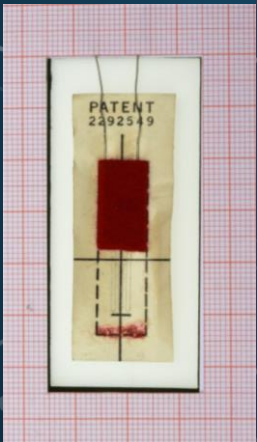


PAST, PRESENT, AND IS THERE A FUTURE OF STRAIN GAUGES?

A BRIEF HISTORY OF THE RESISTANCE STRAIN GAUGE AND THE LINKS TO BSSM



Ian Jones
BSSM CERCO Chairman

OVERVIEW

- Enabling Technologies
- The first use of a Strain Gauge
- The etched foil Strain Gauge
- BSSM's continued relationship with "Strain Gauges"



ENABLING DISCOVERIES



1856
Discovery

WHERE DID IT ALL START ?

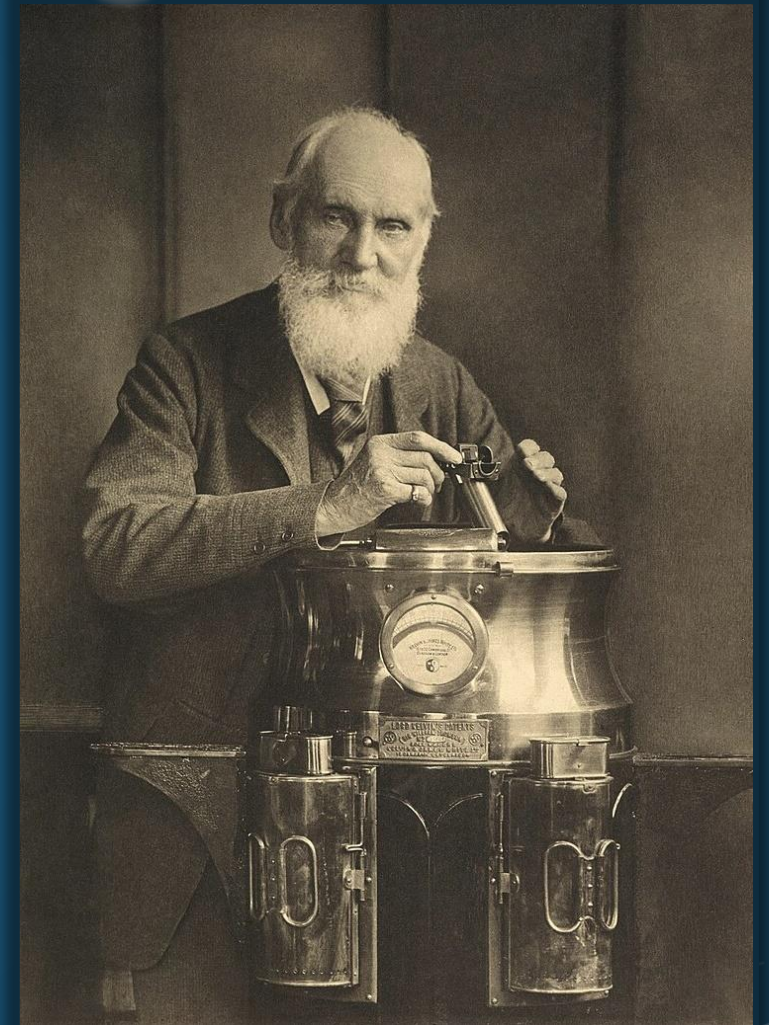
In 1856, British Physicist Lord Kelvin (William Thomson) communicated to the Royal Society, the principal:

“Electrical resistance of copper or Iron wire changes when the wire is either stretched or compressed”

$$R = \rho \frac{L}{A}$$

R = Resistance (Ω)
P = Resistivity constant
L = Length of wire
A = Cros- sectional area

The investigations had, under the instructions of Lord Kelvin, been completed by James Gray and James Henderson in 1855 during their experiments to obtain quantitative results on the variations of resistance of metals due to stretching, twisting and drawing through a hole in a steel plate.





1856-1936
Further Discovery



- The phenomenon of utilising resistance changes in strained materials was further utilised:
 - In 1908 Dr. S. Lindek at the National Technical Institute in Berlin experimented with pressure measurements using manganin wire embedded in shellac onto brass tubes, but no one took up his idea that this effect could be used to measure pressure.
 - In 1928 German Physicist Walther Nernst developed a pressure indicator using “freely tensioned” resistance wires and used it to show the pressure characteristics in the cylinder of a combustion engine.
 - In 1931 E.C.Eaton used “electrical resistance Gauges” for strain measurements when mounted on concrete.
 - In 1935 R. W. Carlson encapsulated Eaton’s gauge and cast it into the concrete but noted problems due to temperature effects and corrosion.

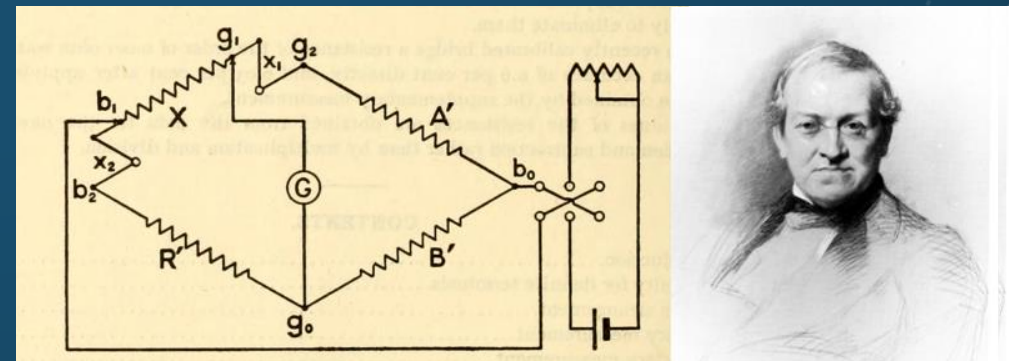
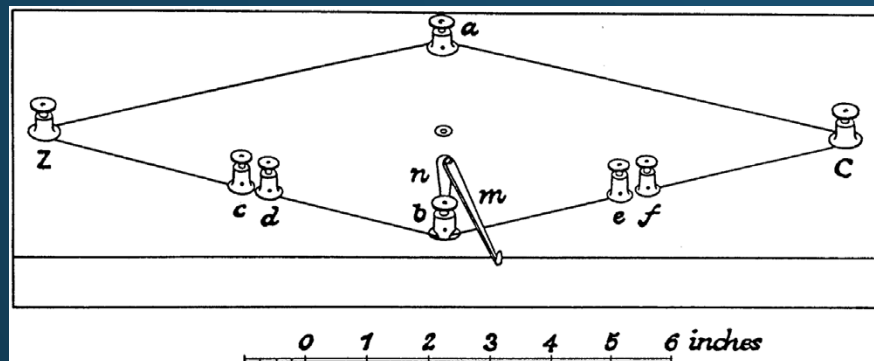
But all of these were working independently!

1833-1843

The Wheatstone bridge



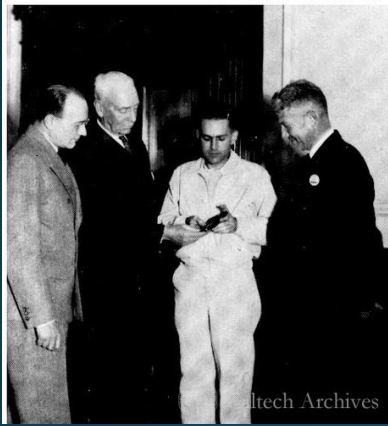
- In 1833 Samuel Hunter Christie (Royal Military Academy, Woolwich), published his “Diamond” method for comparing resistances of wires of different thicknesses, however it went unrecognised
- In 1843 Charles Wheatstone communicated a paper to the Royal Society:
“An Account of Several New Processes for Determining the Constants of a Voltaic Circuit.”
- This contained details of the balance circuit for measuring electrical resistance of a conductor, the principals of which are still in use today within resistance strain measuring equipment.





THE FIRST USE OF A “STRAIN GAUGE”

1936 - 1944
The wire strain gauge

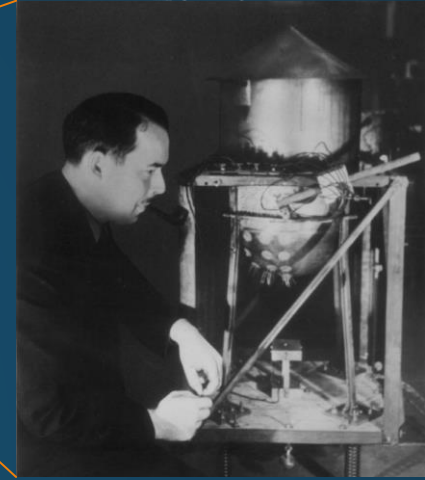


Caltech Archives

Caltech



MIT



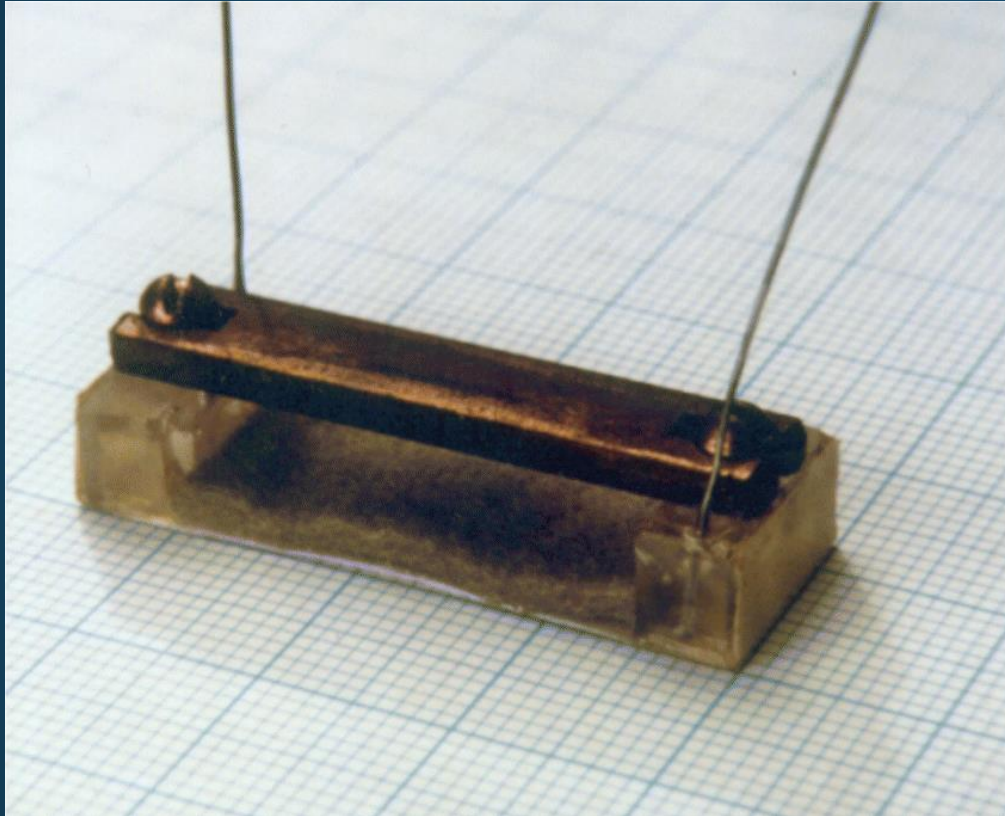
Prof. Arthur C. Ruge

Edward E. Simmons

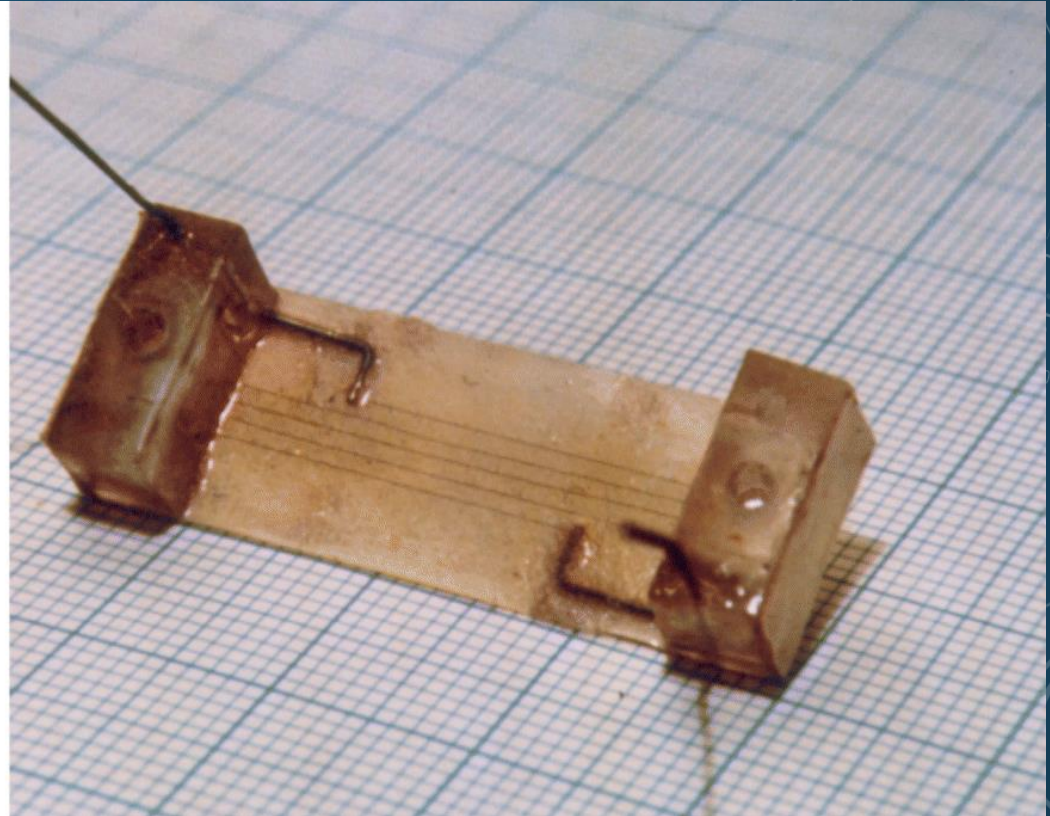
- In 1936 working as a Student/Research assistant at Caltech working for Dätwyler and Clark.
- Investigating stress-strain behaviour of metals under shock loading using a dynamometer equipped with fine resistance wires made from constantan
- A "strain gauge" based transducer patented in 1940.

- In 1940 whilst Investigating the influence of earthquakes on mechanical structures, using small scale models. Ruge attached a thin wire from a potentiometer to the model using "Duco" adhesive
- Excellent and repeatable measurement values, using a simple bridge circuit.
- The first strain gauge was patented in 1944.

1936 - 1944
The wire strain gauge



With brass bar to aid installation



Without brass bar and grid protection layer

Ruge's strain gauge (1938)



1936 - 1944 The wire strain gauge



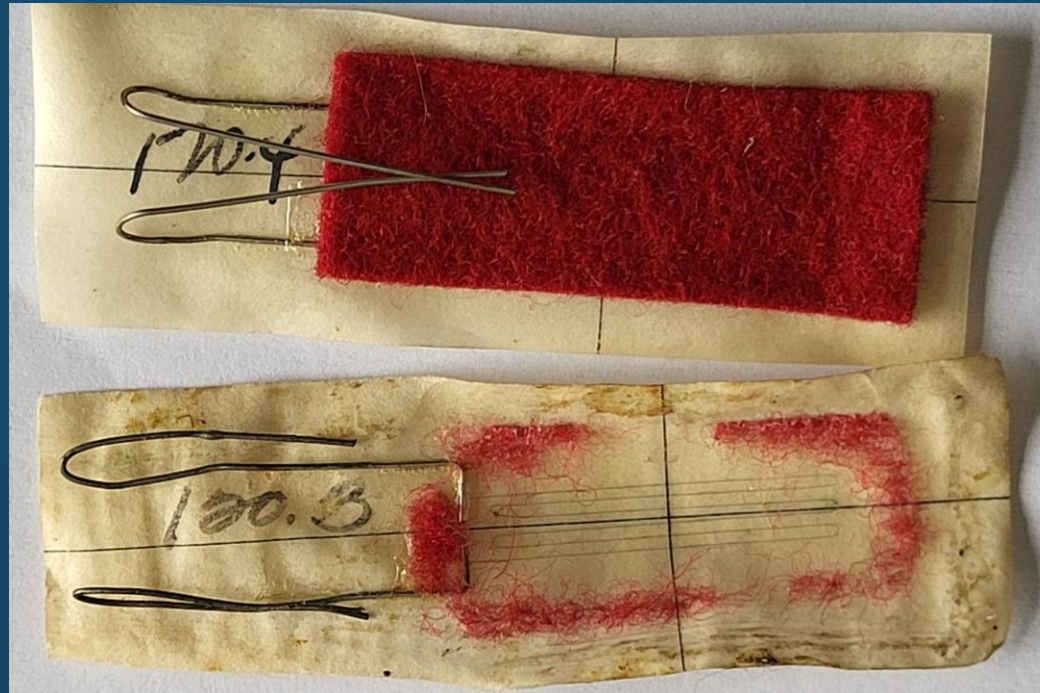
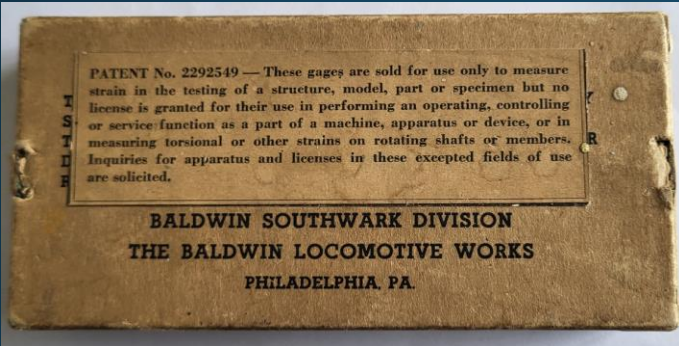
- In 1938 Ruge submitted the bonded wire “resistant strain gauge “ to the MIT patent committee.

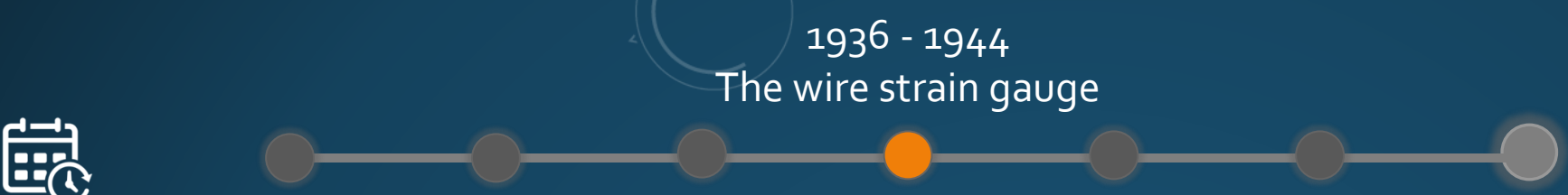
‘ . . . this development is interesting; the Committee does not feel that the commercial use is likely to be of major importance... any rights which the Institute may have in this invention should be waived in your favour . . . ’

This allowed Ruge to exploit the invention on his own.

- In 1939 Ruge and his colleague Prof. Alfred v. deForest persuaded Baldwin-Southwark Corp. (a locomotive manufacture) to start the manufacture of the first commercial strain gauges. They set up a company “Ruge Consulting” to commercialise the idea.
- The first strain gauges were named “SR4” after Simmonds and Ruge and the 4 people who took part in the final discussions; Ruge, Simmonds, Clark and deForest.
- The first commercial shipment of strain gauges was for 50,000 in 1941.
- A Strain gauge patent was granted in 1944, naming both Simmonds and Ruge as co-inventors.

1936 - 1944
The wire strain gauge





1936 - 1944
The wire strain gauge



- After the invention of the strain gauge in 1938 it was quickly recognised that they could measure more than just strain. All mechanical quantities that cause strain in materials such as load, pressure, torque, etc. can be detected indirectly and converted into an electrical signal that can be recorded, this led to their extensive use in transducers, particularly in the aeronautical industry.
- Further developments to :
 - Make them smaller,
 - Less sensitive to temperature,
 - Improvement in Creep behaviour,
 - Improvement in Fatigue strength,made them more suitable to attach to real structures for strain and direct “Quantity” measurements.
- In 1941 due to limited availability of strain gauges from the USA, the National Physical Laboratory (NPL) were asked to manufacture initially a dozen gauges to meet an urgent need, they did in fact continue making them until 1958.
- In 1944 D.C.Gall (Tinsley) patented an improved method for producing drawn wire gauges that led to manufacturing improvements for batch making gauges, reducing the manufacturing costs which made them more attractive to industry.



THE ETCHED FOIL “STRAIN GAUGE”



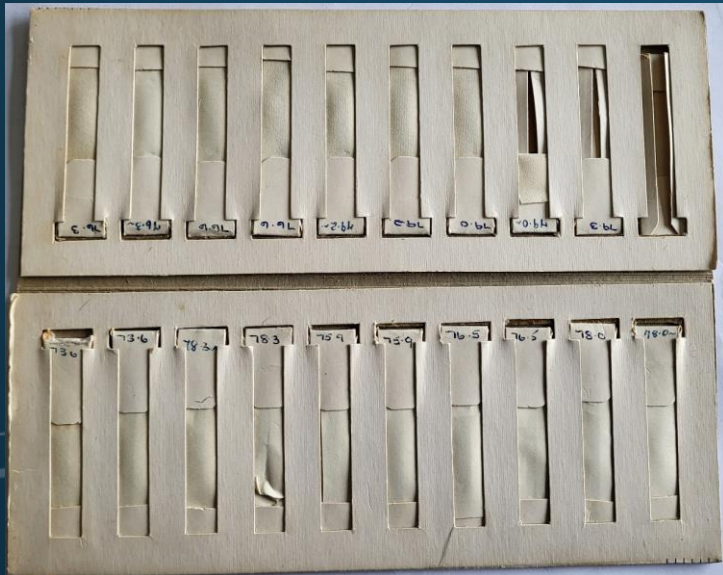
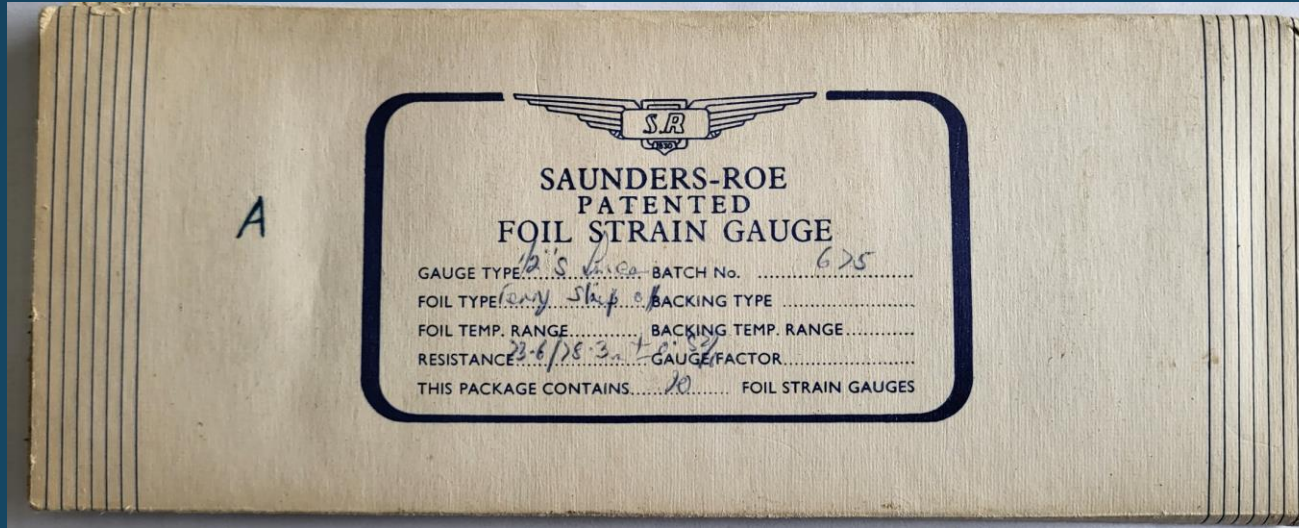
1952 Etched Foil Gauges



- In 1952 Peter Jackson, whilst working at Saunders-Roe on stress analysis of helicopter rotors found difficulties using wire strain gauges because of fatigue failures, lack of sensitivity and slip ring noise.
- Talking with colleagues on his daily commute from Southampton to Cowes he learnt about circuits being made by the Technograph company by etching copper clad Bakelite and decided to discuss with them the possibilities of making strain gauges by this method.
- Early gauges were large and could only be made with a resistance of $\sim 55 \Omega$, but they were much better at dissipating heat, so could carry more current and therefore output more signal than a wire gauge; although these initial gauges suffered from imperfect etching resulting in jagged edges which reduced their fatigue life.
- Jackson applied for the foil gauge patent in 1953 and assigned it to Saunders-Roe.
- Dr Paul Eisler (Technograph), who already held the original PCB patent, without Peter Jackson's knowledge applied for an application patent in 1952 (granted in 1955) and for many years, this was cited as the basic foil strain gauge patent.



1952 Etched Foil Gauges





1952 -2024 Strain Gauges

- In Jackson's view, wire strain gauges were expensive and "future" foil gauges would cost pennies, however due to the high initial manufacturing costs, this did not become true until after the 1970's when manufacturing techniques had matured, so wire gauges lived along side foil gauges for many years. Today wire gauges are mainly used for high temperature strain measurements and specialist applications.
- The first foil gauges were only available in low ($\sim 50\Omega$) resistances, with manufacturing developments, 120Ω , 350Ω and 1000Ω versions became the standard; today they are available with resistances of up to $20k\Omega$, significantly reducing their power consumption making them ideally suited as a sensor for today's battery-operated equipment.
- Some of the major challenges that have been overcome include:
 - Introduction of self temperature compensation.
 - Introduction of different foil materials allowing higher gauge factors and higher resistances.
 - Developments in strain measuring equipment.
- In 1954 the discovery of the piezoresistive effect led to the development of semiconductor strain gauges with higher strain sensitivity than conventional metallic strain gauges. Further developments have led to MEMS technology, allowing the miniaturisation of sensors for force, pressure, sound etc. measurements.



1952 -2024
Strain Gauges



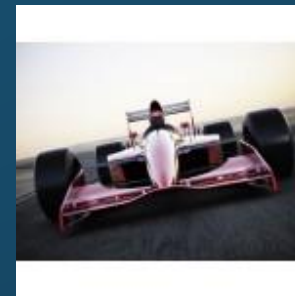
- Strain gauges usage can be grouped into two main categories:

1. Strain Measurement

- In the field of Experimental Mechanics and structural analysis, to understand behaviour of structures subjected to loading, a full field test method is the best way of gathering data and for comparison with digital models. Today there are many such techniques, and, in the future, more will become available, however the majority of these require a “line of Site” view of structure under test. This is not always possible and therefore the strain gauge becomes the “go to” method, due to their : reliability, accuracy, versatility and maturity.
Strain gauges are still, after 72 + years, one of the most used strain measurement methods available in the measurement toolbox.

2. Strain Sensor

- With the emergence of the data hungry IOT, everyday objects with embedded sensors are becoming more important, this will increase the requirement of strain gauges for data gathering, thus pushing the boundaries of today’s strain gauge technology.

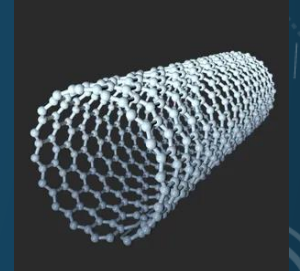
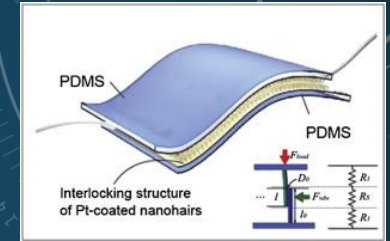




2024 - >>>>
Looking to the future



- Some of the latest advances in “Strain Gauge Sensors” have been in the field of wearable tech, Flexible sensors made from polydimethylsiloxane (PDMS) are used in various applications, including entertainment tech, human-machine interfaces, personal healthcare, and sports performance monitoring.
- Research is being conducted into multi-walled carbon nanotubes (MWCNT) in a silicone elastomer matrix to make stretchable sensors sensitive to mechanical strain, with the possibilities of 3D printing gauges.
- The story of the strain gauge is a testament to human ingenuity; the drive to create, and the yearning for recognition. The strain gauge's influence continues today, some 80 years since its first commercial availability. As we strive to push the boundaries of technological innovation, we face similar challenges in other technologies. The story serves as a reminder: where there's a will, there's a way. The enduring impact of the strain gauge across various industries demonstrates this.



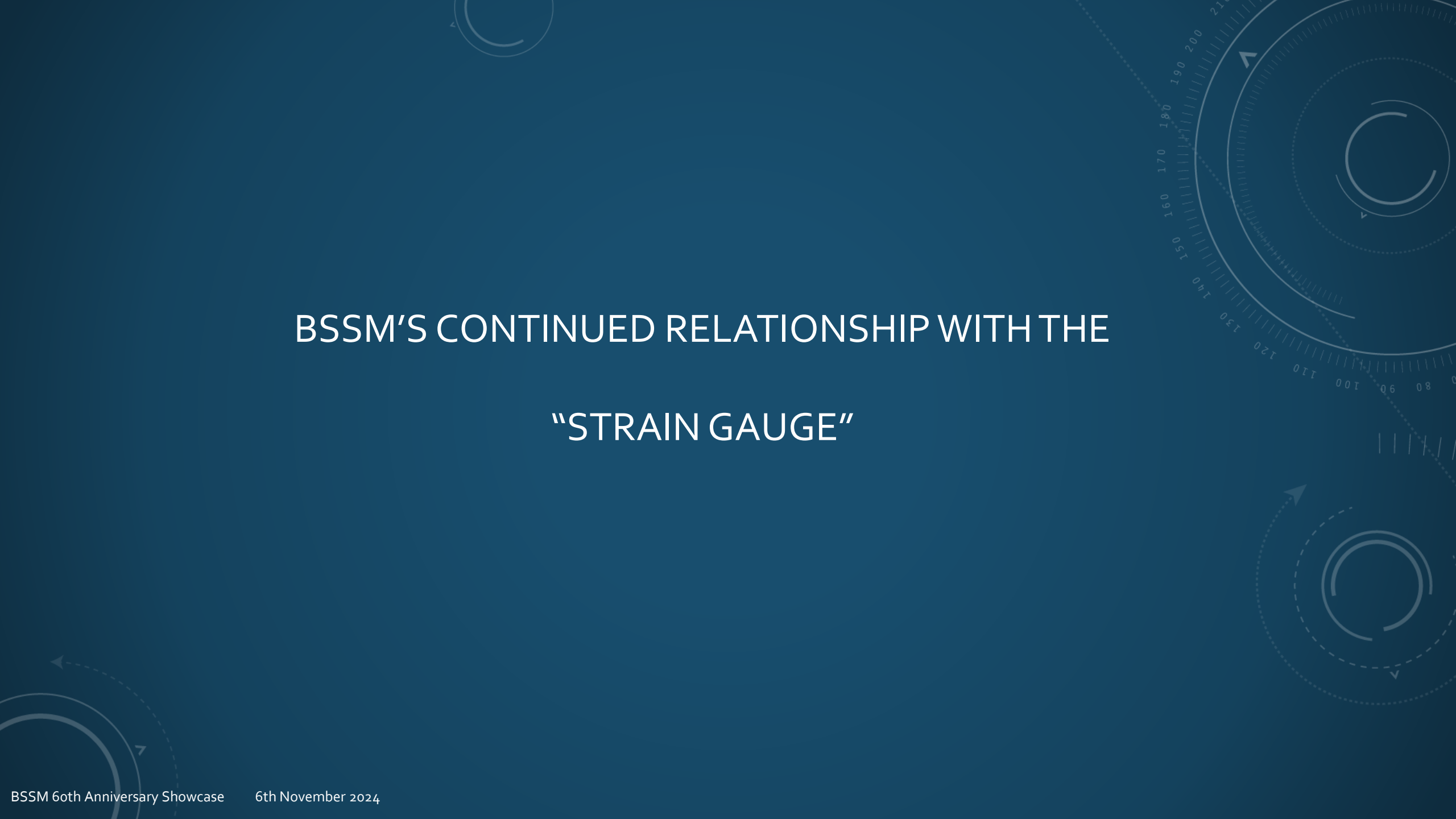
// Are strain gauges a thing of the past ?

No, strain gauges are not a thing of the past. In fact, they remain a crucial tool in many industries due to their reliability, accuracy, and versatility.

Is there a future for strain gauges ?

Despite the advent of newer technologies, strain gauges continue to be a cornerstone of strain measurement. Their reliability, accuracy, and versatility make them a staple in various industries. However, the future holds exciting possibilities for further advancements.





BSSM'S CONTINUED RELATIONSHIP WITH THE "STRAIN GAUGE"



1959 - 1964 The idea for a New Society

- In 1959, following a foil strain gauges seminar at Saunders-Rowe, a few of the delegates started a conversation about the need for a society of engineers specifically interested in using strain gauges.
- Despite opposition from the Institute of Physics, as they already had a “Stress Analysis Group”, formed in 1949, The British Society for Strain Measurement was eventually formed in 1964.
- In January 1965 Volume 1, Issue 1 of the BSSM’s Journal – “Strain” was published and in the editorial on page 2 the editor G.S Hollister wrote a paragraph outlining the reasons for the society:
 - “The British Society for Strain Measurement was formed because of a need for a society that would concern itself with the more practical side of stress analysis – particularly industrial applications -and this orientation towards applied subjects will also be in evidence in the contents of this journal, although occasional papers of a more theoretical nature will be included from time to time”
- To emphasise the importance of foil strain gauges, the first article in Volume 1 Issue 1, written by J. Avril (Budd S.A Paris) was entitled:

“The Strain Sensitivity and Cross Sensitivity of Foil Gauges”



1976 -1998 BSSM Certification Scheme



- One of the original aims of the Society as given in its Articles of Association was:
'...to promote and encourage technical education in the field of strain measurement.'
- In 1976 after growing pressure from industry, a Course committee was formed under the chairmanship of S. J. Collins (BAC Guided Weapons Division, Bristol) to develop a framework for a “Technical Validation Certificate” and a pilot scheme was introduced with the help of Birmingham Polytechnic.
- This new scheme had two routes and two qualifications with no entry requirements, but candidates had to attend compulsory modules either by attending BSSM seminars or short courses, with a Certificate or a Diploma for successful candidates after completing practical and written examinations:

Strain Gauges
and
Brittle Lacquers

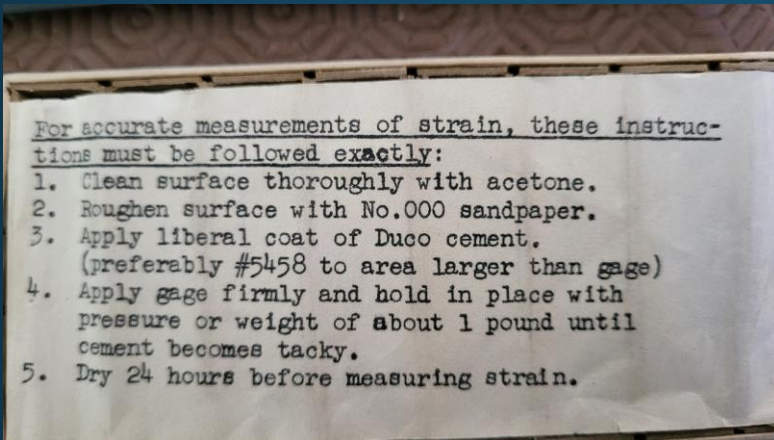
Basic
Photoelastic
Techniques

- The first examination of the Certification scheme took place in 1977 with Geoff Chalmers (Vishay) as the first Chief Examiner and Moderator.
- From 1978 BSSM began running strain gauge workshops and dedicated strain measurement courses.

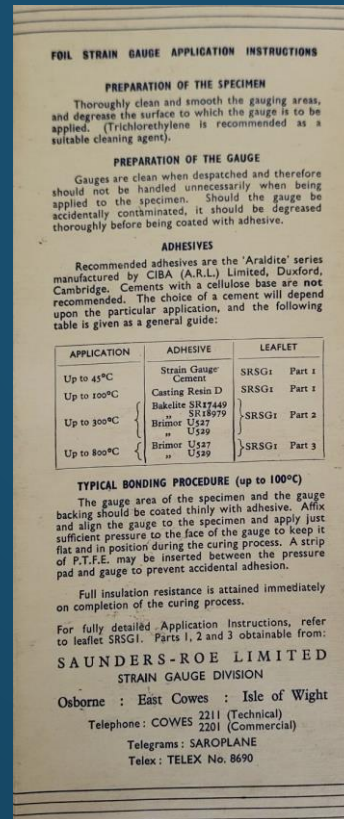
1992 Standardisation



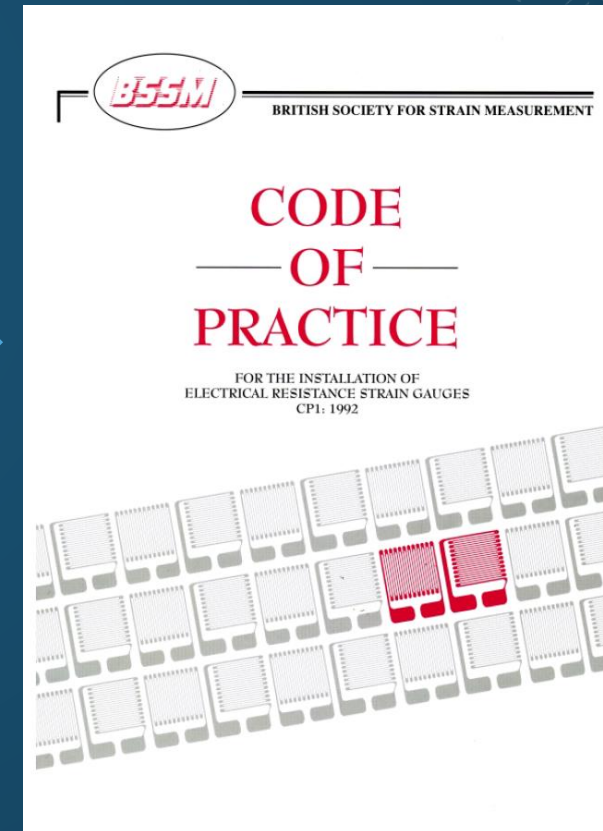
- In 1992 BSSM published a Code of Practice for the Installation of Resistance Strain gauges as it was recognised that although strain gauge standards existed (BS 6888, NAS 942 & OIML 62) none of these described the methods of installation and simply left these to manufacturers instructions. BSSM believed that a common standard universally agreed would be beneficial.



Baldwin Southwark Instructions



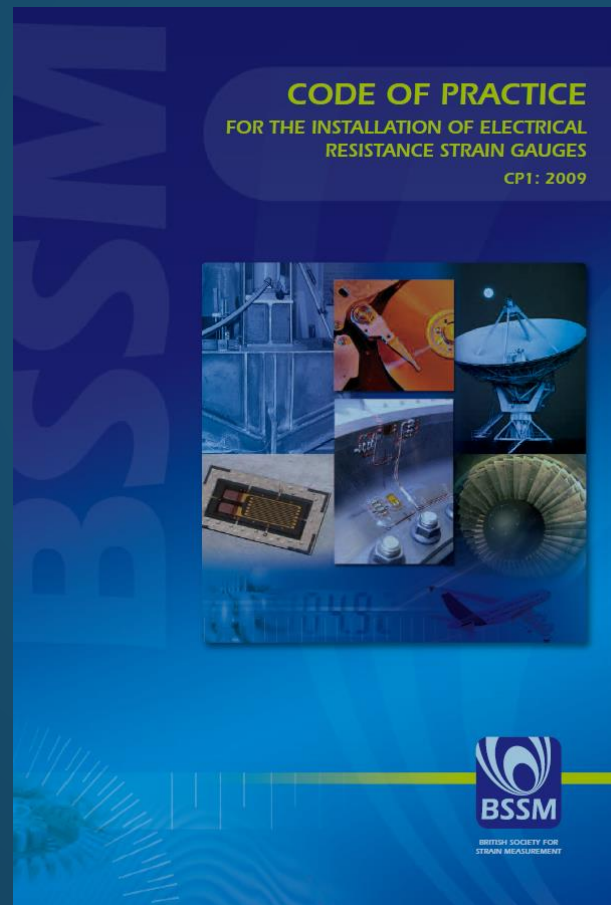
Saunders-Roe Instructions



2009
New Code of Practice



- In 2009 an updated Code of Practice was released after extensive collaboration between the major strain gauge manufactures, to reflect current (non-commercial) installation methods, and to become the backbone of the current BSSM Certification scheme.





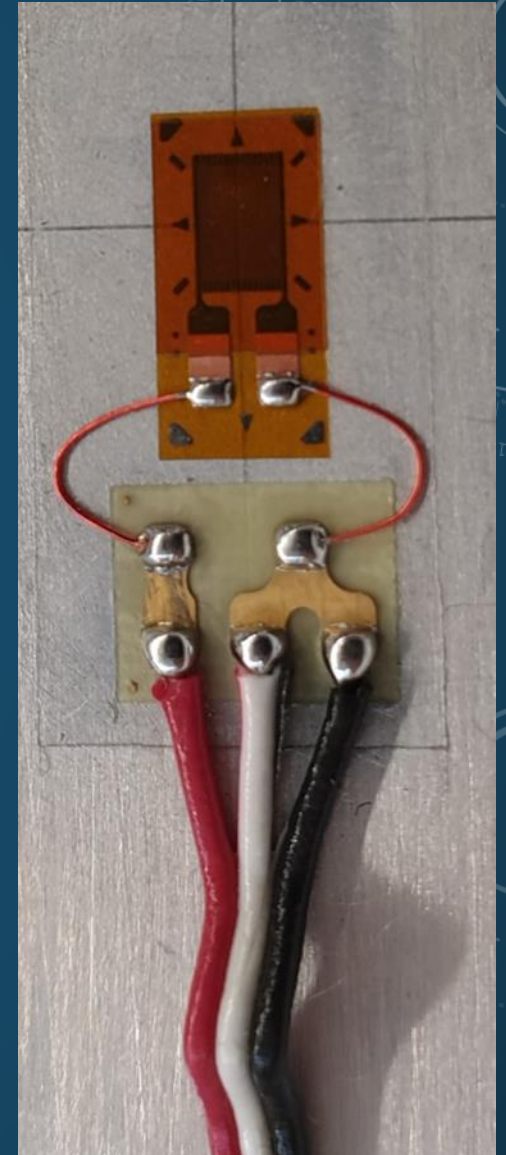
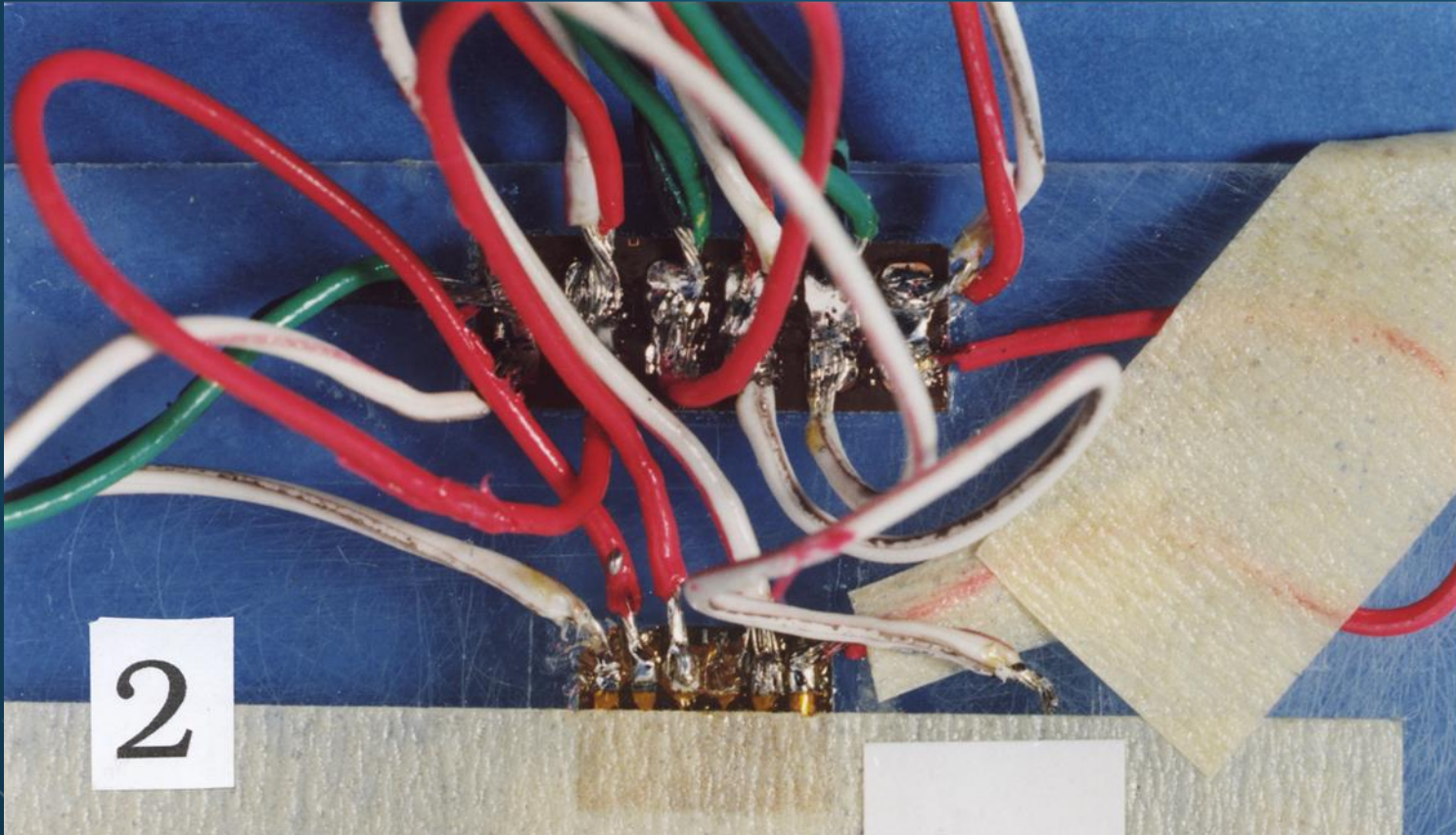
1998 - Present
New Certification Scheme



- The certification scheme continued successfully from 1977, but in the mid 90's under the CERCOC chairmanship of John Adlington, a new 3 level scheme was developed that followed the principals of the NDT certification process EN 473 (superseded by EN ISO 9712).
- This new scheme concentrated on Strain gauge certification and provided qualifications for:
 - Those who install strain gauges..... Level 1
 - Those who supervise installers and designers of strain gauge-based transducers.....Level 2
 - Those that use strain gauge data for Stress analysis or advanced transducer design..... Level 3
- This scheme is constantly under review by the CERCOC committee to ensure that it is still relevant and accurate, it has been accepted by industry organisations as a validated external quality system that enables them to demonstrate the capabilities of their strain gauge installations to accreditation bodies.



Why do we need a Strain Gauge Installation Certification??



Summary

- It is now 80 years since the first strain gauge was patented and in one form or other is still in constant use for:
 - Strain measurement for stress analysis of structures.
 - A sensor used to convert mechanical strain to a measurand i.e. force, pressure etc.etc.

and is guaranteed to be used for the foreseeable future!

- The advent of powerful digital analysis methods have transformed our understanding of the way that structures behave under service loading conditions and the development of new and novel full-field measuring techniques have and will continue to be used to validate these numerical models; however, there is still a place in the measurement toolbox for the simple strain gauge that has been positioned with an understanding of measured strain field. BSSM provide training courses that have been developed to help practitioners develop these skills.
- Regardless of the type of strain gauge used, the most important aspect of the measurement process is the installation. The BSSM Certification is an independent scheme that has been developed to allow organisations to demonstrate the capability of their installers.



**BRITISH SOCIETY FOR
STRAIN MEASUREMENT**