A balance vibrating tool

Guy Gibbons, OBE

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Buckingham Palace, 2003: Guy receiving his OBE accompanied by his wife, Celia

After his early years in West Africa, Guy attended King Edward's Primary School and Queen Elizabeth's Grammar School in Mansfield, Nottinghamshire. Many week-ends were spent making Meccano models, 00 gauge train layouts and radio controlled model boats which he sailed on the Berry Hill boating pond.

On graduating in Mechanical Engineering from Loughborough University Guy joined the Royal Corps of Naval Constructors (UK Ministry of Defence) in 1973. His thirty-year career included appointments to Portsmouth Dockyard refitting ships, designing and supporting submarines at Bath and Faslane, providing design and support for destroyers, frigates and aircraft carriers before finally becoming the chief structural engineer for surface ships and (latterly) working with Lloyd's Register of Shipping in the development of Naval Ship Classification. In 1990 he married his wife, Celia, and in 2003 he was awarded the OBE.

After leaving MoD service, Guy shortly afterwards achieved a pass with merit in the clock pathway examinations of the British Horological Institute (BHI) after which he established a modest clock repair business. Guy has made four new construction clocks: a Wilding English regulator and an English bracket clock based on the designs of Claude B Reeve, together with his own design wall clock and mystery clock. Guy has also been a member of the Society of Model and Experimental Engineers continuously from 1974, learning much from fellow members in the Wanless Road workshops.

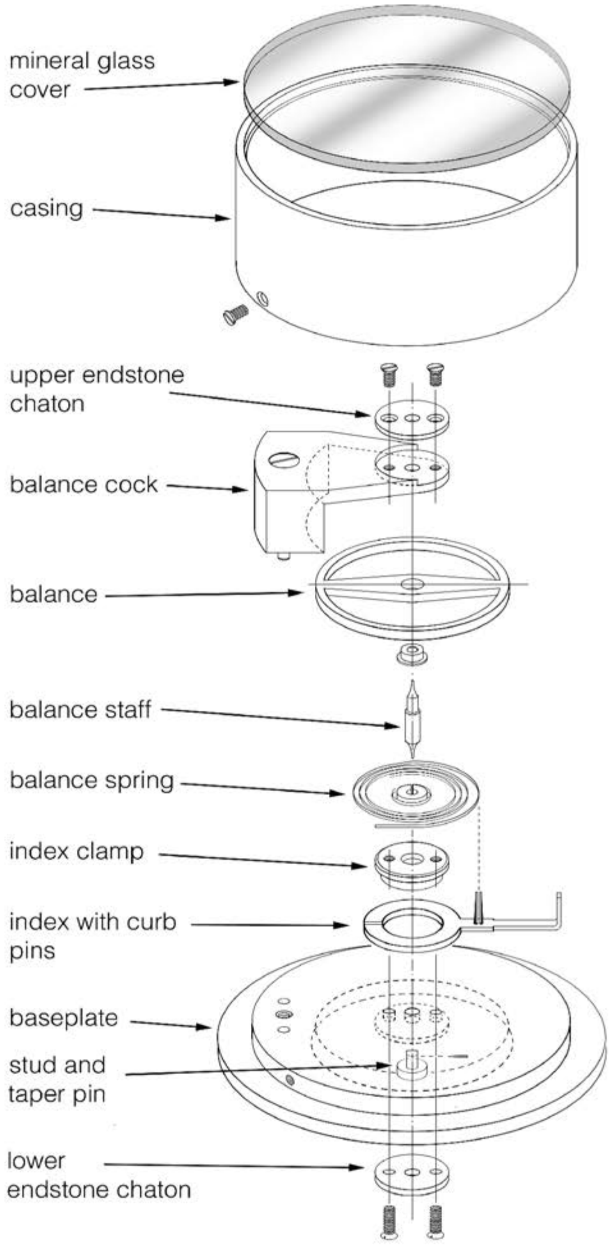
From his earliest years when found dismantling his pram, Guy developed a deep love and commitment to engineering excellence through a lifetime of engineering in both his service life and through his well-equipped workshop. A regular contributor to horological journals, Guy has also contributed to the revision of the BHI Distance Learning Course (DLC) as well as acting as tutor to a number of DLC students.

Foreword

The design and construction of a balance vibrating tool suitable for second year clock and watch students or those with a good understanding of workshop and horological practices. Not only does the construction of this tool provide an advanced project for students but also results in a tool that enables a quick selection and adjustment of a balance spring in subsequent spring-balance clock and watch repair work.

A degree of skill is needed for its successful completion and any person achieving success should not only be congratulated but can also consider him or herself as a skilled craftsperson.

Guy Gibbons, OBE, MIMechE, MBHI
Bath, 2019



Contents

The processes described for the manufacture of this tool may in certain circumstances be considered dangerous. It is the responsibility of users of this book to satisfy themselves that all necessary precautions have been taken to ensure the safety of themselves and others.

1. Introduction

Acknowledgment: Politikaner/Wikimedia

What is a balance vibrating tool?

A balance vibrating tool is a tool that permits a spring-balance assembly to be brought approximately to the desired rate before fitting into the clock or watch. The balance of the vibrating tool is adjusted to a standard rate, typically 18,000 beats per hour (but could be 14,400 bph for a marine chronometer or 21,600 bph for some watches) and then sealed in a glass-topped casing.

The photograph shows a Swiss Luthy-Hirt balance vibrating tool which, as you can see is of sophisticated construction. Using the lever on the table (left hand side in the photograph), the table can be flicked to rotate it and so set oscillating both the vibrating tool balance and the spring-balance being tested. The scaffold has a comprehensive range of adjustments to centre the spring-balance under test with the vibrating tool balance as well as to arrange that the balance staff pivot just rests on the glass cover.

The balance vibrating tool described in the following chapters is far less sophisticated but is nevertheless quite capable of providing the essential functions that will make it suitable for subsequent workshop use.

The spring of the spring-balance assembly to be tested is lightly gripped by a clip in the form of a pair of tweezers at the approximate position of the boot or curb pins, and dangled so that the lower end of the balance staff just rests on the glass cover. The vibrating tool and the spring-balance under test are set in motion by a sharp twisting action and the spokes of the two balance wheels checked for synchronisation. By altering the position of the grip of the tweezers on the balance spring (the length of the balance spring), the balance wheel under test can be brought into synchronisation with the vibrating tool balance. The position of the tweezers is now marked (perhaps with a fine felt tip pen). If the spring-balance assembly is now fitted to the platform escapement with the felt tip pen mark on the balance spring lying between the boot or curb pins, the escapement should only need final rate adjustment in the watch, clock or platform escapement to which it is fitted.

Manufacture of a balance vibrating tool

Before a start is made on the description a few general points are worth making. The primary target audience is advanced horology students who want to prepare for practical examinations and to gain the practical skills needed for their future career. Consequently the style of writing makes frequent use of the second person as is appropriate to a teaching lesson. To the more experienced reader this may seem condescending and/or arrogant, but it is hoped the reader will understand the primary purpose of the description is for teaching purposes.

Design considerations

The first consideration is that the exercise should be relevant to both watch pathway and clock pathway students alike, and with a lever escapement being central to watches as well as mass-produced balance wheel clocks and clocks with platform escapements, the vibrating tool remains as relevant today as it was in the past.

Another important consideration is that the tool should make full use of commercial items (notably jewel holes and endstones, the balance spring and the glass disc) that cannot be made in the normal workshop. Equally important is that these components are available from material suppliers which, at the date of writing, they were. All other items are made from stock materials (brass sheet, tube and section, pivot steel, and silver steel).

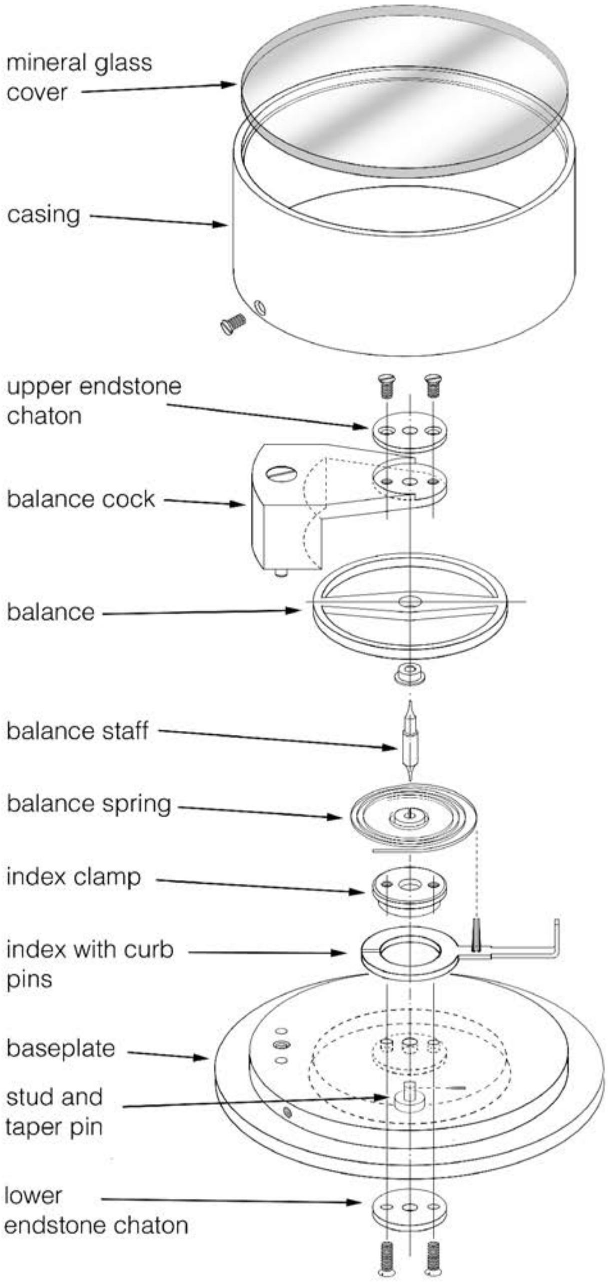
The design embraces a wide range of horological repair activities such as jewelling, making small components and screws and, most importantly, accurate assembly, fitting and timing. The manufacture of larger components is also required, and lacquering is recommended for some parts – a skill that clock pathway students will need at some stage in their future careers.

Compared with a commercial vibrating tool, the design has been greatly simplified so that its manufacture should be within the abilities of all third-year and many second-year horology students. There is no temperature compensation, so a change in rate can be expected between warm and cold weather. Indeed the curious student will want to check the rate at different temperatures to see just how the rate of an uncompensated balance can vary with temperature, and a procedure is described in Chapter 12.

To give maximum visibility to the balance wheel spokes used to observe the rate of the spring-balance assembly under test, the tool's balance spring is mounted below the balance. This is the opposite of the normal arrangement, made possible because neither lever nor roller assembly is fitted. No timing weights are fitted, fine adjustment relying on adjustment of the index after the balance spring has been brought to its approximately correct length.

<u>Drawings</u>: The drawings are presented at the start of each Chapter. They are all presented in first angle projection which, although considered obsolete in all other walks of engineering design, still sees to be the horology teaching establishments' preferred angle of projection. Providing you can read drawings, the difference is not something that matters as far as manufacture of the vibrating tool is concerned.

<u>Exploded diagram</u>: Before going any further, study the exploded diagram of the tool so that you can start to think about how you might make the parts.



One of the most obvious differences between the exploded diagram and the photograph of the tool is the absence of the 'scaffold' for supporting the spring-balance to be tested. This is deliberate; manufacture of the scaffold does not practise the essential skills needed to service a clock movement or watch. However, the construction of a scaffold is highly recommended, and a simplified design is described towards the end of this booklet. It is essential if one is to learn about spring/balance adjustment and use the tool for subsequent testing of spring-balance assemblies.

Manufacture: The design does not have to be followed slavishly and students may even have better ideas for the design, or may wish to make modifications better suited to your method of working or the manufacturing tools available to you. Remember, we are teaching horologists; we are not teaching copy machinists with no interest in how the components fit or work together. So it you think you have a better way by all means try it, though you are encouraged to think carefully about the consequences elsewhere of any changes you make.

Structure of this book

This book is in twelve Chapters, and is essentially structured to be completed over the course of an academic year. It represents about three weeks per chapter, though some Chapters such as (this) Chapter 1 will be completed in a far shorter time.

1. Introduction
2. The casing
3. The baseplate
4. The balance cock
5. The index, index clamp and endstone chatons
6. The screws
7. The balance
8. Jewelling and the balance staff
9. The balance spring and stud
10. Preliminary timing
11. The scaffold
12. Using the tool

In addition, an Appendix A describes the construction of a screw head polishing tool which is something no serious horologist can be without. A screw head polishing tool will be needed if a high quality finish is to be imparted to the screws used in this balance vibrating tool.

It is strongly recommend that constructors read through the whole twelve Chapters describing this project and study the drawings before getting started on the work.

2. The casing

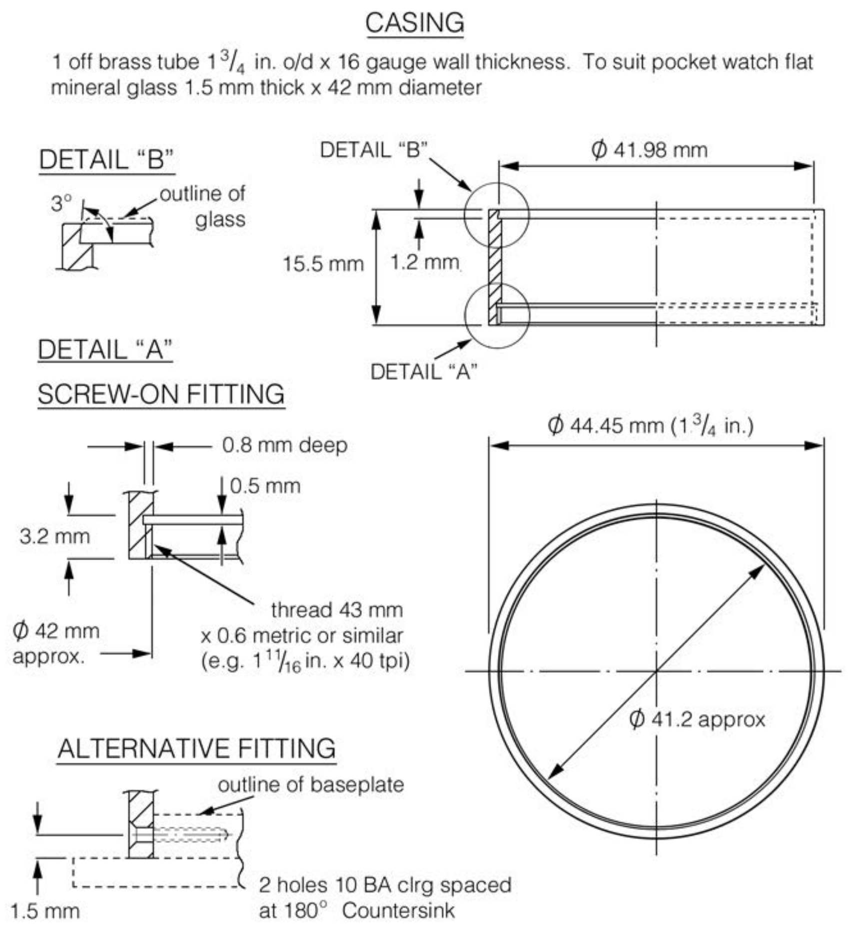
Design and drawings

The casing is a short length of brass tube that has a snap fit flat mineral glass in one end on which the balance assembly to be tested rests. The casing is ideally screwed onto the base, but this does mean you need a screwcutting lathe. A screw-on casing offers the security of a screw back to a watch; if the vibrating tool is picked up by the casing, the base assembly will not drop off which might cause damage to the delicate balance staff. The casing is also easily removed without the risk of marking from a screwdriver or case opening knife slipping as might happen with a casing secured by screws or by being a push or snap fit.

If you do not have the facilities to screw cut the lower end, it is recommended that you use two screws set into the side as shown in the exploded diagram and the alternative fitting detail on the drawing. A push-fit casing is not recommended as it may allow the base and balance to drop off if it is not that secure and is lifted. Better would be a snap-fit, but it would be very difficult to achieve as both the casing and base are relatively rigid and will not allow any significant flexure necessary to make a snap fit work without the use of some considerable force.

Materials required

- 18 mm length (3/4 in.) brass tube 1 3/4 in. dia. x 16 gauge wall thickness (1/16 in. or 1.6 mm)
- 1 piece flat mineral glass 1.5 mm thick x 42 mm dia. Suitable glasses are available from material suppliers as replacements for pocket watches.



Construction

Lightly grip the brass tube in a three-jaw chuck making sure that the tube is gripped truly; as the sawn end is unlikely to be square, do not press the sawn end against the back of the chuck body. Face one end flat, and remove the burrs to provide a clean, true face. Reverse in the chuck and face off the other end to bring it to 16 mm in length (slightly over the finished length of 15.5 mm). Deburr the edges.

Lower end – screw-on fitting

If you are screwcutting the tube, the tube will need to be bored for a length of 3.4 mm (slightly over the finished length of 3.2 mm). The exact diameter is not important; the main purpose is to remove any eccentricity in the tube wall. Once the tool is cutting for the full (360 degree) internal periphery of the tube, stop.

With an internal screw-cutting tool create a 0.8 mm deep recess 0.5 mm long to allow the tool to run-out when cutting the thread. Now set up the lathe for screwcutting and cut the thread, making sure that the 'V' of the thread is to its full depth so that the thread crests are not truncated. The depth of thread (the in-feed of the cutting tool) is determined solely by the pitch and thread form; the diameter of the thread is not relevant.

The depth of the recommended threads is given below, but if you use an alternative, this can be got from engineering tables for the thread form and pitch you have chosen.

40 tpi Whitworth (Whit) form (55°):	Thread depth (tool in-feed) = 0.016 in. (0.41 mm)
0.6 mm pitch metric form (60°):	Thread depth (tool in-feed) = 0.32 mm

As you approach the finished size, make sure you remove any burrs from the crests of the thread so you are left with a perfectly shaped thread that will have a smooth action. In practice you will need to cut the depth of the thread very slightly (about 0.1 mm) deeper to get a good crest form; this is because the tip of the screw-cutting tool usually comes to a point whereas in a real thread the root 'valley' is radiused off. Moreover, there will be a little spring even in the sharpest of internal screw-cutting tools which will probably be of fairly slender form for such a fine pitch thread.

Once you are satisfied with the thread form, re-face the end of the brass tube to bring the total thread length plus run-out space to 3.2 mm length and chamfer the outer end internally to remove any finger-cutting sharp edges and give an easy lead-in when screwing the cover onto the base.

Lower end – alternative fitting

If you choose not to screwcut the casing, at one end of the faced tube, mark two screw positions as shown in the drawing and drill two holes at the tapping diameter of the chosen screws (10 BA shown). The holes will be opened up to the clearance size once the casing has been used as a jig for marking and drilling the holes in the base.

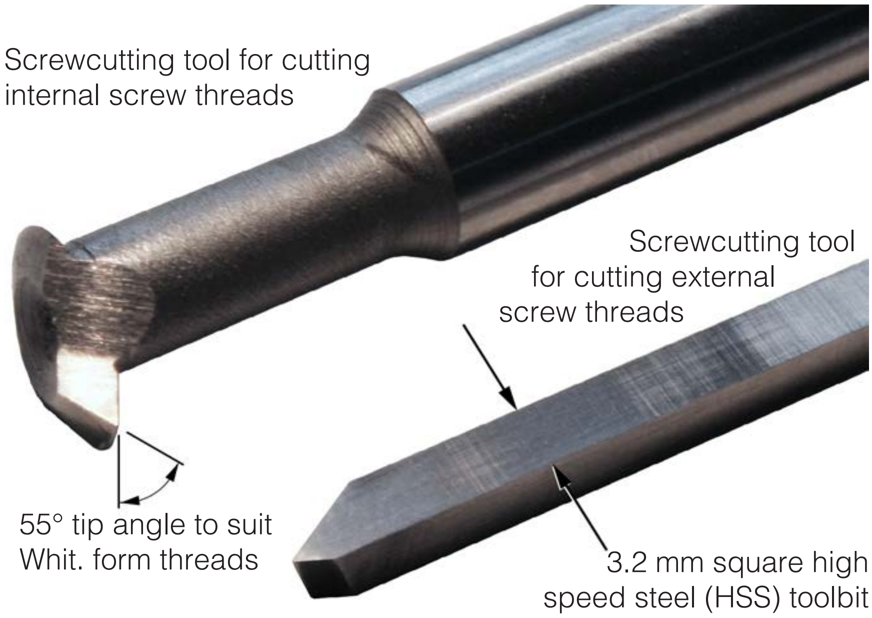
If you think you might use roundhead screws and you have a staking tool set with piloted spotfacing (counterbore) cutters, you should drill these two holes to suit the pilot on the counterbore rather than the tapping size of the screw. We will discuss this a little more when we finish the baseplate.

You will also need to make (or buy) 2 off 10 BA x 3/16 in. slotted screws (roundhead (rh) or countersunk (csk)). Steel screws are preferable to brass as the slots will quickly become bruised if used frequently during assembly and disassembly later on. Other similar sizes are acceptable. Making screws is described in a later Chapter.

A note on screwcutting

Screwcutting using the lathe leadscrew (as distinct from a tap and die) is perhaps not an essential part of horologist's training. However, many may well find it a useful process to master, especially if you intend to make replacement parts for larger clocks or even screwcut watch cases. If you do wish to learn and practise screwcutting but have never done it before, you should refer to one of the several books that describe how to select, sharpen and set-up the cutting tools, and how to set up the lathe and use the leadscrew arrangements fitted to your lathe.

For those keen to master this skill, shown below are the tools used for cutting the screw threads on the prototype.



Upper end

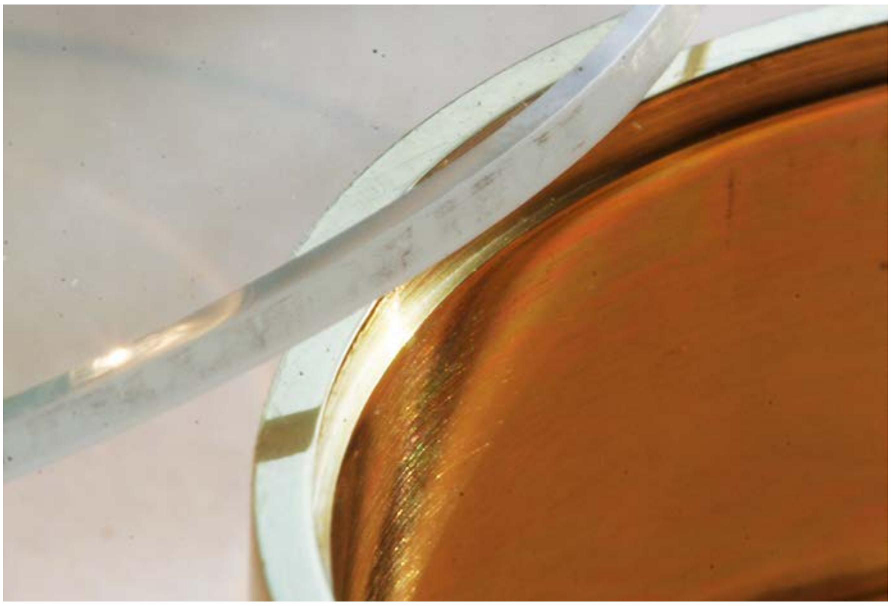
Before going any further, measure the exact diameter of your mineral glass (normally they are very accurately ground to the stated diameter) and make a note of it.

The brass tube is chucked in the lathe and the upper end brought to its finished length of 15.5 mm. Using a graver or boring tool cut a recess 1.2 mm deep to 0.2 mm smaller than the diameter of the glass. The 3 degree angle is not critical (± 1 degree) and can be cut using the rake of the boring tool; the angle is there to retain the glass firmly after it has been snapped into position.

Ensuring that the chuck jaws are not squeezing the casing to a three-lobed shape (reduce the tightening grip of the chuck jaws if you think they are), continue to make very fine cuts of about 0.02 mm (1 thou) depth, making sure you clean and remove all burrs after each cut. After each cut check the glass for fit by firmly pressing it into the bore. Sooner or later it will snap into position at which stage you will not be able to get it out.

To get the glass out, remove the brass tube from the lathe. Fill a shallow bowl with water mixed to about 60 degrees Celsius to a depth roughly equal to half the height of the casing (filling the bowl much deeper will cause it to float, which is inconvenient). 60°C is just too hot to keep your finger in, if that makes sense. Put the casing into the water, trying not to splash hot water on the glass or it may break under the thermal shock.

After a minute or so the internal diameter of the brass tube will have slightly expanded from the warmth of the water. Take the casing out of the water (it will be hot so you may need to use

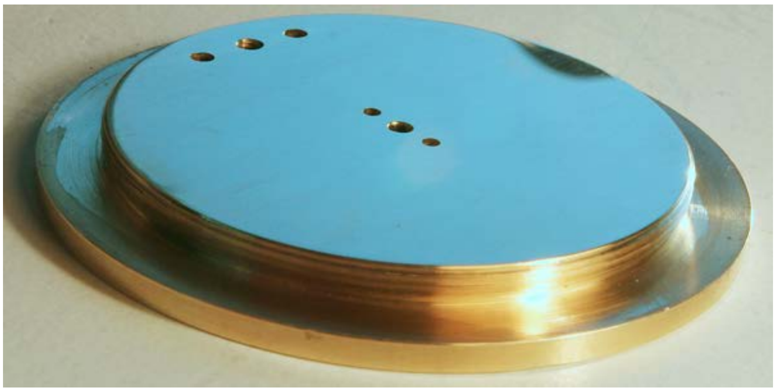


a cloth or gloves) and the glass should pop out under gentle pressure applied near the edge by your finger and thumb. If it does not, it is probably because the cold casing has taken too much heat out of the water, so keep on refilling the bowl with fresh hot water and trying again until the glass does pop out.

If you are unlucky and you make the recess too large in diameter, do not worry. If it is by just a tiny amount (a barely perceptible 'side-shake') while still being retained in position (will not drop out) it will probably be fine once the casing has been lacquered as inevitably some lacquer will find its way into the recess and fill up the gap (effectively glue the glass in position). Alternatively you can secure the glass with adhesive designed for fixing and waterproofing loose watch crystals. However, if you feel the fit is too loose for either of these options to be successful, you can open out the bore to the next commercially available size of glass (43 mm).

Once the glass has been removed, tidy up any final rough edges on the brass casing and bring it to its preliminary finish with 600 grade wet and dry paper. Wash thoroughly in warm water and detergent (washing-up liquid) making sure there is no dirt remaining in the threads. Rinse in clean water and dry.

3. The baseplate



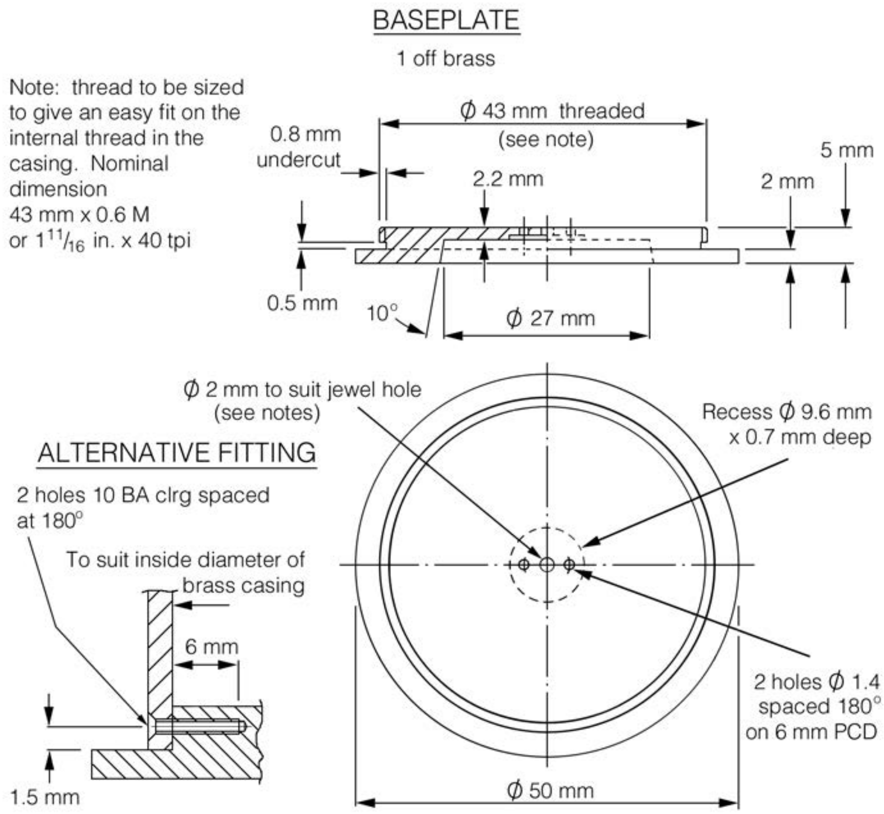
Design and drawings

The baseplate is the foundation on which all else is built. It holds the lower jewel hole for the balance staff as well as providing the anchor point (the stud) for the outer end of the balance spring. The underside of the base is recessed 27 mm dia. to reduce the tendency to rock if there is any unevenness in the surface on which it rests. The dimensions and thicknesses at the jewel hole position are identical to those in the balance cock.

Before going any further, refer back to the exploded diagram to help visualise the baseplate and cock assembly. It is always important to keep in mind what you are trying to achieve rather than robotically make the components to the drawings; unless you do so any adjustments needed because of slight deviations from the drawings will not be possible. To be able to spot what is going wrong and adjust in good time is the mark of a true craftsman.

Materials required

- Brass disc 50 mm dia. cut from 5 mm thick plate brass. Alternative: 6 mm (1/4 in.) slice from the end of a 2 in. dia. brass bar.



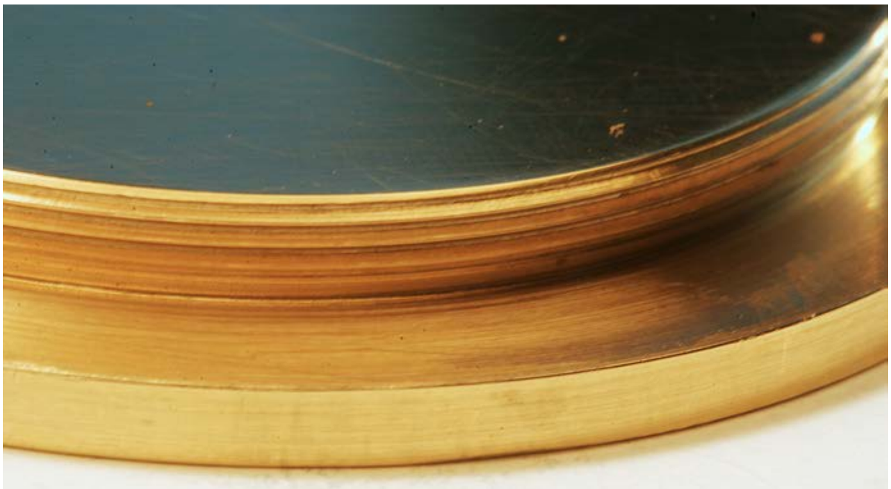
Construction – screw-on fitting

Hold the brass disc in a three-jaw chuck in the lathe so that at least 3 mm protrudes beyond the end of the chuck jaws. If you do not have a suitable lathe chuck you will have to secure it to a faceplate in such a way that you can turn the spigot that fits inside the brass casing tube. Perhaps this can be done by using an adhesive (such as 'Superglue') or shellac to secure it to a faceplate or large 'wax chuck', but if you do, you will need to take very small cuts if the work is not to be dislodged under the cutting forces from the lathe tool.

Make sure the face of the disc is truly at right angles to the lathe axis. If you are using a sawn slice from the end of a brass bar, face the end flat. If you are using brass plate and providing you have set up the face truly at right angles to the lathe axis, the surface should be flat enough not to require facing. Whatever your choice of material (disc or slice of bar), turn the outer diameter of the protruding length to 50 mm dia. or a little less and deburr.

Remove the disc from the chuck and reverse so that again at least 3 mm protrudes beyond the end of the chuck jaws. Turn the 3 mm long step and flange face. You now need to cut a thread that perfectly matches the casing thread, taking great care not to catch the side of the screwcutting tool on the edge of the flange at the completion of each pass. You will also need to ensure that the screwcutting tool and toolpost will not foul the chuck jaws, and this may mean that the vee-tip of the screwcutting tool must be slim and/or ground off centre (see photograph in Chapter 2) or be ground at an angle to the tool shank.

Deburr the threads and make sure the baseplate is a nice easy but rattle-free fit in the tube and seats right to the flange. Remove the baseplate from the lathe.



Construction – alternative fitting

If you are using two securing screws to hold the cover in position, turn the spigot to be a snug, rattle-free fit in the end of the tube. Deburr the end and remove from the lathe. You can now fit the cover and, keeping it pressed hard against the flange, spot through the pilot securing screw holes with a drill size equal to the tapping size of the 10 BA screw (the same size as you have used to drill the pilot holes in the periphery of the cover). Drill to a depth of 6 mm and tap 10 BA (or your chosen thread size). If you have used a drill of the pilot size of a counterbore you will need to open this up to 10 BA tapping size. Deburr the end of the holes, finally running down a bottoming tap to clear out any remaining debris.

The holes in the cover can now be opened up to the clearance size for the screws. If it is your intention to fit commercial countersunk screws the holes can be countersunk using a countersunk screw as a gauge for the depth of the countersink. Alternatively you can delay making a decision until you have made your own screws.

The problem with fitting round or cheesehead (‘instrument head’) screws to a curved surface such as the cover is that the underside of the screw heads will not lie flat on the periphery of the surface. The benefit of a countersunk head is that the underside of the head will bear all around its periphery whereas a roundhead screw will only bear at two points unless the hole is spot-faced to provide a full bearing surface. Counterbore cutters with a pilot suitable for making a spot-faced seating for a roundhead screw can sometimes be found in staking tool sets; if you have something suitable drill the pilot holes in the casing to suit the pilot on the counterbore before opening out to take the screw. The counterbore is fed in until it just cuts a complete circle – a ‘spot-face’ – at its full diameter and no more.

Finishing the other end (the bottom)

The baseplate is now returned to the chuck. If you are using 5 mm plate, then facing the end flat should not be necessary. If you are using a slice from a 2 in. dia. bar, face off the end truly flat. In both cases, once you are satisfied that the end is truly flat, measure the actual thickness and make a note of it.

If you have screwcut the spigot, the best way to grip the work is by the cover itself. Screw on the cover tightly (with finger-pressure only) and wrap a strip of paper around the outer surface of the cover before gripping it in a four-jaw chuck with the flange pressed against the chuck body or chuck jaws. (The paper will prevent difficult-to-remove marks being left by the chuck jaws.) You could use a three-jaw chuck but a four-jaw chuck will not only give a firmer, yet more gentle grip but also allow you to centre the work accurately by means of the periphery of the 50 mm dia. portion. Soft jaws in the three-jaw specially machined to take the cover are an even better alternative. However, true concentricity is not that important in this application.

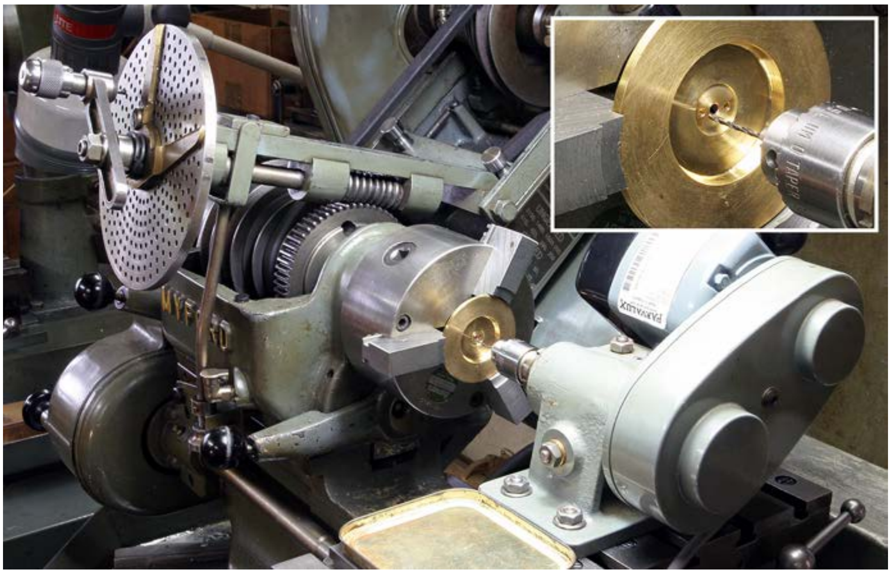
If you are using the alternative two-screw fitting, centralising the work is easy as the spigot can be gripped directly by the jaws of the three-jaw or four-jaw chuck.

The 27 mm dia. recess is now bored to a depth that will leave the jewelled centre portion 2.2 mm thick. The sides are tapered at 10 degrees primarily for appearance, though this taper is optional. It is good practice to leave a small radius in the inner corner of the recess; about 0.2 mm radius is fine. (Note: both the taper and the radius will prevent the baseplate being gripped internally in a three-jaw lathe chuck, so if you feel this might be necessary, both taper and radius may be omitted.)

The next step is to drill the hole for the jewel hole, which should be smaller than the outside diameter of the jewel hole you will be using. If you are using the recommended 200 size jewel (2 mm outside diameter) drill 1.7 mm dia., which will allow you to use a commercial 10 BA screw and nut to clamp things together as will be described later on. The jewel is not fitted at this stage. Now bore the recess for the end stone chaton to an outside diameter of 9.6 mm and 0.7 mm deep.

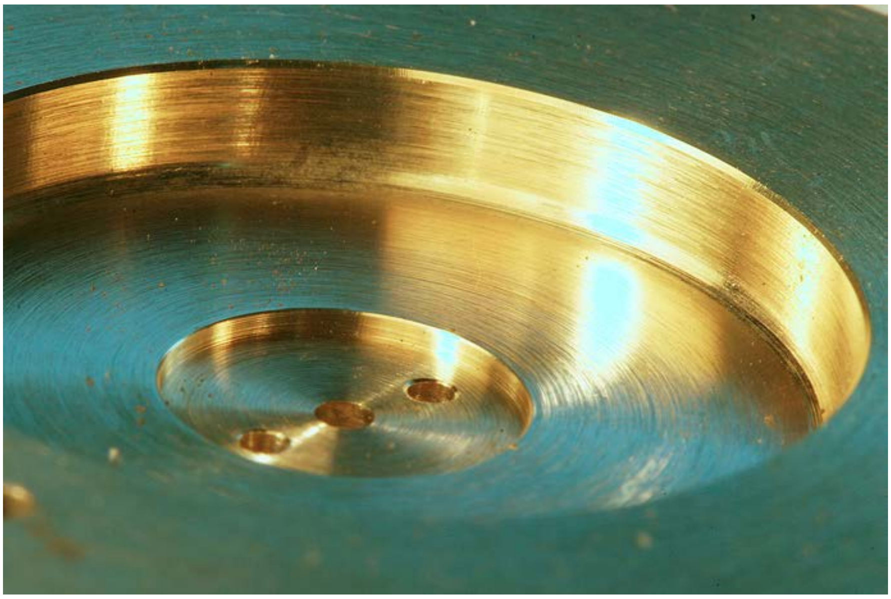
Drilling the pitch circle diameter (PCD) holes

To drill these holes while the work is set up in the lathe will need an indexing attachment for the lathe headstock and a cross-slide motorised drilling spindle. If you have suitable equipment, then you will know how to use it, and gripping the work in a three-jaw chuck with soft jaws, my drilling spindle is shown in use below.



If you do not have a suitable lathe attachment or cannot transfer the chuck complete with the workpiece to another machine tool (such as a rotary table on a vertical milling machine), then do not drill the two 1.4 mm dia. holes at this stage; these will be jig-drilled later. Nor should you mark or drill the balance cock securing screw and steady-pin holes or the balance spring stud hole, which are deliberately not shown on the drawing accompanying this section.

The baseplate can now be removed. If faced from a 2 in. dia. bar, the upper surface should be rubbing on a 50 mm wide stone both to remove machining marks and bring it truly flat in preparation for fitting the balance cock.



Other options

Whenever faced with the manufacture of new or replacement parts, one primary consideration is how you can make it with the tools and materials at your disposal.

If machining the fairly heavy baseplate from one piece of brass does not appeal to you, it would be possible to fabricate the baseplate from two discs of brass. The upper disc is cut and turned from 3 mm thick sheet and the lower disc from 2 mm thick sheet. After turning the outside diameters to size, the two sheets could be screwed or riveted together using (say) four 10 BA countersunk screws or 1.6 mm dia. brass rivets spaced at 90 degrees on a 35 mm PCD.

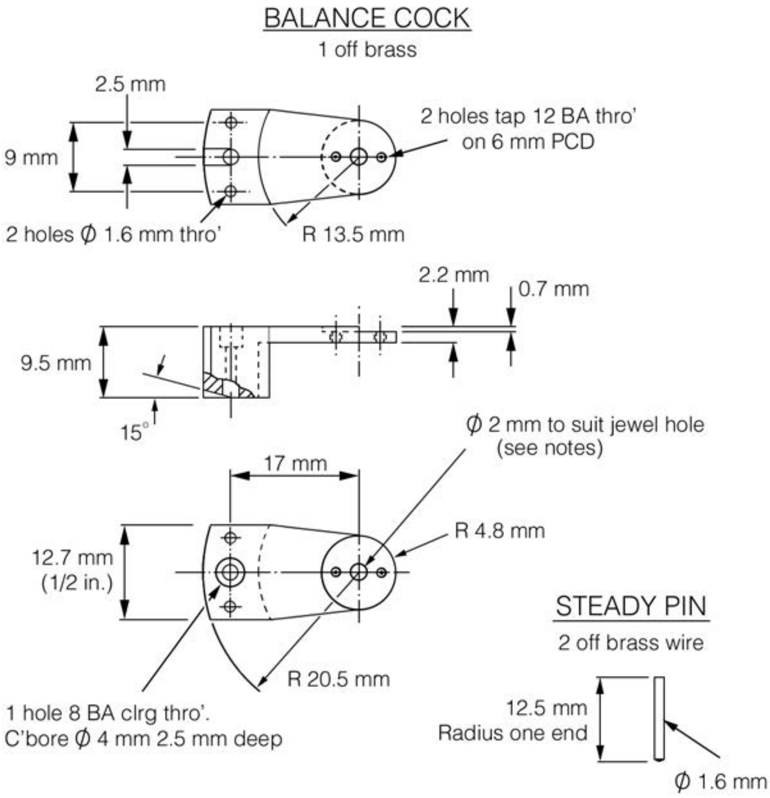
The point to emphasise is just because these notes suggest one method of manufacture it does not mean it is the only way or the way best suited to the tools and materials at your disposal. With a little ingenuity many seemingly insuperable problems can be overcome.

4. The balance cock

Design and drawings

Never an easy component to make (and in particular hold during manufacture), the cock provides the upper support for the balance staff. It is of vital importance that the hole for the upper jewel is precisely above the lower jewel so that the balance staff is truly upright. As we will be using cylindrical train jewels rather than jewels with an olive-shaped hole, any angular misalignment will cause the pivots to become scored very quickly as they bear on the edges of the hole. We will not be using olive-shaped jewel holes because they might not be available in the larger hole sizes we want.

As for the baseplate, the cock ideally requires equipment that will permit two diametrically opposed holes to be drilled in mating components on a pitch circle diameter. In a well-equipped workshop this would be done on an indexing rotary table or a lathe headstock-mounted dividing attachment and cross-slide drilling spindle as illustrated in the Chapter 3. But do not worry if you do not have such equipment as an alternative method will be described.



Materials required

- 1/2 in. x 1.1/2 in. rectangular brass bar (section) x 1/2 in. long
- length of 1.6 mm dia. approx. brass wire for steady pins
- short length of 4 mm dia. silver steel rod for the securing screw
- temporary 8 BA x ½ in. screw (or screw to suit the thread you will be using)
- length of 10 mm dia. silver steel (for filing buttons).

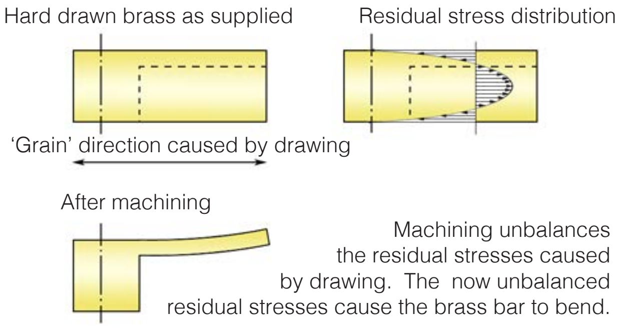
Drawn bar*

A length of 3/8 in. x 1/2 in. rectangular brass bar may seem more suitable and can indeed be used. However, because of the high internal stresses in the 'skin' caused by the drawing process, the cock will bend when the underside recess is cut away (see diagram). If you use drawn bar in this orientation you will need to straighten it before bringing to final size (height). Alternatively, the brass can be annealed by heating to red heat and allowing to cool slowly, but this will make the cock softer and more liable to be subsequently bent.

By using the recommended material (1/2 x 1.1/2 in. brass rectangle) with the upper and lower surfaces of the cock formed from the 'end grain' of the drawn brass rectangle, this diagram does not apply; no significant bending will occur and, with no need to anneal the bar, the brass will remain in its half-hard condition.

* In this context, 'drawn' describes the process of drawing (pushing or pulling) the brass through a rectangular die plate at the brass works in order to produce its rectangular shape. In so doing, the brass is work-hardened.

RESIDUAL STRESSES



Drilling the holes

Using a four-jaw chuck, machine flat one sawn end of the 1/2 x 1.1/2 in. brass rectangle. Reverse and bring the brass bar to a finished height of 9.5 mm, making sure it is truly parallel with the first surface. To ensure it is parallel, press the work hard against the chuck body as you tighten the jaws, which with an engineer's lathe can sometimes be facilitated by applying light pressure from the end of the tailstock barrel as the jaws are tightened.

Remove from the chuck and mark out the position of the holes on the upper and lower surfaces, and scribe the lower surface with arcs struck from the balance staff position.

At the centre of each hole press the scriber point lightly into the surface of the brass, inspecting with an eye-glass whether you have got the indentation exactly on the cross-lines. Adjust until perfectly centred and press harder so that the indentation from the scriber is deep enough to take the point of a centre punch. Tap the centre punch with a hammer and check again with the eye-glass. If necessary, draw the punch mark over by leaning the punch in the required direction and tapping again

The holes need to be drilled truly vertically, so use a drilling machine. If a drilling machine is not available, hold the brass bar against a pad in the tailstock and drill from the lathe spindle. But before you drill the holes, it is now important to think ahead before selecting the drill size for each hole:

- Steady pin holes: Check the diameter of the brass wire and drill to the exact same size or very slightly smaller. For example, if the brass wire is measured at 1.57 mm diameter, drill 1.55 mm or 1.50 mm. We will bring the brass wire to a push fit in the holes using a piece of fine grade (600 or 1200 grade) wet and dry paper
- Cock securing screw: Drill the hole the tapping size for an 8 BA screw or the thread you intend to use (e.g. M2). Counterbore to a depth of 3 mm using a 4 mm dia. drill, making sure you clamp the brass bar and using a depth stop in case the drill 'snatches' in the work. Finally fit a 4 mm dia. cutter with a flat end to flat face the bottom of the counterbore. If you do not have one, you can made a D-bit from 4 mm dia. silver steel
- Balance staff hole: Drill a 1.7 mm dia. hole at the jewel hole position (being the outside diameter of a 10 BA screw, 1.7 mm is suggested for the reasons mentioned when drilling the baseplate jewel hole position)
- Upper end stone chaton securing screw holes: do not drill at this stage.

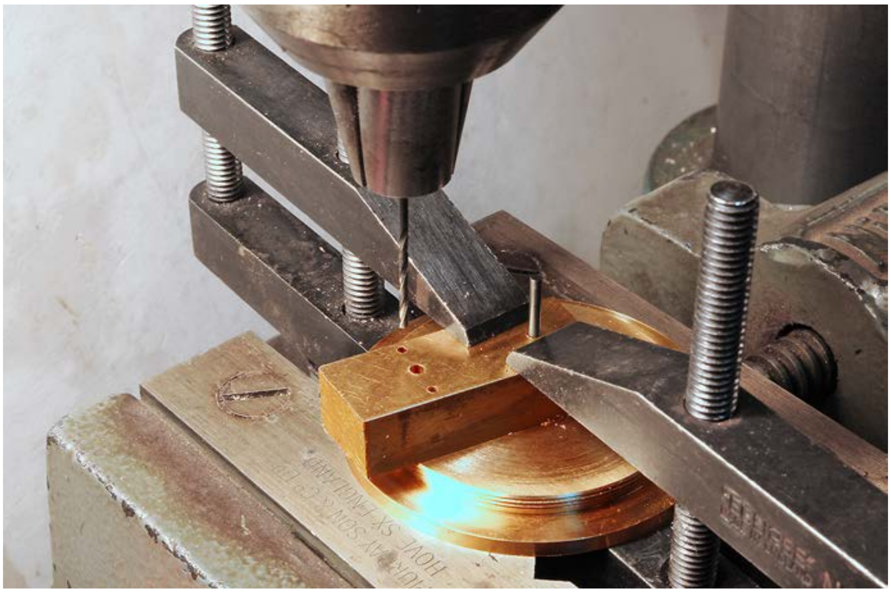
Very lightly de-burr all holes so the brass bar will lie flat and free from any 'rocking' on a surface plate. If the holes are truly square to the top and bottom of the cock, you can now use a bit of cunning to avoid the need to 'upright' the balance staff when planting the cock securing screw and steady pins. If there is any doubt, then you will need to 'upright the holes' (see later).

Holes drilled truly square

Using a 1.7 mm dia. drill shank, locate the cock by the balance staff hole on the base plate. Check the drill shank is truly vertical and clamp the two components together using two toolmaker's clamps. Using the already drilled holes in the cock as a guide, drill the baseplate for the securing screw using a drill of the correct tapping size for the screw thread. Also drill the two steady pin holes.

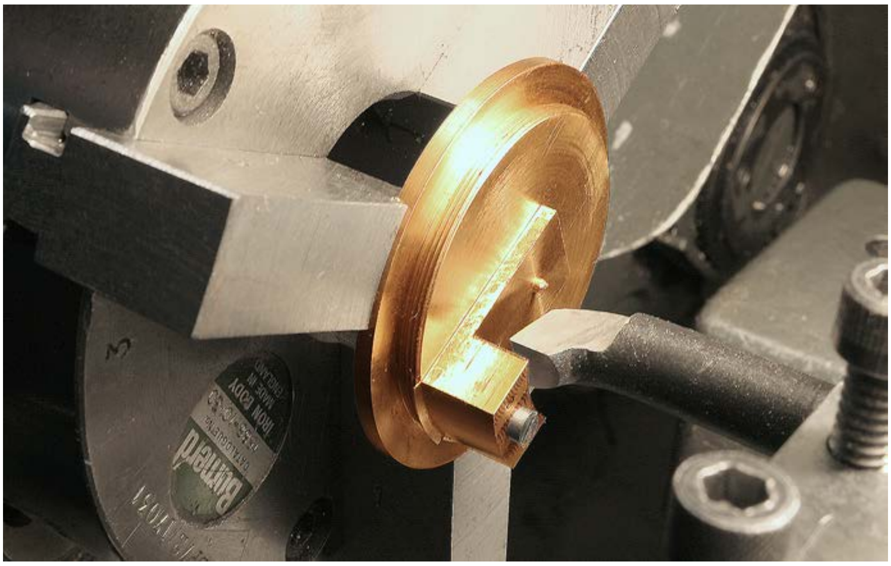
Make sure you have marked which side is the top side of the cock (the side from which you have drilled the original holes), and separate the components. Open the securing screw hole in the cock to the tabulated clearance diameter for the screw thread; if you do not know what this is, choose a drill 0.1 mm larger in diameter than the measured major diameter (outer diameter) of the screw thread. Tap (thread) the hole in the baseplate and remove the burrs.

Next rough out the bulk of the metal to form the recess using a hacksaw. If you have used 3/8 in. high drawn barstock you will now find that it has bent and will need straightening by gripping in the bench vice and giving the projecting 'wing' a few gentle taps with a hammer. It may be necessary to rub it on a truly flat bench stone (e.g. a diamond bench stone) reserved for brass to bring it truly flat. Alternatively you can stick down a piece of 600 grade wet and dry paper to a hard, flat surface. Sticking the paper down will minimise the rounding of the edges of the work.



Once the upper surface has been brought to a flat plane again, we can now use the baseplate to hold the cock to bring it to its final thickness of 2.2 mm across its entire surface. This is done by holding it upside down against the baseplate, locating it with a drill shank through the 1.7 mm pilot hole for the jewel hole and securing the cock to the baseplate with a temporary 8 BA screw through its foot. The baseplate is held in a lathe chuck or mandrel and the underside of the cock brought to size using a boring tool. At this same setting, we can also cut the internal radius for clearing the rim of the balance wheel.

While at this setting we can also finish the 20.5 mm back radius using a normal lathe turning tool, taking care not to feed the tool into the baseplate. If anything, make this radius slightly smaller so it will fit comfortably within the casing.



Holes not truly square – ‘uprighting’

If you are not confident of your equipment to drill the holes truly square, you should drill the securing screw hole as described previously but not the two steady pin holes. Finish the securing screw hole to size (8 BA clearing) and tap the hole in the baseplate, deburring the holes on completion. Now rough out and finish machine the underside of the cock as described before.

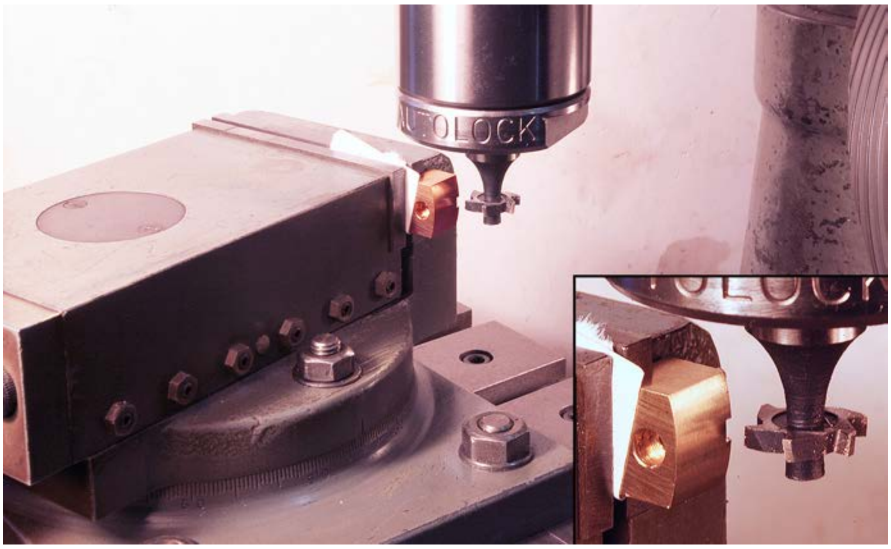
Turn the cock the right way up and secure to the baseplate with a temporary screw, adjusting the position until a drill shank through the balance staff pilot holes is truly upright in both the fore and aft and sideways planes. This can be done by eye, but do hold the cock at eye level and observe it against a strong light uncluttered by extraneous background equipment (a background of daylight through an outside window is ideal). It may be necessary to increase the clearance diameter of the securing screw hole slightly to get the drill shank truly upright. Once satisfied, tighten the securing screw and drill the two steady pin holes (remember: as we described earlier these holes are sized slightly small than the diameter of the wire you will be using for the steady pins). Deburr the holes on the underside only.

Cock removing notch

Before we fit the steady pins you should cut the cock removing notch. When removing the cock, the notch is a useful feature allowing the use of a screwdriver to help lift the cock to reduce the chance of the balance staff pivots being bent or broken. The notch should not be omitted. It can easily be cut with a file; alternatively it can be machined using a slitting saw or woodruff cutter (photograph).

Fitting the steady pins

Take the brass wire selected for the steady pin holes and hold in a collet in the lathe and finish one end. Now try to push the wire into the cock steady pin hole, reducing its diameter using wet and dry paper until it is a light push fit through the whole thickness of the cock and 3 mm beyond. Remove and cut the wire off, reverse in the collet and finish the other end to length. Repeat for the second pin and clean thoroughly with methylated spirits in preparation for the next step.



The pins may now be permanently fitted to the cock, using a dab of Loctite or other anaerobic adhesive to ensure they stay firmly fitted. The outer flat end can also be lightly riveted just to fill any slight chamfer left by over-enthusiastic deburring operations on the hole, but do not use heavy blows or you will bruise the domed lower end. Make sure both pins protrude by an equal amount below the cock. Allow the Loctite to cure for 30 minutes after which time the upper surface can be rubbed on a stone to leave the ends of the pins all but invisible.

Perhaps a ‘bearing fit’ grade of Loctite is most appropriate for this low duty application, but the actual grade is not important as you should never want to get the pins out again.

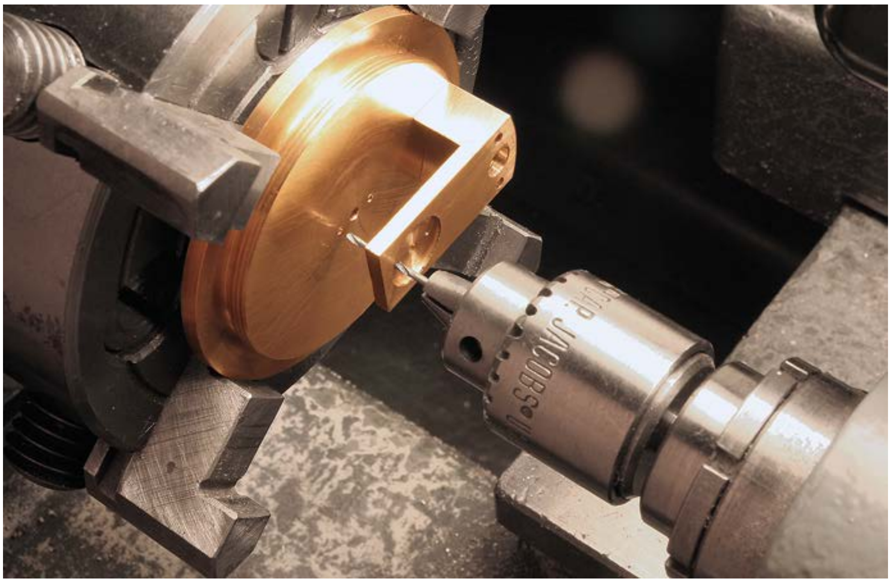
Once the pins are secured and finished, the cock is tried in position on the baseplate. Very gently, ease the steady pin holes in the baseplate using a taper reamer until it fits into position with just a hint of stiffness. Very lightly deburr the holes.

Cutting the end stone chaton recess

Fit the cock to the baseplate using a temporary screw and mount the baseplate in a four-jaw chuck in the lathe. Use your locating drill shank to make sure all is well, and centralise the centre hole and tighten the chuck jaws firmly but not so much that they will bruise the edge of the baseplate. Using a boring tool, bore the end stone chaton recess to 9.6 mm diameter 0.7 mm deep.

If you are index drilling the holes for the 10 BA securing screws, set up the headstock dividing attachment and fit the motorised spindle. After centring the motorised spindle, offset the cross-slide by 3 mm ready for centring the two holes on their 6 mm PCD. Centre with a centre drill and then follow up with a 12 BA tapping drill. Tap by hand using the motorised spindle as a back steady and deburr all the holes.

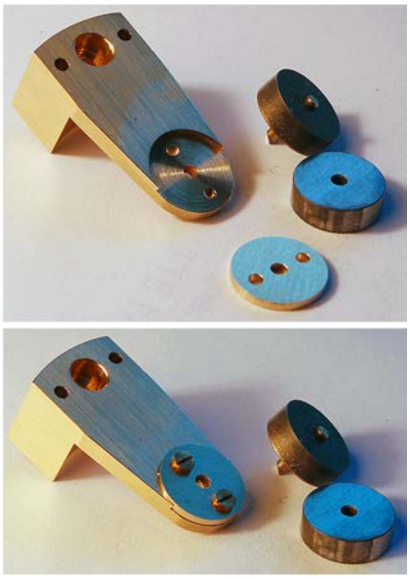
If you are not index drilling the holes, do not mark and drill the holes yet as an alternative, equally satisfactory approach will be described later. In either case the baseplate can now be removed from the chuck.



Filing buttons

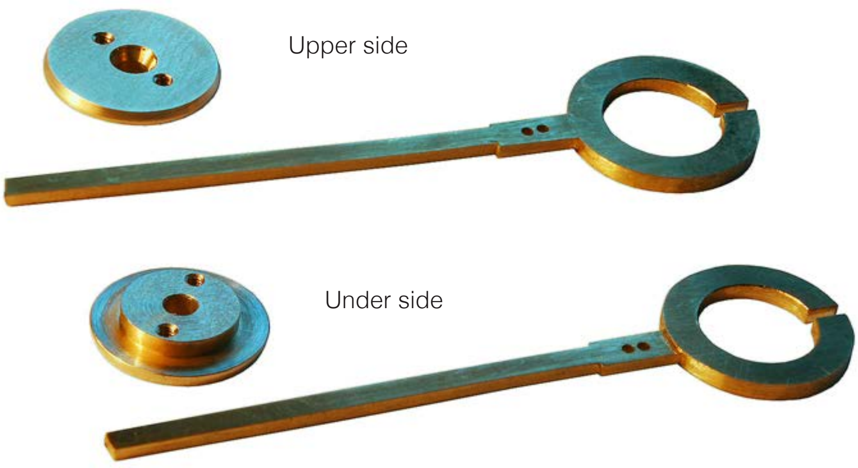
The next job is to radius the end of the cock and this is best done with a pair of filing buttons. Take a length of 10 mm diameter silver steel and turn down the outer diameter for a length of 12 mm so that it is an exact fit in the 9.6 mm dia. chaton recess. Drill a central hole to take a short length of wire of the same diameter as the central hole in the cock that will eventually be opened out to take the jewel holes (1.7 mm dia.). Face and part off two lengths about 4 mm long, deburring the holes well and making sure that both ends are flat. Heat the two buttons to bright red heat and quench in cold water to leave them dead-hard.

Polish one end of each button on a stone so that they will not mark the chaton recess and sandwich the cock in between before clamping in the bench vice. You can now file down the sides and end of the cock to a perfect fit on the endstone chaton. Tidy-up any burrs on sharp edges with a fine needle file.



The dead hard filing button fits perfectly into the upper recess. The lower button is centralised by the pin passing through the centre.
To profile the edge of the cock, the buttons are sandwiched in the bench vice for filing

5. The index, index clamp and endstone chatons



Design and drawings

As mentioned last time, the rate is adjusted by the index. It is made from a piece of sheet brass and will require skilful sawing and filing if it is to look good. The index clamp and chatons also require some precision in their manufacture if they are to fit well.

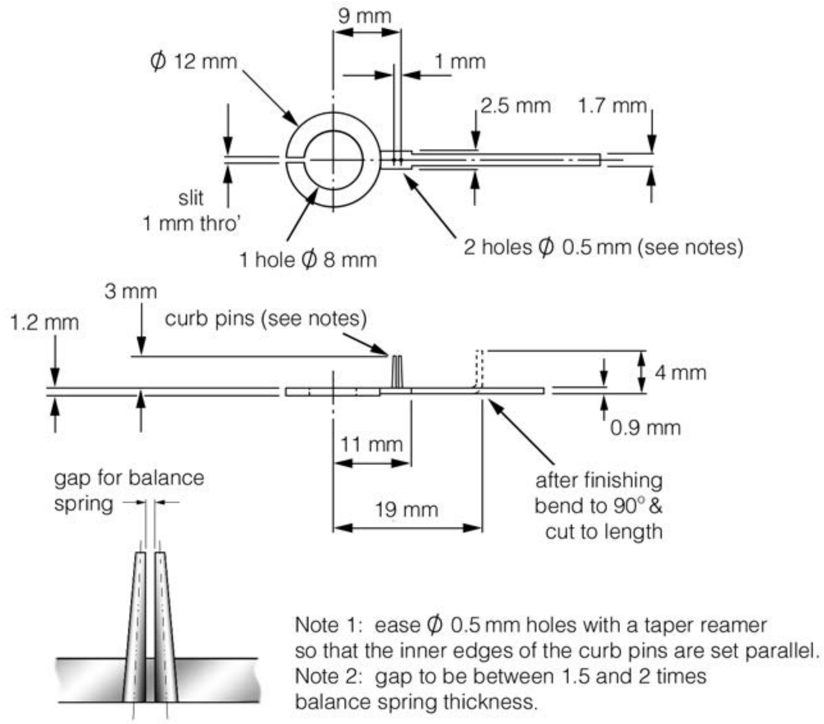
The index lever is relieved by 0.3 mm on its underside so that it does not scrape on the upper surface of the baseplate when adjusted. The 8 mm dia. hole fits on the retaining clamp, which has a shank diameter that is a light interference fit, the slit providing a good friction fit to the index so that it stays put.

Materials required

- 1.2 mm (18 gauge) brass or nickel alloy sheet approx. 40 mm x 15 mm
- selection of brass taper pins (to make curb pins)
- 10 mm (3/8 in.) dia. brass bar about 50 mm long
- (optional) 1 off commercial 10 BA x 10 mm (3/8 in.) screw, nut and two washers.

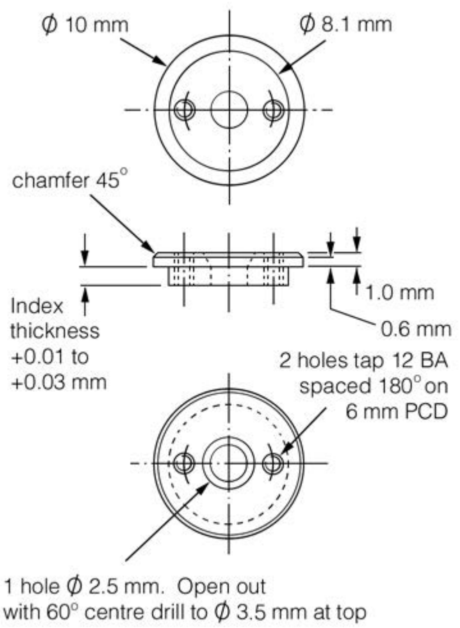
INDEX

brass or nickel sheet



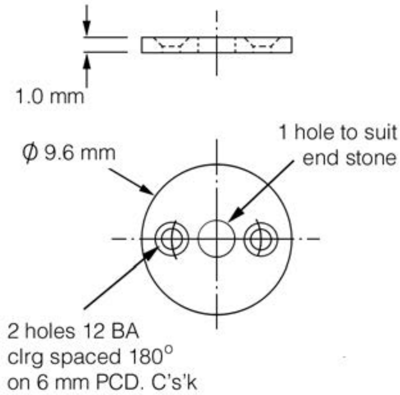
INDEX RETAINING CLAMP

1 off brass



ENDSTONE CHATON

2 off brass



The index

After marking out the brass sheet the first thing to do is to bore the hole to 8 mm dia. This can be done in the lathe by holding the brass sheet on a wax chuck or a faceplate. Do not profile the outer edge until you have made the 8 mm dia. hole.

I do not recommend that you use a large drill to drill the 8 mm hole; even if the brass is firmly clamped it is very likely to 'snatch' and damage the work, and this tendency to snatch is made much worse by the fact that it is thin sheet. Better is to drill with a small drill of about 3 or 4 mm dia. and open the hole up to 8 mm in the lathe by boring or by using a graver.

The outer shape is profiled using a selection of files. To shape the boss you may find it useful to make up a pair of filing buttons as described in Chapter 4. The holes for the curb pins now need to be drilled 0.5 mm, and some notes appear on the drawing. Use commercial brass taper pins pressed-in and filed off flush once cut to length with nippers. No. 3 taper pins are about right, but the key thing is to get the gap between the curb pins correct. While it might be possible to use pins of different diameter to adjust any slight errors in the gap width, bear in mind that too large a diameter pin on the inner-side may foul the next coil in on the balance spring.

The slit in the index is now cut, and this can be done either with a slitting saw or by hand. Deburr the sharp edges and bring all surfaces to a good grained finish either by draw filing or by rubbing on a fine diamond stone. You could also use 600 grit paper, but you will need to make sure you do not round the edges. Measure the thickness at the boss end at three points spaced at about 120^{o}; all readings should be within 0.02 mm (i.e. have a tolerance of ± 0.01 mm). If it is not within this tolerance, stone it down until the upper and lower surfaces are truly parallel and make a note of the maximum thickness.

The index is relieved on its underside by 0.3 mm so that the lever extension cannot scratch the baseplate when it is adjusted, and here you will find the filing buttons come in useful to avoid filing into the 0.3 mm up-stand to the boss. Do not be tempted to omit this relief as not only is it good practise for when you may have to make clock or watch hands, but it marks out the difference between a high-quality tool (and workman) and one made by someone with an 'it'll do' attitude.

The index retaining clamp

The retaining clamp is a simple brass turning to the dimensions shown, but does require some precision in its dimensioning to suit the actual dimensions of the index.

After chucking and facing a short length of 10 mm brass bar, the first thing to do is drill the central hole to 1.7 mm dia. to suit the drill shank or 10 BA screw we will be using to centralise the components on the balance staff axis. It will be opened up to its final size of 2.5 mm later.

Next turn the stepped portion to 8.1 mm dia. which will provide good friction in the 8 mm dia. hole in the index. If your index hole is greater or less that 8 mm you will need to adjust the clamp diameter accordingly.

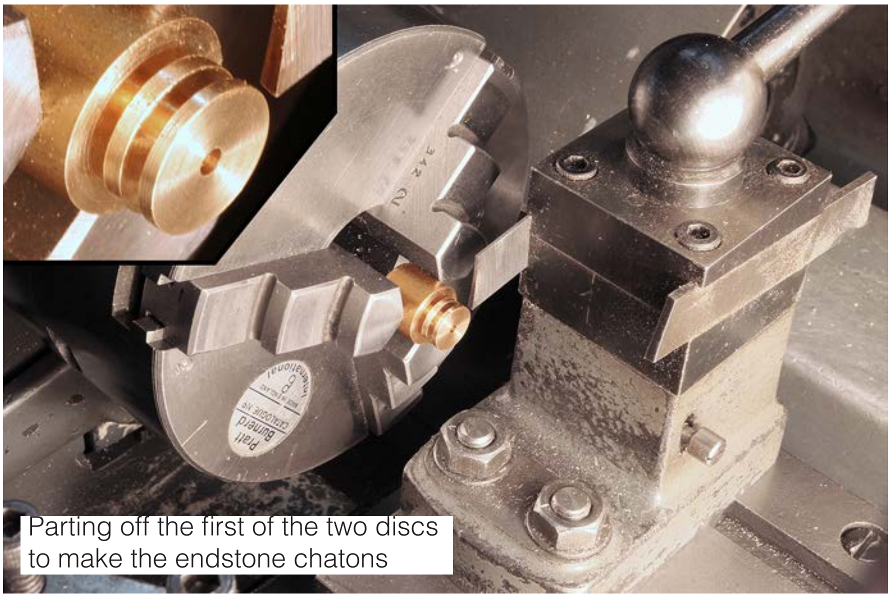
The length of the shoulder should be brought to 0.05 mm longer than the maximum thickness of your index. The index lever will be finished to length once we have made the index screw holes so that its final length can be checked when fitted into position.

Now mark and lightly centre punch the two screw positions on the underside (the smaller diameter side) of the retaining clamp and drill through truly vertical for the tapping size of the retaining screws (1.0 mm if using 12 BA screws). Remove the burrs from each hole.

The endstone chatons

Before going any further, it is appropriate to make the two endstone chatons.

There is really not much to say about these items which can be made from the same piece of 10 mm dia. brass bar used for the index retaining clamp. The central hole is again pilot-drilled 1.7 mm; however bringing the two chatons to 1 mm thickness requires the discs to be set up perfectly square in order to face them off. This can be done in a number of ways; you can use a wax chuck, or very carefully grip them in a three-jaw chuck. If you have parted the discs off with less than 0.1 mm excess length you can rub them on a coarse stone to bring them to their correct thickness, always taking care that they are kept an even thickness all round.


Parting off the first of the two discs to make the endstone chatons

Bear in mind that if you part off thin discs from 10 mm dia. bar with a less than perfectly sharp parting tool the disc is likely to 'dish', so it is always as well to take the parting tool to three-quarters of the cut-off depth at which point you should stop. Re-face the outer end of the disc flat before finally parting off completely. The second side can be finished flat on a stone, and both faces brought to a reasonably good finish in preparation for final polishing later on.

Endstone chatons – drilling the securing screw holes

Fit the index clamp on the baseplate, locating it by its central hole with a commercial 10 BA x 10 mm (3/8 in.) long screw (or longer) together with a nut and a pair of washers. The 10 BA screw will be found to be a snug fit in the 1.7 mm hole and will provide both accurate location as well as reliable clamping for the two components. If you do not have a 10 BA screw, you could always thread each end of a short length of brass rod turned to 1.7 mm dia. and use two nuts to make a clamp. You should also set up one of the endstone chatons below the baseplate at the same time.

Using the holes previously made in the index clamp, the two securing screw holes are drilled 1.0 mm dia. through the baseplate and lower endstone chaton. After drilling the first hole, fit a short length of 1 mm dia. wire (a broken 1 mm dia. drill shank is suitable) through this first hole so that the index clamp and chaton cannot rotate when drilling the second hole. Use a drilling machine to ensure the holes are truly upright; if you do not have a drilling machine, drill from the lathe headstock, resting the baseplate on a tailstock pad.

Drilling the second securing screw hole in the index retaining clamp. Note the old (broken) drill shank located in the first hole to prevent rotation.

The temporary 10BA brass screw and nut both locate and clamp the components securely together.

Disassemble and make sure you have marked the correct orientation with light centre pop mark on the top-side of the clamp near to one of the holes and similar one on the baseplate and endstone chaton; this is to aid assembly because the accuracy you achieve may not result in the holes aligning perfectly if the clamp is rotated through 180 degrees. Stone off the raised edge around the pop marks and tap the holes in the clamp to the clearance diameter of the screws. Open out the holes in the baseplate and endstone chaton to 1.4 mm dia. and deburr.

The other endstone chaton is now marked for the two securing screws and centred in its correct position. Drill through the two holes 1 mm dia. Using the same temporary 10 BA screw used for the lower (baseplate) assembly and the chaton as a drilling guide, the cock is drilled before removing the chaton and tapping the cock securing screw holes 12 BA.

Both pairs of endstone chaton holes are opened out to 12 BA clearing (1.4 mm dia.) and countersunk to a depth so that the previously-made countersunk screws come just level or slightly below the surface of the chaton.

Once you are satisfied that the index securing clamp is fitted correctly, the central hole is opened out to the dimensions shown in the drawing so that it clears the balance staff. However do not do any more work on the central holes in the balance cock, the baseplate or the endstone chatons at this stage; these will be opened out when we come to jewelling.

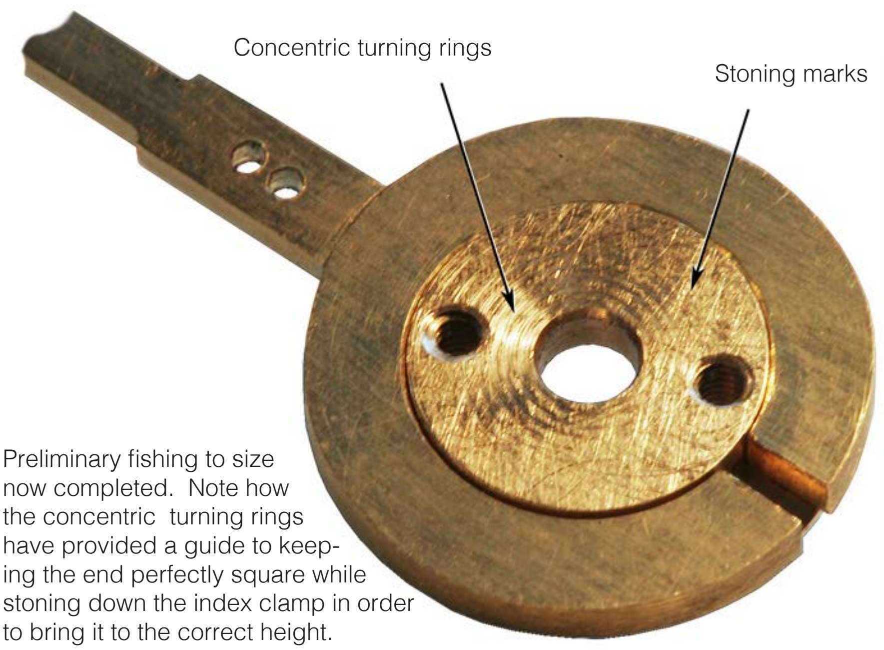
Bringing the index clamp shoulder to length

The length of the clamp on which the index rotates needs to be brought to a precise length which lies between + 0.01 and + 0.03 mm of the as-measured maximum thickness of the index.

To achieve these tolerance limits is truly demanding, and many lathes and measuring instruments will not be up to it. Not only does the underside of the flange have to be faced truly flat, but the average cross-slide index and feedscrew will be at the limits of their accuracy. Moreover, measuring to this accuracy with a vernier caliper will again demand a degree of precision not likely to be achievable, and a micrometer is by far the preferred instrument.

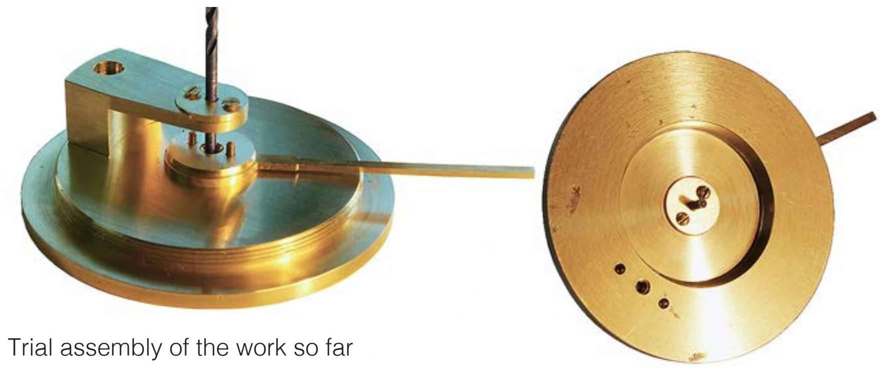
With all these possible errors conspiring against you, it will probably be necessary to leave the under-flange part of the clamp slightly over length (say by 0.1 mm) and rub it on a diamond stone to bring it to the required length. In so doing, keeping an even pressure is not easy; the clamp must be checked regularly to ensure that it remains of equal length at three points around its periphery. A good guide as to whether things are going well can be the concentric turning tool rings; if they are abraded away more on one side that the other, it is time to make an adjustment.

When rubbing anything on a stone, the leading side (edge) on the pushing-away stroke tends to be abraded away faster than the other side (the side being pulled towards you). Ro-



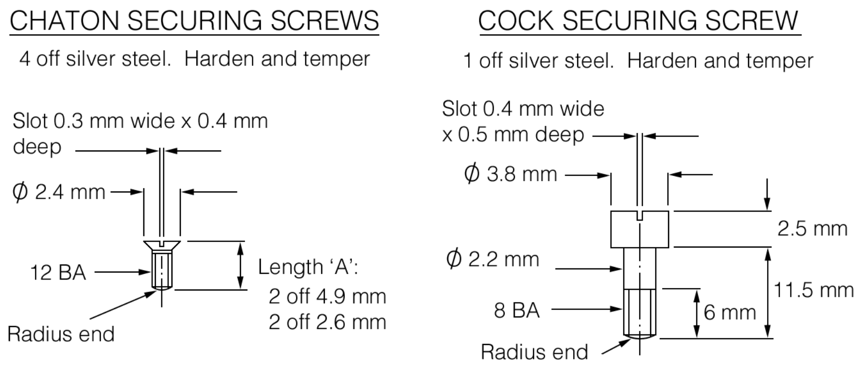
Preliminary fishing to size now completed. Note how the concentric turning rings have provided a guide to keeping the end perfectly square while stoning down the index clamp in order to bring it to the correct height.

tate through 180 degrees regularly to keep things even. (Aide-memoire: think of moving a long plank of wood with one end resting on the ground; dragging it behind you is far easier that pushing it ahead of you (there is far less likelihood of it digging-in).)



Trial assembly of the work so far

6. The screws



Design and drawings

The ability to make screws is one of those skills essential if one is to become a true master of horological work. Commercial replacements may not be available and, when only one screw is required, it is often far quicker to make a replacement than spending hours searching for a suitable ready-made screw.

Some screws are easier to make than others, and by far the most challenging is the countersunk screw. For our vibrating tool, countersunk screws are not essential and could be designed out (for example, by increasing the casing height slightly). But this design shows countersunk screws mainly to enable students to practise their manufacture and become aware of the difficulties.

The screws are shown in the drawing. Dimensions are given but you may find it necessary to adjust the lengths to give the perfect thread tip protuberance for your components.

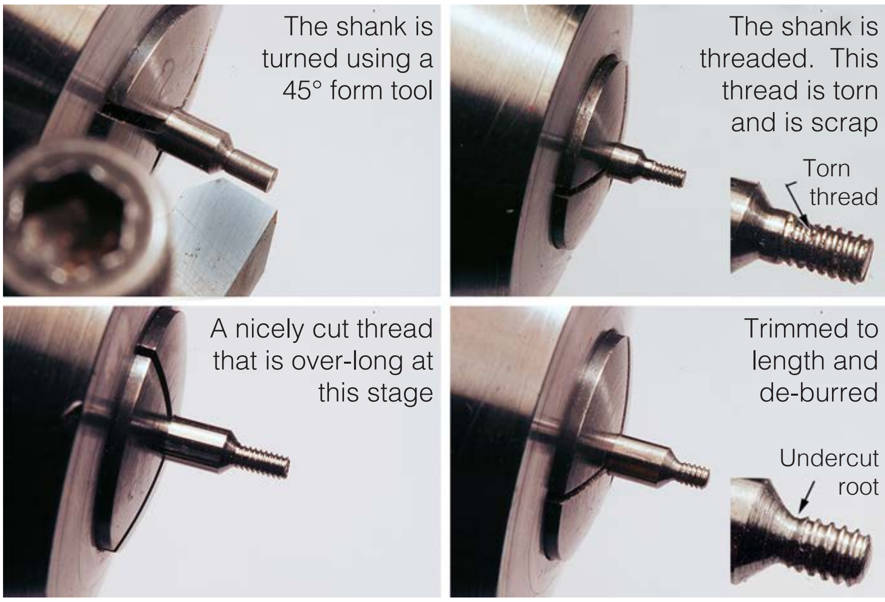
Materials required

- length (165 mm) of 4 mm dia. silver steel rod
- length (165 mm) of 2.5 mm dia. silver steel rod
- length (15 mm) of brass bar about 6 mm dia. (to suit the largest collet you have).

Construction

The manufacture of the 8 BA cheesehead (sometimes called ‘instrument head’) balance cock securing screw will not be described, which is relatively easy compared with the countersunk chaton securing screws.

For the chaton securing screws, the first machining operations are shown in the sequence of photographs. In the first set of photographs, the toolpost on a cross slide is being used, but you could equally well use a graver, in which case the major diameter of the screw and the underside of the head are shaped by manipulating the graver on the tee rest.



If using a toolpost and cross slide, you should grind up a simple form tool at 45 degrees so that the underside of the head is formed at the same time as the shank, as to use a set-over top slide set over at 45 degrees will be very inconvenient. Turn down the end to the major diameter of the thread you will be using. If anything turn it 0.02 mm smaller in diameter as this will reduce the likelihood of the threads being torn by the die.

Ideally a second lathe tool (in the form of a slightly rounded tip thin parting tool or V-form screwcutting tool (not shown)) is used to form a slight undercut to the screw head as it does help to ensure that the underside seats properly in the countersunk recess in the chaton. It also provides the opportunity to remove the burr thrown up at the end of the thread by the thread-cutting die.

At this stage the screw should be slightly long (by about 0.3 to 0.5 mm); not only does this give us a ‘trimming length’ but also allows us to remove any poorly formed thread at the end caused when the die starts to ‘bite’ into the work. (At the start, the die is not self-feeding and for the first thread or two relies on operator pressure to get it to advance forward.) Moreover, measuring the length specified on the drawing is not easy as there is no clear datum plane under the head. The screw will be brought to its final length during trial fitting.

Now cut the thread using a die of the correct size. For the two shorter screws you should reverse the die to get a full depth of thread right up to the head. Do not be tempted to by-pass this step as the lead-in on some dies can be quite long which will make the screw a tight fit in its hole. We want the screw to become a close fit when the underside of the head starts to clamp the two components together. Worse still, do not be tempted to start the thread with the die held in reverse; having no lead-in all you will do is chip the end tooth of the die rendering it useless for anything other than for making torn threads.

Clean up the ends with a touch from a fine needle file and check the fit in a master threaded hole such as a piece of 1.6 mm brass plate previously drilled and tapped with the tap you are using for the index retaining clamp and balance cock. Adjust the split die until the fit is shake-free; if it is loose or the threads are torn, cut off the silver steel rod and start again.

Once you have a clean, tear-free thread, make sure there is no roughness to the crests of the threads, treating them with a fine needle file or stone if necessary.

A note on torn threads

Torn threads can be caused by several factors:

- the die is not sharp (remedy: buy a new die)
- the diameter of the rod to be threaded is above the major diameter of the thread so there is nowhere for the metal to go (remedy: make the shank 0.02 mm smaller than the major diameter)
- the chips have not been cleared by regularly reversing the die to clear the chips
- cutting lubricant has not been used on steel (not normally necessary for brass) (remedy: apply a little cutting compound or spot of oil)
- the die is not presented squarely to the work (remedy: use a tailstock dieholder and make sure the die is seated truly flat).


Checking the screw before it is cut from the rod

How it should look when finished to length


Facing the head to length


Slitting the slot

Finishing the head

This is the last time you will have easy access to the underside of the head, so make sure it has a good finish and is at the correct 45 degree angle. Before cutting off the rod, it might be prudent to check that the thread size is correct for your application, which will also enable you to check that the length is slightly over-long. Remove the rod from the collet and use the excess length as a handle to screw it into the components (see the sequence of photographs). Once satisfied remove from the collet for the last time, and holding the rod in a vice saw off just above the head.

The next step is to turn the head by gripping the screwed thread in a collet. Using very gentle cuts, face off the head until the 2.5 mm diameter is just about to disappear. Deburr the sharp edge.

The slot must now be cut. A slotting file will probably be too large for this size of screw, so if you are not able to use a slitting saw in a lathe or milling machine (photograph) you must cut the slot with a piercing saw. Keep everything as clean and sharp as possible, as any unevenness in the slot of a screw head is very visible in the finished article. Remove the burrs from the underside of the head thrown up by the slotting operation.

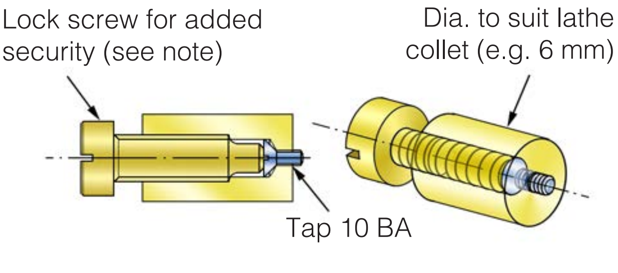
Finishing the screw tip

Once you have made one (or both) pairs of screws, they need to be brought to length. To do this, the countersinks in the chatons first need to be finished. Fit the appropriate chaton to the cock or baseplate and fit the chaton using the screws you have just made. The top of the head will probably stand proud of the surface. Check that this is not because of dirt under the head, a curl of swarf from the slot-slitting operation, or stiffness in the thread or clearance hole. Separate and increase the depth of the countersink in the chaton slightly and in stages until the head is just level with, or slightly (up to 0.1 mm) below, the top surface of the chaton. Make sure the countersunk hole is round and free from chatter marks.

Once the countersink holes are the correct depth, there should be a short length of thread protruding beyond the cock or baseplate, which needs trimming off so that the domed end of the screw just stands 0.1 mm proud of the surface. Measure or estimate how much needs to be taken off and make a note of it.

To hold the screw for turning the end, a sort of ‘stud box’ is needed, which is simply a 6 mm dia. piece of brass (or the largest size that will fit in you lathe collets) about 10 mm long. Assuming it is exactly 10 mm long, centre and drill through the tapping size for your screw (1.05 mm for a 12 BA screw). Open out the hole to 2.6 mm dia. for a depth of 8.8 mm and tap the residual length 12 BA. If you will be taking very light cuts with a very sharp tool that is all you need to do, but for added security the 2.6 mm dia. length should be threaded 3 mm or 5 BA to take a brass lock screw.

STUD BOX FOR HOLDING SCREWS

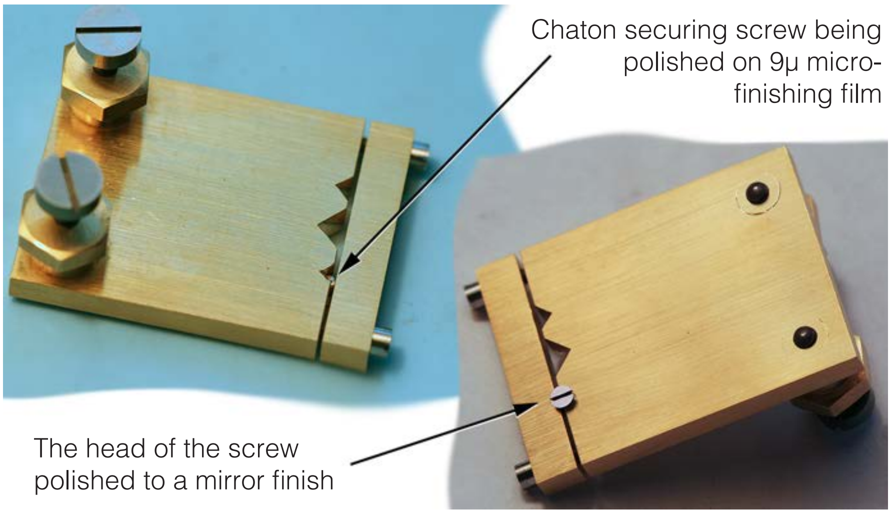


Note: The head of the lock screw may need to be reduced in diameter to pass through the collet bore

You can now fit the chaton securing screw so that it protrudes from the end of the stud box, and tighten it well. Lock it into position is you have made a lock screw. You can now turn the end of the steel thread to the correct length and dome the end, finishing the dome with a burnisher. For the finest finish, the screw will be returned to the stud box for final polishing and burnishing after hardening and tempering.

Hardening and tempering

After hardening and tempering you will need a bolt polishing tool, and if you do not have one, construction of a suitable tool is described in Appendix A. Making such a tool (the one illustrated below) will be of immense use to you in your subsequent horological career.



The next process is to harden and temper the screw, which we must do if we want the head to take a high finish and to minimise bruising of the slot by the screwdriver. Heat the screw to cherry red head and quench in water. Put the screw in a bolt polishing tool and polish the head so you will be able to see the temper colours during the next operation. Using a blueing plate* slip the screw into an appropriate hole and heat to blue before immediately dropping the screw into water. By tempering on a blueing plate with the flame applied to the underside, the tempering colours rise upwards so the tip will be softer (the hardness let down more) than the head, which is what we want in order to trim the thread to length later on. Clean off loose heat scale and dirt, making sure you get all the dirt out of the threads, and dry well. Return the screw to the bolt polishing tool and give the head a preliminary polish so that it is flat all over and free from any remaining turning marks.

* Blueing plate: Typically a piece of 3 mm brass about 20 mm x 50 mm in which a number of clearance holes have been drilled to take the shanks of the screws to be blued. It is fitted with a handle and the plate is heated by a flame from the underside. When the desired head colour is achieved, the plate is inverted over a jar of quenching oil (or water) to let the screw fall out. Below is a photograph of the writer's workshop-made and frequently used blueing plate.

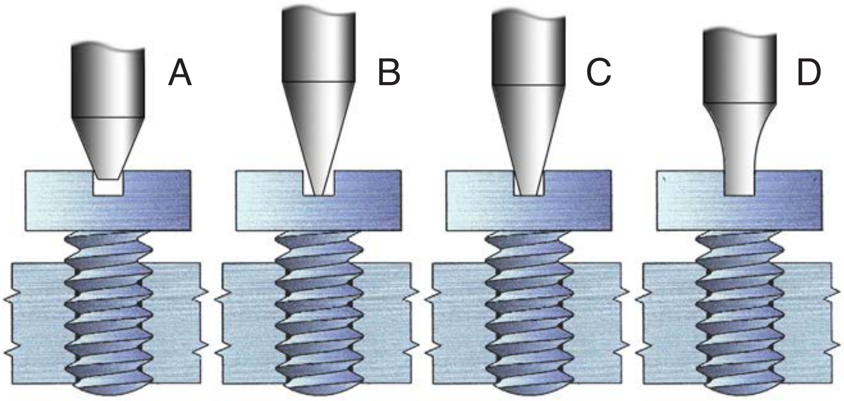
If one wanted the screws left with a blue finish, the screws can be re-blued by repeating the blueing process (but not the hardening (heating to red) process) after final polishing; within reason repolishing an unevenly blued screw can be followed by re-blueing as often as is necessary to get a good, even blue of the desired colour.

Whether the screws are left in a blued or polished finish, tempering is best done by quenching in oil; the high quench rate required when hardening (quenching from red) by the use of water is not needed, and using oil will avoid any rusting.

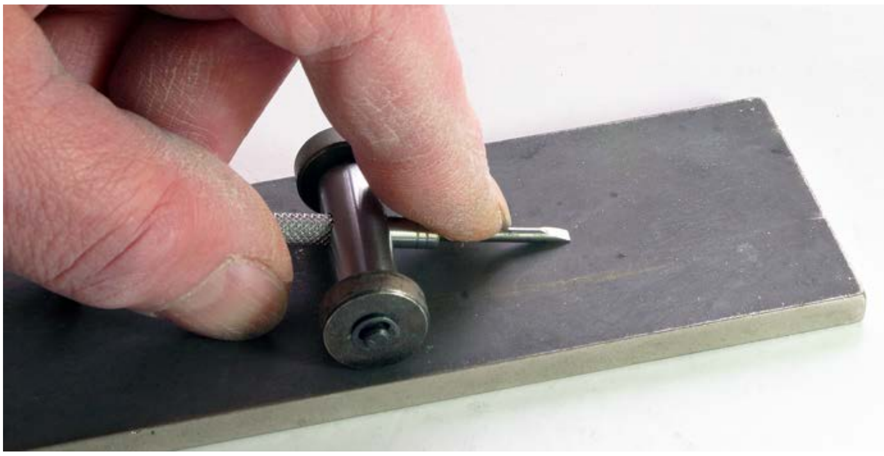
A note on screwdrivers

Before leaving the subject of screws, it is worth mentioning that all one's work will be spoilt if a screwdriver of the incorrect size or tip shape is used.

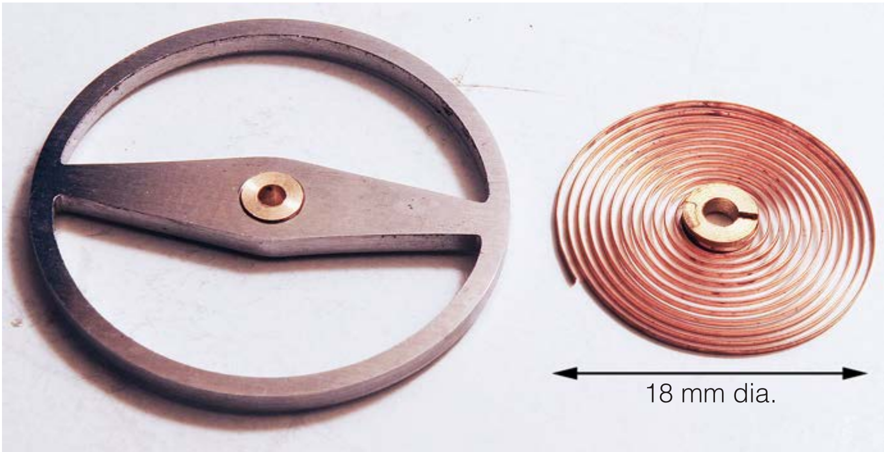
The sketch shows four typical screwdriver tips fitted to the respective slot of a screw. The screwdriver tip at sketch 'A' is bad and will almost certainly damage the slot or surface of the screw head when it slips out, while sketches 'B' and 'C' show screwdriver tip shapes in improving order of merit. Sketch 'D' is ideal, though whether it will be realised in practise for anything other than specialised applications is more questionable.



Finally, the condition of the screwdriver tip is important; if worn or rounded (or used to open tins!), there will always be a far greater risk of the screwdriver slipping out and marking the screw. Consequently, screwdrivers should be reshaped if showing signs of wear, watchmakers' screwdrivers most conveniently reshaped to shape 'B' and 'C' by using a commercial screwdriver polishing tool on a diamond stone as shown.



7. The balance



Design and drawings

The natural frequency of oscillation of a spring/balance is determined by the moment of inertia of the balance wheel and the stiffness of the balance spring (sometimes called the hair-spring). This is not easy to determine as it requires a detailed knowledge of the disposition of the mass in the balance, which we will not attempt to calculate.

The balance Suffice it to say that the more the mass is concentrated at the rim, the greater the moment of inertia which, to minimise mass (weight) and maximise inertia, is why balances are crossed out to leave the bulk of the metal in the rim:

- increasing the mass of the balance (and especially the balance rim) will increase the period of oscillation (slow it down).

The balance spring In order for the balance to become an oscillator, it needs to be combined with a spring – the balance spring. For a given material, the stiffness of the balance spring is determined by its length and cross-sectional dimensions:

- increasing the stiffness of the spring will reduce the period of oscillation (speed it up).

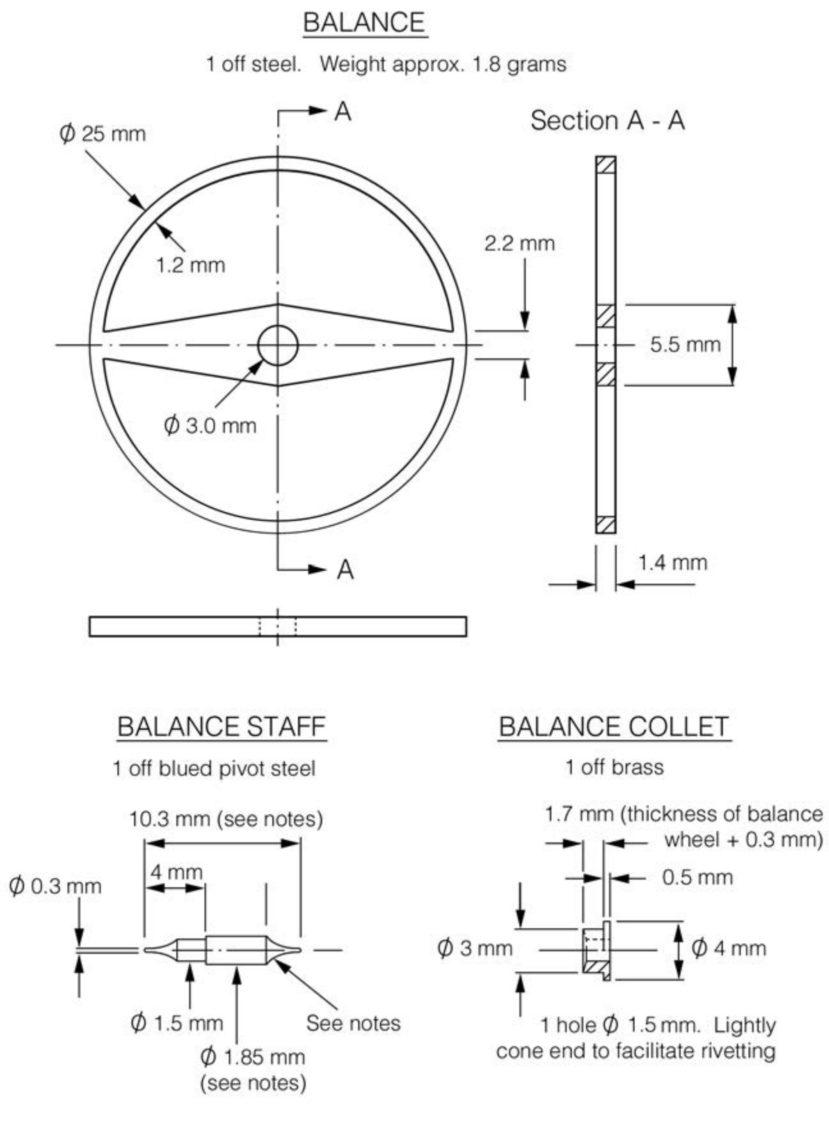
Period of oscillation To bring a balance and balance spring assembly to the required period (rate or frequency of oscillation), two methods are used in combination:

- to vary the moment of inertia of the balance, timing screws (weights) on the balance rim can be added, adjusted or removed. The lighter the balance (rim), the faster the rate of oscillation (shorter the period), and
- to vary the stiffness of the spring the effective spring length can be adjusted by means of the index on which the curb pins or boot are fixed. The shorter (stiffer) the spring the faster the rate of oscillation (the shorter the period).

In this vibrating tool we will be making a plain uncompensated balance. Timing screws will not be fitted to the rim so the moment of inertia cannot be adjusted, and the design will rely solely on adjustment of the length of the balance spring by means of the index. As the balance is uncompensated (it is not a split bimetallic balance), the rate will vary with temperature which we will briefly discuss in Chapter 12.

To suit most platform escapements and watches we need a rate of 18,000 beats per hour, which can be restated as a period of oscillation of 0.4 seconds (scientific notation) or, in horologists' notation, a frequency of 5 beats per second. Note that scientific notation defines the period over one complete cycle; horologists' notation defines the period over half a complete cycle. Beats per hour is a horologists' notation for frequency, and each beat per interval of time represents twice the scientific frequency (18,000 beats per hour = 9,000 (scientific notation) cycles per hour).

The balance has been proportioned (sized) to accept balance springs that are readily available at the time of writing; if you vary the dimensions or mass significantly (and this includes making it in a material of a different density to the steel chosen (e.g. brass), the balance spring may not be suitable.



In the balance shown on the drawings, the rim is not raised up partly to simplify the crossing out and partly because a greater rim depth to accommodate timing screws is not needed. In addition the balance is riveted onto a collet rather than directly onto the balance staff, so that should things go wrong during its construction, the balance and/or balance staff will not have to be scrapped and a new one made.

Materials required

- steel disc 25 mm dia. x 1.5mm thick
- short length (25 mm) of 4 mm dia. brass rod.

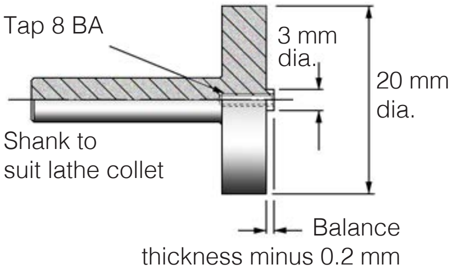
Construction – balance wheel and collet

Take or cut a disc of steel slightly larger than 25 mm diameter from dead-flat 1.5 mm steel sheet. Chuck in the lathe using a four-jaw chuck so it runs as truly as possible and drill and ream a hole 3.0 mm diameter at its centre. Deburr the edges of the hole. If you do not have a reamer, do not worry; just drill the hole 2.9 mm dia and broach to make it a snug fit on the spigot of the stub arbor we will be describing next.

Note: Coincidentally the balance wheel is slightly smaller than the size of a UK two pence piece, those made after 1991 being copper-plated steel. As it is illegal to deface coinage, a two pence piece cannot be used legally as a source of material.

Make a stub arbor with a spigot of 3.0 mm dia. that protrudes by 1.2 mm and drill it centrally for a depth of 8 mm. Tap the hole 8 BA or similar. Make sure the stub arbor is running true to the lathe centres (for example, by holding in a collet or four-jaw chuck) and mount the disc on the stub arbor. Clamp the disc to the stub arbor with a washer and 8 BA screw, and turn the outer diameter to 25 mm.

STUB ARBOR FOR BALANCE



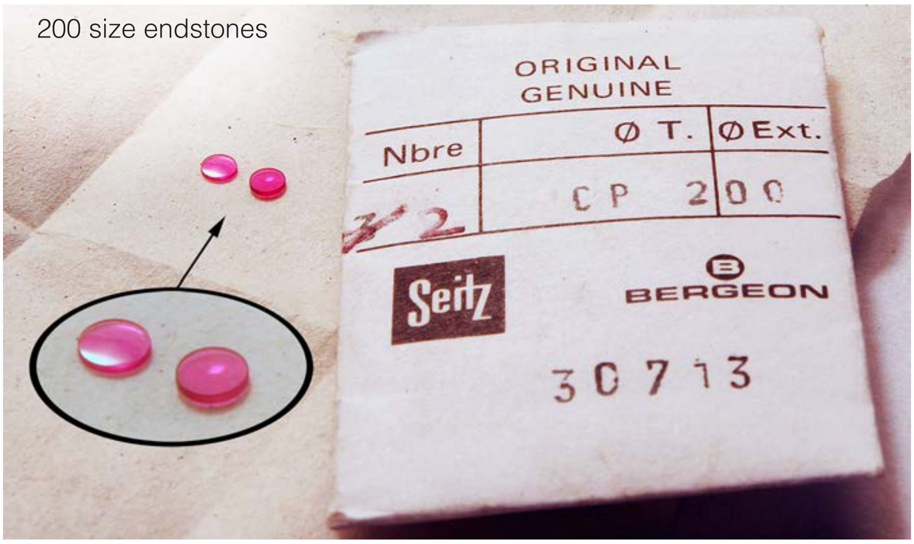
Once the balance wheel has been brought to its outside dimensions, mark the balance wheel for the spokes and crossing out. After drilling a 2 mm dia. hole at the four corners where each cut-out will be, insert a piercing saw blade and cut out the waste material. File the two spaces to the shape and dimensions given. Filing the rim to its correct width (inside diameter) can be simplified by the use of a filing jig (a variation of the filing button - see Chapter 4), which is turned and hardened from silver steel as shown in the photograph, though as it will blunt the needle files you should not use your best files. Final draw-filing of the edges is done with the balance wheel removed from the jig.

The balance wheel is finally finished on its upper and lower surfaces by rubbing on a fine diamond stone or wet and dry paper. The surfaces may be polished if you wish.

The weight of the balance should be not exceed 1.8 grams or the balance spring will need to be made excessively short to get the correct 18,000 beats per hour. This is important, so it is necessary to weigh the balance and, if necessary, remove more metal until the weight equals 1.8 grams.

The next step is to make the brass balance collet which is a simple turning job, though it is as well to leave the central hole slightly small so that it can be broached to a good push fit on the balance staff once it has been made. Once complete, the bush can be riveted into the centre hole and the riveted end brought flush with the surface of the balance wheel before re-finishing the balance wheel face to the same standard as the upper surface (the side with the flange of the bush). Annealing the brass bush before riveting will make the riveting easier.

8. Jewelling and the balance staff



200 size endstones

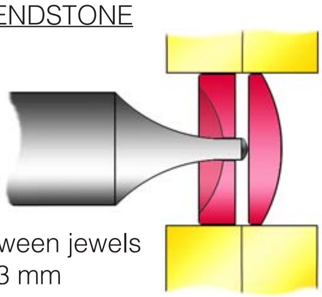
Design

The relationship of the jewels and balance staff pivot is important, so take a look at the arrangement sketch below if you are not familiar with jewelled pivots. Traditionally jewel holes and end stones were 'rubbed-in' to brass chatons, but today friction fit jewels can be pressed directly into the brass.

Friction fit jewels are available in a wide variety of shapes and sizes, and the recommended jewels are listed below. Other sizes are acceptable; the outside diameter is of no great significance for this application, so if 200 size jewels (2 mm outside diameter) are not available use whatever size you have, though bear in mind that if they are smaller this may require some adjustment to the jigging arrangements that centralise the cock to the baseplate. The end stone does not have to be the same outside diameter as the jewel hole.

The hole size is a little more important; too large and the balance will come to rest more quickly than a balance fitted with smaller diameter pivots (and hence smaller jewel holes). Too

ARRANGEMENT OF JEWEL HOLE AND ENDSTONE



small and the pivots may be too fragile for a workshop tool. The balance wheel is larger than a typical watch or even a platform escapement balance, so it is suggested that you aim for a hole size between 20 and 30 (20/100 to 30/100 or 0.2 mm dia. to 0.3 mm dia.), the smaller the size the lower the frictional torque and therefore the longer the balance will maintain a reasonable amplitude of oscillation after it has been set going. If this is the first time you will be making balance staff pivots a larger, a 30 size jewel hole bore may be the most appropriate.

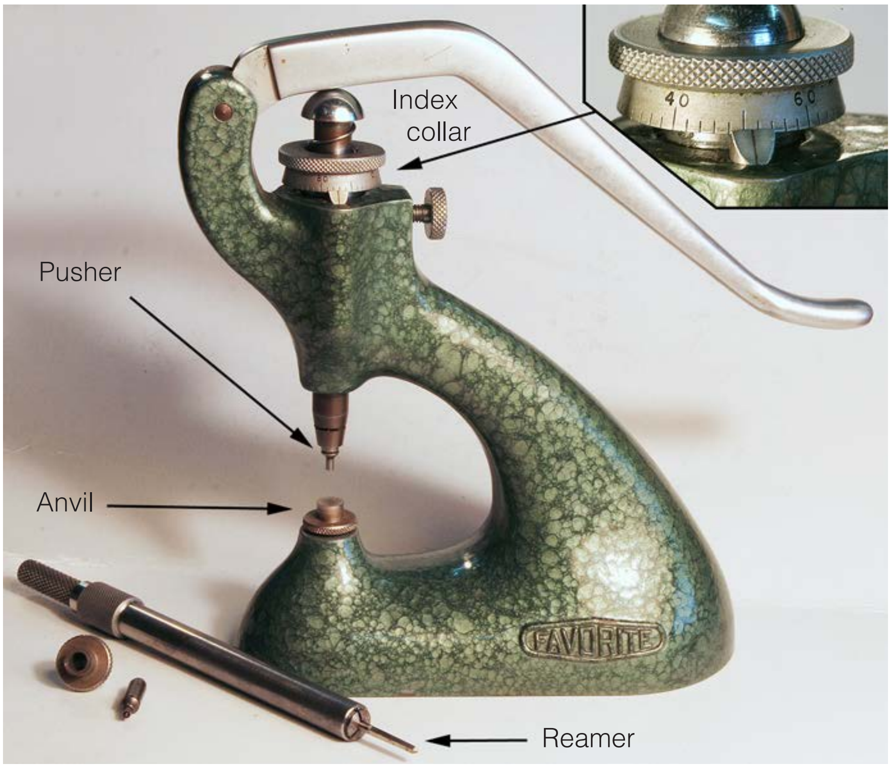
If you cannot source endstones it would be possible to replace the endstone chatons with dead hard polished steel discs made from silver steel, which would be perfectly adequate for demonstration purposes. The top end stone in particular could easily be made of hard steel polished to a high finish; being at the top it carries no weight at all and so is subject to very little wear.

As the turning the balance staff pivots requires the jewels to be at hand, so a description of the manufacture of the balance staff is included in this Chapter.

Jewelling

Although it is possible to fit jewels without a jewelling tool, using an appropriate tool will make it far more certain. This design uses friction fit jewels which are much easier to fit than the old rub-in jewels. Friction fit jewels are made to very accurate tolerances and are simply pressed with a very slight interference fit into the chaton or other component into which they are fitted.

Jewelling tools come with precision ground reamers designed to ensure the correct interference fit, and most have a graduated collar at the upper end which controls the depth to which the jewel is pressed. A selection of pushers and anvils is provided to suit the various sizes of jewels.



Materials required

- 2 off size 200 x 30 train jewels (available in packs of three)
- 2 off size 200 endstones (available in packs of three)
- length (100mm) of blue pivot steel, 1.85 mm dia.
- short length (50 mm) of brass wire 1.6 mm dia. (16 gauge or 1/16 in.)

Fitting the endstones

The steps in fitting an endstone are illustrated in the sequence of numbered photographs.

1. The first step is to ream the hole in the upper and lower endstone chatons, which is done by fitting the appropriate sized reamer into the colleted reamer head. The reamer is fitted to the jewelling tool and the central hole in the first chaton reamed to just short of the full length of the flutes. Use a hollow anvil. Very lightly deburr the edge of the hole so that when the jewel is pressed-in no burr will be raised by any metal deformed by the pressing-in operation.

2. The reamer head is removed and an appropriate size pusher fitted. If you are using 200 size endstones, a 180 size (1.8 mm outside diameter) pusher is appropriate. The first chaton

1. Reaming to 2.0 mm dia.

2. Adjusting the index collar

3. Pressing in the endstone

4. The endstone fitted

is placed the correct way up on a solid anvil and the pusher pressed against the chaton so the index collar can be adjusted so the chaton just slides between the gap between pusher and anvil. Note the index collar reading. The index collar is now lowered by about 10 graduations or 0.1 mm so that when the jewel is pressed in, its flat face will lie just below the surface of the chaton.

3. Now place the endstone convex side down on the chaton and position the chaton so the pusher is perfectly central on the endstone. Press the endstone into the full depth as set by the index collar, making absolutely sure that it stays flat to the surface of the chaton.

If you have to use what appears to be excessive force on the lever, you may need to ream the hole out slightly by repeating the reaming operation to a slightly greater depth. This is a process which requires a knowledge of your jewelling tool and its idiosyncrasies. If you open the hole out too far and the endstone drops through, you have two choices; either start again with a new chaton or use a larger diameter endstone. Punching-up the hole and re-reaming is not recommended.

4. Once complete make sure that the flat face of the endstone is just slightly below the surface of the chaton. Repeat for the second endstone chaton.

The balance staff

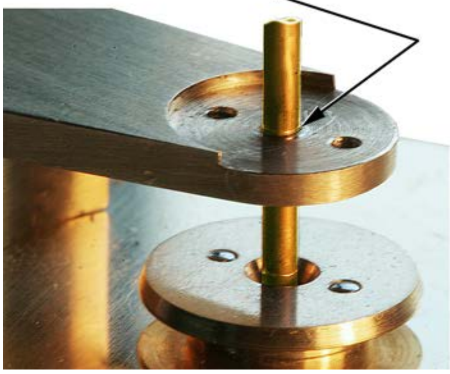
Shown in the drawing in Chapter 7, the balance staff is of a simple form as it is anticipated that this might be your first exercise in turning pivots to fit jewel holes. Before you start you need to have the jewel holes you will be using to hand so that you can try the fit as the final finishing cuts are taken on the pivots. In the drawings it is assumed that you will use 30 size jewel holes (0.3 mm bore).

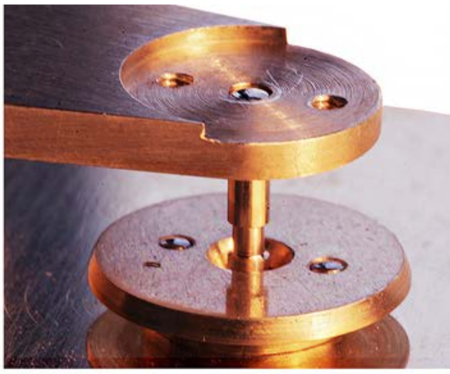
You also need to have the balance spring to hand; as the split in the centre collet will prevent it from being opened out by a cutting tool (drill, reamer or cutting broach) the balance staff needs to be the correct diameter for the collet.

Now make up a dummy balance staff to ascertain the length between endstones. To do this the balance cock and lower endstone chaton are fitted to the baseplate. Make sure the mating surfaces are scrupulously clean and free from burrs before fitting them.

1. Take a piece of 1.6 mm dia. brass wire and radius and polish one end in the lathe to a slightly domed shape. Remove the wire from the lathe collet and slip it though the holes for

1. A 1.6 mm dia. brass rod is inserted and the length of the balance staff marked with a scriber





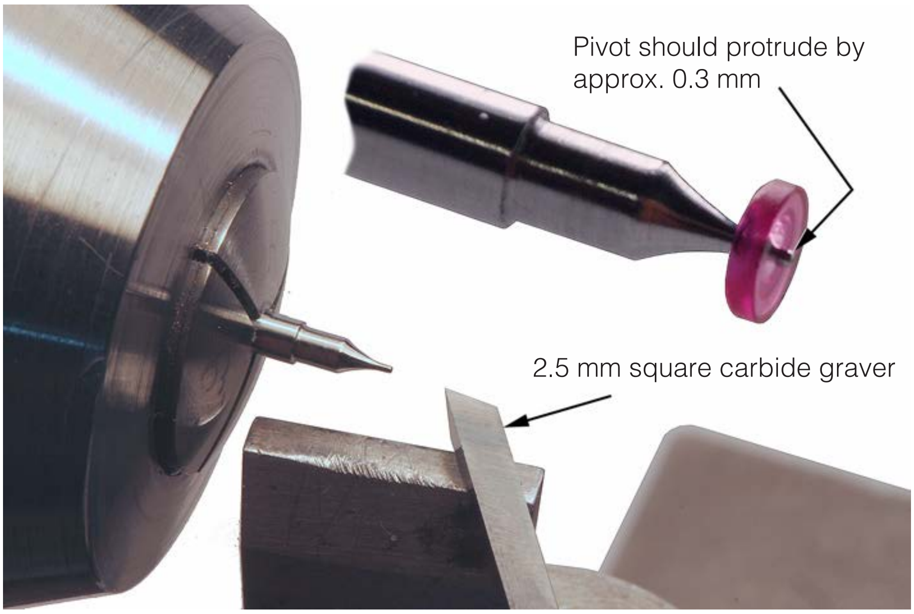
2. The brass rod is brought to length to make a dummy balance staff of the correct length

the balance staff jewels in the cock and baseplate so that the radiused end rests on the lower endstone. Mark with a scriber and cut off.

2. Turn the dummy balance staff to the exact length by a process of trial and error so that there is just a perceptible amount of end shake when the upper endstone chaton is fitted. Again make sure the end is domed so it rests on the endstone and not the edge of the hole. Measure its length with a micrometer or digital calipers and set it aside.

The balance staff proper can now be turned. If you have access to 1.85 mm dia blued pivot steel, this is ideal for the balance springs recommended, which are a good fit on a slightly-expanded 1.80 mm dia. split collet. However, the main thing is to ascertain what size you need to suit your selected balance spring centre collet. A little more will be said about this in the next Chapter.

Turning pivots is not easy and you will probably have to make several attempts, especially when turning the second end as it is essential to get the length overall a perfect fit between the endstones. Using a graver and tee rest, turn the pivot to the shape shown, taking very fine cuts as you near the final size. You can measure the tip diameter with calipers, making sure that you achieve a fine finish before trying the jewel hole onto the pivot. When it just won't fit (if that makes sense), set up the jacot head in the tailstock and burnish with a burnisher. It is probable that the tip will be slightly tapered so you will need to turn it parallel for the last few fractions of a millimetre until it fits with the tip protruding as shown. There should be no perceptible sideshake and the jewel, having a parallel hole, it should show very little sign of wobbling when on the pivot. It will be given its final freedom when burnished for the very last time.



Describing what is wanted is difficult, and the only way to learn is by making pivots. Once you are satisfied with your first pivot, turn the 1.5 mm dia. portion to the length shown on the drawing and bring it to a fine finish. Remove the pivot steel from your collet and cut to length using your dummy balance staff as a gauge.

The second end is now faced off to 0.1 mm over-length and the pivot turned in the same way as the first. Once the pivot fits in the jewel hole you need to bring the staff to an identical length to the dummy balance staff. If you are uncertain of your ability not to bend the pivot with the graver when reducing its length, a fine stone can be used, removing and checking the length and fit frequently as you near the finished size.

Finally burnish the pivot diameters using a Jacot tool and burnisher, treating the ends of the pivots at the same time to bring the length exactly the same as your dummy staff. Keep your dummy staff in case you have to make a replacement staff for any reason.

Fitting the jewel holes

Now the jewel holes can be fitted to the cock and baseplate using much the same technique as for the endstones. If your jewelling tool has them, a pusher that has a sprung-loaded centre can be used so as to makes sure the hole is being pushed centrally and hence evenly into its housing. The jewel hole should be pressed in to lie about 0.2 mm below the surface of its chaton, which will ensure the pivot runs on its full diameter (not the domed end) and allow a space for a drop of oil (see the arrangement sketch at the start of this Chapter). Finally try the balance staff in position and check that it runs freely without any perceptible sideshake and just a perceptible touch of endshake. If it does, congratulations – you have made your first balance staff!

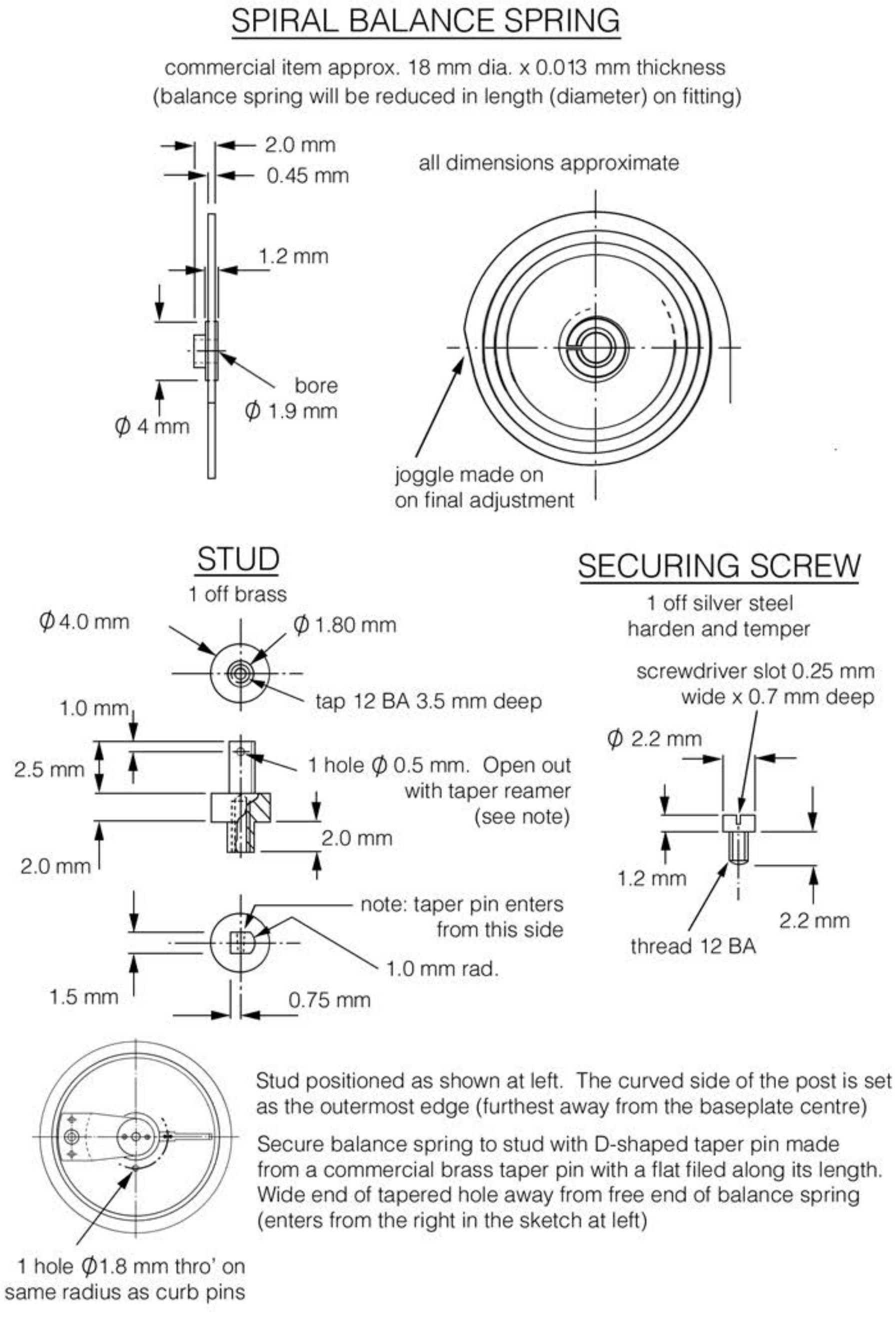
Now broach out the bush in the balance wheel so that it is a light push fit on the 1.5 mm dia. part of the balance staff. Very lightly chamfer the hole at the shouldered end so it seats well against the shoulder of the staff. If you broach out the hole too much you will probably have to make a new bush, so take great care with this operation.

A first fitting of the balance staff with jewel holes and endstones pressed in place

A first fitting

After all the work so far, you are now in a position to assemble the balance for the first time to see if it swings freely. If it does you will probably find that it is not 'poised' (balanced), always coming to rest in one position when held on its side. While this is not critical for a vibrating tool that only has to work in an upright position (i.e. with the staff upright), it is good practise to bring it as closely as possible to being in poise. As there are no posing weights fitted to the balance rim, this can only be done by filing metal from the edge of the spokes or the inside of the rim.

9. The balance spring and stud



Design and drawings

Many designs of stud can be found in spring-balance clocks and watches, and all make use of a D-shaped taper pin to secure the end of the balance spring in a circular hole. But when it comes to the location of the stud in the frame or cock the designs vary considerably, and can perhaps be categorised under three headings:

1. a circular, friction-fit peg with neither vertical nor rotational constraint. Commonly found in wrist watches where space is at a premium and cylinder platform escapements. Some variants may be shouldered to offer axial restraint.
2. a triangular peg or a circular peg with a vee-groove planed in it and given vertical and circular restraint by a set-screw tightened onto the flat side (triangular) or into the vee-groove. Perhaps the most common type today, and found in many lever escapements
3. an angular stud located by an adjacent flat face and secured by a screw. Generally found in chronometers with helical balance springs and occasionally other free-sprung escapements. No vertical adjustment is possible.

The first type is very neat and might seem the easiest to make but in reality obtaining a perfect friction-fit is not easy, and the fit will suffer if the stud is removed several times during final assembly. Best suited to batch production with a standardised balance and balance spring where the initial fit of the balance spring can be sure to be correct.

The second type is equally neat and is an excellent solution, ensuring that the stud goes back in its correct circular position every time it is fitted, with vertical adjustment to ensure the balance spring lies truly flat. But for our vibrating tool there are two big difficulties; there is no easy location for the set-screw, and making a wobble-free peg and triangular hole in the baseplate or cutting a longitudinal V-groove in the peg requires considerable skill.

For the vibrating tool, an easy location for the set-screw might be created by rivetting a 5 mm dia. boss standing proud of the upper surface by 2.2 mm high, which could be tapped to take a set-screw. But the problem of cutting the vee-groove remains.

The third type is less neat but entirely possible, especially if two screws (or one screw and a steady pin) are used to secure the stud to the baseplate in the absence of an adjacent flat locating surface.

With all these issues to consider, the simplest design is perhaps a simple post as shown in the drawing. As it offers no vertical adjustment, getting the balance spring flat when in position requires the balance spring to be adjusted axially (vertically) on the balance staff. Nevertheless, it is this design that will be described.

The balance spring is not an easy item to make and few horologists will ever attempt it, so this tool uses commercial balance springs. From the assortment mentioned below, the most suitable balance spring is the largest diameter spring with a stepped centre collet. The balance staff on which it fits has no axial location shoulder so that the balance spring can be adjusted axially to ensure there is no 'wobble' when oscillating.

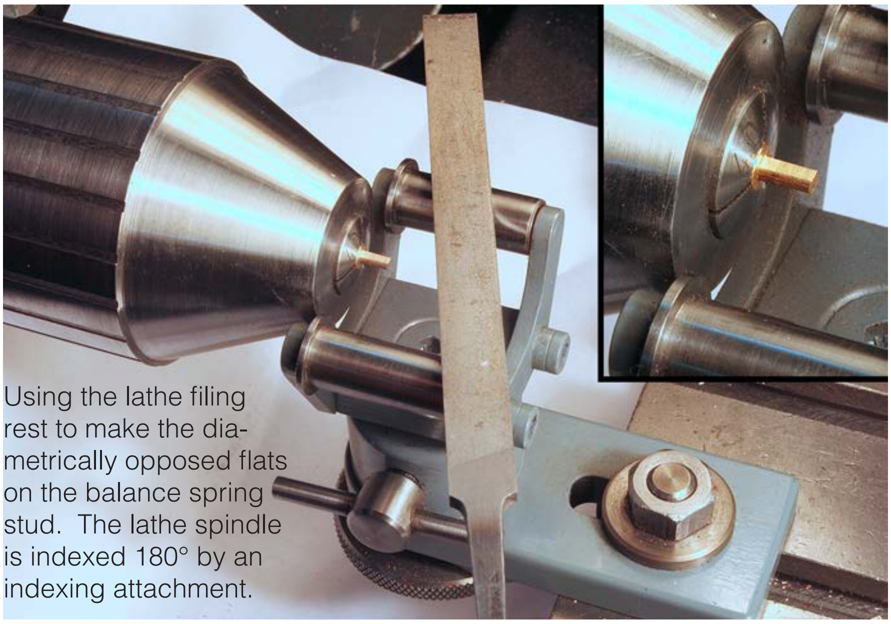
Materials required

- balance spring. Bronze clock balance springs are available from most material dealers in assortment boxes of 72
- short length (50 mm) of 4 mm dia. brass rod
- selection of small brass taper pins.

Making the stud

Take a length of 4 mm dia. brass rod and drill and tap the end 12 BA, finishing with a plug or bottoming tap. Now turn the peg to 1.8 mm dia., making sure you very slightly undercut the base so it bears on the baseplate at its outer 4 mm diameter. As the base is larger in diameter than the underside of the securing screw head (4 mm cf. 2.2 mm dia.), the greater frictional torque will help prevent the stud from turning when the screw is tightened from beneath.

Cut off and reverse in the collet, and turn and file the stud post to the dimensions shown. A lathe filing rest helps to get the three flats at right angles and of the same depth. The two opposing flats could be omitted, but not only do they make drilling the cross hole for the balance spring easier but also proved something to grip when bringing the stud to its correct alignment when tightening to the baseplate. The third flat should not be omitted as this provides clearance for the balance spring coil one in from the outer coil.

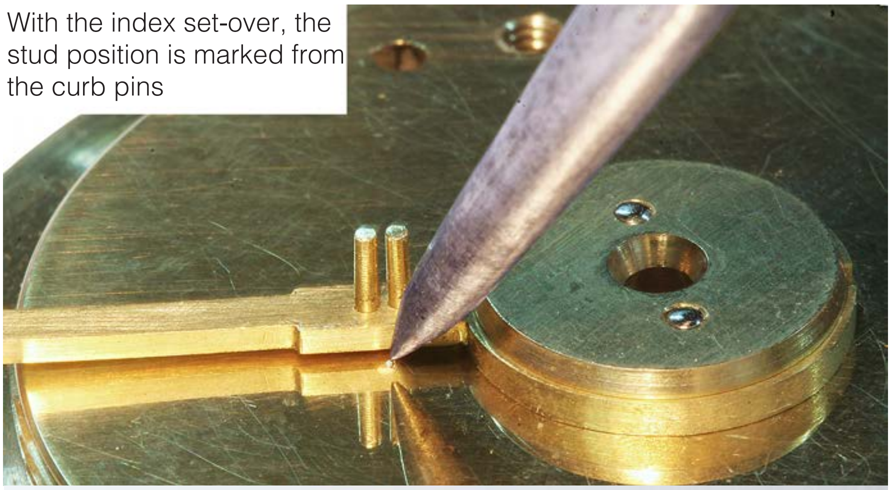


Using the lathe filing rest to make the diametrically opposed flats on the balance spring stud. The lathe spindle is indexed 180° by an indexing attachment.

The cross hole is drilled 0.5 mm dia. and opened out gently from one side with a broach. Make sure you broach with the point in the same direction as the end of the balance spring. Once the taper broach is cutting for the full length of the hole, stop and lightly deburr the open ends. Prepare a small brass taper pin by filing one side flat to give a D-shape and, with the clearance flat on the inside, try to fit it into the hole alongside the balance spring. Adjust the taper pin (you may need to make several to get a good fit) and/or the hole until the balance spring is nicely held. On final fitting the taper pin should protrude about 1 mm each side.

Finally make the 12 BA cheesehead screw, making sure that the underside of the cheesehead is smooth and the corner very slightly radiused so that it (rather than the stud) will rotate when tightened. Also make sure it is does not bottom in the threaded hole; if it does you must cut the threaded hole deeper or shorten the screw. Finish by hardening, tempering and polishing.

The stud must be fitted so that its centre is at the same radius as the gap between the curb pins from the centre of the balance staff. If it is not, the symmetry with which the balance spring expands and contracts ('breathes') as the balance oscillates will be uneven. Fit the index to the baseplate and mark the stud position from the centre of the curb pins, and drill slightly small. Now very carefully broach the hole in the baseplate so that the spigot on the stud is a good fit, making sure the peg is slightly short of the end of the hole in the baseplate. Fit the screw to check it tightens properly.



With the index set-over, the stud position is marked from the curb pins

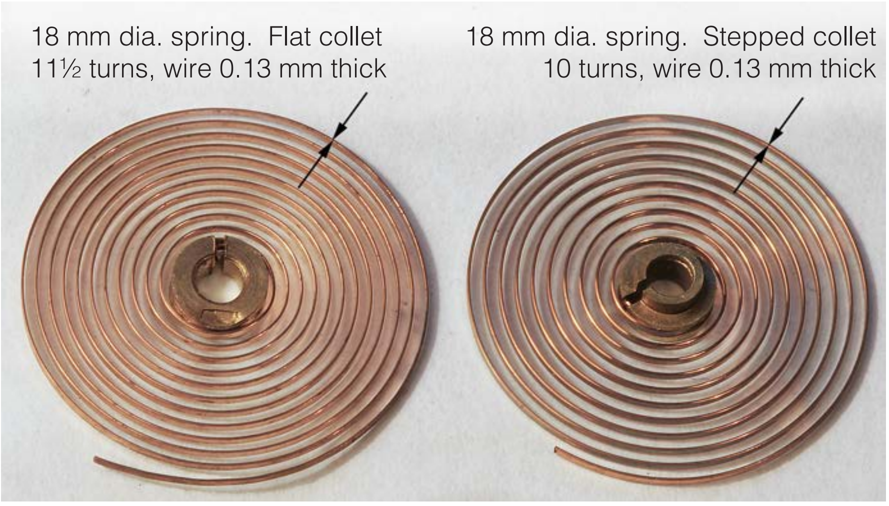
Once you have completed this job we are in a position to prepare and fit the balance spring and make a preliminary assembly, so clean all components thoroughly and re-assemble in preparation for this next process.

Preparing the balance spring

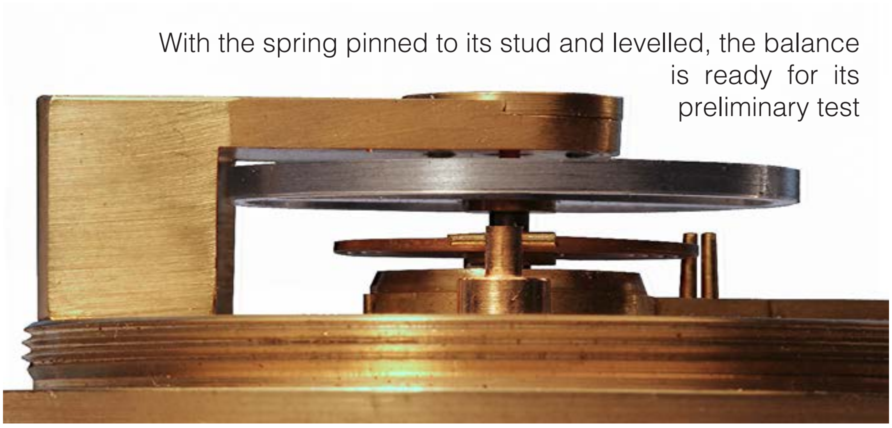
As mentioned in Chapter 8, the balance staff diameter has been determined on the basis of the internal bore of the balance spring split collet. From the recommended assortment of balance springs (which are in a bronze rather than a steel or other more exotic material), two are possible and these are illustrated. Both springs are too long to give 18,000 bph for the balance wheel as dimensioned, but this is no great problem as they are also too big in diameter. The balance spring should be about half or a little over half the diameter of the balance wheel.

Note: At around 100GPa, bronze has a considerably lower modulus of elasticity than steel (approx 200GPa), so if you use a steel balance spring with a similar cross-section either the length of the balance spring or the mass of the balance will need to be increased.

It is suggested you choose the slightly wider-spaced 10 turn spring as it will require less turns to be cropped off; in the prototype it was found that about 2½ turns needed to be cut off to give 18,000 bph, leaving the diameter just over half that of the balance wheel. Care is needed in handling them so they are not unintentionally distorted.



Make sure any burrs are removed from around the balance spring collet hole edges and check the fit. If the collet is too tight it can be opened out by lightly tapping a second-grade tapered smoothing broach into the bore to expand it so it is a firm but gentle push-fit on the balance staff. If you open it up too far, close the collet gently with a pair of pliers. Once it is a nice snug push fit, ease it into position so that the spring lies along the 1.85 mm dia. parallel portion equidistant between the underside of the balance wheel and upper side of the index.



It is now possible to assemble the tool for a preliminary trial fitting to check all is well. As it will be necessary to assemble and disassemble the balance several times, it is probably best not to lubricate the balance staff pivots at this stage as the oil will only attract dirt.

Referring to the photograph above, note particularly that:

- the gap between the curb pins allows the balance spring a slight freedom (11/2 to 2 times the spring thickness)
- the balance spring is neatly pinned to the stud, and
- the balance spring is flat and level, which is achieved by adjusting the axial position of the balance spring collet on the balance staff and ensuring the D-shaped taper pin has not rotated in the hole in the stud to cause the end of the spring to be twisted.

10. Preliminary timing

Procedure

One thing that will be useful to know is the effect of the length of the balance spring on the number of beats per hour. To do this (assuming you have used the suggested spring), first install the balance spring cropped with one full turn; if you do you will find that the number of beats per hour is quite low (around 16,000 bph), so it will need cutting to an even shorter length in order to achieve 18,000 bph. Of course you may wish to achieve 14,400 bph suitable for a marine chronometer in which case the longer, 11½ turn spring is more suitable.

For the 10-turn 18 mm outside diameter balance spring suggested we can calculate the very approximate effect of a length reduction on the increased number of beats per hour (bph) and this is tabulated below.

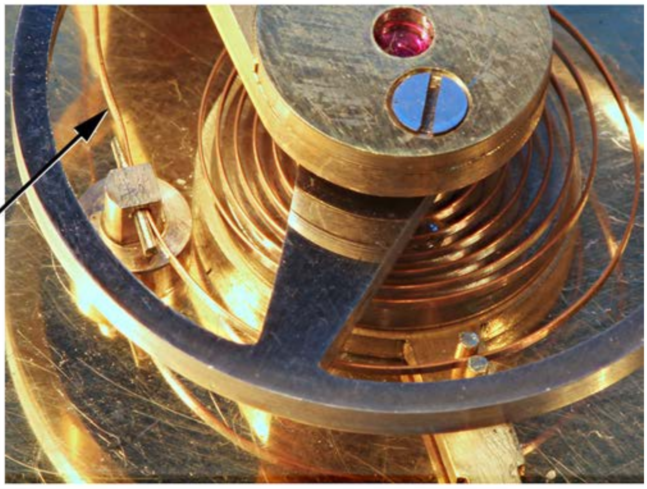
Removal of one complete turn	Percentage increase in bph	Outside dia. of balance spring
None	0%	18
Turn 1 (outer turn)	7%	16.7
Turns 1 & 2	13%	15.4
Turns 1 to 3	19%	14.1
Turns 1 to 4	24%	12.8

Example: 1.4 mm thick steel balance wheel, mass 1.8 grams fitted with a 10 turn balance spring 18 mm dia.
Required bph = 18,000; timed bph (by timing machine) = 15,120
Therefore the percentage increase required = 100 x (18,000 – 15,120)/18,000 = 16%
From the above table, this suggests about 2½ turns in total need to be cut off the balance spring.

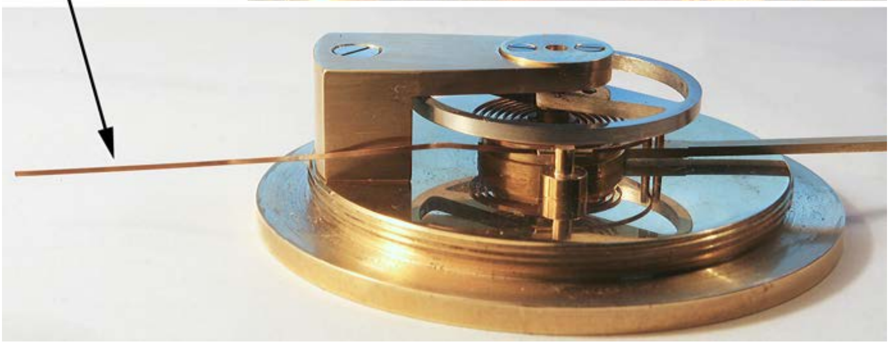
As mentioned before, the balance spring is ideally about half the diameter of the balance wheel or slightly larger, so if you need to remove more than four turns you should consider reducing the thickness (and hence the mass) of the balance wheel or (if possible) selecting a stiffer spring.

You do not need to make the joggle at this stage or worry whether it 'breathes' particularly evenly as it oscillates, but do make sure that the coil one turn in from the outside of the balance spring does not touch either the innermost surface of the inner curb pin or the inside of the stud when set oscillating; not only will this affect the period of oscillation but the friction caused by the spring coil dragging on the touching surface will quickly bring the balance to rest. Some careful manipulation of the balance spring may be necessary to make sure this doesn't happen, and if you have set your curb pins to the dimensions shown on the drawing, probably the best way to do this is to remove one complete coil (turn) from the balance spring before even starting as suggested above.

With the balance spring fitted to the balance staff and the tool fully assembled, thread the outer end of the balance spring through the stud and pin with the D-shaped taper pin. Once you are satisfied the balance spring is clear of all obstructions, give the balance an initial twist of half a turn (turn the spoke through 180 degrees) and let it go. The balance amplitude should not fall ('decay') below 90 degrees (i.e. half its original amplitude) for at least 60 complete oscillations (120 'beats'). If it does, then either there is excessive friction in the balance staff pivots or the balance spring is rubbing on something. Going on further is pointless until this has been corrected.



Preliminary timing: after each rate check, the excess length of the balance spring is pulled through the stud and repinned. Cropping to its final length is left until the end.

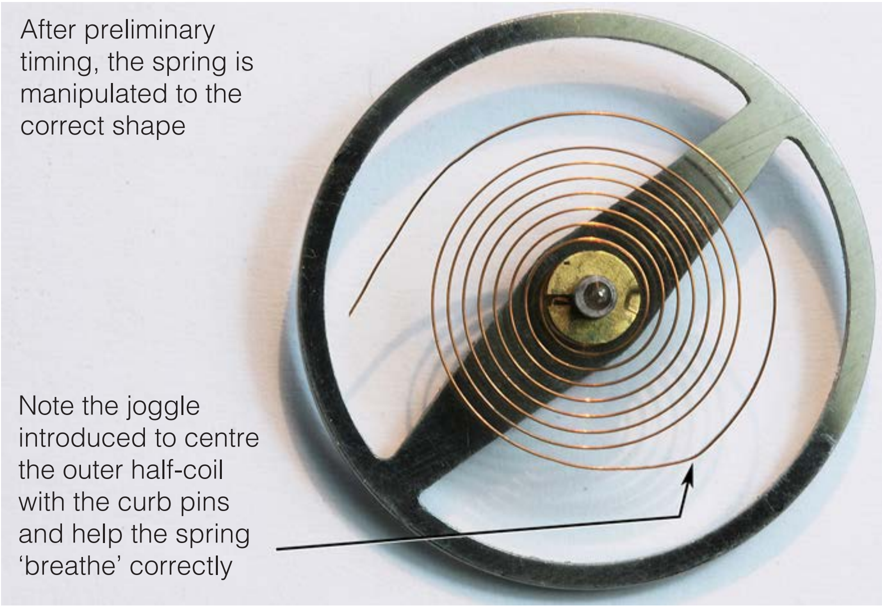


A timing machine such as the one shown is now set up using the optical sensor. If you do not have one, timing will be difficult, but a close approximation can be obtained by visually comparing the balance with a pocket watch from which the back has been removed. An acoustic pick-up is not useful as there is no escapement to tick.

Set the optical sensor to 'observe' the balance wheel spoke. Set the timing machine to average ten counts, and set it going. Now give the balance a 180 degree turn and let it go, and after ten oscillations (half cycles or 'beats') a reading will appear and then be refreshed every

ten counts thereafter. It would be very surprising if the count were anywhere near the desired 18,000 bph so you must now loosen the D-shaped taper pin and pull a length of the balance spring through the stud. Re-pin the balance spring. The spring will again probably need some manipulation to get it approximately concentric and clear of any obstructions, which can be done with tweezers.

Once you have got it to within ±100 bph (i.e. between 17,900 and 18,100 bph), this is probably as close as reasonably practicable at this stage.



Now the spring is at its approximately correct length, cut it off about 5 mm to 10 mm overlong. The spring must now be brought to its final shape by manipulating it with tweezers, the aim being to ensure:

- the spring is flat
- the radius either side of the index mid-point is constant so that adjustment of the index does not distort to the balance
- the spring is concentric with the balance staff
- the spring should 'breathe' evenly (concentrically) about the balance staff as the balance oscillates
- the balance should oscillate at between 17,950 bph and 18,050 bph with the index centralised.

Once you are satisfied strip, finish and polish any parts that still need it before a final clean. Reassemble the vibrating tool, this time lubricating the pivots with a tiny drop of oil such as Moebius 8010 placed in the centre of each endstone.

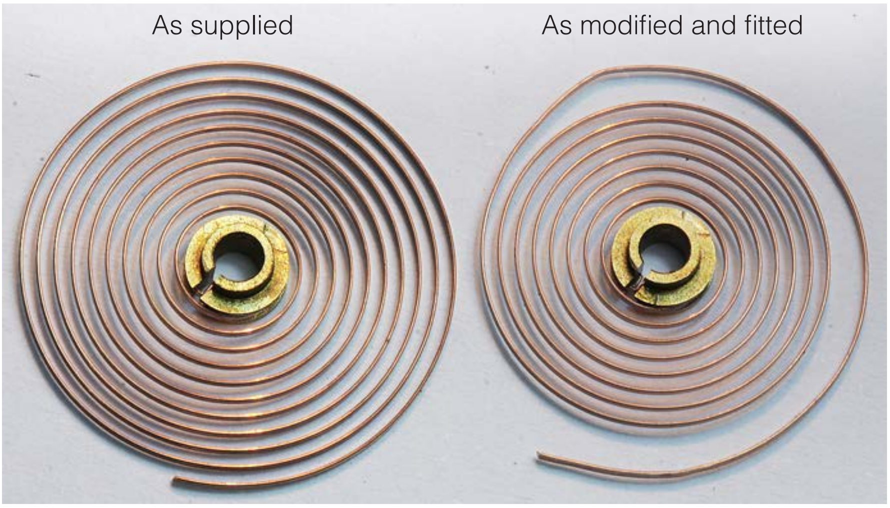
Repeat the pinning and timing as before to bring it to as close to 18,000 bph as you can, again ensuring that the decay to half the initial amplitude takes more than 120 beats (50 complete cycles). It is good practise to get as close to the required bph with the index centralised, using the index only for small final adjustments. A useful refinement that will make testing easier is to adjust the balance spring collet on the staff so that the spoke lies in line with the axis of the cock and the centralised index when the balance is at rest.

Isochronism

Isochronism is a word that (in this case) means the period of the spring/balance assembly does not vary as the amplitude of the balance changes. Unless you are extraordinarily lucky, you will have noted that the measured rate changes as the balance amplitude decreases; i.e. the balance is not isochronous. Correcting for the balance being anisochronous ('not isochronous') is something that is not within the scope of this practical exercise, partly because the basic spring balance is never going to be that accurate due to the use of a balance spring that may be mismatched to the mass and dimensions of the balance wheel, and partly because of the generally simplified design. Moreover, in a real watch or clock fitted with an escapement, the escapement itself introduces errors, which can to some extent be compensated for by the anisochronism of the basic spring-balance assembly.

'Springing' as it is known in the trade is a highly skilled job, and factors such as the total number of turns in the coil, the number of quarter turns above or below a whole position of the start point to the end point (number of quarter turns on the coil), the relative dimensions of the spring and balance all have an influence. Overcoils (e.g. the Breguet overcoil) and the shape of the terminal curve are all designed to reduce isochronism errors, and this is particularly important for a wrist or pocket watch that would otherwise suffer from positional errors.

All of these factors conspire against us, but we can use this to our advantage as a teaching aid in that it clearly demonstrates some of the problems associated with spring-balance design and timing.



Finishing the casing

The casing of the balance assembly still needs to be finished before final assembly. Remove any marks with 600 grade wet and dry paper before polishing to a good finish inside and out.

Clock pathway students will sooner or later need to re-lacquer brass parts, so the casing is a good opportunity to practise lacquering. Use a proprietary horological lacquer applied with a pad folded-up from a soft lint-free rag (a bit of old, well-washed bed sheet or tea-towel is good). After shaking well, up-end the bottle to lightly soak a small patch of the pad and quickly wipe a very thin film all over the inside surface. If you have made a screw-on casing, try not to get any lacquer in the threads. Set aside to dry for 24 hours before repeating for the outer surface, finally setting aside for several days to harden before finally pressing-in ('popping-in') the glass.

11. The scaffold

Design and drawings

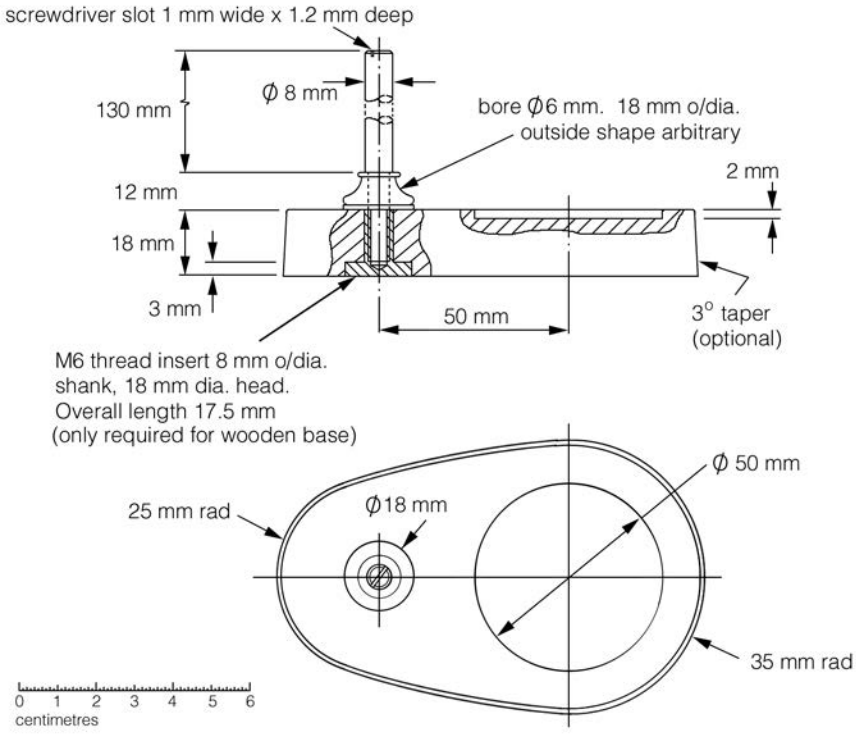
If constructors of the vibrating tool are pleased with their work, they really should construct a ‘scaffold’ (or perhaps ‘potence’, which is French for scaffold or gallows) to allow them to experiment with bringing spring-balance assemblies to their approximate rate in their future careers. A design for a scaffold is now described which, while it does not have the sophistication of a professional tool, does allow the tool to be used for testing spring-balance assemblies.

The constructional processes are not representative of the core skills needed for an horologist, though clock pathway students will find the ability to make highly-finished wood and brass parts useful in their future careers. Consequently, no detailed drawings or description of how to make it are included; rather a general appreciation is provided, highlighting a few options for its manufacture.

Because the drawings are not fully detailed, a scale is included for information. Drawings should not normally be scaled, partly because draughtsmen work to the stated measured di-

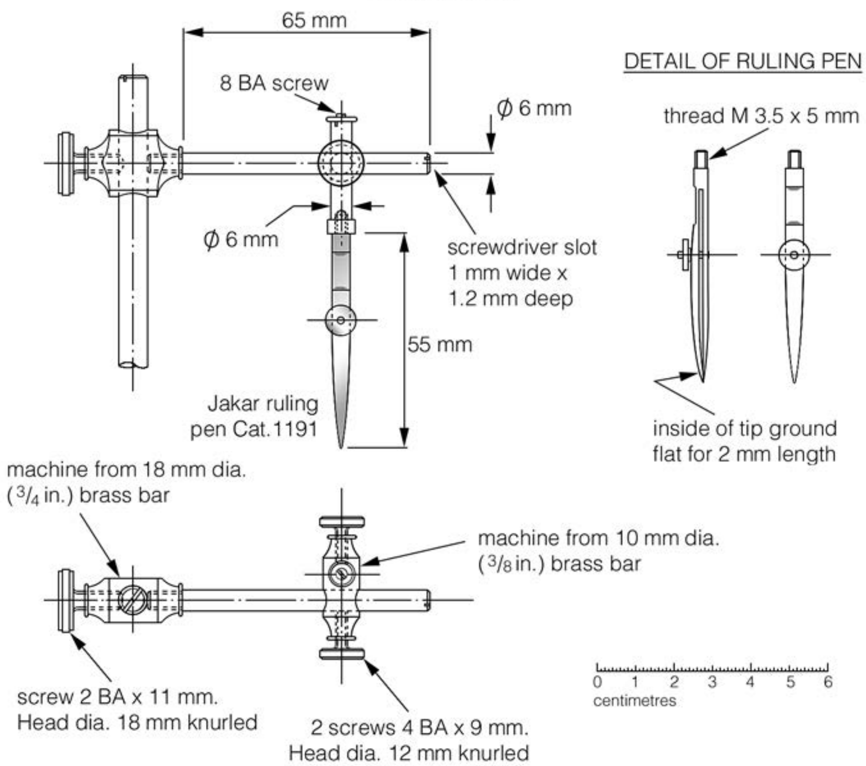
'SCAFFOLD' BASE ASSEMBLY

base: wood, aluminium, brass or cast iron. Mountings: brass



'SCAFFOLD' SUPERSTRUCTURE

material: brass



mensions and partly because one can never be sure how much distortion has been introduced by the reprographics machine. Drawings should never be scaled for critical dimensions without additional numerical checks for corroboration.

Materials required

For the most part materials can be selected from oddments that you might have to hand as some variation is possible. However, most of the components can be got out of the material in the following list:

- 150 mm length of 3/4 in. dia. (20 mm) brass bar
- 50 mm length of 1/2 in. dia. (12 mm) brass bar
- 50 mm length of 3/8 in. dia. (10 mm) brass bar
- 200 mm length of 8 mm dia. brass bar
- 150 mm length of 6 mm dia. brass bar
- Either: 110 mm length of 75 mm x 18 mm thick metal section (aluminium, brass or cast iron),
  Or: If a large piece of metal for the base is not available, a piece of mahogany or other hardwood is eminently suitable (as used in the prototype).
- Jakar ruling pen, Cat. 1191. The 'tweezers' for gripping the balance spring would be awkward to make, so the design uses a modified ruling pen available from artist's suppliers.

Other materials you may need include a short length of silver steel to make the 8 BA screw, a piece of baize, and paints, lacquers and/or polishes to finish the base.

The base

Making the scaffold will not be possible on a watchmaker's lathe, though that having been said, it is quite possible that some ingenious students will prove this statement to be wrong. In the drawing, the base is shown pear-shaped with some taper and curvature to the sides, but a rectangular block would save quite a lot of sawing out, especially if starting from a slab of metal. Indeed, several of the shapes shown are primarily there for aesthetic reasons rather than functionality.

There are no particular features that need special consideration, though the 50 mm dia. recess for the vibrating tool should be a snug fit on the base flange, which means it must be

Upper surface

Lower surface

Above left and right: The brass inserts to the mahogany base

Right: The lower surface after glueing-on and trimming the baize bored in the lathe by holding it in a four jaw chuck or routed (milled out) on a rotary table held in the vertical milling machine. It is possible to fit two diametrically-opposed screws to clip the base flange it into position, but these are not essential.

If using wood for the base, a thread insert to take the post should be fitted and secured with an epoxy adhesive (e.g. Araldite). The loose shaped collar above provides a larger bearing surface to prevent crushing of the wood from above; note the bore of this shaped collar is 6 mm dia., and the post is 8 mm dia. to provide the clamping effect.

Once you are satisfied that the base is complete (and the recess is the correct size for the vibrating tool baseplate), the base can be finished in whatever way you want. However, there is always pride to be taken in using a well-finished tool so do not skimp on it. If using brass, bring it to an appropriate finish and lacquer it; if using aluminium of cast iron for the base you will probably want to paint it. If you have used a piece of hardwood as in the prototype, rub it down with 600 grade wet and dry paper before finishing with an appropriate varnish, lacquer or polish.

Once the base has been completed, a piece of baize (not felt – baize is woven, felt is not) should be glued to the underside. If wood, use a thin and even layer of PVA woodworking adhesive; if metal, an impact adhesive again spread in a thin and even layer may be more appropriate. Once set, trim any excess baize and whiskers off with a sharp pair of scissors, taking care not to damage the paint or polished finish.

The superstructure

All components are made from brass bar or rod, and the more tricky items are the two right angle clamp blocks that support the rods. Round bar is suggested, but they could be made of rectangular or square section, which will make accurate cross-drilling easier, especially for the smaller clamp with its two cross-holes at 90 degrees. The outside shape of the clamp bosses is largely a matter of choice, but some shaping makes the tool look more professional. For the brass parts illustrated this was achieved by a combination of a shaped lathe tool held on



Details of the scaffold components

a top-slide to remove excess metal and define lengths and diameters before finishing with a hand-held graver and tee rest.

The clamp screws are ideally knurled, which, because knurling involves high forces, should be done as the first operation. A good knurled finish is distinguished by the crests of the knurl being formed to a sharp vee edge. If you are knurling dry (i.e. without a copious supply of cutting fluid) you should stop now and again and remove any slivers of brass with a wire brush so they do not become embedded in and/or tear the knurled work. M5 and M3.5 threads are suitable alternatives to the 2 BA and 4 BA threads shown in the drawing. A screwdriver slot cut in the end of each rod facilitates tightening in the respective boss.

The clamp blocks are brought to a high finish before lacquering with a proprietary metal lacquer. The rods are not lacquered as lacquer would both prevent the clamp blocks sliding easily and be scraped away; instead they are brought to a good finish and protected with a light coat of easily-repairable microcrystalline wax.

The ruling pen 'tweezers'

The Jakar ruling pen is a well-made instrument for its price but does need a little modification. Firstly unscrew the plastic handle, which is secured by a M3.5 thread (3.5 mm dia., 0.6 mm pitch). You will need M3.5 mm taper and plug (bottoming) taps to thread the brass rod to which it is secured. You may also need to clean the threads of the ruling pen with a 3.5 mm die; in the prototype the thread was slightly large in diameter, perhaps to ensure it was a tight fit in the plastic handle.

The tips also need some attention; as a ruling pen the two tips do not close up parallel but touch at a point. We need them to close parallel (see inset, photograph below) so they will grip the balance spring correctly, and this is best done by stoning then using a diamond slip; these are available in a variety of grits in the form of a thin card (the size of a credit card). Aim to get a 2 mm length to close parallel before removing any roughness to the edges by drawing them through wet and dry paper down to 1200 grade. Finish the tips so they are of equal length.

The ruling pen head is screwed into the 6 mm dia. rod finished in the same way as the other rods. A stop washer held to the upper end by an 8 BA screw as shown in the drawing helps prevent the tweezers dropping through when being finally adjusted for height. If it drops down it may damage the spring balance assembly under test. If you fit a washer, make sure you tap the hole for its 8 BA securing screw before you cut the screwdriver slot in the end of the rod.

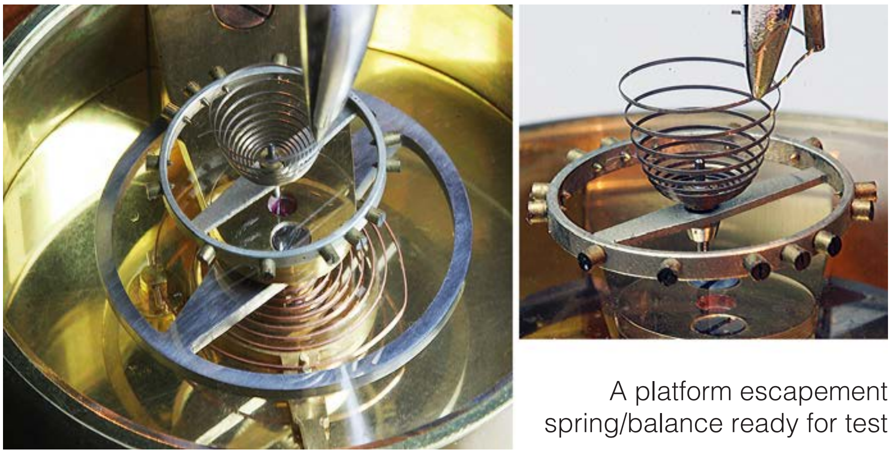
12. Using the tool

First use

Now all work is complete on the tool it is as well to calibrate it for rate. This should ideally be done for temperature and isochronism using a timing instrument of known accuracy. But before this is done, try fitting a spring/balance assembly to get a feel for how the tool is used.

Select a spring/balance assembly (e.g. from a discarded platform escapement) making sure the lower pivot is in good condition (not broken) and clip the balance spring between the tips of the tweezer jaws at the curb pins or boot position. Tighten the tweezer jaws onto the spring. Do not worry if the inner jaw tends to contact the adjacent balance spring coil; once it is dangling it will take up a beehive shape and be clear. With the spring and balance dangling, adjust the height of the scaffold so the balance is (a) level, (b) centred on the cover of the tool, (c) the lower balance staff pivot just rests on the glass cover, and (d) the spokes of the two balance wheels line up (adjusted by rotating the vibrating tool in the recess in the scaffold base). As the balance under test will tend to rise and fall as it oscillates due to the winding and unwinding of the balance spring, you may need to make small adjustment to the height of the scaffold to ensure it remains in contact with the cover.

Some authorities suggest the balance staff should leave and re-contact the cover at each oscillation, so the 'tap' at each contact can be heard and counted (each tap being equivalent to two 'beats'). This is a technique probably more appropriate to counting mentally oscillations for visual comparison with a reference timekeeper with a sweep-seconds hand but is less important if an optical timing machine is used.



A platform escapement spring/balance ready for test

Grip the scaffold base and give it a sharp twist centred on the centre of the balance (see introductory photograph). If you twist it about any other axis or move it laterally, the balance under test will tend to skate across the surface of the cover. (In a professionally made tool this is cannot happen as the base is designed to rotate about the balance staff axis.) Aim for an amplitude of oscillation of about ± 90°, and with any luck you should see the two balance wheels stay approximately in synchronisation. More probably the balance wheels will gradually drift out of synchronisation; this is what needs to be corrected by re-clipping the balance spring at a different place to make the effective length of the spring shorter (= faster) or longer (= slower).

As the oscillations decay you will also note that, free from any pivot holes, the balance under test oscillates for far longer than the vibrating tool balance, which just indicates how much friction there is even in a jewelled pivot hole.

Calibration

With the casing removed and using the timing machine with an optical sensor set-up shown in Chapter 10, the spring/balance needs to be finally checked for timing, adjusting the Index for as near to 18,000 beats per hour as you can get it.

While the cover is off, it is possible to see how isochronism is affected by balance amplitude and room temperature. To give yourself time to note down the readings and estimate the balance amplitude at the time each reading is recorded, set the timing machine to measure 60 counts (60 beats). Start the timing machine and give the balance an initial twist of 180° and release. The first timing machine reading will be in error but the next one should be recorded.

If your machine is set to beep at each refresh (60-count) note down an estimate of the balance amplitude and then the timing machine reading. Repeat until the amplitude drops to about ± 40 degrees. Repeat the trial several times (Trial A, Trial B, etc.) to get an average trend.

Now tabulate your results, and a suggested format is shown below.

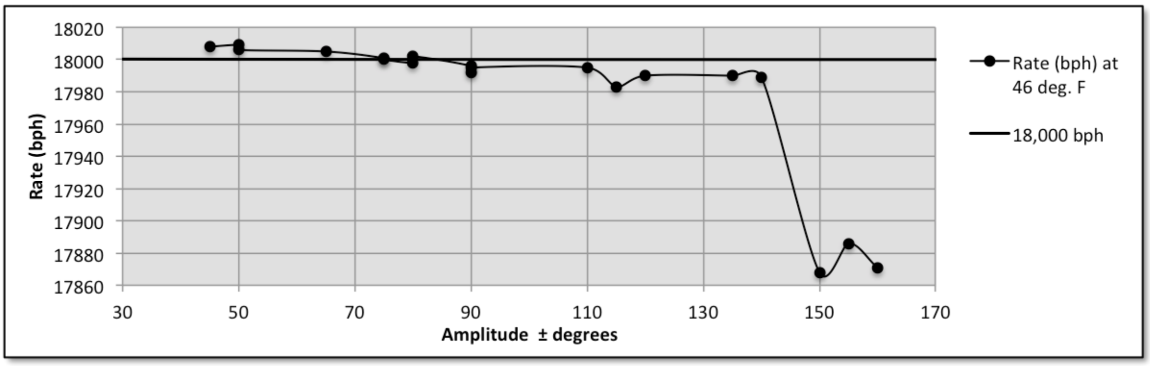
Temperature = 8 degrees C (46 ° F)	*Initial amplitude ± 180 degrees*
Timing machine count interval: 60 counts (60 beats). 60 counts represents one count group	

Trial "A"		
Count group	*Estimated amplitude*	*Recorded bph*
0	*Not recorded*	*Not recorded*
1	*±135 degrees*	*17990*
2	*±90 degrees*	*17995*
3	*±75 degrees*	*18001*
Etc.		

Notes
1. Index not adjusted during trials
2. Timing machine: Mumford Microset timer fitted with optical sensor
Etc.

The results from four trials conducted on for the prototype instrument were plotted on the first graph below. From this it is possible to deduce:

- 18,000 beats per hour is achieved at ±80° amplitude
- isochronism is good between about ±50° and ±140° amplitude
- isochronism is poor above about ±140° amplitude.



Analysis

Looking at the graph, the first comment is that the steep drop-off in rate above ±140° amplitude suggests some fault with the balance/spring assembly. This was subsequently determined to be caused by the expanded balance spring catching on the base assembly. Once the cover is in place, it will not be found possible to induce more than about ±120° by twisting the tool; as this was unimportant it was not corrected at the time of the tests subsequently described.

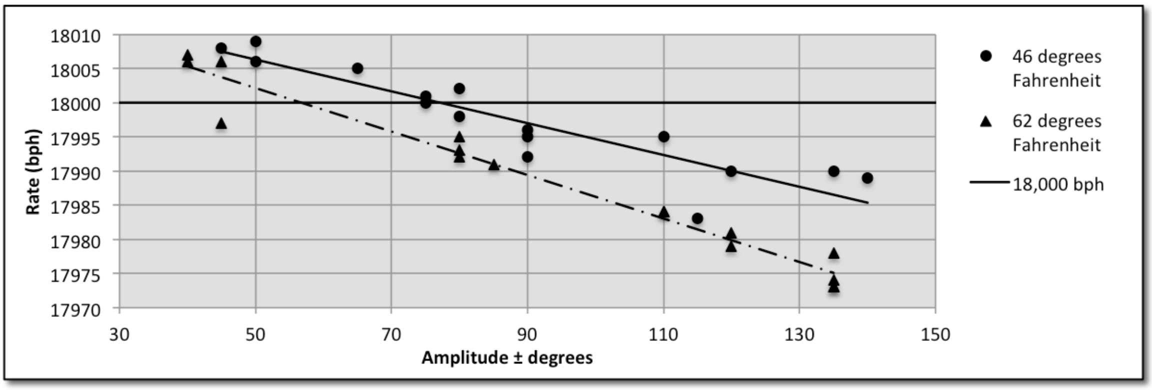
It is also possible to make some other comments:

- there is a variation of less than ±10 beats per hour between an amplitude of ±50 degrees and ±110 degrees (note: a change of one beat per hour is equivalent to a change of 4.8 seconds per day)

- the decay in balance amplitude from the initial ±180° starting position over 60 beats (each count group) is very roughly ±15°.

The trials were undertaken in a cool workshop of just 46° F (8° C). They were repeated some hours later after the vibrating tool had been transferred to a warmer room at 62° F (17° C). The second graph shows an enlarged detail of the earlier (now linearised) graph up to 140° balance amplitude along with a new (dashed) line plotted at the higher temperature.

Unsurprisingly anisochronism versus amplitude remained much the same, but the rate dropped by an average of 8 beats per hour over the range of amplitude of interest (equivalent to a change in rate of 38 seconds a day). This is primarily caused by a decrease in the modulus of elasticity of the balance spring material (in this case bronze) coupled with, to a lesser extent, increases in the balance and spring dimensions due to thermal expansion.



This is not the place to discuss why our vibrating tool does not perform perfectly as the factors affecting isochronism and temperature compensation are worthy of a book in themselves. Students are encouraged to think about the results they obtain from trials on their own vibrating tool, and study an appropriate text on spring/balance theory.

Summary

What the above calibration trials tell us is that within the amplitude limits identified, the tool is quite capable of being used to make a preliminary selection and adjustment of a suitable balance springs for a clock or watch where the spring is damaged or missing.

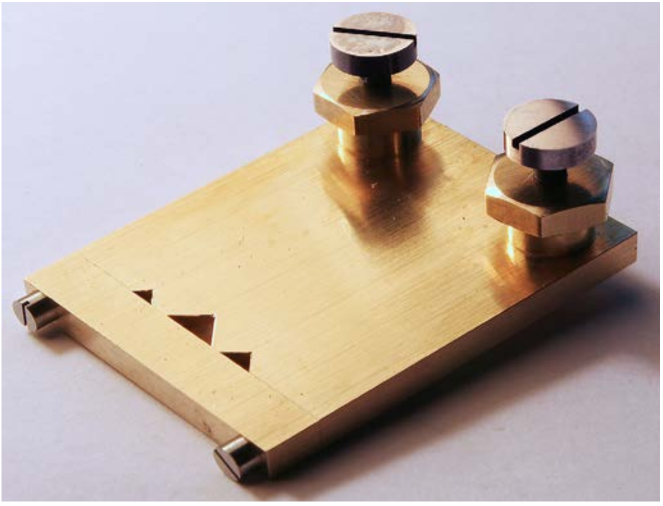
Final remarks

Congratulations - you have now completed the balance vibrating tool, and during its construction you will have learned much about the skills of working with spring/balance assemblies and the issues that affect spring/balance design and manufacture.

Of course real clocks and watches have an escapement, but the experience you gain from making this tool will give you an excellent understanding of the fundamentals of the spring/balance oscillator whether you follow a watch or clock pathway.

You also have a tool of which you can be proud, and very soon will be of use to you in your future horological career.

Appendix A.
Making a bolt polishing tool



Design and drawings

The ability to polish the heads of screws is an essential skill and to polish the head of screw flat requires the use of a tool. This bolt tool is designed for polishing screw heads ranging from 12 BA (1.4 mm) up to 8 BA (2.2 mm), though with a little adjustment it can polish a range of sizes from about 1 mm right up to 3 mm and will be useful for both clock and watch repairs.

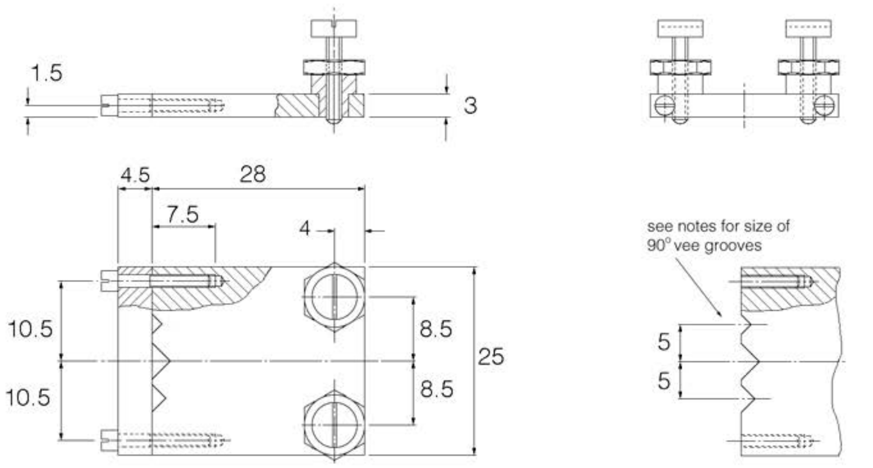
To use the bolt tool the screw to be polished is clipped between the clamp bar so that it is located in an appropriate vee-notch in the body. The two screws forming the adjustable feet are turned so that the flat head lies in a plane formed by the screw itself and the two adjustable feet. The tool is then rubbed on progressively fine abrasive material fixed or applied to a flat plate until a mirror finish is achieved.

Materials required

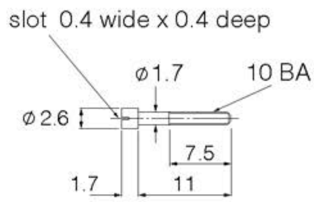
- Brass plate 3 mm thick, not less than 50 mm x 25 mm
- Round brass rod 6 mm dia. not less than 20 mm long
- Brass hexagon 5/16 in. (8 mm) across flats not less than 20 mm long
- Silver steel 3 mm dia. not less than 50 mm long
- Silver steel 6 mm dia. not less than 50 mm long.

During manufacture you will also need the following commercial screws:

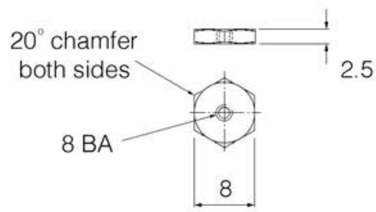
- 2 off 10 BA x 3/8 in. steel cheesehead screws, and
- 3 off 8 BA x 1/2 in. steel cheesehead screws.



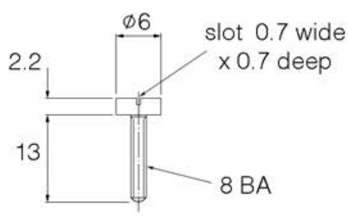
BODY ASSEMBLY
body and clamp from 3mm brass



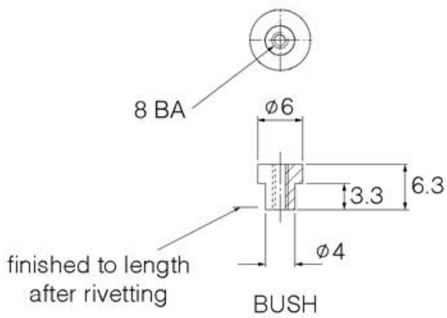
CLAMP SCREWS
2 off silver steel



LOCK NUT
2 off brass hex.



ADJUSTMENT SCREWS
2 off silver steel



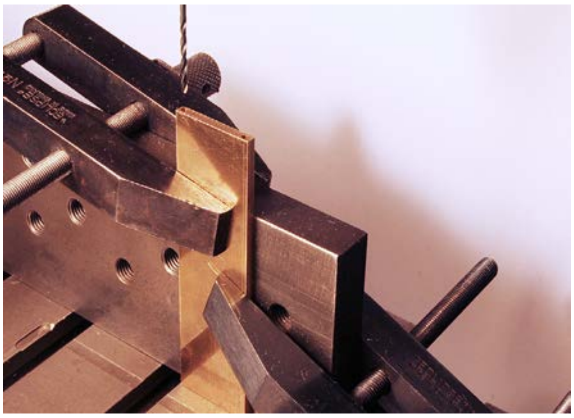
BUSH
2 off brass

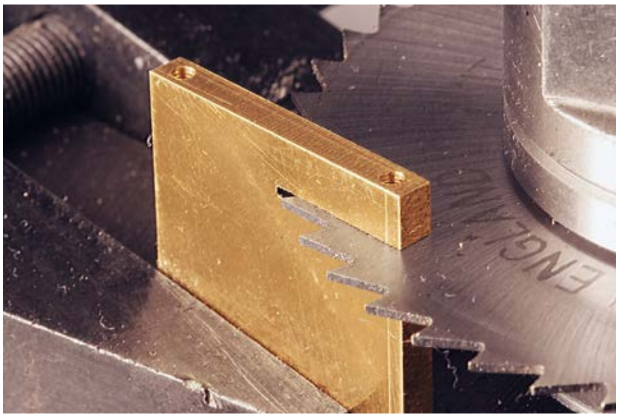
all dimensions in millimetres

The baseplate

Before marking out, the 3 mm plate is finished to exactly 25 mm wide and square one end. Now mark out the squared end with the hole centres, ensuring that they are perfectly centred on the thickness and centre punch. Inspect the centre punch marks with a 3 x loupe (a loupe with a magnification of three times) and adjust until they are truly central; there is very little leeway for error if the 2.6 mm diameter screw heads are not to lie outside the 3 mm plate thickness.

The two holes in the clamp bar need to be both perfectly centred on the thickness of the 3 mm plate and perfectly aligned with the threaded holes in the body. This is achieved by drilling and tapping the holes before cutting off the end of the 3 mm plate to form clamp bar. Clamp the plate to an angle plate and adjust so that the long edge is perfectly upright when measured by an engineer's square on the drilling machine table. Drill to a depth of 15 mm with a 1.4 mm diameter drill (the tapping size for 10 BA) before changing the drill to 1.7 mm (the outside diameter of a 10 BA screw) and open out the holes to 5 mm depth (photograph below left).





These holes are now partially threaded with a taper tap for total depth of about 9 mm while the clamp and body are still in one piece, which will ensure that the screws will perfectly align when assembled in due course. The clamp bar may now be cut off and the sawn ends finished so they are perfectly flat. The photograph (above right) shows this being done with a slitting saw, but it could be done equally well with a hacksaw. Slightly de-burr the holes and complete the threading of the 10 BA holes in the body using a taper, second and bottoming tap sequentially. Using two commercial 10 BA x 3/8 in. steel cheesehead screws assemble the clamp bar to the plate to check for correct alignment.

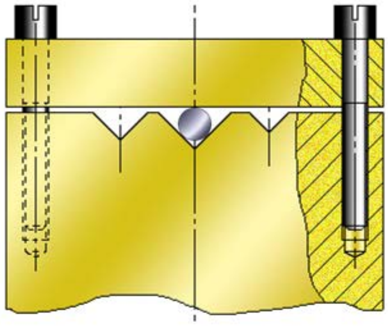
Cut the plate body to length and finish all edges with the clamp bar in position. Finally mark and drill the 4 mm dia. holes in the body for the bosses, lightly countersinking the underside to no more than 0.2 mm depth in preparation for rivetting.

Cutting the vee-notches

The vee-notches should be cut before the bushes are rivetted on; once they are rivetted on, holding the body in the vice will be more difficult and may mark the upper surface that will be grained before fitting the bushes.

To ensure the screws to be polished are held perfectly upright we need to introduce some grooves into the edge of the body. While dimensions are given in the drawing, working to them is not really practical if they are to be filed rather than machined; if so the shanks of three twist drills can be used as gauges. The correct depth has been reached when a straight edge (simulating the clamp bar) placed on the edge of the plate just traps the drill shank in its respective vee-groove – see diagram.

The notches are cut with a square file, making sure that it is kept perfectly straight and at 45 degrees to the edge of the plate to give a symmetrical vee-notch. Cutting out the bulk of the metal for the larger grooves with a piercing saw may help. The surfaces of the vee-notches are finished with fine flat needle files.



Screw size	Depth of vee groove	Drill shank to be used as a gauge
12 BA	1.4 mm	1.1 mm diameter
10 BA	1.8 mm	1.4 mm diameter
8 BA	2.4 mm	1.9 mm diameter
Depth of vee-notch ≈ 0.5 x screw dia x (1 + √2) - 0.25 mm		

The upper face of the plate and clamp can now be finished, which is done with the two components bolted together using two 10 BA commercial screws. Use 360 grade wet and dry paper stuck to a flat surface. The lower face will be finished after rivetting on the bosses.

Making the bushes

You should note in the drawing that the bushes are not shown at their finished length, and include an allowance for rivetting over. Make sure that you allow this extra 0.3 mm; too little and you will not have enough to fill the slight countersink into which the bush is spread; too much and you will just 'mushroom' over the head and not spread the metal into the hole. Making the end slightly hollow will make it considerably easier to spread the rivet into the hole.

Start by holding the 6 mm dia. brass bar in a chuck or collet and finish the outside 6 mm diameter using 600 grade wet and dry paper; by doing this now you will not round the corner of the as-yet uncut shoulder. Now turn the shoulder, and drill and tap (thread) 8 BA for the length of the bush. As the shoulder nears its finished size, check the fit in the hole in the plate and bring the diameter of the shouldered length to a light friction fit in the hole. It should not be a loose fit as rivetting will be less effective. Part or cut off, and face the other end to length. The 3 mm length of the 6 mm diameter portion is important as we will use the offcut of the 3 mm thick body plate to support the body while rivetting the bushes into place. Make two identical bushes.

While we are turning brass in the lathe we can also make the two lock nuts. These are made from 5/16 in. or 8 mm hexagon brass bar, this being the measurement across flats (a/f).

Hexagon bar can be easily held in a three-jaw chuck, but before this is done you may wish to grain the sides of the hexagon bar on 360 grade wet and dry while it is still in a convenient length to hold. If you do, protect the finish by wrapping the hexagon in paper for gripping in the chuck jaws.

The bar is faced, drilled and tapped 8 BA, and a 90 degree countersink applied to the hole to just ease the entry of the screw into the washer. The countersink should just remove the sharp feather edge of the end of the thread and should be no greater in diameter than the major diameter of the thread.

After cutting off you will be left with a thin hexagonal disc which needs to be held for back-facing (facing the other side or 'back'). It is not easy to hold a short length in a chuck perfectly square without the use of some aid. This can be in the form of a step chuck against which the lock-nut can be pressed while tightening the chuck jaws, but if you do not have one, an alternative solution is now described.

Take one commercial 8 BA screws and cut off its head as close as possible to the underside of the head and discard the head. Making sure there are no burrs at the cuter end, hold the screwed shank in the three-jaw chuck so that just a fraction over 2 mm protrudes from the jaws. We can now screw the lock nut onto this protruding length so that it is tightened against the face of the chuck jaws and, providing we take cuts of no more than 0.1 to 0.2 mm, this will allow us to bring the lock nut to its faced 2.5 mm thickness.

This time it may be necessary to countersink the threaded hole by hand after removing from the lathe as the 8 BA screw shank in the chuck will prevent the countersink from entering the hole. Make a second identical lock nut.

The final lathe operation is to create the 20 degree chamfer on each side of the lock nut. The precise angle is not important, but it is important that they all look the same. Consequently it is preferable to fit each lock nut in turn and chamfer all four faces at the same lathe set-up.

Rivetting the bushes into position

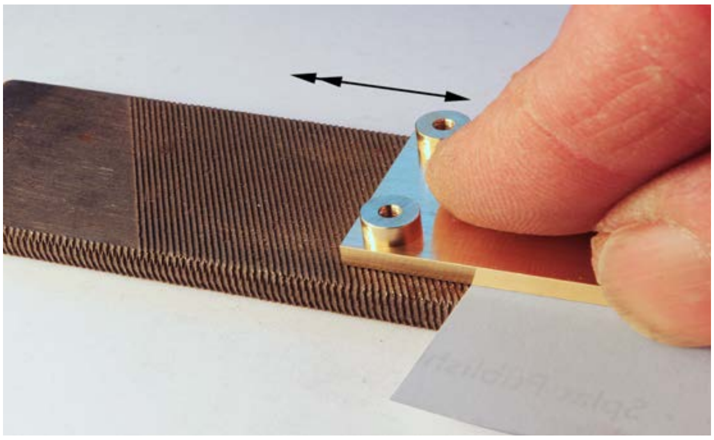
Make sure the shoulder and hole are scrupulously clean; if not the dirt may prevent the bush from fitting tightly against the plate and you will embed dirt into the rivet joint line. Set the bush in position from the grained side of the plate and support the other end of the body plate on the 3 mm brass plate (de-burred) offcut so that the bushes will be perfectly seated in their holes. Use a thin piece of polythene to protect the grained surface resting on the brass offcut, and rivet the bushes in position.

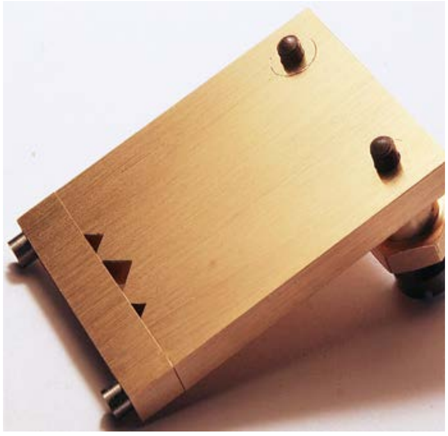
Having satisfied yourself that the rivetted bush has completely filled the countersunk hole the excess length of the bush can now be filed away. Start by rubbing on a file (see photograph) and proceed with finer files, finishing with 360 grade wet and dry paper to grain the underside so that it matches the upper face grained in the last Lesson. The clamp bar should again be fitted using the two 10 BA commercial screws.

The hexagonal lock nuts are polished to a high finish on their upper and lower surfaces; for this you should use successive grades of wet and dry paper and micro finishing film down to 3 microns. The sides of the hexagon should be left grained to provide a little more friction when finger tightening and loosening the lock nuts.

Clamp screws

Take the length of 3 mm diameter silver steel and turn the shank to diameter make sure it is a snug fit in the hole in the brass clamp bar. It is important that this fit is correct for the 4.5





mm length below the screw head as it is this length that locates the clamp accurately into position. Cut the thread using a split die, adjusting the die so that the screw is also a snug fit in the threaded hole in the brass bush. Finish the end. After cutting off the bar, reverse and hold in a 1.7 mm collet to turn the head to 2.6 mm diameter. Finish the head ready for cutting the screwdriver slot.

The slots can be cut by hand or by slitting saw and the screws are then hardened and tempered to blue. The screws are returned to the lathe for polishing the head circumference to a fine 3 micron finish using micro-finishing film stuck to a length of flat strip to minimise rounding of the edges. Polishing the flat upper faces of the heads will be one of the first tasks for your new tool.

Adjustment screws

Making the two adjustment screws requires the use of identical processes and they are finished in exactly the same way. Finishing the tops of the heads will the second task for you new tool.

Polishing the screw heads

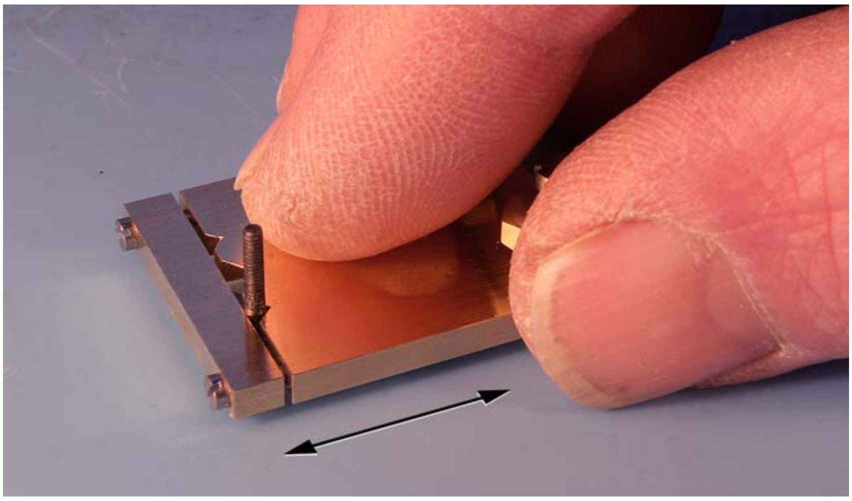
To polish the heads of the four screws used in the tool itself, fit the commercial 8 BA and 10 BA screws. Clamp the first screw to be polished in the appropriate vee-notch and adjust the two adjusting screws so that the body appears parallel both along its length and across its width to the hard surface on which it is standing. Lightly nip up the hexagon lock nuts with your fingers.

The bolt tool can be used with wet and dry paper or micro-finishing film, or the more traditional diamantine paste. For this work the heads should be finally finished on 3 micron micro-finishing film.

With the screws mounted in the bolt tool and using a first light stroke, pass the bolt tool over a piece of well stuck down 600 grade wet and dry paper. Alternatively, it is sometimes beneficial to make the first few passes over a large (50 mm wide) diamond slip stone as this will remove any tiny burrs around the screwdriver slot; if there are any burrs, they will quickly tear the wet and dry paper if not first removed. (As a rough guide, 1200 grit paper is equivalent to about 15 microns (15μ).)

The first pass will quickly show how you need to adjust the adjustment feet for a perfectly flat finish, and by a short process of trial and error you should have brought the adjustment screws to a perfect level to give a uniform finish over the entire head. Once satisfied, nip the lock nuts up finger tight, and continue finishing on successive grades of paper and film until you have achieved a perfectly flat, mirror finish. Repeat for the other three screws.

Finally we must make sure that all traces of grit and abrasive dust are removed by thoroughly clean the screw slots and threads in cleaning fluid or white spirit between grades of polishing paper. Once polished to your satisfaction, give the screw a final clean, watchmaker's cleaning putty being useful for removing any final specks of grit between the screw threads.



General comments on using the bolt tool

In using the tool it is important to keep the tool pressed hard against the polishing medium; if at any time either of the adjustment feet leaves the surface, the screw head being polished will develop a flat to its edge that will take a lot of removal.

The tips of the adjustment screws (feet) will be very gradually worn away as successive screws are polished but this will take many, many years before they get to a length that makes their replacement necessary. To minimise this wear some suggest using a narrow strip of wet and dry paper or micro finishing film secured to a hard block so that the adjustment feet travel outside either edge. Others suggest that a letter-box slot be cut in a piece of plain paper laid over the wet and dry paper to achieve a similar effect. The additional constraint placed on ensuring that the feet do not scuff-up the edges of the slot in the paper and the restricted opportunity for developing a circular or figure-of-eight motion during early polishing stages means that it is probably not worth while for any but the earliest 'roughing' strokes on the coarser wet and dry papers.