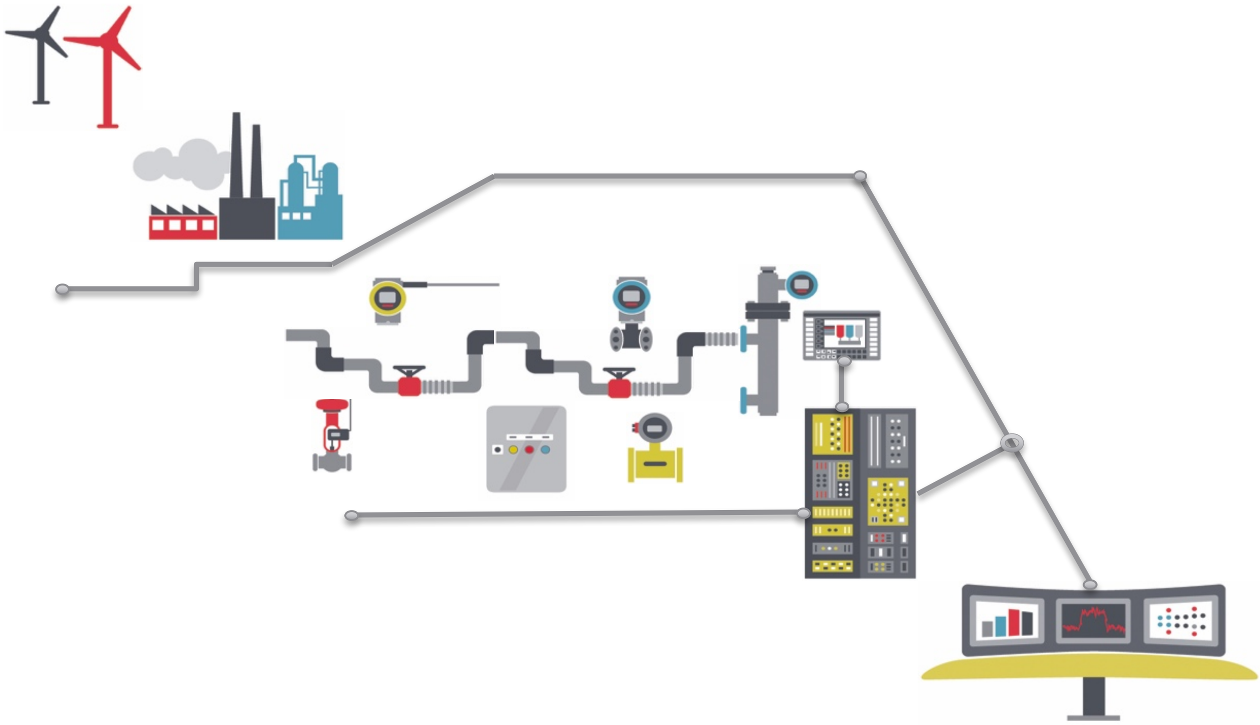
GAMBICA

A Brief History & Future of Instrumentation

A short investigation into when and why instrumentation was invented, its development through the Industrial Revolutions and a peek into the future.

Discussion Paper



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Introduction

Instrumentation is a collective term for sensors incorporated into measuring instruments used for indicating, measuring and recording physical quantities. Forming the basis of process control, instruments continue to improve their capability, repeatability, accuracy, reliability and cost.

Throughout the first and second industrial revolutions of mechanical innovation and mass production, instrumentation and its development were a key supporting technology.

Instrument developments at the sensor level have engaged both the mechanical, and chemical sectors, whilst the transmission of values has made use of the electronic industries forging the advancements through the third industrial revolution using electronics and computers to further the analysis of signal data processing.

As we enter the period dubbed the fourth industrial revolution, Artificial Intelligence, Big Data and more, this article follows the impact of instrumentation within the first three revolutions and examines how the instrumentation industry must engage in a world of digital data and forensic analytics to meet the challenges and expectations of this fourth industrial revolution.

Early History – The First Industrial Revolution

With the coming of mechanisation, their soon developed a need for very basic control, but to control something, you first need a measure something.

It is probable that the steam engine governor could be considered the first closed loop control system using instrumentation. Invented in 1788 by James Watt, this very basic and functional solution was able to measure engine speed through the rotation of two metal balls. As the machine went faster, the balls would simply move apart through centrifugal force. This provided a direct measurement of speed and when coupled into a steam control valve, controlled the final speed of the engine by regulating flow. Wikipedia provides a good article on how the system works. [(1)]

Whilst the governor is still with us today, the next step in instrumentation needed to be measurement in a format that could be visualised, recorded and understood.

Continuing the steam engine theme, the possible measurements that can be taken include steam pressure and temperature, water levels, flow rates and speed. The instruments were mechanical, using basic sensors for example; bimetallic strips for temperature, bellows for pressure and simple sight glasses for level. The instruments, by today's standards, were works of art. Large brass enclosures and carefully inscribed dials.

These original instruments are now confined to working museums, where basic maintenance requires a tin of Brasso™.

The picture below shows these basic instruments as installed on the Mid Hants Railway 34007 Wadebridge Footplate, built in 1945.

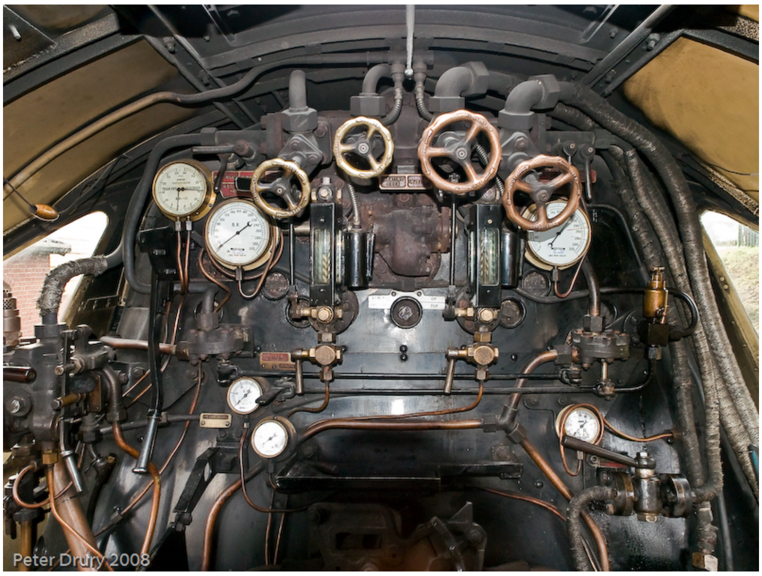

Fig 1. 34007 Wadebridge Footplate [2]

Focusing on pressure, measuring pressure is one of the most basic instrumentation functions in any industry and certainly on early steam powered machines. Three types are of key interest; Absolute Pressure, measuring against a vacuum, Differential Pressure, measuring against two specific points with basic calculations deriving flow and Gauge Pressure, measuring against atmospheric pressure. Traditional systems used mercury manometers as seen in barometers and the Bourdon tube, a very simple system still widely manufactured and used.

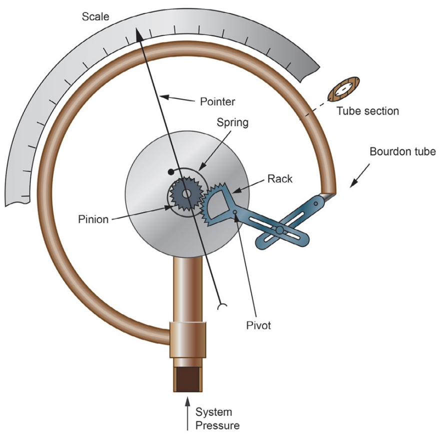

Fig 2: Taken from an article in Flow Control magazine [3]

Early History – The Second Industrial Revolution

In terms of instrumentation, there is a blur between the first and second industrial revolutions. The first brought the steam engine and the second focussed on motive electricity with the start of mass production, initially in steel and then into the chemical and petroleum sectors in the early 1900's. The real start of the second industrial revolution could be defined as mass production in the automotive industry at the start of the 20th century, still requiring nearly 100% manual labour and yet to progress more mechanised automation.

Instrumentation was developing but the sensors were still basically mechanical.

A recent trip to HMS Belfast, built in 1936 and now moored near Tower Bridge in London, had me examining the gauges installed on the boiler panels. Many manufacturers devices are present and key to their procurement would have been their ability to show the same readings regardless.

Consequently, once there is a mechanism for measurement, there needs to be standards to enable all manufacturers to develop instruments that provide repeatable readings, in units engineers understand, that can be calibrated, are long lasting and of course are directly compatible with each other. The second industrial revolution focused on these areas.

As the ability to measure improved, so the ability to control also made leaps forwards. Other than speed, governed automatically on steam engines, control was still a very manual activity.

Industrial control systems were developing, with the introduction of pneumatic solutions. For example, absolute pressure can be measured using bellows containing a vacuum and instead of driving a needle on an instrument, a setpoint is provided through an air valve into the system and there is a pneumatic connection to a control valve providing proportional and integral functionality. There are many examples of developments in these technologies, no more so than in the aircraft and process industries.

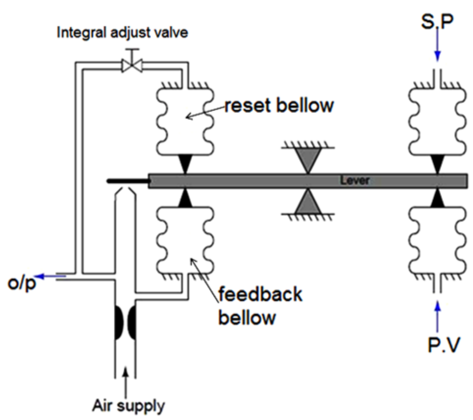

Fig 3 – Pneumatic PI Controller Fundamentals [4]

In addition to these pneumatic measurements, there would be a mechanical gauge mounted close by. Even today, many Process & Instrumentation Diagrams (P&IDs) still identify both a control instrument and a local mechanical/electrical gauge.

The second industrial revolution remained broadly static in instrumentation technology and it was not until the 1960's that major innovations took place. For example, electronic pressure sensors are now available with at least 10 additional measuring technologies.

The Electrical Revolution – The Third Industrial Revolution

Up until the start of the third industrial revolution with the explosion in development of electronic systems in the 1960's, instrumentation had still been largely based on the mechanical sensors and gauge readouts from the earlier steam engines.

In 1875, the Metre Convention was signed by 17 nations to coordinate international metrology. Whilst there had been a number of updates along the way, in 1960, the system was overhauled and relaunched where International Standards were defined and SI units, established from the French Système International d'Unités, identified the seven base units from which all measurements can be calculated; Length (m), Mass (kg), Time (S), Electric Current (A), Thermodynamic Temperature (K), Luminosity (Cd) and the Amount of Substance (Mol).

Electrical primary sensors were developing. Simple physics i.e. pressure = force/area enabled Bordon gauges to be replaced with strain gauges. Simple electronics provided temperature stabilisation and linearization. Temperature devices were able to take input from a range of thermocouples and provide linear outputs. Indicators could now be mounted remotely in large mimic panels and data collected on paper chart recorders.

Boiler Operator Jeff Craigie sits in the Boiler Room and monitors flows, temperatures and pressures of the boilers and feed-water system. Photo by Ryan Solomon

Fig 4. Boiler Room Analog Control Room [5]

One key area of innovation was, and still is, the use of 4-20mA as a standard instrument output. The standard seems to have be set up in the mid 1970's and in the UK, developments are still managed under the BSI GEL65 committee.

Areas of improvement were vast including; accuracy, precision, resolution, repeatability, linearity, hysteresis, the list goes on. Developments in measurement techniques have been continuous. Pressure transducers now include differential capacitance and load cell, flow systems use ultrasonic, vortex and electromagnetic measurements, level uses nucleonics, weight has new strain gauges, and the number of temperature measuring thermocouples continues to grow along with IR systems. A good reference is found in Section 2 of Jonathan Love's Process Automation Handbook. [(6)]

The world of small analogue electronic packages opened up sensor design and signal processing.

The Future of Instrumentation – The Fourth Industrial Revolution

The fourth industrial revolution is really a focus on the digitisation of industry. The process industries have their challenges in this area as do those engaged with manufacturing. The end game should be a completely integrated supply chain, from feedstock specification and order, through high quality and efficient manufacturing to providing customers with their specific order. Mass customisation at mass production costs.

We have discussed at a very high level how instrumentation has developed from the simple steam governor back in 1788, through the explosion in scientific and material innovations around the primary sensors, analogue signal processing and on to early adoption of some digital integration through such solutions as HART. Computer systems from the late 1960's were already taking advantage of the ability to take the electrical signals and now represent them on computer generated mimics. Some of the original systems were based on the DEC PDP8 introduced in 1965, a computer system designed for use in industry.

We now need to look at the basis of the digital revolution, that is the focus on digital data, either raw or pre-processed, and its transmission.

As we saw during the previous revolutions, it is not just the sensors that have improved. As digital has taken over from analogue, computer power has increased and reduced in size and cost, signal conditioning, processing and conditioning has become more effective. Universities continue to develop new ways to process signals and remove noise. Oxford University is in the process of licencing it's PRISM technology that is a major leap in signal processing capabilities only possible with the huge processing power now available. [(7)]

It is not only the physical manufacturing of sensors and instruments that has evolved, with the start of the 3D printing revolution, we can now print temperature and humidity sensors. The CPI Printed Electronics group has already published and proven the concept of printed sensors for manufacturing processes and healthcare. [4]

Our view is that the digitisation developments required for the instrumentation industry need to follow a structured thought process.

1. Digitisation of the value from the primary measuring element.

Whilst this does not preclude the continuation of an analogue interface e.g. 4-20mA, it would be true to say that this technology could now be retired. All instrumentation that is integrated into the digital supply chain will need to have some technology embedded that provides not only configuration parameters, but connectivity. It is not easy to predict the protocols required but as the size and power of embedded processing coupled with its low cost, adopting configurable systems would be a safe bet.

2. Pre-processing either at the instrument or a local edge computer

As the quantity of available data increases, and the prediction is that this will be exponential, a reduction of raw data transfer will be required. There are still limits to the communications bandwidths, especially if radio networks are considered. Edge computing will allow the pre-processing of raw data into manageable packets. The use of embedded processing will provide an instrument with its own edge processing and configurable data compression algorithms.

3. Embrace Digital

Users of instrumentation will need to embrace the wholly digital concept. There is an older generation who will need to accept that what they see on a computer screen is accurate and that there is no longer a need to tap the glass on the front of the instrument. The younger generation will simply expect to stand next to the process line and see the values on their tablet.

Manufacturers of instrumentation need to plan. Their development budgets need to recognise that in parallel with the continuing development of the instruments, packaging and certifications, the interface must have equal focus. There are several SME instrumentation companies in the UK who still believe that a 4-20mA interface is all that is, and will ever be, required. So, as was stated at the start, in order to control something, we need to measure something, but the concept of control has developed to include many more systems than just the control of the physical process. Manufacturers need to understand that while making products, constant monitoring of raw materials, process variables and control, digital instrumentation is key to any enterprise in the digital revolution.

There are many organisations that can help companies on-board the digital revolution. GAMBICA is able to help and we can be contacted through our website.

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