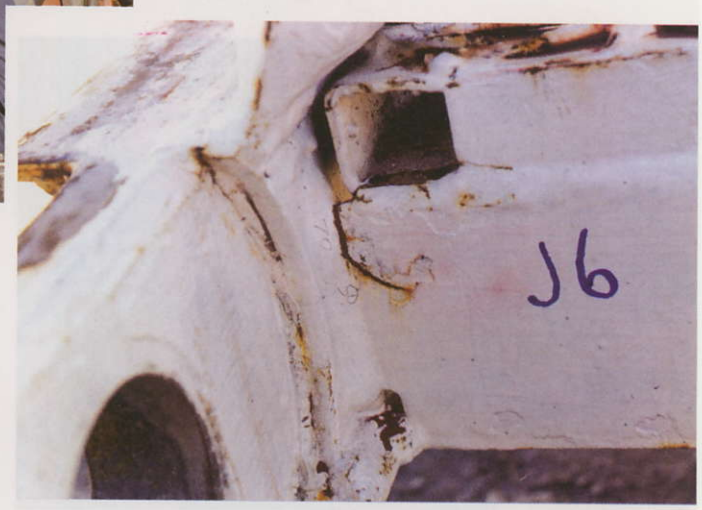
Inspector Richard Seals introduces non-destructive testing techniques and explains where to find fatigue cracks



Is your crack showing?

All of the structural elements of a working crane experience loading and unloading. This in turn cyclically stresses these elements and can eventually create fatigue cracks that start out very small, but over time can grow to weaken the structure until it can no longer carry the strain forces that it has been designed for. If another part of the structure cannot take those forces, the crane falls down. With their lightweight and flexible structural members, modern cranes are fairly fatigue-resistant.

If one looks closely at the frame of an expensive racing or touring bicycle, one will see oh-so-smooth transitions with welds that either look picture perfect, or have been ground invisible. No lumps, bumps, or ripples to act as stress intensifying points.

Cranes are a rough and tumble lot compared to a racing machine. Their usage can be tough, and the construction can be rough. Sometimes the worst case is where a quick weld repair is made without much technical engineering support. This rough care can create spots where the stress is concentrated, and every one of these places is an incubator for a fatigue crack to be born and grow.

The being born part takes the most time. About 80–90% of a fatigue crack's life cycle is spent forming the initial microscopic break in the metal's microstructure. That means that the crack is only detectable for the last 10–20% of its life cycle—its life ending with a catastrophic failure of the structural element. If small cracks are missed during an inspection interval, they may mature to a fracture in a relatively short time.

Where to look

Fatigue cracks always start at a weak spot. Defects such as welding flaws, accidental or sloppy thermal cuts, misaligned members, and other abuses to the structure are all weak spots.

A most insidious weakening occurs not where there is a defect, but where the crane gets stronger! As cranes are loaded and unloaded, their elements must flex and stretch. An overly strong place in the structure will force the flexing and stretching to take place somewhere else. Stresses are concentrated at sharp transitions from weak to strong, because the strong portion keeps the weak portion from yielding to the stresses, and actually creates an overload condition that would not have occurred if the strong portion had not been there. One must include in the inspection plan every change in section that is not bicycle smooth. Section changes occur everywhere.

Where a diagonal member welds to the chord, the chord is stronger where the diagonal is attached. The two together are thicker, and thus weaker where they are not attached. This means that it could crack at the edge of the diagonal weld.

Where one plate welds into the side of another plate, both plates are flexible (stronger) away from where they attach, and rigid (weaker) at the join. So both sides of the attaching weld are suspect. It doesn't matter if one is not meant to be load-carrying. A deck, catwalk, or operator's cab welded to a boom chord will help carry the chord's load, so the ends of those welds need inspection.

Tremendous rigidity occurs where three plates come together. If this area is welded solid, with defect-free welding, there will be no obvious stress risers to start a crack. But the rigidity stresses are so high, the smallest imperfection may become a crack-starter. On the other hand, if the intersection point of the three way join is cut out (called variously a rat hole, access hole, cope, or limber hole) the stresses are greatly reduced. This is not exactly a perfect solution however, because the potential for thermal-cutting gouges and weld end defects still exist in this hard-to-weld place.

Plate intersection details seem to differ depending on the country where they were designed. The important point is that intersections inherently produce the highest stresses, and they are hardest to weld. Plus, they are tricky to inspect. So they are the most important place to inspect very carefully for fatigue cracks.

Above from left to right: Magnetic testing on a dockside crane with an electromagnet and squeeze ball of magnetic particles; Rust helps locate possible crack locations - but only further testing can confirm their existence

Usually, the big and important places are on everybody's schedule to inspect. These include boom chord splices, diagonal-to-chord connections, the hook, and all around where stays and hangers connect. These areas are always worthy of very careful inspections; however, lesser places like those described above must be checked too.

It is also possible that a structural member has been weakened by an aftermarket modification. Any addition to the continuous flow of stress becomes suspect. An often overlooked example of a part added on is where a small steel bar—say 20 x 20mm square stock and 100mm long—is welded in a way to stop a pin from drifting out of a hole, or to prevent a nut from turning. Usually the welds are fairly small. This welded bar can incubate fatigue cracks because it acts as if it is part of the load-carrying member. It is welded to the member, so it shares the load and this makes the adjacent member, which was designed to carry the load, the weaker part.

In eddy-current testing, an inspector manipulates a sensitive probe near suspected crack areas

This is not a one in a million scenario. I have found this scenario happening a fair number of times and I definitely have not inspected anywhere near a million stops.

Fatigue cracking almost always occurs on the external surface of structural members. The first inspection to employ is inspecting visually for external cracking.

Visual testing is quick, easy, and effective. In some instances, binoculars can assist, but good old crawling and climbing is always needed.

Once in a while, an entire member will be seen to have broken free, but this is rare. Usually, the surveyors look for paint cracks, on the theory that paint will crack if the material underneath it moves, like a tiny earthquake. Cranes that are kept outside actually make the process of looking for cracks easier, because the steel exposed by a paint crack will start to rust in contact with rainwater or salt air. The telltale reddish-brown signs are easy markers of places to start looking for cracks. But there are inevitably many false positives – not every rust spot comes from a crack.

This technique uses natural and portable lighting and occasionally a small magnifying glass. Cranes painted white or yellow are easiest to inspect this way. Black is more difficult. Of course, cranes painted reddish-brown are out of the question. Oily and greasy areas don't rust. Neither does aluminium nor stainless steel, but I have never encountered stainless steel on cranes, and structural aluminium inspection is a whole topic in itself.

Plate intersections inherently produce the highest stresses, are hardest to weld and are tricky to inspect. They are the most important place to inspect for fatigue cracks

The main strike against finding cracks by looking for rust stains is the huge amount of rust that occurs on cranes. The many false positives are usually created by crevasses in the structure, such as corners where the paint was never really applied well. These always look linear and crack like and must be considered for further inspection as crevasses are fatigue crack initiators. Patches of rust not near a joint or connection are unlikely to be associated with cracking. The crevasse situation is the prime reason for using eddy current testing.

Eddy current testing requires that a small electronic probe be drawn along the edges of a weld. It emits an electromagnetic field that interacts with linear defects (cracks). The beauty of this use of eddy current testing is that it is relatively immune to paint coverings (intact or cracked), grease and oil, moisture, light dirt and grime, rust and rust staining. And even though the probe is a fussy thing to manipulate accurately along the weld edges (that's where the fatigue cracks are), the test moves along quite rapidly. Cracked metal shows a reading, and cracked paint doesn't, so visual rust indication can be instantly checked for cracking. The evaluation takes about one minute to check 100mm of weld length (the average rust indication). Needless to say, this test equipment can be used on welds that don't have visual cues of cracking, and thus can be used as an additional check for important welds that warrant such scrutiny.

Magnetic particle testing is the definitive test for evaluating cracks in magnetisable metals (steel). It traces the exact shape of the imperfection right on the test object with a visible line of attracted particles. Provided surveyors know the welding process and welding defect characteristics well enough to interpret subtle distinguishing marks, they will be able to tell if it is an incomplete fusion, undercut, cold lap or a crack. Usually, they can then determine whether a crack occurred during welding or during service.

Radiographic Testing (RT)—commonly called X-ray—is not very effective at finding fatigue cracks. Radiography is effective at finding flaws that have volume. Slag pockets and porosity fit this description and RT finds them very well; however, fatigue cracks are almost always very tight (around .02 mm wide) so they essentially have no volume. Radiography is almost never recommended nor used for fatigue crack detection on structures made of steel. There are several other compelling reasons that make RT unfavourable.

Determining the defect type is an important step, especially early on in the inspection program. As defects are found and characterised, the sampling techniques can be adjusted to ensure certain flaw types are covered. If fatigue cracks are being found, the programme can be considered on target and should maybe be expanded. If on the other hand inspectors are picking up cracking or incomplete fusion that are formed during welding, fatigue may not be a problem.

An effective method consists of 1) visually looking for rust stains, 2) eddy current testing all the stains that are suspect, and 3) using magnetic particle testing on those spots that fail the eddy current. It could be argued to be a more effective crack finding program than removing paint from all of the stressed areas. A significant reason for the enhanced effectiveness of the visual, eddy current, magnetic particle system is that the few sites inspected receive a lot of inspection attention. Once the paint of a weld connection is removed, there is nothing guiding the inspector's investigatory approach. A second reason is that the pre-cleaning and repainting can use up more time and monetary resources than the inspection phase.

Next month Richard Seals discusses the strategic role of grinding in repair and inspection