



# Exhaust Gas Temperature Monitoring in Armored Vehicle Engines: Role, Implementation, and Diagnostic Value

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*Abstract* : This report provides an overview of exhaust gas temperature (EGT) monitoring and its importance for the performance and maintenance of armored vehicle engines. It focuses on supercharged and turbocharged diesel powerplants. The study outlines how thermocouples work and looks at how sensor placement affects combustion efficiency, turbocharger performance, and infrared signature reduction. It also addresses practical challenges like signal interference, thermal degradation, and vibration fatigue. The report suggests reliable sensor technologies and installation strategies to address these issues. EGT monitoring is shown to be crucial for real-time diagnostics and preventive maintenance in combat vehicles. It helps protect engines, improve efficiency, and enhance battlefield survivability.

## I. INTRODUCTION

Internal combustion engines, especially those in military armored vehicles, face extreme mechanical and thermal loads during active duty. Monitoring the temperature of exhaust gases is a key method for evaluating engine health and operational efficiency. EGT readings provide immediate insight into combustion quality, air-fuel ratio balance, and whether there are overheating or fuel delivery problems.

In combat scenarios, EGT monitoring aids not just mechanical performance but also strategic functionality. High exhaust temperatures can cause early component failure, and poor thermal regulation may raise the vehicle's infrared visibility, making it easier to detect. By adding EGT sensors to the engine system, operators can optimize fuel use, extend component life, and support thermal stealth systems that hide the vehicle's heat signature.

This section highlights the essential role of EGT measurement as a non-invasive, real-time diagnostic method that improves both operational reliability and combat readiness.

### 2.1 Thermocouple Fundamentals

Thermocouples are often used in high-temperature settings because they are durable, cost-effective, and respond quickly. The main principle behind how thermocouples work is the Seebeck effect. This effect explains that a voltage is produced at the junction of two different metals when there is a temperature difference between that junction (hot) and another reference junction (cold).

In practical use, a thermocouple includes:

- A hot junction, which is positioned at the measurement site (for example, within an exhaust stream).
- A cold junction, which is found near the data collection system or in a temperature-controlled area.

The voltage generated across the two wires directly relates to the temperature difference and is interpreted using calibration curves or electronic converters.

## 2.2 How a Thermocouple Works: Step-by-Step

1. Material Selection: Two different wires (for example, Nickel-Chromium and Nickel-Aluminum) are chosen.
2. Formation of Junctions: These wires are connected at one end (hot junction) and separated at the other end (cold junction).
3. Exposure to Heat: The hot junction is exposed to exhaust gases, while the cold junction stays at a known reference temperature.
4. Voltage Generation: A thermoelectric voltage forms based on the temperature difference.
5. Signal Interpretation: This voltage is read by a controller or data logger and converted into a temperature reading.

## 2.3 Comparison of Common Thermocouple Types

Type K and Type J are two of the most commonly used thermocouples in military engine diagnostics. Each type has its own benefits and drawbacks based on the operating environment.

Feature	Type K (Chromel–Alumel)	Type J (Iron–Constantan)
Temperature Range	-200°C to +1260°C	-40°C to +750°C
Sensitivity	~41 $\mu\text{V}/^\circ\text{C}$	~55 $\mu\text{V}/^\circ\text{C}$
Oxidation Resistance	High (suitable for oxidizing)	Low (iron prone to rust)
Durability	Excellent	Moderate
Preferred Environment	Industrial, high-temp	Indoor, controlled temp
Cost	Moderate	Low
Typical Applications	Turbines, diesel engines	Lab equipment, ovens

## 2.4 Suitability in Military Vehicles

Due to their exposure to wide temperature fluctuations, mechanical vibrations, and corrosive exhaust gases, armored vehicles demand sensors with high thermal stability and mechanical robustness. Type K thermocouples, with their broader temperature range and resistance to oxidation, are generally preferred. In some upgraded systems, mineral-insulated, metal-sheathed (MIMS) Type N thermocouples are used for their superior resistance to drift under cyclic heating conditions.

## 3. Integration of EGT Monitoring in Modern Armored Vehicles

The use of EGT monitoring systems in military engines affects both mechanical diagnostics and mission success. EGT sensors are essential for managing thermal profiles, improving fuel efficiency, preventing component failure, and keeping a low infrared signature.

This section discusses key main battle tanks (MBTs) that use EGT-based systems, their sensor layouts, control methods, and benefits observed.

### 3.1 M1 Abrams – Gas Turbine Engine (AGT1500)

The M1 Abrams has a multi-fuel turbine engine known as the AGT1500. Unlike traditional diesel engines, gas turbines run at extremely high temperatures. Therefore, EGT monitoring is crucial for turbine health and safety.

Sensor Placement:

Location	Purpose
Power Turbine Exit	Core EGT measurement; thermal protection and derating
Combustion Chamber Outlet	Early indication of combustion issues
Rear Exhaust Duct	Temperature averaging and system backup

Functions:

- Input to the Full Authority Digital Engine Control (FADEC) system.
- Regulates temperature during startup and continuous operation.
- Alerts for over-temperature situations and provides predictive maintenance logs.

### 3.2 Leopard 2 – MTU MB 873 Ka-501 V12 Diesel Engine

The Leopard 2 features a high-output, turbocharged diesel engine. Its advanced engine management system uses EGT data for performance tuning and infrared suppression.

Sensor Layout:

Location	Function
Turbocharger Inlets (L & R)	Monitors pre-turbine temperature for fuel-air balance
Pre-Muffler Junction	Checks combined exhaust gas flow
IR Suppressor Housing	Validates cooled exhaust stream for stealth compliance

Role of EGT Data:

- Guides boost control and injection strategies.
- Keeps the infrared signature within acceptable limits.
- Helps diagnose thermal inconsistencies across engine banks.

### 3.3 Challenger 2 – Perkins CV12 Diesel Engine

Challenger 2 features a Health and Usage Monitoring System (HUMS) that incorporates EGT data along with coolant and oil temperature, engine RPM, and pressure readings.

EGT Sensor Points:

Location	Objective
Manifold Junctions (L & R Banks)	Tracks thermal load per bank
Post-Turbo Outlet	Detects turbo performance and exhaust backpressure
Muffler Exit (with IR kit)	Ensures exhaust complies with emission and stealth standards

Diagnostic Use:

- Identifies unbalanced combustion.
- Initiates derating protocols if temperature limits are exceeded.
- Assists in long-term engine wear analysis.

### 3.4 T-72 and Variants – V-46, V-84, V-92S2F Engines

The Soviet-designed T-72 family has gone through several upgrades. Recent variants like the T-72B3 and T-72M4 CZ include EGT sensors for modernized digital controls and infrared suppression.

EGT Implementation Examples:

Variant	Key Sensor Locations	Special Features
T-72B3 (Russia)	Turbo outlet, exhaust collector, IR diffuser exit	Digital dashboard display with overheat warnings
T-72M4 CZ	Per-bank manifold, post-turbo, muffler outlet	Integrated with NATO-standard diagnostics
T-72AMT (Ukraine)	Turbo outlet, heat exchanger inlet, tailpipe sensor	Real-time control of coolant flow in infrared system

Operational Benefits:

- Monitors thermal differences between cylinder banks.
- Prevents thermal overrun in high-load battlefield conditions.
- Improves survivability through temperature-based infrared control systems.

Choosing the right locations for EGT sensor installation is critical to ensuring meaningful and accurate thermal data. Incorrect placement can result in misleading temperature readings, delayed fault detection, or ineffective thermal management. Placement must balance accessibility, data precision, thermal representativeness, and environmental protection.

Below are the most commonly used mounting zones for EGT thermocouples in supercharged and turbocharged diesel engines used in armored vehicles like the T-72, T-90, and Challenger 2.

#### 4.1 Exhaust Port Zone (Per Cylinder)

**Location:** Just outside the cylinder head, where exhaust gases exit individual combustion chambers.

**Advantages:**

- Provides high-resolution data per cylinder.
- Useful for diagnosing injector or valve faults.

**Limitations:**

- Not always practical in fielded vehicles due to space constraints.
- Typically reserved for testbeds and performance tuning.

Diagnostic Value	High	(per-cylinder tuning)
Deployment Feasibility	Low (space and cost intensive)	

#### 4.2 Exhaust Manifold Collector (Bank-Level)

**Location:** At the junction where cylinders 1–6 and 7–12 merge into left and right exhaust manifolds.

**Advantages:**

- Captures average thermal load for each engine bank.
- Balances diagnostic value and installation feasibility.

**Applications:**

- Widely used in modern T-72 variants and NATO-aligned upgrades.

Diagnostic Value	Moderate–High
Deployment Feasibility	High

#### 4.3 Mid-Manifold Sections

**Location:** Between the cylinder ports and the collector in each manifold.

**Purpose:**

- Identifies localized hotspots or flow imbalances before gases fully merge.
- Adds redundancy in fault tracing.

Diagnostic Value	Moderate
Deployment Feasibility	Medium

#### 4.4 Turbocharger Inlet and Outlet

**Inlet:** Measures raw combustion temperature entering the turbine.

**Outlet:** Assesses how much energy was extracted from the exhaust gases.

**Location Insight Provided**

Pre-Turbo Indicates combustion intensity and fuel-air ratio

Post-Turbo Evaluates turbo performance and flow efficiency

This delta (inlet–outlet) can also be used to infer **turbine efficiency** and detect backpressure issues.

#### 4.5 Exhaust Collector (Post-Turbo)

**Location:** Where both sides of the engine's exhaust system merge before entering the muffler or IR suppressor.

**Role:**

- Monitors combined thermal load.
- Acts as a catch-all for system-level exhaust heat trends.

Diagnostic Value	High	(system-level health)
Deployment Feasibility	Very High	

#### 4.6 Muffler Entry and Exit

**Entry Point:**

- Tracks input heat into noise reduction or IR control systems.

**Exit Point:**

- Verifies final exhaust temperature before release to atmosphere.

Use Case	Purpose
Pre-Muffler Probe	Optimize IR masking initiation
Tailpipe Exit Sensor	Assess stealth effectiveness and overheating risk

### 5. Assessing Engine Efficiency Using EGT Data

EGT sensors offer a way to assess engine thermal behavior without interfering. By measuring the heat energy that comes from the combustion chambers, engineers can understand how well fuel is turning into mechanical work. Variations in EGT in different parts of the exhaust system can indicate inefficiencies, combustion imbalance, or incomplete fuel burn. This section presents a comparison of how supercharged and turbocharged setups differ in terms of EGT-based efficiency.

#### 5.1 Supercharged Diesel Engines

Superchargers mechanically force air into the engine using a crank-driven compressor. Unlike turbochargers, they do not utilize exhaust gases for boost, so their influence on the EGT profile is more indirect.

**System Setup (e.g., V-46 in older T-72 models):**

- 12-cylinder diesel engine
- Supercharger intake
- Dual exhaust manifolds
- Single or dual mufflers

**Recommended Sensor Points:**

Location	Purpose
Left and Right Manifold Outlets	Track thermal output of each engine bank
Post-Manifold Collector	Evaluate average exhaust temp under load
Tailpipe Exit	Validate IR suppression and total thermal loss
Mid-Manifold (optional)	Spot uneven combustion or injector issues

**Interpreting Readings:**

EGT Behavior	Inferred Condition
Consistently high EGT	Over-fueling, late injection
Low and flat EGT	Lean mix, poor combustion
Left/right imbalance	Injector mismatch, valve fault, compression loss
Tailpipe EGT above threshold	IR suppression failure, high external visibility

**5.2 Turbocharged Diesel Engines**

In turbocharged tanks (T-72B3, T-90M, Leopard 2), the turbo extracts energy from exhaust gases. EGT measurements before and after the turbo can indicate both **combustion quality** and **turbocharger efficiency**.

**System Setup (e.g., V-92S2F engine):**

- Twin exhaust manifolds feeding into a single or dual turbo setup
- Cooled muffler with IR suppression
- Digital engine management

**Sensor Layout:**

Location	Diagnostic Purpose
Turbo Inlets (L/R manifolds)	Primary measure of combustion heat
Turbo Outlets	Check turbine effectiveness
Pre-Muffler Collector	Total exhaust energy profile
Tailpipe Exit	IR control and stealth effectiveness

**Efficiency Inference:**

Comparison	Insight Provided
Turbo Inlet vs Outlet EGT	High delta = good turbo performance
Left vs Right Manifold EGT	Imbalance = combustion irregularities
Tailpipe EGT vs Load	Low efficiency at high tailpipe temps

**5.3 Practical Example: T-90M EGT Setup****Sensor Location Data Utility**

Turbo Inlet – Left	Raw combustion temp of one engine bank
Turbo Inlet – Right	Comparison point for thermal balance
Turbo Outlet	Thermal energy recovered by the turbine
Tailpipe Exit	Final IR-emission profile

By monitoring these zones and comparing EGT values with different engine loads, we can create a diagnostic map of the engine's thermal efficiency. This map is particularly helpful for tuning, predictive maintenance, and assessing battlefield survivability based on heat output.

#### 5.4 Intake vs Exhaust Delta Method

Another method involves comparing intake air temperature after the supercharger or intercooler with exhaust temperatures. This temperature difference ( $\Delta T$ ) shows the energy released during combustion.

##### Formulaic Inference:

$$\Delta T = \text{Exhaust Port Temp} - \text{Intake Air Temp}$$

Higher  $\Delta T$  generally correlates with efficient combustion. However, excessively high  $\Delta T$  may indicate energy wastage or over-fueling.

#### 6. Limitations of EGT Thermocouples in Armored Vehicles

While thermocouples are sturdy and suited for high-temperature settings, using them in armored vehicles brings up several reliability issues. Environmental factors like vibration, quick temperature changes, soot exposure, and electromagnetic interference (EMI) can skew readings or cause early sensor failure. Recognizing these problems is essential for designing durable and precise EGT monitoring systems.

##### 6.1 Ambient Temperature Drift and Cold-Junction Instability

Thermocouples measure temperature differences between the hot and reference junctions. If the reference junction faces ambient conditions that change greatly, which is common for tanks operating in both cold and hot climates, measurement errors can reach  $\pm 10^\circ\text{C}$  or more. Example: Opening hatches in freezing temperatures or idling under the desert sun can disturb the stability of the cold junction, leading to miscalibration.

6.2 Thermal Cycling and Fatigue Armored vehicles often switch quickly between operational modes, starting cold, speeding up rapidly, and then idling. These thermal cycles cause thermocouple materials to expand and contract.

Consequences:

- Microcracks in thermocouple wires
- Degradation of insulation layers
- Intermittent or permanent signal failure

##### 6.3 Oxidation and Material Degradation

At temperatures over  $600^\circ\text{C}$ , thermocouple materials like Chromel and Alumel can oxidize or react with sulfur residues from diesel combustion.

Effects:

- Altered Seebeck coefficient (sensor no longer provides the correct voltage)
- Reduced lifespan due to thinning and brittleness of materials

##### 6.4 Vibration and Mechanical Shock Military

tanks move over rough terrain, withstand explosive recoil, and experience extended engine vibration. These mechanical forces can harm sensors mounted in the exhaust system.

Failures Include:

- Sensor tip detachment
- Cracked sensor housings
- Loosened wire connectors and mounting clamps

## 6.5 Electrical Noise and EMI EGT

thermocouples produce very small voltages, from microvolts to millivolts, making them very vulnerable to EMI from onboard electronics such as:

- Communication radios
- Digital fire control systems
- Power converters and turret motors Impact:
- Signal distortion
- False temperature spikes
- Data acquisition failure or incorrect fault codes

## 6.6 Other Secondary Issues

Issue	Description
<b>Slow Response Time</b>	Large-sheath or poorly positioned probes may not detect rapid EGT changes during throttle shifts.
<b>Lead Wire Gradients</b>	Long wire runs through variable-temperature zones generate spurious thermoelectric voltages.
<b>Sensor Drift</b>	Long-term exposure leads to gradual changes in voltage output, requiring periodic recalibration.
<b>Access Constraints</b>	Optimal locations for sensor mounting are often blocked by armor, ducts, or cooling equipment.

## 7. Engineering Solutions for Enhanced EGT Monitoring Reliability

Given the demanding environments in which armored vehicles operate, EGT monitoring systems must be engineered for resilience. The following solutions are aimed at minimizing sensor failure, reducing data inaccuracies, and extending operational life.

### 7.1 Addressing Cold-Junction Instability

**Problem:** Temperature fluctuations at the cold junction cause unstable or inaccurate readings.

#### Solutions:

- Use thermocouple interface chips with integrated **Cold Junction Compensation (CJC)** such as the MAX31856 or AD8495.
- House the reference junction in a **thermally insulated compartment**, away from engine heat and airflow changes.
- Add a **precision RTD (Resistance Temperature Detector)** or thermistor near the junction to calibrate for environmental changes.

### 7.2 Managing Thermal Fatigue

**Problem:** Frequent thermal cycling leads to material fatigue and signal failure.

#### Solutions:

- Deploy **mineral-insulated thermocouples** with stainless steel or Inconel sheaths to withstand repeated heating and cooling.
- Choose **Type N thermocouples** (Nicrosil-Nisil), which offer better stability under thermal cycling than Type K.
- Use **strain-relief fittings** and flexible sensor mounting to absorb expansion without stressing the sensor core.

### 7.3 Preventing Oxidation and Chemical Attack

**Problem:** Exhaust exposure causes sensor degradation due to oxidation, soot, or sulfuric contamination.

**Solutions:**

- Use high-temperature alloys like **Inconel 600** or **Type S/R (platinum-based)** thermocouples for harsh environments.
- Apply **ceramic coatings or sleeves** on exposed sensors to resist chemical corrosion.
- Position sensors slightly downstream from the hottest zones to reduce thermal and chemical exposure without losing accuracy.

### 7.4 Withstanding Vibration and Mechanical Shock

**Problem:** Physical vibration causes sensor or wire failure.

**Solutions:**

- Use **military-grade armored cables** and welded-tip probes designed for high mechanical stress.
- Secure sensors using **anti-vibration mounts, rubber grommets, or spring-loaded holders**.
- Route wires through **flexible conduits** and include service loops to absorb movement.

### 7.5 Eliminating EMI and Electrical Interference

**Problem:** Low-voltage signals from thermocouples are vulnerable to EMI from internal electronics.

**Solutions:**

- Use **twisted-pair shielded cables**, grounded at a single point to prevent signal degradation.
- Place **signal conditioning circuits** close to the sensors to amplify and filter the signal.
- Use **differential-input ADCs (analog-to-digital converters)** for noise-resistant data acquisition.
- Route signal wires **away from high-current or high-frequency devices** like motor drives and comms systems.

### 7.6 Overcoming Secondary Limitations

Limitation	Engineering Solution
Slow response time	Use <b>exposed-junction or grounded-junction</b> thermocouples
Lead wire temperature error	Run wires through <b>temperature-stable zones or conduit</b>
Sensor drift	Implement <b>dual-redundant sensors</b> and schedule <b>calibration checks</b>
Access difficulty	Use <b>angled, side-entry probes</b> or <b>integrated manifold sensors</b>

### 7.7 Smart Sensor Integration

Advanced engine monitoring systems increasingly incorporate **microcontroller-based EGT modules** that include:

- **Onboard signal processing**
- **Built-in diagnostics**
- **Digital outputs (e.g., CAN bus compatible)**

These systems reduce the need for complex analog signal paths and provide **real-time fault alerts, drift correction, and data logging** for predictive maintenance.

## 8. Conclusion and Future Outlook

Monitoring Exhaust Gas Temperature (EGT) has become essential for engine health checks and thermal management in modern armored vehicles. Whether part of the turbine system in gas-powered tanks like the M1 Abrams or used in diesel engines like the T-72, Leopard 2, or Challenger 2, EGT sensors provide important information about combustion efficiency, turbocharger performance, and exhaust system behavior.

This report has outlined:

- The operational principles of thermocouples and their use in high-temperature settings.
- Strategies for deploying sensors in different areas of the exhaust system, each offering distinct diagnostic benefits.
- Specific applications across various main battle tanks, showing both traditional and digital sensor integration.
- How to interpret EGT data to gauge mechanical efficiency and fuel-energy conversion in real-world conditions.
- A detailed look at the limitations of EGT measurement in combat vehicles.
- Engineering solutions to address mechanical, electrical, thermal, and chemical issues that impact data reliability.

As military platforms move toward digital systems and AI-enabled controls, EGT data will play a larger role not just as a diagnostic tool but also in real-time decision-making processes. When combined with data from other sensors, such as intake air temperature, boost pressure, fuel injection rate, and coolant flow, EGT readings can help with:

- Predicting faults and providing early warnings
- Adjusting engine performance in real-time based on combined thresholds
- Managing infrared signatures automatically to improve survival on the battlefield

Emerging technologies like wireless high-temperature sensors, ceramic-based thermoelectrics, and self-calibrating smart probes are likely to enhance accuracy, lower maintenance needs, and support modular plug-and-play designs. Future research should focus on:

- Combining data from EGT and cylinder pressure sensors
- Developing AI models that analyze thermal signatures to detect anomalies
- Creating calibration systems that can adapt in remote or combat environments

In conclusion, effective and well-placed EGT monitoring systems protect engine components and provide tactical advantages by enhancing stealth, efficiency, and operational readiness in the toughest battlefield conditions.

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