



# Introduction to Gears

First Edition



***KOHARA GEAR INDUSTRY CO., LTD.***



# Preface

The history of gears is probably as old as civilization itself. And yet today, the importance of gears in manufacturing industry is undwindling and even more growing.

The purpose of this handbook is to provide an outline of gear fundamentals for those who want to acquire knowledge about mechanics of gears. In reading through this handbook, if you have any questions please refer them to us and we would be happy to respond.

We hope this can start you down the road with a good sence of direction.

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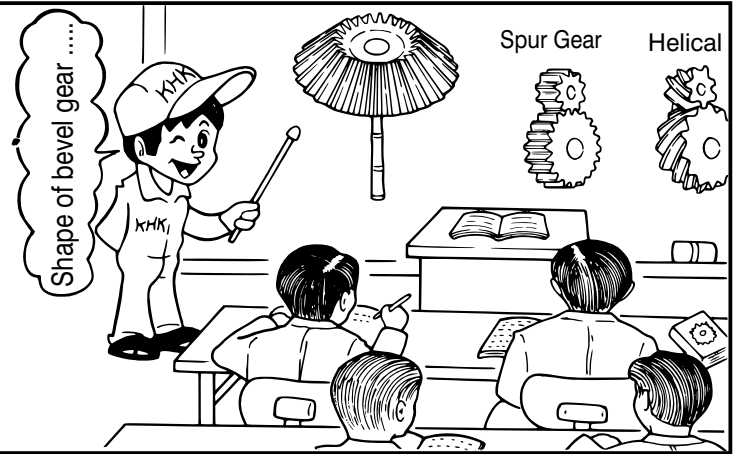
# **Part 1**

## **About Gears**

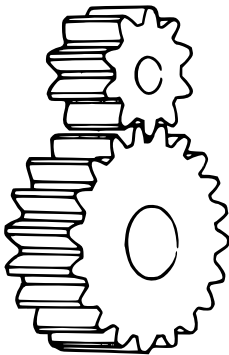
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- 9. Gear Noise**
- 10. Q & A**

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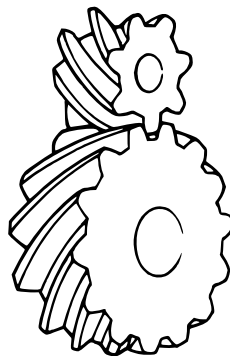
# Types of Gears



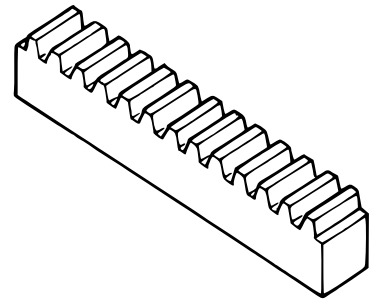
Spur Gear



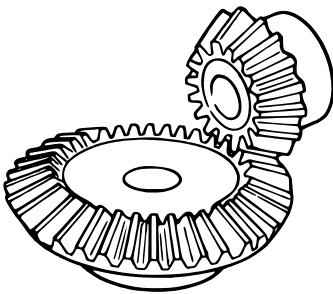
Helical Gear



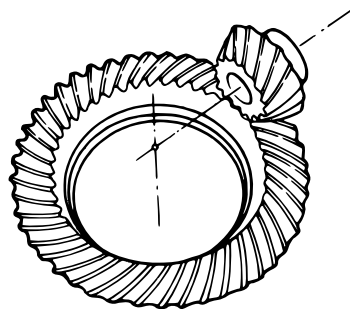
Rack



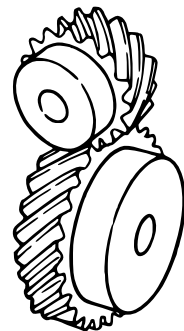
Bevel Gear



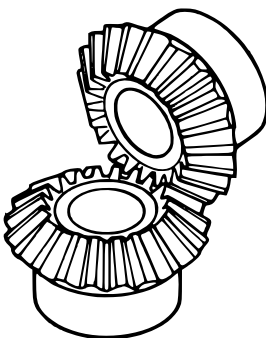
Spiral Bevel Gear



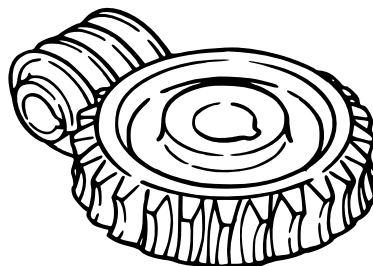
Screw Gear



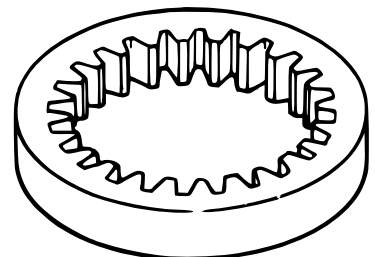
Miter Gear

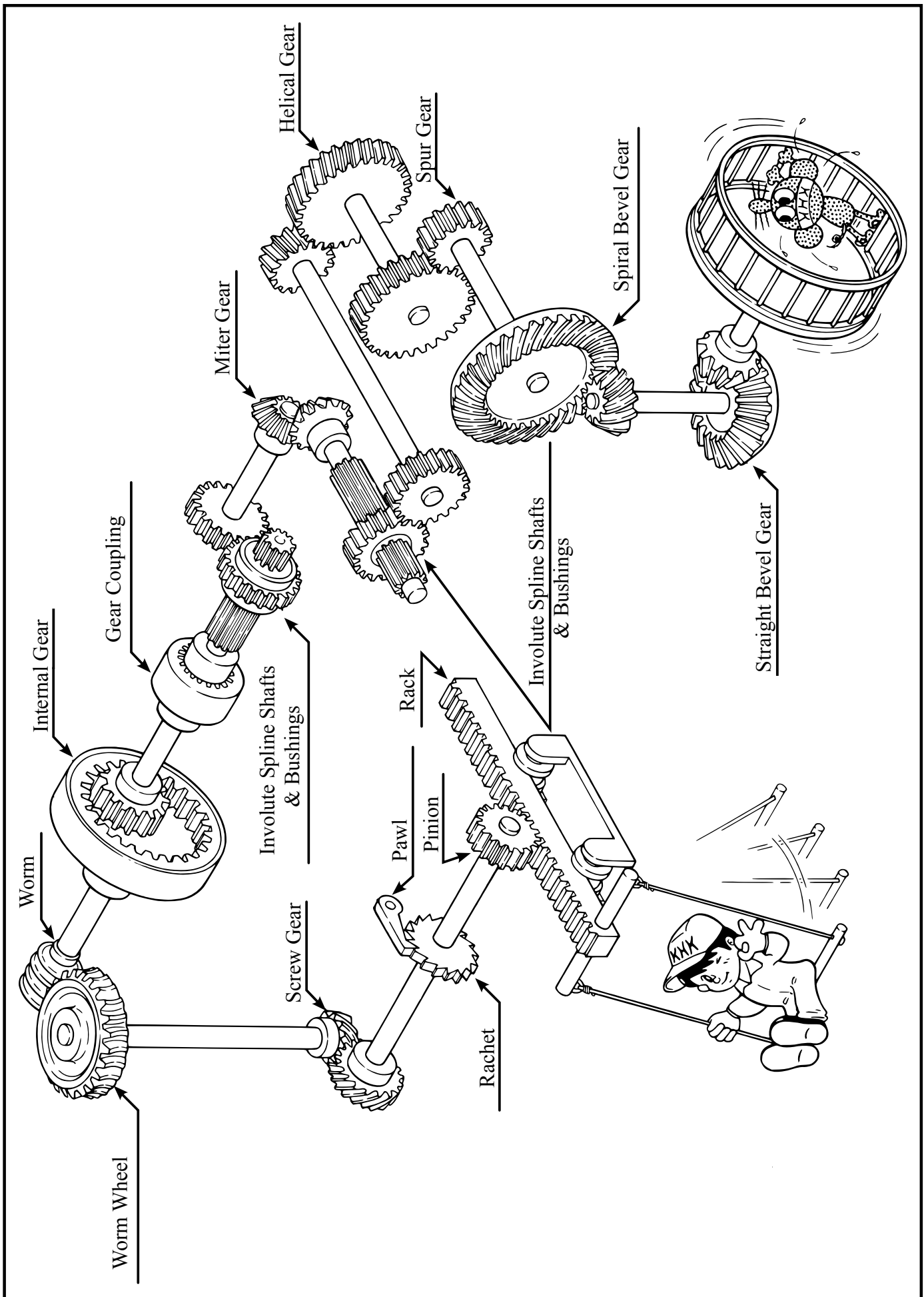


Worm & Worm Wheel



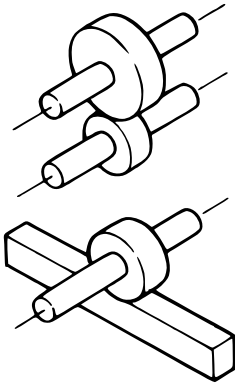
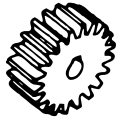
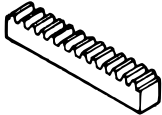
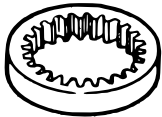
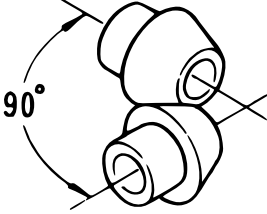
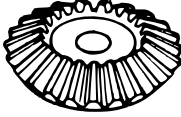
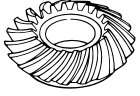
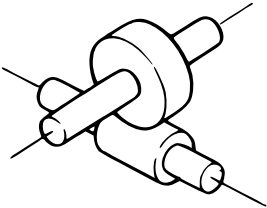
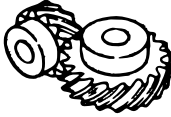
Internal Gear





## (1) About Gears

There are three categories of gears in accordance with the orientation of axes.

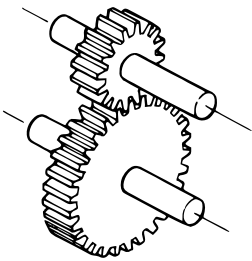
|                                                                                                                                 |                                 |                                                                                      |                                                                                                                                    |
|---------------------------------------------------------------------------------------------------------------------------------|---------------------------------|--------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------|
| <p>1) Parallel Axes</p>                        | Spur Gear                       |     | MSG(A,B),SSG(S),SS,SSA,SSY,SSAY,LS,SUS,SUSA,SUSL,DSL,NSU,PU,PS,PSA,DS,BSS,SSCPG(S),SSCP,SUSCP,SSR,KTSCP                            |
|                                                                                                                                 | Helical Gear                    |     | KHG,SH                                                                                                                             |
|                                                                                                                                 | Rack                            |     | KRG(F),KRGD,SRGF,KRF,SR(F),SRFD,SUR(F),SURFD,BSR,DR,PR(F),SRO,SROS,SURO,KRHG(F),SRH,KRG(F)(D),SRCF(F)(D),KRCPF,SURCPF(D),SRCF,FRCP |
|                                                                                                                                 | Internal Gear                   |     | SI,SIR                                                                                                                             |
| <p>2) Intersecting Axes</p>                   | Miter Gear                      |     | MMSG,SMSG,MMSA(B),MMS,SMS,SMA(B)(C),MM,LM,SM,SAM,SUM,PM,DM                                                                         |
|                                                                                                                                 | Straight Bevel Gear             |   | SB,CB,SBY,SUB,PB,DB                                                                                                                |
|                                                                                                                                 | Spiral Bevel Gear               |   | MBSG,SBSG,MBSA(B),SBS,KSP                                                                                                          |
| <p>3) Nonparallel, Nonintersecting Axes</p>  | Screw Gear                      |  | AN,SN,PN,SUN                                                                                                                       |
|                                                                                                                                 | Worm                            |  | KWGD(L,S),KWG,SWG,SW,SUW                                                                                                           |
|                                                                                                                                 | Worm Wheel                      |   | AGDL,AGF,AG,PG,CG,BG                                                                                                               |
| <p>4) Others</p>                                                                                                                | Involute Spline Shaft & Bushing |  | SV,SVI                                                                                                                             |
|                                                                                                                                 | Gear Coupling                   |  | GC,GC-I                                                                                                                            |
|                                                                                                                                 | Pawl & Ratchet                  |   | SRT,SRT-C                                                                                                                          |

# ( 1 ) - 2

## Characteristics of Each Type of Gears



### Spur Gear



Teeth are straight and parallel to shaft axis. Transmits power and motion between rotating two parallel shafts.

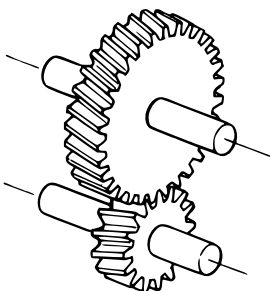
#### [Features]

- ( 1 ) Easy to manufacture.
- ( 2 ) There will be no axial force.
- ( 3 ) Relatively easy to produce high quality gears.
- ( 4 ) The commonest type.

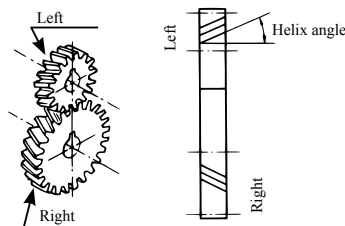
#### [Applications]

Transmission components

### Helical Gear



Teeth are twisted oblique to the gear axis.



The hand of helix is designated as either left or right.

Right hand and left hand helical gears mate as a set. But they have the same helix angle.

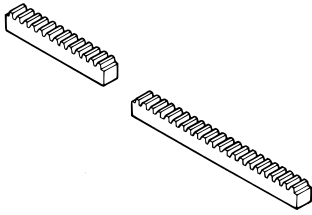
#### [Features]

- ( 1 ) Has higher strength compared with spur gear.
- ( 2 ) Effective in reducing noise and vibration compared with spur gear.
- ( 3 ) Gears in mesh produce thrust forces in the axial directions.

#### [Applications]

Transmission components, automobile, speed reducers etc.

## Rack



The rack is a bar containing teeth on one face for meshing with a gear. The basic rack form is the profile of the gear of infinite diameter.

Racks with machined ends can be joined together to make any desired length.

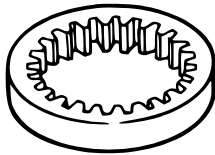
### [Features]

- ( 1 ) Changes a rotary motion into a rectilinear motion.

### [Applications]

A transfer system for machine tools, printing press, robots, etc.

## Internal Gear



An annular gear having teeth on the inner surface of its rim.

The internal gear always meshes with the external gear.

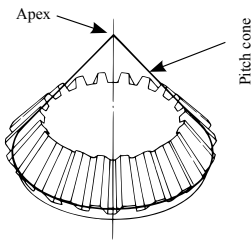
### [Features]

- ( 1 ) In the meshing of two external gears, rotation goes in the opposite direction. In the meshing of an internal gear with an external gear the rotation goes in the same direction.
- ( 2 ) Care should be taken to the number of teeth when meshing a large (internal) gear with a small (external) gear, since three types of interference can occur.
- ( 3 ) Usually internal gear is driven by external (small) gear.
- ( 4 ) Allows compact design of the machine.

### [Applications]

Planetary gear drive of high reduction ratios, clutches etc.

## Bevel Gear

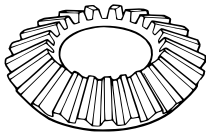


One of a pair of gears used to connect two shafts whose axes intersect, and the pitch surfaces are cones.

Teeth are cut along the pitch cone. Depending on tooth trace bevel gear is classified:

- 1) Straight bevel gear
- 2) Spiral bevel gear

### 1 ) Straight Bevel Gear



A simple form of bevel gear having straight teeth which, if extended inward, would come together at the intersection of the shaft axes.

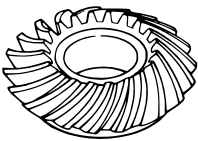
#### [Features]

- ( 1 ) Relatively easy to manufacture.    ( 2 ) Provides reduction ratio up to approx. 1:5.

#### [Applications]

Machine tools, printing press, etc. Especially suitable for a differential gear unit.

### 2 ) Spiral Bevel Gear



Bevel gear with curved, oblique teeth to provide gradual engagement and bring more teeth together at a given time than an equivalent straight bevel gear.

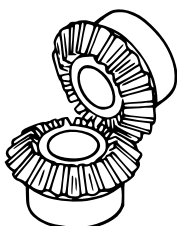
#### [Features]

- ( 1 ) Has higher contact ratio, higher strength and durability than an equivalent straight bevel gear.
- ( 2 ) Allows a higher reduction ratio.
- ( 3 ) Has better efficiency of transmission with reduced gear noise.
- ( 4 ) Involves some technical difficulties in manufacturing.

#### [Applications]

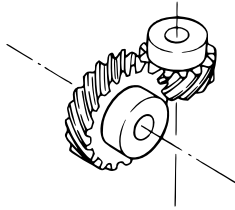
Automobile, tractor, vehicles, final reduction gearing for ships.

## Miter Gears



A special class of bevel gear where the shafts intersect at  $90^\circ$  and the gear ratio is 1:1.

## Screw Gear



A helical gear that transmit power from one shaft to another, non-parallel, non-intersecting shafts.

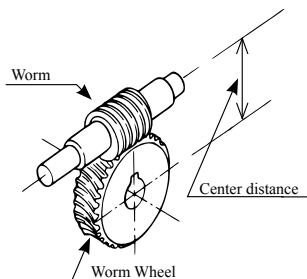
### [Features]

- ( 1 ) Used in a speed reducer and/or a multiplying gear.
- ( 2 ) Tends to wear as the gear come in sliding contact.
- ( 3 ) Not suitable for transmission of high horsepower.

### [Applications]

Driving gear for automobile. Automatic machines that require intricate movement.

## Worm Gear Pair



Worm is a shank having at least one complete tooth (thread) around the pitch surface; the driver of a worm wheel.

Worm wheel is a gear with teeth cut on an angle to be driven by a worm.

### [Features]

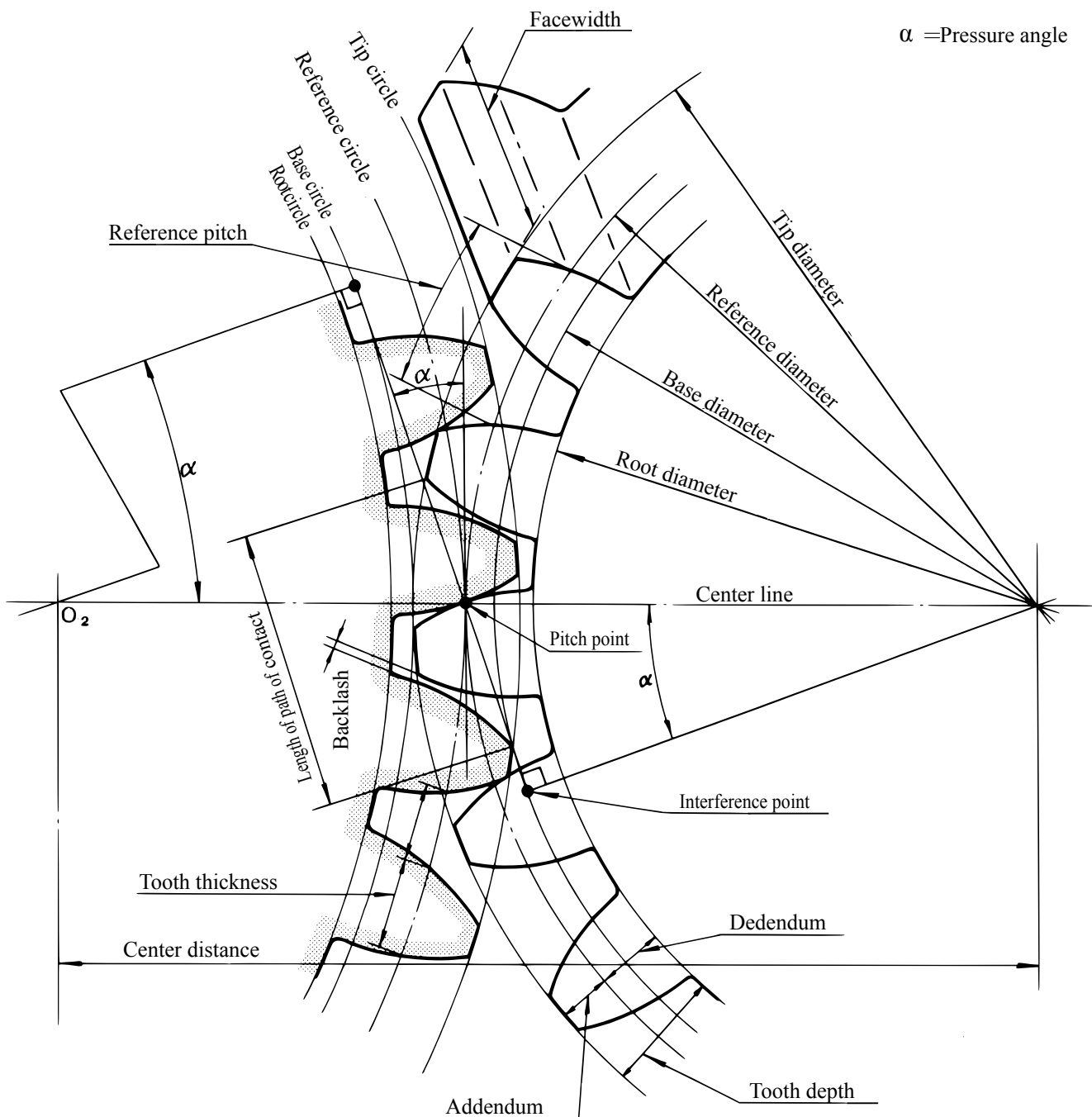
- ( 1 ) Provides large reduction ratios for a given center distance.
- ( 2 ) Quiet and smooth action.
- ( 3 ) A worm wheel is not feasible to drive a worm except for special occasions.

### [Applications]

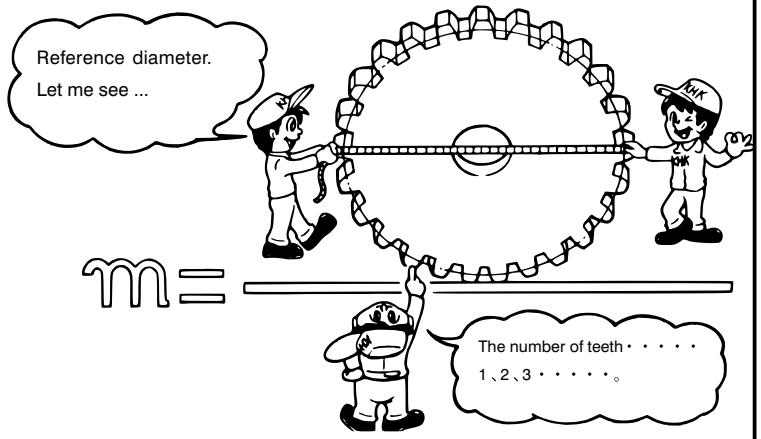
Speed reducers, anti-reversing gear device making the most of its self-locking features, machine tools, indexing device, chain block, portable generator, etc.

## ( 1 ) - 3

## Gear Terminology


 $\alpha$  = Pressure angle


# The Module of a Gear



"Module" is the unit of size to indicate how big or small a gear is. It is the ratio of the reference diameter of the gear divided by the number of teeth.

Thus:  $m = \frac{d}{z}$  (Module =  $\frac{\text{Reference diameter}}{\text{Number of teeth}}$  )

The mutual relation between the module and the reference diameter etc. is as follows:

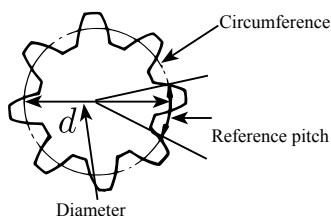
Reference diameter  $d = mz$  ( Reference diameter = Module  $\times$  Number of teeth )

Number of teeth  $z = \frac{d}{m}$  ( Number of teeth =  $\frac{\text{Reference diameter}}{\text{Module}}$  )

Reference pitch  $p = \pi m$  ( Reference pitch =  $\pi \times$  Module )

Then, what is the reference pitch?

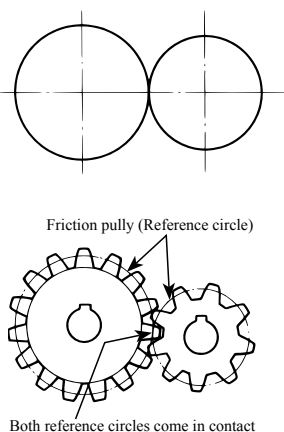
It is equal to the circumference divided by the number of teeth.



$$\text{Reference pitch} = \frac{\text{Circumference } (\pi d)}{\text{Number of teeth } (z)}$$

Then, what is the reference circle?

This is a friction pulley. As the surfaces are smooth, the rotation will not go properly when great force is applied. This problem will be solved if there are teeth on the periphery of the friction pulley. And this is the concept of gearing.



[Summary]

( 1 ) The module describes the size of a gear.

( 2 ) A pair of gears can only mesh correctly if and when the base pitch is the same.

## Practicing What You've Learned

### Spur Gear

Module  $m = 3$       Pinion  $z_1 = 15$       Gear  $z_2 = 55$

(a) Reference diameter

$$\text{Number of teeth} \times \text{Module} = \begin{cases} z_1 \cdots \cdots \boxed{\phantom{00}} \times \boxed{\phantom{00}} = \boxed{\phantom{00}} \\ z_2 \cdots \cdots \boxed{\phantom{00}} \times \boxed{\phantom{00}} = \boxed{\phantom{00}} \end{cases}$$

(b) Tip diameter

$$\text{Reference diameter} + \text{a double module} = \begin{cases} z_1 \cdots \cdots \boxed{\phantom{00}} + \boxed{2} \times \boxed{\phantom{00}} = \boxed{\phantom{00}} \\ z_2 \cdots \cdots \boxed{\phantom{00}} + \boxed{2} \times \boxed{\phantom{00}} = \boxed{\phantom{00}} \end{cases}$$

(c) Center distance

$$\text{Add reference diameters then divide by two} \quad \cdots \cdots \frac{\boxed{\phantom{00}} + \boxed{\phantom{00}}}{\boxed{\phantom{00}}} = \boxed{\phantom{00}}$$

### Helical Gear

Module  $m = 3$       Pinion  $z_1 = 15$       Gear  $z_2 = 55$       Helix angle  $\beta = 16^\circ 15'$   
 $\times$  when  $\cos \beta = 0.96$

(a) Reference diameter

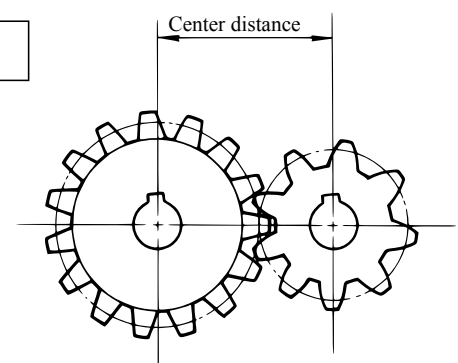
$$\begin{cases} z_1 \cdots \cdots \frac{\boxed{\phantom{00}} \times \boxed{\phantom{00}}}{\boxed{\phantom{00}}} = \boxed{\phantom{00}} \\ z_2 \cdots \cdots \frac{\boxed{\phantom{00}} \times \boxed{\phantom{00}}}{\boxed{\phantom{00}}} = \boxed{\phantom{00}} \end{cases}$$

(b) Tip diameter

$$\begin{aligned} z_1 \cdots \cdots \boxed{\phantom{00}} + \boxed{2} \times \boxed{\phantom{00}} &= \boxed{\phantom{00}} \\ z_2 \cdots \cdots \boxed{\phantom{00}} + \boxed{2} \times \boxed{\phantom{00}} &= \boxed{\phantom{00}} \end{aligned}$$

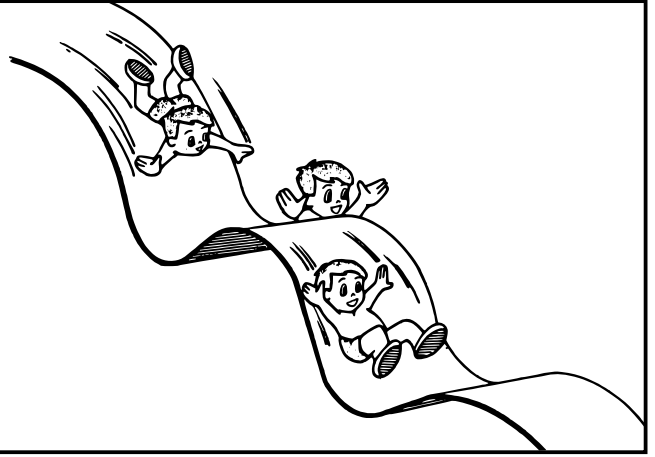
(c) Center distance

$$\cdots \cdots \frac{\boxed{\phantom{00}} + \boxed{\phantom{00}}}{\boxed{\phantom{00}}} = \boxed{\phantom{00}}$$



# ( 1 ) - 4

## Involute Tooth Profile

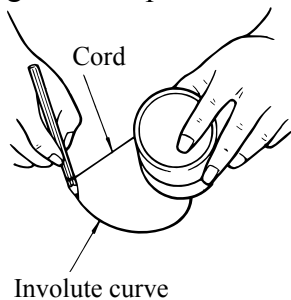


Imagine pulleys with indentations on their periphery. These pulleys, when moved, would:

- cause slipping,
- do not rotate smoothly,
- produce vibration and noise.

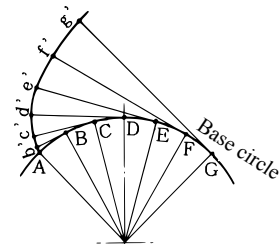
They are improper and unsuitable as a gear.

Satisfactory gears must transmit power smoothly. The involute curve meets all the requirements for a gear-tooth profile.



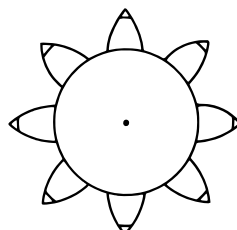
### The involute curve:

If a cord is wrapped around a cylinder, as shown in this figure, a point on the cord, as it is unwrapped from the cylinder, traces a curve called an involute. The circle from which the string is unwound is called the base circle.



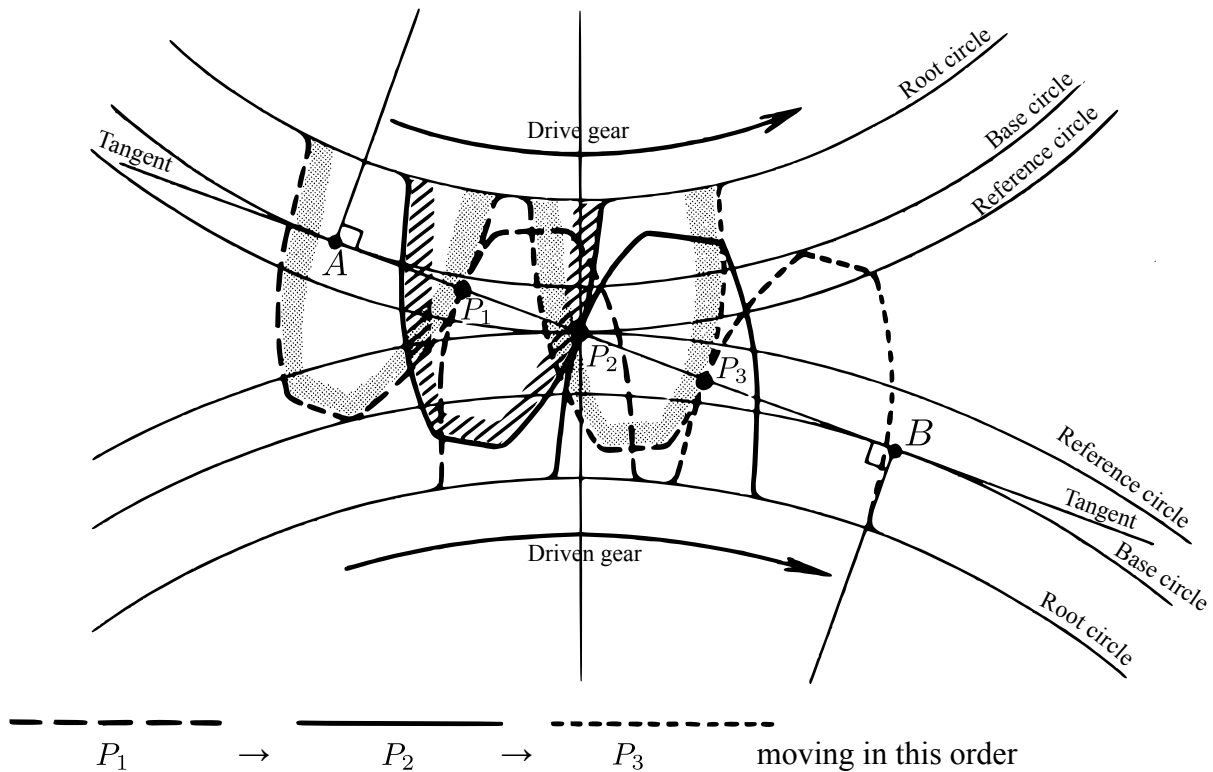
Let us try to make a simple drawing of a eight-toothed gear;

First, divide a cylinder into eight equal parts. Then, from each part unwrap a cord drawing a line with pencil. After you have completed eight lines, do the same manual work from the opposite side. The diagram thus drawn is the involute tooth profile.

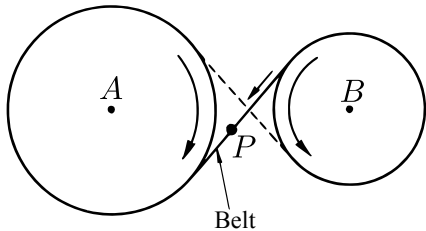


## Involute Gear

This figure indicates how two involute teeth in mesh are moving to transmit rotary motion.



When Gear 1 drives Gear 2 by acting at the instantaneous contact point, the contact point moves on the common tangent in the order of  $P_1 \rightarrow P_2 \rightarrow P_3$ . These points are on the common tangent outward from the base circle.



It is like  $P$  point of a belt on the periphery of two discs is travelling. The involute profile makes it possible to transmit rotary motion smoothly.

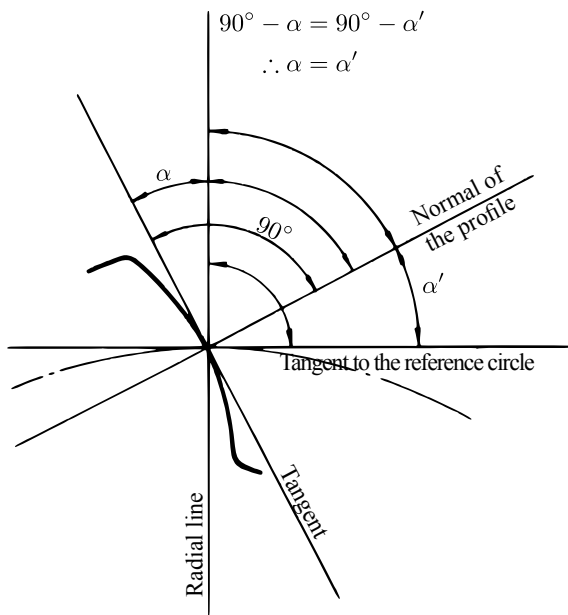
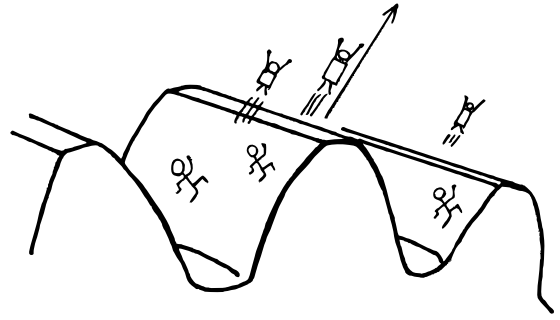
### [Features]

- ( 1 ) Conjugate action is independent of changes in center distance.
- ( 2 ) Can be manufactured at low cost since the tooth profile is relatively simple.
- ( 3 ) A typical tooth profile used almost exclusively for gears.



## ( 1 ) - 5

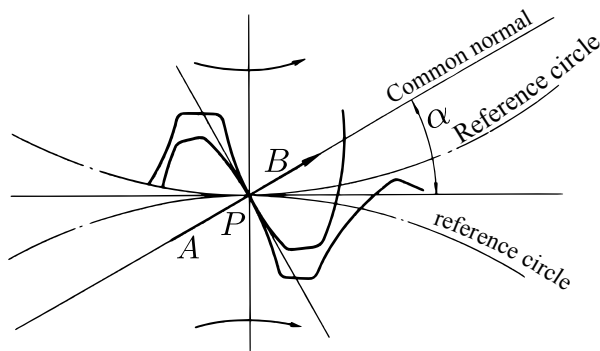
## Pressure Angle



The pressure angle between the tooth profile and a radial line at its pitch point. In involute teeth it is often described as the angle between the line of action and the line tangent to the pitch circle.

Here  $\alpha = \alpha'$ . Therefore,  $\alpha'$  also is the pressure angle.

This figure indicates the meshing of a gear *A* and a gear *B* at the pitch point.



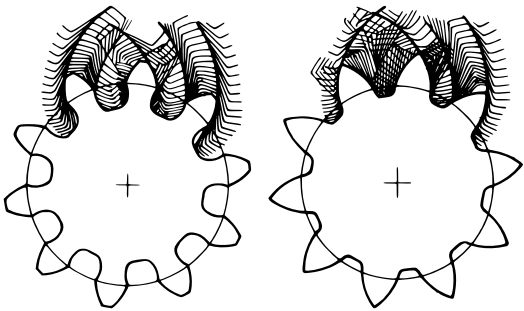
At the pitch point, the gear *A* is pushing the gear *B*. The pushing force acts toward the common normal of the gear *A* and the gear *B*. The pressure angle  $\alpha$  can be described as the angle between the line of action and the line tangent to the reference circle.

[For reference]

The commonest pressure angle is  $20^\circ$ . Formerly the pressure angle of  $14.5^\circ$  was also used.

# (1)-6

## Profile Shifted Gears



Example of undercut gear

Example of gear without undercut

When the number of gear teeth to be cut becomes small, the generating tool will sweep out its path, remove some of the profile, and produce an undercut tooth form. To prevent undercut, some correction must be introduced, and it is called profile shifting. Profile shifting can not only prevent undercut, but also can adjust center distance between two gears.

An example of profile shifting is given here.

$$m = 3 \quad z_1 = 10 \quad z_2 = 60 \quad \alpha = 20^\circ$$

The positive correction of 0.5 is to be made on 10-toothed gear ( $z_1 = 10 \quad x_1 = +0.5$ )

The calculations to be made:

( I ) Determine working pressure angle  $\alpha'$

$$\begin{aligned} \text{inv } \alpha' &= 2 \tan \alpha \left( \frac{x_1 + x_2}{z_1 + z_2} \right) + \text{inv } \alpha \\ &= 2 \times 0.36397 \left( \frac{0.5}{10 + 60} \right) + 0.014904 \\ &= 0.020104 \\ \alpha' &= 22^\circ 01' 03'' \end{aligned}$$

( II ) Find center distance

modification coefficient  $y$

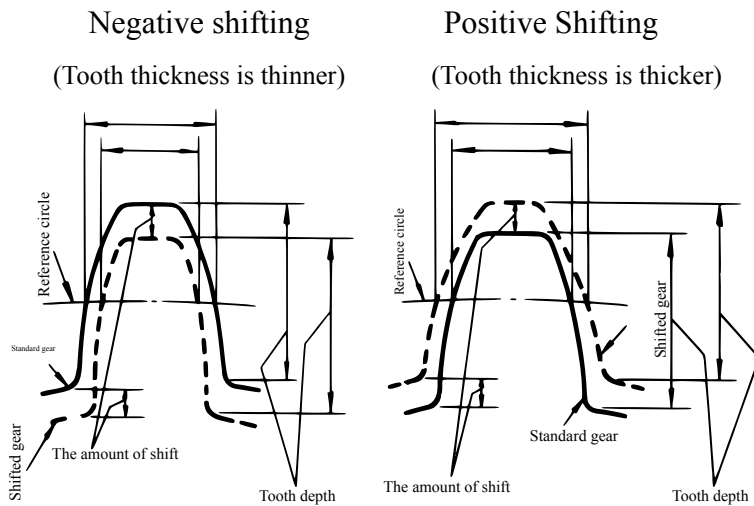
$$\begin{aligned} y &= \frac{z_1 + z_2}{2} \left( \frac{\cos \alpha}{\cos \alpha'} - 1 \right) \\ &= \frac{10 + 60}{2} \left( \frac{0.93969}{0.92707} - 1 \right) \\ &= 0.476447 \end{aligned}$$

( III ) Determine center distance  $a$

$$\begin{aligned} a &= \left( \frac{z_1 + z_2}{2} + y \right) m \\ &= \left( \frac{10 + 60}{2} + 0.4764 \right) 3 \\ &= 106.43 \end{aligned}$$

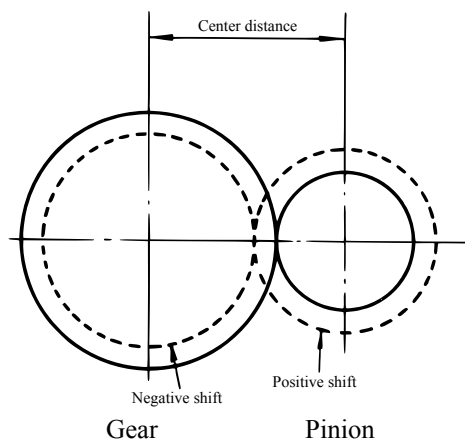
( IV ) Find tip diameter  $d_a$

$$\begin{aligned} d_{a1} &= \{ z_1 + 2 ( 1 + y - x_2 ) \} m \\ &= \{ 10 + 2 ( 1.4764 - 0 ) \} 3 \\ &= 38.86 \end{aligned}$$

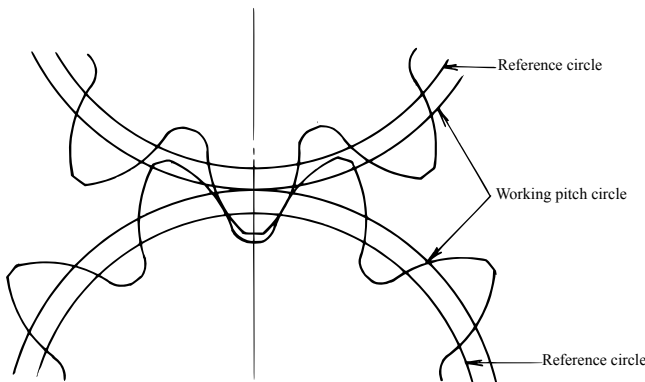


There are both positive and negative shifting.

There will be change in tooth thickness; In the case of positive shifting (+), tooth thickness will become thicker, while in the case of negative shifting (-), it will become thinner. Tooth depth will not change.



This figure shows that a gear is negative shifted and a pinion positive shifted, and the absolute value of profile shift is identical. Attention is to be paid that there is no change in center distance. If there is a condition that center distance is invariable, the profile shifting will solve the problem as illustrated here.



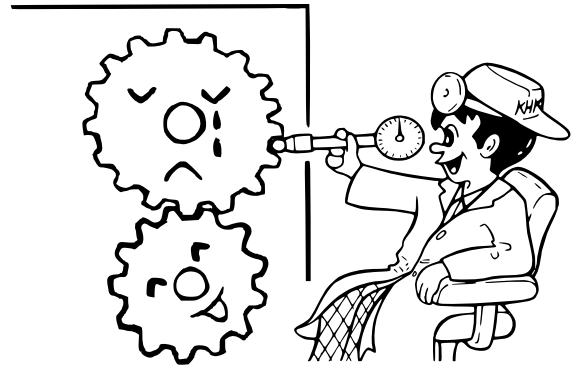
The meshing of standard spur gear means reference circles of two gears contact and roll with each other. The same of the profile shifted spur gear means working pitch circles of two gears contact and roll with each other. The pressure angle at the working pitch circle is called working pressure angle. And this is different from reference pressure angle. In designing profile shifted gear this working pressure angle will be an important factor.

### [Features]

- ( 1 ) Prevents undercutting when the number of teeth is small.
- ( 2 ) Helps adjusting center distance
- ( 3 ) Possible to equalize the strength of a pinion and the same of a gear by profile shifting; Make correction (shifting) of the pinion positive. Then make correction of the gear negative. This results in thicker tooth thickness of the pinion and the thinner tooth thickness of the gear, or equalization of the strength.

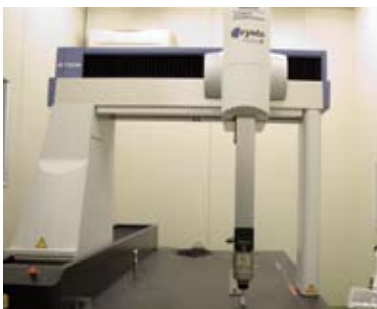
# ( 1 ) - 7

## Gear Accuracy - Testing and Inspecting



At KHK, the following measuring instruments are used to test and inspect the gear accuracy.

- ( 1 ) Gear measuring machine.....To measure the accuracy of tooth profile, trace, pitch and runout.
- ( 2 ) 3-D coordinate measuring machine.....To measure the pitch accuracy of racks
- ( 3 ) Composite gear tester.....To test composite deviation



3-D coordinate measuring machine



Gear measuring machine

The measuring apparatuses used while working on a gear production are:

- (1) Vernier calipers, Micrometer calipers, Cylinder gauge.....To measure inside and outside diameters and tooth thickness.
- (2) Runout tester.....To measure side face runout, and circumference (radial) runout.
- (3) Hardness testing machine..... To measure hardness
- (4) Micrometer calipers ..... To find span measurement
- (5) Gear tooth vernier calipers ..... To measure tooth thickness of worm
- (6) Worm gear tester ..... To measure tooth contact and backlash
- (7) Bevel gear tester ..... To measure tooth contact and backlash



Vernier calipers



Micrometer  
calipers



Cylinder  
gauge

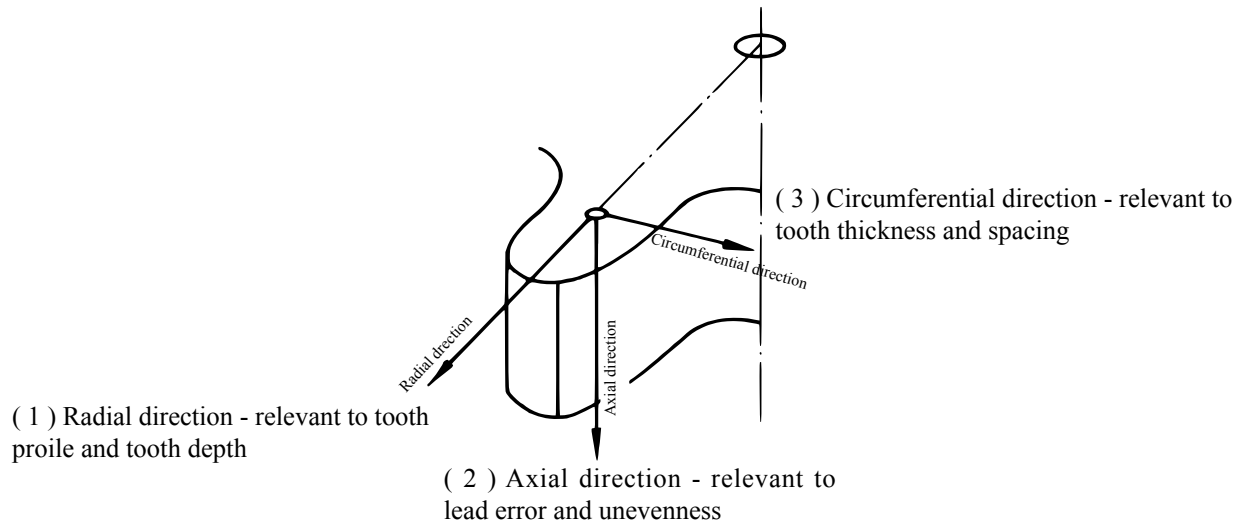


Gear tooth vernier  
calipers



Runout tester

### 《Gear Accuracy in 3-D》

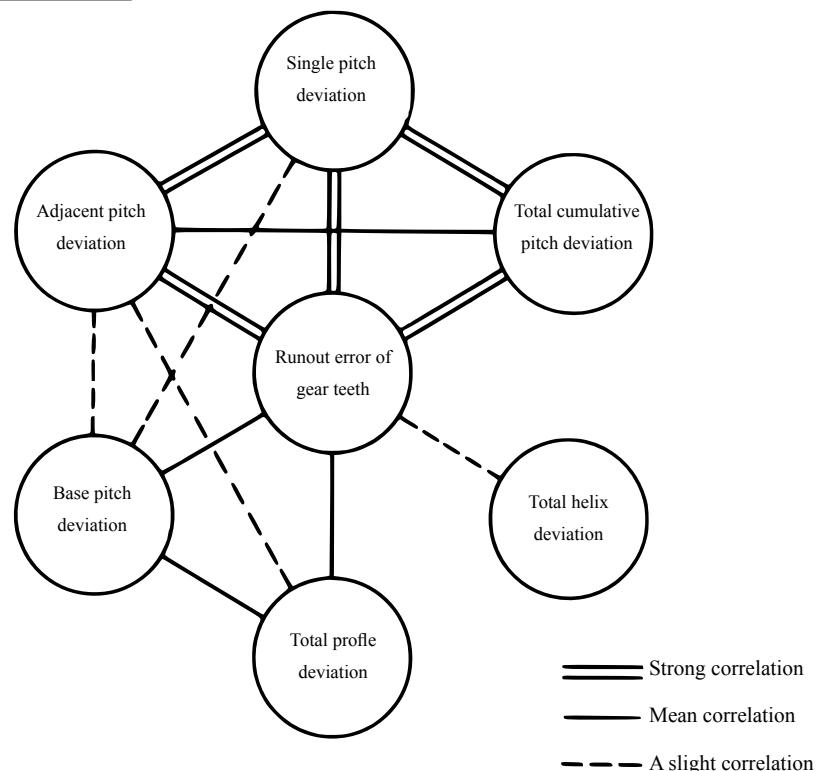


In order to test gear accuracy three-dimensional measurements are necessary, and the following measuring instruments and/or apparatuses are to be used properly.

- ( 1 ) Radial direction ..... Gear measuring machine, 3-D coordinate measuring machine
- ( 2 ) Axial direction ..... Gear measuring machine, 3-D coordinate measuring machine
- (3)Circumferential direction .... Micrometer calipers, gear tooth vernier calipers, rollers (pins), ball micrometer calipers.

Shown in this figure is the correlation between each individual errors. There is a strong correlation between each pitch errors. Also, runout error widely influence each individual errors.

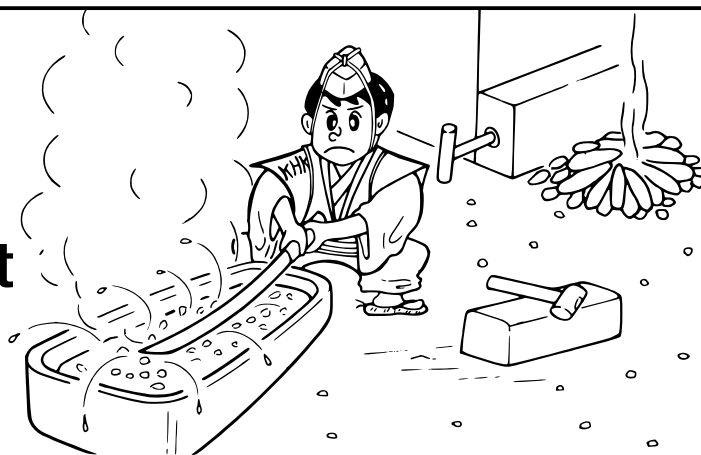
### 《Correlation between Errors》



Correlation between each individual errors (in case of ground gear)

## ( 1 ) - 8

# Metallic Materials for Gears and Heat Treatment



The materials herein described are generally used domestically.

## 〈Case-hardening steel〉

The carbon content of case-hardening steel is low, usually about 0.15 through 0.20%. Case-hardening steel also contains Ni, Cr, Mo, Mn, etc. It is suitable for carburizing and quenching.

| JIS Designation | Chemical composition % |             |             |        |        |             |             |             |
|-----------------|------------------------|-------------|-------------|--------|--------|-------------|-------------|-------------|
|                 | C                      | Si          | Mn          | P      | S      | Ni          | Cr          | Mo          |
| SCr420          | 0.18 ~ 0.23            | 0.15 ~ 0.35 | 0.60 ~ 0.90 | <0.030 | <0.030 | —           | 0.90 ~ 1.20 | —           |
| SCM415          | 0.13 ~ 0.18            | 〃           | 〃           | 〃      | 〃      | —           | 〃           | 0.15 ~ 0.25 |
| SCM420          | 0.18 ~ 0.23            | 〃           | 〃           | 〃      | 〃      | —           | 〃           | 〃           |
| SNC815          | 0.12 ~ 0.18            | 〃           | 0.35 ~ 0.65 | 〃      | 〃      | 3.00 ~ 3.50 | 0.60 ~ 1.00 | —           |
| SNCM220         | 0.17 ~ 0.23            | 〃           | 0.60 ~ 0.90 | 〃      | 〃      | 0.40 ~ 0.70 | 0.40 ~ 0.60 | 0.15 ~ 0.25 |

## 〈Aluminium bronze casting〉

| Descriptions                       | Symbol | Chemical composition % |          |         |         |      |        | Tensile test                          |            | Hardness test | Applications                                                                                                                                    |
|------------------------------------|--------|------------------------|----------|---------|---------|------|--------|---------------------------------------|------------|---------------|-------------------------------------------------------------------------------------------------------------------------------------------------|
|                                    |        | Cu                     | Al       | Fe      | Ni      | Mn   | Others | Tensile strength<br>N/mm <sup>2</sup> | Elongation | HB<br>10/1000 |                                                                                                                                                 |
| Aluminium bronze casting<br>Type 2 | CAC702 | 80.0~88.0              | 8.0~10.5 | 2.5~5.0 | 1.0~3.0 | <1.5 | >0.5   | >490                                  | >20        | >120          | Gear, bearing, bush, valve seat, impeller, propeller for ships etc.<br>(Suitable for those which require rust, erosion and/or wear resistance.) |

## 〈Bronze casting〉

| Descriptions                        | Symbol  | Chemical composition % |         |         |         |        | Tensile test                          |            | Applications                                                                                                                     |
|-------------------------------------|---------|------------------------|---------|---------|---------|--------|---------------------------------------|------------|----------------------------------------------------------------------------------------------------------------------------------|
|                                     |         | Cu                     | Sn      | Zn      | Pb      | Others | Tensile strength<br>N/mm <sup>2</sup> | Elongation |                                                                                                                                  |
| Bronze continuous casting<br>Type 6 | CAC406C | 83.0~87.0              | 4.0~6.0 | 4.0~6.0 | 4.0~6.0 | >2.0   | >245                                  | >15        | Valve cock, machine parts etc. (Suitable for those which require pressure resistance, machinability and suitability to casting.) |

### 〈Carbon steels for machine structural use〉

The most commonly used material. KHK mainly uses S45C. Suitable for high-frequency induction hardening.

| Symbol | Chemical composition % |             |             |        |        |
|--------|------------------------|-------------|-------------|--------|--------|
|        | C                      | Si          | Mn          | P      | S      |
| S43C   | 0.40 ~ 0.46            | 0.15 ~ 0.35 | 0.60 ~ 0.90 | <0.030 | <0.035 |
| S45C   | 0.42 ~ 0.48            | //          | //          | //     | //     |
| S48C   | 0.45 ~ 0.51            | //          | //          | //     | //     |

### 〈Chromium molybdenum steel〉

Chromium molybdenum steel is thermal-refined and then hardened by high-frequency induction hardening.

| Descriptions | Symbol | Chemical composition % |             |             |        |        |             |             |
|--------------|--------|------------------------|-------------|-------------|--------|--------|-------------|-------------|
|              |        | C                      | Si          | Mn          | P      | S      | Cr          | Mo          |
| Type 3       | SCM435 | 0.33 ~ 0.38            | 0.15 ~ 0.35 | 0.60 ~ 0.90 | <0.030 | <0.030 | 0.90 ~ 1.20 | 0.15 ~ 0.30 |
| Type 4       | SCM440 | 0.38 ~ 0.43            | //          | //          | //     | //     | //          | //          |

### 〈Quenching〉

Quenching is the process to surface-harden tooth areas to increase their strength. Cited here are two, among others, processes - (a) carburizing and quenching, and (b) high-frequency induction hardening.

#### Carburizing and Quenching

The suitable material - SCM415 etc.

Carburizing → Quenching → Cleaning → Tempering → Shot blast → Testing/Inspecting

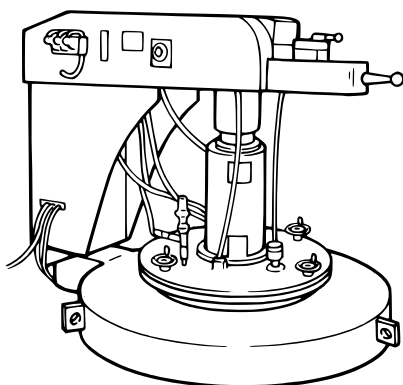
Case hardened steel is usually formed by diffusing carbon (carburizing) into the outer layer of the steel at high temperature. And putting carbon into the surface of steel makes it a high-carbon steel like S45C, which can be hardened by heat treatment.

- Surface hardness.....55~60HRC
- Depth of surface hardening.....Approx. 1.0mm

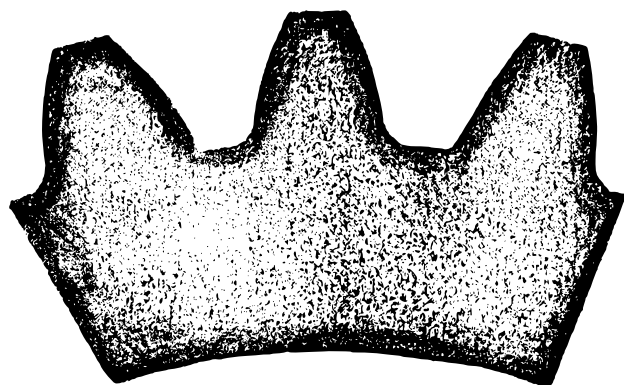
#### [Features]

Carburizing and Quenching produces a hard, wear-resistant surface over a strong tough core.

《Carburizing & quenching furnace》

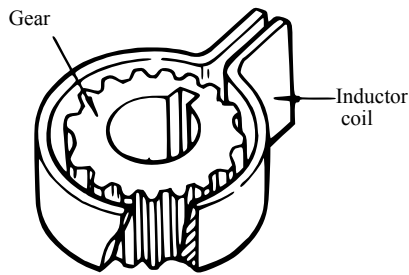


《Hardened layers》

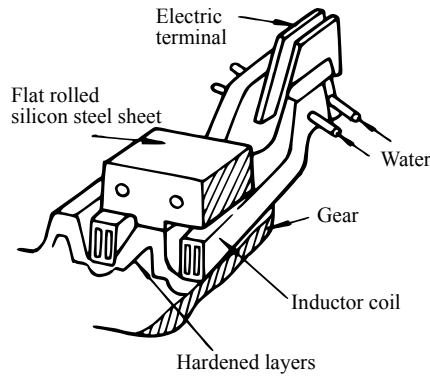


## High-Frequency Induction Hardening

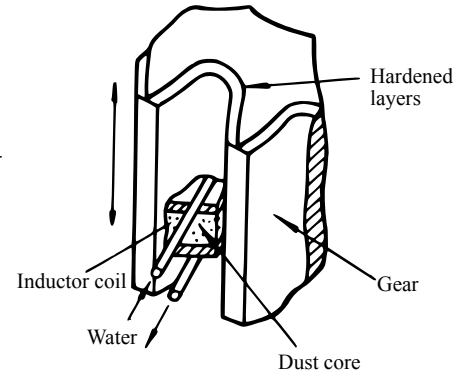
The suitable material - S45C, SCM440 etc.



( a ) One-shot entire perimeter hardening



( b ) One-shot single tooth hardening



( c ) Continuous hardening

Thermal refining → Hardening → Tempering

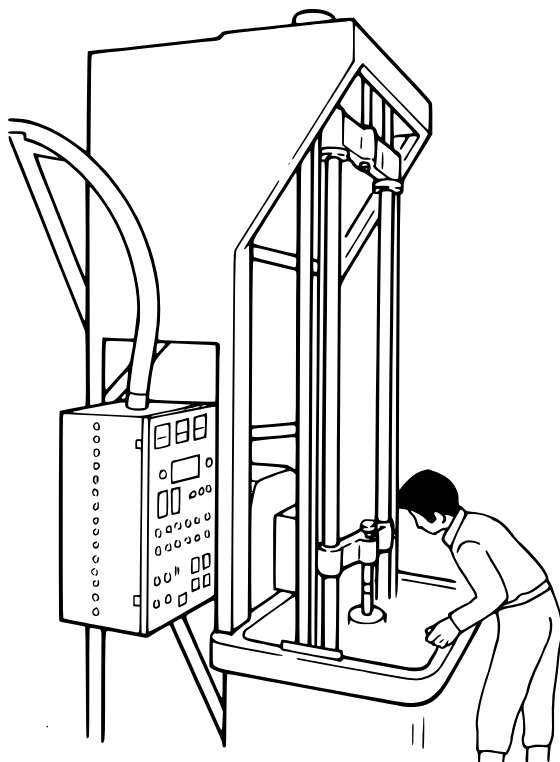
### [Features]

When heated with the inductor coil, the steel is hardened. But hardened area is limited to the surrounding area of the coil.

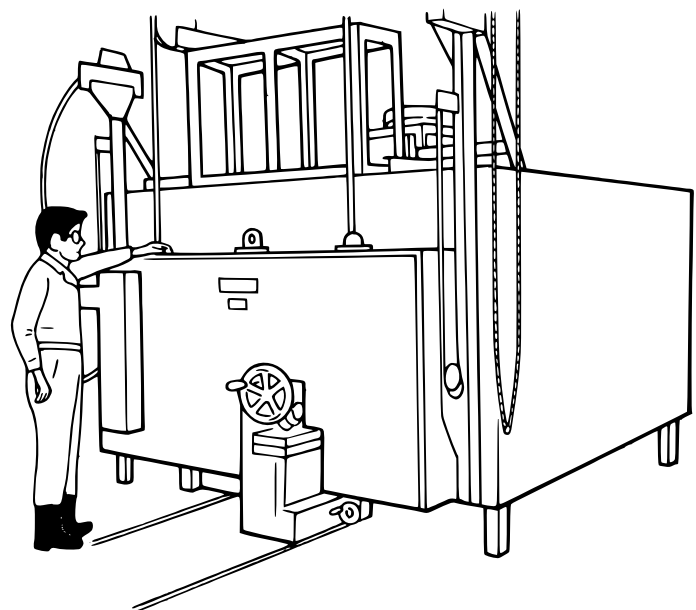
Sulphur (S) and phosphorus (P) may cause hardening cracks. Carbon (C) content is preferable less than 0.55%.

Various types of inductor coil are used depending on the shape of the gear. Some experience is required to do this work as cracking and/or deformation are apt to happen.

### 《Hardening apparatus》



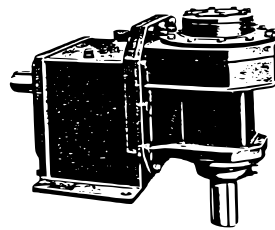
### 《Tempering furnace》



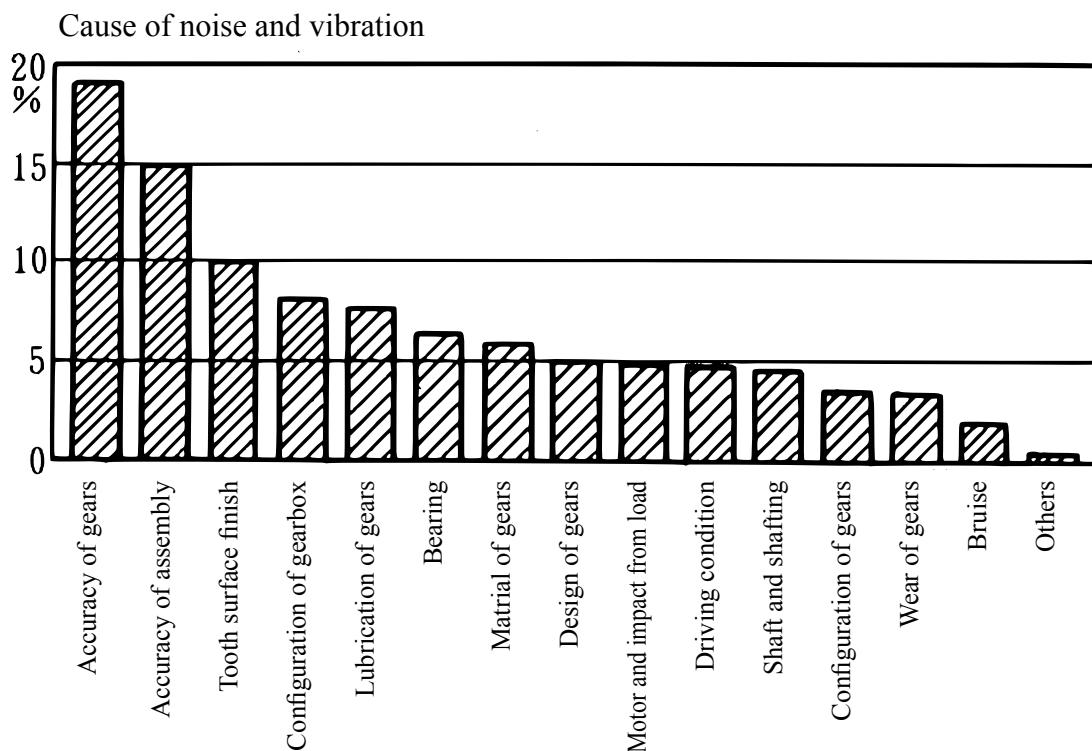
# ( 1 ) - 9

## Gear Noise

Krrrrrrrr Krrrrrrrr



This figure indicates the result of survey conducted by a manufacturer that produces gears for automobile, machine tools and speed reducers.



### Factors contributing to gear noise (%)

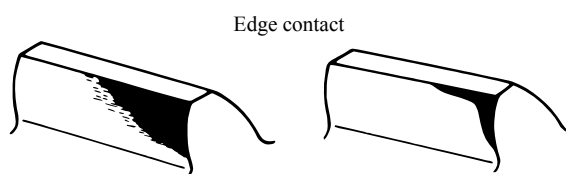
|                  |     |
|------------------|-----|
| Design.....      | 35% |
| Fabrication..... | 30% |
| Usage.....       | 20% |
| Assembly.....    | 15% |

### Technical problem:

- Tooth contact
- Tooth profile
- Tooth surface finish
- Pitch
- Center distance
- Heat treatment
- Shafting
- Size of gearbox
- Ball bearing, roller bearing
- Rotational speed

[In order to manufacture gears that materialize quietness of operation:]

- Reduce the pitch error.
- Reduce the tooth profile error.
- Reduce the runout error.
- Reduce the lead error.
- Modify tooth surface by crowning.
- Modify tooth surface by tip relieving.
- Improve the smoothness of tooth by chamfering.
- Eliminate the roughness on the tooth surface by grinding.
- Increase the contact ratio - bigger contact ratio lowers the noise.
- At the stage of designing, try to shape gearbox as round as possible.
- At the stage of designing, try to decide what type of shockabsorber to be set up for maximum effect.
- Use flexible coupling properly between the shafts.
- Take care to make the mounting holes of gearbox precisely so that it can be mounted correctly.
- When setting up gears into gearbox, care must be taken that gears come in contact properly to void edge contact.



This figure shows an example of data regarding noise level as a result of test on KHK stock gears.

▲ — ▲ : S45C without heat treatment.

)SS2.5-24, SS2.5-48)

△ — △ : Plastic.

(PS2.5-24, PS2.5-48)

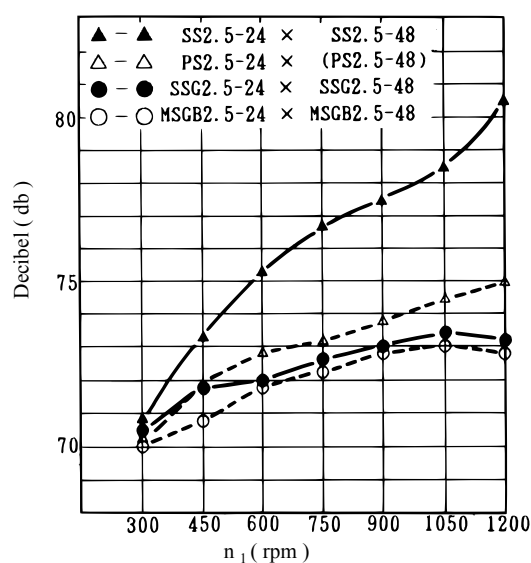
● — ● : S45C Tooth surface high-frequency induction hardened and ground.

(SSG2.5-24, SSG2.5-48)

○ — ○ : SCM415 Overall carburizing and quenching, tooth surface ground

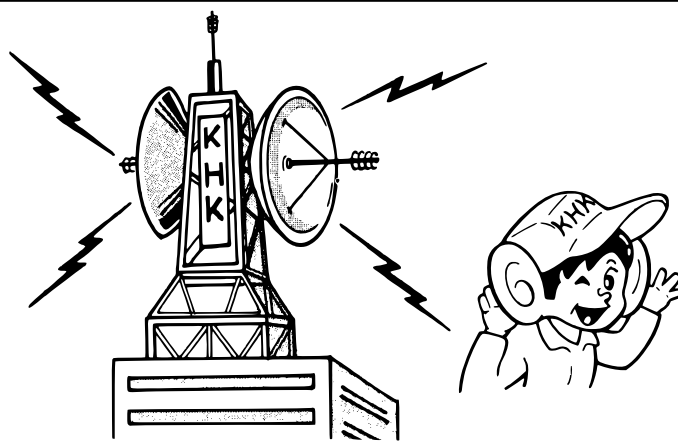
(MSGB2.5-24, MSGB2.5-48)

Noise level of KHK stock gears 1984~1985



**( 1 ) - 10**

**Q & A**



Q : Quietness of operation is very specific demand. What type of gear do you recommend ?

A : We recommend high-precision gears with better tooth-surface finish, the type tooth-surface is ground, such as MSGA(B). Helical gears are effective for reduction of noise than spur gears. Plastic gears are also quiet, though the strength decreases.

Q : What type of gear is rustproof ?

A : Stainless steel gears and plastic gears. Plastic gears can operate with continuous lubrication, initial lubrication, or no lubrication. Meshing of plastic gears with plastic gears may cause generation of heat, or dimensional changes as a result of moisture absorption. Meshing of a plastic gear with a metal gear is recommended.

Q : I want to know about "backlash". Will you please explain a little about it ?

A : "Backlash" in assembled gear set is the clearance between the teeth of the meshing gears. Some backlash should be present in all gear meshes for smoother revolution.

Q : Do you carry any products that have the ability to adjust backlash to minimum ?

A : KHK carries, as standard products, items with ability to adjust backlash such as Tapered Racks and Pinions, and Duplex Worms and Worm Wheels.

Q : Will you please explain about the effect of heat quenching ?

A : In case of gears made from S45C such as SS spur gear, the quenching will increase strength 400%. However, the precision grade such as pitch deviation will drop about one grade.

# **Part 2**

## **Production Processes**

- 1. Spur Gears**
- 2. Racks**
- 3. Bevel Gears**
- 4. Production Facilities**

## ( 2 ) - 1

# Spur Gears

Illustrated here is a typical process of making SS type spur gears.

Raw Materials



Raw materials bought from material makers are kept in stock. The materials are six meters in length.

Sawing



The materials are cut to size.

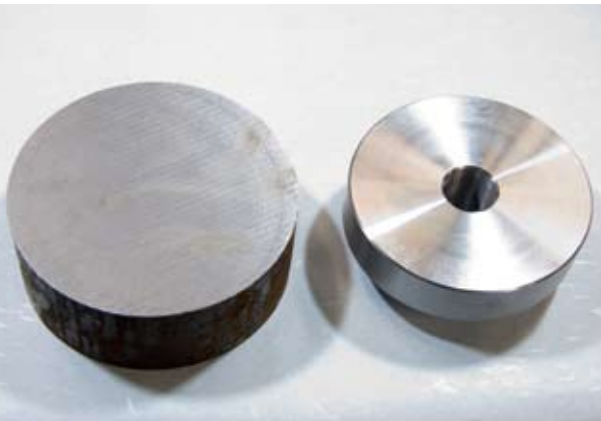
Packaging



To ensure delivery in good condition each and every spur gear is individually packaged.



Shaping



With a lathe, a cut workpiece is shaped into gear blank.



Tooth-Cutting



Tooth-cutting has been done with a gear hobbing machine. The cutting usually leaves burrs on the teeth.



Black Oxide Finish



The black oxide finish is somewhat effective in preventing rust.



Deburring



Rough spots on the teeth have been smoothed with a deburring machine.

## ( 2 ) - 2

# Racks

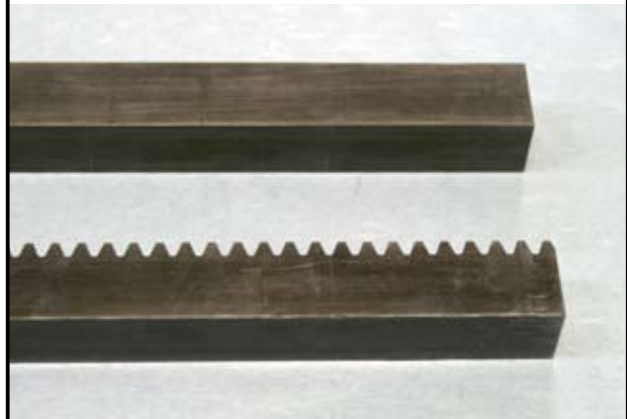
Illustrated here is a typical process of making SRFD type racks.

Raw Materials



Raw Materials bought from material makers are kept in stock.

Tooth-Cutting



Tooth-cutting has been done with a rack cutting machine. The cutting usually leaves burrs on the teeth.

Packaging



To ensure delivery in good condition each and every rack is individually packaged.

Black Oxide Finish



The black oxide finish is somewhat effective in preventing rust.



Deburring



Rough spots on the teeth have been smoothed with a deburring machine.



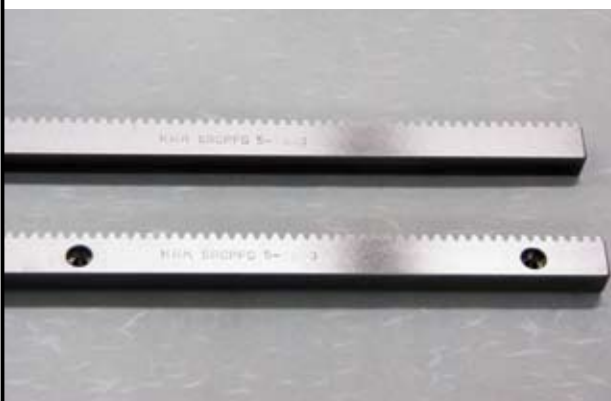
Straightening



To straighten warping, pressure is applied on racks with a hydraulic press



Processing holes



Mounting screw holes have been drilled for easier assembly.



Machining Ends



Both ends have been machined so that racks can be butted against each other to make any desired length.

( 2 ) - 3

## Bevel Gears

Shown here is a typical process of making SM type bevel gears.

Raw aterials



Raw materials bought from material makers are kept in stock. The materials are six meters in length.

Sawing



The materials are cut to size.

Packaging



To ensure delivery in good condition each and every bevel gear is individually packaged.



Shaping



With a lathe, a cut workpiece is shaped into gear blank.



Tooth-Cutting



Tooth-cutting has been done with a Coniflex generator. The cutting usually leaves burrs on the teeth.



Black Oxide Finish



The black oxide finish is somewhat effective in preventing rust.



Deburring



Rough spots on the teeth are being smoothed with a deburring machine.

## ( 2 ) - 4

# Production Facilities

Shown here is an example of machines and equipment used in gear making.



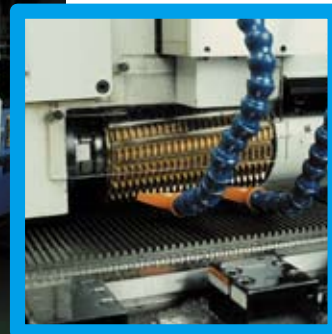
CNC Rack Grinding Machine (NRG-100)



CNC Dry Cut Gear Hobbing Machine (N60)

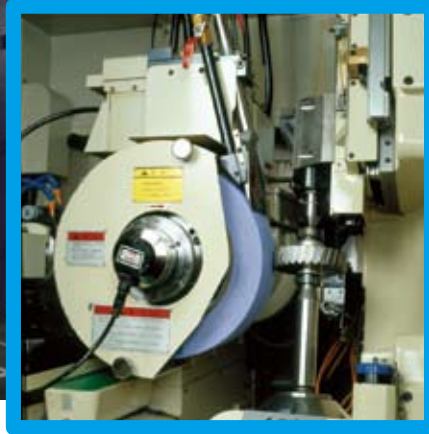


CNC Rack Cutting Machine (NR-18S)





CNC Gear Grinding Machine (TAG400)



CNC Dry Cut Hobbing Machine (GP130)



CNC Hypoid Grinding Machine (PH-200G)







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