Keels. Why Compromise?

Conrad Cockburn CEng MRINA, GT Yachts Ltd. January 2015

Summary

Brought into sharp focus by the tragic Cheeki Rafiki accident in May 2014 and continuing to be discussed online as in Matthew Sheahan's discussion on YachtingWorld.com, the design of ballast keels seems to be receiving a lot of attention at the moment. So, GT Yachts being a yacht engineering business, I thought it would be interesting to people to understand how we approach the issue. This article looks at a few common solutions and also describes the GT Yachts keel design.

Discussion

Practically all catastrophic keel failures have occurred at the keel-hull intersection. Without getting too deep in structural engineering, in structural terms it can be argued that this location is effectively a structural hinge. Here the structure flexes at this hinge and can go on flexing happily as long as the structure is ultimately strong enough not to fail. Issues have arisen because there seems to have been either a lack of strength (either through material properties or poor design) or lack of material consolidation in way of the hinge, thus rendering it weaker than it ought to be. Result is structural failure during some extreme event or after a number of events (fatigue). In order to design out the problem, first question is, what is the keel for? What's its purpose in life? The modern keel performs two jobs:

- Provides hydrodynamic lift to reduce leeway,
- Provides a volume in which we can place ballast to increase stability.

So, given its purpose, how can we mitigate against the risk of keel failure?

Well, there are a couple of options:

Strengthen the Hinge

An obvious one is to strengthen the area where the keel meets the hull. This means adding material or using a stronger material. Stronger materials usually bring a big cost implication so adding material is usually the way forward. The most common way to do this is by increasing the fillet radius at the hull intersection thereby providing support to the fin further down and away from the hull. The problem this brings is that the thicker the fin towards the top, the deeper the mid-body wave trough will be when heeled and this wave trough absorbs energy creating an element of drag, termed wave-making resistance. An example of this method being taken to the extreme is the fully encapsulated keels, with the hull material extending right through the radius and down the fin, often not using keel bolts at all. However encapsulating the keel brings a large increase in buoyancy and reduces the effect of the ballast by increasing the height of the centre of gravity, which is undesirable. Another extreme form is the wine glass section shape, commonly associated with long keels; practically no hinge at all. Whilst long keels have their proponents, with correctly engineered modern technology they are not needed; long keels bring an undesirable increase in resistance due to a proportionally higher wetted surface area, as well as being very heavy.

Lighten the keel

Engineering, in this case, is dealing with loads. The load, or moment, on the hull created by the mass of the keel is what we need to deal with. This load is necessary, of course, to provide righting moment so it cannot be removed entirely. However, many manufacturers have gone down the route of providing (initial) stability through hull geometry - ie making the hull wider. This then allows a lighter and much cheaper keel to be fitted, given that a greater proportion of the stability is provided by the hull form. While this hull form increases the metacentric height, it does not lower the centre of gravity. There are a number of issues with this approach. Firstly a beamy yacht might handle a little better downwind, but upwind you need profile lift, especially in light airs, to avoid excessive leeway. A beamy hull gets more displacement from being wider and so is necessarily shallower in form. The result is less transverse profile resulting in greater leeway. In extreme designs, the

VO65 is typical, extra foils are deployed to increase lift to prevent the slip sideways. Beamy production yachts are not as extreme in form as this and the result is that they can heel much more before they pick up the form stability, therefore adopting uncomfortable heel angles even in light airs. An upright yacht is a fast and comfortable yacht, so low centre of gravity is the best option.

<u>The GT Yachts Approach</u>

A fin configuration is clearly the winner in terms of resistance, and lead is clearly the superior material in terms of density. For a cruising yacht, a good length of keel is required to prevent excessive leeway in light airs or lumpy seas, but should retain a respectable aspect ratio. So, a lead fin being the keel of choice to meet the functional requirements of leeway and stability, how do we attach and integrate it properly with the rest of the structure?

An encapsulated keel, again, has its proponents, but as an engineered solution it only really skirts the issue. An encapsulated keel adds buoyancy volume of GRP reducing the effect of the ballast, in a kind of self-defeating way. However, the fact that an encapsulated keel has continuous structure from fin to hull does appeal. In order to adopt this aspect of good design, the G35 has been designed with an integral keel stub, so the external laminate of the hull is laid-up into the stub, creating a very stiff structure at the intersection. This can be clearly seen in the photo above. The keel floors, or transverse beams (laid up as an integral part of the hull layup structure as opposed to commonly fitted secondary moulding), which dissipate keel and rigging loads into the hull, are laid through the stub, thus increasing the stiffness and strength in this area. A substantial inner structural laminate is laid over the top once the stub has been filled and large stainless steel plates are employed to spread the bolt loads. The bolts themselves extend from the threaded stainless steel cage within

the lead fin, through bonded compression tubes all the way to the top of the stub, and secured above the inner structural laminate. Structurally, the result is effectively a dual fixing. The stub is an exact match of the lead fin section, and is faired to a seamless finish. Why go to all this trouble? After all, it's a man-hour intensive solution. Well, this solution is the best of many worlds:

- For strength it provides a continuous structure at the hull intersection,
- for stability it allows a non-encapsulated lead fin to be fitted,
- for surety it allows the ballast fin to be through bolted,
- for increased stability, it provides a very low centre of gravity and,
- the dual connection of the stub and the bolts enhance resistance to grounding loads,
- in addition, it allows a bilge sump to be integrated into the design.

The result is a hyrodynamically efficient structurally integrated lead fin keel that creates an extraordinarily stiff yacht in terms of stability [STIX 54, angle of vanishing stability 144 degrees]. It's attached to the hull with continuous structure as well as through bolted with stainless steel bolts. Although not the cheapest nor easiest way to fit a keel to a cruising yacht, the result is both structurally robust as well as efficient in terms of sailing performance.