Game, set

The famous Wimbledon sliding roof is often held up as a triumph of engineering ingenuity. Brian Tinham takes us behind the scenes, with its designers

Picture the scene. It is Wimbledon fortnight. You've got tickets for Centre Court and it's a British summer, so it's just started raining. The new roof, with its sports luminaries, glides over your head. Easy: except that each of the 10 triangular profile trusses, that carries the micro-thin retracting roof membrane over the 77 metre span stadium, weighs in at a full 100 tonnes. Each also runs on two massive motorised bogies, either side of the court, that are part of a sophisticated electromechanically controlled automation system. And that entire giant articulating mechanism – working as two sets of five trusses, sliding from opposite ends of the stadium – has to operate with sub-millimetre, machine tool precision.

Now there's clever. So clever, it's well worth taking a guided tour through this bespoke piece of engineering, in the capable hands of chief structural engineer John Westmuckett, of Westmuckett Hawkes (at the time, with Wimbledon engineering consultant Capita Symonds), and Daniel Salthouse, project manager for the retractable roof system, with mechanical handling specialist Street CraneXpress.

First, some background. Initial design work began back in 2003, leading to the project itself starting in 2006 as three main phases. First came the ground works and demolition of the east wing and removal of the roof, followed by rebuilding, including six additional rows of terracing, all within nine months, ready for the 2007 championship. Next came the interior fitting out of the stadium and a fixed roof, with a couple of retractable trusses, for the 2008 tournament. Then, last year saw the championship performed beneath its new, fully retractable roof.

Looking at that roof, the grass, and its requirement for sunlight and rain, was always going to be a challenge. And not just on Centre Court, but also the surrounding courts. Indeed, that's what dictated its final form: the All England Club mandated that, with the roof retracted, sunlight exposure be at least as good as the existing court – and that it must not overshadow neighbouring courts.

"That meant designing a low profile, but compact roof that could park at the northern end of the stadium for most of the year, so as not to obscure the sun from the southern end. But that, in turn, meant that half would have to be able to migrate to the southern end, ready for deployment, if rain threatened play," explains Salthouse.

"That meant it took us the best part of a year to develop the geometry of the roof. We tried around 15 different configurations – creating a design that was feasible, but then having to revisit the envelope when analysis revealed inadequate light levels at some point during the 12 months' cycle," comments Westmuckett.

Design difficulties

"So we started with circular edge profiles, then cut the corners back for more light. But then we found that, when the sun was at certain levels in certain months, the top of the roof would create shadows. That's why the final shape is quite strange, with the main trusses cut and curved to follow the sun," he adds.

And much the same applied to the retractable roof membrane, which concertinas over and between the trusses. In this case, the development process was about adjusting the number and height of folds to maximise light and minimise the impact on the surrounding courts.

Turning to the trusses' engineering, Westmuckett

Pointers

- The Centre Court roof harnesses 10 triangular profile trusses
- Span is 77 metres and each truss, including automation mechanisms, weighs in at 100 tonnes
- Each truss runs on two large motorised bogies, either side of the court
- Bespoke 25-tonne precision actuators open each roof truss
- The roof design alone took one year and 15 iterations to get right
- The entire structure works to sub-millimetre machine tool precision

and match

explains that the triangular section – one bottom beam and two top – was selected for its slender 6m height. Each truss is then designed to maintain tension on the fabric, gently but firmly unfolding it in a perfectly choreographed manoeuvre, as it moves – one bay at a time – out over the court.

"Each truss sits on two bogies, on tracks that run either side of the length of Centre Court," explains Westmuckett. "The folded fabric sits between the trusses, held in position by a stretched cable along the valley. Then, as each truss moves in turn, so its two massive end arms open, unfurling the fabric. That's how it stays in tension, whether the roof is parked, on the move, or extended. That's important, too, in terms of preventing wind damage and helping to maintain the integrity of the structure."

Massive structures

Still sounds simple? Let's put some meat on the bones. Each of those side hinges weighs 12.5 tonnes and comprises seven different castings – creating an interesting manufacturing and assembly challenge on its own. Their job is not only to open, but also to prevent the trusses from flexing under tension from the roof membrane. When fully extended, each fabric bay is 8m wide by 3.5m high. Overall, the valley cable, which connects the end arms, is tensioned up to 60 tonnes and insets into each end arm bearing – which, itself, is a meaty unit (supplied by Schaeffler), combined with a sprung arrangement that retains the valley cable tension.

As for the roof movement, opening each truss is performed by four bespoke ultra-precision 25-tonne Moog electromechanical actuators, equipped with absolute encoders and situated at the top of each pair of end arms, which then lock in place when fully deployed. With the first truss deployed, the next comes into play – with the valley cable and four articulating restraint arms, connected between the adjacent trusses' top booms (and rotating under the control of a further four 10-tonne actuators), maintaining spacing and stability. And so the process repeats until all five trusses are deployed from each end and locked in position.

Completing the picture of automation are the 10 pairs of electric motor-powered, four-wheel drive bogies at the base of the trusses, which move them forward or back. These also have position feedback, via an absolute encoder running alongside the main crane rail. They are also equipped with their own bridge bearings (elastomeric pot, sliding and pivoting) to allow the roof to align, without fighting its opposite member. Each truss then sits on top of the bogies, with each bridge bearing supporting its half of the 100 tonnes truss weight.

So there you have it: with that arrangement, the roof accelerates for 10 seconds, reaching a speed of 13 metres per minute, before decelerating for a further 50 seconds – fully closing or opening in just one minute. Westmuckett explains that everything moves in sync, under computer control, to within 1mm accuracy.

"There is a certain amount of flexibility, albeit within a constrained envelope, aided by the bearings. This is a very big machine, and trusses can expand and contract, but our design ensures that those don't generate excessive forces as the roof moves." Game, set and, yes, match. PE

Wimbledon's new roof in all its glory: weighing in at a staggering 100 tonnes