

Breakage of a Connecting Rod on a Reciprocating Gas Compressor.

Introduction-

A chemical plant manufacturing a solvent product operated with a compressor as part of its plant equipment. Apparently without warning, one of the connecting rods of the compressor snapped and smashed the machine's crankcase to pieces.

Machinery details-

Two compressors are installed in this process plant. They are installed as two 100% duty machines, one standby, one operating. They are four cylinder, double acting, single stage machines. The four cylinders being in a flat horizontally opposed format. The machinery is driven by an electric motor.

The gas being compressed is both hazardous and flammable, the compressors being installed in the heart of a large chemical plant, itself surrounded by other operating plant. There is an 8" high pressure natural gas main close to where the compressors are installed.

Details of failure -

The operating machine, apparently without warning, broke one of its connecting rods.

The connecting rod broke underneath the small end eye. After the connecting rod parted company, the machine continued to run, the connecting rod still attached to the crankshaft was flailing about smashing the crankcase of the machine as it went.

Fortunately, someone heard the machine break and ran to the control room shouting for the shift supervisor to stop the machine, which he did by pressing a hard wired trip button installed in the control room.

The containment envelope of the machine was not breached, which is rather lucky, since an escape of flammable gas would certainly have been ignited by the broken connecting rod flailing as it went through the crankcase.

It was extremely fortuitous that a person actually heard the machine break and informed the control room. If he hadn't done that, it would have been some valuable seconds or minutes before the control room bound shift supervisor would have known what was happening.

There were no devices fitted that would stop the machine in such an event. If it hadn't been stopped manually, it could have kept running until it completely destroyed itself.

Investigation-

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When I was called to the site the machine was in a safe condition but major damage was immediately obvious from a quick look over.

From a cursory glance it was clear that the top of the crankcase was pushed upwards and had holes punctured in it.

The sides of the crankcase were bulging outwards and the distance pieces between the cylinder and the crankcase on the failed cylinder were pushed upwards.

The pressure envelope was fortunately not breached and all pipework connections were secure.

Just after the machine failure, the liquid knock out pots upstream of the compressor were checked and were empty.

After taking initial observations, a careful strip down of the machine was carried out.

Since the machine had had an overhaul only two weeks previously by the original manufacturer, their service department was requested to assist in the investigations.

The machine was dismantled by the manufacturers representative under my own guidance. Detailed findings being taken at each stage.

Upon lifting the top crankcase cover off it could be readily seen that the stiffening ribs cast into the inside of the crankcase had been smashed completely off by the flailing loose end of the connecting rod.

This loss of integrity had caused multiple cracks to grow through the surrounding areas of the crankcase. This major component was declared unusable at an early stage of the investigation.

All main bearing bolts were checked and found to be secure and all the big end bearing cap bolts were secure, even the bolts on the failed connecting rod were still perfectly tight.

The cylinder that had the failed connecting rod was next stripped.

Starting with cylinder head removal, there was noted to be fresh marking (along with previous old marks) from a grub screw. The grub screw had since disappeared down through the discharge valves. This was the first evidence that something credible had caused the catastrophic failure.

On closer examination of the cylinder head surface, it could be seen that the piston retaining nut had also hit the head. The nut was found to be loose on the rod. When

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the piston nut was sectioned it could clearly be seen that the internal threads of the nut were pushed and bent backwards by the effect of hitting the head.

Also noticeable though, was that the threads were worn and the outer surface of the nut had been drilled several times where the locking grub screw had been installed several times. In fact, the piston securing nut was found to be in generally less than perfect condition even discounting the failure damage.

When the piston rod and piston were removed, the only visible damage was the imprint of the previously mentioned grub screw.

The piston rod was in good condition, but the nut securing the piston rod into the crosshead was loose.

When the piston and rod assembly was removed it could be seen that the piston had contacted the inner cylinder head on its backward stroke. Presumably, when the crosshead nut had loosened off, the piston rod had screwed itself into the crosshead, allowing contact to be made between the head and piston at bottom dead centre.

Removing the cracked distance pieces from the broken crankcase revealed that all the fasteners on the distance piece attachments were loose, but this is not surprising given the amount of cracking and breakage in the general area of the failure.

The gas packings, oil wiper packings and crosshead showed no sign of damage.

The crankshaft was removed along with the failed connecting rod, leaving the three undamaged components temporarily assembled.

There was no visible damage to the flywheel, coupling or crankshaft.

Further Investigations-

Having collected all the evidence from the machine, all the plant operating parameters were collected in order to see if any unusual circumstances had occurred while the machine was being damaged.

The pistons, piston rods and other parts were shipped back to the factory.

The crankshaft, the three good connecting rods and the crossheads were sent to the manufacturers supplier.

The failed connecting rod pieces were sent to the engineering research department of a UK University.

Finally, the component parts that had failed were modelled in software to analyse the

failure mode.

The feedback from these investigations showed-

The plant records were scrutinised by chemical engineers and no failure mechanism or off specification operation of the plant was found. In particular, the operating pressures and temperatures demonstrated that liquid product could not have existed inside the machine at the time of failure.

Despite the piston apparently touching the inner cylinder head at bottom dead centre of the inward cylinder stroke and its securing nut being found loose, the factory found that the piston was still located against its locating shoulder on the piston rod.

The crankshaft, crossheads and three good connecting rods were subjected to intensive non destructive testing. There was minor cracking found in all the components, but this was thought to have been present from the original manufacturing process. Since all the parts were more than ten years old, the NDT done at the time of manufacture would not have picked up the defects. In addition, the company had moved from Cast to Forged components in this time.

There was no cracking found in the area of failure on the three surviving rods.

The University report on the connecting rod failure was very inconclusive. Due to the flailing around of the broken rod, the fracture surfaces were completely obliterated by post failure damage. No conclusive failure data was given by the University. However, they did speculate that the failure was a “fast fracture” given that there was little or no evidence of yield at the failure location.

Analysis and calculation showed that if the piston hit the cylinder head on the backward stroke, the rear head should fail before the connecting rod should snap. The reason for this was that the head is water cooled and so is a hollow grey cast iron piece. It has little strength beyond what is need to retain the working pressure of the machine.

As can be seen from the above investigation results, there are conflicting aspects. The investigation concluded that the failure mode was-

1. The piston securing nut grub screw fell out of the piston securing nut for reasons unknown except it was possibly not tightened sufficiently. Its security relied entirely on the friction between the threads of the screw and the nut.
2. Once the locking grub screw fell out, the piston nut loosened.
3. The reason for this was that the nut was installed at site on the rod and there is no

equipment at site to tighten it sufficiently to the required torque.

4. The piston nut was of poor quality and had been used too many times. It should have been replaced with new.
5. The piston nut once unscrewed contacted the outer cylinder head, the vibration of which loosened the crosshead to piston rod securing nut.
6. The piston rod then screwed back into the crosshead and the piston touched the inner cylinder head.
7. When the piston touched the cylinder head the connecting rod broke into two pieces.
8. It was likely that the failure occurred at an existing minor crack in the connecting rod which had been there since manufacture.
9. The failure was a “fast fracture”.

The problems with this scenario are-

1. Why wasn't the piston moved on its piston rod by A) The gas pressure? or B) contact with the inner cylinder head?
2. All calculations and simulations said that the inner head should fail before the connecting rod.
3. Though cracks were indeed found in the other three connecting rods, none were present in the area of failure. This however, is not conclusive evidence that the failed part was likewise. It simply could not be determined due to the post failure damage.

Actions Taken-

A plan was drawn up to rebuild both the failed machine and the standby machine. A combination of stock spares and newly manufactured spares were used firstly to rebuild the failed unit and then the spare machine. Several changes were made as a result of the failure and these are-

A vibration trip was fitted to the machines. This is probably the most important learning aspect of this failure. Without manual intervention the machine would not stop. It could self destruct.

The crosshead to piston securing method was modified so that instead of relying on friction between the piston rod, nut and crosshead threads to secure the

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connection, positive locking of the rod and nut threads was achieved. This was in fact a feature introduced on machines made a few years after these were built.

A procedure was adopted where piston securing nuts would never be used more than once and they would only be supplied tightened properly at the factory. Instead of stocking spare pistons, rods and nuts separately, the engineering stores stocks now only built up assemblies that have been built at the manufacturers workshop.

A preventive maintenance programme was drawn up which included NDT crack detection of major components periodically.

Conclusion-

A major catastrophe was averted by chance. A contractor happened to be near the compressors when the failure occurred. Fortunately the person had the good sense to realise that something was badly wrong on the operating machine and he had the common sense to go and tell the control room to stop the unit.

Several things could have gone wrong here, the person could have been hit by flying debris, there could have been a fire or explosion or the natural gas main could have been hit by flying debris.

There is no doubt that the quick reactions of the contractor saved the day.

One thing that is open to question however, is why a major operating company could operate large machines in hazardous conditions without any protection built into the system at all. All major companies have engineering groups that specify machines either through contractors or directly themselves. And yet the machines were operated for ten years with no protection to shut them down in the event of an emergency.

It is my own experience that this indeed is not unusual. Some companies specify them when buying a machine and some don't.

From the time of this event, it is the practice of the author to advise all operators of reciprocating machinery to fit a vibration trip to their machines. The devices are cheap, reliable and potentially save an incident becoming a major disaster.

Follow Up-

The machines continue to operate on this plant. There has never been another incident of this nature on the machines. At the time of writing this paper, it is about fifteen years since the incident happened and it is doubtful whether anyone still working at the facility remembers the incident. It is however, to be hoped that the

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vibration sensors trip the machines should they ever be required.

It has never really been fully understood why the contradictions occur in the accepted explanation of the failure.

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The consultancy welcomes contact from all who are interested in plant and machinery maintenance, systems and development.