BELL CASTING

by Geoffrey Poole

In the earliest days they were cast in different sizes to produce different notes but no attempt was made to tune bells until the 16th Century with the advent of change ringing.

In those times bells were roughly tuned – where the inside of the bell or the edge of the lip was chipped away with a hammer and chisel – eight bells could be tuned to an octave of eight notes.

Some deprived communities used a hagiosideron, a shaped piece of metal which was struck in a similar way to a bell.

Also again due to lack of money bellcotes were used instead of costly towers.

A bell-cot, bell-cote or bellcote is a small framework and shelter for one or more bells. Bellcotes are most common in church architecture but are also seen on institutions such as schools. The bellcote may be carried on brackets projecting from a wall or built on the roof of chapels or churches that have no towers. The bellcote often holds the Sanctus bell that is rung at the consecration of the Eucharist.

Bellcote is a compound noun of the words bell and cot or cote. Bell is self-explanatory. The word cot or cote is Old English, from the Germanic. It means a shelter of some kind, especially for birds or animals (see dovecote), a shed, or stall.

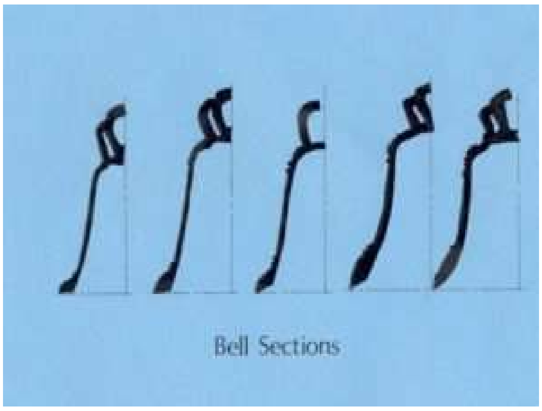
Examples of bellcotes

In order

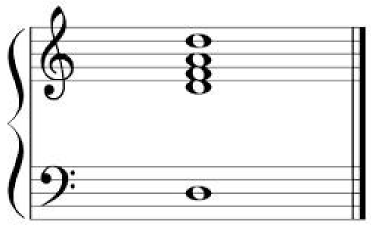
- Bell-cot at St Edmund's Church, Church Road, Wootton, Isle of Wight, England
- Church of England parish church of St Alban the Martyr, CharlesStreet, Oxford.
- Bellcot on St Thomas's Church, Eaton.

But a bell is an unusual instrument in that it sounds a number of different notes at the same time. It can therefore sound chords – like chords on a piano, or chords on a guitar – but only harmoniously if the notes are in tune.

In the 17th Century a brilliant but blind Dutch Musician, Jacob van Eyck identified the different notes produced by bells and began to work with famous Dutch Bellfounding brothers – Pieter and Francois Hemony. After the deaths of Francois and Pierre and that of their star pupil, Caes Noorder, in the 18th century, the art suffered a decline. It was not until the 20th century that tuning techniques once again gained excellence. Hemony had developed a tuning system for the five separate and distinct tones contained in each bell's ring. The Hemony brothers were carillon builders and set out to tune all their bells so that the individual notes were in harmony with each other. They realised that the frequency of a bell’s notes varies with both the thickness and its diameter at various points along its length.



Thus a carefully shaped bell, cast in different thicknesses along its length, could be made to produce both a nominal note and tuned notes above and below the nominal. This is still the essence of a harmonically tuned bell today.



And the Hemony brothers went one step further. In about 1644 they fixed their cast bells to a capstan lathe, turned by five or six men, and with sharpened iron tools shaved portions off the inside of their bronze bells until the required tones were reached. To know the correct pitch over the screeching of tool on metal they used tuning forks set under dry sand. Bell tuning had become the Craft of Turners

The Hemonys tried to keep much of their work secret but the English Bellfounders Rudhalls of Gloucester introduced lathe turning to England in the 1680’s. The Hemony Brothers are regarded as the first of the modern western bell-founders who used a scientific approach to casting the optimum shape and tuning bells to enable them to be harmonically tuned.

Bellfounding is a process that in Europe dates to the 4th or 5th century

With the passing of the Puritan Commonwealth and the Restoration of the Monarchy in 1660, for the next hundred years the English bell founding business was brisk and lathe turning was used more and more by the country's founders.

By the 19th Century the science of bell tuning became highly developed. It was realised that over the length of a bell the frequency of the note varied with the square of its thickness and inversely with its diameter.

With a tuned note called the nominal there were four overtones: hum – two octaves lower, prime – one octave lower, tierce – a minor third above prime and quint a perfect fifth above prime. This was the scientific world of harmonically tuned English church bells when St Paul's Cathedral decided to install a ring of twelve bells in 1876 to fit inside Sir Christopher Wren's, still vacant, North West Tower.

By the way the Great Paul bell is still the heaviest bell in Britain weighing some 16 tons.

They were to be made by John Taylor & Co of Loughborough, established in 1782, although there were probably more than twenty founders to choose from. This is the maker of the St Paul's bells.

It was to be the heaviest ring of twelve bells in the world at the time and recognising turning's contribution to the Art and Science of tuning bells, four of the twelve bells (Numbers 3,4,5 and 6) were presented to the Cathedral by the Turners' Company in and through a generous donation from a Benefactor Baroness Angela Burdett-Coutts. (Of the Coutts banking family and she was at that time one of the wealthiest women in England, in 1881 the Baroness married Ashmead Bartlett who took her surname and, as Ashmead Burdett-Coutts, was Master of the Turners' Company for two years in 1988 and 1889.)

The Turners' Arms and the monogram and coronet of the Baroness were cast in relief on each side of the bells with the Company's motto "By Faith I Obteigne" and the name of the then Master Edward Caffin.

One hundred and forty years ago on All Saints' Day 1878, the twelve bells in the north-west tower of St Paul's Cathedral were dedicated and rung for the first time.

This isn't the Company's only association with bells in City of London churches. In 1956 the Turners' Company made a contribution to the resurrection of St Mary Le Bow Church by paying for the turning of its twelve newly cast Bow Bells.

St Mary Le Bow Church

I recommend that you have a look at their web site and read the fascinating history of the bells.

The Tenor Bell called the "Big Bell of Bow" is the direct descendant of London's old curfew bell which Dick Whittington heard when he turned on Highgate Hill in 1375. In the following year, in 1957 The Company paid for the tuning of the new bells of St Lawrence Jewry, next to Guildhall.

With this history it was inevitable that the Turners Company should want to make a major contribution to the eventually inevitable first refurbishment of the Bells of St Pauls. With its St Paul's Bells Appeal, the Turners' Company joined the five other Livery Companies who subscribed in 1878.

St Paul's Bells have hung for 140 years and are rung more than any other set in the country.

In 2018 the bells were lowered, taken back to Taylors in Loughborough, cleaned, tested, given new headstocks and returned and rededicated on All Saints Day – 1st November.

Now aa little about the casting processes.

WHAT IS LOST-WAX BELL CASTING?

The lost-wax bell casting process is a method of bell casting in which a molten metal (usually bronze, brass, gold or silver) is poured into a mold created by a wax model of the original bell sculpture. The lost-wax casting process was widespread in Europe until the 18th century, when the piece-moulding process became a more prominent method of bell casting.

The making of a lost-wax casting bell starts with the inside and the outside drawing of the original bell shape on a metallic or a wooden board, called a strickle board. These two

drawings define the bell profile while the musical characteristics of a bell, such as note accuracy, sound, depth, and tonal richness are determined by its shape and as we saw earlier the thickness of the metal at various points.

The strickle board, once mounted on a pivot, is used to build the bell mold, which is composed of three well defined superimposed parts: the core, the false bell and the cope.

THE CORE

The core, also called the inside mold of the bell, is made of sand and bricks covered with clay.

THE FALSE BELL

The false bell, made with sand, has the exact same dimensions, diameter, height, thickness and profile as the original bell. It is coated with a thin layer of soft wax, then decorated with design garlands, ornamentations and inscriptions. All letters and decorations are made of wax and are raised from the surface of the false bell.

THE COPE

The cope, which is the outside part of the mold, is built up by the foundry craftsmen on the false bell and is made of several coats of clay reinforced by hemp. When the parts are dry, the inside of the core is heated. The wax melts and then drains out from the mold, creating an indentation (or hollow relief) in the cope for the decorations and inscriptions.

The cope is secured in a metallic cover called the molding flask. Using overhead rigging, rope and tackle, the cope is raised and the false bell is broken away and removed. The cope is then placed back on top of the core, leaving an empty space where the false bell was created. The molten metal will then be poured into the empty space.

Burning of the mold from the lost-wax bell casting process

The bronze, an alloy of approximately 78% copper and 22% tin, is melted and checked after five hours of heating. When it reaches 2,200 degrees Fahrenheit, the molten metal is poured into the mold through a channel where the gas flames also escape.

A few days later, the burnt mold is lifted up and broken to reveal a black and gray bell. After a careful sandblasting of the larger remaining particles of the mold and a fine polish, the final lustrous bronze bell emerges.

https://www.youtube.com/watch?v=CRum2ARetTI

This 31min video shows the process. It is casting the Lutheran Reform Bell to celebrate 500 years of the reformation. (only available if you are reading this on our web site)

Bellfounding has been important throughout the history of ancient civilizations. Eastern bells, known for their tremendous size, were some of the earliest bells, cast many centuries before the European Iron Age. The earliest bells were made of pottery, developing later into the casting of metal bells. Archaeological evidence of bellfounding appears in Neolithic China. The earliest metal bells, with one found in the Taosi site, and four in the Erlitou site, are dated to about 2000 BC. Portable bells came to Britain with the spread of Celtic Christianity, and most of those still remaining share an association with Scotland, Wales and Ireland. Bells are traditionally cast in foundries for use in churches, clocks, and public buildings. A practitioner of the craft is called a bellfounder or bellmaker.

Britain

Bellfounding in Britain, as with other scientific crafts, had its origins with monasticism and throughout the early medieval period and in centuries following, it was carried out predominantly by monks. Large bells in England are mentioned by Bede as early as 670 CE and by the seventh or eighth century the use of bells had become incorporated into church services. Nearly 200 years later, in the tenth century is the first record of a complete peal of bells. The chronologies of the abbot Ingulf suggest that Thurcytel, the first Abbot of Crowland, presented the Abbey with a bell named Guthlac, after which his successor, Egelric the Elder cast an additional six bells—two large, two of medium size and two small—to complete a peal of seven. The same period saw other ecclesiastics involved in the founding of bells. St. Dunstan, "The Chief of Monks", was an expert worker in metals and known bell caster. Two bells were cast under his direction at Abingdon which also held two others cast by St. Ethelwold. Methods of moulding by lost-wax casting(see above) were described by the thirteenth-century Benedictine monk Walter de Odyngton of Evesham Abbey.

Bellfounding as a regular trade followed later. Independent craftsmen set up small, permanent foundries in towns. Although these attracted trade from the surrounding countryside, mediaeval founders did not confine themselves to bellmaking as their only source of livelihood. Instead, they often combined it with related trades, such as metal ware, utensil manufacturing and gunmaking. Traveling from church to church the itinerant craftsmen cast bells on site near to the church and often local names such as Bell Lane, Bell Corner etc lend credence to this. But the majority had settled works in large towns. Among other places London, Gloucester, Loughbrough, Salisbury, Bury St Edmunds, Norwich, and Colchester were seats of eminent foundries.

These early bells had tonal discrepancies; a result of their weight and alloy composition as well as uniform thickness and profile—where the height was disproportionate to the diameter. The next century brought advances in all aspects of bellfounding where a better understanding of principles of bell design contributed to the introduction of a superior shape. The angles at the crown and soundbow were gradually flattened out and the waist became shorter, flaring toward the mouth. Although tuning methods were still uncertain and empirical, sets of bells in diatonic sequence were installed at important parish churches and monasteries.

Archaeological excavations of churchyards in Britain have revealed furnaces, which add more support to the idea that bells were often cast on site in pits dug in the building grounds. Great Tom of Lincoln Cathedral was cast in the Minster yard in 1610, and the great bell of Canterbury in the Cathedral yard in 1762. When the casting was complete, a tower was built over the casting pit, and the bell raised directly up into the tower. In some instances, such as in Kirkby Malzeard and Haddenham the bells were actually cast in the church.

Bell metal

Bells for the intention of producing functional sound are usually made by casting bell metal, an alloy of bronze. Much experimentation with composition has existed throughout history; the bells of Henry II had nearly twice as much copper as tin, while much earlier Assyrian bronze bells had ten times the amount of copper to tin. The recognized best composition for bell metal though is a ratio of approximately 80 per cent copper and 20 per cent tin. Bell metal of these ratios has been used for more than 3,000 years and is known for its resonance and "attractive sound".Tin and copper are relatively soft metals that will deform on striking. By alloying, a harder and more rigid metal is created but also one with more elasticity than the use of one alone. This allows for a better resonance and causes the bell to "vibrate like a spring when struck", a necessary quality as the clapper may strike at speeds of up to 600 miles per hour. The forces holding the tin and copper together cause vibrations rather than cracks when the bell is struck which creates a resonant tone. This metal combination also results in a tough, long-wearing material that is resistant to oxidation and subject only to an initial surface weathering. Verdigris forms a protective patina on the surface of the bell which coats it against further oxidation. The hardest and strongest bronze contains large amounts of tin and little lead though an alloy with more than 25 per cent tin will have a low melting point and become brittle and susceptible to cracking. This low melting point proved to be the nemesis of Russia's third attempt at casting the Tsar Bell from 1733 to 1735. The bell was never rung, and a huge slab cracked off (11.5 tons) during a fire in the Kremlin in 1737 before it could ever be raised from its casting pit. Burning timber fell into the casting pit, and the decision was whether to let it burn and risk melting the bell or pour water on it and risk causing it cracking from cooling it too quickly. The latter risk was chosen and, as feared, because of the low melting point of the bronze and uneven cooling, the bell was damage.

The Tsar Bell showing the crack caused by low melting point during casting. The present bell is sometimes referred to as Kolokol III (Bell III), because it is the third recasting; remnants from the old bell were melted down and the metal reused to cast the new bell. This practice was fairly commonplace, as the metal materials were very costly. Bell metal was considered so valuable that the first bronze coins for England were made in France out of melted-down old bells.

Other metals

Other materials occasionally used for bell casting are brass or iron. Steel was tried during the busy church-building period of mid-nineteenth century England, for its economy over bronze, but was found not to be durable and manufacture ceased in the 1870s. They have also been made of glass, but although bells of this type produced a successful tone, this substance being very brittle was unable to withstand the continued use of the clapper.

By popular tradition the bell metal contained gold and silver, as component parts of the alloy, as it is recorded that rich and devout people threw coins into the furnace when bells were cast in the churchyard. The practice was believed to improve the tone of the bell. This however is probably erroneous as there are no authentic analyses of bell metal, ancient or modern, which show that gold or silver has ever been used as a component part of the alloy. If used to any great extent, the addition would injure the tone not improve it. Small quantities of other metals found in old bell metal are likely to be impurities in the metals used to form the alloy.

Decorative bells can be made of such materials as horn, wood, and clay.

Casting bells by pouring molten metal into the moulds

The craft of casting bells has remained essentially the same since the 12th century; bells are cast mouth down, in a two-part mold consisting of the core, and the shell, or cope, clamped to a base-plate. There are variations in the process, principally in the quality-control standards.

Measurement and templating

Firstly the bell design is calculated to precise specifications where the bellmaker determines the shape the bell will need to take in order to resonate with the proper number of vibrations and create the right pitch. The bell pattern is then cut out in two wooden templates called

"strickle boards". One matches the dimensions of the outer bell (called the case or cope); the other matches that of the inner bell (called the core). The boards are used to create the inner and outer molds of the final bell.

Bell molds in the bell museum (Glockenmuseum) in Gescher, Germany

Constructing the mold

An exact model of the outer bell, sometimes called a false bell, is built on a base-plate using porous materials such as coke, stone, or brick. It is then covered first with sand or loam (sometimes mixed with straw and horse manure). This is given a profile corresponding to the outside shape of the finished bell and dried with gentle heat. The false bell is then covered with molten wax and figures and inscriptions, also made of wax, applied on top by hand. The false bell is painted over with three coats of fireproof clay and then enclosed by a steel mantle overcasing. The empty space between the false bell and the mantle is filled in with cement and left to harden before the mantle is lifted off. The false bell is chipped away from the inner core to leave the wax and cement. Any leftover scraps of the false bell are removed with a blow torch. The mold is then set over a coke fire to melt the remaining wax and evaporate any water that has accumulated. A model of the inner bell is then constructed of stone and coated with fireproof cement. It is then smoothed to remove any irregularities.

Instead of using a steel mantle and cement, the inner and outer moulds can also be made completely out of loam. In that case, the moulds are usually constructed inside out—first the inner mould on top of a coke, stone, or brick core, then the false bell including wax decorations as above, and finally the outer mould with added iron ring and fiber (e.g. hemp) reinforcements. Separating agents are used to prevent the false bell from sticking too closely to both of the moulds. Finally, after lifting up the outer mould, the false bell can be destroyed and the outer mould lowered back down onto the inner mould, ready for casting.

Bell casting mould demonstrating the process at the Technical Museum Vienna, Austria, showing the mould being closed by lowering the lined case over the core. The two sections must correspond precisely or the bell cannot be uniform in shape and thickness.

After the outer steel mantle has been cleaned, it is again lowered over the outer bell model. The mantle and the outer bell mould are then lowered over the inner mould and the outer and inner sections are clamped together, leaving a space between them. The clamped mould is supported by being buried in a casting pit which bears the weight of metal and allows even

cooling. Ingots of either ready-made bronze or its component metals are melted in a melting furnace and heated until liquid at a temperature of approximately 1,100 °C (2,010 °F). The liquid metal is then skimmed to remove impurities. When everything is ready, the molten bronze is transferred to the moulds using either ladles or a system of brick channels specially constructed in the casting pit, through which the hot metal can then flow from the melting furnace into the space between the two moulds. Holes in the top of the mantle ensure that gases are able to escape. If gas remained in the metal, the bell would be porous and susceptible to cracking. Porousness can also develop if the mould is damp, is not at the proper temperature, or the metal, when poured, is not hot enough. The bell is allowed to cool for several days. Large bells can take over a week to cool. Small bells, those under 500 pounds (230 kg), can be removed from the moulding pit the following day.

After the bell and equipment have cooled, the mould, containing the newly cast bell, is raised from the pit by the projecting trunnions of the bell case. The core plate is unclamped and the core broken out. The bell is then carefully extracted from the case. At this stage, any remaining loam adhered to the bell is brushed away and flash (excess metal), which may have formed below the bell's rim—owing to mould contraction in the presence of hot metal—is trimmed off. This completes the casting process.

Bells are manufactured with exact formulas, so that using the diameter it is possible to calculate precisely every dimension of the bell, and in turn its note or tone. Much experimentation and testing have been devoted to determining the exact shape that will resonate the best tone. In general, the smaller the bell the higher the pitch, with the frequency of a bell's note varying with the square of its thickness and inversely with its diameter. The thickness of a church bell at its thickest part (the "sound bow") is usually one thirteenth its diameter. If the bell is mounted as cast, it is called a "maiden bell". Russian bells are treated in this way and cast for a certain tone. "Tuned bells", which were common practice in Britain and Europe, are worked after casting to produce a precise note.

In the early days of bellfounding, bells were tuned using an imprecise method whereby the inside of the bell or edge of the lip was chipped away. With the improvement of machinery, this was done using a lathe. The bell is cast with slightly thicker sides before being inverted and gripped by vises to keep it perfectly firm. The bell is then ground as it rotates on a circular lathe to acquire the precise tone. The bell tuner must be highly skilled as it takes years of experience to know how much metal to remove. By this means, bells can be very accurately tuned. In casting, the tone of the bell is best left sharp because it is much easier to flatten the tone. A bell may readily be flattened one-eighth of a tone or even more, but it cannot be sharpened so much; indeed, any sharpening is to be deprecated and if at all possible should be avoided. The bell tone is tested frequently during the tuning process usually with tuning forks or an electronic stroboscopic tuning device commonly called a strobe tuner, which registers the vibrations as the bell is struck. If the tone is too low, the lathe operator grinds more metal off the lower edge. If the tone is too high, the bell is thinned with a file.[13] The bell's strongest harmonics are tuned to be at octave intervals below the nominal note, but other notes also need to be brought into their proper relationship.

Cutaway drawing of a bell, showing the clapper and interior

The clapper or tongue is manufactured in a similar process as the bell. Special care is given to cast the clapper at the proper weight, as a clapper that is too light will not bring out the true tones of the bell and a heavy clapper might cause the bell to crack. Holes are drilled into the top of the bell. The clapper or tongue is attached to the inside of the bell either by a metal link or (in olden times) by a leather strap. Finally the bell is installed in the tower. Large bells were often cast in the ground where the tower was to be built; when the casting was complete, the tower was built over the casting pit, and the bell raised directly up into the tower. Bells are often decorated with designs. Russian bells often feature icons, the name of the saint to whom the bell is dedicated, the year of casting, a prayer or some other commemorative inscription, and of course, usually the name of the founder or foundry.

Before the bells were hung, they were consecrated

Since prehistoric times bells have been used to herald significant events. Bells call the faithful to worship and toll the time. The sound of a bell can express great joy, sound a warning, or signal mourning. Bells have also been rung to bring on or stop the rain, keep evil spirits at bay, invoke curses, and lift spells.

Bells hold an honored place in religious ceremonies. In both Buddhism and Christianity, bells are blessed before each ceremony. In Roman Catholicism, bells are symbols of paradise and the voice of God. The Russian Orthodox and the Chinese employ bells to speak to spirits or God.

Bells are also revered as patriotic symbols, and it was not unusual for invading conquerors to capture and silence the town bell. In the U.S., the great symbol of the American republic is the Liberty Bell.

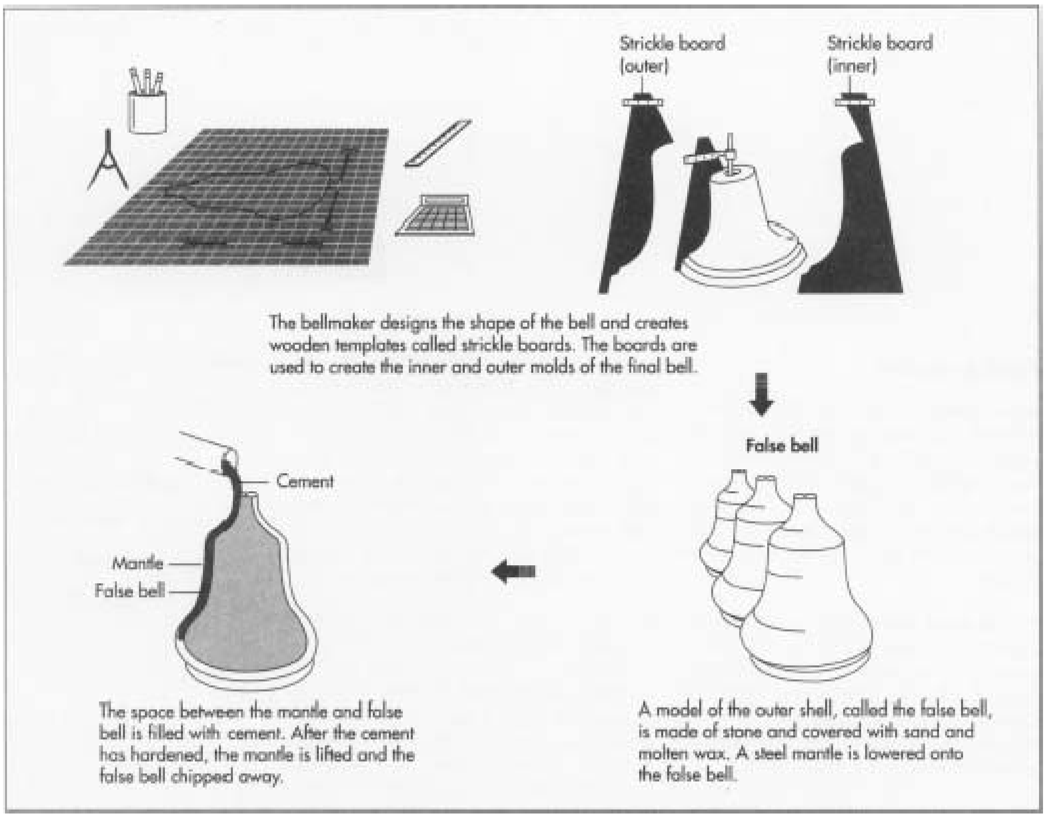
The Chou Dynasty, which reigned in China from 1122 to 221 B.C. , was particularly known for its superior bell founding. European bell founding occurred much later and originated in medieval monasteries. The first European bells resembled cow bells: iron plates that had been hammered square and then riveted together. By the 15th century, founders began to experiment with bell shape and tone. Secular bellmakers gained prestige in the Renaissance with the flourishing of Gothic architecture which featured grand bell towers.

Bell shapes vary by country and culture. The sides can be straight, convex, concave, or hemispherical. East Asian bells tend to be barrel-shaped while Western bells are tulip-shaped with a bulge near the rim. Chinese bells often have lotus-shaped rims. Bells of Western cultures are generally struck by an interior metal striker as the bell swings back and forth. Asian bells are non-swinging and are usually struck manually on the outside with a wooden mallet.

Raw Materials

While decorative bells can be made of such materials as horn, wood, glass, and clay, bells that are designed to ring or to play music are cast in a bronze alloy of approximately 77% copper and 23% tin. This combination produces a tough, long-lasting material that resists rusting. Bell founders must be careful not to mix in more than 25% tin or the bell will be brittle and susceptible to cracking. It is not unusual for old bells to be melted down and the metal re-used to cast new bells.

The craft of casting bells has remained essentially the same since the 12th century.



The one singular innovation was the invention of the tuning machine in the 19th century. Prior to that time, the proper tone was achieved by chipping the sides of the bell with a hammer and chisel. This procedure carried a high risk of damaging the bell. The tuning machine, which is essentially a vertical lathe, has reduced that risk. Electronic tuning machines have increased the bell founder's ability to test the accuracy of the bell's tone.

Tuning the bell

• 5 The bell is cast with slightly thicker sides so that the bell can be ground as it twirls slowly upside down on a circular lathe to acquire the precise tone. The bell tuner is highly skilled; it takes years of experience to know just how much metal to remove. The bell tone is tested frequently during the tuning process using an electronic device that registers the

vibrations as the bell is struck. If the tone is too low, the lathe operator grinds more metal off the lower edge of the bell. If the tone is too high, the bell is thinned with a file.

Fitting the clapper into the bell

- 6 The clapper is manufactured in much the same manner as the bell itself. Special care is given to cast the clapper at the proper weight. A clapper that is too light-weight will not bring out the true tones of the bell. A heavy clapper might cause the bell to crack.

Holes are drilled into the top of the bell. Using mounting bolts and supports, the clapper is fastened to the bell.

Great care is taken to calculate the precise weight and size of the bell before it is cast. If the finished bell does not meet specifications, it is completely melted down and recast. Should a bell crack at a future date, it might be welded and patched, but that is rare. The bell is more likely to be retired, as in the case of the Liberty Bell, or it is melted down and recast.

All in all, however, creating a bell is still very much a hands-on process and we can only but admire the skill and dedication of the craftsmen.

The next and final article in this series will be Bell Ringing to appear soon.

MORE ARTICLES TOFOLLOW

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