet joint. The electrical connection to the pulsed power supply system is realized by coaxial cables. Projectiles of approximately 8.4 kg are accelerated in the 6m long barrel. The volume of the charge chamber is approximately 10 l. The maximum operation pressure of this test gun is 700 MPa and the design pressure is 800 MPa.

Up to now a variety of firings have been performed with a granular NENA propellant charge at two different propellant temperatures. Fig. 6 gives the measured signals of a characteristic shot in which the 8.4 kg projectile was accelerated to a muzzle energy of 14 MJ at a propellant temperature of 50°C.

Discharge current, plasma voltage, breech pressure and energy absorbing power are plotted versus time. The duration of the electric pulse igniting the propellant is 1.2 ms. The maximum discharge current is 12.5 kA. 0.3 ms after igniting the electric discharge the voltage signal shows the characteristic peak due to the explosion of the fuze wires.

In the following time period the plasma voltage increases from about 4 kV to a maximum of about 16 kV at the end of the electric discharge pulse.

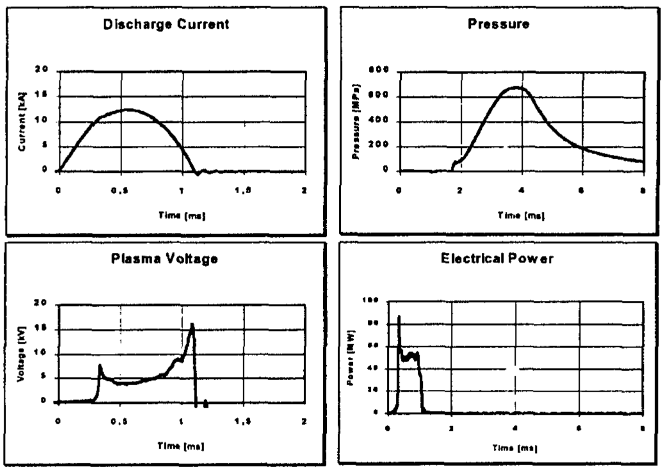


Fig 6: Measurements of a characteristic NENA Firing

The breech pressure starts rising at about 1.8 ms and reaches its maximum of 670 MPa at t = 3.8 ms. The average power of the energy absorption is about 50 MW. For igniting the charge an electric energy of only 39 kJ is released into the plasma channels.

Table 1 gives an overview on the main results of the NENA firings obtained at two different propellant temperatures in comparision to the performance of the LKEII cartridge which provides the current maximum performance level of conventional 120mm ammunition.

With the NENA1 propellant muzzle energies of 14 MJ are demonstrated at propellant temperatures of 21°C and 50°C. The temperature compensation is performed by an increase of the electrically released energy to 110 kJ. The firings with the NENA2 propellant which differs by its larger web size from the NENA1 propellant are performed at 50°C up to now.

Charge	Vo [m/s]		Wo [MJ]		El. Energy [kJ]	
	21°C	50°C	21°C	50°C	21°C	50°C
LKE II	1,750	1,830	12.8	14.0		
ETC NENA1	1,822	1,831	13.9	14.0	110	39
ETC NENA2		1,839		14.1		101

Table 1: Results of 120mm NENA Firings

A further increase of the muzzle velocity to 1.839 m/s is obtained with a slightly increased amount of electrically released energy of 101 kJ.

By a proper design of the Plasma Channel Ignition and the adjustment of the electric ignition pulseshape the requirements of electric energy for igniting the NENA charge set-up are significantly reduced in the 120mm cartridge. It is expected that energies of only several 100 kJs are sufficient for a fully temperature compensated performance of NENA charge set-ups in a 120mm cartridge providing gun applicable ballistics with high firepower due to the properties of the electrothermal plasma ignition method.

4 Medium Calibre Gun Investigations

First investigations on ETC technologies for medium calibre guns have been performed at Rheinmetall. It is the goal to provide a plasma ignition system for rapid firing guns with the lowest requirements of the electric energy consumption. The current investigations therefore concentrate on the development of a plasma ignition system which is combined with pyrotechnics. First ignition experiments in closed vessels indicate that the electric energy can be further reduced with this approach without loosing the properties of the plasma ignition. In the next step improved propellant formulations and charge set-ups will be tested in order to explore the potential of this method in terms of muzzle velocity increase without decreasing barrel lifetime.

5 Pulsed Power Supply Development

In order to provide proper pulsed power supply technology for the ETC gun developments R&D programs on critical components have been under conductance since 1998. High energy discharge capacitors have been developed with energy densities up to $2 MJ/m^3$ based on conventional metallized film technology and certified for ETC application. Optical triggered semiconducting switches are in the final testing phase. Compact high power charging devices will be available in 2002. Based on these components a first pulsed power system is in the final design stage and will be completed in the beginning of 2002 in order to be used for the large calibre ETC demonstrations at the end of the R&D phase II.

6 Summary and Conclusion

The results of the basic investigations, the theoretical simulations and the experimental firings in the large calibre guns show the important properties of the ETC ignition technology in terms of:

- ignition system with low mass, high geometric flexibility, low volume requirements and short energy transfer times at high interaction temperatures
- adjustable ignition power influencing the whole ignition process
- temperature compensation properties
- combustion control properties
- access to high loading densities by volume effect of plasma radiation

By applying these properties the currently existing performance of conventional 120mm gun technologies could be achieved and slightly improved already during the first phase of the German ETC program. Further increase of the loading density in combination with the application of high energetic propellants, i.e. NENA, will lead to a further improvement of the interior ballistic performance in the 120mm gun. Muzzle energies of more than 15 MJ at muzzle volocities of more than 1.900 m/s can be expected during the running phase of the German ETC program.

The limited requirements of electric energy of only several 100 kJ per shot lead to feasible solutions for the realisation of the power supply technology based on the progress obtained from the R&D programmes performed on the energy density improvement [3,4]. The bandwidth of ETC technologies and its electric energy requirements opens the access to increased firepower and survivability of existing and succeeding main battle tank systems without leaving the currently introduced boundary conditions of the large calibre weapons.

Acknowledges

This work is performed under contract of the German BWB and we greatfully thank our contractors for their support.

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