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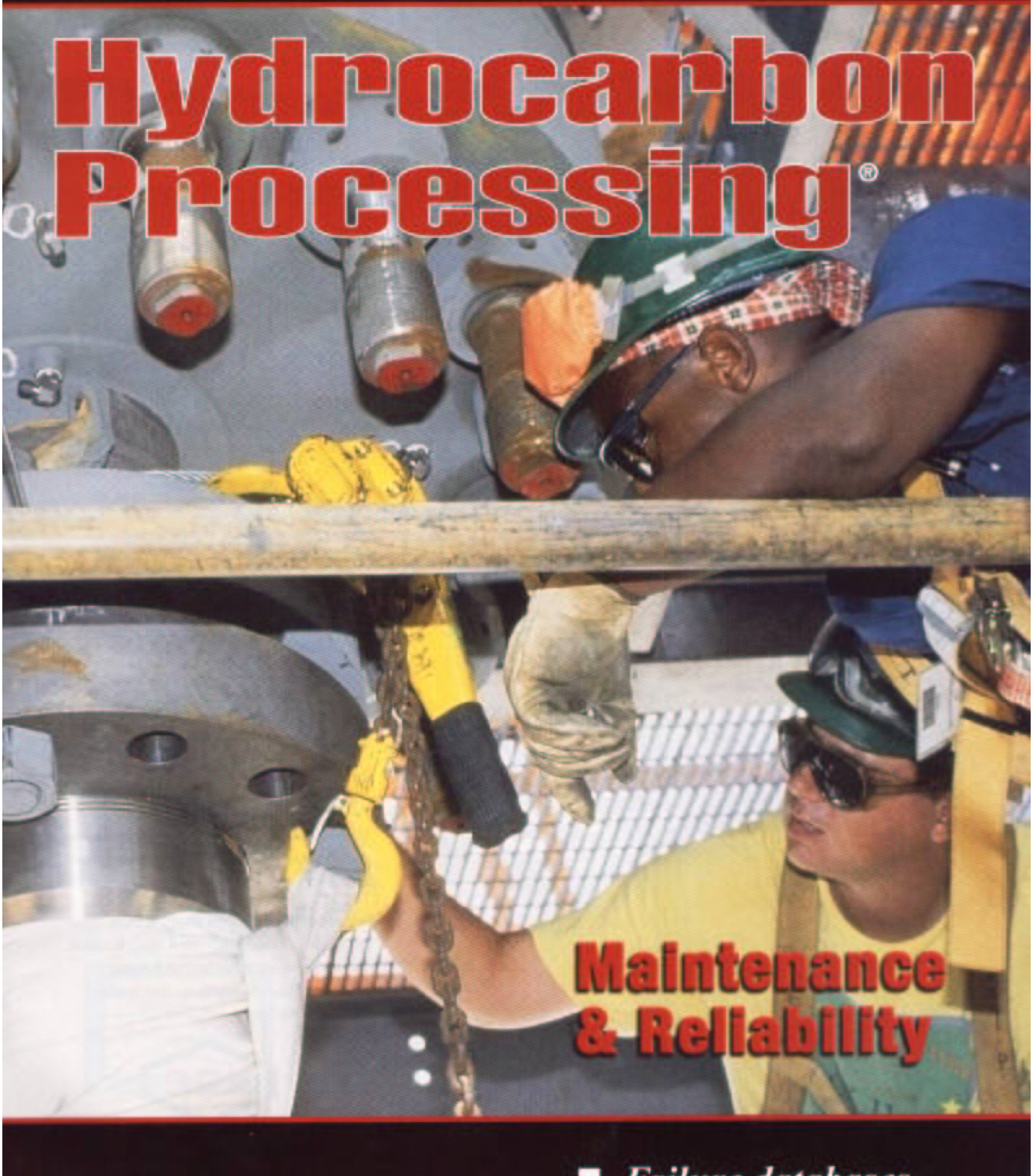

Maintenance & Reliability

- *Failure databases*
- *Risk-based inspection*
- *Asset management*

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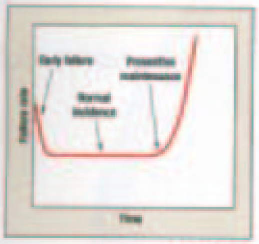
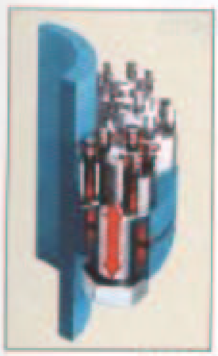


Page 39: The traditional bathtub curve illustrates machine life.



Page 48: The cross-section helps to visualize how an MJT works.

Page 59: Plot of pilot sound pressure levels.

SPECIAL REPORT: MAINTENANCE AND RELIABILITY

ENVIRONMENT

Retrofitting multijack tensioners on a combustion gas turbine generator

Consider this technology for difficult bolting applications

. Al-Mohssen, Saudi Arabian Oil Co., Dhahran, audi Arabia

Global competition has been moving the hydrocarbon processing industry to ever-higher levels of efficiency and production rates. This has led to an increased emand on both equipment and manpower to produce higher eliability and shorter turnaround times. One major problem aced when dealing with high-temperature and pressure quipment is its bolting and unbolting. This is due to the very irge torque required to properly seal the joint and the difiiculty of its application, especially in the field.

One of main gas turbine generators in a large refinery has een notoriously known for being very hard to bolt and for eveloping leaks when olted. A number of methods re available to help with olting problems, but for this articular application none ould be used. Multijack tenoners (MJTs) seemed to be ery promising to help in lleviating some of these roblems. Consequently, ome replacement bolts were pecified, designed, manuictured and installed on the nit to see if they could help ith the problem.

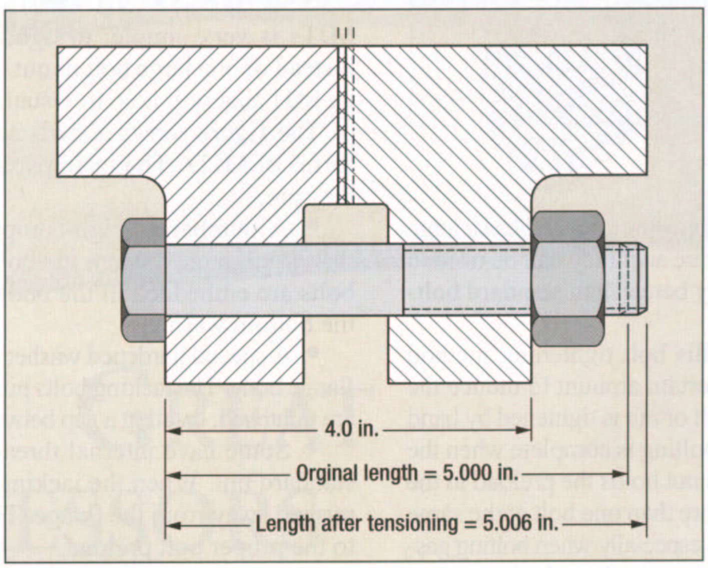


Fig. 1. As the nut is tightened the stud elongates.

he basics. Fig. 1 shows a ketch of a typical bolted onnection. When the boltig is tightened, the main ody of the bolt (or the stud if there is a stud and two nuts) elongated. The increase in bolt length introduces tenonal stresses into the bolt or stud. At the same time, the disince between the nuts decreases by the same amount. This itroduces compressive stresses in the flange faces, which old the flange together and prevent leaks.

The tensional stress in the stud is produced by the rotaon of the nut or bolt. Essentially the bolt is a tool that conerts the torque applied into stress in the stud or bolt. This iduced stress is called *preload*. The torquing value required achieve a certain preload varies and depends on many facirs. This includes the friction coefficient between the nut id bolt, the cross-section of the bolts as well as many other ictors. By far the biggest contributor to the required torquing alue is the bolt or stud cross-sectional area. Fig. 2 and Table 1 show the different values recommended from one gas turbine manufacturer for casing bolts. These torquing values are representative of most other manufacturers as well as many local and industrial standards.

As can be seen from the table and the plot, the torquing value required to set a bolt to its proper preload is a very nonlinear function of the bolt diameter. While it only takes 369 ft lb to seat a bolt to 45,000 psi preload when its diameter is 1 in., it takes 3,313 ft lb (8.9 times as much!) to set a 2-in. diameter bolt to the same preload. In fact, the required torque is a third power of the bolt diameter if other parameters are kept constant.

Hand tools can be used to apply the required torque with relative ease and accuracy for smaller diameter bolting. However, as bolting diameter—and consequently torquing requirement—gets higher, methods for applying the required torque get more and more extreme. For example, it is quite common to use large sledgehammers and field-made "tools" to bolt and unbolt large joints. In fact, sometimes so much force is required that cranes and/or other heavy equipment have to be used to tighten large nuts or free seized bolts.

Apart from providing totally inaccurate preloading to the joint and possibly causing joint failure, these extreme methods have major safety concerns especially when the bolting is in confined or awkward areas. In fact, there are many reported cases of serious injuries as a consequence of trying to bolt or unbolt a large bolt or stud. In addition, the inaccurate, uneven and often insufficient bolting stress will sometimes lead to serious joint leaks that will be a major problem.

A number of methods have been proposed and used to help in solving or easing the large-diameter bolting problem. Some of the most common are:

- Bolt heating: In this method, the studs have a specially designed heating cavity in their center. The principle is to heat the bolt or stud using special heating rods and tighten it while it is hot. The rods are later removed and the preload will gradually develop as the bolt cools to the casing temperature. This method, although helpful in many

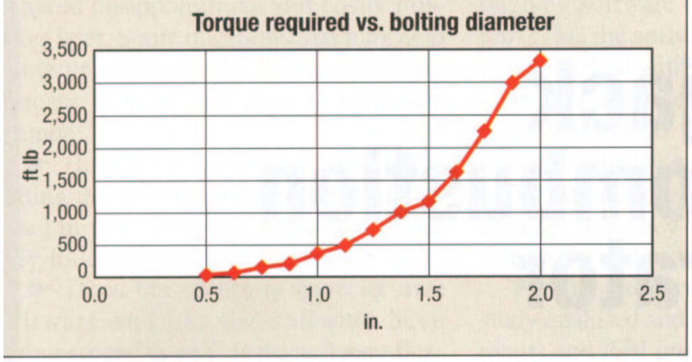


Fig. 2. Torque required to set a bolt to its proper preload is a nonlinear function of bolt diameter.

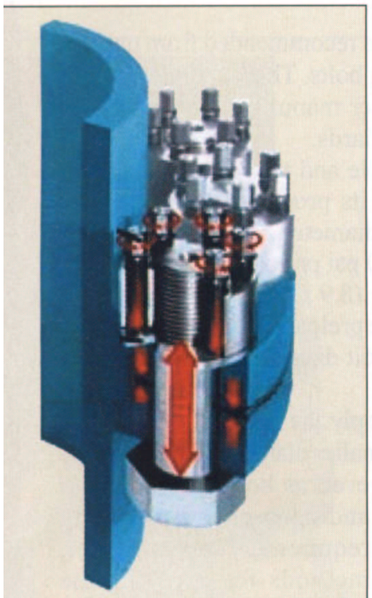


Fig. 3. The cross-section helps to visualize how an MJT works.

Table 1. Torque value to reach 45,000 psi preload

Nominal diameter (in.)	Torque (ft lb)
0.5	43
0.625	90
0.75	150
0.875	240
1	369
1.125	534
1.25	750
1.375	1,019
1.5	1,200
1.625	1,650
1.75	2,250
1.875	3,000
2	3,313

cases, requires special studs and heating elements and has a large torque requirement. In addition, torque accuracy can be limited in many cases, though it is generally better than standard bolting practices.

- Hydraulic stud tensioning: This bolt tightening method relies on stretching the bolt stud a certain amount to induce the proper preload in it. After that, the bolt or nut is tightened by hand until it touches the flange face. The bolting is complete when the hydraulic tension is removed and the nut holds the preload in the bolt. This method can be used for more than one bolt at the same time, which can be very advantageous especially when bolting gasketed flanges. On the other hand, this method can be inaccurate (especially for short studs), and it can't be used for all types of bolting. In addition, special hydraulic tensioning devices and associated pumps and auxiliaries have to be purchased and maintained.
- Hydraulic bolting: It is identical to normal bolting except that the normal torque is applied using a special hydraulic mechanism. Again, this method works in many applications but can't always be used, especially when there are space limitations. Apart from not having a high accuracy of preload, they suffer from some of the same limitations of normal bolting including thread galling. And like hydraulic stud tensioning, there is the upfront cost of the hydraulic mechanism. This can be significant.

Multijack tensioners. Multijack tensioners (MJTs) are a relatively new method of trying to deal with the problems described in the previous section. MJTs are special patented design fasteners that replace existing bolts or nuts. The main idea behind MJTs is very simple: to tighten a number of smaller jacks instead of one large bolt or nut. Fig. 3 shows a cross-section of an MJT that will help to visualize how it works.

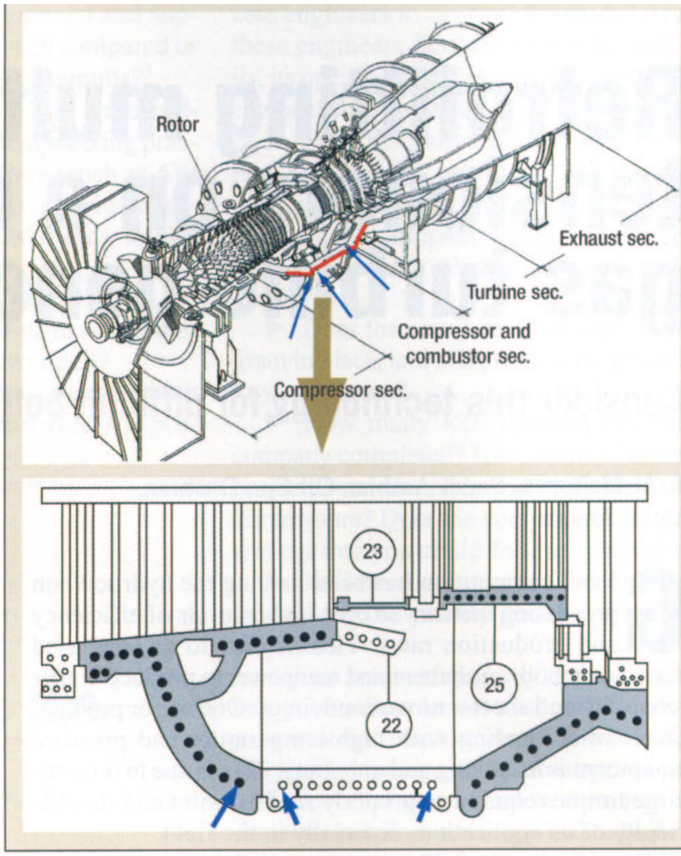


Fig. 4. The red line shows the location of the leaks while the blue arrows show the location of the bolts to be replaced.

The figure shows a cross section of just one of the many forms of MJTs. The main parts are common to all MJTs and they are:

- A number of high-compressive strength jacking bolts that are tightened when the bolts are installed. These jacking bolts are embedded in the body of the MJT and push against the bottom washer.
- A special hardened washer located between the bolt and the flange body. The jacking bolts push against this washer when they are tightened, creating a gap between the bolt body and the washer.
- Some have internal threading that holds the stud like a standard nut. When the jacking bolts are tightened, the nut is pushed away from the flange. This causes the stud to be pulled to the proper bolt preload.

The advantage of MJTs is that torque required to achieve the target preload using the jacking bolts is much less than that required to preload the big nut or bolt. Table 2 shows the jacking bolt torquing required verses the original bolt for one particular application. In addition, the last column shows the torque advantage, which varies from 26:1 to 273:1 for larger diameter bolting!

Retrofitting MJTs onto combustion gas turbine. Industrial combustion gas turbines are well known for being especially hard to bolt and unbolt. Not only are the bolts and nuts very large, they are not forgiving and will leak when not preloaded properly since the flanges are metal-to-metal with no gaskets. The problem can be exacerbated when the bolts are in a hard-to-access area or lack heating holes for thermal tightening.

One particular unit in a refinery suffered from all of these problems with a large number of its bolts. Some bolts literally took

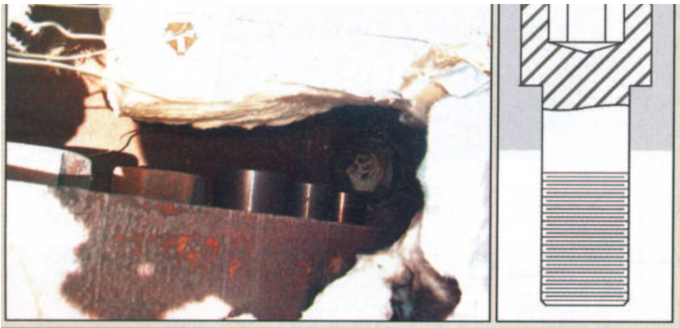
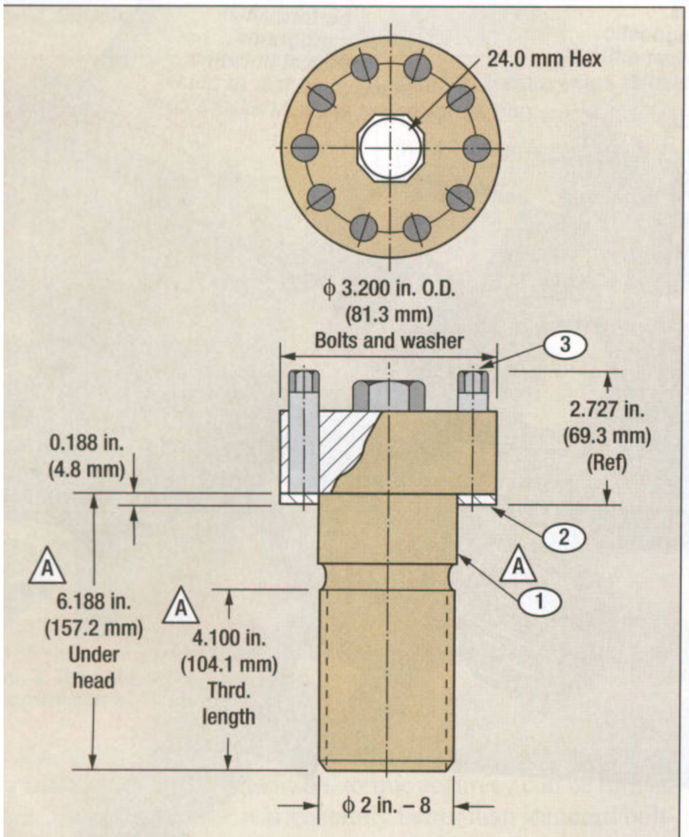


Fig. 5. The photo and sketch show the original bolts.



ig. 6. Cross-section of an MJT used to replace the original bolts.

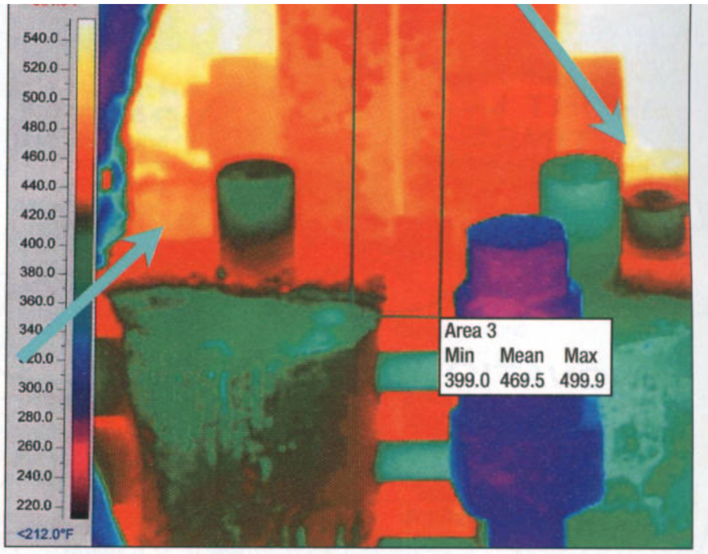


Fig. 7. The arrows point to the areas where the bolts would be replaced.

Table 2. Torque required for standard bolts and MJTs of the same size. Last column shows the ratio between them.

Size (in)	Torque required for standard hex nut	Torque required for MJT	Advantage (regular torque/ MJT torque)
1	955	36	26.53
1.5	2,890	65	44.46
2	6,880	152	45.26
3	25,200	310	81.29
4	50,500	310	162.90
5	99,000	520	190.38
6	142,000	520	273.08

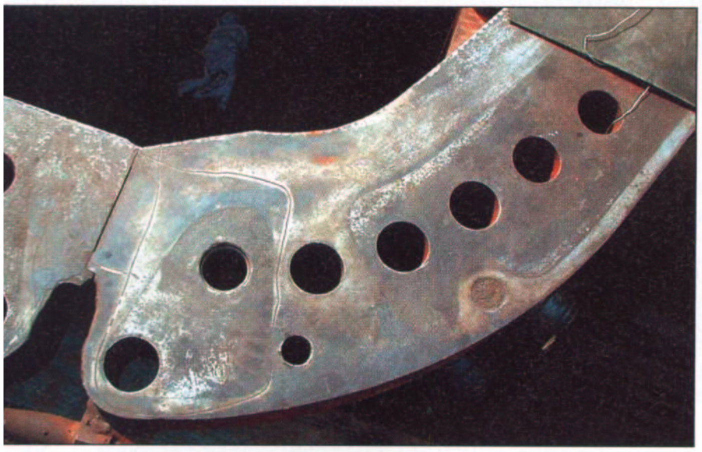
ıours to bolt and unbolt, especially when they had not been ɪpened in a long time. Sometimes bolts could not be freed and vould have to be cut with a torch to be removed. In addition, the ınit was notorious for developing hot air leaks after being overıauled and, consequently, would have to be shut down for bolt etightening. Even then the leak would not completely disappear, ince the casing faces were distorted due to previous leaks.

All of these problems made this unit a very good candidate ɔ replace the original turbine bolting with MJTs. The first step vas to decide which bolts to replace with MJTs during the next nit overhaul. The unit had many bolts and it would have been neconomical to replace them all. Instead, efforts were concenrated on selecting a few large-diameter bolts in inaccessible nd critical areas to be replaced. Fig. 4 shows a cross-section of ıe gas turbine casing, with arrows pointing to the bolts that were elected to be changed. As can be seen from Fig. 5, these bolts re situated at the corners of the casings and are among the ırgest in diameter (2 in.). Furthermore, the original bolts had a ırge hexagonal socket cap, which meant that a special socket had ɔ be used to torque them. It was felt that replacing these bolts vould not only take care of the most problematic bolts in the area ut would also have the most positive effect on reducing leaks.

Once it was decided which bolts would be retrofitted with MJTs, a custom design was developed with help from the manufacturer. The bolt would have to fit in the recessed area intended for the original bolt. It would also have to allow enough clearance above it to access the jacking bolts. Since detailed drawings for the bolts and the casing were not available, detailed measurements of some spare bolts along with the casing had to be taken. Once these details were collected, they were sent to the manufacturer. It came up with a design similar to what is shown in Fig.6.

The next step was to come up with an appropriate material for this application, taking into account both the designed preload of the bolting and the temperature that the bolts will have to withstand. After some background search as well as consultation with different turbine manufacturers, a preload close to the original design was selected that would help in minimizing the leak problem. Actual casing operating temperature was measured by taking a thermal image of the unit when it was running (Fig. 7). Consequently, an estimate of the maximum temperatures the bolting will be exposed to over its life was determined. Samples of the original bolting material were analyzed to try to guess its composition and the design constraints of the original bolting designer. A final selection of bolting materials was reached with help from the MJT manufacturer as well as in-house company engineering expertise. Finally, the designed bolts were manufactured and installed in a major unit overhaul.

MJT Assessment. We found that they were more expensive than the original OEM bolts (about 40% more in this particular application). In addition, most machinists do not know how to properly install MJTs, so some time has to be spent explaining the proper



ı. 8. **Leaks caused uneveness in the turbine casing. The deep groove is caused previous attempts to stop the leak by crushing a wire between the two flanges.**

stallation sequence. Having said this, we feel that MJTs have per-rmed very well in our particular application. Time required to stall bolts has shrunk from about 30–60 min. to less than 5 min. ·r bolt. Moreover, all the problems that we were facing with the iginal bolts have now disappeared. No heavy hammering or ·ating with torches is required to set these bolts. In our applica-ɪn, the required torque has decreased from the original 3,313 lb to 65 ft lb (an advantage of more than 50:1). This new torque n be easily and accurately applied by hand. This is achieved with ınfidence that the bolts were tightened to the target preload.

As has been mentioned earlier, this turbine had a long his-ry of developing leaks in its horizontal and vertical flanges. the past, the leaks were so severe that they have caused ıevenness in the turbine casing (Fig. 8). After MJTs were stalled and the unit was run, some clear leaks did develop but only in the areas where the new bolts were not installed on the casing. This shows that these bolts are as good or most likely better than the original bolts in applying the proper preload and preventing hot air leaks on the casing.

The decision to use MJTs should not be automatic; each bolting problem should be evaluated separately to decide if they can be used and are worth the engineering effort to retrofit them to solve the problem. Other bolting methods are very useful and effective in many applications. In our opinion, however, MJTs should be at least considered for large or especially critical bolting applications to improve safety and reliability. They should be considered for new installations that require large bolts or high torquing values and preloads. ■

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