# Decorative heat bluing of steels

Guy Gibbons

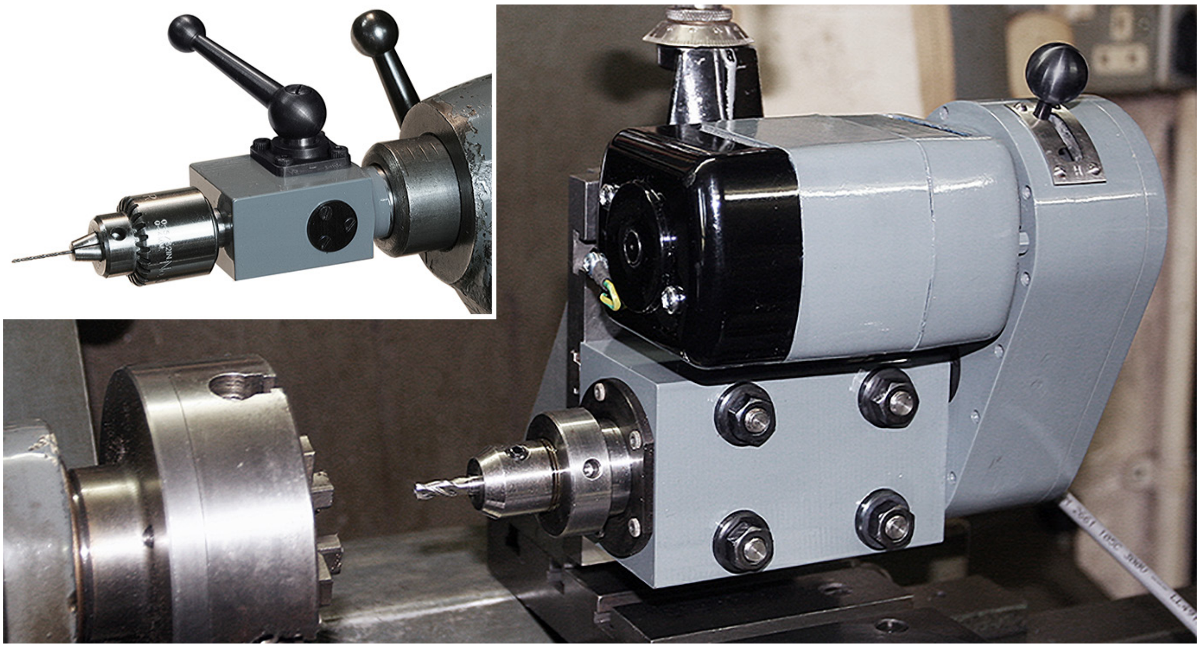


*Figure 1. Machine tool handles and other parts decoratively heat blued*

## Introduction

Decorative heat-bluing of steels is a process which can find many applications, several examples of handles and other components heat-blued in the small workshop being shown in Figure 1.

Firmly rooted in engineering, this paper is a balance between scientific research and practical implementation. Starting from published research that colour is dependent on both the temperature and the time for which the component is soaked at that temperature, this paper describes the engineering design and practical construction of an electrically heated bluing box under digital temperature control and the author's subsequent development and evaluation trials.

# Processes

Colouring steels to blue is primarily a decorative process, and heat bluing is imparting an oxide film to the outer surface, the colour of which depends upon the temperature to which the component is raised and the time for which the component is 'soaked' at that temperature. Tempering steels to remove hardness (e.g. to impart toughness on wearing surfaces or avoid brittle fracture in springs) is also frequently determined by raising a previously hardened steel component to a specific colour before again quenching. Much literature covers the hardening and tempering of steels, so the author will not dwell on these processes.

In the smaller engineering workshop, decorative bluing of components is sometimes required for screws and other small components used in internal combustion engines (and may also be required for a finned steel cylinder head), in stationary steam engines for cylinder cleading, and for those who make machine tool replacements and accessories, ball handles, etc. so as to match those on their associated lathes, etc. Others will use oil blackening (see box), which may give a better colour match with other machine tool components.

## Oil blackening

Perhaps the most traditional method of colouring steel is oil blackening (not really bluing as it results in a black colour) that builds up an opaque oxide layer of magnetite similar to that developed during bluing.

Porosity in the magnetite absorbs the oxidised oil with which the component is coated during heating to red heat (or into which the heated component is plunged) to give a dark black finish and a degree of corrosion protection.

Many proprietary products are also available for hot (and cold) blackening but I have no experience of them. Along with oil blackening, I shall not consider proprietary blackening processes further in this paper.

Heat bluing is also valuable for bluing engraved or punched numerals and fiducial marks on feed screw thimbles for an easy-read contrast with a shiny steel surface (discussed in a later section).

Decorative steel bluing is regularly used by horologists for screws, clock hands and watch hands, which will again be discussed in a later section.

Gun makers also use decorative heat bluing, but as I have no experience of gun making coupled with it not being an activity to be encouraged in the UK, I can offer no experience-based comment.

## Making steel appear blue

Bluing primarily depends on converting the steel surface to a thin film (layer) of magnetite ($Fe_3O_4$), magnetite being black in colour (black oxide). If the oxide layer is comparable in thickness to the quarter wavelength of light, the film will be translucent and some of the colours in the spectrum will (effectively) be absorbed so causing the steel to appear blue or other colour* between pale straw through browns and purples to blue and eventually grey.

* These colours are generally called steel tempering colours, and are illustrated in many published reference works or on the Internet.

Theoretically, bluing also imparts a slight degree of corrosion resistance to the surface of ferritic steels, though in the author's experience, the oxide film is so thin as to be of little value. But whatever the bluing process used, cleanliness is essential, requiring time to be spent degreasing the component using, for example, methylated spirits followed by washing-up detergent and a thorough rinse in warm running water. For heavier contamination or complex shapes, an ultrasonic tank and associated cleaning and rinsing fluids is useful.

The pre-bluing surface finish is also critical and, for the best colour rendition, polishing down to 2000 grit (10 microns) is required. This can be achieved on an extra fine diamond whetstone, 3M brand microfinishing film or, for lower quality work where one is not too worried about rounded edges caused by 'sandpapering', 2000 grit silicon carbide wet and dry paper.

For the finest finish to precision instrument screw heads, screws should always be made from hardenable steel and hardened right out and polished before heat bluing, the heating process tempering the screw so as not to make them prone to brittle fracture under the head when tightened. For the highest quality work, horologists use a specialist screw-head polishing tool (Figure 2). which they call a 'bolt polishing tool'*.

* The writer's self-made screw head polishing tool is made from a commercial Eclipse brand Cat.160 collet set. The fourth 2.5 to 3 mm collet is specially made and heat-blued.

*Figure 2 The author's screw head polishing tool*

It is not essential to quench the component once the correct colour of blue has been achieved, but it does help to arrest any further heating (limit the soak time) from residual heat. If the component is to be lacquered using a blue lacquer, quenching should be done in pure water and dried immediately. If lacquering is not required (e.g. for machine tool components) the author prefers to quench in mineral oil in the hope that it might 'condition' the surface*.

* 'Conditioning' or 'seasoning': A term used by cooks to describe the preparation of a new (non-PTFE coated) frying pan with a cooking oil, so making it more non-stick and giving it a slightly improved anti-rusting surface.

## Decorative heat bluing in air

Decorative bluing or colouring of steel is always a difficult business not only to get the correct colour but, perhaps more importantly for one-off work, an even colour across the entire surface. Many methods are available, and the author will concentrate on those that are most easily undertaken in the home workshop. Even taking the most stringent precautions, first time success at uniform heat bluing is often elusive, especially where the utmost perfection in uniformity of colour is required. Fortunately one can repeat the process as many times as is necessary (sanding off the defective finish, re-polishing, cleaning/degreasing, and re-bluing) with no detriment to the component being blued.

The most common method involving no chemicals and little investment in equipment is heating directly in an open flame or by a hot air gun, the component being placed on a bed of finely-divided material such as sand or brass filings. During the process, some temperature control in order to get a uniform colour during bluing is achievable by moving either the component or heat source to provide localised additional 'top heat' as required.

Some report success with the component placed directly on an electrically-heated hotplate (cooker or specialised instrument), but the author has found this rather unsuccessful

*Figure 3  Heat bluing plate for screws*

for anything but the smallest of 2-dimensional components  Apocryphally, some horological authorities suggest that even dragging a tiny, flat component such as a watch hand over a heated rod can be successful, but I have not tried it.

One particularly useful piece of equipment for open-flame bluing of one or perhaps two screws at a time is a bluing plate consisting of little more than a flat plate of brass drilled with multiple holes that can be held over a Bunsen burner before inverting over a dish of mineral oil to let the screw drop out so arresting any further heating (change in colour) – Figure 3.

## Decorative heat bluing in a liquid

Of all these methods, the author has found bluing salts by far the most satisfactory method of achieving a uniform blue, especially for a component that is irregularly-shaped or 3-dimensional.  But even using bluing salts, it not infrequently takes the author two or three attempts primarily because, however well degreased the components are before bluing, the salts seem poor at removing any remaining traces of oil.  Suggested from the above observations, therefore, what is ideally required is a high thermal capacity 'fluid' of both uniform and constant temperature that is well circulated around the component.   Largely achieved by the use of fluid bluing salts, these conditions are far from satisfied by bluing in air*.

*  It is not dissimilar to pan-frying rather than boiling or deep-fat frying, and all will be aware of the difference and unevenness in colour taken on by food cooked using these methods.

Bluing salts are generally composed of a mixture of sodium hydroxide (NaOH, melting point Ca. 320˚C) and potassium nitrate ($KNO_3$, melting point Ca. 330˚  Neither are particularly pleasant materials to handle especially in molten form, and for those who may have concerns, COSHH health and safety data can be found on the Internet.  The bluing salt mixture (a proprietary item) melts at around 280˚C to 300˚C and can be 'soaked' for a longer or shorter time or the temperature increased to get the colour of blue one desires.

During the process, oxygen combines with the surface of the immersed steel to form the blue colour; it is not  a 'chemical' colouring process but simple colouring by oxidation*.  Temperature control is not needed as this is automatically controlled by the salts becoming liquid at the lower temperature bound for bluing the steel component by surface oxidation.

*  Strictly, oxidation is of course a chemical process, but the colour has little to do with the sodium or potassium compounds in the bluing salts.

When melted in their undiluted form, the salts essentially provide uniform bluing that oxidises the surface of the steel in much the same way as heating in a flame but under far greater temperature control and with far greater thermal circulation of the liquid than can be achieved by unassisted air convection (hot air not circulated by a fan).

Bluing salts can also be used to uniformly temper hardened steel components, which can be particularly useful in tempering springs so that no hard spots prone to brittle fracture remain.

Capable of taking a standard wheel barometer hand, one of my bluing pans is a specially made tray capable of taking the majority of domestic clock and barometer hands – Figure 4.

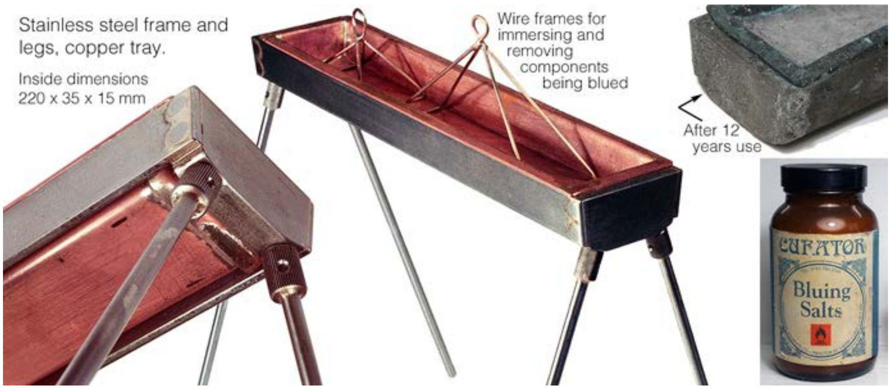


*Figure 4  Bluing salts tray*

As mentioned above, bluing using bluing salts is a very messy process and, using my tray, requires a propane flame of some considerable size to get the bluing salts molten.  Typically I use a Sievert 2942 burner (as a sort of Bunsen burner) delivering a huge 26 kW of heat and consuming up to half a kilogram of propane over a 15 minute burn time.  Moreover after about twelve years in service, the whole tray has got so caked in hardened salts that it has become pretty unusable, not least because the solidifying salts on cooling caused the sides of the copper tray to bend inwards, and the Whitworth coarse screw threads on the legs to become clogged with solidified salts – Figure 4, top right.

## Other methods

Setting aside painting, as hinted earlier there are several proprietary products available for colouring steels, all tending to be cold processes using a chemical reaction.  However, I have no experience of them, so I cannot comment further.

At a professional level, manufacturers of watch hands use hugely specialised processes for achieving a whole range of colours.  But let me quote from one manufacturer supplying to luxury Swiss watch marques:

‘*The blue hands that are favoured on high-end timepieces are fabricated by heating steel hands to high temperatures for a determined period of time to create the beautiful blue effect. In fact, steel goes through a whole range of colours as it is heated - from yellow, orange, pink, purple through to blue and turquoise – although these other colours aren’t often seen in a watch.*’  (Fiedler SA, Genève)

What is notable is the use of words I underline; rarely considered outside the professional bluing works, time is critical, and I shall return to this in the next section.

# Temperature and time

From now on I shall primarily be considering the decorative heat bluing of steels, so those wanting to colour aluminium or brass, or learn about hardening and tempering will be disappointed. But before I completely leave these materials, a few points are worth mentioning:

- Heat bluing is not a coating process. The colour is imparted by the oxidation of the surface layer of the steel, so negligible dimensional changes to the workpiece will take place.
- Heat bluing is primarily only applicable to mild, carbon and alloy ferritic steels, though bluing is possible on some austenitic stainless steels and other metals such as titanium. However, the author has no experience of non-ferritic metals so cannot comment further.
- If silver solder is used to repair or join steel components that need subsequent (e.g. a repair to a broken component such as a clock hand), then the silver solder will not be coloured blue and a joint line will forever show.
- The hues of blue are generally both dependent upon metallurgical composition (alloy), steel hardness and surface finish (polish), the former due to the alloying elements causing changes in the colour spectrum, and the latter two the quality (polish) of the surface resulting in changes to the perceived reflected light.

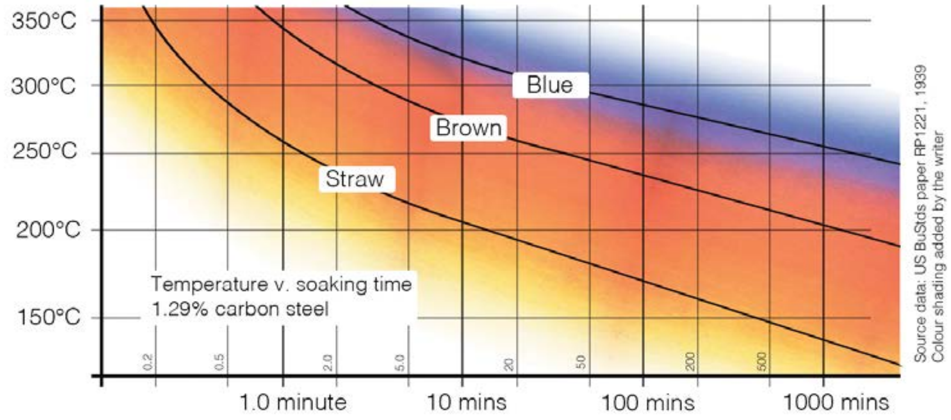
## Colour, time and temperature

Heat bluing steel oxidises the surface of the steel, and the thickness of this thin oxide layer (just a few microns thick) causes destructive interference between the light reflected from the base of the oxide layer and the surface of the oxide layer. As the thickness of this layer increases due to temperature or heating time (soaking time) the colour changes. This colour change has been used throughout the centuries for gauging the temperature of the steel, and is particularly useful as it also indicates the degree of hardness removed (called tempering) from a fully hardened (heated to red and quenched) steel component. Tempering makes a steel less susceptible to brittle fracture, so making it tougher)

Not all steels can be hardened and tempered (for example, mild steel can be neither hardened nor tempered), but for the purposes of colouration, this is irrelevant as the oxide colours will still be formed on heating. However, if the component is made of a heat-hardenable steel (e.g. carbon or alloy steel) and needs to be in a hard condition to meet its in-service requirements, heat bluing will remove some of this hardness (temper the component to blue). For example, if the component needs to be used in a straw colour temper condition (eg. a sharp-edge cutting tool or a punch), decorative heat colouring can only be taken to straw colour (≈ 230˚C cf. ≈ 290˚ for blue).

Steel tempering charts invariably assign a specific temperature to a specific colour, but to do so fails to recognise that colour is dependent on heat soaking time. These authorities are wrong – soaking time must be specified, and to claim otherwise is either from ignorance or because, in traditional 'blacksmiths' flame-bluing, the component is removed from the heat and quenched the instant the desired colour is achieved. Dependence upon soaking time is confirmed from research undertaken in 1939* as shown in Figure 5, and further corroboration is provided from a number of trials undertaken by the author, and a few will be reported in later sections.

* *Rate of oxidation of steels as determined from interference colors of oxide films*, Dunlap J McAdam et al, National Bureau of Standards, July 1939



Source data: US BuStds paper RP1221, 1939
Colour shading added by the writer

*Figure 5  Heat colouring chart showing dependency on both temperature and time*

With the possible exception of bluing salts, all the heating methods previously described do not attempt automatic temperature control, accurate control by one method or another being necessary because the achieved colour is very sensitive to just a few degrees change in temperature.  Bluing salts perhaps come closest to automatic control, primarily because of the vigorous circulation and high thermal conductivity of the liquid salts at the melting point of the chemicals ensures a uniform temperature reaches all parts of even 3-dimensional components.  It is analogous to deep-fat frying potato chips (‘fries’) so the surface takes on an even colouration.

When it comes to a less messy process that is temperature-controlled, one must look to electrical heating elements or hotplates, but this causes significant problems in achieving uniformity of colour in 3-dimensional components if relying on convection currents set up in a fluid (air) of low thermal conductivity and low thermal capacity.  Hotplates open to air are decidedly a poor solution for anything other than 2-dimensional (flat) components; by analogy, hotplates may be suitable for nicely colouring a flat beefsteak on the outside (which is all we are looking for in decorative colouring as, by analogy, we are not concerned how rare the inside meat is cooked), but cooking a 3-dimensional Sunday roast on a hotplate would be considered by very few*.  Cooking oven manufacturers know this, which is why they fit circulating fans to ovens to ensure even (and slightly quicker) cooking (see box).

## Fan ovens

It is difficult (if not impossible) to find an electric motor with electrical insulation that can withstand operating temperatures above 200˚C, which is probably why the manufacturers of domestic electrical cooker fan-ovens draw in air from outside the back of the oven over the fan motor in order to keep the windings cool.

Many modern domestic cooking ovens appear to have an oven door that (superficially) allows the ‘over-pressure’ so created to vent through the top of the closed front door, though some divert a perhaps significant proportion of this fan air around the outside of the internal oven casing.

Modern cookers may also have a second, smaller fan to cool the electronic control panels and display driver circuitry that may suffer from being close to the oven.

But whatever the detail arrangements, it does appear that ovens fitted with fans to improve the uniformity of cooking do inevitably bleed a certain amount of (wasted) hot air into the environment.

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* At the very least, cooks would cover the roast with an upturned bowl (lid).

# Decorative bluing using a temperature controlled bluing box

*Figure 6 Version 4 of the author's PID-controlled bluing box and accessories*

I have little doubt that an oven is the best type of machine for bluing steel, and when an article appeared in the horological press some ten years ago describing the construction of a PID-controlled bluing box* I took note, pondering over the design long and hard. In essence, it seemed to be a 'deconstructed' electrically-heated hotplate such as found in domestic cooker hotplates but with the heating element extracted from the plate and replaced by a radiant heater. It had many unstated drawbacks and the article contained inaccuracies and could not be considered an acceptable design for general workshop use; nevertheless the concept offered a zero-mess bluing process, so I set about a comprehensive redesign and trials programme lasting over several years.

* PID: Proportional-Integral-Derivative controller. Providing closed-loop feedback control and adjusting the delivered heater power in an optimal fashion, the hotplate will typically neither overshoot nor deviate from the set temperature value measured by the thermocouple by more than ≈ ±2˚C.

And was it a success? In overall terms, yes, but it does not offer the performance the horological press implied, it failing to deliver a uniform 'plug and play' colouration of long clock and barometer hands. Nor is it, I suspect, useful for uniformly tempering 3-dimensional components such as springs, and I largely ascribe both shortcomings to its use of a hotplate and no forced air circulation.

My design will be presented in more detail in the next section together with the results of selected trials. Four versions were made (though the earlier versions will not be described in any detail for the sake of brevity), my final version – Version 4 – being shown in Figure 6. It is potentially capable of bluing components measuring up to 180 x 35 x 25 mm.

## The PID controller

Before going any further it is perhaps appropriate to say a little about a PID controller – Figure 7. A Proportional–Integral–Derivative controller (PID controller) is a control loop instrument employing feedback that is widely used in industrial control systems and a variety of other applications requiring continuously modulated control, one common application being temperature control.

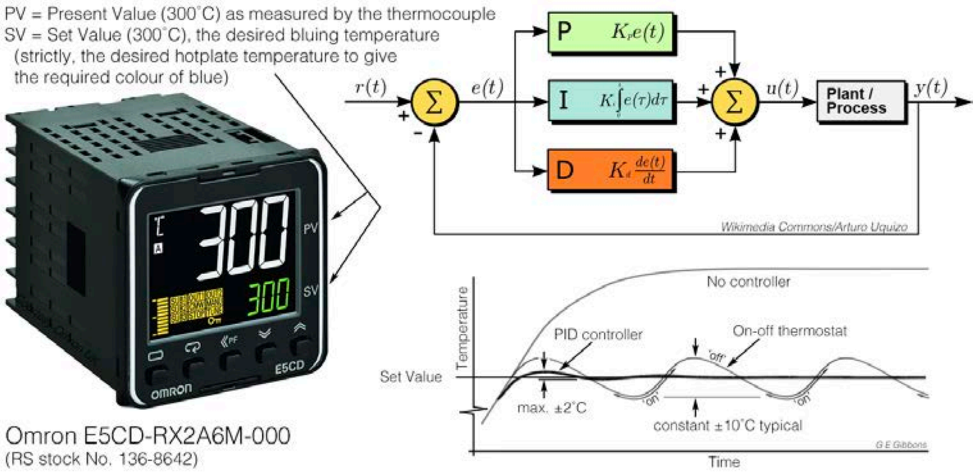


*Figure 7 The PID controller and an outline of its system diagram (top right) and a comparison of alternative methods of control (bottom right)*

Unlike a simple thermostatic controller as found in domestic cookers or laundry irons that switches off when the set value of temperature is achieved and relies on a degree of inherent on-off hysteresis perhaps approaching ±10˚C before switching back on again ad infinitum*, a PID-controller seeks to minimise overshoot, undershoot and offset between the required temperature (the set value or SV) and the measured temperature (the present value or PV**). The PID-controller continuously calculates an error value as the difference between the desired set value and the temperature measured by the thermocouple, and applies a correction based on Proportional, Integral and Derivative terms (hence the name). The diagram lower right in Figure 7 indicates the difference between these control methods.

* ±10˚C (a 20˚C range) is rather too coarse for accurate control of the colour (shade) of blue as can be seen from an inspection of the colour chart in the last Section.

** If the thermocouple is embedded in the hotplate as in my design, the PV is essentially the hotplate temperature. Other locations may be preferable. For example. in a domestic cooking oven the thermocouple often measures the air temperature at the top of the oven rather than the temperature of the roasting tin.

Mathematically, the workings of the PID are rather beyond the author, but a generalised description can be found on the Internet. In essence, the Proportional term describes change needed to correct the current difference (error) between the measured temperature and the set value, the Integral term corrects for past values of this difference and the Derivative term predicts the future differences.

As far as uncomplicated selection of the PID is concerned, one needs to ensure the PID has an automatic tuning capability, which will reduce the overshoot and undershoot after automatic tuning to typically better than ±1˚C, and the PID output (for simplicity, a relay) is capable of switching the cartridge heater electrical current reliably.

The PID-controller shown in Figure 7 is by a reputable manufacturer (Omron) and housed remotely from the heated box – Figure 6 – so that it always remains comfortably within its specified upper thermal limit (+55˚C).

# Fire and electrocution safety considerations

ELECTROCUTION AND FIRE HAZARD
240 VOLT MAINS ELECTRICITY CAN BE DANGEROUS, ESPECIALLY IF ASSOCIATED WITH AN ENCLOSED HEATING DEVICE ACHIEVING IN EXCESS OF 300˚C (≈ 600˚F)

Before moving on to constructional details, the author strongly recommends that safety matters be considered from the outset. A bluing box is a potentially dangerous piece of equipment representing both a fire and electrocution hazard not dissimilar to switching on a domestic laundry iron at the 'linen' setting, placing it in a close-fitting box and walking away. Temperatures held at around 300˚C for a perhaps considerable length of time unattended are potentially far more destructive than temperatures typically found in the machinist's workshop, and require the utmost respect during material and component selection – as well as in the design itself.

The key difference to most other workshop equipment or engineering activities is that the necessary long soak times at high temperature (well over 1 hour, as will be described later) will almost guarantee the bluing box is left switched on unattended, and it is essential that all materials are suitable for use at 300˚C, and safety features incorporated to guard against fire.

Plywood or MDF boxes are a definite no-no, the self-ignition temperature of wood being perhaps as low as 300˚C, as too is soft-soldering of any electrical connections. Similarly, PVC insulated cables should not be routed anywhere near the heated parts of the box, and all insulation and other materials should be able to withstand fault conditions without charring or catching fire.

At 240 volts, reliable earthing arrangements are essential, and the instrument should be supplied from an RCD-protected workshop supply. All electrical equipment

## Thermal insulation

The primary purpose of thermal insulation is to reduce thermal gradients within the box while keeping the outer temperature of the box at a level that does not present a fire or major burn risk.

All solids (metals, plastics, glass, ceramics) have a higher thermal conductivity than still air, the thermal conductivity of air being perhaps just 30% that of the 'wool' in Superwool blanket. Consequently, wool-like thermal insulation blanket provides thermal insulation not primarily by the thermal properties of the 'wool' insulation but by preventing the entrapped air from circulating throughout its thickness of the blanket.

It is worth bearing in mind that compressing a wool-like thermal blanket in the hope of increasing its insulating properties may, by increasing the glass content per mm of thickness, be counter-productive and actually decrease its insulating properties.

Closed-pore Aerogel blanket with its very high insulating properties may offer an improvement over Superwool, but I have not tested it, so cannot say.

should be accompanied by fully traceable safety documentation and manufactured bya manufacturer of repute. Cheap offerings bought from Internet market sites are merely a recipe for a repetition of another fire tragedy, and I like to think no reader would wish to be party to purchasing such equipment, especially when the lives of other persons occupying the building might be at stake*.

* That a reader cannot afford it is no excuse. The starting point of any adjudication authority will be that you introduced the hazard, so you are responsible for the consequences.

*Figure 8 The results of the fire test*

A simple fire safety test on the author's box under a simulated accident condition was conducted. The scenario was the bluing box being left switched on overnight, and a piece of kitchen towel being blown by a breeze to rest on top of the unattended bluing box – Figure 8. The conclusions drawn from this test were the fitting of a 250˚C overheat thermostat inside the casing (box), together with a rotary timer in the control box limiting the maximum unattended heating time to no more than 2 hours.

Before leaving the issue of fire safety, one final warning is appropriate. My fire tests were conducted on my 3.2 mm steel-covered workshop bench, so those that might consider using a bluing box on a wooden-topped or Melamine-topped workbench may need to consider using it on a heat-resisting mat or tray.

# Some design and constructional details

The final Version 4 of the bluing box is shown in Figures 9 and 10, and the significant thermal properties of the materials used in its construction are shown in the Table below.

| Material | Coefficient of thermal expansion (m/m.˚K x 106) | Coefficient of thermal conductivity (W/m.˚K) | Colour coding used in the schematic drawing |
|---|---|---|---|
| Aluminium | 22 | 200 | Light grey shading |
| Brass | 19 | 100 | - |
| Stainless steel (304) | 17 | 15.0 | Dark grey |
| Schott Robax® ceramic glass | 0 | 1.5 | Light blue shading |
| Macor® machinable ceramic | - | 1.5 | Blue |
| Superwool® insulation | - | 0.04 | Yellow |
| Nomex® aramid ‘paper’ sheet | - | 0.13 | - |
| Ceramic electrical insulator | - | 40 | Light blue shading |

The maximum plan area of the bluing compartment is approximately 180 mm x 40 mm. The 15 mm thick aluminium hotplate houses four cartridge heaters* wired in series/parallel and fitted in reamed bores capable of delivering 320 watts. By connecting in series/parallel, the 220 volt cartridge heaters are effectively down-rated quite significantly to give a surface area watt density of 17 watts/sq. inch; in comparison, domestic oven heating elements typically have a watt density of 25 watts/sq. inch.

* Cartridge heaters must be fitted into a block with a smear of high-temperature anti-seize grease to facilitate removal. If they are used directly in air, on initial warm-up they will glow red hot and have a short life.

The hotplate temperature is monitored by a grounded-tip K-type thermocouple, a typical output being 4 mV/100˚C which can be monitored during trials with any high-quality digital multimeter (DMM). Heating from cold takes 10 minutes, and the box reaches a steady state temperature after 1 hour. All unused internal space is filled with Morgan Thermal Ceramics Superwool® insulation, and the entire unit is wrapped in a high tear strength 0.25 mm Du Pont Nomex® flame resistant outer liner before being slipped inside an outer casing of stainless steel rectangular hollow section (RHS).

Much care was taken to select materials, electrical equipment and cabling with insulation

*Figure 9 The lower part of Version 4 of the bluing box*

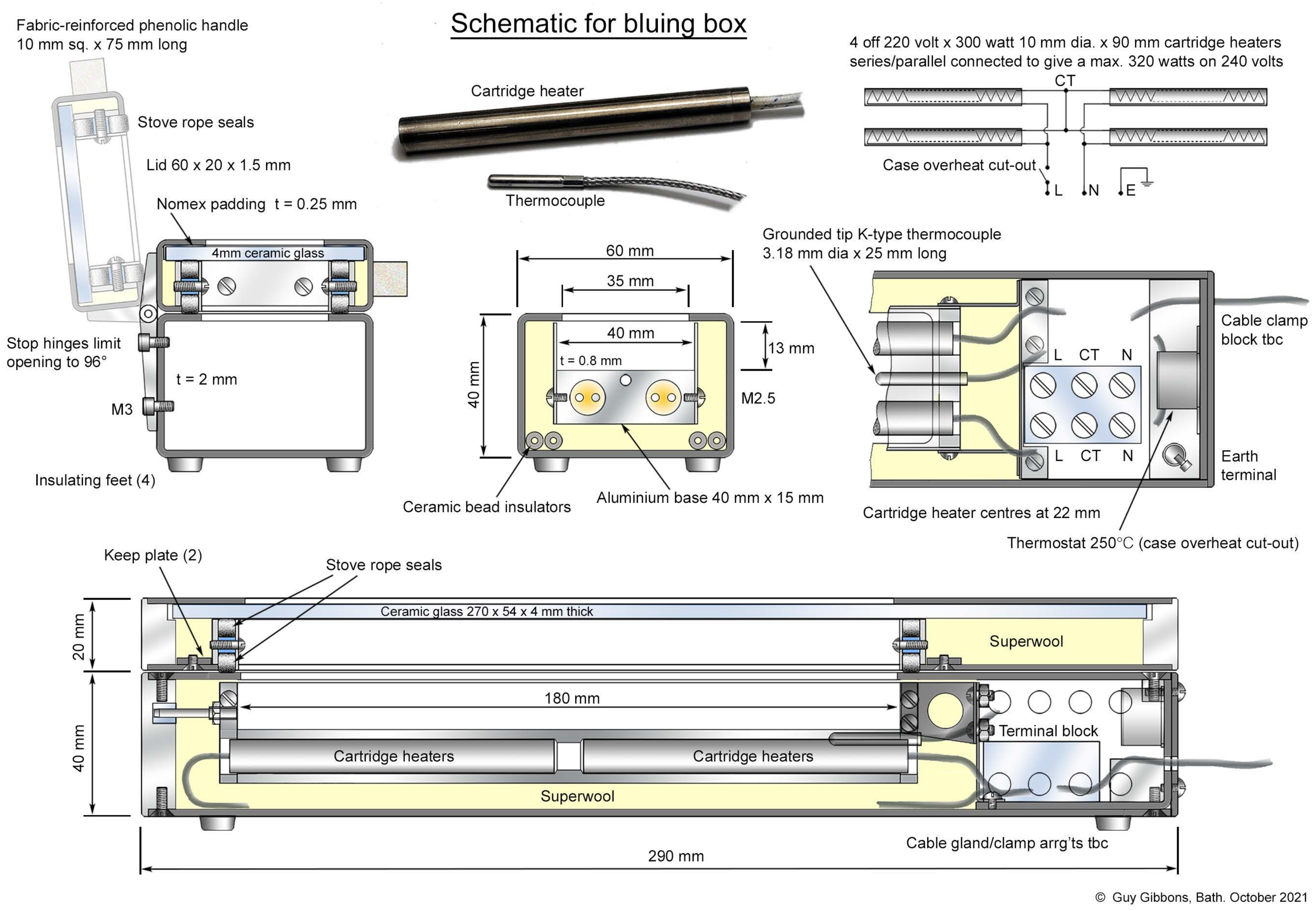


*Figure 10 Schematic drawing of Version 4 of the bluing box*

capable of withstanding high temperatures (generally ceramic or fibreglass), and the fibreglass insulated cables to the cartridge heater cables close to the hotplate are double-insulated with ceramic beads. The thermal conductivity and thermal expansion of all materials was considered and appropriate clearances allowed for movement at the operating temperatures.

All cabling is sleeved and harnessed where appropriate, and cable clamps designed, made and fitted where cables might be subject to strain. With its low melting point, soft soldered electrical cable connections are, of course, not used in the heated box, crimped spade connectors and ceramic screw terminal blocks being used.

The outer body is made from 60 x 40 x 2 mm stainless steel rectangular hollow section (RHS), and the opening cut using 3-flute throw-away cutters in the milling machine – Figure 11. The body end closures are machined from aluminium flat bar, and great care and attention is placed on good-quality cable glanding and anchoring. Screws are generally M2, M2.5 and M3 304-grade stainless steel hex. socket head screws.

*Figure 11 Cutting the openings in the stainless steel RHS, and (right) drilling the hotplate for the cartridge heaters*

Drilling and reaming the hotplate for the cartridge heaters needs care and was done from both ends – Figure 11 right – so as to leave a mid-length stop as can be seen in Figure 10..

Lid construction also uses a stainless steel RHS (60 x 20 x 1.5 mm) and, as are all the ends of the RHS, machined to length using a fly-cutte, the work beiong held on the 6 $^{1}/_{2}$ inch square Myford cross-slide boring table. The lid is filled with Superwool, an insulated handle being provided to facilitate opening when hot. Hinges are fitted to avoid the need to find a place to which to remove a hot separate lid, the author's adjustable purpose-made stainless steel stop hinges permitting a maximum opening of 96˚ ensuring not only a good seal between lid and outer body but also preventing the box from over-balancing when the lid is opened – Figure 12 left. Heat resisting phenolic feet were also made and fitted.

The observation window in the lid is of 4 mm thick Schott Robax® ceramic glass. This ceramic glass is similar in its properties to ceramic domestic cooker hobs and is largely immune from thermal shock (e.g. drops of water when hot) due to its zero coefficient of thermal expansion. It is available cut to size from suppliers of spare parts for domestic wood-burning stoves; alternatively, it can be cut easily from a larger sheet with a standard glass cutter in the home workshop, and the sharp edges ground on a coarse, second-grade diamond whetstone.

5 mm fibreglass 'stove rope' again obtainable from suppliers of spare parts for wood-burning stoves is fitted into specially-designed and made channel sections to provide a seal between both box and lid, and the lid and ceramic glass. Machinable Corning Macor® ceramic is used to space the specially-made aluminium inner and outer guards in the seal frame and to provide the correct depth U-section for locating the stove rope – Figure 12 right.

Separated from the bluing box in order to ensure the operating temperature limits of the PID-controller are not exceeded, the control box is shaped to give a stylish appearance, and

Specially-made stop hinges

The seal frame serving both to seal the observation window and the lid to the body. Upper right; a trial fit of the upper (glass seal) stove rope

*Figure 12  Further details of the bluing box*

is fabricated from 0.8 mm folded stainless steel sheet attached to 3.2 mm aluminium end plates. Some protection of the PID display screen from dropped objects is provided by purpose-made stainless steel bumper bars either side –Figure 13.

Amphenol® DIN-type locking connectors for the armoured Alphawire® power cable are used, both protecting against mechanical damage to the electrical cable connection and cable insulation. The braided screen thermocouple cable is to an industry standard for high-quality installations, as too is the thermocouple plug in order to ensure the polarity is always correct when inserted into its mating socket.

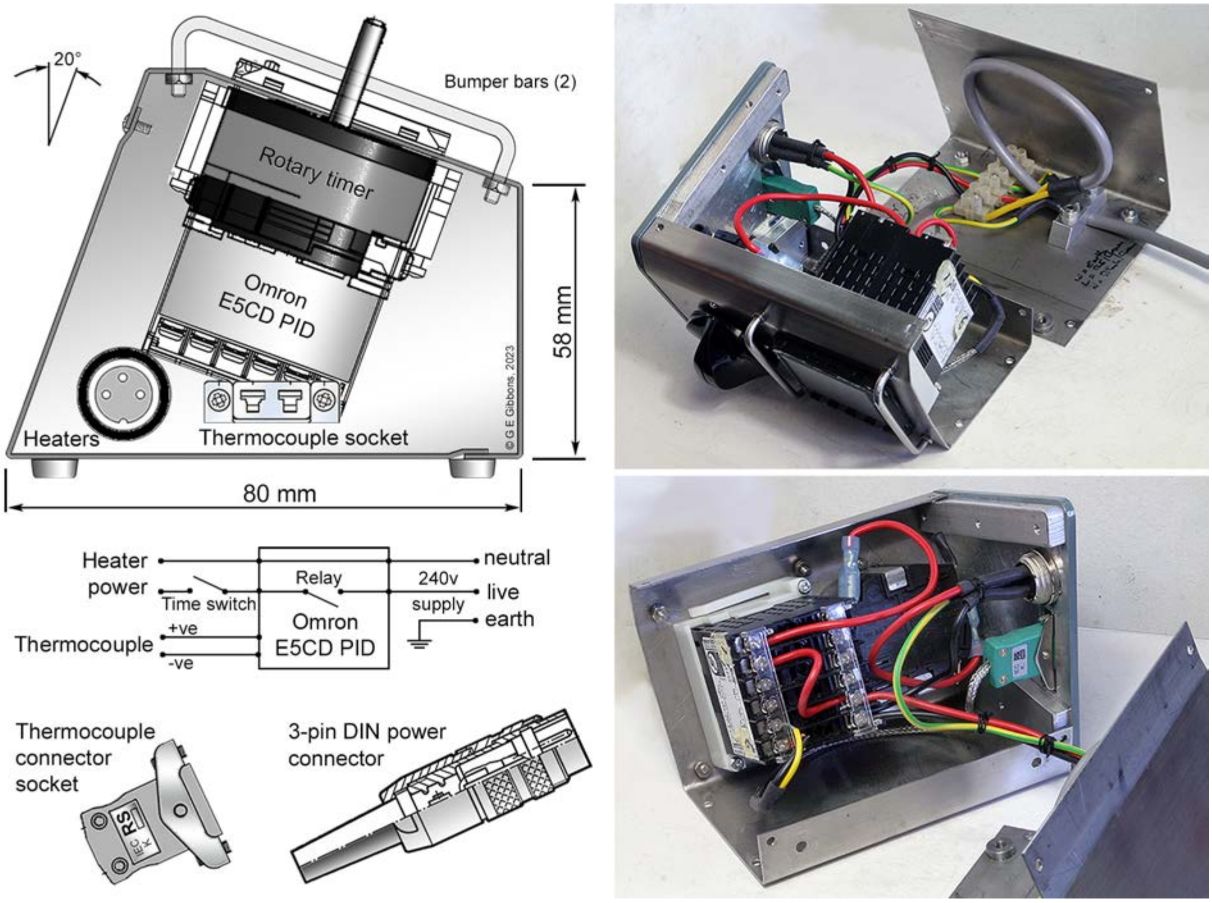


*Figure 13  The control box housing the PID and timer, and (bottom left) the wiring diagram*

## Earlier trials

I shall not dwell on the earlier trials on earlier versions of the bluing box, but a couple of views of Versions 1 and 2 are included in Figure 14. These used lower power (nominal 150 watts in total*) cartridge heaters, one box being made with Macor to the sides of the hotplate, and one with a stainless steel mesh shelf over cartridge heaters clipped in air and no hotplate.

The thermocouple in the latter measured the air temperature (rather than the hotplate temperature) but only at the thermal layer it was fitted. It also caused the cartridge heaters to glow red which is not an operating mode for which they are designed. Moreover, the mesh shelf caused mesh 'burns' (centre, extreme right in Figure 14) on the component being blued; not unlike a steak cooked on a griddle, it was not a success.

* The final (Version 4) of the box used a total of 320 watts to reduce the warm-up time.

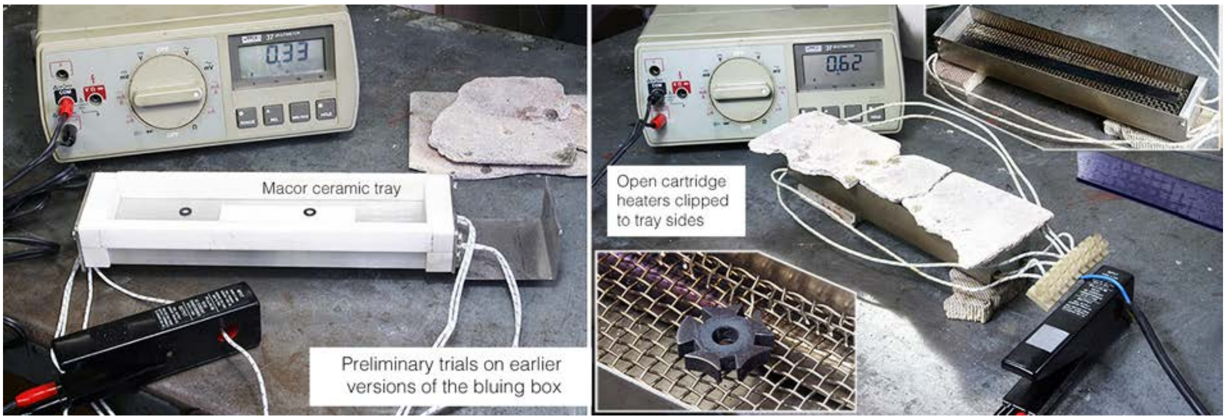


*Figure 14 Trials on earlier Versions of the bluing box*

## Materials

Many of the materials are not available from model engineering requisites suppliers, but suppliers can be found on the Internet. Amongst these, RS(UK) (formerly 'Radiospares') is probably the most useful UK source of supply, while some other supplies can be obtained from a horological requisites supplier such as CousinsUK or Cooksongold.

# PID-controlled bluing of screws and small components

In an earlier section, I suggested the achieved colour of blue was not independent of soaking time. One trial used two lengths of flat steel placed on the bluing box hotplate and blued at a SV of 310˚C – Figure 15 right. The first sample was removed after a soaking time of 20 minutes (blue) and the second after 120 minutes (turning to grey). A similar soak time dependency was found in trials with several mild steel nuts at an SV of 285˚C from 30 to 120 minutes – Figure 15 left.

*Figure 15 Trials on earlier Versions of the bluing box*

This dependency of colour on soaking time perhaps reflects our experience of domestic oven cookware (or even motor cycle chrome-plated exhaust pipes?), both of which alter their colour over a lengthening in-service time (length of time heated). Further implicit corroboration is available from flame-bluing, where blue can be achieved in a matter of a few tens of seconds, any extended heating time turning the steel to grey. While this is off the top of the colour chart in Figure 5, that it is so becomes apparent when one considers that the average temperature of a propane flame is in the order of 1000˚C.

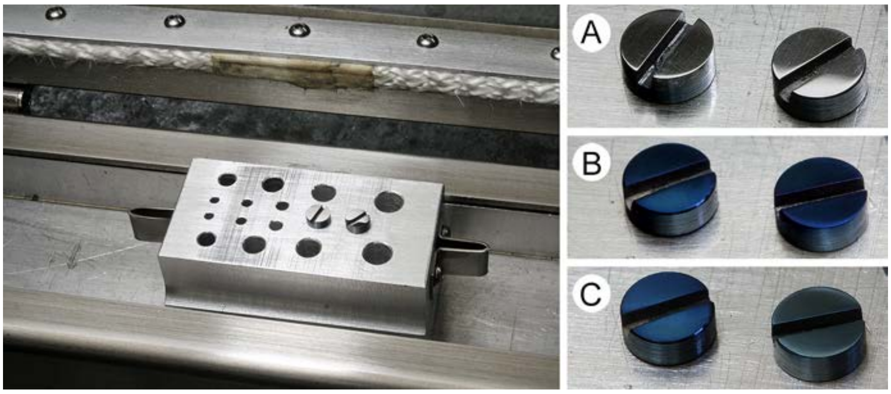


*Figure 16 Trials on bluing screws:*

*A As polished 'to black' (also main photograph). Bluing box and block at room temperature*
*B Box and block preheated to 290˚C SV for 1 hour. Screws placed in block and blued for 10 minutes*
*C Left hand screw removed, right hand screw blued for a further 30 minutes (total 40 minutes) before replacing left hand screw for the photograph*

## Bluing screws

The screw is by far the most common component needing bluing, and if one has multiple screws to blue all to the same shade of blue, a bluing box is very useful. But thermal gradients within the box mean that just upending them into the box does not produce the best result.

In the trial illustrated in Figure 16, the results obtained using a bluing block of aluminium, once again illustrates the dependency of colour on soaking time. The screws are polished 6 BA x 25 mm higher-tensile strength commercial screws. An even blue is clearly apparent across the head, the lower insert 'C' clearly demonstrating this dependency of colour on soaking time.

The ceramic glass observation window in the lid of the box helps considerably in ascertaining when the required colour has been achieved. The box is a success, the 10 minutes bluing time giving far greater control of the colour than that resulting from uncontrolled heating by propane flame.

For smaller screws, a borosilicate chamber can considerably reduce the variation in the blue colour due to thermal gradients. The chamber, which should be as low in height as possible, was created by using a diamond saw to slice off the end of a 20 mm diameter borosilicate test tube – Figure 17. With the test tube slowly rotated in the lathe chuck, a bit of lubricant and a cross-slide mounted diamond disc cutter it is not at all difficult, the cut edges being finished on a second-grade coarse diamond whetstone.

*Figure 17 Cutting a borosilicate chamber from a test tube*

Figure 18 compares the trial results of these three different methods (bluing block, chamber bluing and direct bluing in the box). On this 8 BA screw, there is little difference between block and chamber bluing, but direct bluing in the box with the screw standing up (the right hand screw), being subject to a large thermal gradient, shows a markedly less uniform colouration.

*Figure 18 Comparison of the results of bluing screws using a block and chamber with the screws in differing orientations*

*Figure 19  A crystal chamber made from a watch glass*

## Bluing small components

For small components, a further refinement was to make use of an alternative bluing chamber within the bluing box made from a sapphire watch crystal*. Figure 19 shows a successful bluing trial on a 15 mm pressed-collet clock hand, the pressed collet preventing the hand from lying flat on the hotplate and so exposing it to the thermal gradients above.

* A 'crystal' is a horologist's term for a watch glass.

The sapphire crystal is a standard replacement watch part available from a watch repairer's requisites supplier, sapphire glass being selected in preference to the cheaper 'mineral glass' to assuredly withstand bluing temperatures without distress. It is equally successful at bluing small screws below, say, 10 BA (1.7 mm thread diameter).

## Hotplate thickness and material

On a point of detail, the aluminium from which the hotplate is made is very soft at 300˚C (perhaps just 15% of its room temperature strength) and will scratch very easily at this temperature. Cast iron might have been a better choice of material, which is perhaps why domestic hotplates are invariably made of cast iron.

Moreover, a thicker hotplate (say 25 or 30 mm rather than the 15 mm I used) would provide a greater volumetric thermal mass whether of aluminium or cast iron*, this greater thermal mass perhaps making the bluing box less sensitive when bluing of larger components. However, while a thicker hotplate is suggested by some, this remains untested by me.

* For comparison the volumetric specific heat of aluminium is around 2.3 MJ/m$^3$°K compared to cast iron at around 3.5 MJ/m$^3$°K

## Summary – bluing screws and small components

Overall, bluing screws in a bluing block is successful, and bluing in a small test tube or crystal chamber (the equivalent of a cook putting a lid on the pan) also shows considerable success with small components and small screws.

# PID-controlled bluing of instrument hands

One of the primary reasons for the shape of my bluing box was to be able to blue clock and barometer hands which, if requiring restoration, are generally not flat. Such hands are often curved in both cross-section and length, and invariably have a riveted or pressed collet one end.

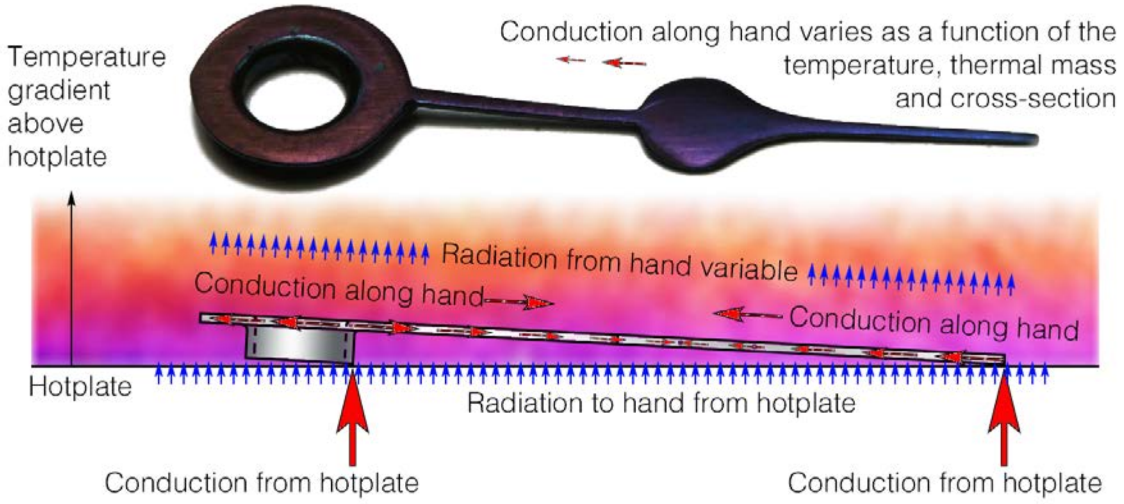
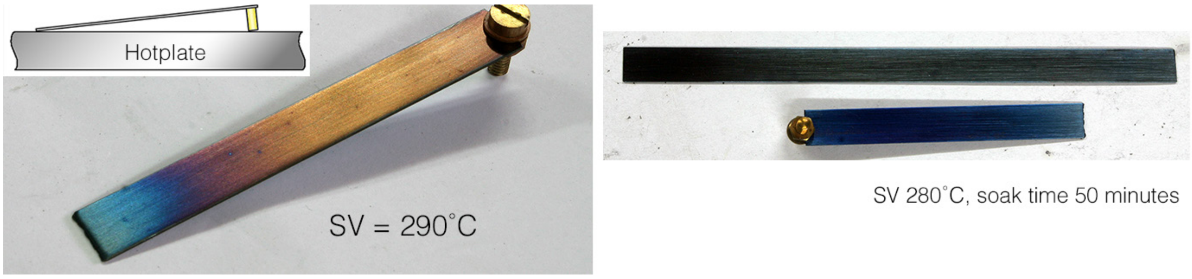


*Figure 20 Heat transfer mechanisms from hotplate to a clock hand*

The heat transfer diagram in Figure 20 attempts to show the problem when heating on a hotplate, the heat transfer being by a combination of conduction, convection and radiation in a fluid (air) that has thermal layers. Rather than line by line explanation, it needs a bit of study by those wishing to understand the problems; suffice it to say that a different rate of heating at different sections along the component will affect the colouration.

In addition, thermal gradients within the box will conspire to affect further the soaking temperature, and trials with strips of flat steel suggested the thermal gradient above my hotplate with the box with its lid closed approaches 5˚C temperature reduction for every millimetre above the hotplate (5˚C/mm) – Figure 21. Further demonstration of the colour being dependent upon heat transfer mechanism is shown at the right of the trial illustrated in Figure 21, both carbon steel strips being blued alongside one another in the same trial. In the upper (longer) strip, heat transfer is primarily by conduction (the upper strip is lying flat on hotplate) and in the lower strip primarily by convection (one end being propped up).



SV 280˚C, soak time 50 minutes

*Figure 21 Trials illustrating the thermal gradients within the bluing box*

## Clock hand bluing trials

Numerous trials were conducted using stainless steel mesh, and beds of finely divided brass stainless steel and brass machining swarf. Even copper powder was tried, but it is hugely messy rather like handling baker's flour during cooking. None of these was successful, but rather than present pages and pages of photographs of failures, I shall confine myself to the techniques that I found were most successful. In the following trials, all the old stock hands had any kinks straightened out and rust patches removed before finishing with 2000 grit paper and cleaning. In all trials the bluing box was pre-heated from cold for 1 hour before placing in the chamber and the hand in position.

*Figure 22 Comparison of a professionally blued hand (upper right) with one blued in the bluing box (lower right)*

Fortunate in having two identical commercially-made clock hands, Figure 22 compares one in its original as-supplied finish and one polished and blued in the bluing box inside a shallow chamber fitted with a close-fitting Schott Robax ceramic glass lid.

This hand is 31 mm long and has a pressed collet about 1.2 mm deep. Resting on its tip at one end and soaked at 290˚C for 14 minutes, it can just be seen that there still remains a greyish tint to the tip caused by it reaching the soaking temperature far more quickly than the rest of the hand. Nevertheless, the result is a far more uniform colouration than when blued without the non-lidded chamber as can be seen by comparison with the hand in the heat transfer diagram at Figure 20.

One way of avoiding this is not to let the tip rest on the hotplate by using a slip of 0.25 mm Nomex paper under the tip, and Figure 23 compares the results on two more clock hands. The left hand trial shows a hand fitted with a riveted-in collet, which is accommodated in a bored hole in the chamber, so allowing the hand to lie essentially flat*. Again the result is good but with a slightly greyish tinge to the tip.

* Having no immediate use in a repaired clock, I ask readers to forgive the poor finish around the collet.

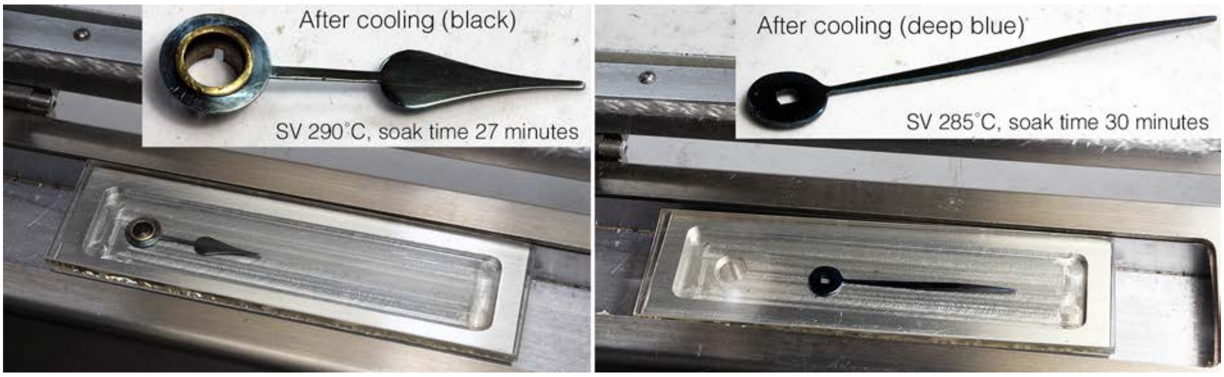


*Figure 23 Further trial results on bluing clock hands*

The longer right hand trial shows no tip greying, primarily because the curvature along its length raises the tip slightly above the inner surface of the chamber base.

## Barometer hand bluing trials

Mercury wheel barometer hands are very thin so as to be light in weight due to the extremely low driving torque available from the mechanism. Trials with chamber-bluing an old 155 mm steel barometer hand just 0.2 mm thick needing to be re-blued were initially less successful . Suspecting part of the problem might be the very low thermal mass of the hand coupled with 'hot spot' hotplate contact of a hand so thin it only touched the hotplate at two points no matter how well it was straightened, considerable improvement resulted from resting it on 0.25 mm Nomex thermal insulating paper sheet inside the glass-covered chamber.

The result is shown in Figure 24, and for the finest work, a thin coat ('wipe') of horologist's bluing lacquer may also be appropriate on completion.

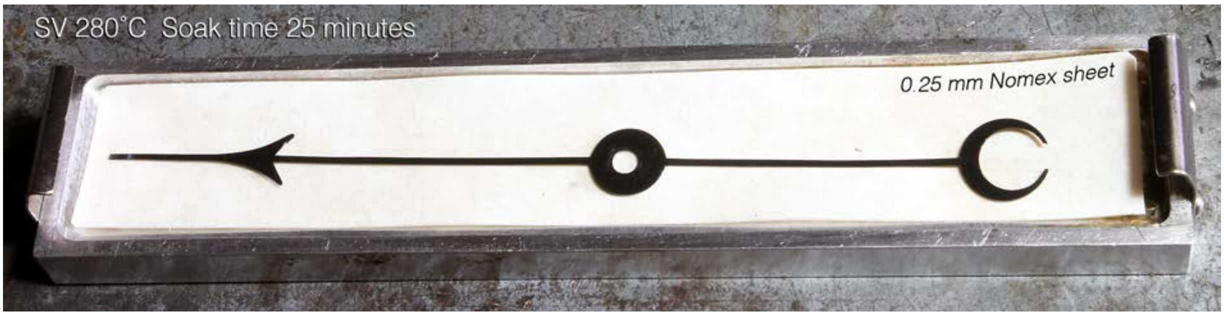


*Figure 24 A successful trial on a barometer hand using Nomex paper*

## Summary – bluing instrument hands

In summary, the trialled clock and barometer hands were all successfully blued using one of the techniques described, though none was achieved simply by dropping the hand in the box, switching on the heaters for a set temperature (SV) and set time, and walking away.

One other point worthy of note is that, compared to the use of bluing salts, the bluing box does appear to be more tolerant of imperfect cleaning of the hand before bluing.

# Bluing machine tool components

## Machine tool handles

Which brings me back full-circle to the Figure 1 image at the beginning and the PID-controlled bluing box's performance on ball handles.

Having a few spare second-grade ball handles made for my Quorn tool and cutter grinder using my own design ball turning attachment – Figure 25, I experimented with bluing them in the PID-controlled bluing box on a sheet of 0.25 mm Nomex, the smaller one at a SV of 290˚C for 100 minutes and the larger one at a SV of 295˚C for 160 minutes.

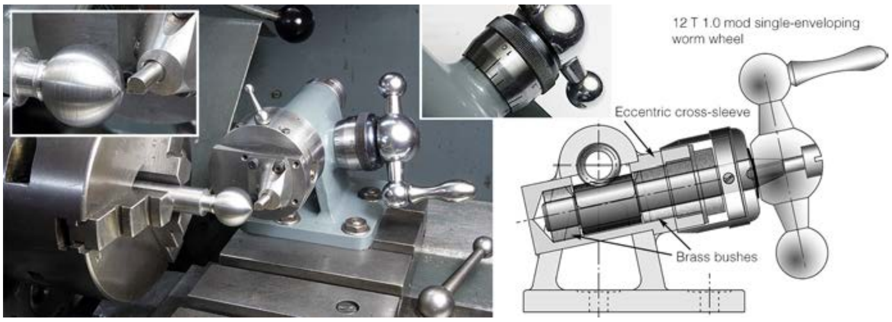


*Figure 25  The author's spherical turning attachment*

Machined from EN1A steel and finished with 150 grit paper before heat bluing, the results were successful – Figure 26, the blue colour taking on a darker hue when wiped with oil as is appropriate for a machine tool handle. Indeed, the larger (upper left hand) handle with its longer soak time at a slightly higher temperature (SV) took on a slightly blacker hue as perhaps can be seen.

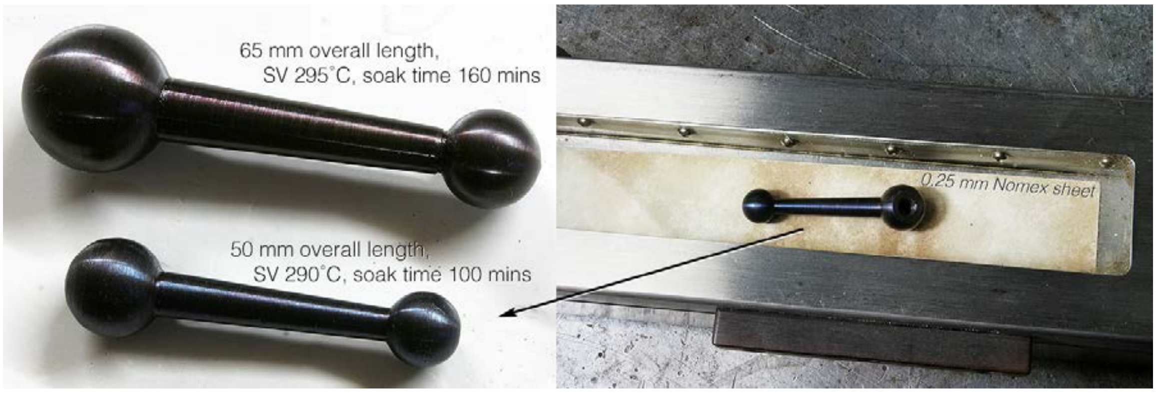


*Figure 26  Bluing ball handles for machine tools*

## Feed screw thimbles

Another example of the author bluing machine tool components can be seen at the top centre of Figure 25. Made in the style of those fitted to Myford Super 7 lathes, the fine straight-knurl to this friction-adjustable feed screw thimble was the first machining job while there was plenty of bar stock to hold in the lathe 3-jaw. After finish machining, the fiducial marks were then engraved using a Vee-point screwcutting tool set on its side in the set-over lathe topslide before stamping the numerals with a punch. The punch burrs were dressed off with a smooth flat needle file.

Being too large to fit in my PID-controlled bluing box or bluing salts tray, and perhaps being less critical on uniformity of colour, the whole index thimble was then heat-blued over a tray of brass swarf using a flame and quenched in oil. The bright steel areas were then polished with 1200 grit paper to leave the fiducial marks and numerals clearly readable*.

* A method described, I think, in one of Geo. H Thomas's writings many years ago.

Were my bluing box was a little larger or the index thimble a little smaller, I have no doubt that the bluing box would have successfully blued this component.

# Overall summary

Heat bluing undoubtedly has a place in the skill-set needed by both engineers and horologists whether it is by flame heating in air, heated bluing salts, or electrical heating in air. But electrical heating is without doubt the least messy process.

The PID-controlled electrically-heated bluing box definitely does have advantages in many applications. As in all 'ovens', one crucial factor is the avoidance of thermal gradients above the hotplate, and no matter how well-fitted the lid, the temperature does decrease with distance above the hotplate. It is why domestic ovens are fitted with circulating fans and top-mounted heaters. The effect of these thermal gradients can be minimised by placing the component to be blued parallel to the hotplate surface and keeping the gap between hotplate and lid as small as possible (i.e. immersing the component in a thermal layer with as uniform a temperature gradient as possible).

Whatever bluing method is used, the time taken to achieve the correct blue colour will vary depending on the soaking time. This is dependent upon the method and rate of heat transfer (conduction from touching the hotplate or convection from the fluid (air)), the number of touching points, and the rate of heat absorption at other non-touching points. In this respect, 0.25 mm Nomex sheet does help considerably in improving the uniformity of the achieved shade of blue, even if it does increase the soaking time.

The thermal mass varying along the length of the component will also affect the local heating (and hence soaking) time, and the consequential uniformity of the blued colour. This lack of uniformity can be minimised by using a lower temperature for longer soaking times (eg. 10 minutes or more).

Bluing larger components such as machine tool ball handles was successful using Nomex insulating sheet and long soak times (> 60 minutes). Cooling in oil also tends to improve the uniformity and darkness of the finished handle.

The achieved shade of blue will vary depending upon the alloy content of the steel and the surface roughness (surface finish), but these factors I have not investigated in any depth*. Nor have I investigated heat colouring to temper colours other than blue (eg. straw, browns or purples), but in all cases the changes in colour take place over a very narrow temperature/time band. It is on this point that, theoretically, the PID-controlled bluing box should score heavily, especially if the exact shade of colour needs to be the same on a number of identical components.

* In general terms, the higher the polish and harder the steel, the more iridescent the blue.

An observation window in a bluing box is a real asset in determining the temperature/time settings for a repeatable colour.

## The future of PID-controlled bluing

Overall, I think I can say that the PID-controlled bluing box does result in successful bluing, though, perhaps like all workshop equipment, it does not entirely remove the human element both in set-up for the specific type of component coupled with operator gaining experience in its use from bluing components. As mentioned before, using long soak times at a lower temperature does improves the uniformity of the colouration*. However, one huge benefit of the PID-controlled bluing box is to remove the messy elements of flame bluing or bluing in salts.

* Staying with an analogy to domestic kitchen equipment, it is perhaps like a dishwasher: you get good results, but whereas hand-washing the dishes perhaps takes a few tens of minutes, a dishwasher takes a few hours.

I have a number of thoughts about how the primary issue of avoiding thermal gradients and ensuring a uniform soaking time at all points in the component being blued might be addressed, but to do so would require a fundamental reconfiguration of my design. My wilder thoughts suggest induction heating under the control of some type of thermal imaging device, but this really is blue sky thinking – Figure 27.

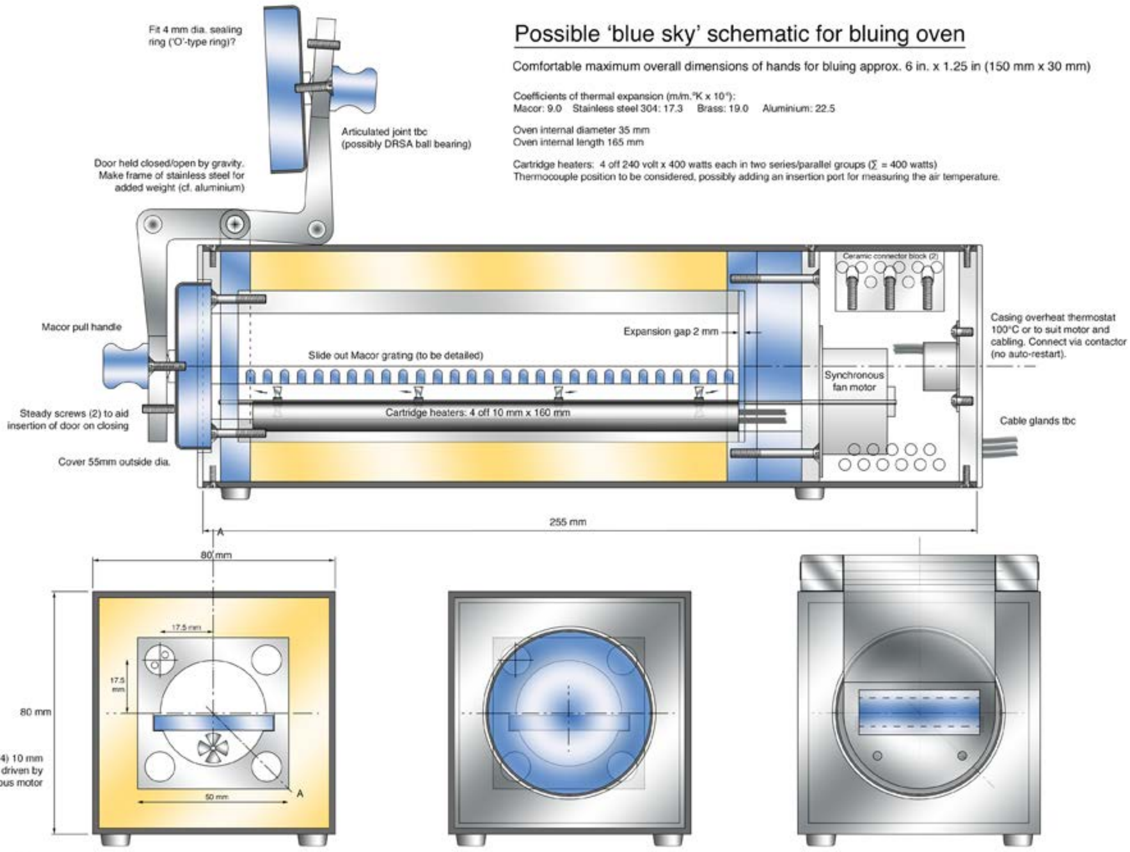


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*Figure 27 Lacking an observation window, perhaps a few ideas for a future development are suggested in this schematic?*

Coming back closer to ground, perhaps the most fundamental need is to learn from domestic cooking oven manufacturers and provide vigorous fan-circulation* of the heating fluid while supporting the component preferably on an insulated shelf in a lidded casserole dish? But having already taken thousands of hours work (and thousands of pounds Sterling) on my research, it would be a new design project for which I have no immediate plans.

* Maybe a Peltier effect motor driver ('stove fan') could be used to avoid the need for an additional power supply?

## Acknowledgments

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My thanks also to Justin Koullapis of WatchClub (Royal Exchange, London) for his experiments that led to the development of my borosilicate test tube chambers for bluing small components.