CFT Cartridge Flow Meters: Enabling Continuous In-Circuit Hydraulic Diagnostics

Dale G. Dietel
Alpena, MI, United States
ddietel@DGDFluidPower.com

March 2026

Abstract

Hydraulic system diagnostics have historically been constrained by the inability to measure flow directly within integrated hydraulic circuits. Conventional flow meters typically require external plumbing, additional fittings, and manual installation during diagnostic procedures, increasing system complexity and discouraging continuous flow monitoring.

This paper presents the **CFT Cartridge Flow Meter**, a turbine-based flow measurement architecture that is fully integrated within a standard cartridge valve cavity. By embedding sensing, signal processing, and mechanical flow measurement elements inside the cartridge envelope, the CFT makes flow a permanently measured variable without altering the existing hydraulic architecture.

This paper describes the design philosophy, mechanical and sensing architecture and key engineering solutions that enable low loss repeatable measurement in confined geometries. It then outlines system level benefits such as earlier fault detection, remote monitoring of distributed hydraulic systems and closed loop control based on real time flow feedback. The results demonstrate that cartridge-integrated flow measurement provides a practical and scalable foundation for predictive maintenance and digitally connected hydraulic equipment.

KEY WORDS—Hydraulic diagnostics, flow measurement, cartridge valves, turbine flow meters, condition monitoring, in-circuit sensing.

I. INTRODUCTION

Flow is one of the most critical parameters in hydraulic systems, yet it remains among the least accessible during normal operation. While pressure and temperature are commonly monitored, flow measurement has traditionally relied on external devices that are connected temporarily or installed outside the primary hydraulic circuit. This approach limits diagnostic resolution, delays fault detection, and discourages continuous monitoring.

The **CFT Cartridge Flow Meter** addresses these limitations by redefining flow measurement as an intrinsic function of the hydraulic circuit rather than an external diagnostic accessory. In one embodiment, the CFT fits entirely within a standard cartridge valve cavity, enabling permanent, protected, and real-time flow measurement without requiring manifold redesign or additional plumbing. The cartridge-integrated architecture further provides a platform extensible to additional cavity formats and sensing modalities. This paper first contrasts conventional external flow meters with cartridge integrate sensing and then details the CFT mechanical and electronic architecture, addresses key engineering challenges and concludes with system level benefits and directions for future development.

II. LIMITATIONS OF TRADITIONAL FLOW MEASUREMENT

Conventional hydraulic flow meters typically require external plumbing loops, additional fittings and hoses, and dedicated installation space. In many applications, flow meters are installed only during troubleshooting and removed afterward due to cost, leak risk, or space constraints.

These limitations introduce several disadvantages:

1. Increased potential for leakage and contamination
2. Higher installation and maintenance costs
3. Poor suitability for mobile or hazardous environments
4. Incompatibility with continuous monitoring strategies

As a result, flow data is often unavailable during normal system operation, preventing early fault detection and masking inefficiencies that could otherwise be identified through trend analysis.

III. CONCEPT ORIGIN AND DESIGN PHILOSOPHY

The development of the CFT Cartridge Flow Meter originated from a fundamental question: *Why has in-circuit hydraulic flow measurement long been considered impractical?* Addressing this question required re-examining long-standing assumptions related to space constraints, sensor survivability, and measurement accuracy within hydraulic manifolds.

The resulting design philosophy prioritizes integration, robustness, and serviceability. Rather than maximizing laboratory-grade accuracy at the expense of deployability, the CFT architecture emphasizes repeatable, real-time measurement within the constraints of practical hydraulic systems. This approach supports a cartridge-style diagnostic device that preserves standard cavity dimensions while remaining extensible to additional form factors and performance requirements.

IV. MECHANICAL AND SENSING ARCHITECTURE

A. Cartridge Integration

In one embodiment, the CFT is contained within the envelope of a standard cartridge valve cavity. This integration eliminates external flow paths and preserves existing hydraulic architecture, allowing installation in both new and legacy manifolds. The cartridge format provides mechanical protection for sensitive components and enables modular replacement during service operations.

Fig. 1 illustrates an internal architecture of the CFT Cartridge Flow Meter, showing how the turbine impeller, sensing elements, and electronics may be integrated within the cartridge body while maintaining uninterrupted primary flow through the hydraulic circuit. The cartridge-integrated approach is extensible to multiple cavity sizes while preserving in-circuit flow measurement functionality.

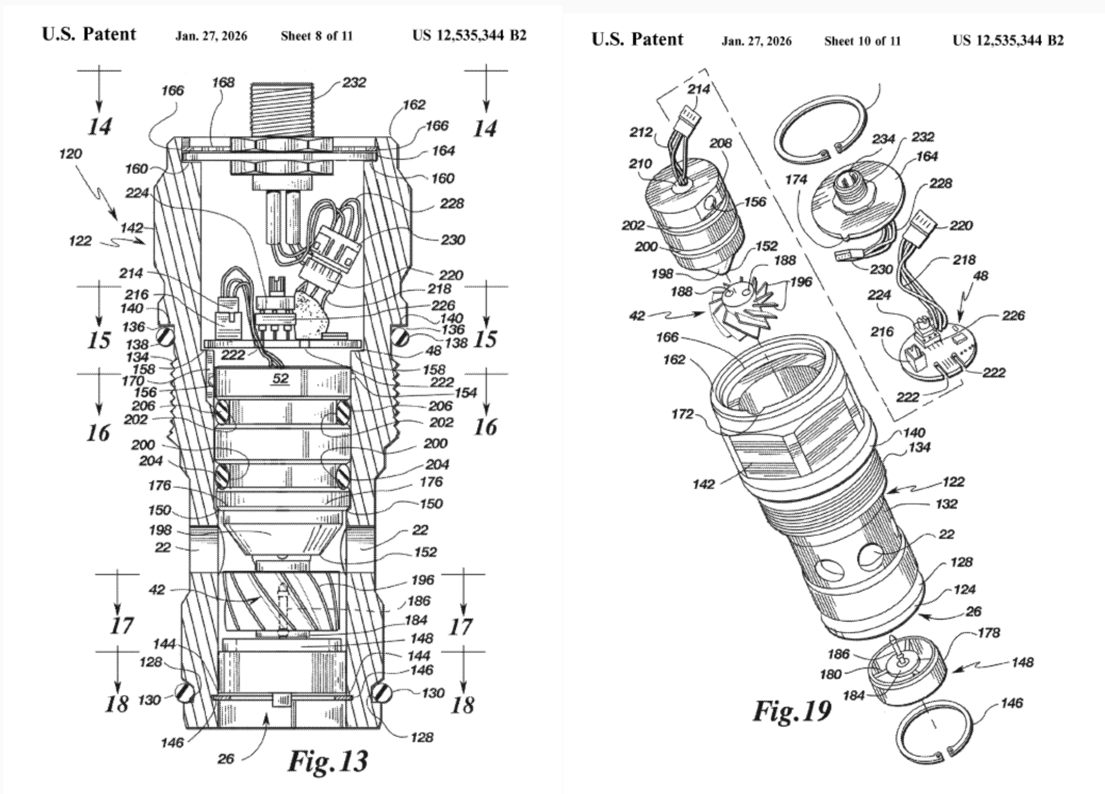

Fig. 1. Internal architecture of a cartridge-integrated flow measurement device. The cross-section illustrates a turbine impeller positioned within the primary flow path, Hall-effect sensing elements embedded in the cartridge body, and a compact electronics package contained within a protected cartridge envelope. *Adapted from U.S. Patent No. 12,535,344, Fig. 13 & Fig. 19. Additional Patents: US Patent No. 11,614,351 & US Patent No. 11,892,331*

B. Turbine and Impeller Design

At the core of the CFT architecture is a turbine impeller configured to rotate in response to hydraulic flow. In various embodiments, impeller geometry may be optimized to balance pressure drop, sensitivity at low flow rates, and stability across a wide operating range. This optimization enables diagnostic insight while minimizing hydraulic disturbance.

Scaling of impeller geometry and flow passages enables adaptation to different flow ranges and cavity sizes, supporting performance optimization across diverse system requirements.

C. Hall-Effect Sensing and Electronics

Flow induced impeller rotation is detected using a noncontact Halleffect sensing architecture integrated within the cartridge body. Small magnetic features integrated into the impeller pass in close proximity to stationary Hall effect sensor elements embedded in the cartridge, generating a series of electrical pulses proportional to impeller speed and thus volumetric flow rate for the given geometry. Because the sensors are magnetically coupled to the impeller rather than mechanically linked, they are fully isolated from the hydraulic fluid and do not introduce additional wear interfaces. This configuration is well suited to high pressure, high vibration environments and compact manifolds where space for traditional transducers is limited. The conditioned pulse stream is processed by embedded electronics that convert impeller speed into calibrated flow outputs for real-time monitoring and control. The same electronics platform supports multiple interface options, including 4–20 mA current loop, analog voltage ranges, and J1939 CAN-bus communication, allowing the CFT to connect directly to legacy PLCs, modern ECUs, and networked vehicle architectures.

Additional detail on the Hall effect sensing principle, sensor configurations, and magnetic feature geometry is provided in Appendix 1.

V. ENGINEERING CHALLENGES AND SOLUTIONS

The development of cartridge-integrated flow measurement required addressing several engineering challenges, including minimizing pressure loss within confined geometry, ensuring sensor stability in high-pressure and high-vibration environments, achieving repeatable and linear outputs and protecting electronics from hydraulic fluid exposure.

These challenges are addressed through mechanical optimization, robust sensor placement, and integrated electronics packaging. Various aspects of the architecture have been formalized through U.S. patents covering mechanical, sensing, and system-level innovations.

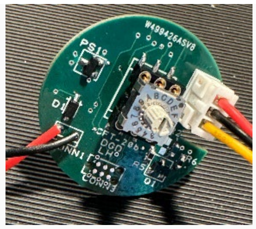

Fig. 2. Embedded electronics used in the 4–20 mA and analog voltage (VDC) versions of the CFT Cartridge Flow Meter. The electronics condition and process Hall-effect pulse data to generate calibrated flow-proportional analog outputs. A **16-position rotary switch** allows selection of the optimum flow range for each application, enabling flexible scaling and compatibility with a wide range of hydraulic system requirements.

VI. SYSTEM-LEVEL BENEFITS

The cartridge integrated flow measurement architecture enables diagnostic and control capabilities that are difficult or impractical to achieve with traditional external flow meters. By making flow a permanently measured variable inside the manifold, the CFT Cartridge Flow Meter provides continuous visibility into how hydraulic energy is actually being delivered to critical functions, rather than inferring performance only from pressure or actuator motion. Continuous in circuit flow data supports earlier detection of inefficiencies and component wear. Gradual changes in flow at constant command can indicate internal leakage, pump degradation, or valve erosion well before these issues appear as lost speed or failed cycles. This enables predictive maintenance strategies in which service actions are scheduled based on measured degradation trends instead of fixed time intervals or unexpected failures. In distributed or inaccessible hydraulic systems, such as mobile equipment and remote industrial installations, permanent flow monitoring also improves operational safety and uptime. Flow data can be logged and analyzed over time, used to verify proper function after software or hardware changes, and checked remotely to confirm that circuits are operating within expected ranges. When combined with pressure and temperature information, in circuit flow measurement supports more accurate system models and control algorithms, improving overall efficiency and dynamic response. For closed-loop hydraulic control, direct flow feedback enables functions that are not feasible when only pressure or position is measured. Examples include actively limiting flow to protect sensitive actuators, enforcing ramp profiles during startup and shutdown, and adapting control parameters as components age. Because the CFT architecture fits within standard cartridge cavities, these capabilities can be added without redesigning manifolds or introducing external plumbing, allowing both new designs and existing platforms to adopt continuous flow diagnostics with minimal disruption.

A. Predictive maintenance examples

• In a hydraulic power unit driving multiple actuators, continuous in circuit flow measurement at the pump outlet can reveal a slow increase in leakage long before operators notice reduced speed or pressure loss. A gradual rise in flow at a fixed command and pressure setpoint indicates internal wear, allowing maintenance to schedule pump replacement during planned downtime instead of responding to an unexpected failure.

• In a manifold controlling a critical cylinder on production machinery, a CFT installed in the cylinder supply line can detect subtle changes in flow dynamics as valve clearances change or spool edges erode. Deviations from the learned “normal” flow profile for each stroke can be used to flag emerging valve faults, enabling technicians to replace or service the valve before it sticks or causes a process interruption.

• On mobile equipment connected via J1939, multiple cartridge integrated flow meters can stream flow data to the vehicle ECU and telematics platform alongside existing pressure and temperature signals. Fleet operators can correlate changes in commanded versus measured flow with duty cycle and environment, identifying machines that are trending toward cavitation, filter blockage, or abnormal internal leakage and prioritizing those assets for inspection

VII. OUTPUT INTERFACES AND SYSTEM INTEGRATION

To support integration across a wide range of hydraulic platforms, the CFT Cartridge Flow Meter is available with multiple electrical output options. These outputs allow the same cartridge integrated flow hardware to interface with legacy control systems, modern electronic controllers, and networked vehicle architectures commonly used in mobile equipment.

In current implementations, the CFT platform supports **three primary output formats**: analog current, analog voltage, and digital CAN-bus communication. Each output format addresses distinct system requirements and integration preferences.

A. Analog Current Output (4–20 mA)

This format is particularly attractive for plant and maintenance engineers retrofitting existing PLCbased systems where long cable runs and electrical noise are common.

B. Analog Voltage Outputs (1–10 V and 0.5–5 VDC)

These outputs align with electronic control units and embedded controllers on compact machinery, where short harnesses and high resolution analog to digital conversion are available.

C. J1939 CAN-Bus Digital Output

In addition to analog signaling, the CFT is available with a **J1939 CAN-bus digital output**, supporting direct integration into networked mobile equipment architectures. J1939 is widely adopted in off-highway, agricultural, construction, and commercial vehicle applications, providing a standardized, robust communication framework for distributed electronic systems.

The use of J1939 offers several system-level advantages, including:

- **Reduced wiring complexity**, as multiple devices share a common bus
- **Improved noise immunity** through differential signaling
- **Standardized message structures** that simplify system integration
- **Scalability**, enabling multiple CFT devices to coexist on the same network
- **Direct compatibility with modern vehicle ECUs and telematics systems**

By transmitting flow data digitally over the CAN-bus, the CFT can support real-time monitoring, coordinated control strategies, and remote diagnostics without additional analog signal conditioning. In networked systems, flow information can be shared across controllers, logged for trend analysis, or transmitted off-board for fleet-level monitoring and predictive maintenance.

The availability of J1939 output further aligns the CFT platform with current and emerging mobile equipment architectures, positioning cartridge-integrated flow measurement as a native element within digitally connected hydraulic systems.

As a result, a cartridge integrated CFT can appear as just another node on the vehicle network, streaming flow data to ECUs and telematics systems alongside existing pressure, speed, and position sensors.

VIII. APPLICATIONS AND IMPACT

Cartridge-integrated flow measurement is applicable to mobile equipment, industrial automation, distributed hydraulic networks, and safety-critical or inaccessible systems. Permanent flow visibility fundamentally changes how engineers observe system health, diagnose faults, and optimize performance across the equipment lifecycle.

IX. FUTURE WORK

Future development of the CFT Cartridge Flow Meter will focus on expanding sensing capability and optimizing performance through architectural scalability, while preserving the cartridge-integrated diagnostic philosophy.

In future embodiments, **temperature sensing may be integrated across CFT variants**, enabling synchronized flow and temperature measurement at the point of use. Hydraulic fluid temperature directly influences viscosity, internal leakage, and volumetric efficiency, and its integration within the cartridge enables improved diagnostic correlation, compensation algorithms, and system modeling. Temperature sensing may be implemented using one or more sensor technologies integrated within the cartridge body and interfaced through existing or expanded electrical connections.

Future work also includes support for **additional cartridge cavity sizes**. Scaling the cartridge-integrated flow measurement architecture to multiple cavity formats enables optimization of impeller geometry, pressure drop, and measurement resolution across broader flow ranges and operating conditions. Multiple cavity sizes further support adaptation to diverse manifold standards and performance requirements.

Collectively, these developments extend the CFT platform toward a **multi-parameter, scalable in-circuit diagnostic architecture**, supporting future implementations that integrate flow, temperature, and additional sensing functions without external instrumentation.

X. CONCLUSION

The CFT Cartridge Flow Meter demonstrates that real-time, in-circuit flow measurement can be practical, reliable, and scalable within standard hydraulic manifolds. By integrating a turbine flow element, noncontact Hall effect sensing, and embedded electronics into a standard cartridge valve cavity, the CFT eliminates external flow loops' potential leak paths and makes flow a permanently measured variable alongside other key system health data like pressure and temperature. Continuous in-circuit flow data enables earlier fault detection, supports predictive maintenance and remote monitoring, and allows closed-loop hydraulic control based on direct flow feedback rather than indirect symptoms. The same cartridge integrated architecture provides an extendable platform for multiparameter sensing, including future integration of fluid temperature and additional diagnostics, positioning flow cartridges as native elements of smarter, more connected hydraulic systems

REFERENCES

[1] U.S. Patent No. 12,535,344, *Cartridge-Integrated Flow Measurement System*, 2025.

[2] R. W. Fox, A. T. McDonald, and P. J. Pritchard, *Introduction to Fluid Mechanics*, 9th ed. Hoboken, NJ, USA: Wiley, 2016.

[3] ISO 1219-1, *Fluid Power Systems and Components—Graphical Symbols*, International Organization for Standardization.

(4) U.S Patent No. 11,614,351

(5) U.S. Patent No. 11,892,331

Appendix:

1.

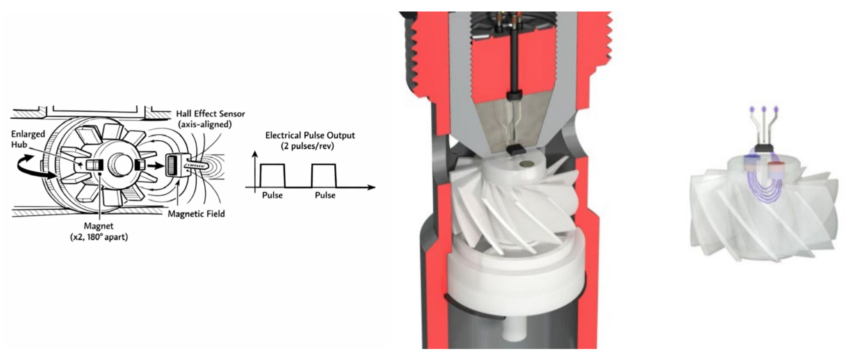

Fig. 3 - Axis-aligned Hall-effect sensor. Two magnets embedded in the hub and positioned 180° apart pass a stationary Hall-effect sensor aligned with the impeller axis, producing two electrical pulses per revolution. The resulting pulse frequency is proportional to impeller rotational speed and volumetric flow rate. Refer to U.S. Patents: No. 11,614,351 / No. 11,892,331 / No.12,535,344

2.

Here's a simplified sketch of the test stand circuit:

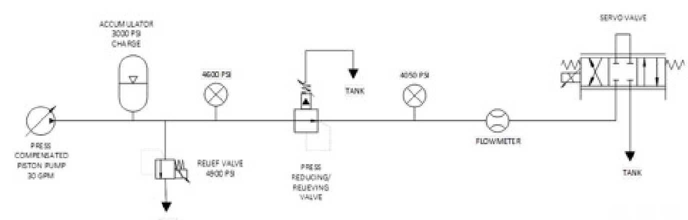

Fig. 4 - CFT Cartridge Flow Meter – shown prior to and after installation in a hydraulic manifold