# Introduction to Gears

First Edition

KOHARA GEAR INDUSTRY CO., LTD

## Preface

The history of gears is probably as old as civilization itself. Still today, the importance of gears in the manufacturing industry is undiminished and even continues to grow.

The purpose of this handbook is to provide an outline of gear fundamentals for those who want to acquire knowledge about the 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 handbook will act as a starting point for you in understanding gears.

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# Part 1

## About Gears

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7. Gear Accuracy - Testing and Inspecting
8. Metallic Materials and Heat Treatment
9. Gear Noise
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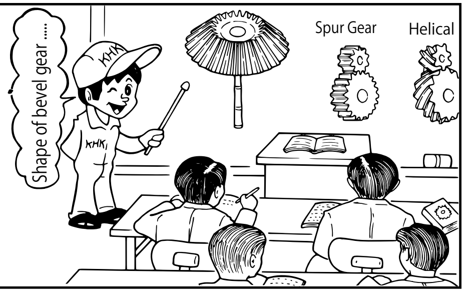
# (1) —1
# Types of Gears

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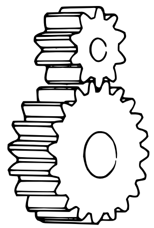
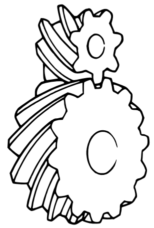
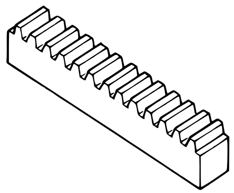
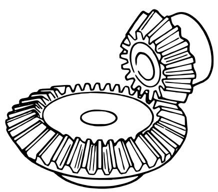
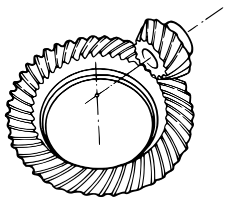
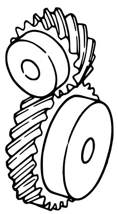
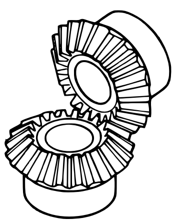
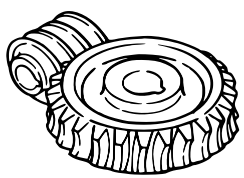
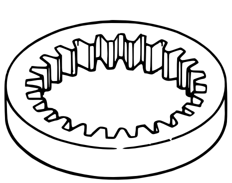
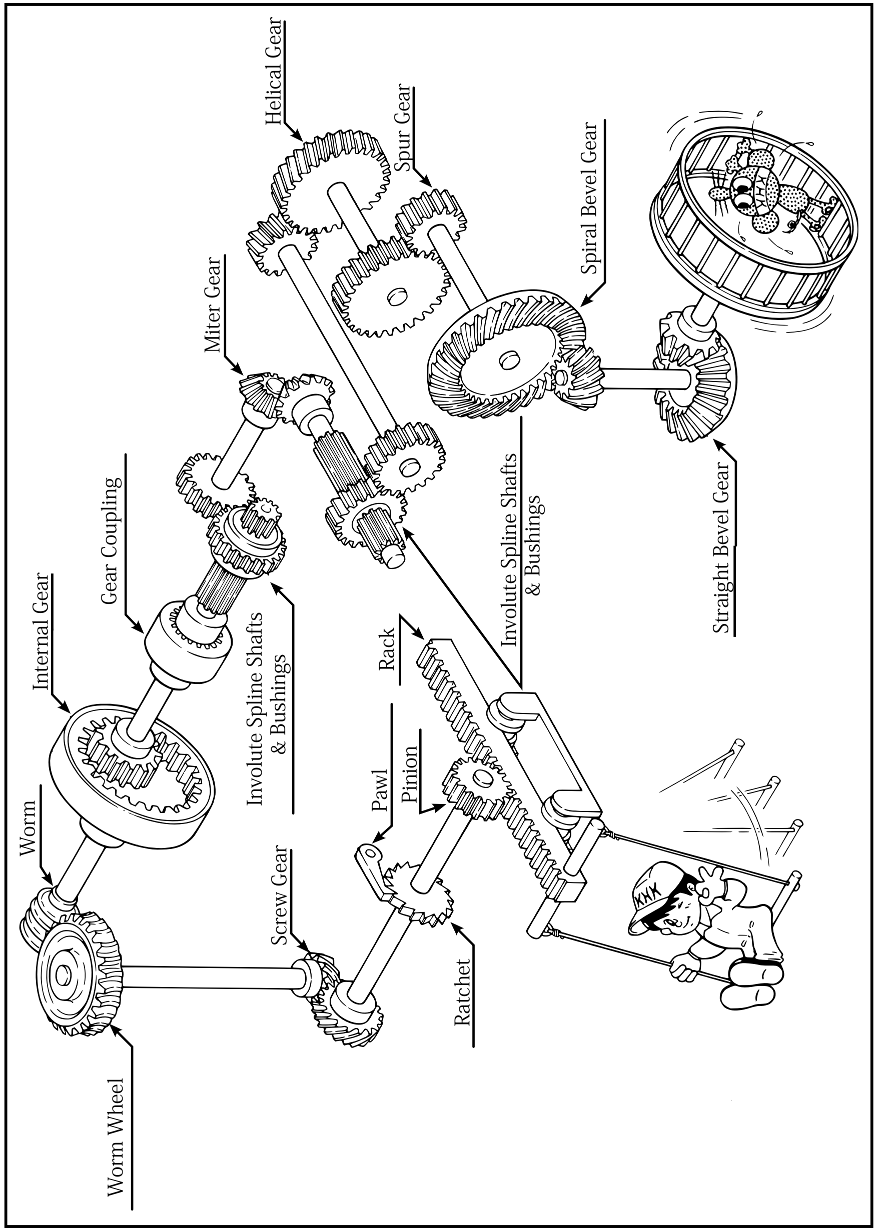
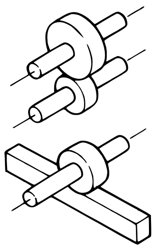
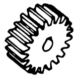
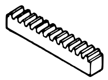
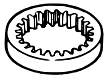
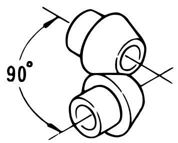
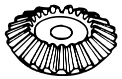
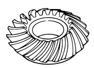
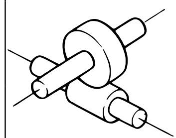
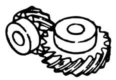
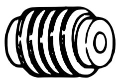
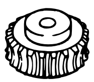
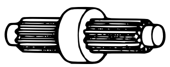
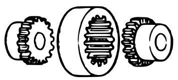
| Spur Gear  | Helical Gear  | Rack  |
| Bevel Gear  | Spiral Bevel Gear  | Screw Gear  |
| Miter Gear  | Worm & Worm Wheel  | Internal Gear  |



(1) About Gears



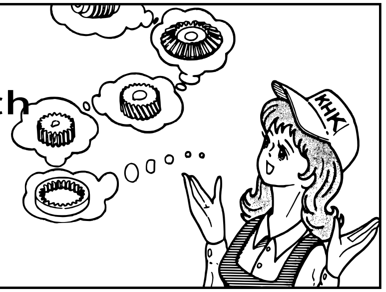
There are three major categories of gears in accordance with the orientation of their axes.

| Configuration | Type of Gear | Shape | KHK Catalog Number Series |
|---|---|---|---|
| 1）Parallel Axes  | Spur Gear |  | MSGA(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),SRCP(F)(D),KRCPF, SURCPF(D),SRCP,FRCP |
| | Internal Gear |  | SI,SIR |
| 2）Intersecting Axes  | 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 |
| 3）Nonparallel, Nonintersecting Axes  | Screw Gear |  | AN,SN,PN,SUN |
| | Worm |  | KWGDL(S),KWG,SWG,SW,SUW |
| | Worm Wheel |  | AGDL,AGF,AG,PG,CG,BG |
| 4）Others | Involute Spline Shaft & Bushing |  | SV,SVI |
| | Gear Coupling |  | GC,GC-I |
| | Pawl & Ratchet |  | SRT,SRT-C |

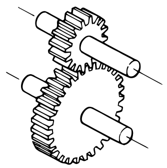




# (1)—2 Characteristics of Each Type of Gear




## Spur Gear



The teeth are straight and parallel to the shaft axis. Transmits power and motion between rotating two parallel shafts.

〔Features〕

（1）Easy to manufacture.

（2）There are no axial force.

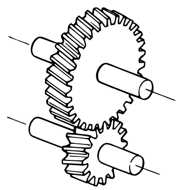
（3）Relatively easy to produce high-quality gears.

（4）The most common type of gear.

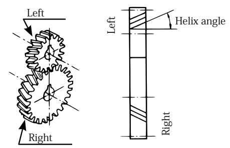
〔Applications〕

Transmission components

## Helical Gear



The 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 must have the same helix angle.

〔Features〕

（1）Has higher strength compared with a spur gear.

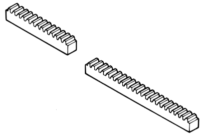
（2）More effective in reducing noise and vibration when compared with a spur gear.

（3）Gears in mesh produce thrust forces in the axial direction.

〔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 a gear of infinite diameter.

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

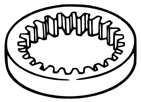
〔Features〕

（１）Changes a rotary motion into a rectilinear motion and vice versa.

〔Applications〕

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

## Internal Gear



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

The internal gear always meshes with an external gear.

〔Features〕

(1) When meshing two external gears, the rotation occurs in the opposite directions.
When meshing an internal gear with an external gear the rotation occurs in the same direction.

（２）Care should be taken with regard to the number of teeth on each gear when meshing a large (internal) gear with a small (external) gear, since three types of interference can occur.

（３）Usually internal gears are driven by small external gears.

（４）Allows for a compact design of the machine.

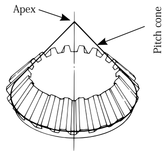
〔Applications〕

Planetary gear drive of high reduction ratios, clutches, etc.





## Bevel Gear



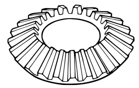

One of a pair of gears used to connect two shafts whose axes intersect, and the pitch surfaces are cones.

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

１）Straight bevel gear, or

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 intersetion of the shaft axes.

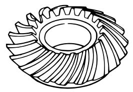
〔Features〕

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

〔Applications〕

Machine tools, printing presses, etc. Especially suitable for use as a differential gear unit.

### ２）Spiral Bevel Gear



Bevel gear with curved, oblique teeth to provide gradual engagement and larger contact surface 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.

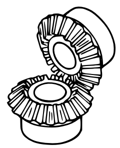
（３）Has better efficiency of transmission with reduced gear noise.

（４）Involves some technical difficulties in manufacturing.

〔Applications〕

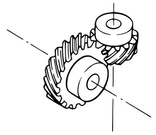
Automobiles, tractors, vehicles, final reduction gearing for ships. Especially suitable for high-speed, heavy load drives.

## Miter Gears



A special class of bevel gear where the shafts intersect at 90° and the gear ratio is 1:1. It is used to change the direction of shaft rotation without change in speed.

## Screw Gear



A helical gear that transmits power from one shaft to another, nonparallel, nonintersecting shaft.

〔Features〕

（1） Can be used as a speed reducer or as a speed increaser.

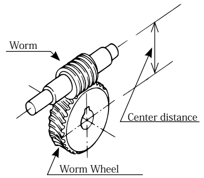
（2） Due to sliding contact, has higher friction.

（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 and is the driver of a worm wheel.

Worm wheel is a gear with teeth cut on an angle to be driven by a worm. The worm gear pair is used to transmit motion between two shafts which are at 90° to each other and lie on a plane.

〔Features〕

（1）Provides large reduction ratios for a given center distance.

（2） Quiet and smooth meshing action.

（3） It is not possible for a worm wheel to drive a worm unless certain conditions are met.

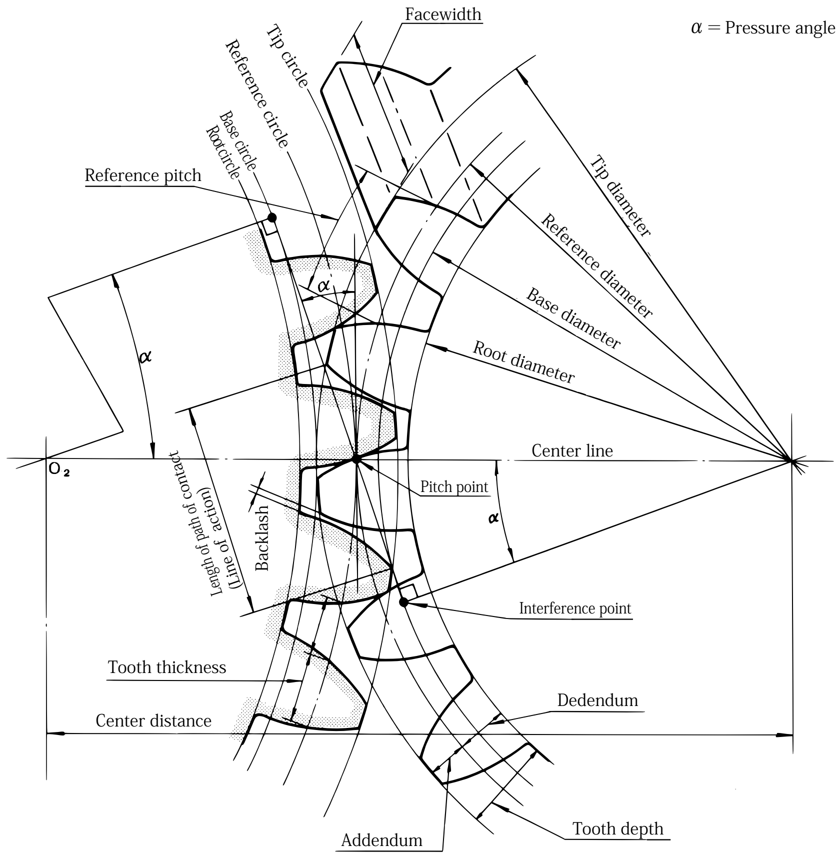
〔Applications〕

Speed reducers, antireversing gear devices making the most of its self-locking features, machine tools, indexing devices, chain blocks, portable generators, etc.

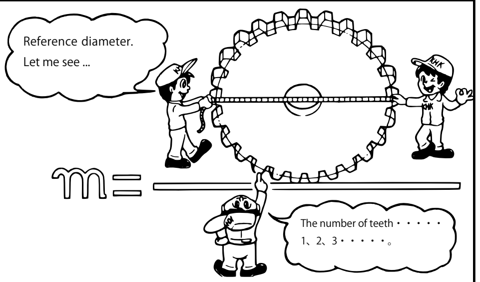




# (1)―3 Gear Terminology



# The Module of a Gear




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

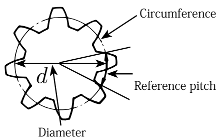
Thus: $m = \frac{d}{z}$ (Module = $\frac{\text{Reference diameter}}{\text{Number of teeth}}$ )

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

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

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

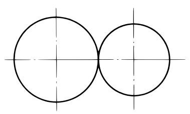
Reference pitch $p = \pi m$ ( Reference pitch = $\pi$ × Module )



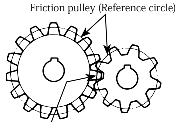

Then, what is the reference pitch?

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

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



Friction pulley (Reference circle)



Both reference circles come in contact

Then, what is the reference circle?

Assume that there are two friction pulleys in contact whose diameters are equal to the reference diameters. 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

Number of teeth × Module = 

$z_1 \cdots\cdots \square \times \square = \square$

$z_2 \cdots\cdots \square \times \square = \square$

### (b) Tip diameter

Reference diameter + 2 x the module =

$z_1 \cdots\cdots \square + \boxed{2} \times \square = \square$

$z_2 \cdots\cdots \square + \boxed{2} \times \square = \square$

### (c) Center distance

Add reference diameters then divide by two $\cdots\cdots \frac{\square + \square}{\square} = \square$

Helical Gear

Module $m = 3$ Pinion $z_1 = 15$ Gear $z_2 = 55$ Helix angle $\beta = 16°15'$

※ then $\cos\beta = 0.96$

### (a) Reference diameter

$z_1 \cdots\cdots \frac{\square \times \square}{\square} = \square$

$z_2 \cdots\cdots \frac{\square \times \square}{\square} = \square$

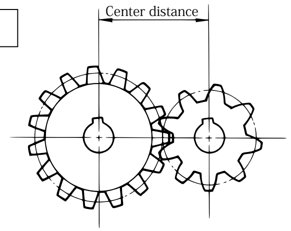
### (b) Tip diameter

$z_1 \cdots\cdots \square + \boxed{2} \times \square = \square$

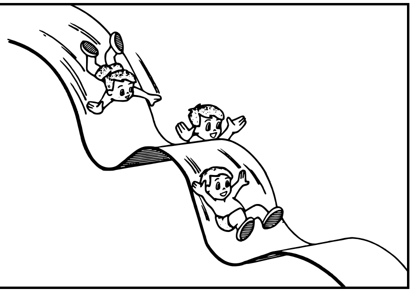
$z_2 \cdots\cdots \square + \boxed{2} \times \square = \square$

### (c) Center distance

$\cdots\cdots \frac{\square + \square}{\square} = \square$



# (1)—4 Involute Tooth Profile

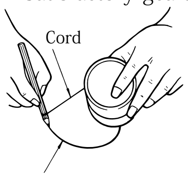


Imagine pulleys with simple indentations on their periphery equally spaced by pitch. These pulleys, when moved, would:

- slip at the contact point
- not rotate smoothly,
- produce vibration and noise.

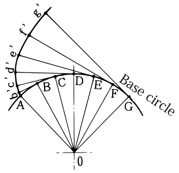
They are improperly suited for use as gears.

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



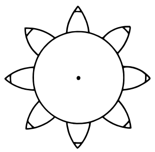

<u>The involute curve:</u>

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 an eight-toothed gear;

First, divide a cylinder into eight equal parts. Then, from each part unwrap a cord drawing a line with a 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.

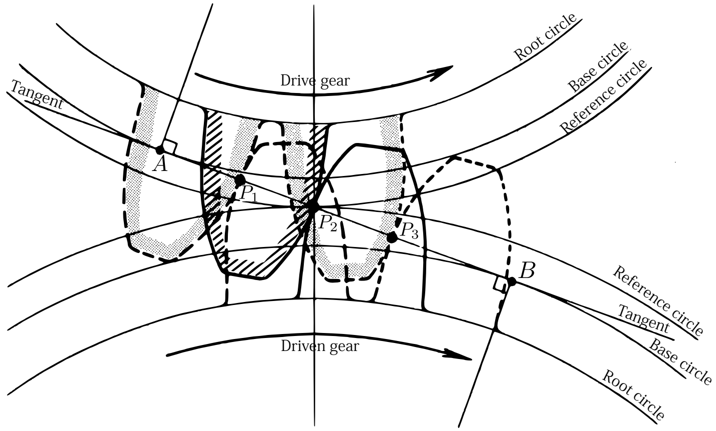






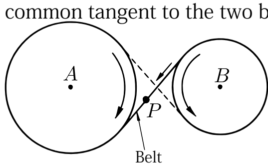
Involute Gear

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




$P_1$ → $P_2$ → $P_3$ rotational sequence of the gears

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 $P_1 \to P_2 \to P_3$. You can see that the contact point rolls along the involute curves of the gears. Moreover, the points P1, P2 and P3 lie on the common tangent to the two base circles.




It is similar to the point, *P*, on a criss-crossed belt as the disks rotate. In effect, the involute shape of the gear teeth allows the contact point to move smoothly, transmitting the motion. Therefore, the involute curve is the ideal shape for gear teeth.

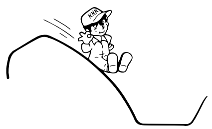
〔Features〕

（1）Conjugate action is relatively independent of small errors in center distance.

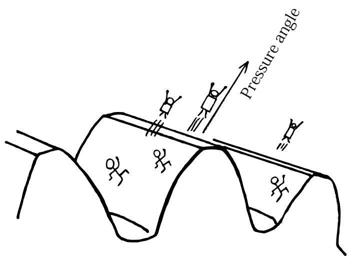
（2）Can be manufactured at low cost since the tooth profile is relatively simple.

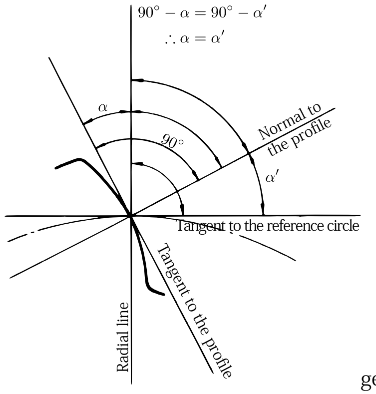
（3） Its root thickness makes it strong.

（4）A typical tooth profile used almost exclusively for gears.



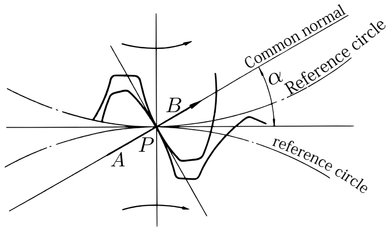
# (1)—5 Pressure Angle




The pressure angle exists between the tooth profile and a radial line to its pitch point. In involute teeth, it is defined as the angle formed by the radial line and the line tangent to the profile at the pitch point. Here $\alpha = \alpha'$. Therefore, $\alpha'$ is also 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 along the common normal of the gear $A$ and the gear $B$. The pressure angle $\alpha$ can be described as the angle between the common normal and the line tangent to the reference circle.

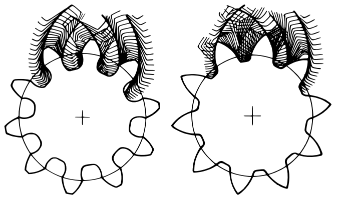
〔For reference〕

The most common pressure angle is $20°$. Formerly, a pressure angle of $14.5°$ 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, removing some of the profile, and producing 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.

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

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

The calculations to be made are:

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

$$\mathrm{inv}\ \alpha' = 2\tan\alpha\left(\frac{x_1+x_2}{z_1+z_2}\right) + \mathrm{inv}\ \alpha$$
$$= 2 \times 0.36397\left(\frac{0.5}{10+60}\right) + 0.014904$$
$$= 0.020104$$
$$\alpha' = 22°01'03''$$

(Ⅱ) Find center distance modification coefficient, $y$

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

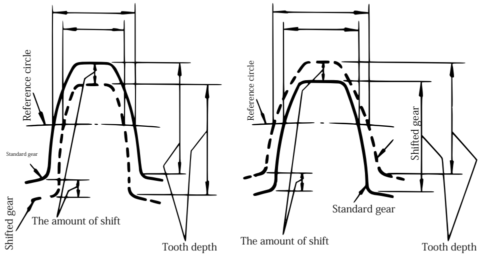
(Ⅲ) Determine center distance $a$

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

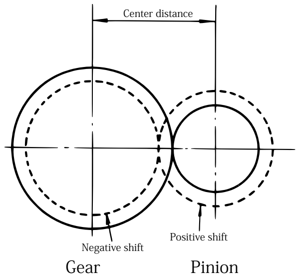
(Ⅳ) Find tip diameter $d_a$

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

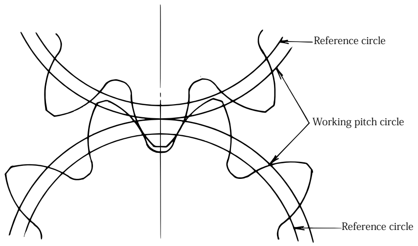
Negative shifting (Tooth thickness is thinner)　　Positive Shifting (Tooth thickness is thicker)




There is 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. The tooth depth will not change.




This figure shows a gear that is negative shifted and a pinion that is 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 and the pinion tooth has undercut, profile shifting will solve the problem as illustrated here.




The meshing of standard spur gears means reference circles of two gears contact and roll with each other. The same of the profile shifted spur gears 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 standard pressure angle. In designing profile shifted gears 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

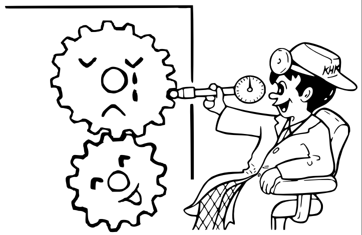
(3) For large gear ratio pairs, the pinion will wear out much faster than the gear. It is possible to equalize the strengths of a pinion and a gear by profile shifting; Make correction (shifting) of the pinion positive. Then make correction of the gear negative. This results in thicker tooth thickness of the pinion and the thinner tooth thickness of the gear, or equalization of the wear life.





# (1) —7

# Gear Accuracy - Testing and Inspecting

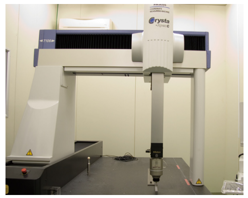


At KHK, the following measuring instruments are used to test and inspect the gear accuracy.

（1）Gear measuring machine......To measure the accuracy of tooth profile, tooth trace (flank line), 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 equipment used while working on 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.

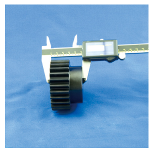
(3) Hardness testing machine ................................ To measure hardness

(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

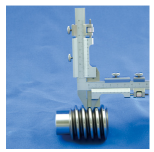
(7) Bevel gear tester................................................... To measure tooth contact and backlash



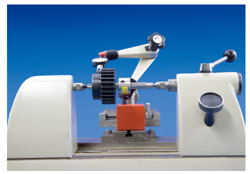
Vernier calipers

Micrometer calipers

Cylinder gauge

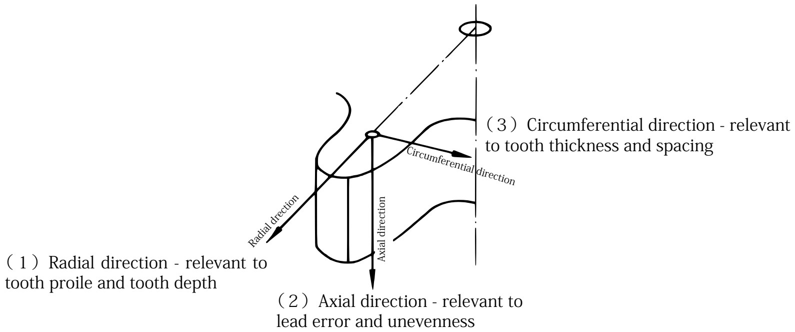


Gear tooth vernier calipers



Runout tester

《Gear Accuracy in 3-D》

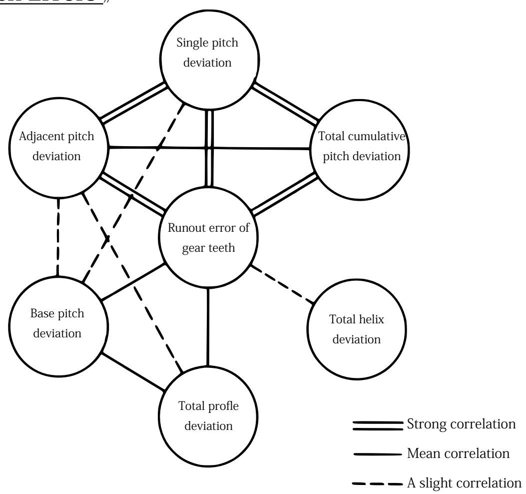



In order to test gear accuracy, three-dimensional measurements are necessary, and the following measuring instruments and/or apparatus are to be used properly.

(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, pins (rollers), and ball micrometer calipers.

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

《Correlation between Errors》

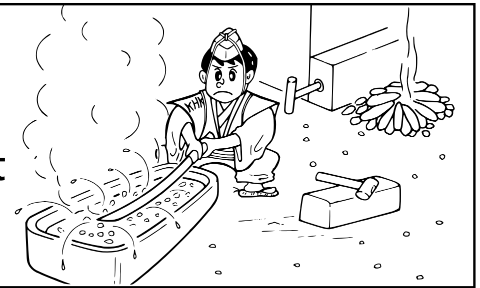



Correlation between each individual error (in case of ground gear)





# (1)—8 Metallic Materials for Gears and Heat Treatment



The materials herein described are generally used in Japan.

〈Case-hardening steel〉

The carbon content of case-hardening steel is low, usually about 0.15 to 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〉

| Description | Symbol | Chemical composition % | | | | | | Tensile test | | Hardness test | Applications |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Cu | Al | Fe | Ni | Mn | Impurities | Tensile strength N/㎟ | Elongation | HB 10/1000 | |
| Aluminium bronze casting 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, bushing, valve seat, impeller, propeller for ships, etc. (Suitable for those which require strength and rust, erosion and/or wear resistance.) |

〈Bronze casting〉

| Description | Symbol | Chemical composition % | | | | | Tensile test | | Applications |
|---|---|---|---|---|---|---|---|---|---|
| | | Cu | Sn | Zn | Pb | Impurities | Tensile strength N/㎟ | Elongation | |
| Bronze continuous casting 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.

| Descripions | 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 a process to surface-harden tooth areas to increase their strength. Cited here are two processes among others - (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

By heating low carbon steel in carbon gas atmosphere to high temperature and holding, carbon molecules are diffused into the surface making the material similar to S45C. This, in turn, allows the surface to be hardened by quenching.

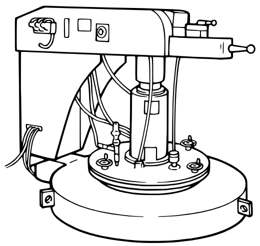
- Surface hardness………55 ～ 60HRC
- Depth of surface hardening……Approx. 1.0㎜

(Use thicker depth as the load increases)

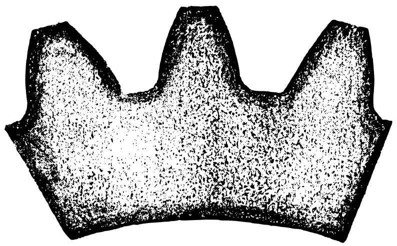
〔Features〕

Carburizing and Quenching produces a hard, wear-resistant surface with progressively softer core which retain ductility.

《Carburizing & quenching furnace》



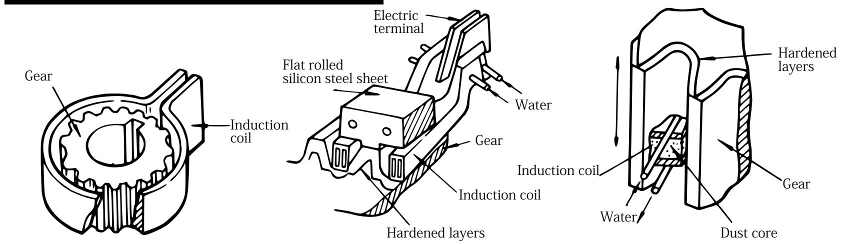
《Hardened layers》







**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

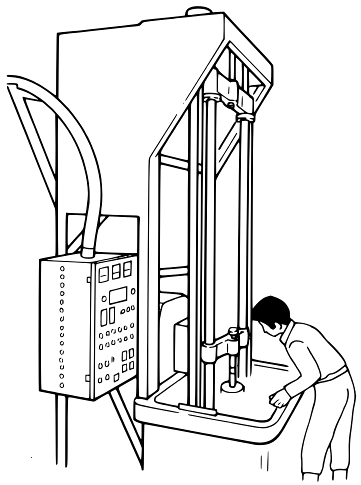
〔Features〕

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

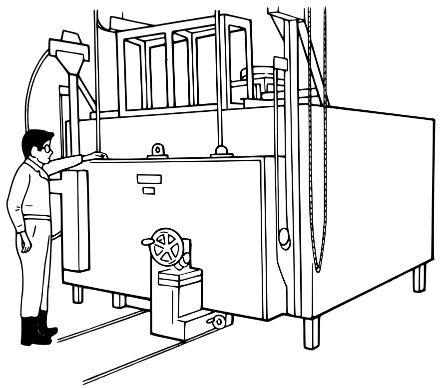
In order to reduce the chance of cracking, it is desirable to have material with low sulphur (S) and phosphorus (P) content and carbon content of less than 0.55% .

Various types of induction coils 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》

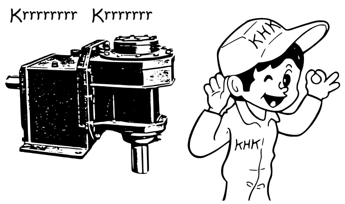


《Tempering furnace》



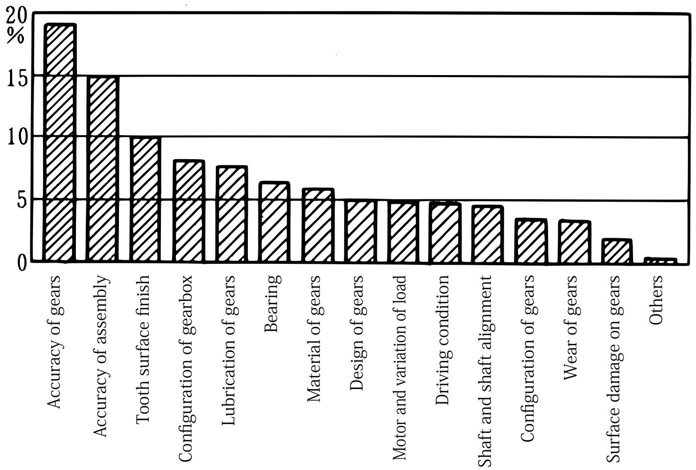
# (1)—9

# Gear Noise




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

Cause of noise and vibration




Broken down by the factors contributing to gear noise, it becomes:

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

[ Causes ] (Items assumed to have effects on noise)

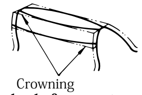
- Bad tooth contact
- Large tooth profile error
- Poor tooth surface finish
- Rotation is too fast
- Gearbox is amplifying noise
- Large pitch error
- Oscillating torque load on the gear shaft
- Center distance is too small
- Ball and roller bearings are causing noise
- Deformation of gear due to heat treating

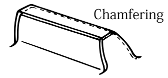




[In order to manufacture gears that minimize noise during operation, ]

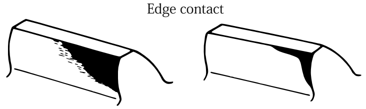
- Reduce the pitch error.
- Reduce the tooth profile error.
- Reduce the runout error.
- Reduce the lead error.
- Modify tooth surface by crowning.
- Tip relieving may correct pitch error from tooth deformation.
- Remove sharp corners of tooth by chamfering.
- Eliminate the roughness on the tooth surface.
- Increase the contact ratio - bigger contact ratio lowers the noise.
- Try to design gearboxes as close to round shape as possible.
- Use a flexible coupling between the prime mover and the gearbox.
- Machine the mounting holes of gearbox precisely so that gears can be mounted accurately.
- When assembling gears into gearbox, care must be taken that gears come in contact properly - to avoid edge contact.




To improve surface finish, gears are generally shaved or ground. Spiral bevel gears are lapped or ground.

Edge contact



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

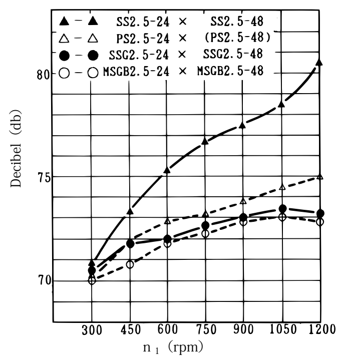
▲—▲：S45C without heat treatment. (SS2.5-24, SS2.5-48)

△—△：Plastic. (PS2.5-24, PS2.5-48)

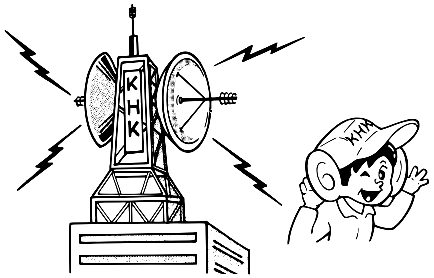
●—●：S45C Tooth surface high-frequency induction hardened and ground. (SSG2.5-24, SSG2.5-48)

○—○：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：Which type of gears are quiet?
A：The high precision gears with ground finish are quiet. The noise level can be further reduced by using helical gears which increases the contact ratio. Plastic gears are also quiet but the strength is lower.

Q：What type of gears are good against rusting?
A：Stainless steel and plastic gears are good against rusting. Plastic gears can also be used without lubrication. However, using plastic against plastic is not desirable since they tend to heat up and expand. It is better to mate a plastic gear with a metal gear.

Q：What is backlash?
A：It is the clearance space between the teeth of mating gears. It is necessary for smooth operation of the gears.

Q：Can you eliminate backlash?
A：KHK does not make products with no backlash, but do carry items that allow you to adjust the amount of backlash. These are "Tapered Racks and Pinions" and "Duplex Worms and Worm Wheels".

Q：How much can you raise the strength by quenching?
A：For gears made from S45C such as SS Spur Gears, if they are high frequency induction heat treated, the tooth surface strength increases about four-fold. On the other hand, the precision grade such as pitch error will drop one grade.



# Part 2

## Production Processes

# (2) —1
# Spur Gears

Illustrated here is a typical process of making spur gears.

## Raw Materials

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

## Sawing

The materials are cut to size.

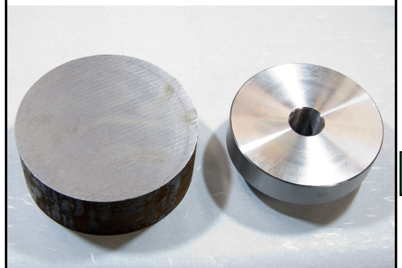
## Packaging

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



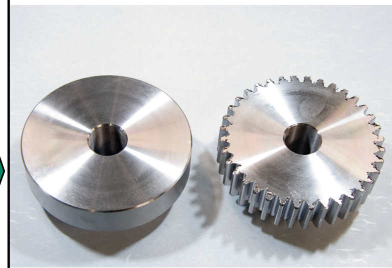


## Turning



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

## Gear Cutting

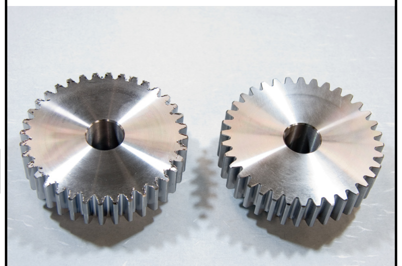


Gear cutting is done with a gear hobbing machine. The hobbing usually leaves burrs on the teeth.

## Black Oxide Finish

The black oxide finish is somewhat effective in preventing rust.

## Deburring



Burrs on the teeth have been removed with a deburring machine.

# (2) —2

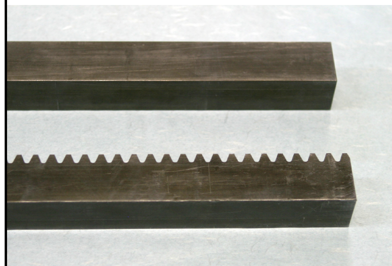
# Racks

Illustrated here is a typical process of making racks.

### Raw Materials

Raw Materials bought from material suppliers are kept in stock.

### Gear Cutting



Gear cutting is done with a rack cutting machine. The cutting usually leaves burrs on the teeth.

### Packaging

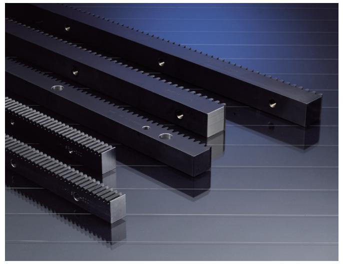
To ensure delivery in good condition, each and every rack is individually packaged.

### Black Oxide Finish

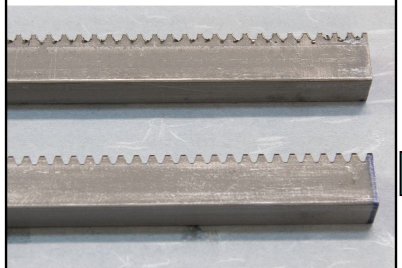
The black oxide finish is somewhat effective in preventing rust.







### Deburring

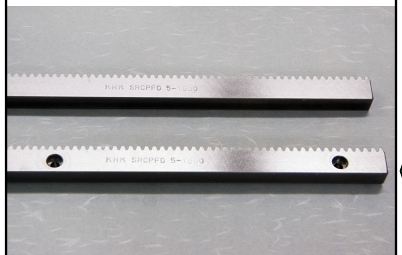


Burrs on the teeth are removed with a deburring machine.

### Straightening

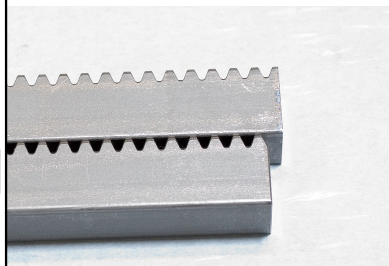
To straighten warping, pressure is applied on racks with a hydraulic press.

### Processing holes



Mounting screw holes are drilled for easier assembly.

### Machining Ends



Both ends are 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 bevel gears.

### Raw aterials

Raw materials bought from material suppliers 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.





### Turning

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

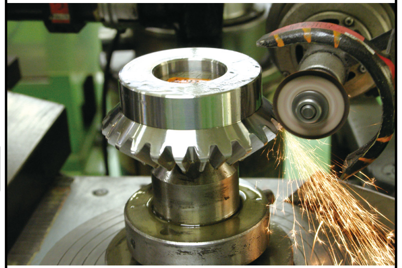
### Gear Cutting

Gear cutting is 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

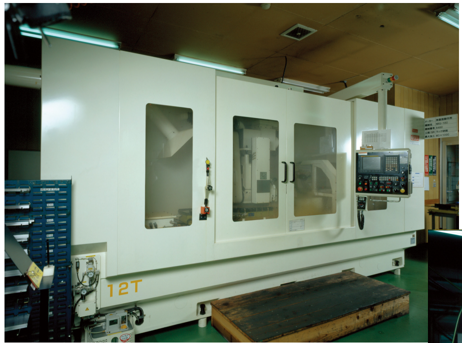


Burrs on the teeth are being removed with a deburring machine.

# (2) —4

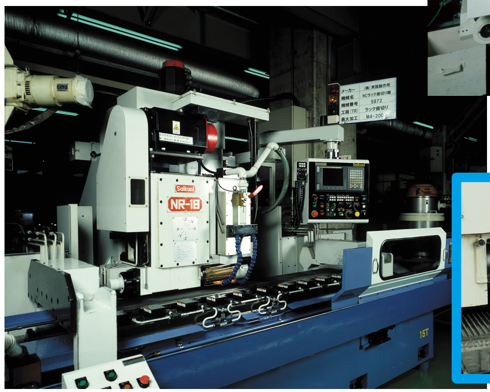
# Production Facilities

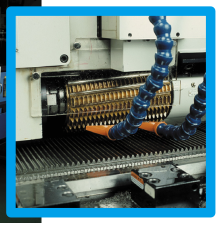
Shown here are examples of machines and equipment used in gear making.



CNC Rack Grinding Machine (NRG-100)

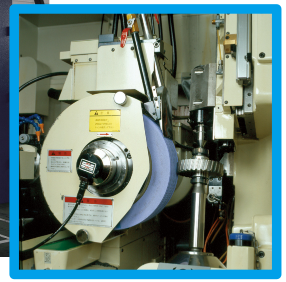
CNC Dry Cut Gear Hobbing Machine (N60)




CNC Rack Cutting Machine (NR-18S)






CNC Gear Grinding Machine (TAG400)


CNC Dry Cut Hobbing Machine (GP130)

CNC Hypoid Grinding Machine (PH-200G)

KHK®

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