Novel Concepts in the Design of

Bell Clappers

for the 21st Century

by Stephen W Barton, Jim Wheeler & Mark Regan,
Worcester Cathedral.

November 2006

Contents

1. Background

1.1. Wrought iron

Traditionally bell clappers have been manufacture from wrought iron (WI), the only suitable material available to the bell founders six hundred years ago prior to the industrial revolution and the manufacture of steel. In fact, despite major technical advances during the 18th and 19th centuries, WI continued to be used as the material of choice by bell founders. This state of affairs continued throughout the latter part of the 20th century when WI was becoming more and more difficult to procure with fewer and fewer manufacturers in Europe producing this anachronistic material. Equally, blacksmiths had all but disappeared and small forging shops capable of doing this type of “metal-bashing” were few and far between.

Wrought iron[(5)] is the product of early attempts to refine the crude, brittle “pig” iron produced when iron ore is reacted with charcoal and limestone in a blast furnace. As the carbon was removed in the “puddling” furnace so the melting point of the iron increased until the furnace contents took on the consistency of toffee. This semi-plastic iron “bloom” was removed from the furnace, together with some of the slag, and forged, folded and re-forged under the blacksmith’s hammer to squeeze out the non-metallic impurities. What was left was something akin to Blackpool rock; fairly pure, soft iron interlaced with stringers of slag. Quality was generally defined by the degree of folding and re-forging, and the final product was a soft, malleable iron which could be shaped into fencing, weapons, agricultural equipment and bell clappers, and satisfied almost all everyday applications. Purely by coincidence, the fibrous nature of the finished product improved its toughness and fracture resistance. The only other ferrous material available at the time was cast iron; easy to melt and pour into castings but very brittle in its finished condition, and totally unsuitable for bell clappers.

Historically then, the early bell founders had little choice of materials so WI became the default choice for clappers.

1.2. Spheroidal graphite cast iron

In the mid 1970’s a leading UK bell founder[(12)] consulted BCIRA (British Cast Iron Research Association) with a view to replacing scarce WI for the commercially viable production of clappers. They came up with spheroidal graphite (SG) cast iron, a material easy to procure and cast, and with reasonable mechanical properties. This material worked well for most smaller bells and was cheap to produce compared with alternatives (see below). However, for larger bells it was necessary to produce clappers with thicker shafts to compensate for the material’s poorer strength, and so such clappers became inherently heavier.

Much of the criticism[(2,3,4)] of SG iron clappers when compared with WI clappers seems to stem from this design change rather than from the material change per se. It is often said that SG clappers produce a dead sound compared with WI clappers, and this is more than likely because of a change to the centre of percussion[10,11,14]: the clapper rests on the bell after impact and deadens the sound rather than bouncing off and allowing the bell to resonate. However, SG iron, cast and processed to laboratory standards, has been used successfully for "Great Paul" at York Minster, though this is used for tolling rather than full-circle ringing. The sound is claimed to be comparable with WI[7].

The choice of SG iron as a replacement for WI was therefore more about convenience and the commercial cost of manufacture rather than the ideal material for the job[13].

1.3. Alternative materials

WI clappers can be repaired by forge welding when they break until eventually, after repeated breaks and repairs, the inherent structure and strength of the material is damaged and further repair becomes pointless. SG iron clappers are generally considered barely worth the cost of repairing compared with a brand new replacement. Repair welding SG iron is a specialist process and requires a great deal of expertise and complex welding processes and consumables. Had life-time costs been considered, SG iron may not have been the bell founders' first choice,

By the end of WW2 a wide range of steel specifications had been developed, tailor made for a wide range of applications from fence posts to artillery shells, tin cans and motor cars to armour plate, stainless cutlery to high temperature resistant steels. It seems surprising therefore that so little effort went into identifying the most suitable, 20th century material for bell clappers.

In the early 1970's the author was involved in the specification and manufacture of a new clapper for the 11th bell at St Martin's in the Bullring, Birmingham[1]. The clapper was forged from carbon-manganese steel, similar to BS970: En14B typically used for the manufacture of high pressure tubing, gas cylinders and chain, and heat treated according to the material specification, and did not break again. At York Minster, the tenor clapper has been made from BS970: En16 manganese-molybdenum steel which is understood to have performed equally well[6] thus illustrating that alternative materials are available.

Forging is quite an expensive process but ideal for one-off items, though the expertise is disappearing. Machining a clapper from a piece of round bar steel would be costly in material and machine time but quite feasible as an alternative to SG cast iron, and offers the choice of a wide range of steel specifications and heat treatments. Casting steel to shape followed by heat treatment is another alternative, though as yet untried as far as the author is aware.

1.4. Wear and tear

In the clapper-bell system, a heavy, hard iron ball repeatedly strikes a relatively soft, bronze (bell metal) bell. Over a period of time, the soundbow of the bell wears away necessitating either quarter-turning to present a new wear surface, or complete re-casting of the bell. The former process can only be done once and the second is very costly. Ideally, one of the requirements in clapper design would be that it should cause less wear to the bell and be relatively cheap to replace. In practice this is infeasible given the current choice of materials and methods of manufacture.

1.5. Conclusion

Clapper manufacture six hundred years ago was dictated by the very limited availability of materials and equally limited manufacturing processes. The choice of SG iron as a replacement for WI in the 1970's was driven more by convenience and commercial needs than engineering or metallurgical dictates. Given the vast range of materials and manufacturing processes available today, it seems surprising that so little effort has gone into clapper design, particularly in view of the numerous complaints (mostly anecdotal?) from users about SG iron.

2. A New Design Concept; the "Worcester Clapper"

The clapper of the tenor bell at Worcester Cathedral broke on Christmas Day, 2004. A replacement was supplied by the bell foundry a few weeks later, and in the meantime a spare clapper, which had been repair welded earlier by one of the Cathedral ringers, Jim Wheeler, was installed. Jim has spent much of his life in the agricultural engineering trade and has access to workshops and expertise in the fabrication of steel.

Jim[9] had wondered for many years why a wooden shafted clapper wouldn't be better than a solid iron or steel unit. After all, axes, hammers and picks all have wooden handles which absorb the energy from each blow and reduce the shock transmitted back to the user. Thus started Jim's attempts to produce a wooden shafted clapper.

Jim's design utilises a novel jointing technique which allows a range of dissimilar materials to be joined without creating serious stress raisers; a problem which had not previously been overcome. The redesigned clapper was constructed using the top and bottom ends of an old SG clapper. The iron ends were cut into a "V" which was joined to an ash shaft with 4 x 5mm Nyloc nuts and bolts (see illustration). The shaft was made from a piece of ash 1 metre long and 75mm x 62mm cross-section, with the centre section turned on a lathe . (This diameter and length was determined by the original dimensions of the clapper and will vary from bell to bell.) The joint is completed by the use of two face plates which sandwich the wood ends and prevent the nuts and bolts cutting into the timber.

Another innovation was the replacement of the traditional gudgeon pin bush with two sets of single race ball bearings in the staple unit.

Fig.1. Worcester Cathedral tenor bell fitted with three-part composite clapper.

Fig.2 Three piece "Worcester Clapper" showing detail of joints and gudgeon pin bearings.

Fig.3. Two-piece tenor clapper for St Philip & St James, Hallow, Worcs.

Fig.4. Bow tenor clapper and new shaft for 11th bell shown next to unmodified unit.

3. Performance

3.1. Worcester Cathedral

The prototype “Worcester Clapper” was installed early in 2005, some 20 months ago. The unit has been inspected weekly to check for wear and tear, and the nuts and bolts checked for any loosening. No deterioration or loosening of the nuts and bolts has been detected to date. During this period the following have been accomplished:

- 9 full peals - 36 hours
- 10 quarter peals - 10 hours
- 80 weeks of Sunday service ringing and practice nights - 150 hours
- National 12-bell Striking Competition; June 2006 - 4 hours

Of the ringers who ring this bell on a regular basis, all agree that the bell is easier to ring. This is a subjective view but plausible given the reduced rotating mass. In addition, the bell can now be rung up (raised) single handed with the clapper finishing on the correct side, something which was impossible with the old SG iron clapper and almost impossible to do with any bell of this weight, 48 cwt (2450 kgs).

3.2. Tewkesbury Abbey

The tenor clapper has been replaced with a two-piece unit made by Jim Wheeler and a number of peals and quarter peals rung without incident.

3.3. St Philip & St James, Hallow, Worcs.

Clappers in the 7th and tenor bells have been replaced by two-piece units from Jim Wheeler and the bells are now much easier to ring. No problems to date. The bells have been rung regularly since the installation, including a full peal.

3.4. Birmingham Cathedral

A replacement clapper was supplied by Taylors, Eyre & Smith Ltd., Bellfounders to a design generally in accordance with that supplied by Jim Wheeler. However, after a number of successful peals the bolts securing the wooden shaft sheared and are being replaced. A manufacturing defect is suspected, and it appears the bolts used were not as specified and could have been over tightened.

The regular Birmingham Cathedral ringers are generally of the view that the bell seems louder and more sonorous, and a smaller ball may prove beneficial.

3.5. St Mary-le-Bow, Cheapside, London

Composite clappers have been produced for the tenor and 11th bells and will be fitted before Christmas, 2006. The bells are rung regularly, including numerous peals, and the existing clappers have been repair welded several times to the point where the risk of breakages in the future are high.

3.6. St Paul's Cathedral, London

A new clapper for the tenor has been supplied by Whites of Appleton. All reports to date are positive. The bell sounds more sonorous (the SG iron clapper struck the bell too hard and deadened the reverberations) and seems easier to ring. Whites have been asked to manufacture composite clappers for bells 9, 10 and 11.

3.7. Pending projects

There are number of projects planned including Liverpool and Coventry Cathedrals, and Inveraray.

4. Key Features and Benefits

In his quest to produce a wooden shafted clapper, Jim Wheeler has developed a novel jointing technique which allows a variety of dissimilar materials to be joined effectively and suitable for the repetitive shock conditions of a clapper striking a bell. This jointing mechanism provides a number of future options and advantages.

- Various materials for the shaft section could be tried including other hard woods, plastic, carbon fibre, aluminium, steel, etc. One of the disadvantages of using wood is quality consistency that could affect service life.

- The ability to replace the centre section means that a broken clapper can be repaired and returned to service almost as easily as replacing a broken stay, and without the delays of sending it back to the manufacturer for replacement or repair.

- Clapper manufacture for larger bells could be simplified with small castings or forgings for the ball & flight and pivot ends produced separately and in almost any material of choice.

- In the future, clapper design would no longer be dictated by available materials and process considerations, i.e. SG cast iron vs. WI or forged steel.

- It is now feasible to produce composite clappers with specific materials for ball, shaft and pivot sections, optimised for performance in each instance.

- Worn clapper balls can be replaced as necessary without buying a complete new clapper.

5. Advantages

5.1. Manufacture

Because the components of a composite clapper can be made individually, sources of large scale casting, forging, machining and heat treatment are no longer necessary. Shafts can be turned in small workshops, bearings are off the shelf, and castings for the ball and flight can be made relatively cheaply in bulk.

Equally, the design change brings the type of work and expertise into a more general manufacturing environment and thus need not remain the monopoly of the bell founders.

5.2. Materials of construction

The composite nature of the Worcester Clapper implies a far wider choice of materials of construction. Wood may not prove to be the ultimate choice for the clapper shaft and many other modern light weight materials can be tried including aluminium and carbon fibre.

One of the problems mentioned above relates to the relative wear of the bell and the clapper ball. To reduce wear of the bell's soundbow, less abrasive materials can be tried for the ball including mild steel and bell metal (bronze) itself. Within reason, material choice and manufacturing process can be optimised to minimise life time costs for both the bell and the clapper.

5.3. Maintenance

Breakage of the composite clapper components are likely to be restricted to the wooden shaft and the Nyloc nuts and bolts and as such can be serviced easily in the home or small commercial workshop with no special expertise required. Equally, worn bearings and clapper balls can be replaced as necessary.

6. Health & Safety Issues

6.1. Improved clappering

Large bells inevitably "go up wrong": the clapper finishing up on the wrong side of the bell mouth in the up-turned position. This necessitates either a complex mechanism to push the clapper over, or a competent person ascending to the bell chamber and climbing over the frame to do this manually. Experience at Worcester and St Paul's Cathedrals suggests that the tenor bell can be raised successfully with minimal effort with the clapper on the right side for full circle ringing. This is a key benefit and will be of significant interest to the Ecclesiastical Insurance Group, and may result in a review of premiums.

6.2. Clapper breakage

When a WI or SG iron clapper break the detached piece may damage other fittings in the bell chamber through either impact or by becoming trapped in the moving parts of the other bells. This occasionally results in consequential damage greater than the cost of the new clapper. A wooden shafted clapper is lighter and likely to cause less impact damage. In addition, if the broken shaft becomes engaged with other moving parts it is more likely to break and cause little consequential damage to bells, fittings and wheels.

7. Faculty Implications

Just as SG iron replaced WI for the manufacture of new and replacement clappers, ball bearings have replaced shell bearings, and synthetic fibre ropes have now replaced traditional hemp ropes without the need for Faculty applications and approvals, so it is our understanding that the move to composite, fabricated clappers falls within the definition of *De Minimis* work(8): the enhancements are neither irreversible nor impact on the fabric of the building. In fact, the composite clappers lend themselves to local manufacture and repair, and the associated lower costs, and offer potential safety enhancements as above.

8. The Future

8.1. Materials

Experiments will continue with alternative materials for the ball and flight with a view to improving bell tone and minimising bell wear. Ideally, any solution would be aimed at simplifying manufacture and keeping replacement and maintenance within the capabilities of the local ringers.

Although no wooden shafts have broken to date and ash seems to be a suitable material, experiments with alternative materials will be carried out with a view to minimising life time costs.

8.2. Design enhancements

The composite design lends itself to a number of novel enhancements including:

- ball & flight with integrated muffling devices
- sound deadening/reducing inserts in ball
- alternative ball & flight shapes; e.g. cylindrical to simplify manufacture
- removable/replaceable weights to vary ball mass and hence percussive mass

Work will continue for many years to come based on local experience and increasing feedback from other users.

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Acknowledgements

Fig.1 Mark Wilson
Fig.2 Lynda Wheeler
Fig.3 Lynda Wheeler
Fig.4 Mark Wilson

APPENDIX 1.

The Central Council of Church Bell Ringers
Towers and Belfries Committee

CLAPPER NOTES **Quality is defined as warmth in the heart of the customer**

Builders and carpenters know that the doorstop of a door must be positioned correctly if there are to be no impulses sustained by the hinges of the door. For a plain door of uniform material and thickness the correct position of the doorstop is horizontally distant from the hinges by two-thirds of the width of the door. This position is known as the centre of percussion. The skilled man hands down the two-thirds rule to his apprentice, thus passing the knowledge from generation to generation. If the doorstop is otherwise positioned the door loosens on its hinges or the hinges loosen on the wall. This harms the skilled man's reputation.

Cricket, baseball, golf and tennis players swing a bat, club or racquet to apply an impulse to the ball, so as to propel it fast and accurately. Improvements in the design and manufacture of specialised sports tools have taken place, developmental steps have been made by trial and error, and account has been taken of the opinions of players. It has been found best for the player's hands to feel no impulsive reaction at the instant when the bat, club or racquet strikes the ball. When this is so, the whole of the angular momentum applied to the sports tool by the player has been converted into the impulse on the ball and none of the angular momentum provided by the player has been wasted. The correct point on the sports tool has been used to strike the ball. This point is known as the centre of percussion. Its position is dependent upon the materials, shapes, relative shapes and overall shape of the sports tool and its components.

Church bell founders and hangers know the importance of the centre of percussion. To produce a good sound from the bell the clapper ball must deliver a substantial impulse to the sound-bow. At that instant the clapper ball receives from the sound-bow a reactive impulse of equal magnitude. The composite body of shaft, ball and flight bends in response to that impulse and vibrates briefly in bending mode. If the centre of percussion of the clapper is coincident with the centre of the ball, as it should be, there is no impulse at the clapper suspension bearing. If the centre of percussion of the clapper is not coincident with the centre of the clapper ball an impulse takes place at the clapper suspension. The magnitude and direction of action of this unwanted impulse are dependent upon the clapper's material profile and shape profile along its length. Associated with the unwanted impulse is an increased risk of failure of the clapper, crown staple or clapper suspension. The design features which determine the position of the clapper's centre of percussion are the sizes, densities, homogeneities, shapes and proportions of the clapper shaft, ball and flight; and their relative sizes, densities, shapes and proportions in combination. The shaft and flight should be conical along their lengths. The shaft should be slimmer at the suspension end. The flight should be long, stout, conical, and slimmer at the ball end. The shapes of the shaft and flight should blend into the shape of the clapper ball without abrupt discontinuities.

There have been instances reported of clappers breaking in the shaft, and of clapper pivot assemblies wearing prematurely. A supplier of clappers for church bells can perform a check on the position of the centre of percussion, for each design/size of clapper, using a well-braced fabricated steel test rig. A bracket, rigidly mounted on the rig via a load cell sensing horizontal impulses, supports the pivot assembly of the clapper under test. Initially the clapper is positioned on the rig with the shaft horizontal and the flight supported on a latch. The latch is then released and the clapper swings freely downwards under gravity through 90 degrees of arc until its ball impacts horizontally against a massive anvil mounted rigidly onto the base of the rig. The anvil represents a portion of the bell's sound-bow. If the centre of percussion is not coincident with the centre of the clapper ball, an impulse is sustained by the clapper suspension and the electrical output from the load cell gives an indication of the amount by which the centre of percussion is distant from the centre of the clapper ball. If on the other hand the centre of percussion of the clapper is coincident with the centre of the clapper ball, as it should be, no impulse is sustained by the clapper suspension and there is no electrical output from the load cell.

In this age of advancing technology it may be reasonable to expect that suppliers and installers of clappers shall, as standard practice, perform tests to provide the assurance that the centre of percussion is properly coincident with the centre of the ball. This will benefit suppliers, installers and customers alike**.**

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