

From Hydraulics to Pneumatics: The Invention and Evolution of PWM-Controlled Solenoid Valves, 1972–1974

A Technical and Historical Monograph on the Pioneering Work of PWM Fluid-Power Control

1. Introduction

In the early 1970s, fluid-power control was dominated by mechanical linkages, vacuum servos, and expensive analog proportional valves. Solenoid valves were widely used, but only as simple on/off devices. Proportional control required servo valves that were costly, delicate, and unsuitable for mass-market automotive applications.

Into this landscape came a new idea: using **pulse-width modulation (PWM)** to control fluid flow through a solenoid valve. This concept — simple, robust, and decades ahead of its time — would become one of the most influential control principles in modern engineering.

Between 1972 and 1974, two inventions established PWM fluid-power control as a practical reality:

- The **PWM hydraulic solenoid valve** patented as UK **1,414,301** and co-dependent **1,382,331** (both filed January 1972)
- The **PWM pneumatic solenoid valve** patented as UK **1,486,821** (filed January 1974)

These inventions enabled the world's first **electronic PWM cruise-control system**, and the world's first **electronic PWM automatic transmission system**, patented as UK 1,382,331 (filed January 1972) pioneered by Associated Engineering Developments in Rugby (AED), and laid the foundation for global industries that produced **billions** of PWM solenoid valves in 2025.

2. The 1972 Breakthrough: PWM Hydraulic Solenoid Valve

2.1 Engineering Origins

In 1972, as a mechanical engineer at AED in Cawston, Rugby, Norman Hunt recognised that a solenoid valve did not need to be limited to binary operation. By switching the solenoid at approximately **20 Hz**, the *average* hydraulic pressure delivered to an actuator could be controlled with surprising precision by simply controlling the pulsewidth of the signal fed at constant frequency.

This was a radical departure from conventional thinking. It transformed the solenoid valve from a simple switch into a low-cost proportional actuator.

2.2 Technical Principles

Crucially, Hunt's original design:

- Used **low-frequency PWM (~20 Hz)**
- Used a ball-valve that did not require a spring return as does a spool valve.
- Did **not** use dithering to avoid 'stiction' and was more resistant to contamination.

- Did **not** use high-frequency averaging
- Achieved proportional behaviour through **system-level pressure averaging**, not mechanical averaging

The proportional effect came from:

- The hydraulic system's natural pressure dynamics
- The load characteristics
- The controlled duty cycle

This made the valve simple, robust, and inexpensive — ideal for automotive use.

2.3 Early Applications

The hydraulic PWM valve was evaluated for:

- Automatic-transmission pressure control
- Industrial hydraulic actuators
- Automotive subsystems requiring smooth, low-cost modulation

It demonstrated that PWM could replace far more expensive servo valves in many applications.

3. The 1974 PWM Pneumatic Solenoid Valve (UK Patent 1,486,821)

Inventors: Norman Hunt and John Noddings

3.1 Motivation

Pneumatic systems posed different challenges from hydraulics:

- Air is compressible
- Flow velocities are higher
- Pressure dynamics are nonlinear
- Response times are faster

Adapting PWM to pneumatics required new mechanical design and new control strategies.

3.2 Mechanical Innovation

Hunt designed a **rubber bellows actuator** that used engine manifold vacuum to control throttle position. A **PWM-driven pneumatic solenoid valve**, switching at approximately **20 Hz**, regulated the vacuum level with high precision.

This was the first time PWM had ever been used to control a pneumatic actuator in an automotive system.

3.3 Electronic Innovation

John Noddings and his electronics team at AED developed:

- The PWM driver circuitry
- The electronic control logic
- The speed-sensing and feedback electronics

This collaboration produced the world’s first **electronic cruise-control system**.

3.4 Patent Significance

UK Patent 1,486,821 (filed January 1974) was the first patent to describe:

- A PWM-controlled pneumatic solenoid valve
- An electronically regulated vacuum actuator
- A fully electronic cruise-control system

It marked a turning point in automotive control technology.

4. Comparative Engineering Analysis

4.1 Hydraulic vs. Pneumatic PWM Control

Feature	Hydraulic PWM Valve	Pneumatic PWM Valve
Working fluid	Oil (incompressible)	Air (compressible)
Switching frequency	~20 Hz	~20 Hz
Proportional mechanism	Pressure averaging	Vacuum averaging
No inertial averaging	Yes	Yes
No dithering	Yes	Yes
Applications	High-force systems	Light-duty actuators

4.2 Later Developments: High-Frequency PWM, Dither, and Spool Averaging

As PWM control gained popularity, later developers introduced:

- High-frequency PWM (hundreds or thousands of Hz)
- **Inertial averaging** of spool valves
- **Dither** to reduce stiction
- Servo-like behaviour in solenoid valves

Some of these developments were:

- Inspired by Hunt’s original concept
- Attempts to extend it
- Or attempts to **circumvent patent infringement** by altering the mechanism

Hunt’s patents remain historically unique because they describe the **first practical implementation** of PWM fluid-power control — using low-frequency switching and system-level averaging.

5. Applications and Industrial Adoption

5.1 The First Electronic Cruise–Control System (AED, 1972–1974)

The PWM pneumatic valve was designed specifically to power AED’s electronic cruise–control system — the first of its kind. It offered:

- Smooth throttle actuation
- Fast response
- Stable speed control
- Superior performance to mechanical or vacuum–servo systems

This system became the first production use of PWM fluid–power control in the automotive world.

5.2 Rolls–Royce: The First Manufacturer in the World to Use PWM Solenoid Valves (1972–1985)

Rolls–Royce adopted the AED cruise–control system in **1972**, making them:

The first vehicle manufacturer in the world to use PWM solenoid valves in a production car.

They continued using the system until **1985**, a 13–year production run that speaks to its reliability and refinement.

5.3 Ford, Jaguar, Bristol and Jensen

- **Ford** offered the AED system as an optional extra from **1972 to 1978**.
- **Jaguar** fitted it to selected models.
- **Bristol** and **Jensen** also assessed vehicles

This spread Hunt’s invention across both luxury and high–volume manufacturers.

5.4 Retro–Fit Market (Until 1990)

AED sold the system as a retro–fit kit from **1978 to 1990**, when the company was then acquired by Turner & Newall.

6. Legacy and Influence

6.1 A Global Engineering Standard

Today, near **14 billion \$** of PWM–controlled solenoid valves are sold every year. They are used in:

- Spacecraft
- Nuclear submarines
- Aviation
- Automotive systems
- Robotics

- Medical devices
- Industrial automation
- Consumer appliances

The principle Hunt pioneered has become one of the most widely used actuation methods in modern engineering.

6.2 Rolls–Royce Returns to PWM in the 21st Century

In a remarkable full–circle moment, **Rolls–Royce (now under BMW)** — the first company to use Hunt’s PWM pneumatic valve in 1972 — now uses **PWM hydraulic solenoid valves** in:

- The **Spectre EV** (battery thermal–management system)
- Other modern Rolls–Royce automatic transmission models

More than 50 years later, the same manufacturer continues to rely on the same fundamental control principle Hunt introduced and demonstrated to them in 1972

6.3 A Half–Century of Continuity

From carbureted V8s to electric luxury vehicles, PWM fluid–power control has remained a core technology. Hunt’s inventions anticipated the digital control era and helped shape the trajectory of modern automotive engineering.

7. Conclusion

Between 1972 and 1974, Hunt introduced two groundbreaking mechanical inventions:

- The **PWM hydraulic solenoid valve** (UK 1,414,301 and UK 1,382,331)
- The **PWM pneumatic solenoid valve** (UK 1,486,821)

Working alongside John Noddings and his electronics team, Hunt helped create the world’s first **electronic cruise–control system**, adopted by Rolls–Royce in 1972 and later by Ford and Jaguar, and the world’s first **electronic automatic transmission system**, which was demonstrated to Borg–Warner, VW and BMW in the early 1970’s, by AED fitting it in their respective company vehicles and then leaving it with them for assessment. In the years that followed those companies and many others used PWM solenoids in their own production automatic transmission systems and ancillary devices. PWM solenoid valves are now widely used in many other applications, including electric vehicles.

Hunt and Noddings work transformed solenoid valves from simple on/off devices into proportional actuators, enabling a revolution in fluid–power control. Today, billions of PWM solenoid valves are produced annually, used everywhere from spacecraft to nuclear submarines.

Norman Hunt’s inventions were not just ahead of their time — they helped define the future.

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