

Heat Shields for Jet Engines

PROTECTION BY LOW EMISSIVITY GOLD COATINGS

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The very high reflectivity of gold—extending well into the infra-red range—is well known and is surpassed only by that of freshly polished silver. But as silver is readily tarnished, while gold remains unaffected by any atmospheric or corrosive attack, it is true to say that in practice gold, even in the form of a thin film or coating, is the most efficient reflector for infra-red radiation.

Many applications of this property are well established, but the advantages of gold as a very low emitter of radiation have not always been so fully appreciated.

The emissivity of a metal can be derived from the value of its reflectivity by the relationship

$$\epsilon = 1 - r$$

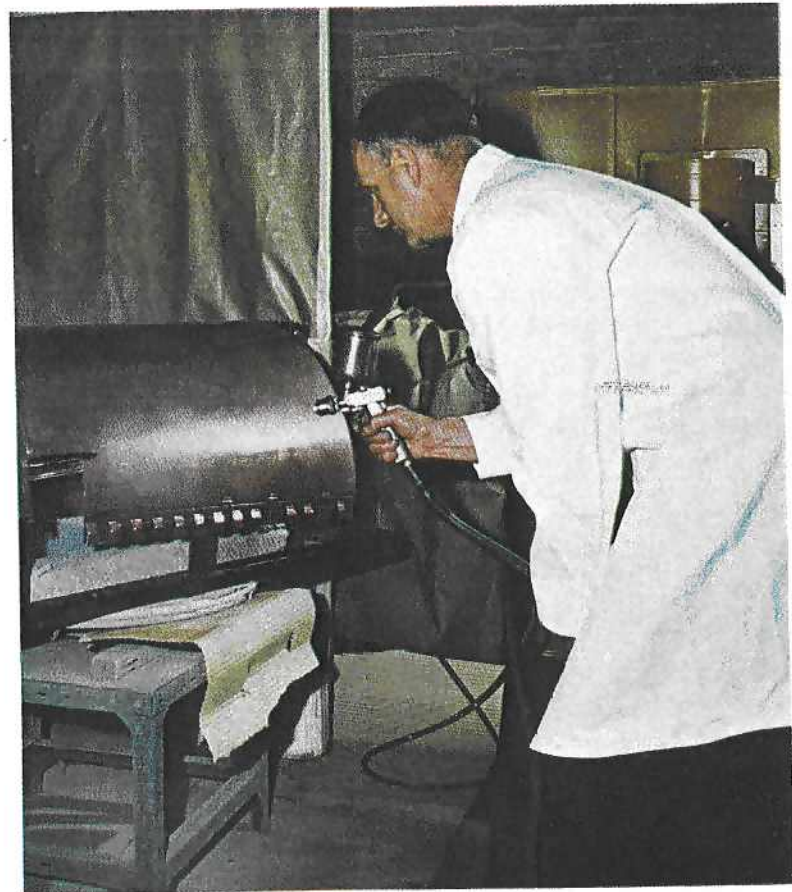
where ϵ is the emissivity and

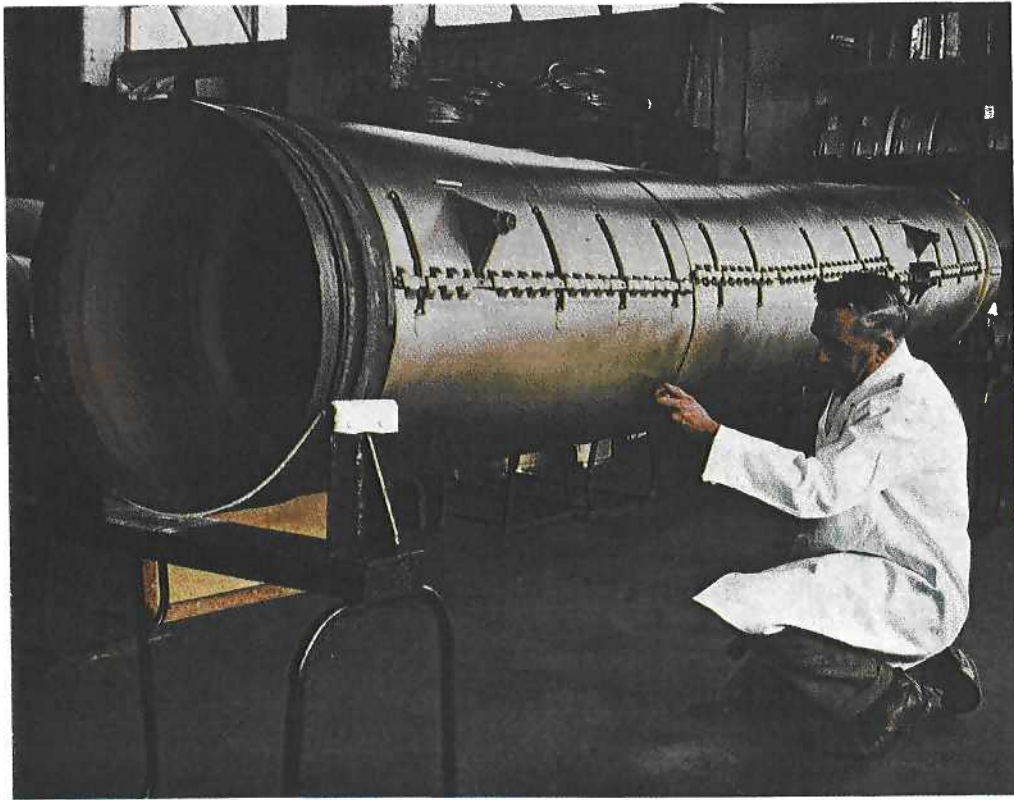
r the reflectivity on the scale 1.0 = 100 per cent.

Thus a metal that is highly reflective will be a poor emitter, and a gold surface having a reflectivity of well over 95 per cent in the infra-red region will have a total emissivity of only 0.05 over a fairly wide range of temperatures. This compares with very much higher values for most constructional metals and alloys; for example stainless steel, if subjected to high temperature and therefore having an oxidised surface, gives a total emissivity of the order of 0.80 and will therefore radiate a very great deal more heat.

This inherent property of gold can be utilised by the application to metal surfaces of a coating of a preparation generally known as "liquid bright gold". Many variations are possible on the basic composition, but essentially these preparations consist of a complex sulphur compound of gold in an organic solvent, with small additions of readily oxidisable metals such

Part of a heat shield for one of the two Rolls-Royce Avon engines that power the British Aircraft Corporation's "Lightning" being sprayed with a liquid gold preparation in the works of Lucas Gas Turbine Equipment. A simple heating operation then decomposes the organic constituents and produces a strongly adherent, continuous and durable film of gold





A completed heat shield for one of the jet pipes of the "Lightning". The low emissivity of the gold coating cuts down radiation from the hot jet stream and avoids overheating of the aircraft

as bismuth or vanadium to ensure good bonding to the substrate. These compositions can be produced with viscosities suitable for application by brushing, spraying or other means, and upon subsequent heating in an oxidising atmosphere they yield a firmly adherent film of gold.

For covering large areas, such as the heat shields on aircraft engines, spraying is preferred to ensure uniform coverage. The compressed air employed must be free from entrained water and dust, either of which could cause pinholes in the fired film, while the parts being coated must be clean and dry. After the coating has been applied it should be fired as soon as possible to avoid contamination. But given these few elementary precautions, a durable film of gold can readily be produced, some 5 millionths of an inch in thickness and of negligible weight. It will resist attack by jet fuel, hydraulic fluid or engine oil, and, provided that the substrate metal is itself unimpaired, will not suffer breakdown or exfoliation at temperatures up to 750°C.

Among a number of applications to modern aircraft engines, perhaps one of the most interesting cases is that of the British Aircraft Corporation's "Lightning". This multi-role machine, designed for high altitude interception, reconnaissance or ground

attack, and capable of speeds up to 1500 miles per hour, is powered by two Rolls-Royce Avon turbo-jet engines, joined by long jet pipes to fully variable reheat units. These are mounted one above the other on the centre-line of the aircraft to reduce the frontal area of the power plant, and the jet pipes run almost the whole length of the fuselage.

This versatile aircraft was originally designed for operation in the temperate climate of Great Britain, but it has for some years now also been in service in the heat and humidity of the Middle East and the Far East.

To avoid overheating problems it was decided at an early stage of the development of the aircraft to provide suitable heat shields, and this task was undertaken by Lucas Gas Turbine Equipment of Clitheroe, Lancashire, in co-operation with Rolls-Royce. It was quickly established that the gold film technique would solve the problem and immediate steps were taken to implement this decision.

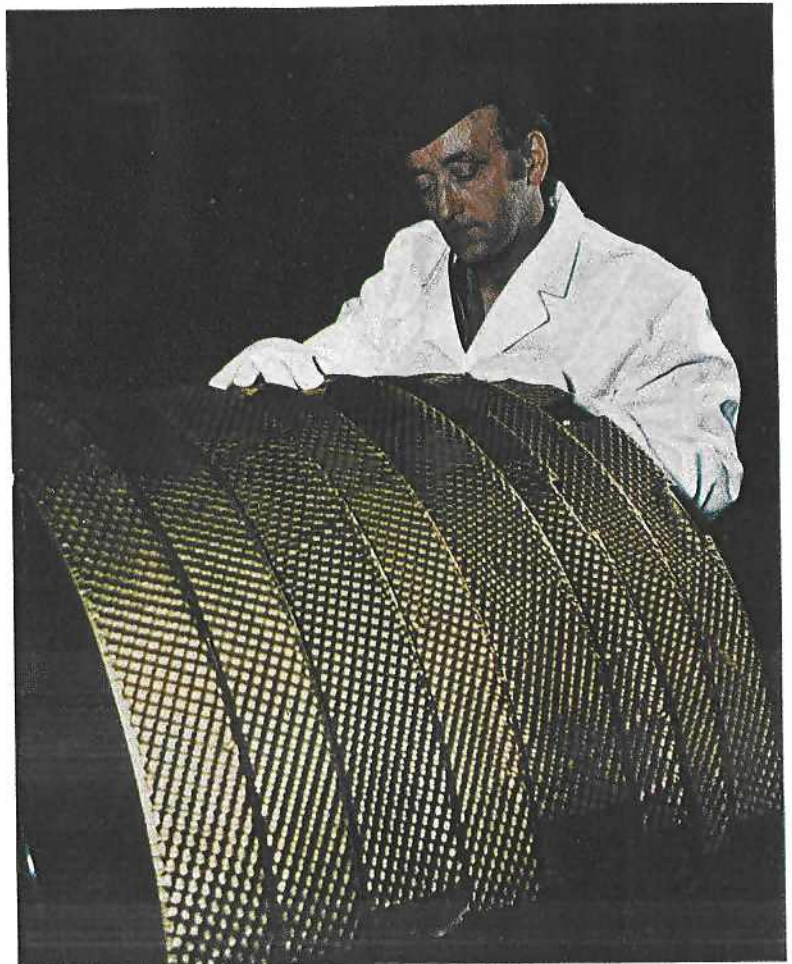
Stainless steel shrouds were designed for the jet pipes, and were given a coating of an Engelhard liquid bright gold by spraying. The units were then given a firing cycle at 400°C, and emerged from the oven with a closely adherent film of gold. A heat-resisting blanket for the exhaust unit of the engine—

This heat-resisting stainless steel blanket fitted to the exhaust unit of the Avon engine is also provided with a gold coating to reduce heat transfer

consisting of two layers of dimpled stainless steel with a filling of silicone fibre glass—was also treated in the same way and with equal success.

This application of the low emissivity property of gold has thus been completely successful in resolving overheating problems without the need for the extensive use of insulating materials.

In addition to this application in the "Lightning" jet aircraft, these gold coatings are being employed to reduce heat transfer on drag-chute containers, tail cone assemblies and missile blast shields.



Methods of Reducing Porosity in Thin Gold Electrodeposits

The British Non-Ferrous Metals Research Association has recently been studying methods by which the residual porosity in thin gold electrodeposits may be reduced. Gold plating for electronic applications has to be reliably pore-free to ensure that even slight corrosion of the substrate cannot occur, particularly in the areas near contacts. A sufficient thickness of gold is therefore applied to ensure a very low density of pores.

The investigation has concentrated upon techniques which could be applied without undue difficulty to current plating procedures, and areas have been identified where an alteration in processing can result in a reduction in residual porosity. Two variables have been shown to be important in the consistent production of low porosity gold coatings. These are the original condition of the substrate to be plated and the method of agitation used during the electro-deposition process.

Surface features present on the substrate have been shown to affect significantly the porosity level of the electrodeposited gold coating. Inclusions have been

identified as a source of residual porosity, but these can be removed by suitable cleaning processes. However, the surface layer of the substrate can be distorted due to working and, also, often contains depressions and craters which form a potential pore site. It has been found that the surface can be considerably improved by electropolishing prior to plating, and a procedure for producing a satisfactory substrate by electropolishing has been developed.

The effects of different methods of agitating the electrolyte during electrodeposition have also been studied. It has been found on a statistical basis that porosity can be reduced still further by utilising ultrasonic agitation during electrodeposition. A combination of the two processes, i.e. electropolishing and ultrasonic agitation, results in a consistently low residual porosity when thin ($2\mu\text{m}$) gold coatings are deposited.

It is hoped to study the causes for this slight residual porosity further and to apply these results on a larger scale in production plating shops.

I. R. A. C.

A New Bonding Process for Ceramics

REACTION WELDING WITH A GOLD FILLER

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Solid state reactions occurring at the interface between ceramic oxides and gold form the basis of a new means of obtaining strong and vacuum-tight joints in a wide range of synthetic ceramics. Industrial applications of the process are now being evaluated.

A wide range of synthetic ceramics, each designed to meet specific requirements, is now available to the electrical and electronic engineer for use in vacuum tube technology, semiconductor devices, high temperature fuel cells, nuclear engineering and other sophisticated equipment. In some cases, however, their applications are limited by the difficulty of joining them to other ceramic bodies to form composite structures. The techniques presently available for this purpose involve a type of brazing operation in which a metal alloy or a glass is heated to above its melting point, the liquid phase then wetting both surfaces. Unfortunately the wetting angles between most alloys and ceramics are substantially larger than 90° and wetting is most difficult to achieve.

A collaborative research programme initiated by the School of Physical Sciences of Flinders University and the Commonwealth Scientific and Industrial Research Organisation has now led to the development of a new method for bonding ceramics,

using thin noble metal foils (1, 2, 3). In this process, in contrast to conventional brazing and welding, no melting is involved.

The mechanism of the bonding process has been shown to result from a chemical reaction taking place at the interface between noble metals and ceramic oxides such as magnesia, alumina, stabilised zirconia, beryllia, thoria, and also quartz and silicate glasses. A striking fact, established by scanning electron microscopy and electron probe microanalysis, is the absence of metal diffusion into the ceramic as shown in Fig. 1.

The process itself consists simply of heating both materials to a specific temperature below the melting point of either component in any compatible atmosphere – usually air or vacuum – and under slight pressure to improve contact. Heating, which can be by any appropriate means such as an induction heater or muffle furnace, ranges from a few minutes to several hours.

Fig. 1 Energy filtered scanning electron micrographs of reaction-welded composites. The absence of metal diffusion into the ceramic in a noble metal bond is shown in (a), which is a micrograph of an $\text{Al}_2\text{O}_3/\text{Au}/\text{Al}_2\text{O}_3$ composite. For comparison a nickel-bonded composite with an obvious diffusion region D is shown in (b)

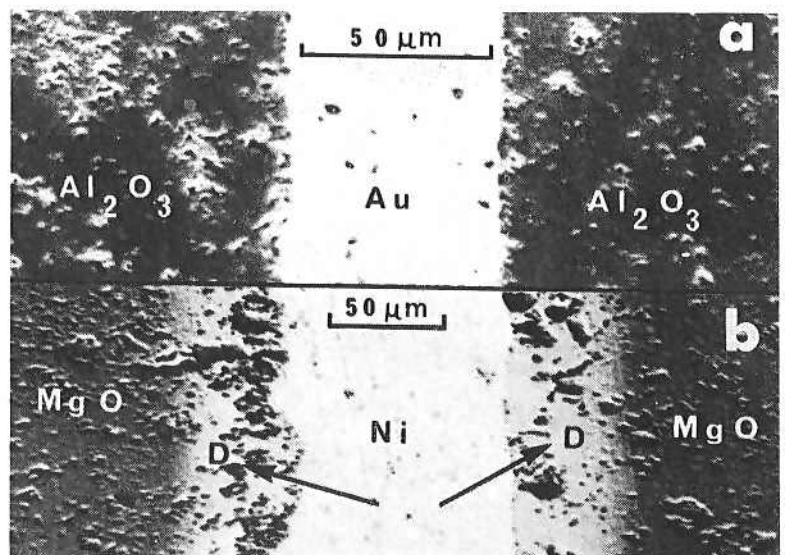
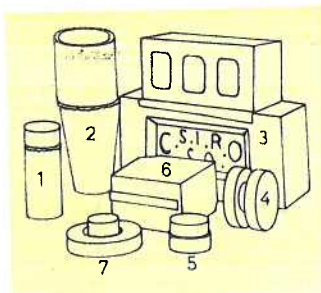
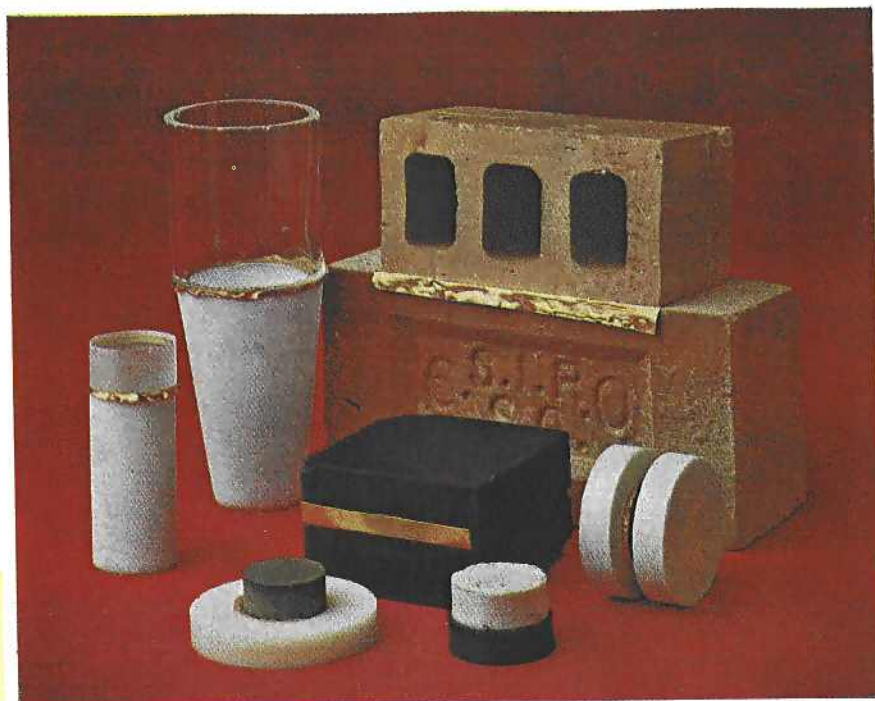


Fig. 2 A group of miscellaneous ceramic components joined by the new reaction welding process, using gold as the joining medium



KEY: The spectrographic cell (1) comprises an alumina container with sapphire windows; (2) is an alumina crucible reaction-welded to a Pyrex glass tube; the clay bricks (3) merely serve to demonstrate the range of ceramics that can be joined by this process. Item (4) is a beryllia-urania-beryllia sandwich while (5), a beryllia-urania couple, shows the principle of a fission product retentive nuclear fuel element. Item (6) shows a couple made of two different ferrites and (7) a nickel oxide-alumina couple

Vacuum-tight bonds are produced in this way, and their ultimate shear strengths have been found to exceed those of the ceramics being joined.

The illustrations show several examples of reaction-welded ceramics, in each case joined with gold foil about 50 μm in thickness. Gold as a filler is often preferred to other noble metals such as platinum or palladium when the particular application does not demand temperatures above 1000°C. Its high ductility, even in the presence of minor impurities that are inevitably introduced, relieves thermal stresses when materials of greatly differing expansion characteristics are bonded. There is substantial evidence (2) to show that the stresses at the metal/ceramic interface are negligible even on quenching from 1000°C to approximately -100°C in one second. However, thermal expansion coefficients of ceramics can vary by a factor of ten or more.

Gold is chemically compatible with almost all oxides even near its melting point. This makes it attractive as a welding filler for equipment used under corrosive conditions. The spectrographic cell



Fig. 3 A close-up view of the bond in the spectrographic cell made from an alumina container with sapphire windows

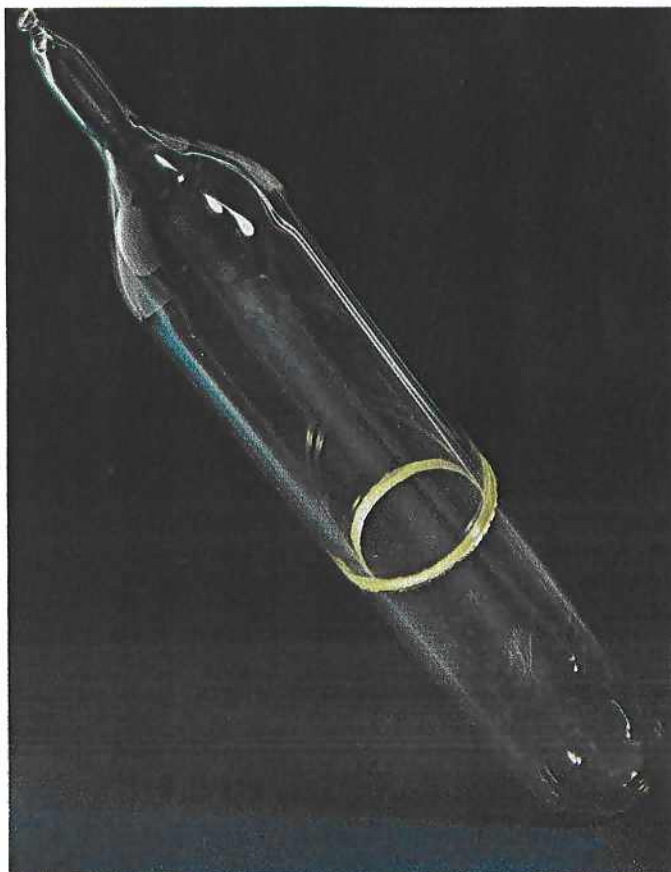


Fig. 4 An example of a vacuum-tight seal made by reaction welding. This Pyrex/gold/Pyrex test assembly has been maintained for eighteen months under a vacuum of 10^{-6} torr

in Fig. 2 (number 1 in the layout diagram) consists of an alumina container with sapphire windows reaction-welded with gold. A close up of the bond is shown in Fig. 3.

Number 2 in Fig. 2 is an alumina crucible reaction welded to a Pyrex glass tube for incorporation in glass equipment as used in high temperature research. The crucible can be simply removed on melting the gold, for instance, by means of a brief burst of power from an induction coil.

It is scarcely suggested that gold should replace mortar in the building industry, but the specimen clay bricks in Fig. 2 (number 3) reaction welded with gold, provide some indication of the range of ceramics that can be bonded by this simple process. Classical ceramics, such as all-clay products for structural and ornamental purposes, so-called super-refractory high purity oxides, as well as many silicates including the glasses fall in this range.

Gold is not an attractive nuclear material. However, the beryllia/urania/beryllia sandwich (number 4 in Fig. 2) and the beryllia/urania couple (number 5 in Fig. 2) reaction welded with gold foil, shows the principle of a fission product retentive nuclear fuel element. This particular fuel-moderator combination has long been under consideration as a heterogeneous fuel element for advanced gas-cooled nuclear reactors.

The use of another metal filler in this case would certainly be more appropriate, but the couple shows the scope of the method.

Perhaps the most important area of potential applications is electronic technology. The possibility of making perfect contact between electrical conductors (metals) and insulators (ceramics) is very attractive. This can be done by the reaction-welding process. Non-conducting and high frequency magnetic oxides (ferrites), piezoelectrics, anti-ferroelectrics, and many other special oxides can be reaction-welded. Fig. 2 shows a couple of two different ferrites (number 6).

The compatibility with most oxides is also shown in the welded nickel oxide/alumina couple in Fig. 2 (number 7). These oxides in contact with each other form a range of spinels. Reactions such as these

occur widely and prevent the formation of stable bonds between differing oxides by hot pressing, or cold pressing and sintering. The gold foil prevents contact between incompatible oxides and yet bonds both of them very strongly.

Gold is an ideal filler for the making of vacuum tight seals. An example is shown in Fig. 4. This Pyrex/gold/Pyrex test assembly has been maintained for eighteen months under a vacuum of 10^{-6} torr (10^{-4} N/m²).

These are a few examples illustrating the scope of the new reaction welding process and the important place that gold occupies in this new technique. All are 'unfinished' because the use of finished products displaying specific industrial applications is precluded by the present stage of negotiations with the industries concerned. The exact nature of the bond between ceramic oxides and the noble metals is currently under investigation by means of electron microscopy, electron probe microanalysis, radiochemical and several other techniques.

References

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The First Electric Clock

ALEXANDER BAIN'S GOLD CONTACT SYSTEM

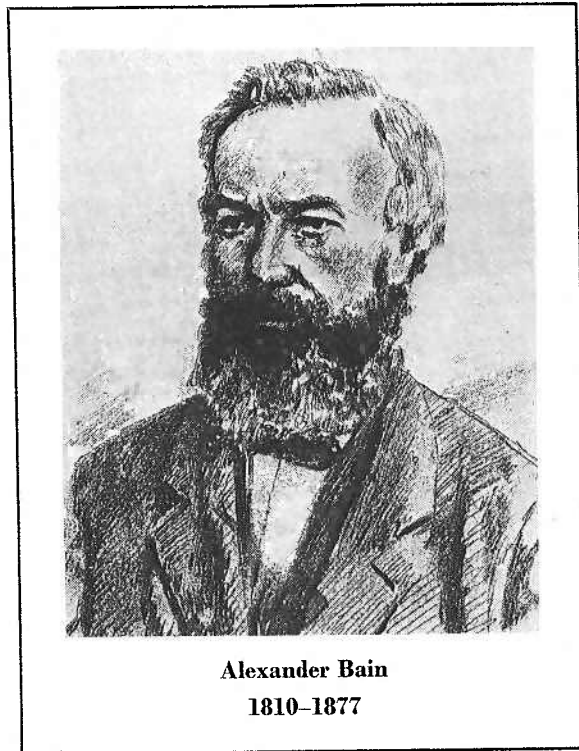
A. G. Thomson

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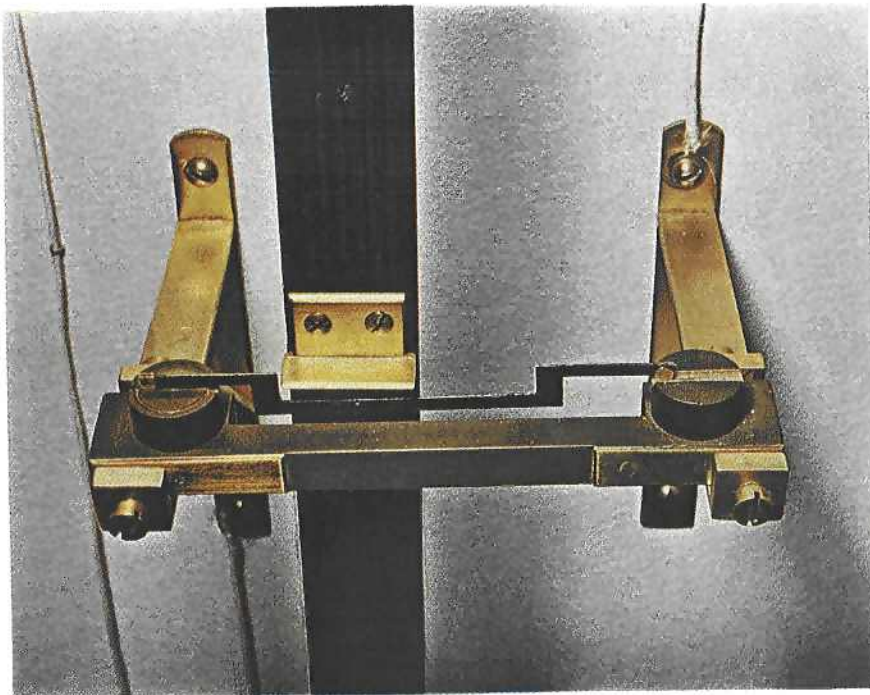
In March 1837 Alexander Bain, a journeyman clockmaker from Wick in the far north of Scotland, came to London at the age of 26 to seek employment. He obtained lodgings and a workshop, first in Wigmore Street and later in Oxford Street, and besides practising his craft he attended lectures at the Polytechnic Institute, having as he later wrote, 'some knowledge of electricity and a strong desire to know more'.

Before long he had conceived the idea of applying the new concepts of electro-magnetism to time-keeping. At that time, of course, the idea that electricity could be carried along wires and could be made to do work had only recently become established and there was very little background knowledge available. However, Bain persisted with his experiments and by the summer of 1840 had designed and built not only a model of an electric clock but also the prototype of a printing electric telegraph.

At this stage Bain began to cast about for someone "to join him in furthering his invention". Now it was in the very month of Bain's arrival in London that Cooke and Wheatstone had agreed to form a partnership, and this uneasy collaboration of two such very



Alexander Bain
1810-1877



The contact system of one of Bain's early electric clocks, now in the Royal Scottish Museum. The slider, impelled by a pin on the pendulum, runs in two grooves, one of which is made of gold and the other partly of gold and partly of ivory, and contact is made only when both ends of the slider are on the metal. This clock is still in good working order

different men had led almost immediately to the filing of their first patent for an electric telegraph. Their achievements had become well known by 1840, and it was not unnatural that Bain should be referred to Professor Wheatstone, who had himself been thinking along the lines of an electric clock. Their first meeting took place at King's College, London, on August 1st, 1840, when Bain produced his drawings of both devices. Wheatstone was interested, and arranged a second meeting at his house in Conduit Street for August 18th for Bain to bring along his models. A vague arrangement was entered into at this meeting, under which Wheatstone paid Bain £5 for his model of the printing telegraph, to be followed by £50 if it became commercially profitable, but advised him to postpone all work on the electric clock.

Unfortunately it was from this meeting that there stemmed a long and embittered controversy as to who was the true inventor of the electric clock. Bain, with his friend John Barwise, the well known chronometer maker, filed his patent—a lengthy and complicated specification—on October 10th and it was granted, as No. 8783, on January 11th, 1841. In the meantime, on November 26th, 1840, Wheatstone exhibited an electric clock at the Royal Society!

The argument and counter-argument raged for some years and involved recourse to the Courts, where it was established that Bain was the first to devise an electric clock. One result was that he was appointed manager for Scotland of the Electric Telegraph Company, which was a Wheatstone foundation, and

on the face of all their clocks was to be engraved "A. Bain, Inventor".

Bain was the first to maintain a clock pendulum in motion by means of electromagnetic impulses. The sequential switching to energise the coil was achieved by means of a cranked bracket actuated by the pendulum and rubbing on an ivory or ebonite block in which were inlaid contacts of gold. The actual motion was induced by the attraction of a sequentially energised coil which formed the pendulum bob and which swung over a group of small permanent magnets enclosed in a brass tube.

Bain had chosen perhaps better than he knew in his selection of gold as his contact material. Though perhaps rather soft, its freedom from oxidation and its low electrical resistance combined to give success to an electrical circuit where losses had perforce to be kept to a minimum.

In the Royal Scottish Museum there are two going examples of Bain's clocks, one of which is thought to be his No. "O" or original model, and both are quite reliable; they operate not off the original earth battery but from a 1½ volt Leclanché cell.

It is perhaps interesting to note that some 60 years after Bain's invention the Bentley Engineering Company of Leicester filed patents for what seems in all respects to have been a replica of Bain's clock. But it is to Alexander Bain that we owe the first successful electrically maintained clock and it depended for its success largely on his choice of gold as the contact material.

THIS metal, as has been said, becomes dense because of its thorough tempering and its perfect and uniform elemental mixture, and of such a density that it is given not only an ordinary permanence but almost an incorruptibility and an incapacity to contain any superfluous material, even if it is subtle and in small amount. For this reason it does not rust, even though it be in the earth or in water for a long time, for neither of these has any effect on it, nor does fire, which has the power to reduce to ashes or dissolve every created thing; indeed gold not only defends itself from fire but continually purifies itself therein and becomes more beautiful; nor does it have any effect on the senses of smell or taste, nor is it poisonous if it is eaten either intentionally or by accident—indeed as a medicine it is beneficial in certain illnesses.

From the translation by
Cyril Stanley Smith and Martha Teach Gnudi,
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VANNOCCIO BIRINGUCCIO
De La Pirotechnia
Venice, 1540