Stephen H Shakeshaft Consulting Ltd
75 Mere Bank, Davenham, Northwich, Cheshire, CW9 8NB.
Tel- 01606 331558 Mobile- 07779 190087 Email- steve@shs-consulting.co.uk

Fatigue Failure of Compressor Bolting.

Introduction-

A plant operator on a routine walk around his plant taking readings noticed that one of the cylinders on a reciprocating compressor was moving up and down.

Immediately realising something was wrong he shut the unit down straight away and informed the plant management.

Description of Machine-

The machine was a single stage double acting compressor with two cylinders.

On this machine, the cylinders were bolted to a distance piece which was in turn bolted to the crankcase of the machine. This is a standard configuration for this type of machine.

The bolted joint where the cylinder bolted to the distance piece was where the operator saw the unusual movement occurring on the machine.

Just one cylinder was affected, the other was still attached.

Investigation-

With the machine made safe one of the plant technicians removed inspection covers in order to gain access to the bolts which at this joint were inside the distance piece.

On this design of machine the cylinder is attached to the distance piece by a ring of 16 stud bolts fitted with “Nyloc” locking nuts.

It was immediately obvious that many of the stud bolts were in fact lying in the bottom of the distance piece. In fact of the 16 bolts, 10 were lying in the bottom of the distance piece, the nuts still in place on the broken studs.

With the cylinder supported the remaining 6 stud bolts were numbered in their positions and then removed.

The broken stud bolts were cleaned up and looked at by a materials laboratory.

In addition, the 6 other stud bolts were sent away for non destructive testing (NDT).

Each of the 10 broken stud bolts was clearly a fatigue failure. The fracture face was smooth across most of its surface where the fatigue cracking had propagated, with a small roughened area where the final tensile failure had occurred.

NDT on the remaining 6 bolts showed that 4 had cracked and only two were found to be free of cracking.

The attachment of the distance piece to the crankcase was inspected and the majority of the bolts were found to have loosened. Some significantly so. The stud bolts from this joint were removed and sent for NDT. Again there were 16 bolts, but this time just two were found to be cracked.

The plant maintenance records were very poor, but the maintenance supervisor who had been on the plant for some time could remember that it was not unusual that when the machines were worked on a bolt may be found broken or a nut found to be vibrated off inside the distance piece.

Apparently, during the early years of operation the nuts vibrated off the cylinder attachment stud bolts so frequently that the manufacturer changed the nuts to “Nyloc” self locking nuts.

This cured the problem of the nuts coming off, but it had not solved problems with the stud bolts snapping off.

Even though the machines were 190 years old at the time of this failure, they had only ever been worked on by the manufacturers service representatives.

It was said that the service technicians had always been vigilant in torquing up the nuts to the design value. In fact there was no reason to doubt this, each representative had his own calibrated torque wrench issued by the company for precisely this purpose.

Further Investigation-

Examination of the details of the bolted joint showed that the metal to metal mating surfaces of the joint were fretting. Clearly this meant that the joint halves were moving relative to each other while the machine was operating.

In turn this meant that there was insufficient clamping force being applied by the bolting to keep the joint stable.

Turning attention to the bolting, the torque applied to the nuts on the stud bolts when the assembly was being tightened was being compromised by the additional friction from the nylon inserts inside the self locking nuts.

The manufacturers service department confirmed that the torque being used for tightening of the fasteners was the same whether they were using regular nuts or self locking nuts.

Further, there was no instruction whether the assembly was torqued with lubricated nuts or dry.

It was therefore deduced that the clamping load applied by the fasteners to the joint was neither sufficient nor being applied consistently enough to prevent vibration loosening or fatigue failure.

Fatigue failure in bolted joints is frequently attributed to insufficient bolt tightening and this certainly appeared to be the case here.

What was required was a method of reliably and accurately getting the desired tension into the bolting. And just as importantly, maintaining it.

A review of bolting techniques was made and the techniques available were narrowed down to two applicable methods of tightening.

The method desired would directly measure the degree of stretch (relating stretch of the bolt to the force applied gives a direct indication of the clamping force applied by the bolt) in the stud bolt as it was tightened and would allow rechecking to ensure that tension was being maintained.

Both the methods selected for further investigation met this criteria.

Method 1- Ultra-Sonic Length Measurement. Using this technique, each bolt is stretched in a laboratory to the design tension. On one end of the bolt an ultra sonic probe (not dissimilar to a material thickness checking probe) is attached.

Each bolt is identified and the stretch required in each bolt to achieve the desired tension is logged.

The bolts are then installed at the job site and the bolts tightened until the previously logged tension is achieved by monitoring the stretch as the fastener is tightened.

Method 2- Load Controlling Fastener. Using this technique, again each bolt is calibrated in the laboratory. However, each bolt is fitted with a gauge pin under the head of which is a washer free to spin. The air gap under the head of the gauge pin is set such that at the desired tension, the bolt is stretched sufficiently to close the air gap and the washer becomes trapped.

Each fastener is calibrated to be within +/-5% of the desired bolt tension.

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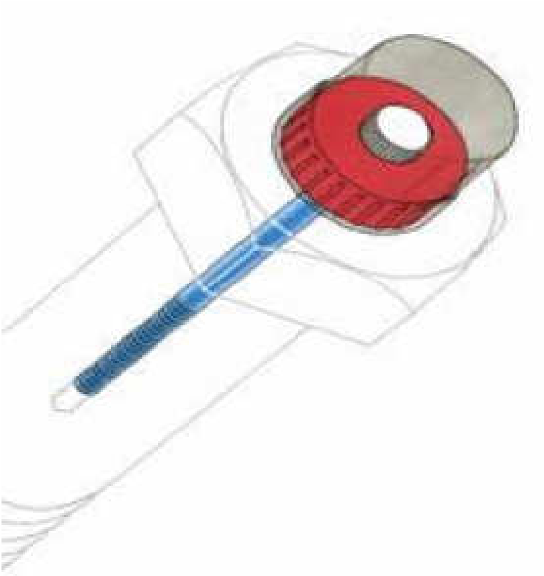
The big advantage of the Load Controlling Fastener is that once it is set up, the bolt can be instantly monitored for tension without use of any tools and while the machine is operating.



This fact was enough to make the decision to use Load Controlling Fasteners on these machines.

Two complete sets of Load Controlling Fasteners were ordered up, one for each cylinder assembly.

The distance pieces and the cylinders were then assembled using the new fasteners. As an experiment the bolted joints were left overnight after tightening in order to see if bolt tension was retained.

In fact, despite the joint being metal to metal and the bolting being tightened properly, 75% of the bolts had lost some tension just by sitting there overnight.

Above- Load Controlled Fastener.

The relaxation seen by leaving the joint overnight was not major but was enough to require tightening to bring the correct tension back to the bolt. This was surprising to find but not entirely unexpected.

The machines were rebuilt and put into service and the bolts checked regularly for tension.

For the first few days some of the fasteners did require further minor re-tightening to bring them back to the correct tension. However, after this was done, the joints were stable and no further relaxation of the bolts was experienced.

Conclusion-

In the earlier days of the machine’s operation a problem had in fact been recognised.

The problem was nuts coming off the stud bolts due to vibration loosening. The solution applied to the problem was to fit self locking nuts.

This unfortunately meant that the applied tension in the bolting (already too low as shown by the nuts loosening) was further lowered due to the additional friction caused by the nylon inserts inside the locking nuts absorbing some of the tightening torque.

This modification in fact stopped the nuts vibrating off but the stud bolts failed in fatigue instead.

This is a classic case of addressing the symptoms and not the cause of a problem.

On this machine it was fortunate that an operator spotted the problem in its final stages and shut the machine down before a product release occurred.

The machines have now operated for several years trouble free. Now that the bolt tension is correct, the joint is fully clamped and vibration loosening and fatigue problems are a thing of the past.

Stephen H Shakeshaft IEng MIMechE MIET MIIE

About the author-

Stephen H Shakeshaft is a Mechanical Engineer based in the United Kingdom. He is the Principal Consultant and Director of Stephen H Shakeshaft Consulting Ltd., an engineering consultancy specialising in optimisation of existing assets and engineering design of new build projects.

Stephen has over 30 years experience of working at the "sharp end" as well as the "back room" of manufacturing industries with clients in the chemical, utility, metals, industrial gases and pharmaceutical businesses.

Stephen is a registered professional engineer in the UK and is a corporate member of both the Institution of Mechanical Engineers and the Institution of Engineering and Technology.

Stephen H Shakeshaft Consulting Ltd. can be found on the internet at the following URL-

www.shs-consulting.co.uk

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