BROMPTON FOLDING BIKES

Brompton Bicycle Ltd is the largest-volume bicycle manufacturer in the UK, with a staff of 160 and a turnover of £16 million. Will Butler-Adams, the company's managing director, explains how engineering innovation has turned its folding bicycle into a major UK manufacturing success story.

Brompton bicycle inventor and company founder Andrew Ritchie (left) continues to be involved in the day-to-day affairs of the company

Folding bikes are not new – they were made for troops to nip around the frontlines in both the First and Second World Wars – but were not seen in great numbers on UK roads until fairly recently. Small wheels on bikes are not new either: there was one on the original penny-farthing, but they were seen as impeding both speed and performance.

It wasn't until small-wheel efficiency was achieved and the mechanics of folding a bicycle small and light enough to carry were sorted that 'folders' became big sellers. Now that both of these hurdles have been overcome and business nous has been introduced to Brompton, a thriving industry has blossomed in Brentford, London.

THINK SMALL

In the late 1950s, the engineer and innovator, Dr Alex Moulton CBE FREng, challenged traditional cycle design when he proved that small wheels with high-pressure tyres would result in less rolling resistance, less inertia and hence greater acceleration. He then went on to develop a range of high-pressure tyres in cooperation with rubber manufacturers Dunlop.

The first Moulton bicycle was launched in 1962. By running efficiency tests in the wind-free environment of an aircraft hangar, Moulton effectively demonstrated that the most efficient bicycle design used a 20-inch wheel with high-pressure tyres.

The next step in the evolution of the folding bicycle came with the launch of the Bickerton folding bike in 1971. Harry Bickerton took the principles of small-wheel design pioneered by Moulton and sought to create a compact and light bicycle that was quick to fold and unfold. The machines even came with a pannier bag in which they could be stored when folded.

The Brompton World Championships are held each year, allowing bike owners to get together, socialise and offer their opinions about the folders to company staff. Jackets and ties are compulsory for the riding part of this event and prizes are awarded for the best-dressed riders © ismaSan/Flickr

While the lightweight small folded size of the Bickerton was well received, the riding properties of the bicycle needed improving. A young Cambridge University engineering graduate, Andrew Ritchie, took one look at the Bickerton and decided that he could design a better folding bicycle.

He went home and started work on what would become the Brompton bicycle. After fundraising through friends, Ritchie smuggled oxy-acetylene cylinders into his West London flat and set about creating a prototype – the view from his window included the Brompton Oratory, hence the bicycle's name.

Ritchie expected to license the Brompton design to a large bicycle manufacturer with ease but, after three fruitless years, he decided that he would have to make it himself. He employed one person and set about making bikes. In two years they built 400 bikes and sold them all. When Ritchie looked at the accounts he realised that even though he was selling them at a good price and they were popular, he was making next to no profit. He decided to hold off production until he had found new investment.

It was a further six years before Ritchie had managed to raise the venture capital to invest in the tooling needed to make the business successful. With critical acclaim and the Best Product award at the Cyclex Exhibition in 1987, the company took off, and demand soon outstripped supply. In recent years, Andrew Ritchie has stepped down from direct control and with new investors the company has expanded to become a major player on the international stage.

THE BROMPTON DESIGN

Most manufacturers will design a bicycle around, say, Shimano's range of gears and braking systems. This standardisation creates more flexibility when it comes to where (and how) the bicycle is manufactured.

However, the evolution of the Brompton has resulted in a bike where nothing is standard. Brake levers, tires, rims, hub gears, derailleurs, chain tensioners and cranks are all designed and developed in-house. In effect, Brompton is an engineering company that happens to make bicycles. This creates significant barriers to entry for competitors, because they can't simply copy the frame and then get the components out of a catalogue. Instead, they would have to invest millions of pounds in tooling and injection-moulded parts. Even after the tooling costs, they would have to reverse engineer the hundreds and thousands of hours of testing and engineering that Brompton has undertaken over the last 30 years. The Brompton bicycle contains 1,200 separate parts, 70% of which are unique to it.

Even today, it is hard to imagine how Ritchie managed to design the bike to be able to make it from scratch. Before CAD was widely available, Ritchie produced thousands of hand drawings of the bike and all the different tooling and fixtures needed to make it.

Today's bicycle is produced to a level of precision normally seen in the motor industry. At Brompton, engineers work to a tolerance of ±0.2 mm, one tenth the tolerance usually seen in bicycle manufacture. When all the parts are put together, the tolerance errors add up. The finished product has the same tolerances as any normal bike, but because it is made up of five major sections, Brompton has to start with far tighter tolerances to be able to get to the same place as everyone else.

To deliver this consistency day in, day out requires significant production engineering innovation to design out error. Brompton relies on world class machinery to support its operations, such as coordinate measuring machines and five-axis computer numerical control machines, but has also developed some of its own machines and processes. The process for attaching the tube that forms the frame to the hinge for folding, for example, is unique, requiring tube forming and hinge machining to meet tolerances of less than 0.1 mm.

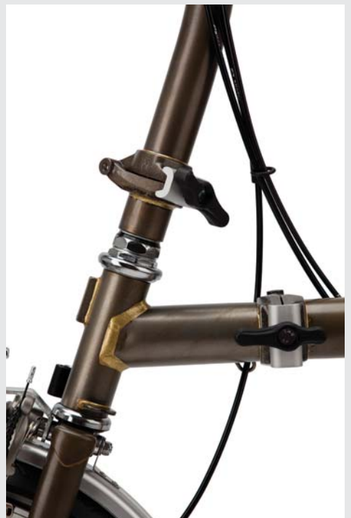
Brompton has developed a thermographic PLC-controlled autobraze machine to braze the two parts together. It delivers reliably consistent quality on an extremely critical area of the bike. This machine was designed and built in-house as the UK supplier went bust. It took two years and an investment of £160,000 to create, but it delivers the goods and would be next to impossible for a competitor to replicate.

BRAZING OR WELDING?

At Brompton, bicycles are assembled using brazing rather than welding. This is a dying art due the skill required to carry out the work, but it does add real value to a folding bike. The method uses less heat than welding and doesn't melt the 'parent metal' on either side of the join.

This results in fewer internal stresses in the metal either side of the joint – referred to as the heat-affected zone – as well as less distortion. As a result, through brazing, Brompton is able to use thinner wall tubes, keeping weight to a minimum and maintaining the tight alignment tolerances the folding bikes demand.

While welding requires temperatures of 1,400° to 1,500°C, brazing is carried out at 950°C, reducing the stresses placed on the metal



Whitehart malleable iron, which has a decarbonised surface, is used for brazing the hinges on the Brompton

NEW DEVELOPMENTS

All of Ritchie's drawings are now on CAD, and all new products are designed in 3D. Brompton also uses a 3D printer to produce rapid prototypes, and a newly designed part can be realised within 24 hours. Using finite element analysis (FEA), design ideas can be tested virtually. While prototypes are still produced for testing, Brompton has been able to halve the amount of time needed to produce them in order to complete the testing process.

FEA also allows for a more accurate assessment of materials. In a folding bicycle, there are three major factors that need to be considered in all aspects of the design process:

- the performance of the bicycle
- the compactness of the bicycle when it is folded
- the weight of the bicycle.

It is unlikely that these factors will 'pull' in the same direction. In the past, the tendency would have been to follow the crowd and err on the side of caution with the design. FEA allows the design team to be more bold, to take time to shave off every gram where possible while improving stiffness and strength. In effect, this is design where form follows function and physics determines the final result.

The potential to develop the Brompton further could include refinement of the frame design. At the moment, it is necessary to source tubing with a specific wall thickness for the maximum applied stresses. These stresses may only be exerted on a small area; for the rest of the bike, the tubing is overspecified. In future, with the aid of FEA, it may be possible to design something that is infinitely variable. The thickness of the wall of the tube can be changed, the profile of the tube can be altered and deeper sections can be used. Calculations can be made about the frame and where it will need the most strength.

A NEW CHAINSET

A good example of dedicated engineering is a new chainset, which is optimised specifically for the Brompton. It accommodates the asymmetries associated with the folding action. The new chainset has also been designed to be fully retro-fittable. As with all cranks, the design seeks to strike a balance between stiffness, weight and strength.

The engineers have also designed other Brompton-specific features such as a folding pedal stop and robust chain guards, which also act as rubbing surfaces that influence the feel of the fold. As the chainwheel assembly is a dominant part of the overall appearance, it was important that the styling complements the rest of the bike.

SAFE STORAGE

In 2011, following conversations between Brompton executives and South West Trains, a cycle hire scheme for rail season ticket

Using Finite Element Analysis (FEA), top, Brompton engineers are able to greatly reduce the need for modeling prototypes when designing components like this new crank. They updated the previous crankset in order to increase the stiffness ratio while maintaining its lightness. The result is the crankset, below left. The folding pedal, below right, is made up of 22 parts, 11 of which are unique to Brompton, that deliver a folding pedal that is the most compact on the market

The Brompton Dock in use at Guildford railway station. This unit has capacity for 40 bicycles, 20 on each side

holders was trialed at Waterloo Station. The scheme was conceived in response to a survey, which showed that a large number of commuters wanted to be able to cycle to or from the station, and it proved to be an instant success.

The company was introduced to Mark Antwis, a mechanical engineer. When Antwis saw a photograph of 42 folded bicycles arranged in a single car parking space, he immediately saw the potential for a compact storage system.

The system Antwis designed has been dubbed the 'Brompton Dock', a folding bike dispenser that consists of 40 secure lockers, each containing a folded bicycle. The standalone unit is solar-powered, uses the mobile telephone network to communicate and allows customers to take the bikes with them on public transport. Brompton has wider aspirations for its docking system.

A scheme like London's hire scheme has installation costs estimated at anything from £17,000 to £24,000 per bicycle. This is not practical for smaller towns and cities, but the Brompton Dock bicycle hire scheme can be set up for £1,700 per bike including the hardware, and once usage rises above 60% the scheme starts to make a profit. So far, the scheme has been sold to 18 cities across the UK.

THE FOLD

There are two important engineering aspects that make the Brompton different from other folding bikes. First, Ritchie's starting point was to build everything around the wheels and to design all the other parts surrounding the wheels. As that idea developed, he realised that if people are going to carry the folded bicycle, then it is necessary to place the dirtiest parts of the bike in the middle so that they're protected by the cleaner parts of the frame.

Secondly, Ritchie decided to place a horizontal hinge just behind the bottom bracket (see below) allowing the rear wheel to swing underneath the main frame. This was a completely new approach, which also allowed the 'half-folded' bicycle to be free standing, leaving the user's hands free for the rest of the folding actions. By putting this hinge behind the centre point of the main frame, the two wheels are placed parallel with each other once the bike is folded.

THE TROUBLE WITH OUTSOURCING

In the early 1990s, the Brompton reputation had spread internationally and the company wanted to sell worldwide. It was approached by a Taiwanese company interested in manufacturing the bicycle (badged as Brompton) under licence for sale to countries around the Pacific Rim.

The deal promised a steady income via royalties while at the same time opening up new markets, but it wasn't long before problems arose. A lack of understanding of the principles of the design, poor quality control and too much outsourcing led to a product that did not deliver and compromised the efficiency of the design. The licence was terminated in 2004, tools were returned and tough lessons were learned. Since then, more 'Bromptons' have appeared from Taiwan bearing even less resemblance to the original, which has led Brompton to engage in a series of legal battles to stop further manufacture and distribution.

PROTECTING THE BRAND

The Taiwanese experience led Brompton to redouble efforts to protect the intellectual property (IP) of its business. Unusually, most of the IP isn't in the bicycle. Around 80% of the innovation at Brompton is to be found in the manufacturing process. This means that the knowledge resides within its London factory and on bicycles all around the world, not in showrooms.

The company now does not patent its new developments because what it creates is unique to its product, so is less likely to have wider applications. Were it to patent new advances, it would effectively put all the technical information in the public domain, enabling the competition to make copies of the Brompton bicycle.

How to carry the Brompton. A publicity shot by the company on Abbey Road shows the point of balance for carrying the bike is at the front of the saddle © Brompton

A further protection of Brompton's intellectual property comes from its location. By making bicycles in London, it is many miles away from any other folding bike manufacturers. This means that when the company spends three years training a new member of staff and teaching them about its processes, machines and technology, the employees are very unlikely to go and work for the competition.

Brompton does outsource some of its manufacturing, but it keeps the 'the DNA of the bike' in-house, where it can focus on the design and manufacture. This also allows it to respond to any feedback it receives from users of the bike.

This end-user feedback is important, both from the purchasers and the employees, all of whom have a Brompton bike. By aspiring to continuous improvement and keeping the key manufacturing elements under their own roof, Brompton feels that it is able to design out error.

Commercially, this seems to have worked. The company now sells 31,000 bikes a year to 38 different countries. The folding bike is proving that it has a unique position in terms of what it can deliver to travel infrastructure for the future, by enabling people to use a mixture of cycling and public transport to get around. It has the added advantage of being compact enough to be stored in small apartments and easily integrates into urban life.

BIOGRAPHY

Will Butler-Adams is Managing Director of Brompton Bicycle Ltd. He worked previously for Nissan, ICI and DuPont, where he was involved in product development, R&D, project management and manufacturing excellence. He studied mechanical engineering at Newcastle University and is a Chartered Mechanical Engineer. Butler-Adams joined Brompton in 2002, became a director in 2006, and took over as the MD in 2008. He is a trustee of the Education and Employers Taskforce and is a Freeman of the City of London.

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