How flutes are made: the keys

In the second of our series we look at key-making

By Jim Phelan

The morning started cool, crisp and bright; redolent with the smell of ripe grapes. I had started a four-or-five-day, two-hundred mile bicycle trip making a loop from my home in Harvard, Massachusetts into Boston across to Cape Cod and back home across the southeastern corner of the state.

My planned route included the Minuteman Trail which, before it became a bicycle trail, was a little-used railroad bed. As I approached Arlington, I realised that this was the same rail bed that ran behind the building where I began making flutes thirty-one years ago. Indeed, I passed the very window from which I looked while making toneholes, screws and other flute parts.

Many things have changed in those years, but the art of making flute keys is still pretty much the same.

Keymaking is the most time-consuming job in the flutemaking shop. It also requires different skills from those of bodymaking, padding and headjoint making. The keymakers usually consider themselves the 'real' flutemakers. After all, a plurality of the total work of making a flute is theirs. Yet, all that work is in making a mechanism to simply cover the holes, a job our fingers did in an earlier time!

Keymakers are also called stringers. This comes from the idea that this worker 'strings' the keys together. At the high-end, that is something of an over-simplification, yet the name sticks.

The key parts, whether they are nickel-silver or precious metal, are made using a variety of methods. Which methods are used depends on the production quantities of the specific firm.

Forging, or forming the key shape between two hardened steel dies, is a very efficient method if the quantities are high enough. I often say, the first forging costs $10,000, the second costs 40 cents because to make the first forging requires making a series of dies, the precisely-machined pieces that form the part and trim it to size. To make forgings one must also have a press which forces the upper and lower dies together under forces of many tons. Forging has the advantage of mechanically deforming the metal. This deformation hardens and refines the grain structure of the key, characteristics that are desirable.

Casting, or pouring molten metal into a mould, works well for smaller quantities. In flutemaking, a process called investment casting is widely used. First, a master pattern of a particular key is made. This pattern is made roughly four per cent larger than the dimensions of the finished part to account for shrinkage along the way. Using this pattern, the caster makes a two-part rubber mould that has a void the shape of the pattern inside. Wax is injected into this void and allowed

Jim Phelan started making flutes in 1976 for a venerable Boston firm. He published the first edition of *The Complete Guide to the Flute* in 1980. That book is now in its second edition and sixth printing. He left the flutemaking world in 1989 and spent six years working in high-tech and the medical instrument industry as a mechanical engineer. In 1996 he joined his wife, Lillian Burkart, to make the Burkart flute. Even so, they are still happily married.

Above: A pile of key parts.

Below: Key parts partly finished.

to harden. These waxes are attached to a rod of the same wax called a sprue. When the sprue has all its waxes attached, it looks like a poplar tree with up-pointing branches. The sprue base is attached to a plastic base to hold it upright. A metal tube called a flask is placed around this assembly and plaster is poured in, submerging the sprue and waxes. Once the plaster hardens, the plastic base is removed. Now the caster has a cylinder of plaster with waxes and sprue inside encased in a metal flask. One end of the flask shows just plaster. The other end has the bottom of the sprue extending out. Now, the flask, plaster, sprue and waxes are placed in an oven that melts out the wax and raises the temperature of the plaster to well over 1000° Fahrenheit or about 540° Celsius, depending on what metal is being used. The wax melts out of the hole at one end of the flask. When the plaster has reached temperature, the molten metal from which the keys will be made is poured into the hole left by the sprue. The metal fills the voids left by the waxes. In a few minutes, the metal has solidified and the flask is plunged into a bucket of water. The plaster, still being quite hot, fractures and, for the most part, falls off the castings. The castings are cut off the sprue and are ready to be made into keys. While cast keys can be hardened using heat-treatment, it is difficult to achieve the hardness imparted by the 'cold-work' of forging.

Pattern-making is always done by the most experienced craftspeople as they possess a consummate knowledge of flutemaking, how the keys must function and how they are likely to be polished.

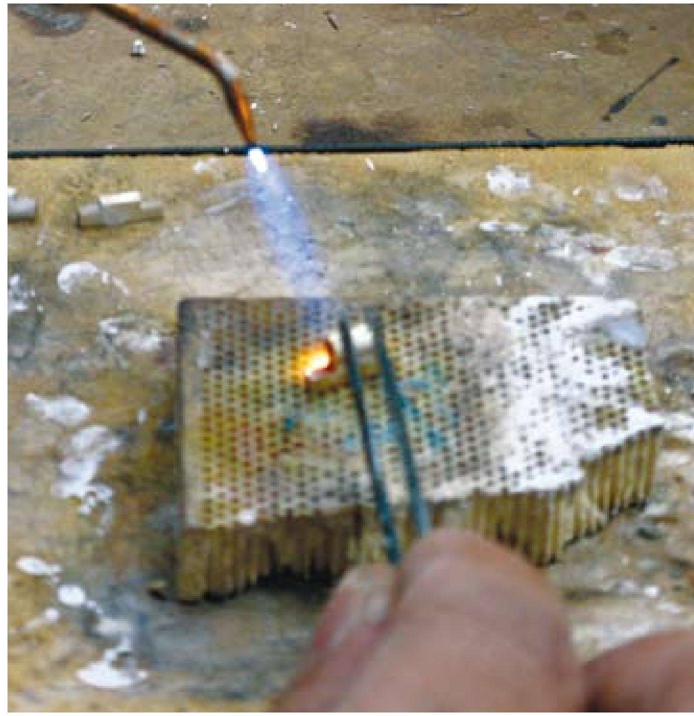
Today, with high-speed CNC (Computer Numerical Control) machines, there is a third option to making keys. Some makers machine complete keys from solid metal. This can be a highly efficient method as the parts are far more precise than either forged or cast keys, they have better surface finishes resulting in less hand polishing and they can be made from full-hard metal. Of course, the firm must have the trained personnel and specialised software to design the parts and program the machines, but, provided the firm stays in business long enough to recoup the costs, the savings and increase in quality can be substantial.

Although stringers take great pride in building beautiful mechanisms, that is the icing on the cake. The cups that hold the pads must be positioned precisely. That is, each must be concentric with its tonehole and the bottom edges of the cups must become parallel with the top of the toneholes at a given height. And, just as important, they must end up in this position without distortion. The pad will perform best under these circumstances.

The cups are attached to the hinge tubing, sometimes called mechanism tubing, by either a pointed arm or a Y-arm. There have been many arguments over beers between stringers about which method is better. Using finite element analysis, or FEA, we have found that the actual design and manufacture of the cup and the arm play a more important role than whether the arms are pointed or in the shape of a Y. That is, posts, toneholes, cups and arms must be manufactured precisely so that after assembly no levelling (read 'bending') is necessary. This is not trivial for the following reason. Imagine a triangle formed by (1) the centre of the flute tube, (2) the centre of the ball of a post and (3) the centre of one of the toneholes. An error of one per cent in the placement of a post or in the machining of an arm results in an error of almost half a millimetre of arc. For an arm to fit the cup such that it is properly positioned, no error greater than 0.03mm can be tolerated. So, it is not so much whether Y-arms or pointed (French) arms are used. What is more important is how precisely they are made and assembled. Either one can distort, simply in different modes.

Most flute players have experienced a sticking key. There are many possible reasons for a key to stick, but often it is because either the hinge tubing or the steel rod inside gets damaged or bent. This is because the tolerance between the hinge tube and the steel is very small. We'll get to that in a minute. First, a bit of background.

One of the most important jobs the keymaker performs is to make the key 'drop': that is, spin freely about the steel rod. On a short key like the A or D keys, this is generally not a problem. With a longer key, like the E or G keys or, longest of all, the trill keys, keymakers may have to struggle a bit. This is because of the close tolerance we just mentioned. On high-end flutes, this tolerance is about 0.005mm. Keeping such a close tolerance contributes to the 'silky' feeling a well-made mechanism has. The other side of the coin is that a bit of dirt or a slight knock can make such a key bind.



Above: Soldering key parts.

Below: Key parts ready to be fitted on the flute body.

The hands that made the keys.

When I started making flutes, the steel used for the steel rods was called W-1, or water-hardening tool steel. It is a good, general purpose steel, but it has one major flaw. It rusts. In those days, stainless steels were not well-known outside of engineering suites. Today, we have very good choices for stainless steels and most flutemakers have moved to using them thereby avoiding keys binding due to oxidation.

While on the subject of hinges and steel rods, we should look at bearings. Bearings are the areas where two surfaces meet and one or both of them rotates. The steel rods are supported at each end by bearings: rather small surfaces and ones that are prone to wear if not kept clean and lubricated. These bearings come in two geometries: conical and cylindrical. While I've heard moderately convincing arguments for the cylindrical bearing, the conical bearing has proven itself over time as a more robust design. The hinge tubing forms what is called a journal bearing with the steel rods. The stringer must build the mechanism keeping all of these bearing surfaces polished and burr-free.

The rest of the keymaking process is rather unexciting; one solders a series of keys together, fits them onto the instrument and goes on to the next set of keys until the instrument is finished. Assuming the reader can picture the rest of the process, a more interesting subject is custom mechanisms.

Holding a flute up against the force of gravity for hours and waggling one's fingers at the same time can lead to all sorts of physical problems. The keymaker can help this by moving key touches and making extensions that customise the flute to an individual flute player's grasp. It is not every keymaker who has the desire or skills to do this sort of work. To be successful, the keymaker needs to understand something about the human anatomy and the typical physical disorders that accompany repetitive motion. The keymaker also needs to know a bit more about physics and materials. It may be straightforward to extend a lever to reach a short finger, but the keymaker must take into account the additional weight of the key and the longer arc through which the key must move to open the pad. Many times this is not done and, while the instrument is easier to play, the player's technique is significantly reduced. To do the job properly, the keymaker should consider lighter materials like aluminium and plastics. Also, the distance from the axis of rotation and the touch point (the lever arm) should not vary too much from its original rotation. Easy to say, difficult to execute.

By this time all the metal bits are assembled onto our flute and we are ready to make it play! On to finishing!