Electromagnetic Weapons: Forensic and Ballistic Examination of Railguns and Coilguns

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Electromagnetic gun has different ballistic dynamics and criminal traces as opposed to traditional firearms. Portable railgun and coilgun systems and similar weapons introduce new challenges in forensic investigations due to their portability and the possibility of being made at home. The ballistic effects of such weapons, physical traces they leave are studied during forensic medical examinations (research on caused fatal and non-fatal injuries). The technical features of railgun and coilgun systems are examined. The effects of ammunition fired using the Lorentz force, compared to those of firearms, are evaluated. The scope of forensic analyses regarding high speed and kinetic energy transfer in attacks using electromagnetic gun is being expanded. Other security risks include the silent operation of portable railgun and coilgun type electromagnetic gun and the reasons why they do not leave chemical waste. With the increasing use of electromagnetic railguns and coilguns, including those produced at home, new approaches and technical methods and examination methods need to be developed in forensic science investigations, as well as relevant international and national legislative rules to govern the proliferation of such weapons and unify research methods. The author *aims to examine technical and physical properties of electromagnetic guns, damage they cause, methods for researching them, and the need to amend relevant international and national regulations on proliferation and research of these and similar weapons. To achieve the set goal, the following scientific methods were used: analysis, synthesis, statistical analysis, generalization, etc.*

Keywords: *Electromagnetic Gun; Railgun; Coilgun; Forensic Investigation; Ballistic Effects; Forensic Medical Examination.*

Research Problem Formulation

Railguns and coilguns are Electromagnetic weapons (EMG) that use electrical energy to launch high-velocity projectiles through magnetic fields. These weapons do not leave the physical marks typical of firearms, but they can cause thermal damage or other deformations at the points of contact [1]. While railguns and coilguns are primarily designed for military and security research, they can be individually manufactured using a variety of materials and 3D printers, increasing the potential for criminal misuse. In terms of forensic science, the effects of EMG such as coilgun and railgun require a different approach compared to firearm or Directed Energy Weapons (DEW) ballistic traces. They can leave physical evidence as well as traces through electronic disruptions. New techniques and methods are needed to prevent the inadequacy of current forensic methodological examinations [2].

EMG systems have become an increasingly important field in modern ballistic engineering. Coilgun and railgun technologies require electrical energy, unlike gunpowder-based firearms. Today, the development of portable coilgun and railgun EMG models increases their accessibility in terms of individual production and criminal use [3]. Depending on many factors, coilgun and railgun models leave different ballistic traces at crime scenes and make it difficult to apply standardized ballistic analysis methods. Similarly, forensic medicine examinations and autopsy studies require different approaches and analyses in addition to technical methods. This study examines the risk factors related to the criminal use of coilgun and railgun models, which are EMG, in terms of forensic science and investigations, and the methodological methods of examination against security threats posed by these weapons in the future [4].

1 Du X. Y., Liu Sh. W., & Guan J. Design and Performance Analysis of an Electromagnetic Railgun. *Journal of Physics: Conference Series.* 2022. Vol. 2378. No. 1. P. 012008. DOI: 10.1088/1742-6596/2378/1/012008 (date accessed: 17.12.2024).

2 Yadav M., Ram R., & Thomas M. J. Comparative Analysis of the Muzzle Velocities of Projectiles in Horizontal and Inclined Configurations of the Coilgun / High Voltage — Energy Storage Capacitors and Their Applications ; A. Sharma (Ed.). Springer Nature Singapore, 2024. Pp. 49—57. DOI: 10.1007/978-981-97-0337-1_6 (date accessed: 25.12.2024).

3 Guo W., Zhang T., Mu Z., Zhu W., & Li M. A magnetic field constrained type of multi-barrel common-rail railgun. *Journal of Physics: Conference Series.* 2023. Vol. 2478. No. 9. P. 092018. DOI: 10.1088/1742-6596/2478/9/092018 (date accessed: 25.12.2024).

4 Pei Ch., Liu X., & Zhou X. Design and simulation analysis of electromagnetic gun feeding and conveying device. *Ibid.* 2024. Vol. 2891. No. 10. P. 102006. DOI: 10.1088/1742-6596/2891/10/102006 (date accessed: 26.12.2024).

While the existing literature has covered a large portion of EMG, there is a significant lack of forensic analysis and evaluation, particularly for portable weapons such as the cailgun and railgun. For example, several studies have addressed the methodological limitations in detecting and analyzing railgun and coilgun ballistic effects and traces.

Article Purpose

The research aims to determine the technical and physical properties of weapons that can grow, such as railguns and coilguns, by examining forensic and ballistic examinations of these weapons, which are different from traditional firearms, and their fragmentation difficulties in criminal cases. EMG are not directly detected by firearm ballistic examination methods since they do not use chemical explosion-based propulsion systems. In this context, the study focuses on the analysis of what the capability, which is specific to technological weapons, may be. In addition, the ballistic performances of railgun and coilgun models, kinetic energy transfer unit and the results on the target are examined comparatively, and the structuring of penetrations on different features is evaluated. New methods such as electromagnetic signature, spectroscopic examinations and similar are discussed in forensic use, and the scientific methods for the treatment of the potential use of these weapons in criminal procedures are emphasized. The security and legal risks related to railgun and coilgun systems and the necessary national and international regulations related to these are emphasized.

Research Methods

To achieve the set goal, the following scientific methods were used: analysis, synthesis, statistical analysis, generalization, etc.

Analysis of Essential Researches and Publications

EMG, especially the railgun and coil gun studies have been discussed in various supporting and engineering publications. However, there is a significant part in the criminal investigations related to the use of these weapons for criminal purposes. Although the technical and ballistic summaries of the existing wide-ranging weapons have been analyzed in some way, the examinations in criminal investigations, especially with ballistic and other evidence that can be considered in forensic sciences, have not yet been sufficiently investigated. This research aims to provide a basic framework for these people to be considered and other detailed information.

Several scientific studies have examined the design, performance and applications of electromagnetic railguns and coilguns [5]. This study investigates the fundamental principles of coilgun electromagnetic weapons technology, including high-velocity projectile capabilities and energy efficiency [6]. Comparatively examines different railgun configurations by analyzing muzzle velocities and energy storage properties that are important for EMG forensic ballistic assessments [7]. It discusses developments in multiple-barrel railgun systems, emphasizing the effects of magnetic field constraints on projectile dynamics.

5 Du X. Y., Liu Sh. W., & Guan J. Op. cit. DOI: 10.1088/1742-6596/2378/1/012008 (date accessed: 17.12.2024).

6 Yadav M., Ram R., & Thomas M. J. Op. cit. Pp. 49—57. DOI: 10.1007/978-981-97-0337-1_6 (date accessed: 25.12.2024).

7 Guo W., Zhang T., Mu Z., Zhu W., & Li M. Op. cit. DOI: 10.1088/1742-6596/2478/9/092018 (date accessed: 25.12.2024).

Despite the existence of these studies, there is a lack of forensic analysis regarding the potential criminal use of coilgun and railgun weapons, which are electromagnetic weapons. Existing forensic methodologies are primarily used on methods and techniques based on residues and ballistic signatures of firearms and non-fire (air) weapons. Railgun and coilgun electromagnetic weapons that are brought into portable form leave different traces and findings. New analyses, techniques and approaches are required due to many such deficiencies.

In this context, it will contribute to closing the gaps including spectroscopic analysis, magnetic field residue detection and impact signature evaluations and so on. The study serves as a basis for forensic methodologies by enabling all forensic investigators to develop an effective investigation approach for crimes related to railgun and coilgun electromagnetic weapons.

Main Content Presentation

Forensic and Security Implications of EMG: Coilgun and Railgun

The study includes evaluations on the traces left by the portable models of coilgun and railgun, which are EMG systems, in forensic ballistic examinations, technical difficulties that may be encountered in criminal investigations, and the potential risks and usage of these weapons. Within the scope of the study, the technical features of EMG are addressed with analytical methods in terms of kinetic energy transfer, ballistic effects and forensic trace detection. By integrating literature reviews, experimental data, spectral analysis, magnetic field measurements, and thermal imaging techniques applicable to crime scene investigations, an evaluation will be conducted on the findings related to EMG using new methodological approaches. In addition, in order to understand the effects of coilgun and railgun bullets on tissue, it is aimed to expand the scope of forensic analyses aimed at determining the effects in forensic medicine and autopsy examinations in comparison with the procedures in the current ballistic examination terminology. Magnetic field residues, thermal traces and spectral analysis results created by coilgun and railgun portable weapons are examined on the existing literature and experimental data.

Magnetic field residues, thermal signatures and spectral analysis of coilguns and railguns were examined in the light of literature and experimental data. Magnetic field measurements were evaluated with Hall effect sensors and gauss meter data, while thermal analyses were compared with experiments conducted with infrared thermal cameras [8]. Chemical changes and oxidation processes caused by EMG on bullet surfaces were discussed using X-ray fluorescence (XRF) and Fourier transform infrared (FTIR) data within the scope of spectral analysis [9].

Coilguns and railguns are EMG that accelerate projectiles using magnetic fields, but differ in their energy and speed. Coilguns use electromagnets to pull metal projectiles forward, requiring direct current to launch, but are effective at short ranges [10].

8 Moskovchenko A., Švantner M., & Honner M. Detection of gunshot residue by flash-pulse and long-pulse infrared thermography. *Infrared Physics & Technology*. 2024. Vol. 140. P. 105366. DOI: 10.1016/j.infrared.2024.105366 (date accessed: 27.12.2024).

9 Minzière V. R., Robyr O., & Weyermann C. Should inorganic or organic gunshot residues be analysed first? *Forensic Science International*. 2023. Vol. 348. P. 111600. DOI: 10.1016/j.forsciint.2023.111600 (date accessed: 28.12.2024).

10 Kakad Y. U., et al. Electromagnetic Projectile Launcher. *International Journal of Scientific Research in Engineering and Management*. 2024. Art. 8 (04):1-5. DOI: 10.55041/ijsrem30997 (date accessed:

In contrast, railguns can reach extreme speeds exceeding Mach 7 in military use, although they do not currently reach high speeds in portables by pushing the bullet with the Lorentz force by passing high current along parallel rails [11].

EMG, especially coilguns and railguns, are generally not considered in the Directed-Energy Weapons (DEW) category, but in the EMG class. These weapons use electromagnetic forces that can launch projectiles at very high speeds. Coilguns and railguns are two different types of weapon systems that launch projectiles rapidly using electromagnetic forces, and these two types of weapons differ fundamentally.

Compared to firearms or non-fire weapons, railguns and coilguns from EMG leave physically different and undetectable traces in evidence [12]. Due to these features, they pose various challenges in forensic analysis and criminal investigations. Railguns and coilguns can be used to damage targets by launching different types of projectors, bullets or torpedoes, especially to disrupt electronics, disable infrastructure and cause potential biological damage [13]. It is now possible to see personalized versions of such weapons and even receive them on special orders, and the fact that there is no legal obstacle in this regard also creates a different problem. This research is carried out in this context to touch upon the evidence that can be encountered and left in forensic investigations with the development of such railgun and coilgun EMG in an individually portable form, and to determine a holistic strategy for new methodological research [14].

Electromagnetic Gun (EMG) Portable Railgun and Coilgun

The TK-20 electromagnetic coilgun can fire at a speed of 136 m/s (446 fps) and the experimental and manufactured weapon, weighing 2.6 kg with a double-row magazine of 16 mm diameter and 15 rounds capacity, can fire 150 shots with a full battery. Projectiles with an energy of 56 J will cause serious injuries; compared to other types of weapons, air guns produce 15—30 J, 9 mm pistols 500 J, and pump-action rifles 1000 J. A projectile or bullet fired at a speed of 136 m/s will cause skin punctures, fractures and internal injuries where it hits; if

29.12.2024) ; Cheng B. The development of a novel coil gun with permanent magnet. *2023 IEEE / ASME International Conference on Advanced Intelligent Mechatronics (AIM)* (28—30 June; Seattle, WA, USA). 2023. Pp. 531—536. DOI: 10.1109/AIM46323.2023.10196246 (date accessed: 29.12.2024).

11 Ram R., & Thomas M. J. Performance of a Four-Stage Induction Coilgun That Uses a Solenoid Projectile. *2023 IEEE International Conference on Plasma Science (ICOPS)* (2023, May; Santa Fe, NM, USA). 2023. Pp. 1—1. DOI: 10.1109/ICOPS45740.2023.10481243 (date accessed: 30.12.2024) ; Raj R., Sesha Talpa Sai P. H. V., Gurudutta A. et al. Design and Numerical Analysis of Electromagnetic Rail Gun for Defense Applications / Intelligent Manufacturing and Energy Sustainability. 2023. Pp. 183—192. DOI: 10.1007/978-981-99-6774-2_17 (date accessed: 30.12.2024).

12 Jia L., Wang Y., Song Y., et al. The Detection Technology of High-Power Microwave: A Review. *IEEE Transactions on Instrumentation and Measurement.* 2024. Vol. 73. DOI: 10.1109/tim.2024.3472802 (date accessed: 02.01.2025).

13 Mykhaylenko O. V., Mishalov V. D., Kozlov S. V., & Varfolomeiev Y. A. Forensic characteristics of injuries from thermo-baric explosive device. *Reports of Morphology*. 2024. Vol. 30. № 2. Pp. 24—30. DOI: 10.31393/morphology-journal-2024-30(2)-03 (date accessed: 02.01.2025).

14 Cheng B. The Design and Simulation of a Novel Electromagnetic Launcher with Permanent Magnet. *7th International Conference on Mechanical Engineering and Robotics Research (ICMERR)*. 2022. Pp. 114—117. DOI: 10.1109/ICMERR56497.2022.10097818 (date accessed: 03.01.2025).

it hits the chest, head or neck area, it will have fatal results [15].

The 100+ pound railgun is a weapon that fires bullets at extremely high speeds, usually used for long-range precision shooting. Its use in competitions such as the 1000 yard (914 meter) Benchrest match shows that such weapons are accurate and powerful. The railgun with bullets used in a magnetic field that can reach Macg 5 and above can reach very high speeds, is more powerful than fire deities and can be deadly [16].

The 250 lb mobile railgun delivers 27,000 J of energy for heavy armor penetration and lethal impact. Its high energy ionizes the metal, creating a plasma explosion that increases both thermal and kinetic damage. In forensic ballistics, the TK-20 coil gun (56 J) causes limited damage, while the railgun's excessive speed and destructive impact make evidence analysis difficult [17].

The GR-1 "Anvil" is an EMG described as a portable shoulder-fired gauss rifle manufactured by Arcflash Labs. They are described as coilguns or linear accelerators, which can launch iron 1/2 diameter dowel pins (bullets) at a speed of 75 m/s (240 fps) by generating magnetic fields from a series of high-voltage coils with electrical energy between 4000 and 16000 amperes. Coilguns (gauss rifles) will launch metal bullets at high speeds, causing serious injuries or fatal consequences. Thanks to the accelerator, the bullet is powerful enough to penetrate armor and cause great damage to the human body [18]. ArcFlash Labs EMG-02 is an electromagnetic coilgun model. It can throw metal bullets weighing 5—10 grams at a speed of approximately 300 fps and above 100 m/s in full automatic mode and 20—30 J of energy, 30 and 50 meter. Although they are not lethal like firearms, they can cause the death of living beings at certain speeds, but they definitely have a serious wounding effect. A projectile with a force of 300 fps and above can cause fractures, holes and internal organ damage with human contact [19].

RARE CA-09 MAX POWER shotgun can fire 67/76 m/s notifications with 40 J energy to a disk or skug bullet. It can be fired at a speed of 1200 rpm and serious traumatic wounds can occur as a result of falling. Forensic investigation and ballistics, high firing speed and bullet structure will make it difficult to analyze different scar continuity [20].

NSSC CA-09 Coil Accelerator, which can shoot silently and without recoil with electromagnetic coils at a speed of 140 fps, with 16 J energy and a range of 12 meter, according to ballistic observations, other coilgun and railgun EMG do not leave gunpowder traces, making criminal investigations difficult [21].

15 Cheng B. Op. cit. DOI: 10.1109/ICMERR56497.2022.10097818 (date accessed: 03.01.2025).

16 Guo W., Zhang T., Mu Z., Zhu W., & Li M. Op. cit. DOI: 10.1088/1742-6596/2478/9/092018 (date accessed: 25.12.2024).

17 Kakad Y. U., et al. Op. cit. DOI: 10.55041/ijsrem30997 (date accessed: 29.12.2024).

18 Abdo M. M. M., Fanni M., Miyashita T., & Ahmed S. M. The Effect of Coil Geometry and Winding Method on the Electromagnetic Launcher Performance. *IECON 2022 — 48th Annual Conference of the IEEE Industrial Electronics Society* (17—20.10.2022). 2022. Pp. 1—5. DOI: 10.1109/IECON49645.2022.9968763 (date accessed: 03.01.2025).

19 Korytkowski K., & Starzyński J. Coilgun Design by Simulation. *22nd International Conference on Computational Problems of Electrical Engineering (CPEE)* (15—17.09.2021; Hrádek u Sušice, Czech Republic). Pp. 1—5. DOI: 10.1109/CPEE54040.2021.9585193 (date accessed: 04.01.2025).

20 Nine S. Z., Hossain M. D., Hasan A. K., et al. Pellet Embolus in Ulnar artery — A rare vascular Injury. *Pulse*. 2018. Pp. 33—37. DOI: 10.3329/pulse.v11i1.62452 (date accessed: 04.01.2025).

21 Shornikov A., Champagne A. E., Walet R. C., & Mous D. J. W. High power DC and ns-pulsed 2 MV accelerator for light ions. *The Review of Scientific Instruments*. 2023. Art. 94(7):073303. DOI: 10.1063/5.0150982 (date accessed: 04.01.2025).

Forensic and Ballistic Comparison of Portable Coilgun and Railgun Systems

EMG	Energy (J)	Speed (m/s)	Range (meter)	Lethal Risk	Injury Risk
Coilgun	56	136	12	Moderate	Serious (skin puncture, fractures, internal injuries)
Railgun	27000	5000	914	High (armor-piercing, fatal)	Fatal (high-speed projectile)
Railgun	27000	5000	914	High (armor-piercing, fatal)	Fatal (high-speed projectile)
Railgun	30	75	50	Low to Moderate (penetrates soft targets, not lethal)	Serious (fractures, internal organ damage)
Coilgun	40	76	30	Moderate (can cause serious injury)	High (serious trauma, fractures, internal bleeding)
Coilgun	16	140	12	Low to Moderate (not lethal, but serious injury possible)	Moderate (soft tissue damage, fractures)

Forensic and Criminalistic Assessment of EMG: Railgun and Coilgun Analysis

EMG, especially the railgun and coilgun types, operate via different mechanisms than firearms. Wounding mechanisms, kinetic energy transfer, and target tissue properties determine the effects of these weapons [22]. The injuries and marks caused by these weapons depend on factors such as kinetic energy, bullet speed, target tissue characteristics and distance [23]. Kinetic energy and injury mechanisms; EMG railguns and coilguns launch bullets or projectiles at high speeds and cause damage to targets through kinetic energy transfer. Kinetic energy (KE) is directly related to bullet speed (v) and mass (m) and is calculated with the formula $KE = ½ mv^2$. Especially the high-energy model 250 lb railgun can directly cause fatal results. We understand that low-energy models such as the TK-20 coilgun can cause serious injuries [24].

Injuries to the skin and underlying soft tissue are caused by the sharp-edged contact of high-speed bullets (100 m/s and below). Bullets that are more similar to projectiles launched by other electromagnetic coilguns and railguns such as the NSSC CA-09 Coil Accelerator or TK-20 may evolve into cartridge-type bullets in the future, causing more serious injuries and deaths. While they may cause smaller diameters and less tissue fragmentation similar to traditional gunshot wounds, EMG at the Mach 5 effect will definitely cause deaths. Contusion (hematoma, ecchymosis) and abrasion are possible in the epidermis and dermis layers [25]. High-speed bullets will penetrate to the hypodermis and muscle tissue, causing skin tissue injuries such as laceration and avulsion. High-energy weapons such as railguns may also cause

22 Zhou Y., Zhang D., & Yan P. Modeling of Electromagnetic Rail Launcher System Based on Multifactor Effects. *IEEE Transactions on Plasma Science*. 2015. Vol. 43. Is. 5. Pp. 1516—1522. DOI: 10.1109/TPS.2015.2403264 (date accessed: 06.01.2025).

23 Ma M. Electromagnetic Railguns and Coil Guns: Comprehensive Analysis of Physical Principles and Applications and Experimental Improvements. *Theoretical and Natural Science*. 2025. Art. 87(1):15—25. DOI: 10.54254/2753-8818/2025.20319 (date accessed: 06.01.2025).

24 Kakad Y. U., et al. Op. cit. DOI: 10.55041/ijsrem30997 (date accessed: 29.12.2024).

25 Elsafty O., Berkey Ch. A., & Dauskardt R. H. Insights and mechanics-driven modeling of human cutaneous impact injuries. *Journal of the Mechanical Behavior of Biomedical Materials*. 2024. May. Art. 153:106456. DOI: 10.1016/j.jmbbm.2024.106456 (date accessed: 16.01.2025).

tissue fragmentation and necrosis due to hydrostatic shock [26].

EMG such as railguns and coilguns can also cause serious bone fractures. The type and severity of the fracture depend on the bullet's energy, speed, impact angle and bone density. When the bullet hits at a right angle, it can create a straight-line transverse fracture or the bone can shatter into multiple fracture fragments, i.e. communal fractures. However, in terms of forensic investigations, even low-energy bullets can cause fractures in individuals with low bone density and create pathological fractures. In particular, tibia and humerus as well as femur fractures carry the risk of massive hemorrhage or shock [27]. In terms of localization, skull fractures may cause brain damage or, in the case of pelvic fractures, they may be associated with internal organ injuries caused by railguns and coilguns. Bullets with a kinetic energy of 50 J and above can cause fractures in the skeletal system, and coilgun and railgun bullets with an energy of 100 J and above in particular will cause complete fractures in long bones. High-velocity bullets fired by EMG will cause severe cranial fractures and brain damage when they hit the skull, with fatal effects. Energy levels of 500 J and above can cause fatal head trauma [28].

Traumatic shock is possible to cause internal organ failure or damage. Perforation, bleeding and organ failure in internal organs due to coilgun and railgun projectiles hitting the chest or abdomen area are expected to occur especially at kinetic energy levels above 200 J. In the case of high energy bullets, shock waves can be created in the organs and secondary injuries can occur [29].

The findings of injuries caused by EMG are of critical importance during crime scene investigation and autopsy. It is characterized by small diameter, smooth edges and minimal tissue fragmentation, and carbonization and burn marks can be seen in wound hemorrhages due to thermal effects when the speed is as effective as Mach 5 [30]. If the bullet energy is high, the exit wound is likely to be more irregular and wider. However, for now, it is more appropriate for portable coilgun or railgun EMG to remain inside by moving through the internal tissue, as they cannot exceed a certain energy.

Railgun or coilgun high speed bullets connected to EMG or projectiles with penetrating power and speed can leave thermal or chemical traces. It is possible to detect coagulation necrosis and protein denaturation during histopathological

26 Jia Y., Wen Y., Dong F., Qin B., & Liu R. Retracted Artıcle: Human vulnerability assessment based on bullet motion and cavity expansion model with tissue identification. *Computer Methods in Biomechanics and Biomedical Engineering*. 2024. Jan. Art. 29:1—15. DOI: 10.1080/10255842.2023.2294263 (date accessed: 17.01.2025).

27 Chen S., Peng A., Chen A., & Liu T. Design and Characterization of High Efficiency Single-stage Electromagnetic Coil Guns. *ArXiv preprint*. 2024. arXiv:2410.07594. DOI: 10.48550/arxiv.2410.07594 (date accessed: 17.01.2025).

28 Yadav M., Ram R., & Thomas M. J. Op. cit. DOI: 10.1007/978-981-97-0337-1_6 (date accessed: 25.12.2024) ; Smith W., Schick S., Arthur R., Paul K., Elphingstone J., et al. Ballistic injuries of the humerus: A matched cohort analysis. *Trauma*. 2024. Vol. 26. Is. 4. Pp. 347—353. DOI: 10.1177/14604086231197053 (date accessed: 25.12.2024).

29 Nelson K. J., Daun M., Mourad T., Wahood W., & Ahmed O. Visceral and Solid Organ Trauma / IR Playbook: A Comprehensive Introduction to Interventional Radiology. 2024. Pp. 401—414. DOI: 10.1007/978-3-031-52546-9_33 (date accessed: 25.12.2024).

30 Guo W., Zhang T., Mu Z., Zhu W., & Li M. Op. cit. DOI: 10.1088/1742-6596/2478/9/092018 (date accessed: 25.12.2024).

examinations [31]. Chemical compounds (e.g. metal ions and carbon particles) released as a result of the interaction between the bullet and the target tissue can be detected in toxicological analyses [32]. X-ray and CT scans can be used to detect bullet paths, fractures, and internal organ damage. Radiopaque particles can be seen if bullets or projectiles have fragmented in tissue. Railguns, in particular, can cause ionization or plasma formation during the launch of the bullet [33].

The technical features and energy values of EMG, coilgun and railgun EMG, differ in terms of the kinetic energy and bullet speeds they create in terms of the damage they can inflict on the body. Coilgun, which fires 16 mm diameter bullets-projectile and ½ metal dowel pins at speeds of 136 m/s and 75 m/s and produces approximately 56 J energy, can cause serious tissue injuries, traumatic shock, bone fractures, organ failure and even organ loss, as well as death when it reaches the carotid artery regions [34]. A coilgun, which fires a small metal disc or slug resembling a watch battery at a speed of 220—250 fps (64—76 m/s) and has an energy of 40 J, can easily break a vehicle window or seriously damage its metal surface, while hitting a human head can cause skull fractures and hematoma formation. Railguns and similar high-kinetic weapons that can produce 27,000 J of energy can easily penetrate heavy armor, and in crimes committed against humans or animals, they not only damage but also cause fragmentation [35].

Forensic analysis of EMG will present different problems due to the lack of gunshot ballistic traces such as gunpowder residue or cartridge cases. In forensic investigations, artificial intelligence system technical approaches should be applied in magnetic field analysis and thermal imaging techniques to detect the fine traces left by these weapons [36]. There are no limitations to such techniques and methods. For example, magnetic field analysis requires precise calibration and is sensitive to environmental factors, and thermal imaging is not always able to capture the transient heat signatures that occur during the launch of a projectile. To overcome or improve such challenges with the use of artificial intelligence, a multimodal approach combining magnetic, thermal and spectroscopic analysis is implemented [37].

Comparative Analysis of Ballistic Effects of Coilgun and Railgun

EMG can reach high speeds in terms of kinetic energy and firearms have higher kinetic energy with heavy bullets, but these change according to the conditions. Although coil-

31 Ma M. Op. cit. DOI: 10.54254/2753-8818/2025.20319 (date accessed: 06.01.2025).

32 Smith W., Schick S., Arthur R., Paul K., Elphingstone J., et al. Op. cit. DOI: 10.1177/14604086231197053 (date accessed: 25.12.2024).

33 Siemenn A. E., Deo Bh., Ng F., Zhou J., et al. A Railgun Secondary Propulsion System for High-Speed Hyperloop Transportation. *IEEE Transactions on Plasma Science*. 2023. Vol. 51. Is. 1. Pp. 243—248. DOI: 10.1109/TPS.2022.3232406 (date accessed: 06.01.2025).

34 Ma M. Op. cit. DOI: 10.54254/2753-8818/2025.20319 (date accessed: 06.01.2025) ; Yadav M., Ram R., & Thomas M. J. Op. cit. DOI: 10.1007/978-981-97-0337-1_6 (date accessed: 25.12.2024).

35 Kakad Y. U., et al. Op. cit. DOI: 10.55041/ijsrem30997 (date accessed: 29.12.2024).

36 Alnafrani R., & Wijesekera D. AIFIS: Artificial Intelligence (AI)-Based Forensic Investigative System. *10th International Symposium on Digital Forensics and Security (ISDFS)* (06—07.06.2022; Istanbul, Turkey). Pp. 1—6. DOI: 10.1109/ISDFS55398.2022.9800801 (date accessed: 22.01.2025).

37 Dudek A., Dąbek A., Zborowska I., & Lichosik J. Integrating artificial intelligence in forensic science. *E-methodology*. 2024. Art. 10(10):15-28. DOI: 10.15503/emet2023.15.28 (date accessed: 22.01.2025).

guns operate at lower energy levels, their projectiles can still cause penetration and fragmentation, depending on the target material and velocity [38].

In terms of comparing wound mechanisms, coilgun bullets are generally considered non-lethal due to their low energy and speed, but they can cause not only blunt trauma and superficial injuries but also other damage that will cause death. Railgun type EMG, on the other hand, cause great damage to human tissue due to their high kinetic energy, create bone fractures and can cause fatal forensic cases with hydrodynamic shock waves [39].

Criminalistic and Ballistic Evaluation of Railgun and Coilgun EMG

Railguns and coilguns, which are EMG, create new challenges in forensic investigations and examinations [40]. Injuries caused by these weapons exhibit different findings than standard firearms and should be detected with advanced analytical techniques. Spectroscopic examinations, thermal and magnetic analyses are especially in question, thus providing various evidences regarding the use of these railgun and coilgun type weapons. When we investigate what can be done about forensic injuries and deaths due to portable and continuously developing railgun and coilgun, it can be seen that it can have serious effects [41].

The risk of their potential use in crimes comes to the forefront due to their portability, not leaving chemical traces, not producing muzzle flames and low recoil properties in certain models. In this context, the following points are important for forensic investigations [42].

In bullet ballistics and evidence analysis, in attacks carried out with coilguns or railguns, bullet ballistic traces can be more irregular compared to firearms. In addition, excessive kinetic energy transfer can be observed at the point of contact due to high speed [43]. There are no traces of grooves or sets, no cartridge cases are found at the crime scenes, and instead of cores or projectile type air gun pellets or hand-made tools are used instead of bullets [44]. Surface deformations, thermal effects and magnetic field-induced changes caused by electromagnetic acceleration need to be investigated. Railgun and coilgun projectiles can be made of certain alloys or magnetic materials for electromagnetic acceleration. Therefore, spectroscopic analysis will be

38 Guo W., Zhang T., Mu Z., Zhu W., & Li M. Op. cit. DOI: 10.1088/1742-6596/2478/9/092018 (date accessed: 25.12.2024).

39 Raj R., Sesha Talpa Sai P. H. V., Gurudutta A. et al. Op. cit. DOI: 10.1007/978-981-99-6774-2_17 (date accessed: 30.12.2024).

40 Guarnera L., Giudice O., Livatino S., Paratore A. B., et al. Assessing forensic ballistics three-dimensionally through graphical reconstruction and immersive VR observation. *Multimedia Tools and Applications*. 2023. Vol. 82. Is. 13. Pp. 20655—20681. DOI: 10.1007/s11042-022-14037-x (date accessed: 25.01.2025).

41 Hayda R. Ballistic, Blast, and Burn Injury: Science and Clinical Implications / Owens B., Belmont Ph. Combat Orthopedic Surgery: Lessons Learned in Iraq and Afghanistan. 2024. Pp. 53—63. DOI: 10.1201/9781003523222 (date accessed: 03.02.2025).

42 Molnar A. The Demonstration Model of an Electromagnetic Accelerator Gun. *Acta Universitatis Sapientiae, Electrical and Mechanical Engineering*. 2018. Ed. 10 (1). Pp. 77—89. DOI: 10.2478/AUSE-ME-2018-0005 (date accessed: 07.02.2025).

43 Reck B., Alouahabi F., Hassler Q., & Schneider M. Railgun Launch of Cylindrical and Conical Projectiles at Muzzle Velocities up to 2100 M/S. *16th Hypervelocity Impact Symposium*. 2022. Nov. P. V001T02A003. DOI: 10.1115/HVIS2022-42 (date accessed: 03.02.2025).

44 Ma M. Op. cit. DOI: 10.54254/2753-8818/2025.20319 (date accessed: 06.01.2025).

required on projectiles or projectiles [45]. In those reaching high speeds, there may be thermal changes in the face due to friction heat, and this can only be determined in forensic and criminalistic analyses [46].

The serial numbers, material composition and production traces of these components will provide information about the origin of the weapon. Electronic trace tracking is an important method for determining the use and origin of these weapons, but new difficulties will arise in this regard in cases where they are produced at home [47]. As energy sources, batteries or external power supply mechanisms may exhibit unique energy consumption patterns and provide data for forensic monitoring. Remaining end-use data, firing counts and energy output levels in circuits with microcontrollers or special control cards will provide important findings in matching suspicious devices found at the scene. Residues left on coils and conductor rails can be detected with high-speed imaging and thermal analysis techniques, providing information about when and how the weapon was used. Considering these factors, effective forensic reverse engineering interdisciplinary investigation is required in railgun and coilgun incidents [48].

In the investigation of electromagnetic railgun and coilgun weapons with criminalistic techniques, it is possible to detect chemical changes on the bullet and target surfaces using raman spectroscopy [49]. Analysis of metallic residues in bullets and tissue is performed by energy dispersive X-ray spectroscopy (EDS) [50]. Thermal imaging can map the thermal damage in the injury area, as well as detailing the bullet energy and interaction process. In magnetic field analysis, magnetic field residues left at the scene of the incident, including coilguns and railguns, can be detected due to the working principle of EMG, and findings about their use can be proven with evidence [51].

Techniques that can be used in Coilgun and Railgun Forensic Examination

Magnetic field analysis and electromagnetic signature detection coilgun and railgun accelerate bullets by electromagnetic fields created by the discharge of high-power capacitors. This process in-

45 Guo W., Zhang T., Mu Z., Zhu W., & Li M. Op. cit. DOI: 10.1088/1742-6596/2478/9/092018 (date accessed: 25.12.2024).

46 Zhang Y., Lu J., Tan S., Li B., & Jiang Y. Dynamic Response of Interior Ballistic Process and Rail Stress in Electromagnetic Rail Launcher. *IEEE Transactions on Plasma Science*. 2019. Vol. 47. Is. 5. Pp. 2172—2178. DOI: 10.1109/TPS.2018.2887006 (date accessed: 11.02.2025).

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48 Ma M. Op. cit. DOI: 10.54254/2753-8818/2025.20319 (date accessed: 06.01.2025).

49 Li Sh., Cao R., Zhou Y., & Li J. Performance Analysis of Electromagnetic Railgun Launch System Based on Multiple Experimental Data. *IEEE Transactions on Plasma Science*. 2019. Vol. 47. Is. 1. Pp. 524—534. DOI: 10.1109/TPS.2018.2883285 (date accessed: 03.02.2025).

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51 Wongpakdeea Th., Crenshaw K., Wong H. M. F., Nacapricha D., & McCord B. Advancements in Analytical Techniques for Rapid Identification of Gunshot Residue and Low Explosives through Electrochemical Detection and Surface-Enhanced Raman Spectroscopy. *Global Forensic and Justice Center Symposium Research*. 7. 2024. DOI: 10.25148/gfjcsr.2024.7 (date accessed: 15.02.2025).

volves magnetic field residues, permanent magnetization in the conductor, and traces of high-frequency electromagnetic radiation. Magnetic flux imaging (MFI) can be used to determine whether a coilgun or railgun was used by examining the residual magnetic fields (remanence) left at the scene or on the weapon. Magnetic field changes can be detected by using Hall effect sensors. Coilgun bullets can acquire temporary magnetization due to the strong magnetic field they are exposed to during launch, which can be detected by special sensors or laboratory analysis [52]. Railguns generate high current electrical discharges, magnetic field fluctuations and radio frequency (RF) signals during use. Spectrum analyzers and RF detection devices can be used to examine electromagnetic signatures in areas where these weapons are used [53].

Spectroscopic analysis and XRF in bullet composition examination, coilgun and railgun bullets contain nickel coating, ferromagnetic alloys (Fe, Co, Ni) or tungsten based metal compounds. XRF analysis can be used to determine the alloy composition of the fired bullets and to determine their source [54]. Chemical changes (oxidation or carbonization, etc.) on the surface of the bullets caused by the heat and current generated during the launch can be detected with FTIR. Energy dispersive EDS and Raman spectroscopy can be used in the examination of ionized chemical residues in metal particle examination.

In the analysis of thermal and plasma signatures, railgun systems accelerate the projectile with the Lorentz force, while high temperature and plasma formation occur during launch [55]. Thermal camera analysis will be able to detect heat-related damage or surface melting at the scene. Railgun and coilgun bullets emit ionized metal particles during launch and are detected by laser-induced plasma spectroscopy (LIBS) analysis. Scanning electron microscope (SEM) will be able to perform surface change examination for microscopic melting, deformation and carbon residue detection [56].

Conclusions

EMG, particularly railguns and coilguns, which are kinetic energy-based weapon systems, have been determined to have the potential to cause serious injuries and deaths. Future forensic research should focus on developing analytical techniques to detect EMG used in criminal cases. The analysis concludes that EMG, especially coilguns, which can be modified using readily available materials and parts, have the potential to cause serious incidents. This research has analyzed how the traces created by EMG such as coilgun and railgun can be examined with scientific tests

52 Guo W., Zhang T., Mu Z., Zhu W., & Li M. Op. cit. DOI: 10.1088/1742-6596/2478/9/092018 (date accessed: 25.12.2024).

53 Ma M. Op. cit. DOI: 10.54254/2753-8818/2025.20319 (date accessed: 06.01.2025).

54 Klisińska-Kopacz A. X-ray fluorescence spectroscopy / Non-Destructive Material Characterization Methods. Elsevier Inc., 2024. Pp. 487—523. DOI: 10.1016/B978-0-323-91150-4.00018-5 (date accessed: 21.02.2025).

55 Vijayan N., Tawale J. S., Kiran, & Joshi D. Characterization of Materials Using X-ray Fluorescence Spectrometry and Energy Dispersive X-Ray Spectroscopy / Characterization of Single Crystals ; Dr. M. S. Pandian & Dr. P. Ramasamy (Eds.). Royal Book Publishing, 2025. Pp. 69—83. DOI: 10.26524/225.4 (date accessed: 21.02.2025).

56 Rajput Sh., Kumar G., Swarup S., Nomula P., Pawar A., Joshi J. C., et al. Modeling and Simulation of High Energy Capacitor Bank based Electromagnetic Railgun / High Voltage ... . Pp. 313—321. DOI: 10.1007/978-981-97-0337-1_31 (date accessed: 21.02.2025).

and how technical and methodological approaches can be used. The risks in terms of ballistics and security have been addressed and the necessities in preventing threats strategically have been emphasized. It has been concluded that the detection of criminal use of EMG will be standardized and facilitated by developing forensic examination techniques. Due to their high speed and penetrating power, these weapons can cause severe traumas in soft tissue and penetration marks on metal surfaces. For this reason, the traces created by EMG have been examined in detail in terms of ballistic examinations and it has been analyzed which techniques should be developed for detection in criminal cases.

More experimental and simulation-supported ballistic data collection is required on coilgun and railgun weapons and their bullets or projectors on different surfaces and ballistic gels similar to human tissue. EMG have been determined to have the potential to cause serious injuries and deaths, depending on the railgun and coilgun, which are kinetic energy-based weapon systems. It has been concluded that EMG, especially coilgun type, which can be created with modifications with the availability of individual materials and parts, can cause serious cases as a result of the analysis. In addition, new analysis methods should be developed to facilitate the detection of EMG in forensic examinations. To improve the detection and analysis of EMG in forensic investigations, standardization of techniques such as magnetic signature analysis, thermal imaging, and spectral analysis is vital. This can be achieved by developing universal protocols for data collection, analysis, and reporting, and ensuring consistency across forensic laboratories.

Railgun and coilgun EMG present new challenges in forensic and ballistic investigations. Unlike firearms, EMG do not leave chemical residue, which makes them technically inadequate for forensic detection methods. They create thermal signatures, magnetic residues, and various deformations on target surfaces.

Projectiles or bullets launched at high speeds can cause severe tissue damage or bone fractures. Techniques such as thermal imaging, XRF, and FTIR spectroscopy are being evaluated in forensic investigations to detect traces left by EMG. Additionally, Gauss meters and Hall effect sensors are important in detecting electromagnetic signatures at the scene.

The fact that these weapons are easily accessible increases the risks. It is possible to produce them personally with 3D printing and high-capacity capacitors. In forensic investigations, methods such as artificial intelligence-supported analysis and determination of electromagnetic signatures need to be developed.

Coilgun and railgun portable weapons create security and legal problems due to their low or silent operation, easy to manufacture and potential for abuse. The fact that they remain in the traditional firearms classification requires special regulatory measures. For example, they can be used in a terrorist attack because they are silent and effective, and the materials and ways they are put together can provide geographical information, and strategic approaches are provided in the detection of railguns and coilguns used in electromagnetic residue detection and spectral analysis. Forensic ballistics standards are open to the opposite idea that they do not provide full performance for EMG in the current situation.

Coilgun and railgun type EMG can be made in homes and therefore pose potential security risks for portable individual and criminal misuse. It is an open issue to develop a legal framework specifically for the production, possession and use of EMG in order to minimize these risks. Therefore, additional research that needs to be added to the literature should also focus on the development of protocols in forensic analysis of coilguns and railguns. Expanding research with coilguns and railguns, which are open to more ballistic tests, will be important not only in terms of ballistics but also in the functioning of justice in criminal investigations and is a strategic issue in preventing crimes before they start. With advanced analysis techniques, it will be more possible to determine the use of these weapons and to solve crimes.

Електромагнітна зброя: судово-медична й балістична експертизи рейкотрона та гармати Ґаусса

Ґоркем Ардакан Тан

Електромагнітна зброя має іншу балістичну динаміку та злочинні сліди, аніж традиційна вогнепальна зброя. Переносні металеві системи (рейкотронні й гармати Ґаусса) і подібна до них зброя створюють нові труднощі для їхнього криміналістичного дослідження через портативність і можливість виготовити їх у домашніх умовах. Під час судово-медичної експертизи (дослідження спричинених летальних і нелетальних травм) вивчають балістичні наслідки влучання такої зброї — фізичні сліди, які вони залишають. Розглянуто технічні характеристики рейкотронних систем і гармати Ґаусса. Оцінено шкоду від боєприпасів, випущених із силою Лоренца, порівняно зі шкодою, яку спричиняє звичайна вогнепальна зброя. Обсяг криміналістичного аналізу від застосування електромагнітної зброї через високу швидкість і передачу кінетичної енергії значно розширюється. Інші ризики безпеці полягають у безшумності портативної електромагнітної зброї та відсутності хімічних залишків (слідів) після їх спрацьовування. Зі збільшенням випадків застосування електромагнітних рейкотронів і гармат Ґаусса (зокрема, виготовлених у домашніх умовах) необхідно розробити нові підходи й методи експертизи для судово-медичних досліджень, а також відповідні міжнародні й національні законодавчі норми з регулювання поширення такої зброї та уніфікації методів її дослідження. Метою автора є розглянути технічні й фізичні властивості електромагнітної зброї, завдані нею ушкодження, методи її дослідження, а також потребу у змінах відповідних міжнародних і національних нормотворчих актів з питань поширення та дослідження цієї і подібної до неї зброї. Для досягнення поставленої мети застосовано такі наукові методи: аналіз, синтез, статистичний аналіз, узагальнення та ін.

Ключові слова: *електромагнітна зброя; рейкотрон; гармата Ґаусса; криміналістичне дослідження; балістичні ефекти; судово-медична експертиза.*

Фінансування

Це дослідження не отримало жодного спеціального гранту від фінансових установ у державному, комерційному або некомерційному секторах.

Відмова від відповідальності

Засновники не грали жодної ролі у розробленні дослідження, добиранні й аналізуванні даних, рішенні про публікацію або підготовку рукопису.

Учасники

Автор зробив свій внесок винятково в інтелектуальну дискусію, що є основою цього документа, дослідження судової практики, написання та редагування, і бере на себе відповідальність за її зміст і тлумачення.

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Автор заявляє, що у нього відсутній конфлікт інтересів.

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