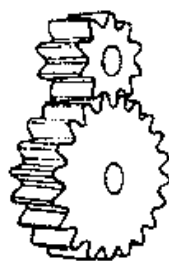


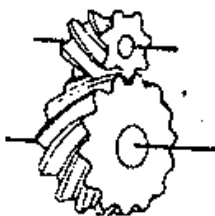
(Fault Diagnosis)

()

1. (Gear)
- 2.
- 3.
- 4.
- 5.
- 6.



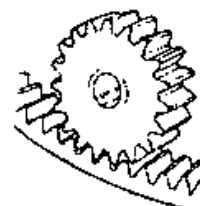
(a) 평기어



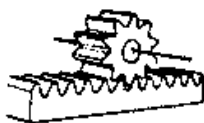
(b) 헬리컬기어



(c) 이중 헬리컬기어



(d) 안기어



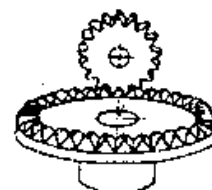
(e) 랙과 피니언



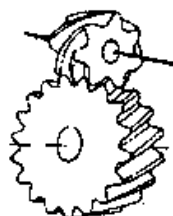
(f) 스피 베벨기어



(g) 스파이럴 베벨기어



(h) 헬리컬 베벨기어



(i) 나사가기어



(j) 원통worm기어



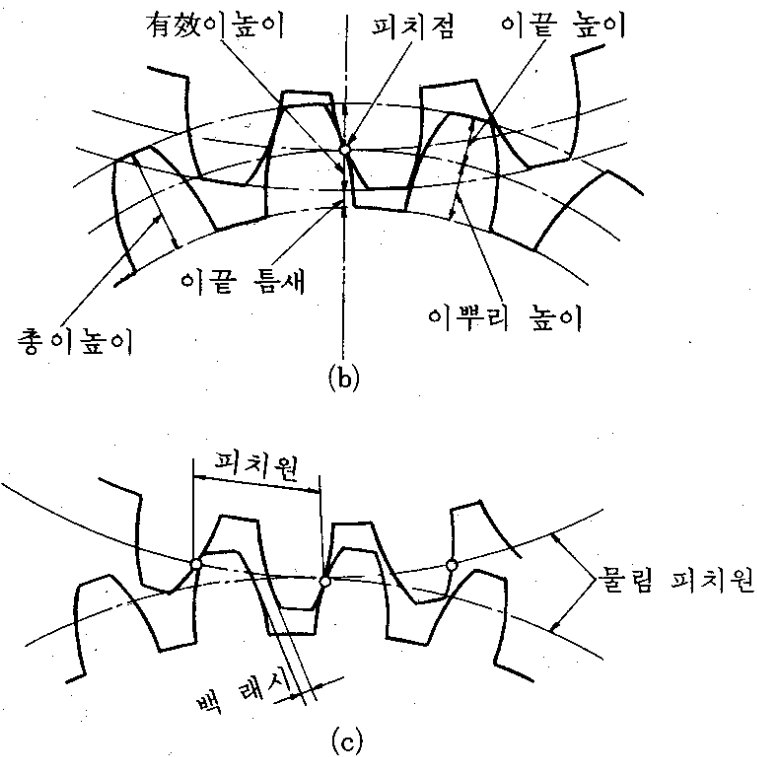
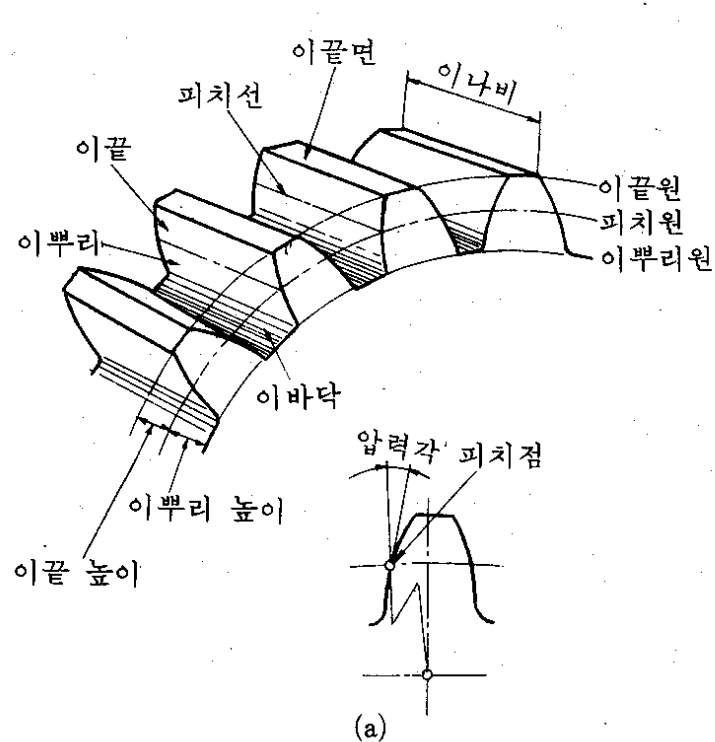
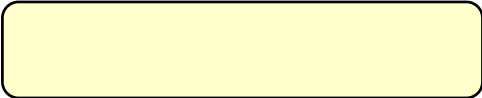
(k) 鼓形worm기어



(l) 하이포이드기어

G-1.

(, , ,)



G-2.

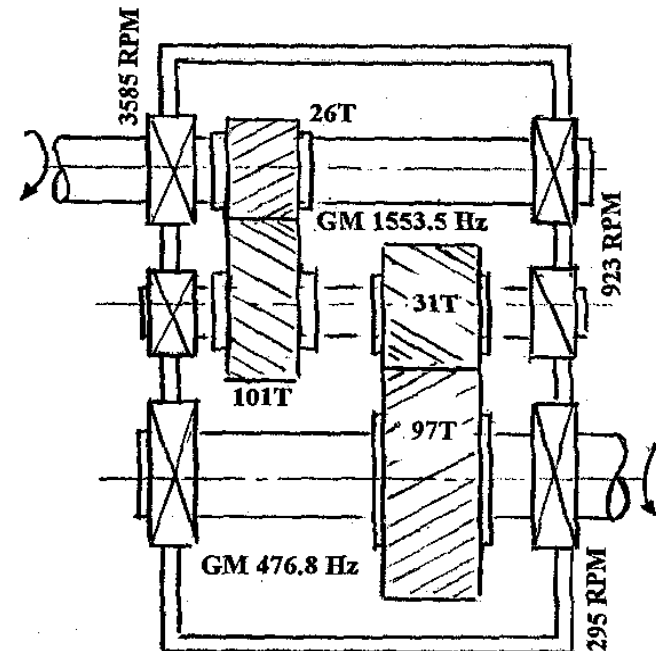
(, , ,)

(gear) :

(tooth)

Zooming

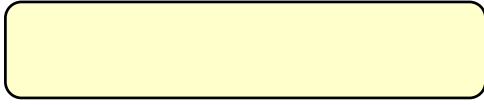
- : 3,585 RPM
- : $3,585 \times 26 / 101 = 923 \text{ RPM}$
- : $923 \times 31 / 97 = 295 \text{ RPM}$
- :
- $3,585 \times 26 = 93,210 \text{ CPM}$
- :
- $923 \times 31 = 28,613 \text{ CPM}$



G-2. 2



	(breakage)	, ,
	(tooth crush)	
	(fusion)	
	(wear)	
	(wear)	, Scratching, Fretting
	(plastic deformation)	, Rippling, Ridging,
		Pitting, Spalling
		Scoring, Burning
		(crack), , , , ,



-
- (eccentricity) (out of round)
- (bent shaft)
- (looseness) : - , - , -
- (misalignment)
- (backlash)
- ,

1. (transducer)

- (spur gear) :
- (helical), (herringbone) :
- 가 가 , 가
- , 가 :

2.

- (gear mesh frequency) 3 2 KHz
, 2KHz 가 (accelerometer)가
- 가 , , (가
- : (proximeter)
(,). / > 10 :
- 500rpm :

()

- (tooth surface) (contact marking)
- 가
- ,
- , 가
- 가
- 가 .
- 가 (misalignment) ,
- (scuffing) ,

:

(Surface Fatigue)

(case exfoliation)

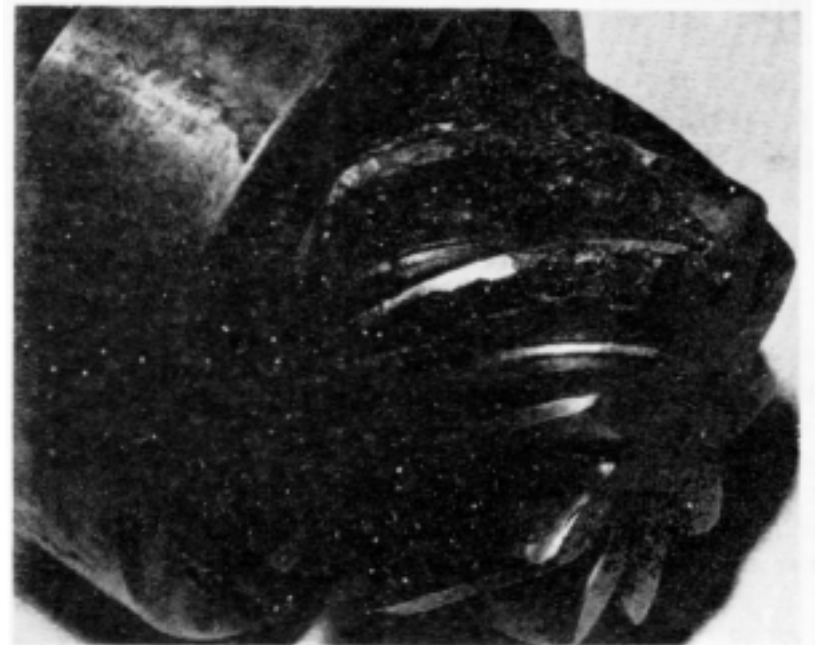
• :

M.J. Neale, Component Failures, Maintenance and Repair, Butterworth-Heinemann, 1995

•
 (carburised) (hardened),
 (nitrided) (induction
 hardened)
 • :
 (teeth) (剝落)

Hertz

가
 (core)



Case exfoliation on a spiral bevel pinion

G-1.

:

(Surface Fatigue)

(Pitting)

- - : (root) 가
 - : Hertz ,
 - : , 가 (exfoliation)

G-3.

(Ref. M.J. Neale, Component Failures, Maintenance and Repair, B&H, 1995)



PITTING ON SOME TEETH IS CONTINUOUS AND QUITE DEEP

: (Surface Fatigue)

• (dedendum attrition)

• :

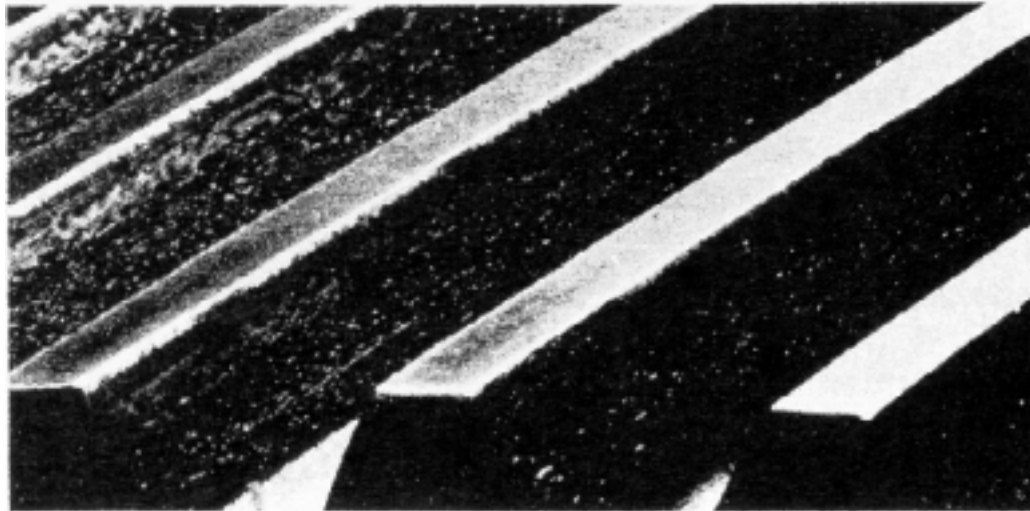
0.5mm

(addendum)

• :

• :

가 .

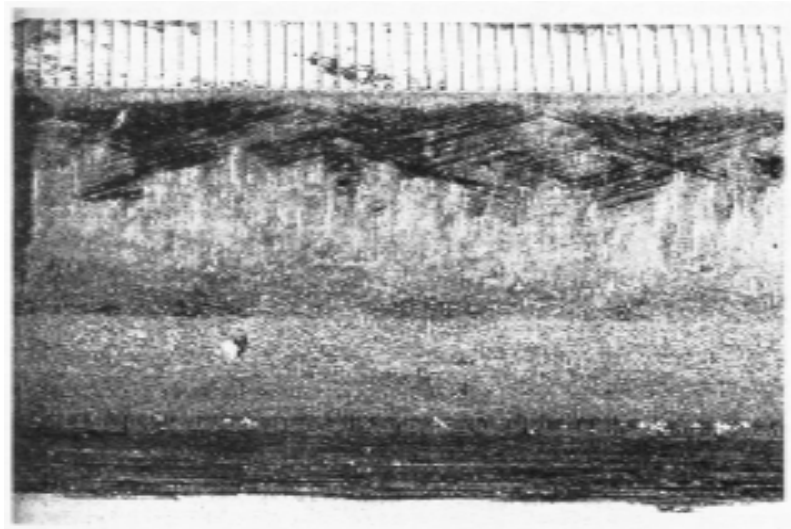


G-4.

: (Surface Fatigue)

- (Micro-pitting)
 - : , 가 . , 0.03-0.08mm, 0.01mm 가 .
 - : , .
 - : 가 (load-carrying additives) 가 .

G-5.



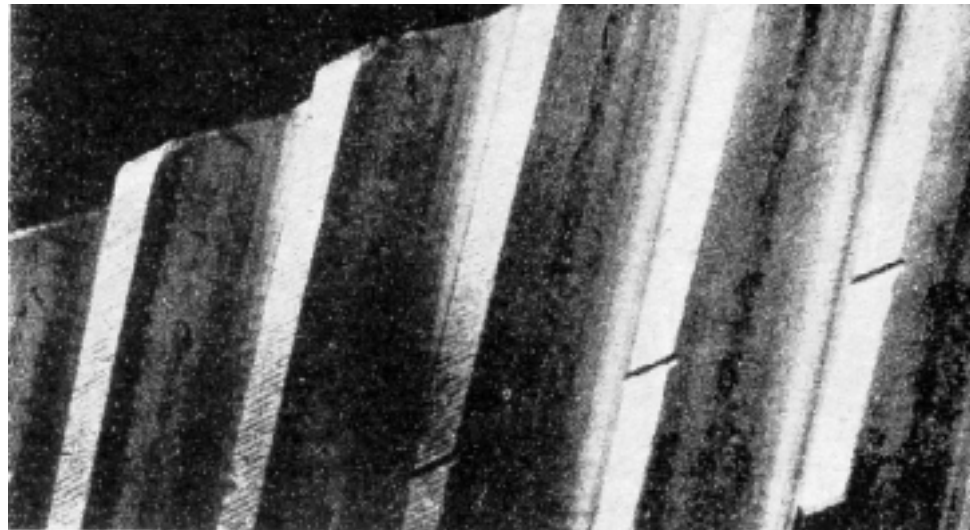
:

(Surface Fatigue)

(Initial Pitting)

- :
flank) , (tooth
(dedendum) .
2mm , .
- : (profile)
(clefts) (tooth) .
 , , .
- :

G-6.



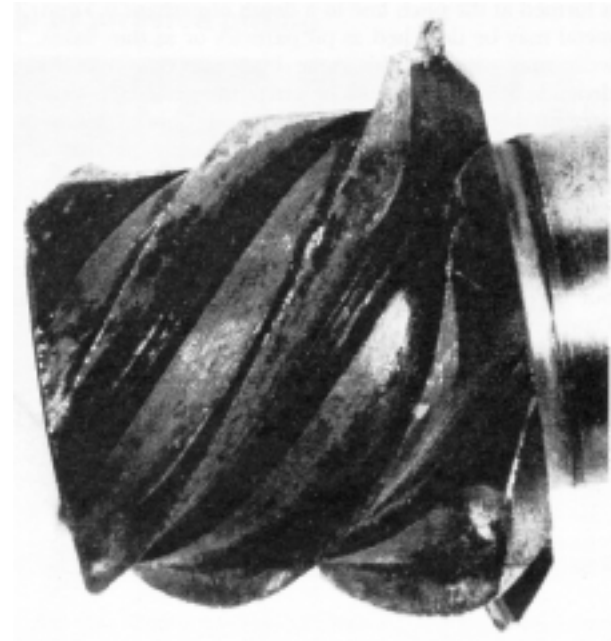
:

(Chemical Wear)

(Smooth Chemical Wear)

-
- :
가 .
- : 가 (steel)
- :
가 (load-carrying additive)

G-7.



: (Scuffing)

• 가 (Light Scuffing)

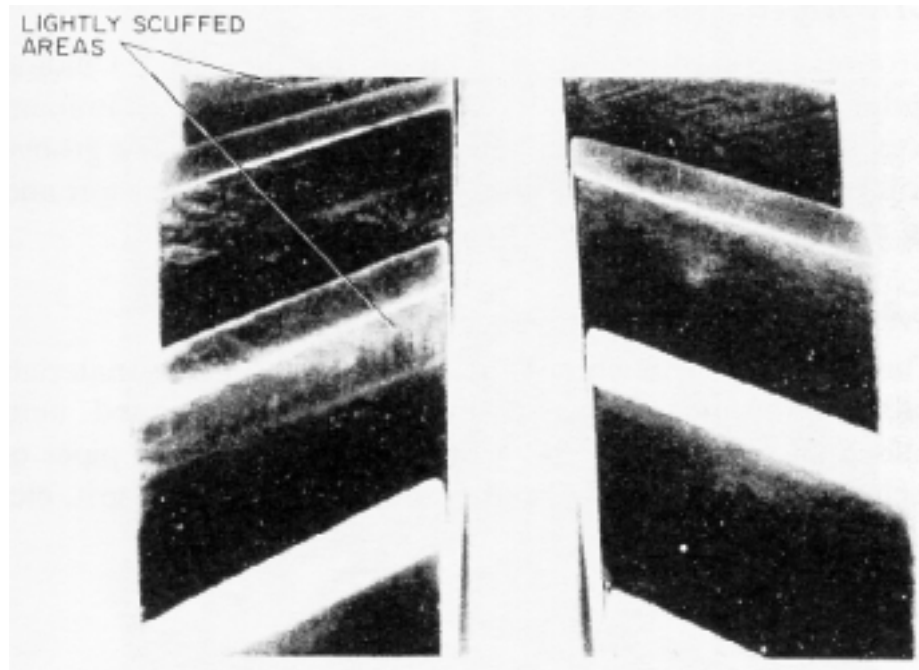
3m/s

가 (welding) (etching) (slight scuffing)
(tearing) heavy scuffing

• : 가
가

• : ,
가 가

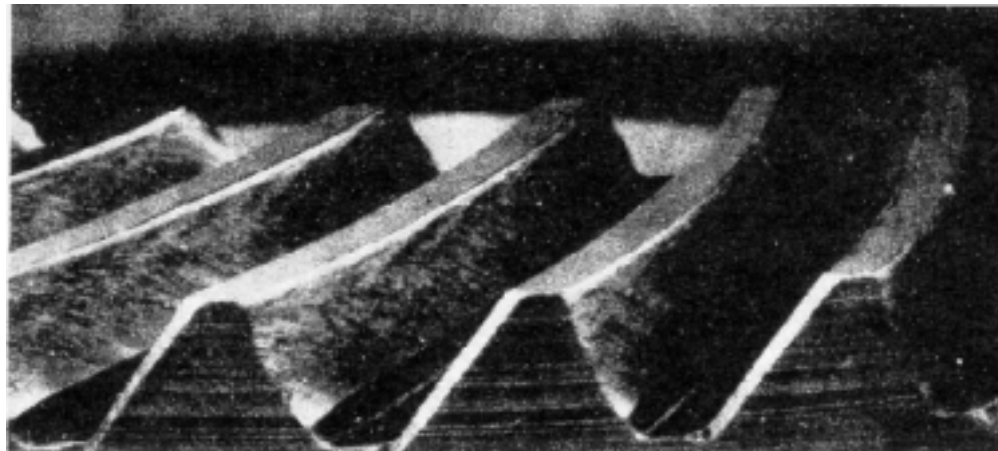
• : (extreme pressure
oil)



G-8. 가

: (Scuffing)

- **(Heavy Scuffing)**
 - : (adhesive wear)
 - : 가 (welding) 가 (tearing)
 - : 가 (ridge)
 - : 가 가



G-9.

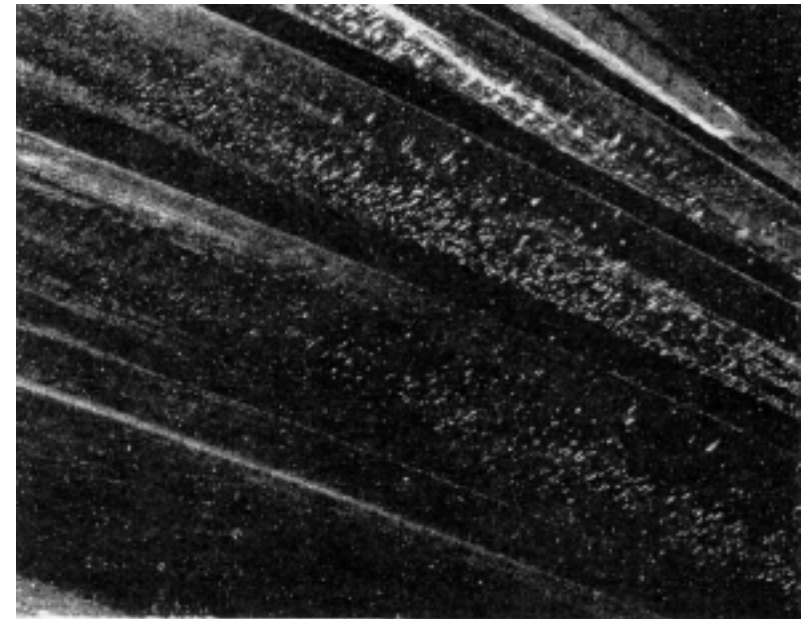
(hypoid wheel)

:

(Abrasive Wear)

- : (three-body abrasion).1
 가 , 0.5um 가 ,
 가 , 가 , two-body abrasion ,

- : (tooth
 flanks)
 (contaminant)
 (cutting)
 , (tooth tip)
 .
- : 가
 ,
 (casting
 sand), shot-blast grit

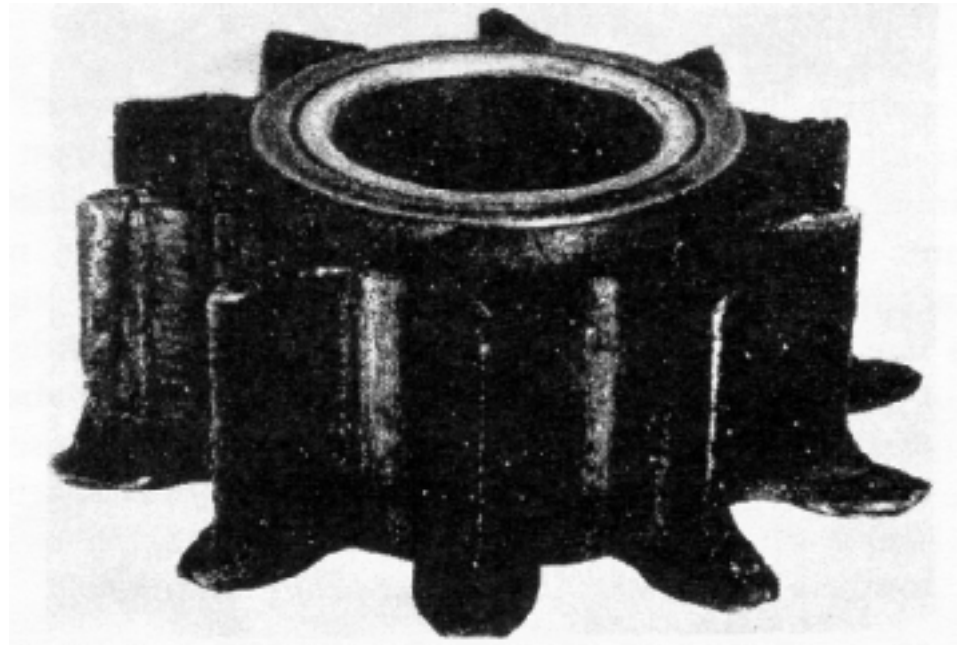


G-10.

: (Abrasive Wear)

(Attrition)

- : (lapping)
- : (mesh)
- 가 . (tooth profile)
- :
- : , (flushing).
가



G-11.
(spur gear)

: (Tooth Breakage)

•

가 가 , 가

.

•

:

(steel)

가

.

.

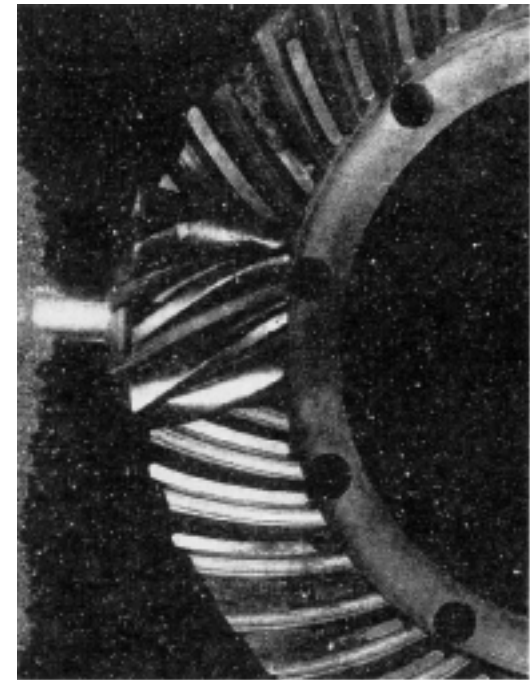
.

•

:

가

.

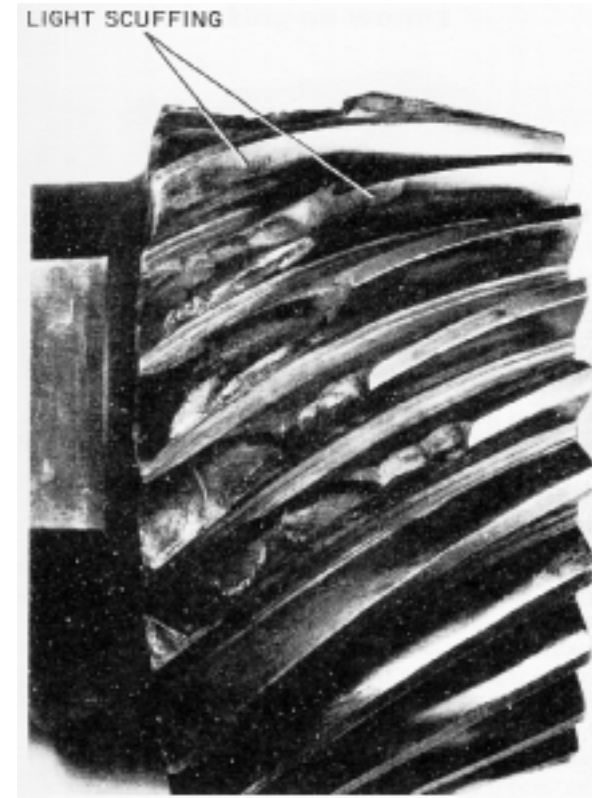


G-12.

: (Tooth Breakage)

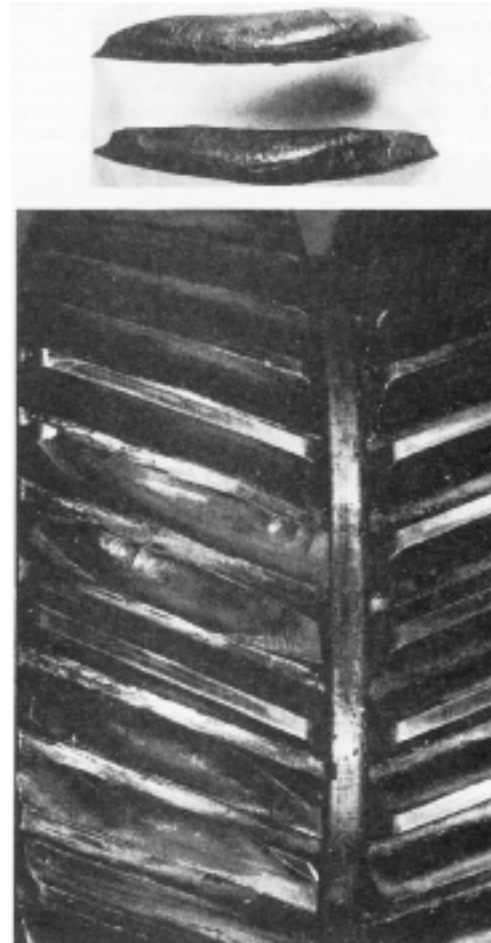
- (end) (tip)

- :
,
- :
,



G-13.

: (Tooth Breakage)



G-14.

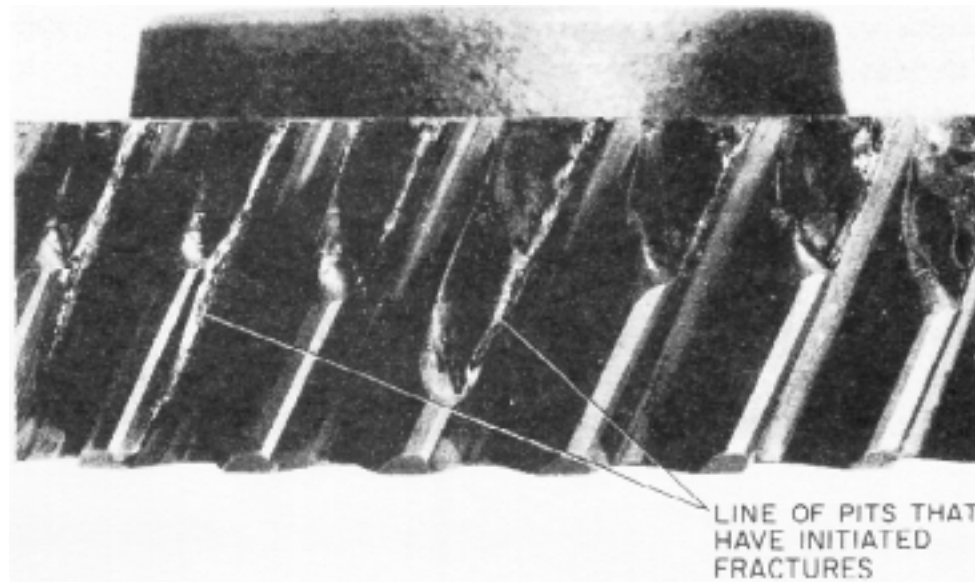
가 (blowhole),
 (bruise), deep machining ,
 (inclusion) .
 ,
 (slow fatigue)
 가 ,
 .

: (Tooth Breakage)

- (pitting)

- :
(dedendum) (pits) ,

- :
가 .



G-15.

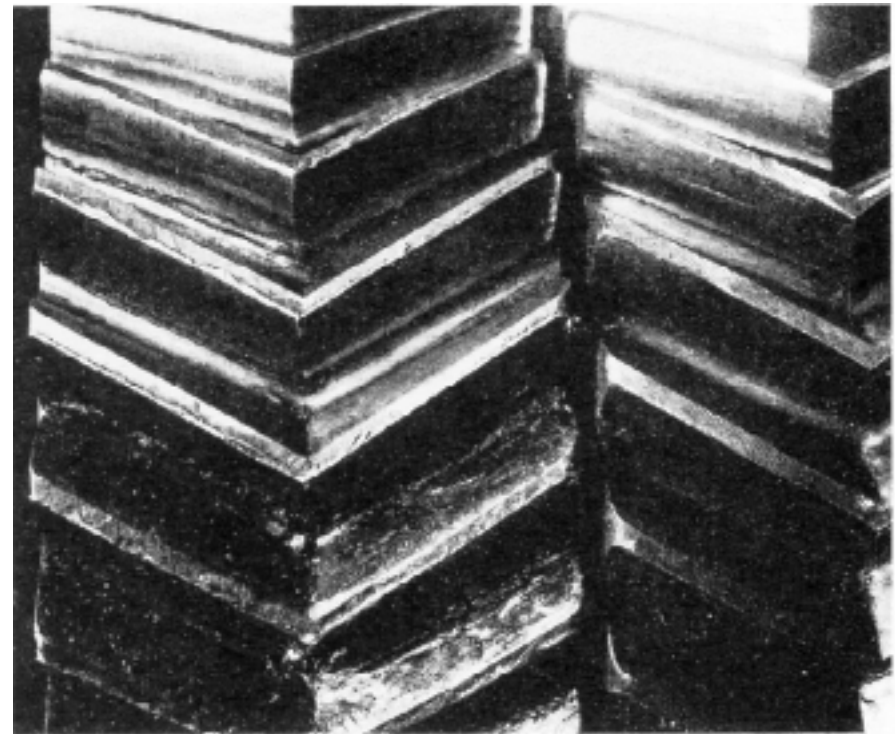
:

(Plastic Deformation)

• (steel gear)

- : (flash)
(knife-edge) (tip) ,
(hollow)
(swelling)
(end)
(burnishing) .
- :
- :
가 (alignment)

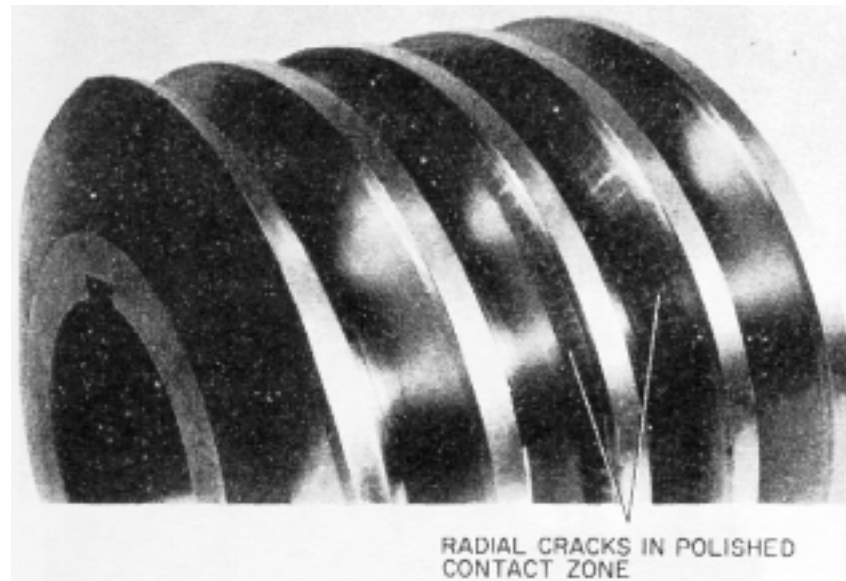
(plastic flow)



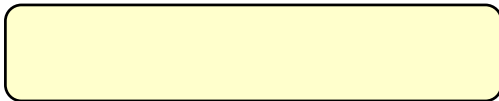
G-16.

(Case Cracking)

- (worm) /
- : (radial crack)
- : (core strength)



G-17. Worm wheel /



2, 가, ,
(eccentricity) (common factor)

1. (Gear Mesh Frequency)

1) (Fundamental Frequency : $f = Z N$ (Hz))

Z : , N : (Hz)

) : (Z) 43 , (N) 1776 rpm (29.6 Hz), $f = 43 \times 29.6 = 1,272.8$ Hz

: (Z) 99 , $N = f / Z = 1,272.8 / 99 = 12.86$ Hz

2) (Harmonics) : $2f, 3f, 4f, \dots$

■ $2f > f, 3f$: Backlash

(1) backlash , (2) 가 , (3) 가
2

■ $f, 2f, 3f$: runout

2.

(Fractional Gear Mesh Frequency)

가 . n 가
가 .
, 가
1 . 2 ,
.
) 가 (common factors) 2, 3, 5 ,

1)

$1/2 f, 1/3 f, 2/3 f, 1/5 f, 2/5 f, 3/5 f, 4/5 f$

2)

$1 \frac{1}{2} f, 1 \frac{1}{3} f, 1 \frac{2}{3} f, 1 \frac{1}{5} f, 1 \frac{2}{5} f, 1 \frac{3}{5} f, 1 \frac{4}{5} f,$

$2 \frac{1}{2} f, 2 \frac{1}{3} f, 2 \frac{2}{3} f, 2 \frac{1}{5} f, 2 \frac{2}{5} f, 2 \frac{3}{5} f, 2 \frac{4}{5} f$

3. (Hunting Tooth Frequency, HTF)

1) 가

2) HTF 가 가

$$HTF = 1 / (L/U \times 1/N)$$

L : , U : , N : (Hz)

) : (43 , 1776 rpm), (99)
가 99 , 43

$$43 \times 99 / 43 = 99 \quad 43 \times 99 / 99 = 43$$

1776 rpm , 1 0.0338 s, 가
3.34 (0.0338 X 99 = 3.34 s)가

$$L = 43 \times 99, U = 43, L/U = 99, N = 1776/60 = 29.6 \text{ Hz}, 1/N = 1/29.6 = 0.0338 \text{ s}$$

$$HTF = 1 / (99 \times 0.0338) = 1/3.34 = 0.299 \text{ Hz}$$

) HTF 가 가
가 , 가 . ,
가 HTF .

G-1.

		Sideband
		, $\frac{1}{2}$, $\frac{1}{3}$, $\frac{1}{4}$
		1, 2, 3
Backlash		
, ,		,

: (Eccentric Gear)

•

- 1) 가 가 , 가
- 2) 가 , 가
- 3) (out-of –round), high place 가
- 4) (bent shaft)

1) 가 가

)

- () : 25 , 20 Hz
- : 115 , $20 \times 25/115 = 4.348 \text{ Hz}$
- (GMF) = $25 \times 20 = 115 \times 4.348 = 500 \text{ Hz}$
- : 5 ($5 \times 5 = 25$, $5 \times 23 = 115$), : 5, 23, : 115

: (Eccentric Gear)

- 가 , bad place
- () 5 (0, 5, 10, 15, 20) ,
가
- 1/5, 2/5, 3/5, 4/5 (100, 200, 300, 400 Hz)가 .
5 가
- 1/5
 $500/5 = 100 \text{ Hz} = 5 \times 20 () = 23 \times 4.348 ()$
- (5) :
- (5, 23) :
- (115/23 = 5, 115/5 = 23) : 가
.
) 23 가 5 23

:

(Eccentric Gear)

• 100Hz (GMF/5 = 500/5 = 100Hz)
가 5

• 100Hz (20 Hz) (sideband)
(4.348 Hz) ().

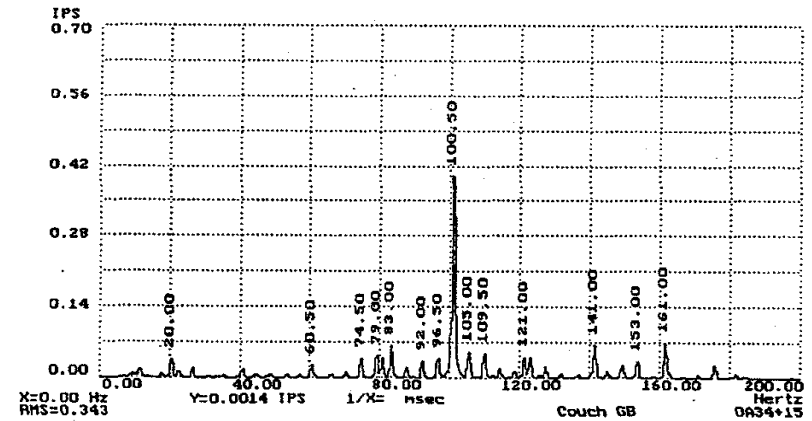
• , 가

• 0.01 (100 Hz). 5 X
23 X

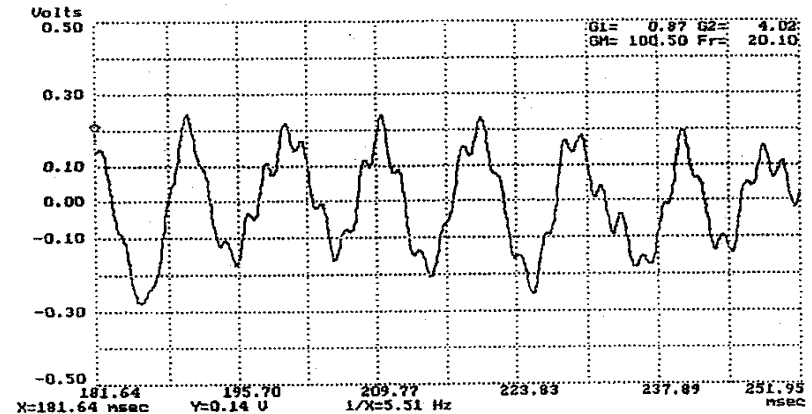
• 5
0.002 (500Hz) ,

• 가 ()
1) 5
2) 1 2
3)

Ref) Vibration Consultants Inc., The Vibration Analysis Handbook.



G-3.



G-4.

•

- (Dryer gear) : $Z = 96$, $N = 3.26\text{Hz}$
- $\text{GMF} = 96 \times 3.26 = 312.5 \text{ Hz}$
- (Idler gear): $Z=52$, $N=312.5/52 = 6.01\text{Hz}$
- $\frac{1}{4}, \frac{1}{2}, \frac{3}{4} \text{ GMF}$: 77.5, 155, 227.5 Hz,

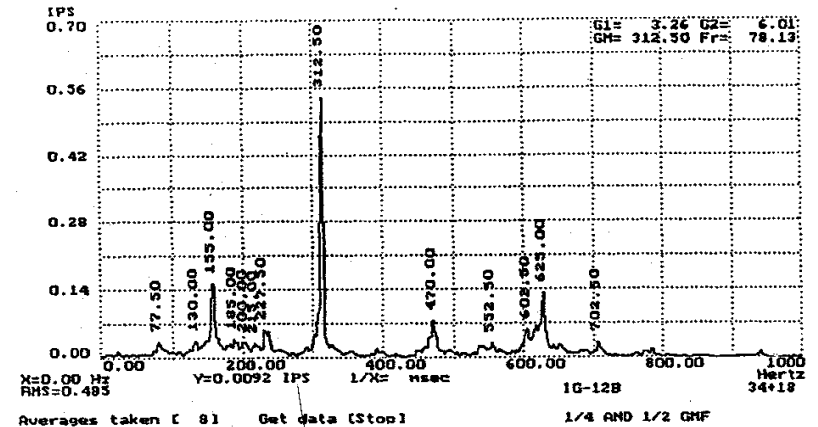
• (2.75Hz) : 309.85, 315.3, 318.05Hz ,

• (sideband) : 0.5 Hz

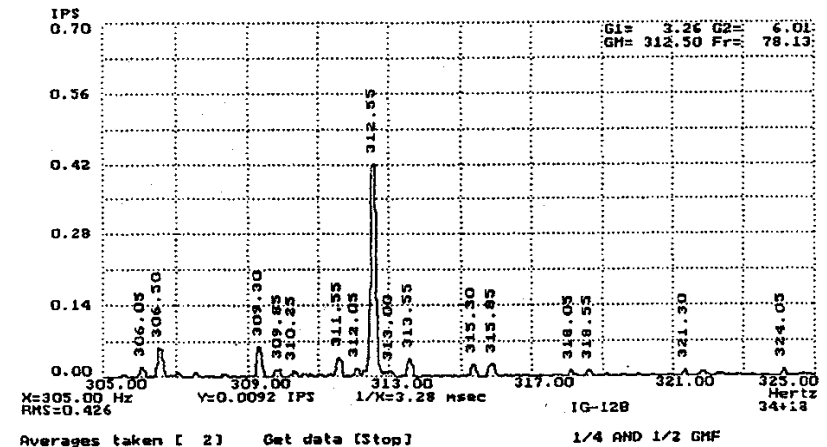
$$2 \times 3.255 - 6.01 = 0.5 \text{ Hz}$$

- (306.05, 309.3, 315.85Hz
(306.5, 318.55 Hz) :
GMF(312.5Hz)

Ref) Vibration Consultants Inc., The Vibration Analysis Handbook.



G-5.



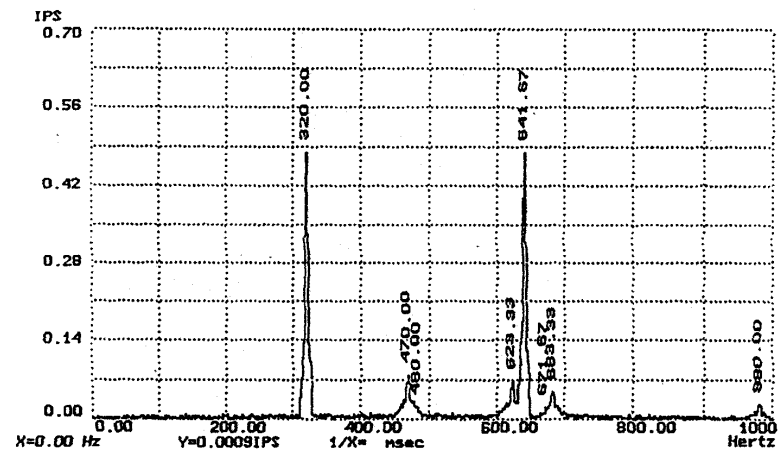
G-6. Zooming

(20Hz)

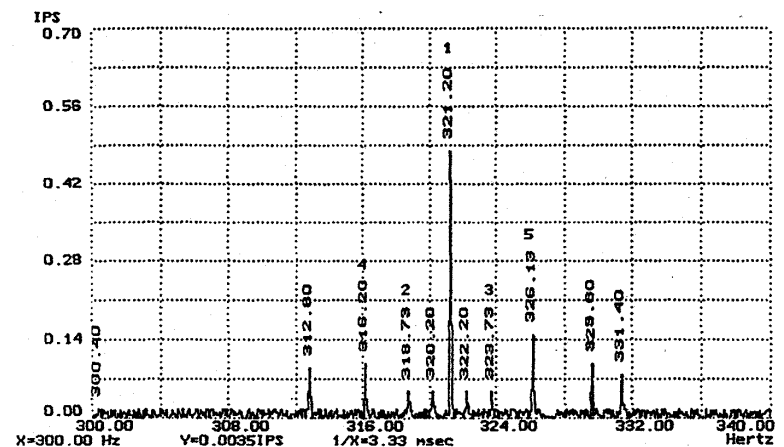
: Backlash

- (Dryer gear) : $Z = 128$, $N = 2.5\text{Hz}$
- $\text{GMF} = 128 \times 2.5 = 320 \text{ Hz}$
- (Idler gear): $Z = 64$, $N = 5\text{Hz}$
- 2 GMF : 640 Hz
- $\text{GMF} \times 2$ Backlash
- 1-2, 1-3 : 2.5Hz ()
- 1-4, 1-5 : 5Hz ()
- GMF
- GMF
- GMF ,

Ref) Vibration Consultants Inc., The Vibration Analysis Handbook.



G-5.

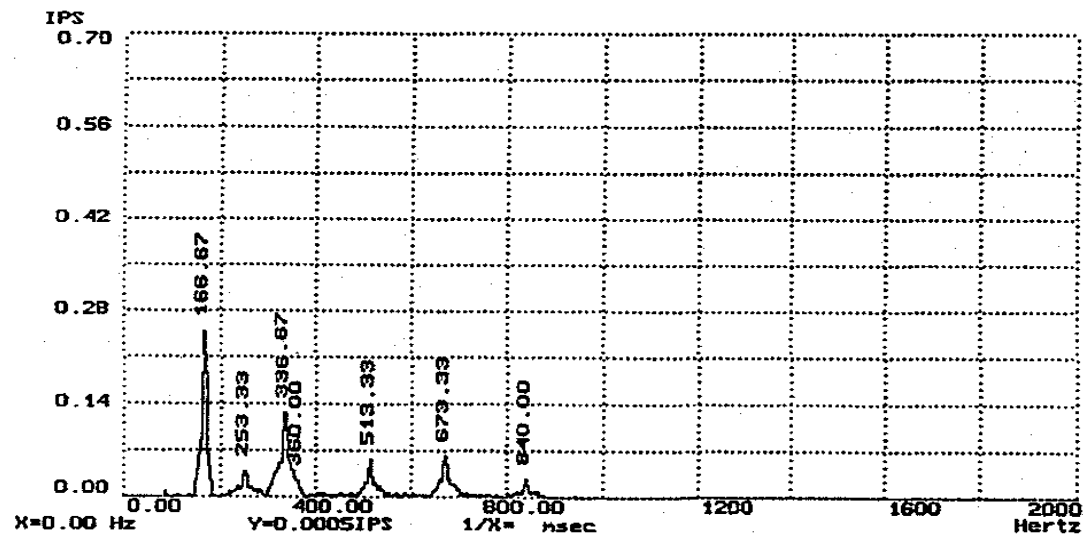


G-6. Zooming

(40Hz)

:

- : (GMF) , 1X, 2X, 3X ,
 $1X > 2X > 3X$. 2X가 Backlash .
- , 가 ,



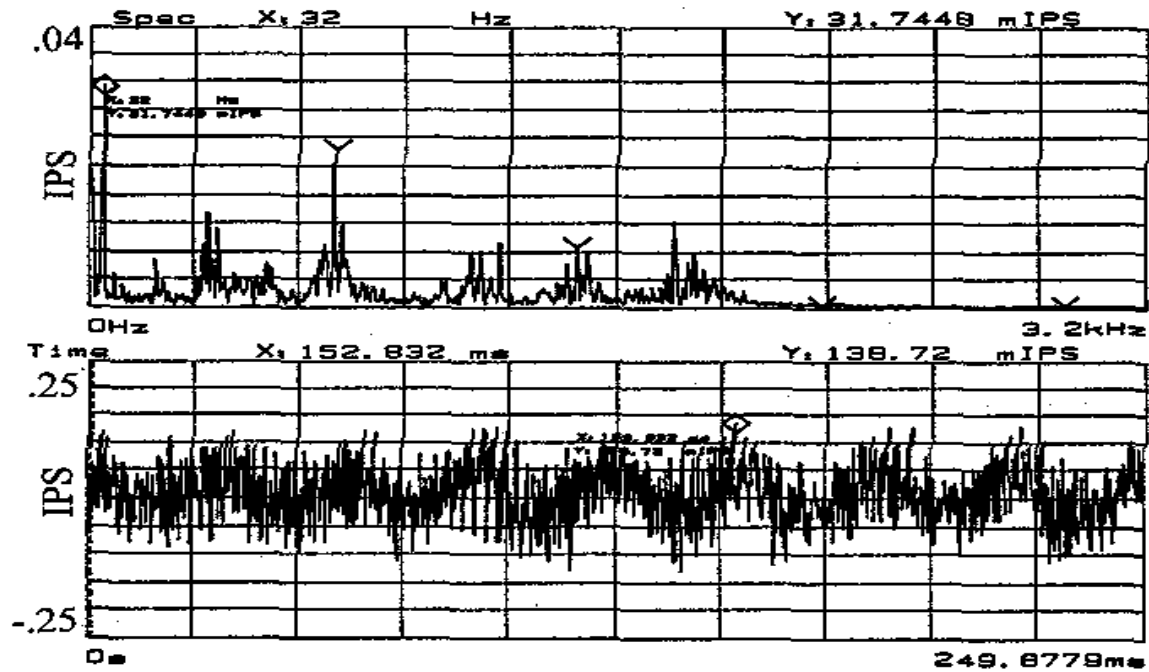
G-7.

⋮



(pinion)

(: 730 Hz , : 30 Hz)

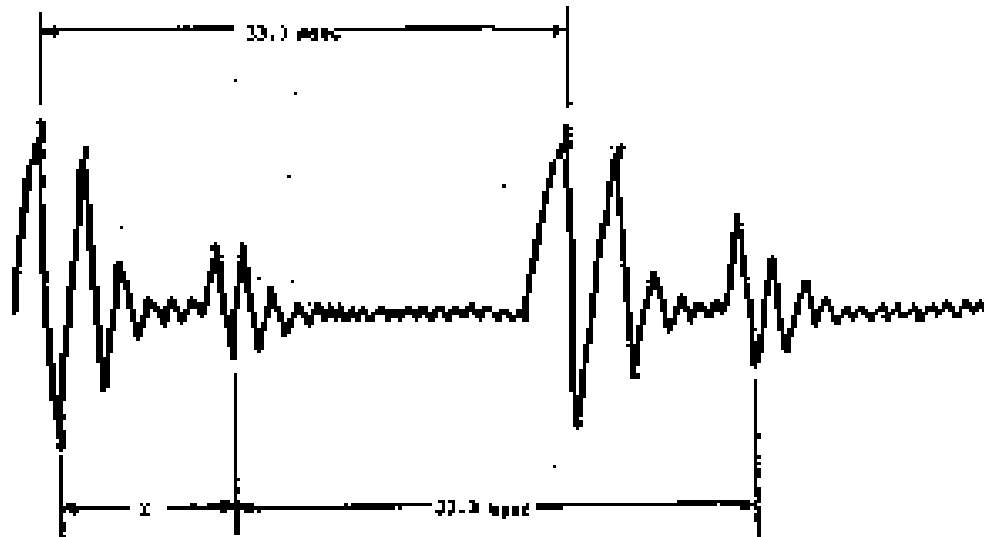


G-8.



(spur gear)

(: 1,800 rpm, : 0.0333 s, : 0.0333 s)



G-9.