4. Tightening Reliability

4-1 Characteristic Factors of Defects in Bolt Tightening

Characteristic factors (4M's) of defects in bolt tightening

1.MAN
- Human Error
- Missed tightening
- Improper tool

2.METHOD
- Improper tightening specification
- Wrong specification
- Wrong fastening procedure
- Wrong tool selection

3.MACHINE
- Improper tightening equipment
- Inaccuracy
- Mechanical failure

4.MATERIAL
- Improper material
- Out of tolerance
- Defective materials
- Insufficient lubricant

4-2 Characteristic Diagram of Defective Joint

Characteristic diagram of defective joint

1. Design failure
- Prospect failure of required tightening torque
- Insufficient strength of bolt joint
- Insufficient permission variation width of tightening force
- Prospect failure of drop of initial tightening force
- Indication failure of tightening operation
- Insufficient loosing measure
- No availability of tightening tools
- No availability of tightening inspection

2. Improper tightening by operator
- Incorrect tightening procedure performed
- Improper handling of tools
- Missed tightening
- Instruction failure to operator

3. Improper tightening tool
- Change of working condition
- Function failure
- Decrease in accuracy
- Improper selection

4. Defective bolt joint
- Excessive variation width of torque coefficient
- Change of condition on friction on part of screw
- Process failure of bolt
- Insufficient strength of bolt
- Size error of bolt
- Right angle defective of bearing surface

5. Failure of service
- Insufficient education to operator
- Check failure of loosening of bolts
- No proper tightening tools available
- Insufficient instruction about tightening spec

6. System failure
- Insufficient standardization of bolt tightening
- Insufficient indication of tightening spec to operator
- Insufficient observation system to tightening failure
- Insufficient system of bolt tightening
- Insufficient training of bolt tightening

Defective Joint
- Damage of joint
- Loose fastener
- Improper alignment
- Conduction defective
- Leakage

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4-3 Bolt Tightening Reliability

(1) Bolt tightening reliability

Bolt tightening reliability means, simply to tighten bolts properly.
However, depending upon the circumstances there are the following assurance levels.

① To pass tightening inspection (by retightening)
② To tighten bolts at the required torque (within the tolerance) specified by the drawing
③ To tighten bolts upto the required initial clamping force (initial axial tension)
④ To tighten bolts upto the required working clamping force (axial tension)
⑤ To achieve the maximum performance of the bolt, use only parts or bolts that are in good condition and do not easily loosen or break and do not create leaks from the bolted joint.

Even if the tightening torque is kept constant, the generated initial clamping force will greatly be dispersed. Therefore, the target of "bolt tightening reliability" by torque method is not to keep working clamping force within the given dispersion width, but to improve the reliability of the bolt tightening work by linking it with one of the assurance levels listed above. This is important so as not to generate any problems even if the clamping force in use is dispersed. This is the feature of "bolt tightening reliability".

(2) Bolt tightening reliability and tightening work

Bolts generate clamping force and can only show its performance after proper tightening work has been completed.
Therefore, we cannot correctly check whether the bolt has been tightened or not until after the bolts has been tightened.
It is important that the operator check the tightening accuracy while performing the work rather than to do the inspection after the work is completed. This is called "containing the quality while tightening".
The factors that obstruct the reliability of the tightening work are classified into two categories, machine error and human error.

(3) Accuracy of tightening torque

In general tightening tools are classified into 3 categories as table 4-1.
Allowable tolerance of tightening torque should appropriately be decided and standardized based upon the relation with the allowance dispersion width. (Figure 4-1)

Figure 4-1 Accuracy of tightening torque and dispersion of tension

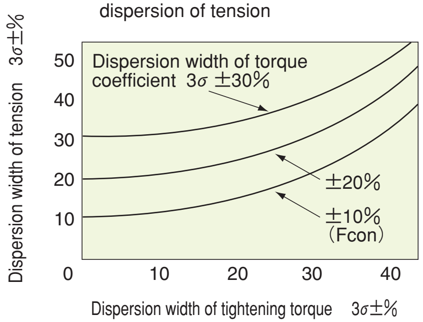


Table 4-1 Tightening method classifications

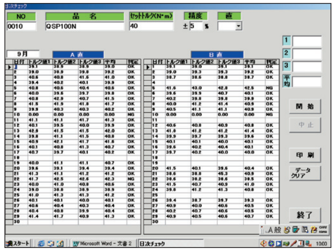
Method	Mechanism	Accuracy range (3σ)	Tightening Tool
①By guessing	The operator judges the tightening condition by force, sound, etc. and stops tightening work.	Over±30%	Manual wrench Manual screwdriver Impact wrench (no control)
②By maximum capacity	The bolt is tightened until motor stalls or clutch slips.	±10~30%	Stall type, Slip clutch type Impact wrench (control type)
③By torque detection	Tightening torque is measured, when the required torque is reached, the tool stops.	Within ±10%	Torque wrench Mechanical type torque control Electric type torque control

(4) Machine error

In any case, sooner or later the tightening torque will change and the accuracy will go out of tolerance in relation to the wearing of tightening tool. In most cases, however, the operators are unaware of the change resulting in the defects of a large quantity of products. The first method focuses on the accuracy of the tightening tool itself. Periodic check of the torque wrenches and nutrunner keeps the tools calibrated properly to insure accurate tightening. One common problem of power tightening tools is that often times the calibration results differ from the actual tightening torque. (Figure 4-2) This difference is due primarily to the fact that the calibration procedure does not accurately replicate the joint conditions simulate the actual bolt tightening.
The second method is to sample the tightened bolts and check them by using the retightening torque inspection method. The tightening torque of the tool is presumed. By these methods, the degree of wear and the tendency of the tightening tools can be predicted and as a result, preventive maintenance becomes possible. The accidental accuracy defect does not usually occur in tightening tools. But if it does, it would result in the defects of a large quantity of products Therefore, it is preferable to keep the tool within a repairable range even if this would result in some possible defects relating to the frequency of periodic calibration retightening inspection.
Creating a system of daily torque wrench checks prior to starting work corresponds to this idea. (Figure 4-3)
Though the development of electronic instruments, tightening torque value and retightening torque values can be monitored and further more, recorded. The recorded data can be submitted to a third party for proof in protection against product liability. The monitoring should be an independent measuring system separate from the control system of the tightening torque. Otherwise, trouble within the control system cannot be observed.

Figure 4-2 Format example of periodic caribration

Figure 4-3 Format example of daily check



Machine error prevention

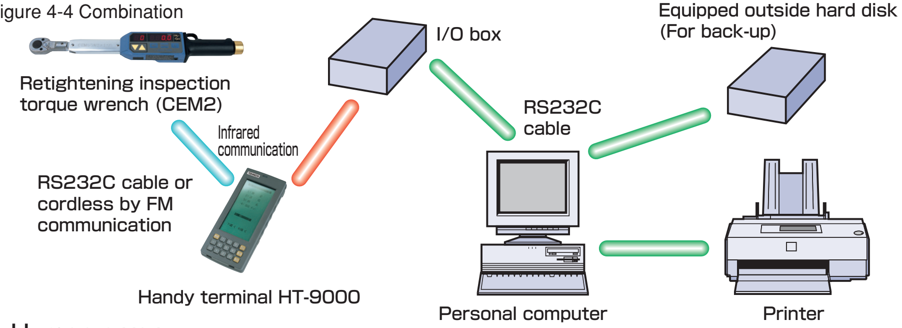
① Tool control system

A system that periodically checks the operation and the torque accuracy of the tightening instruments, and stores the data in order to control the inspection data of the tightening instruments, and to perfor perform preventative maintanance, which will reduce machine error.

② Data file system

A system to track the tightened screws, to do retightening inspections, to store the data, to do statistical analysis in order to know the degree and tendency of damage of the tools, and to perform preventative maintanance, which will reduce machine error.

Figure 4-4 Combination



(5) Human error

In reliability of tightening work, human error is the most difficult problem. We know that people make mistake by human nature. But, it is also difficult to observe and to find any human error by machine.
We always have to take into consideration that human error can be reduced through education.
Tightening by operator means that at the same time the operator can execute a visual inspection in which they can observe bolt tightening defects, such as machine error, galling, etc.
This visual inspection is a very effective method to improve the reliability of bolt tightening.
Among human errors "missed tightening" is the number one problem.
In order to tighten bolts effectively and uniformly, bolts are tightened to the required torque after the provisional tightening. But then the bolts, which have already been tightened to the provisional torque , may have a greater chance of being missed by the operator. Since this kind of human error accidentally happens, it is very difficult to find the error by doing a sampling test.
"Operation error" is also a part of human error. Some errors occur when the tool is not properly handled. For instance, just before tightening completion, the pulling of the torque wrench is stopped or the trigger of power is released in order to eliminate "missed tightening" there is a method that can verify the final tightening. A marking pad is put into the socket and the bolt head is marked as soon as the socket is inserted into the head of the bolt for final tightening. Further more, to eliminate "operation error" a marking torque wrench clicks for an audible alert as well as simultaeously marking the bolt head with ink for a visual check. (P234 MPQL)

Human Error Prevention

① Mark method

The mark method itself will not prevent human error. It is only effective if there is a mark made simultaneously as the bolt is tightened to the set torque value.

<Confirmation on the next step>

The method to confirm on the next step of tightening is done correctly or not on the previous step.

<Missed tightening prevention system of pictorial recognition>

This is a pictorial recognition system uses a marking torque wrench and CCD camera to prevent missed tightening with pictorial analysis through a personal computer.

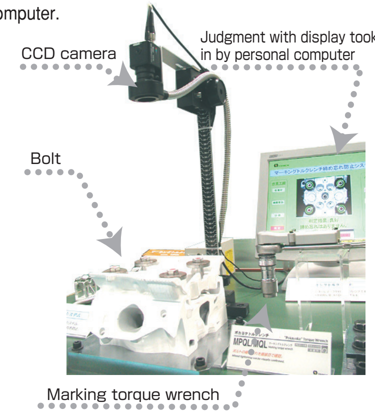
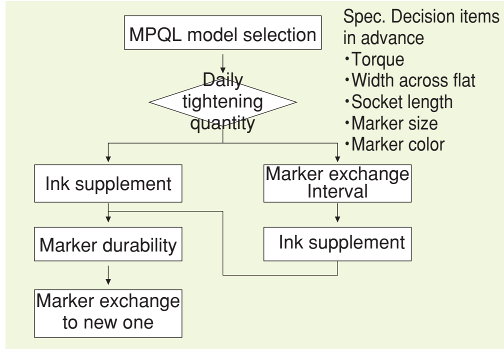
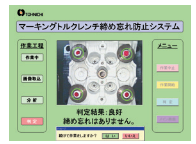


Figure 4-5 Maker exchange system

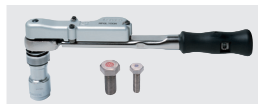


No missed tightening



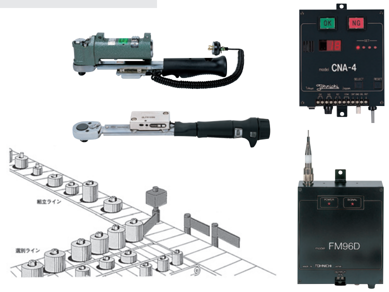
Some missed tightening

Marking torque wrench



② Count method

If it reaches the set torque value, it will send a tightening completion signal and confirm the quantity of missed tightened screws.
The count method utilizes a wireless torque wrench (FM method) or a corded wrench (Limit Switch Series) to count the signal created by the internal micro switch.



Eliminate miss tightening + monitoring system

③ Monitoring method

This method not only checks that the tightening is done or not, but also displays the torque value it was actually tightened to.
The reliability will improve by saving the data on a computer.

Monitoring system

(6) Bolt tightening reliability and bolts

To ensure "bolt tightening reliability", first the reliability of the bolts themselves must be maintained. The initial clamping force has to be controlled so that the force is put into the specified range decided by the standardization or designing when the bolt is tightened to the required torque.
Since the torque coefficient changes due to the friction of bearing surface and threaded parts, oil in the threads, surface hardness, and surface treatment, these factors should remain constant. Like high-tension bolts for construction, the torque coefficient is measured by a tension meter and verified that the torque coefficient is within the specified variation. This can improve the bolt tightening reliability further. In this case, certain sample numbers are required to find the variation of the torque coefficient.
The bolted joint consists of bolts, nuts, and joint members. Therefore, caution should be taken when adding oil to the joint or surface treatment of joint. -especially, when oil of wax sense or lubrication of molybdenum series is used. The torque coefficient will become small and the initial clamping force will sharply increase. The variations of joint face, parallelism, gasket in between, or paint, will all have an affect on the clamping force. "Galling" or "seating defect" also prevents bolt reliability.

(7) Construction of tightening reliability system

There are many obstructive factors in "Bolt tightening reliability" as shown in 4-2 (P38). To properly eliminate these factors it is necessary to consider the total system. Reliability in design, tightening operation and bolts all have to be equally improved at each step. Otherwise the error in the bolt tightening will not increase.
First of all, suitability of design and preconditions has to be verified. In the torque method, mutual consent regarding tightening torque, the tolerance, torque coefficient and clamping force in use and inspection methods, is necessary and must include people from the design engineering, tightening operations and inspection. It is desirable that these have a system of the standardization.
In order to construct a system of "bolt tightening clamping force", the elimination of "machine error" and "human error" has to be included. To maintain this reliability various methods have been designed, but respectively their effect is different. (Table 4-2)
More than one of these methods may be used together to reach the required reliability level, first seeking to eliminate all the obstructive factors at minimum expense and time. Even if an expensive system is adapted but still misses any of the requirements, the reliability will not be maintained.
Standardization of bolt tightening enables easy after service. Even if the special tightening methods can successfully be employed in the plant, the reliability will be ruined when the same tightening cannot be achieved in the field service. The system of "bolt tightening reliability " in a broad sense has to include maintenance.
Since bolts generate large clamping force, many bolts are used in the assembly of the products, but there are uncertain factors in the bolt, tightening and bolt tightening influences on the reliability of products and the entire system.

Table 4-2 Confirmation means of reliability of tightening

Method	Machine error	Human error	Bolt reliability
1) 100% Retightening inspection	◎	◎	×[◎]
2) Two-stage tightening (Double check)	◎	◎	×[◎]
3) Sampling retightening inspection	◎	×	×[○]
4) Periodical inspection for tightening tool	◎	×	×
5) Visual inspection by tightening operator	×	○	◎
6) Marking (Socket)	×	○	×[◎]
7) Tightening completion by marking	×	◎	×[◎]
8) Tightening completion by counting	×	◎	×
9) Tightening torque control data OK-NG judgment	○	◎	×
10) Tightening torque control data preservation	○	◎	×
11) Tightening torque monitoring (Independent)	◎	◎	×
12) Tightening torque and angle monitoring	○	◎	◎
13) Clamping force measurement (Elongation, Ultrasonic)	◎	◎	◎
14) Sampling torque coefficient test	×	×	○
15) Sampling product test	◎	×	○

◎ :effective, ○:slightly effective, ×:inefficient [ ] :visual inspection included

Technical Data

4. Tightening Reliability

4-4 Tightening Control

It is necessary to decide accuracy of tightening control to respond to the importance of tightening position, to choose and to control necessary torque tools for tightening torque.

Table 4-3 Bolt tightening control

Class	Control	Tightening tolerance	Application	Application example	Application tightening equipment	Tightening equipment control	Torque assurance system
A	Standard	±30%	Threaded joint to use fixing parts. (No external force except gravity)	Bolts tightened to static parts such as cover. (Non air-tightness)	Selection by model capacity. (No torque control)	Periodical maximum performance measurement.	Periodical inspection byre-tightening method. (α=1.05)
B	Individual	±20%	Threaded joint with high margin on facter of safety. (Fixing, air tightness, transferability against external force)	Bolts tightened to dynamic parts. (Strength classification no specified) Bolts for low pressure sealing.	Torque controlled tightening device. (Indirect control device)	Periodical tightening torque measurement.	Daily inspection byretightening method. (α : measured values)
C	Individual	±10%	Threaded joint with low margin on facter of safety. (Fixing, air tightness, transferability against external force)	Bolts tightened to dynamic parts. (Strength classification specified) Bolts for high pressure sealing.	Torque controlled tightening device. (Direct control Type)	Periodical tightening torque measurement. Daily tightening torque check.	Daily inspection byretightening method. Daily check of tightening device.
D	Individual	±5% (Angle method)	Threaded joint by limiting design. (Fixing, air tightness, transferability against external force)	Main bolt connecting rod of engine. High pressure hydraulic equipment.	Nutrunner with torque control. (with angle monitoring)	Periodical tightening torque measurement. Daily tightening torque check.	Monitoring. Daily check of tightening device.

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5. Selection of Tightening Tools

5-1 Selection of Tightening Tools

Table 5-1 Selection of tightening tools

I. Screw joint item	
Number, Degree of importance	Important screws, general
Specification of screw	Nominal Class of strength
	Head shape Number of tightening threads Screw thread (P＝)
Limit of strength	Male screw, Female screw, number of bolts tightened (Tmax＝)
Tightening torque	N･m/kgf･cm/lbf･in
Tolerance	Class ± %、T＝ ～
Washer	None, Flat washer, Spring washer (string, Normal)
Surface treatment	None, Parker, plating (Zn, Cr,)
Lubrication	None, machine oil, Wax based oil, double sulfurous molybdenum
Number of bolt tightened	Pieces/day (Time limit Sec/piece, None)
Number of bolt simultaneously tightened	Pieces
Coefficient of joint	Hard, Medium, Soft (e＝)
Tightening space	Socket Usable Not usable
	On the bolt mm, Around the bolt mm, Swing Total length mm
Direction of tightening	Upwards, from the side, Downward
II .Tightening Tool Type	Manual, Power, Manual+Power
Manual Type	Signal type, Direct reading/ Adjustable type, Preset type
Head shape	Square drive, Open end head, Ring head/fixed ratchet/interchangeable head
Capacity, type	T ／weight kg, overall length mm, Manual force N
Power, Power Source	Compressed air (Pressure Mpa or above), Electric (V), Hydraulic
Type	Portable, Fixed ／ Single Axes Multiple Axes
Number of rotations	r.p.m (at)
Torque control method	Direct control (scaled, Non scaled), Direct control, Maximum capa
Capacity, type	T ／ Straight, Pistol, Angle
Tightening Tool Type	
Time required to tighten	sec／piece
Cost of tightening	$ or ¢／piece
Accessory parts	Socket (×), Bit
	Hose diameter