

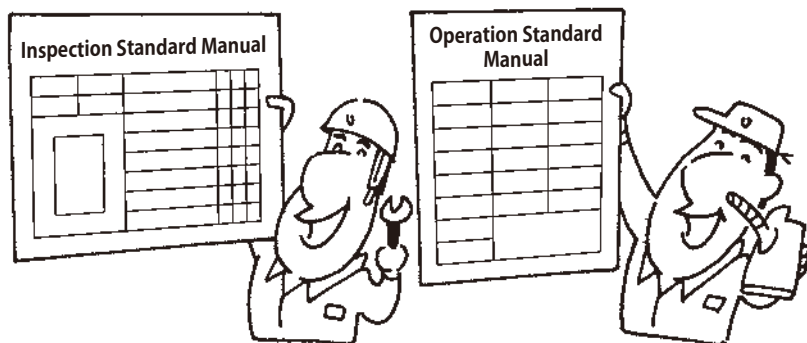
# **Monodzukuri Test Learning Textbook**



Japan Institute of Plant Maintenance

# Chapter 1

## Basics of Production



# 1 Management by 5S

5S stands for the five Japanese words that start with an S: *seiri* (order/clearing up), *seiton* (arrangement), *seiso* (cleaning), *seiketsu* (neatness), and *shitsuke* (discipline). The 5S activities are well-known in Japan and throughout the world alike.

Plant management starts with 5S. Workplaces without *seiri* and *seiton* cannot produce good quality. Almost always, workplaces with low morale are disorderly and lack discipline. Thorough implementation of *seiri* and *seiton* is the first step of making a good workplace. See below for the definition of the 5S:

- ① **Seiri (order/clearing up):** Distinguish between what are needed and what are not, and get rid of unnecessary things and things that should not be seen in a workplace.
- ② **Seiton (arrangement):** Put necessary things in order so that they are easy to use.
- ③ **Seiso (cleaning):** Make sure that everything is clean and well-maintained, including the machines, dies, jigs, tools, measuring instruments. Also make sure that the workers are clean and tidy—your hair, hands, working clothes, and shoes—make it the usual.
- ④ **Seiketsu (neatness):** Maintain high levels of *seiri*, *seiton*, and *seiso*.
- ⑤ **Shitsuke (discipline):** Train everybody so that they abide by the rules and regulations. Make it a practice through mutual admonition.

Here, it is important that you understand the meaning of the 5S correctly.

If you put things away without sorting them, it is mere storage rather than *seiri*. In *seiton*, you always need to consider efficiency—are they easy to fetch and use? The objective is not to make the arrangement look good; make sure that you can find necessary things without effort.

Try not to act superficially. Before implementing the 5S, you need to understand why they should be done.

## 2 Quality

### 1 Basics of Quality Control

Job management has two sides: *maintenance* and *improvement*(*Kaizen*). In maintenance, you need to keep the results of activities at the targeted levels. In improvement, you need to set high levels of goals and achieve them.

In your daily work, you may be involved in a series of activities to change what is not compatible with the goals or change the status quo that should not be. These are typical improvement activities in your daily quality control.

The most important concept in supporting maintenance and improvement is to ***speak on behalf of the data***. This concept is also called *fact-based management*. It is the foundation of quality control.

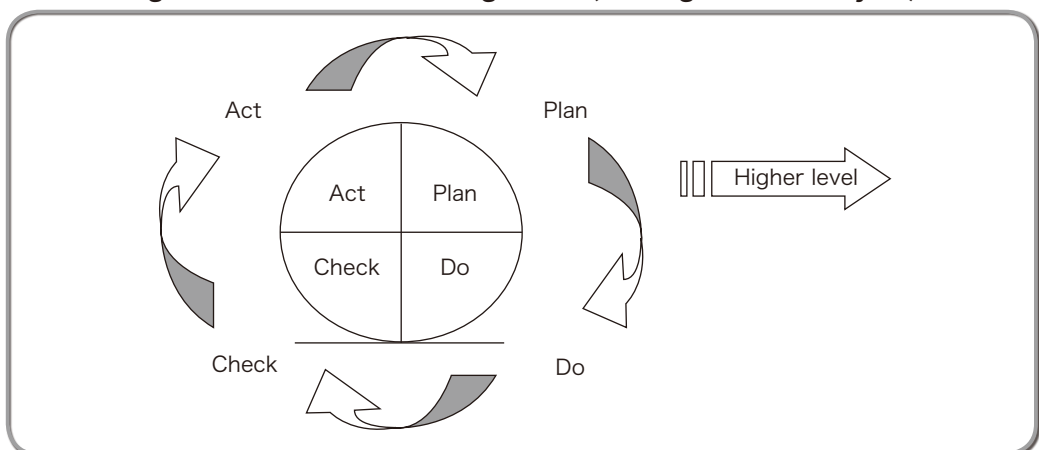
How can you efficiently speak on behalf of the data? Use the seven tools of QC and statistical methods. They will help you process the data quantitatively and find precise conclusions.

Learn the fundamental items that are essential in addressing quality issues around you regarding production activities.

#### 1 Management cycle

In maintenance and improvement alike, use the ***PDCA cycle*** as the principles of job management around you. See **Figure 1-1** for the outline of the PDCA cycle.

Figure 1-1 Basics of management (turning the PDCA cycle)



PDCA stands for plan, do, check, and act.

The P (plan) phase has two factors: deciding the objectives and goals, and deciding the method of achieving the objectives and goals. The D (do) phase has two factors: preparing for implementation, and implementing things as planned. In the C (check) phase, check whether the results of the implementation meet the objectives and goals. , In the A (act) phase, take necessary measures to address the difference between the objectives/goals and the results. If the objectives and goals have not been achieved, clarify the reason why and address it in your action—change the way you do things in the next cycle, for instance. The starting point need not be the P phase; you can start with the C phase by identifying the status quo and turn the CAPD cycle.

2 5W1H

When you collect and organize data or plan how to implement improvement ideas, try **5W1H** as the basic principles.

5W1H stands for ①who, ②what,③when, ④where, ⑤why, and ⑥how. When you speak on behalf of the data, the first thing you need to do before moving on to the next step is to narrow the scope and capture facts and to make the improvement activities concrete. (See 3-1, "Action Standards and 5W1H," Section 6, Chapter 4.)

3 PQCDSME

PQCDSME represents the indices of your daily activities. It stands for production, quality, cost, delivery, safety, morale, and environment. Examples are shown below.

- P: Total efficiency of equipment, number of failures, number of minor stoppages

Q: Process defect rate, number of quality defects in local process, number of complaints on the market

C: Production cost, process defects, material cost

D: Raw materials, products in process, completed products in stock

S: Number of accidents causing major or minor injuries

M: Number of improvement suggestions, number of qualified or certified people (Monodzukuri Test, for instance)

E: Monetary value of energy-saving, reduction in industrial wastes, number of environmental improvements

To use these indices, you need to first identify the current values. If you do not have a current value, collect data for at least three months during the preparation period for the relevant activities and obtain the mean value. The current value



or the mean value is considered the starting value for the activities, and is called the benchmark (BM). Clarifying the BM will allow you to set target values for the future improvement activities.

#### 4 The sangen (3 Gen) principles

As described earlier, *speaking on behalf of the data*, or fact-based management, is the foundation of quality control.

To identify facts, basically you need to make much of the three *gens*—*genba* (work site), *genbutsu* (actual product), and *gensho/genjitsu* (phenomenon/reality). When an issue has occurred, you need to identify the fact by immediately going to the work site and looking straight at the actual product and phenomenon. It will allow you to pursue the cause properly and take necessary measures. Take care to do it until it becomes a habit.

#### 5 Building in quality in local process

Sampling inspection is a method of intermediate inspection of the products output from a production line or the products in process. Certain quantities, which are determined statistically, are sampled at random and tested (measured). The products are deemed good or bad according to the test results.

Total inspection, in contrast, inspects each and every product. When total inspection is done, most importantly, the customer who buys the product believes that the quality of all products is guaranteed by total inspection. Thus, a production system is demanded to work out ways to implement mechanisms that work like total inspection.

Basically, quality assurance should not depend on a particular inspection process; *assurance by the local process* is the norm. The required quality needs to be attained in the work processes; the subsequent processes must be considered as customers. *Poka yoke* (preventing careless errors) measures, which prevent people from *Poka misu* (committing careless errors), can be considered a method of guaranteeing all products (100%).

## 2 The Seven Tools of QC

*The Seven Tools of QC* (Q7) is named after a Japanese legend—the seven tools of Benkei. The seven tools are used widely in the field to analyze and manage issues, and have proven effective in maintaining and improving quality. They are the graph, Pareto diagram, cause-and-effect chart, check sheet, histogram, stratification, scatter diagram, and control chart. There are eight items but the name is seven—from time to time, the graph and control chart are united or stratification is excluded.

# 1 Graph

Graphs are the most basic tool of statistical methods. The objective of using statistical methods is to clarify how serious the issue is and what has caused the issue. You cannot solve problems by using graphs alone. However, you can express data as drawings rather than as numbers, thus stratifying the data in various ways and estimating where the cause is.

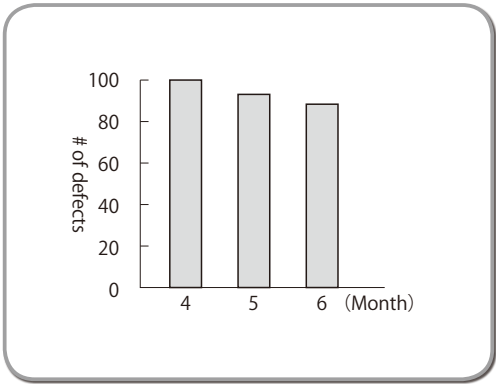
It is very important to use the graph as a tool of problem-solving.

## (1) Bar graph

Bar graphs are intended to compare two or more quantities, represented by the lengths of the bars of a certain width. Bar graphs can be vertical or horizontal; vertical bar graphs are more common.

Bar graphs and line graphs are the two leading types of graphs. Bar graphs, however, are the most popular actually (see **Figure 1-2**).

Figure 1-2 Bar graph

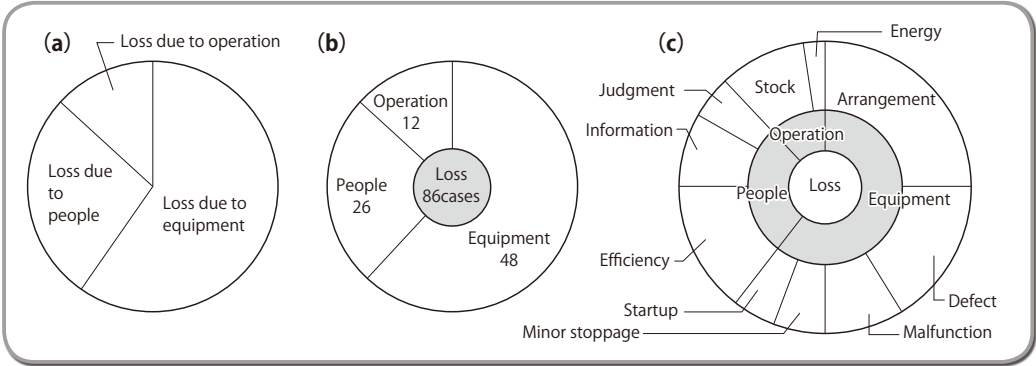


## (2) Circle graph

Circle graphs show the proportions of data as segments of a circle. A circle graph is generated by ①collecting data, ②classifying the data according to the objectives of the analysis, and ③representing the proportions of the classified items by radially dividing a circle into segments. The primary objective of a circle graph is to compare the proportions.

Circle graphs have variations (see **Figure 1-3**)—circular breakdown graphs or fan-shaped graphs (a), pie charts (b), and doughnut graphs that have an inner

Figure 1-3 Circle graph



# Chapter 2

## **Improving Efficiency and Capturing Losses**





# 1 Basics of TPM<sup>®</sup>

## 1 Definition of TPM

**TPM** stands for *total productive maintenance*, which is a short for productive maintenance in which all members participate.

TPM is defined as follows:

- ① The objective is to create a corporate culture that pursues ultimate efficiency of production systems (total efficiency).
- ② Working mechanisms to prevent all kinds of losses, including zero-accident, zero-defect, and zero-failure systems, are built on-site and with actual products. The mechanisms cover the entire life cycle of the production system.
- ③ The efforts encompass all departments, including the development, sales, and management departments, not to mention the production department.
- ④ All members participate, from the top management to the front-line employees.
- ⑤ A zero-loss state is achieved through overlapping small-group activities.

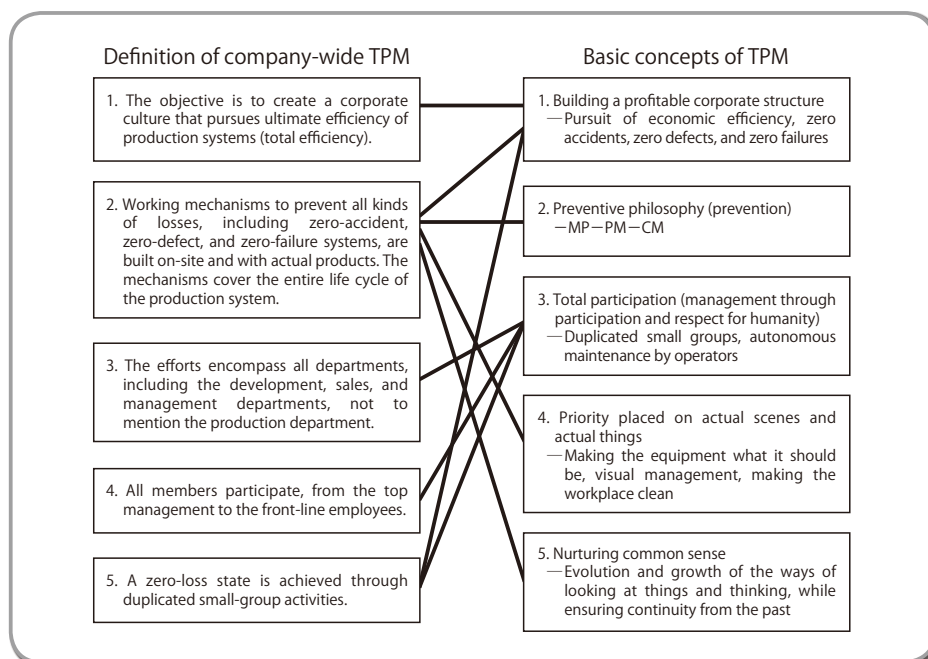
TPM requires the five items listed above. Implementing TPM in its true sense requires implementing all the five items.

## 2 Basic concept of TPM

To deepen your understanding of TPM, check the following five keywords that represent the fundamental principles related to the definition above.

**Figure 2-1** shows the relationship between the TPM definitions and the fundamental principles.

Figure 2-1 Definition and fundamental concept of TPM



- ① Building a profitable corporate structure
- ② Preventive philosophy (prevention)
- ③ Total participation (management through participation and respect for humanity)
- ④ Priority placed on actual work sites and actual things
- ⑤ Nurturing common sense

## 1 Building a profitable corporate structure

By reducing defects and failures to a zero through TPM, customer satisfaction (CS)\* will be maximized in terms of quality (Q), cost (C), and delivery (D).

## 2 Preventive philosophy (prevention)

The preventive philosophy is a concept that has been around since the introduction of preventive maintenance and carried over to TPM.

**\*Customer satisfaction:** The term originated in the U.S. in the 80's. People buy a product when they feel some sort of satisfaction with it. The degree of satisfaction should be regularly evaluated, and the results should be used in developing or improving products. "Customer first" has long been part of management concept, yet too much inclination to productivity and efficiency will not allow you to survive through the severe competition between companies. J. D. Power and Associates is famous for providing related survey services.

### 3 Total participation (management through participation and respect for humanity)

Total participation is nothing but overlapping small-group activities. The autonomous maintenance (Jishu-Hozen) activities by operators embody management through participation and respect for humanity.

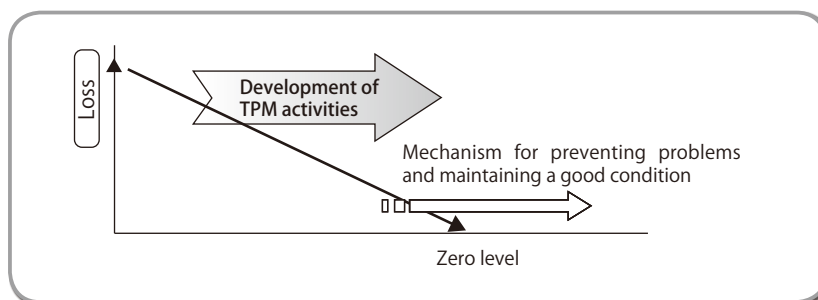
In TPM, small groups at different layers spontaneously define their goals—zero defects or zero failures, for instance. They solve problems through total participation to achieve the goals. All members share the sense of achievement and success, thus their desire for growth is fulfilled.

### 4 Priority placed on actual work sites and actual things

TPM activities avoid conventional "serrated" improvement (Kaizen) activities (in which the original conditions tend to prevail for a certain period after improvements and thus ups and downs are repeated). TPM activities aim to ultimately minimize the losses of equipment throughout its lifespan, and promote building a working mechanism that maintains good conditions (see **Figure 2-2**).

For that purpose, TPM activities address daily issues in the field under the fundamental concept of clarifying and handling true problems and causes, always prioritizing the actual work sites, actual things, and reality. The activities ensure that such an attitude takes root as corporate culture. Effective preventive measures cannot be taken until this process is completed.

Figure 2-2



### 5 Nurturing common sense

People look at and think about things based on their past experience and learning, which is called common sense. It is important that the common sense be nurtured to suit the time and environment and thus human abilities should be evolved and grown. Continuous nurturing allows continuous evolution and growth, thus leading to the prosperity of a company.

### 3 TPM Objectives

#### 1 Nurturing people

The objective of TPM, in short, is to *revamp corporate structures by improving people and equipment*. In terms of people, TPM aims to nurture operators, maintenance personnel, and production engineers who have the following skills:

- **Operators:** Autonomous maintenance skills to protect their own equipment on their own
- **Maintenance personnel:** Skills to maintain mechatronics equipment\* (such as NC machines, industrial robots, and unattended carriers).
- **Production engineers:** Skills to plan and design equipment with high reliability and maintainability

#### 2 Improving equipment (Kaizen of equipment)

Equipment is improved by improving people. The improvement is done in the following two steps:

##### (1) Improving the existing equipment

The first thing you should do is streamline the existing equipment. Implement individual improvements (*kobetsu kaizen*) and autonomous maintenance to reduce losses to a zero—downtime losses, setup and adjustment losses, minor stoppage losses, and poor quality losses, for instance. Thus improve the equipment currently used.

##### (2) Improving new equipment and immediate startup

While improving existing equipment, you can obtain information that can be fed back to the makeup of new equipment. The information is useful in implementing LCC-conscious design and enabling immediate startup.

LCC stands for **life cycle cost**. LCC-conscious design minimizes the total cost throughout the equipment lifecycle, including the purchase and acquisition costs and the operation and maintenance costs. In essence, LCC-conscious design means maintenance prevention (MP) in the design phase—designing equipment so that known problems do not occur.

\***Mechatronics equipment:** Mechanical equipment incorporating expertise on electronics. For instance, computers are introduced to the operation and control of machines to increase their performance, implement automation, and save labor. The term mechatronics is a combination of mechanics and electronics, and was originated in Japan.

Immediate startup means full-scale production immediately after startup. To enable immediate startup, you need to increase the quality of tasks in the development phase, including the designing of new equipment. For instance, you should design new equipment taking care to prevent initial failures and problems and enable full-scale production in month one, rather than scheduling a three-month period between installation and full-scale production. Thus, immediate startup activities are intended to shorten the initial period of uncertainty (the period from the installation and trial operation to full-scale production) and the development lead time and to increase the overall efficiency.

## 4 Distinctive Features of TPM

The American PM is centered on the maintenance department based on the American concept of functional specialization.

In contrast, TPM, the Japanese way of PM, is characterized by total participation, particularly autonomous maintenance by operators (see **Figure 2-3**).

A distinctive feature of TPM is autonomous maintenance. **Figure 2-4** shows the differences in the distinctive features between pre-TPM mainstreams (preventive maintenance and productive maintenance) and TPM.

### 1 Pursuit of economy (profitable PM)

Pursuit of economy (profitable PM) is a feature of TPM. It was inherited from the time of preventive maintenance and productive maintenance.

### 2 Total system (MP—PM—CM)

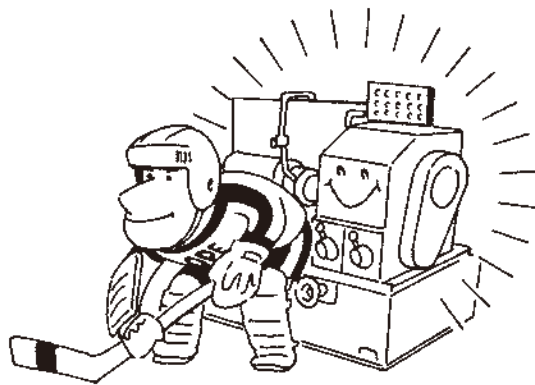
The second feature of TPM is its focus on establishing a total system that

**Figure 2-3 Distinctive features of TPM and differences with American PM**

| Distinctive features of TPM   | American PM   |
|---|---|
| TPM is intended for ultimate pursuit of total production system efficiency.<br>—TPM ultimately increases production efficiency by improving how to make, use, and maintain equipment.   | The American PM is led by equipment specialists, and ultimately pursues equipment efficiency by improving how to make and maintain equipment. However, it does not encompass how to use equipment, thus fails to ultimately pursue total production efficiency. |
| TPM is characterized by autonomous maintenance by operators (protecting their own equipment on their own).<br>—Operators handle routine maintenance (cleaning, lubrication, tightening, and inspection, for instance), and special maintenance staff members closely inspect (diagnose) and repair the equipment.                     | In the American PM, operators focus on production (operation). All the maintenance work, including routine maintenance, inspection, and repair, is handled by the maintenance staff.  |
| TPM consists of small-group activities in which all members participate<br>—The small-group activities are conducted in solidarity with the managers and technical staff. All members, including the top management, middle-level workers, and front-line workers. Thus, the activities are called duplicated small-group activities. | The American PM does not involve small-group activities in which all members participate.   |

# Chapter 3

## **Improvement and Analysis Methods**



# 1 Improvement (Kaizen) and Analysis Techniques

Improving production efficiency requires a system that prevents all losses from occurring. You need to analyze the status quo, find problems, trace causes, and take appropriate measures. This chapter describes several analysis methods that are required in improvement (Kaizen) activities.

## 1 QC story

**QC story** shows the most fundamental steps of problem-solving. The steps are:

- ① Setting a *theme*
- ② *Stating the reason* that you have chosen the theme
- ③ *Capturing the status quo*, showing the problems based on data
- ④ *Setting goals and planning activities*
- ⑤ *Analyzing the problems* to reveal their causes
- ⑥ *Taking measures* against the causes
- ⑦ *Checking the effectiveness*
- ⑧ *Standardizing the measures (setting brakes)* to prevent the situation from going backward
- ⑨ *Considering the remaining issues and what to do in the future*

QC story was devised as a structure of reports to clearly describe the past problem-solving cases. The QC story showed a well-organized procedure of solving problems, and people eventually found that activities in accordance with the QC story work. Now it has taken root as a method of solving problems due to unknown causes.

For your information, **Figure 3-1** shows the relationship between the methods used in the different steps of the QC story. For 5W1H and the seven QC tools, review Chapter 1, *Basics of Production*.

Figure 3-1 The QC story and analysis methods

| No. | QC Story   | Recommended analysis method           | Class          |
|-----|--|---------------------------------------|----------------|
| 1   | Setting a theme: Stat-<br>ing the reason that<br>you have chosen the<br>theme (Background<br>of the theme) | <b>Brainstorming</b>                  |                |
|     |  | Cause-and-effect diagram              | QC7            |
|     |  | <b>"Why-why" analysis</b>             |                |
|     |  | Check sheet<br>(Matrix diagram)       | QC7<br>New QC7 |
| 2   | Capturing the status<br>quo  | <b>Brainstorming</b>                  |                |
|     |  | Cause-and-effect diagram              | QC7            |
|     |  | Graph, Pareto diagram, stratification |                |
|     |  | Histogram                             |                |
|     |  | Element task analysis                 | IE             |
| 3   | Setting goals and<br>planning activities   | <b>5W1H</b>                           |                |
|     |  | Gantt chart                           |                |
|     |  | (PERT)                                | New QC7        |
| 4   | Analyzing causes   | <b>Brainstorming</b>                  |                |
|     |  | Cause-and-effect chart                | QC7            |
|     |  | Stratification, scatter diagram       |                |
|     |  | Correlation analysis                  |                |
|     |  | <b>"Why-why" analysis/PM analysis</b> |                |
|     |  | (Matrix diagram, tree diagram)        | New QC7        |
| 5   | Taking measures  | <b>5W1H</b>                           |                |
|     |  | (Matrix diagram, tree diagram)        | New QC7        |
|     |  | Gantt chart                           |                |
|     |  | (PERT)                                | New QC7        |
|     |  | <b>"Why-why" analysis</b>             |                |
| 6   | Checking the effec-<br>tiveness  | Graph, radar chart                    | QC7            |
|     |  | Histogram, Pareto diagram             |                |
| 7   | Setting brakes (stan-<br>dardization and having<br>the management take<br>root)                            | <b>5W1H</b>                           |                |
|     |  | Graph, control chart                  | QC7            |
|     |  | Standards, QC process table           |                |

\*In the *Recommended analysis method* column, a new QC7 tool is shown in parentheses.



## 2 Brainstorming

Brainstorming is a team activity that involves free exchange of ideas. Some companies provide brainstorming opportunities in the form of a training program, for instance, the Originality Development Course. It is intended for the participants to learn how to originate ideas, as inspired by the way geniuses think. It is encouraged that the method be fully used in workplaces.

### 1 The four rules

Brainstorming is conducted under the following basic rules:

#### ① No criticism

Do not criticize the opinions from others, nor your own ideas. Being critical prevents ideas from coming out.

(Typical criticism: "You can't do that," "It's costly," "I'm embarrassed," "I'd be scolded," "People will laugh at me," and the like)

#### ② Freewheeling

Keep your mind free. Try to think from many points of view.

#### ③ Quantity over quality

To get ideas, you should first give priority to quantity rather than quality.

#### ④ Take advantage of others' ideas

Ideas can be associated. When you present an idea, it is effective to use the thinking of others.

### 2 Effective leverage

Leverage brainstorming in a team in the following ways, for instance:

- ① Plan two sessions for the discussion: discussing the problems from the viewpoints of all, and discussing countermeasures.
- ② *Avoid criticism strictly.* Producing ideas needs no criticism. Later in the *judgment* phase, you will organize and select the ideas while using criticism. In the judgment phase, you will make a judgment from the viewpoints of effectiveness, feasibility, and cost, for example.
- ③ Try the *KJ method* to organize the presented ideas. The KJ method classifies items into several groups according to their similarities. It is effective to organize the ideas in the middle of the discussion; the participants can look at the organized ideas, and will be able to add

freewheeling opinions under the "Take advantage of others' ideas (association)" rule above.

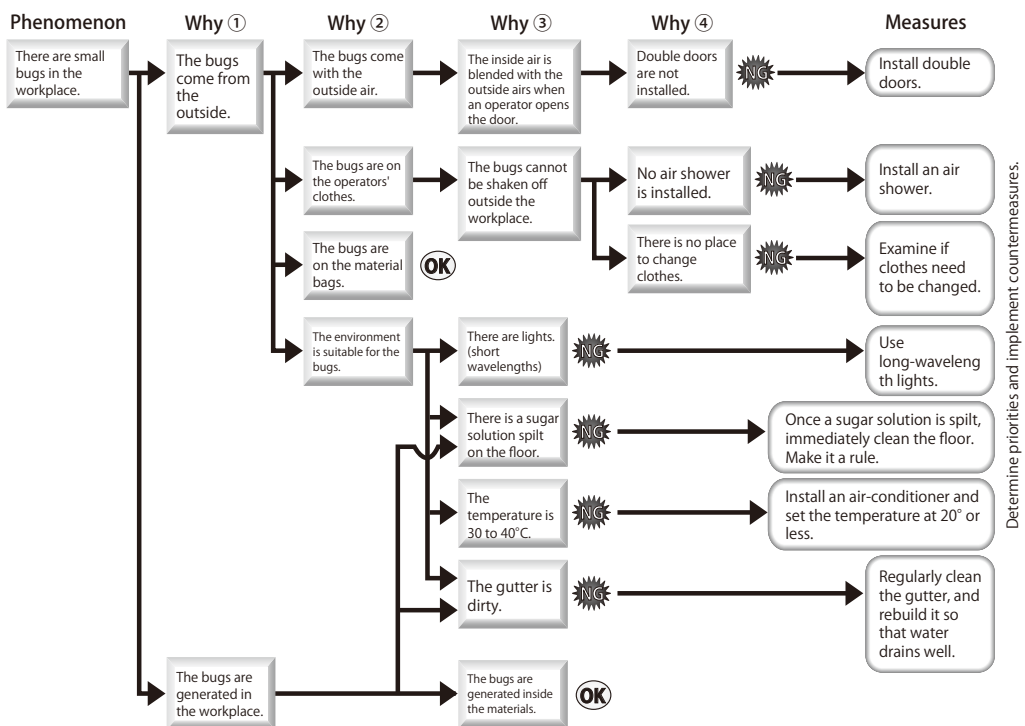
④ Familiarize yourself with the KJ method, and enjoy using it.

### 3 "Why-why" analysis

In the event of a failure or anomaly such as a stoppage or defect, it is important to investigate *why* the cause happened, starting with the phenomenon that occurred. Then, ask *why* again, that is, investigate the results of the first investigation.

Repeat why over and over to find out all the causes (true causes) of failures and anomalies systematically, in the right order, and without omissions. Turn over the last why to plan a precise countermeasure. This method is called "**why-why**" analysis (see **Figure 3-2**).

Figure 3-2 Example of "why-why" analysis



When implementing "why-why" analysis, keep the following in mind:

- (1) Before using the method
  - ① Identify the problem as a specific fact.  
Identify the problem clearly. A vague description like "The line has stopped" is not sufficient. Capture the specific phenomenon, like "XX has been disconnected." It is important to summarize the information by 5W1H or stratification.
  - ② Understand the structure and role (function) of the problem part.
- (2) Once a series of "why-why" analysis is completed, backtrack the logic from the last "why" to the starting phenomenon. Make sure that the path is logical. This is the most vital point, so get accustomed to doing it without fail.
- (3) If you have never done "why-why" analysis before, many causes (factors) may not pop up in your mind. Cover your inexperience by checking the actual work site, actual product, and phenomenon (reality) — the sangen (3 Gen) principle plus the fourth gen (genba, genbutsu, gensho, and genjitsu).
- (4) Avoid vague expressions of causes (factors), for instance:
  - XX is bad.
  - I was tired.
  - I felt faint.
  - I was busy producing something.

## 4 PM analysis

### 1 PM analysis

**PM analysis** is a method and concept of analysis intended for reducing chronic losses (defects and failures). It analyzes the subject *phenomena physically* and clarifies the *mechanisms*. Thus, it is called PM analysis.

PM analysis consists of the following steps:

- ① Carification of phenomena—Stratifying the phenomenon sufficiently\*
  - ② Physical analysis of phenomena
  - ③ Conditions defining phenomena
  - ④ Study of relations with equipment (including jigs/tools), materials, and methods—Listing all the probable causes of the conditions.
- (Details are given later)

# Chapter 4

## **Routine Maintenance of Equipment** (Autonomous Maintenance in General)



# 1 Basic Knowledge about Autonomous Maintenance (Jishu-Hozen)

## 1 Autonomous maintenance (Jishu-Hozen)

### 1 Why is autonomous maintenance required?

What does a company need to survive? In recent years, companies have become increasingly aware of the importance of maintenance activities. Thus, need has arisen for the companies to review their operators and maintenance tasks.

Meanwhile, small-group activities, including QC circles and ZD (zero defect) groups, are widespread today, and people have gotten used to managing their own tasks spontaneously. This idea has strengthened and evolved into the concept of autonomous maintenance—protecting one's own equipment on one's own.

### 2 Protecting one's own equipment on one's own

Equipment has been becoming more advanced and complex with company scales expanding and technologies making remarkable progress.

Accordingly, the concept of "I make, you fix" has taken root gradually. The production department focuses on production, leaving equipment maintenance to the maintenance department.

As a result, people involved with production just make things—setting and removing works or starting and stopping the equipment. They leave everything related to equipment to the maintenance people, including repairs and lubrication, and quality check to the inspection people. That idea, however, has become a major obstacle to companies intending to improve productivity.

Today, prevention has become essential for equipment health maintenance. Just like preventing diseases, you need to prevent equipment failures and quality defects. However, the maintenance department has only a limited number of

\*QC circle: A small group that autonomously conducts quality control activities within a workplace. The members enlighten themselves and each other as part of company-wide quality control activities, and use the QC methods to continuously manage and improve the workplace through participation by all.

†ZD (zero defect): A movement in which people endeavor to rectify their weak points and perform proper tasks (operations), thus eliminating defects. ZD and TPM share the same zero-oriented concept. Yet you can say that TPM is more severe, as it considers attaining zero is required rather than desired.

people; there may be too many pieces of equipment for them to cover. Thus, operators have to share a part of maintenance work in their routine management tasks.

The routine maintenance (daily maintenance) tasks by operators are called *autonomous maintenance by operators*. Operators do what they can do on their own: for instance, inspect the equipment daily, find anomalies early, check the equipment for precision, lubricate the equipment, replace some parts, and make easy repairs. In other words, each and every operator protects the equipment on their own.

### 3 Proficient equipment operators

Autonomous maintenance requires each and every operator to be *proficient in operation and maintenance*. An operator has to be able to operate the equipment correctly, of course. Further, the operator has to be able to perform routine maintenance—cleaning, inspection, and lubrication, for instance. The more the equipment is automated and robotized, the higher the need for autonomous maintenance.

To be *proficient in equipment operation and maintenance*, an operator first needs to *be able to find anomalies*. The operator has to have skills of detecting anomalies (to be a good judge), being able to say "Something is wrong!" with quality or equipment. Namely, a proficient operator has to have the following four skills:

- ① Detect anomalies as anomalies (anomaly finding skill),
- ② Immediately take proper action on the anomalies (treatment and recovery skill),
- ③ Determine quantitative judging criteria for proper operation and anomalies (condition setting skill), and
- ④ Abide by the predetermined rules (maintenance and management skill).

Specifically, each and every operator has to be able to:

- ① Find and rectify defects of equipment,
- ② Find causes\* of anomalies based on the knowledge on the equipment structure and functions,
- ③ Predict quality anomalies and find causes\* based on the understanding of the relationship between equipment and quality, and
- ④ Repair equipment.

\* **Causes:** Factors that can cause failures and defects, such as vibrations due to loose bolts, wear due to poor lubrication, and abnormal heat.

Figure 4-1 Steps to a proficient equipment operator

|   |  |   |
|---|--|---|
| 4 | Able to make minor repairs on the equipment  | An operator truly proficient in equipment                           |
| 3 | Understands the relationship between the 4M conditions (machine, material, man, and method) and product quality              | Skills of maintenance and management                                |
| 2 | Knows the functions and structure of the equipment   | Skill to set up conditions  |
| 1 | Able to see flaws as flaws, and have learned the ways of thinking required for equipment improvement and the actions to take | Skills to find anomalies<br>Skills to address and rectify anomalies |

Those skills cannot be acquired at one time. Through the steps of autonomous maintenance activities, an operator should learn the skills one by one (see **Figure 4-1**).

#### 4 Concept of implementing autonomous maintenance activities

The "I make, you fix" attitude in the field has brought about many evils that impede equipment efficiency. Autonomous maintenance was conceived to correct the situation.

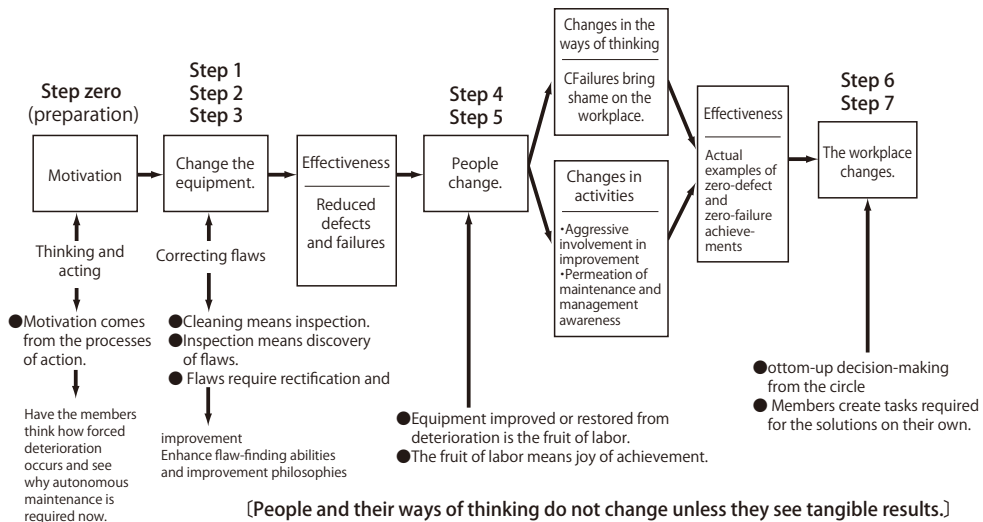
The essential tasks of an operator is to operate equipment and process or assemble products. An operator may not be familiar with sharing part of the maintenance work. Thus, to make autonomous maintenance familiar to the operators, *autonomous maintenance activities* are implemented. The fundamental concept of autonomous maintenance activities is as described below.

##### <Fundamental concept>

- ① Equipment failures and quality defects can be *reduced to a zero* if all people involved with the equipment correct their way of thinking and behavior.
- ② Changing the equipment changes people. Changing people changes the workplace.
- ③ The management leads the activities, and all members participate. The activities are conducted in steps, making sure that the participants are brought to a higher level.

*Bringing workers to a higher level through participation by all*—that is the core idea of autonomous maintenance activities (see **Figure 4-2**).

Figure 4-2 Implementing autonomous maintenance activities in steps



## 2 Roles and activities of production and maintenance departments

### 1 Roles of production and maintenance departments in autonomous maintenance

Quite often, the maintenance department has a passive attitude—*doing construction work upon request from the production department*. It even looks as if the maintenance department is doing it *out of generosity*. When a piece of equipment fails, it is natural that the production department wants it repaired as soon as possible. Thus, the production department tends to *ask for help*. And the maintenance department may be too busy. They may have too many requests for construction work to deal with. Thus, before they know, they tend to take the we-generously-do-it-for-you attitude.

Productivity cannot be improved when the two departments are in that kind of relationship.

The production department must take on the *activities to prevent deterioration*, which is the foundation of maintenance.

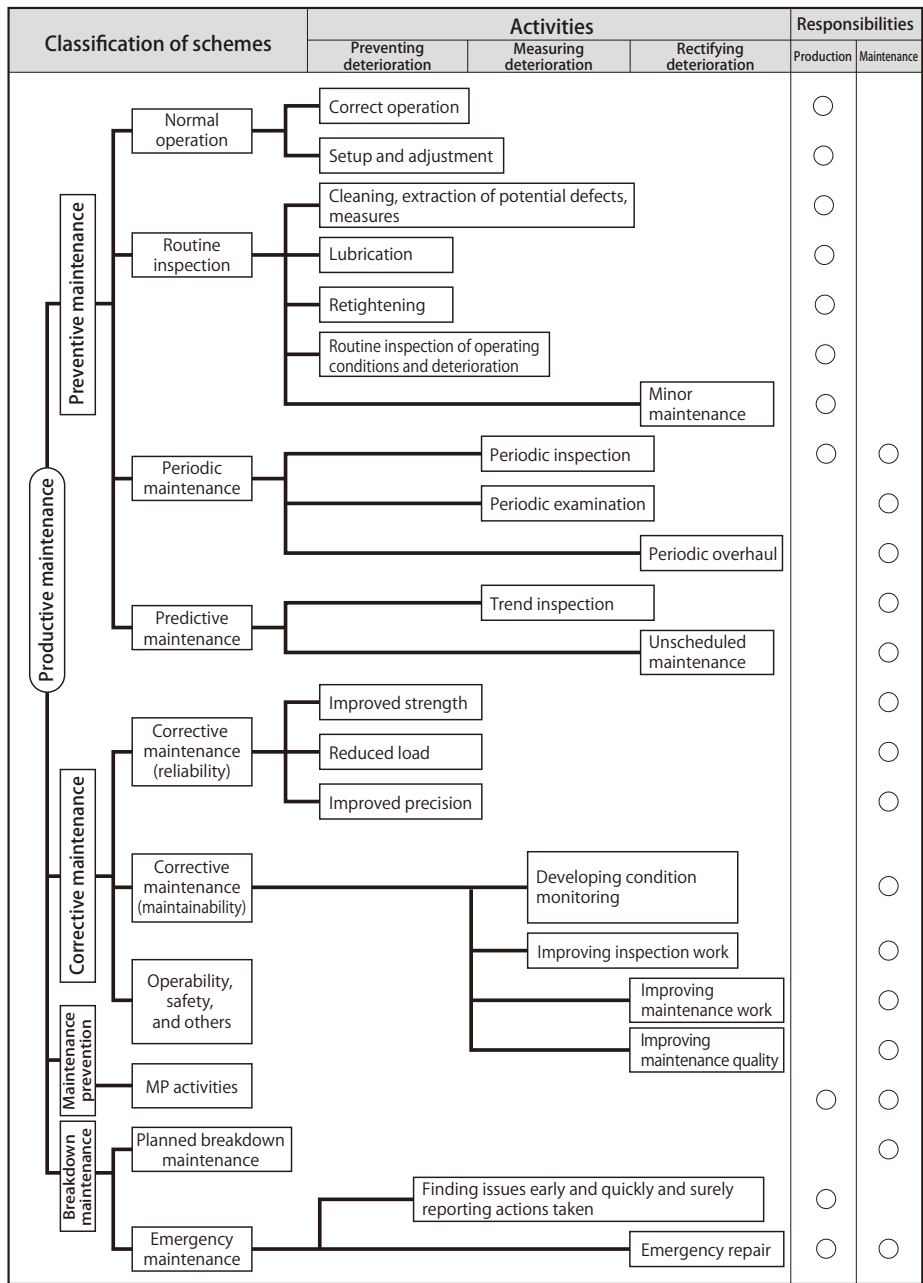
People of the production department handle the equipment every day, so they are the best people to take on the fundamental maintenance role—detecting minor anomalies. With responsibilities thus assigned, the maintenance department can demonstrate the true performance of its special maintenance schemes. It is the first step toward efficient maintenance.

### 2 Classification of maintenance schemes and assignment of responsibilities

This section classifies the maintenance schemes and what responsibilities should be assigned to autonomous maintenance (see **Figure 4-3**).



Figure 4-3 Classification of maintenance schemes and assignment of responsibilities



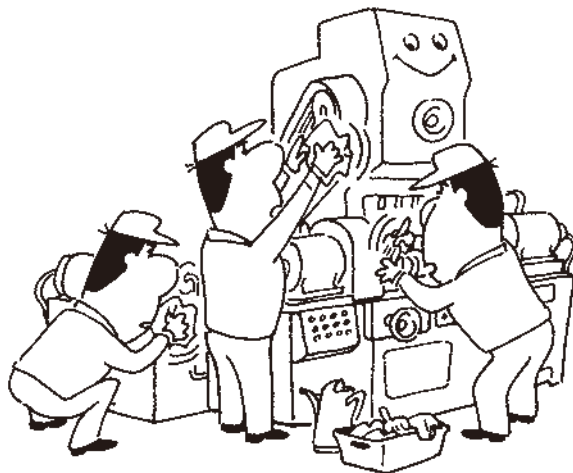
The activities for attaining the maintenance goals are largely classified into the following two:

- ① Maintenance activities: Preventing failures and repairing failures

② Improvement (Kaizen) activities: Extending service life and shortening maintenance time

# **Chapter 5**

## **Basics of Routine Maintenance**



# 1 Basics of Routine Maintenance (Daily Maintenance)

## 1 Fastened components

Mechanical elements are diverse: screws, rivets, keys, cotters, gear transmissions, axles, bearings, links, cams, pipes, joints, and more. It is probably impossible to attain proficiency in all of them; and it is not necessary to do so. This section describes the very basics of mechanical elements—fasteners such as screws and rivets. They are probably the most frequently used components, and affect the precision of machines and the likelihood of failures.

### 1 Precision of machines

Machining tools and presses should be checked for precision at least once a year. Maintaining precision enables good products to be produced safely and at low cost. In overall inspection, check the following items as far as you can and clarify whether anomalies are present:

- ① Machine center
- ② Table levelness
- ③ Main axis squareness and deflection

## 2 Fastening

There are many types of fasteners: keys, rivets, pins, cotters, splines, and screws, for instance. **Figure 5-1** shows their roles, rough sketches, primary applications, and checkpoints in overall inspection.

### 3 Bolts and nuts

#### (1) Principles of screws

When a piece of paper in the shape of a right triangle is wrapped around a cylinder, the long side forms a spiral. This spiral is called a *helix*.

The angle that shows the inclination of a helix ( $\beta$ ) is called a **lead angle**. By combining a cylindrical object with a groove along the helix on the outside with another cylindrical object with the same groove on the inside, you can turn a small force into a large fastening force or change circular motion into linear motion (and vice versa) (see Figure 5 (and vice versa) (see **Figure 5-2**).

Figure 5-1 Types of fasteners and their characteristics

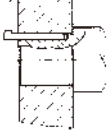
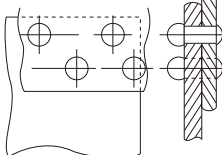
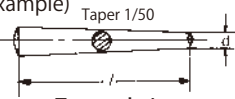

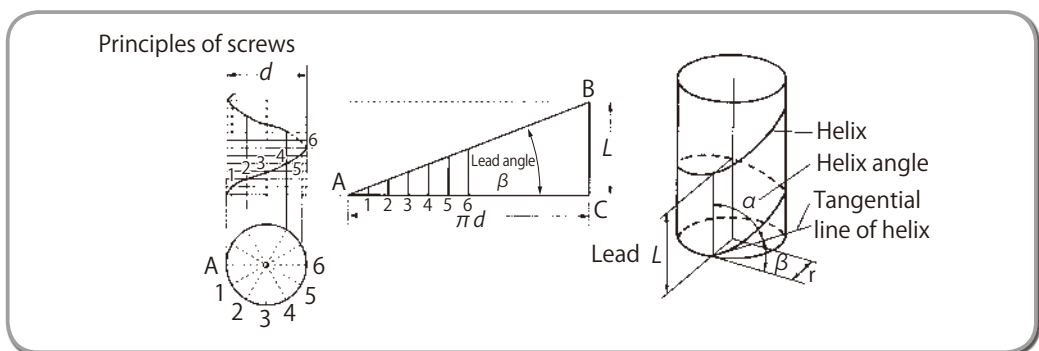
| Fastener type  | Roles and rough sketch   | Applications  | Checkpoints   |
|--|--|---|---|
| 1. Key<br>Parallel key<br>(embedded key)<br>Taper key (Driving key)<br>Woodruff key                                | Transmission of torque<br>(Example)<br><br>Driving key  | Retaining gear, coupling, sprocket, or pulley onto shaft            | ① Noise<br>② Too much play<br>③ Wear<br>④ Stepping<br>⑤ Looseness |
| 2. Rivet<br>Round-head rivet<br>Countersunk rivet<br>Thin flat rivet<br>Pan-head rivet<br>Flathead rivet<br>Others | Couplings and joints<br>  | Pressure vessel (boiler)<br>Bridge<br>Building<br>Aircraft<br>Crane | ① Looseness<br>② Corrosion<br>③ Wear<br>④ Too much play<br>⑤ Bend |
| 3. Pins<br>Tapered pin<br>Parallel pin<br>Cotter pin<br>Spring pin   | Fastening, retaining, locking, positioning<br>(Example)<br><br>Tapered pin                    | Steering Chain<br>Retaining parts<br>Positioning                    | ① Noise<br>② Rust (corrosion)<br>③ Wear<br>④ Omission<br>⑤ Raging |
| 4. Cotter<br>Single-sided<br>Double-sided  | Fastening shafts that receive both tensile and compressive strengths<br><br>Cotter<br>Socket | Locomotive<br>Car pedal   | ① Noise<br>② Too much play<br>③ Wear                              |
| 5. Bolts and nuts  | See subsection 3, Bolts and nuts.  |   |   |

Figure 5-2 Principles of screws



## (2) Basics of screws

### ① Male and female screws

When a cylinder has a groove along a helix on the outside, it is called a **male screw**. When a cylinder has a groove along a helix on the inside, it is called a **female screw**.

② Single- and multi-thread screws

A screw of a single helix is called a **single-thread screw**. A screw with two or more helixes is called a **multi-thread screw**.

③ Lead and pitch

The distance between the center lines of two adjacent ridges is called a **pitch ( $p$ )**. The distance which a ridge travels when a screw is turned once is called a **lead ( $L$ )**. When the lead is expressed as  $L$ , the pitch as  $p$ , and the number of threads as  $n$ , the following relationship is established:  $L = p \times n$ . With a single-thread screw, the formula is  $L = p$ . Thus, a multi-thread screw is tightened more quickly than a single-thread screw for the same number of turns.

④ Effective diameter

The effective diameter ( $d_2$  or  $D_2$ ) of a screw is the diameter of an imaginary cylinder that exists where the thread ridge thickness is equal to the thread valley width.

Figure 5-3 Structure of thread

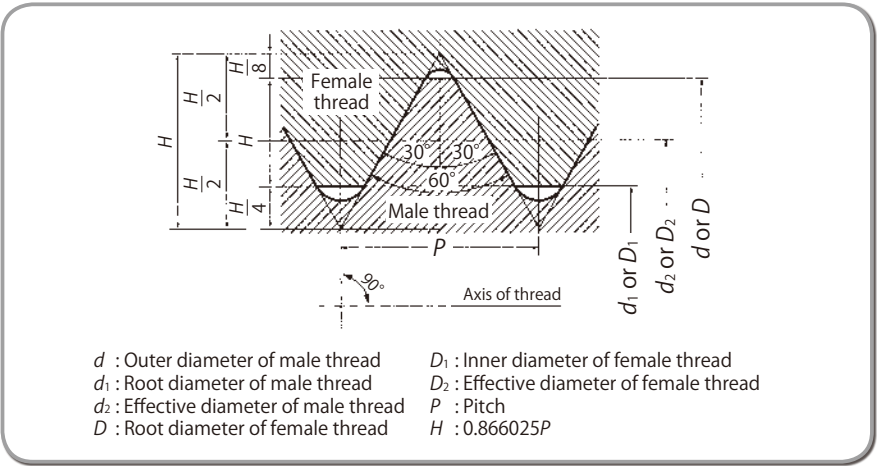


Figure 5-4 Types and characteristics of triangular threads

| Name         |                | Thread angle | Thread shape |        | Unit of pitch    | Nominal diameter                        |
|--------------|----------------|--------------|--------------|--------|------------------|---|
|              |                |              | Ridge        | Groove |                  |   |
| Meter thread |                | 60°          | Flat         | Round  | mm               | mm                                      |
| Inch thread  | Unified thread | 60°          | Flat         | Round  | Threads per inch | Number or inch                          |
|              | Whit thread    | 55°          | Round        | Round  | Threads per inch | Coarse thread: inch;<br>Fine thread: mm |

With a male screw, the outer diameter (crest-to-crest diameter) is called  $d$  and the diameter of the valley (root-to-root diameter) is called  $d_i$  (see **Figure 5-3**).

### ⑤ Nominal diameter

The nominal diameter of a screw represents its size. Mainly, the nominal diameter is the reference size of the outer diameter of the male thread. In **Figure 5-3**, the nominal diameter is the outer diameter  $d$  of the male thread.

### (3) Mechanical properties of screw components

Screw components are for fastening two or more parts, and their most important conditions are their *mechanical properties*. Difficult theories aside, you can easily imagine that you will be in trouble if the two components are torn when pulled. Thus, *tensile strength* is important.

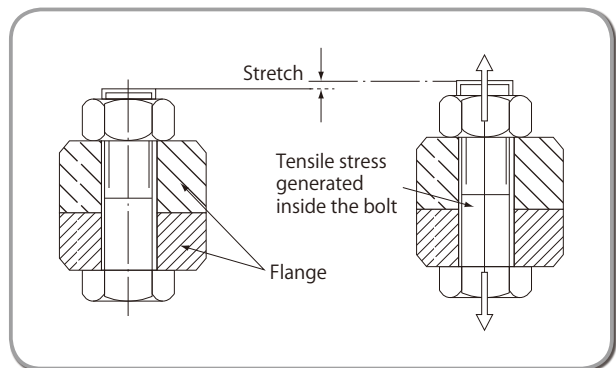
The tensile strength is the reference for the various mechanical strengths of bolts and nuts, which are assigned *strength classes*. Tensile strengths are indicated by the symbol T—4T or 10T, for instance.

### (4) How bolts and nuts are tightened

Imagine fastening two flanges with a bolt and a nut. As you tighten the nut, the bolt is pulled longitudinally. As a result, it is stretched longitudinally, though only slightly.

Inside the bolt, a tensile stress is generated in accordance with the pulling force (axial force). The generated tensile stress fastens the flanges via the seat of the nut. In accordance with the axial force, a compressive stress works on the flanges. A steel bolt is stretched when tightened, though it is not visible to the naked eye. What tightens the object is the elastic force of the stretched bolt shrinking to the original length. **Figure 5-5** shows the stretch of a bolt.

**Figure 5-5 Stretch of a bolt**



### (5) Fastening force of bolts and nuts (tightening torque)

Appropriate tightening means to give the necessary axial force to the bolt. Generally, you use a wrench to tighten a bolt. Specifically, you use a wrench to apply a tightening torque (turning torque) to the nut to generate the necessary axial force (fastening force).

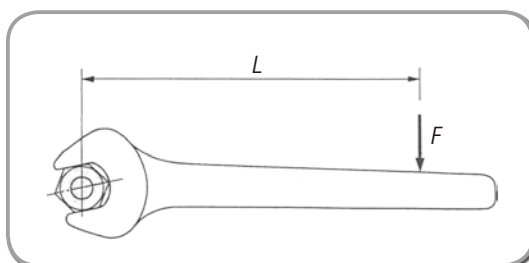
The tightening torque is the product of the distance  $L$  from the axial center of

the bolt to the point of action and the turning force  $F$  (see **Figure 5-6**).

The tightening torque is expressed as follows:

$$T = F \times L \text{ (kgf} \cdot \text{cm)}$$

**Figure 5-6** Tightening a bolt and a nut



## (6) Loosening of bolts and nuts

### ① How does a bolt loosen?

Loosening of bolts and nuts frequently occur in the following places:

- Where impulse load is applied
- Where vibration is likely
- Where temperature changes are severe
- Where bolts and nuts are used on internal structures of a machine or device and are difficult to maintain or manage

**Figure 5-7** shows the types of screw loosening.

**Figure 5-7** Types of screw loosening

| Nut rotation                                  | Cause of loosening   |
|---|--|
| The nut does not turn in loosening direction. | ①Wear of micro irregularities on the contact area<br>②Seat subsiding into fastened object<br>③Worn gasket<br>④Wear of contact area due to micro motions<br>⑤Heat |
| The nut turns in loosening direction.         | ⑥Impulsive external force<br>⑦Relative displacement of fastened objects  |

### ② Loosening as a phenomenon

What is the loosening of a screw? It is a phenomenon in which the axial force that has been generated by tightening a bolt is reduced below the required level or disappears.

### ③ Loosening that occurs without a nut turning

#### • Loss of micro roughness of joined surfaces

As shown in **Figure 5-8**, objects fastened with a screw have surfaces that are joined under compressive force—the seats of the bolts and nuts, and the surfaces of the objects themselves, for instance.

The joined surfaces have micro roughness, which is squashed and flattened by the fluctuating bearing stress. The distance between the objects is shortened as shown in **Figure 5-9**, and so is the tightening length. Thus, the axial force of the bolt decreases.