Theory and Design of Mechanical Systems

Project: Vegetable Chips Processing Machine

Batch C5

Group members

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Guided by

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I. Problem Statement

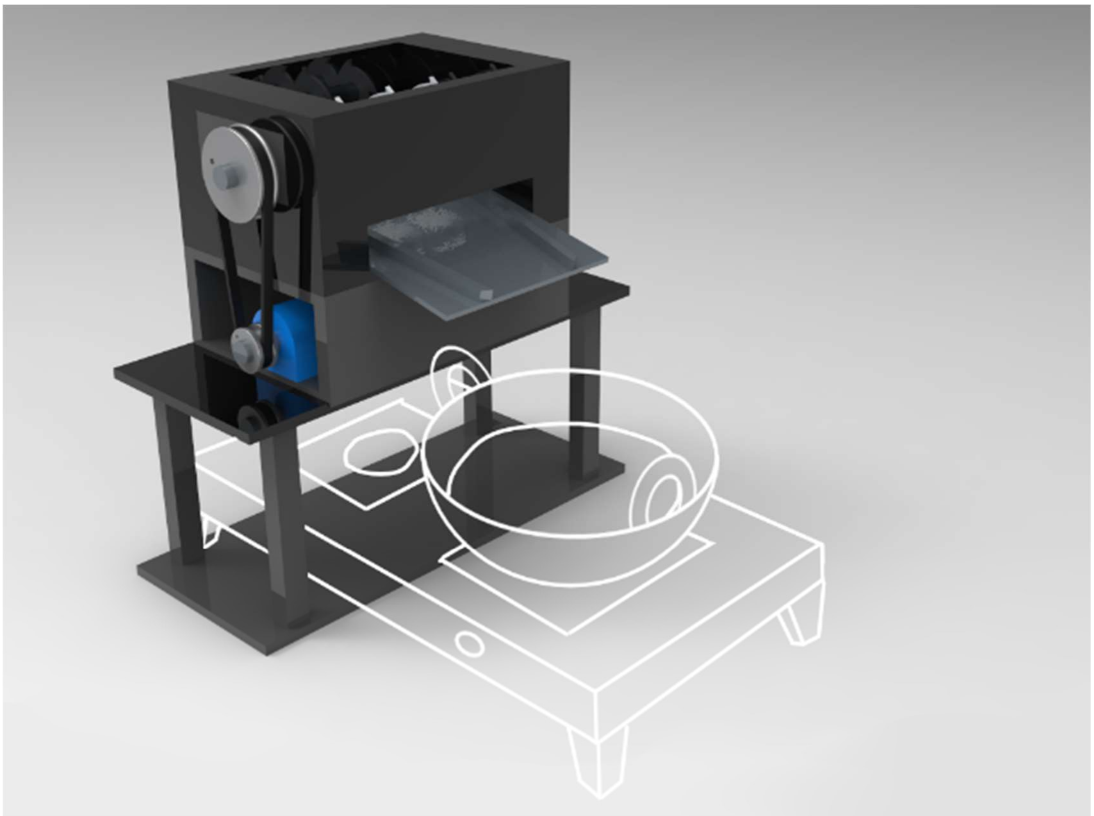
To design a chips processing machine to manufacture jackfruit and potato chips.

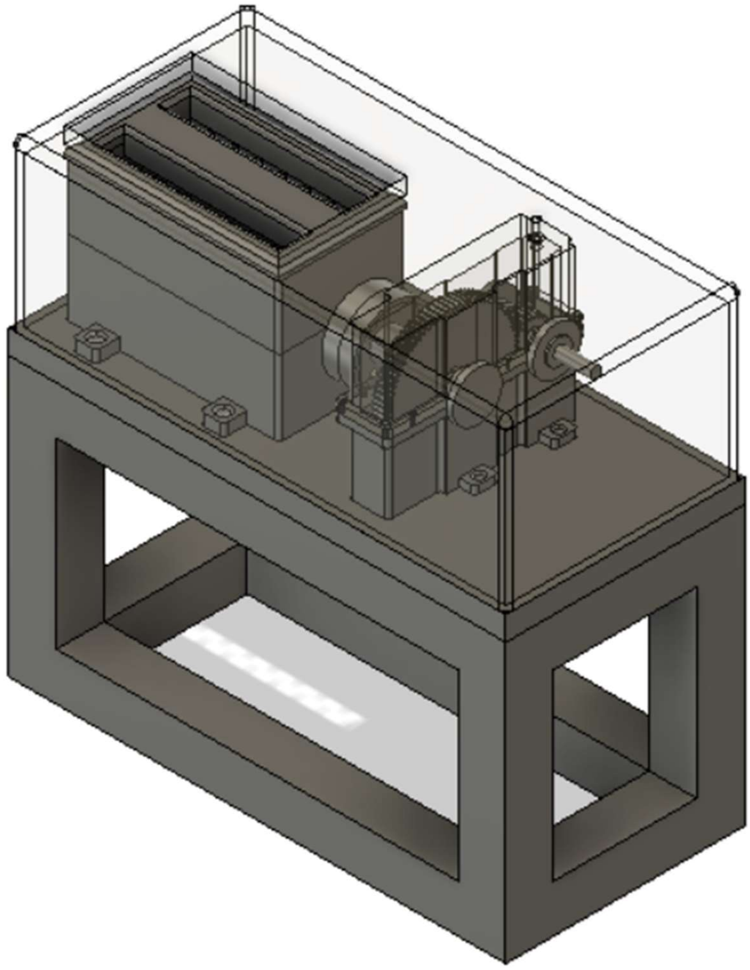
II. Solution

An automated shredding machine with adjustable cutting blades to shred different types of fruits and vegetables.

Specifications:
- Chip processing rate: 10 chips per second
- Space constraints: 0.30 m X 0.30 m X 0.60 m
- Height adjustable stand

III. Diagram





IV. Design Procedure

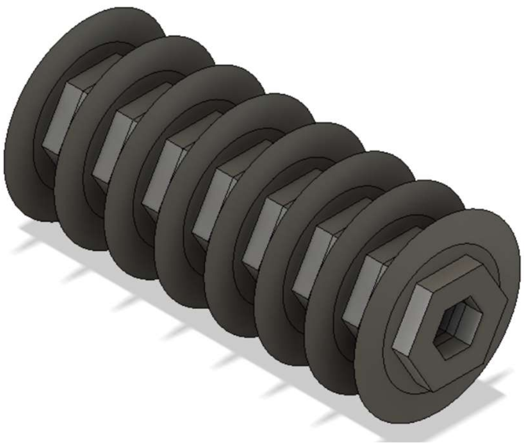
Cutting blade design

Considering a processing machine for jackfruit chips manufacture,
Considering average dimensions of jackfruit bulb,
Jackfruit flesh length = 100mm
Jackfruit flesh width = 50mm
Jackfruit flesh thickness = 10mm
Chip width = 10mm

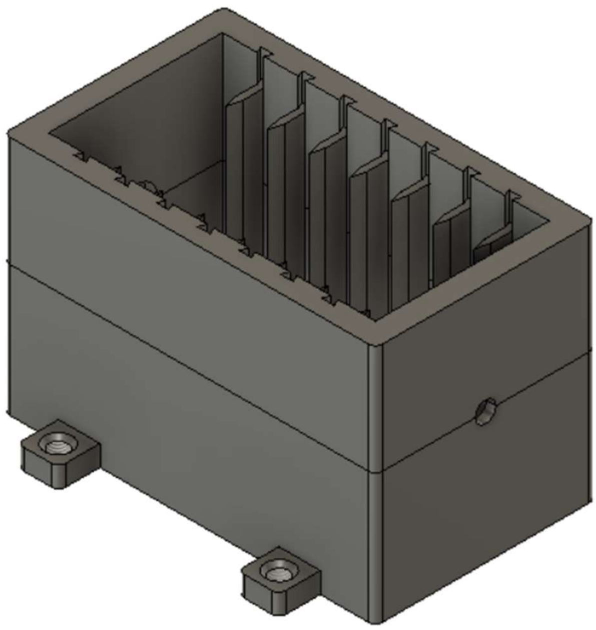
Blade thickness = 5mm
Blade radius = 50mm
Blade Volume = 40,000 mm^3

Blade material = Mild Steel
Blade Density = 7840kg/m^3
Blade Mass = V*rho = 300g

15 Blades will be mounted on two shafts, with 8 blades on one shaft and 7 on another.
On each shaft the blades will be placed with a spacing of 20mm and the total arrangement will be in staggered fashion, achieving the chip width of 10mm



Stationary blades are fixed into the grooves of box's lower casing by press fit.

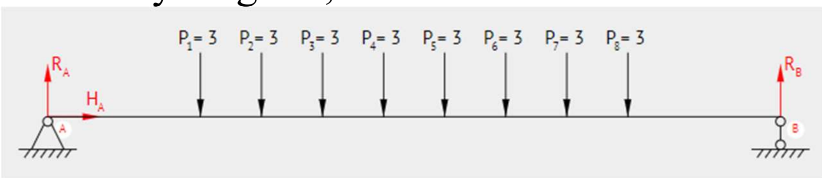


Shaft design

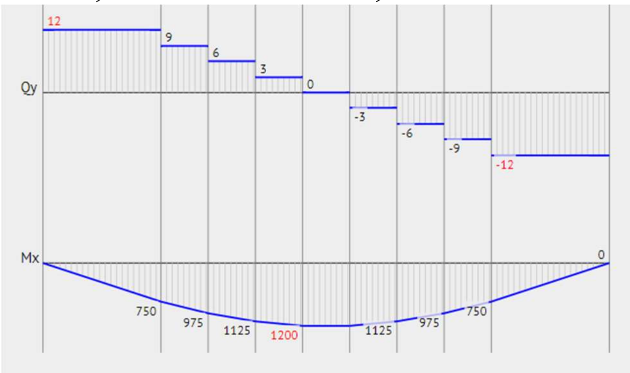
Length = 400 mm

Force applied by one blade = Weight = 3 N

Free body diagram,



From, SFD and BMD,



Maximum bending moment (Mb) = 1200 Nmm = 1.2 Nm

Maximum torque (Mt) = 2 Nm

According to ASME code for shaft design,

kb = 1.5

kt = 1

Shaft material – Aluminium 19000

Tensile yield strength Syt = 65 N/mm2

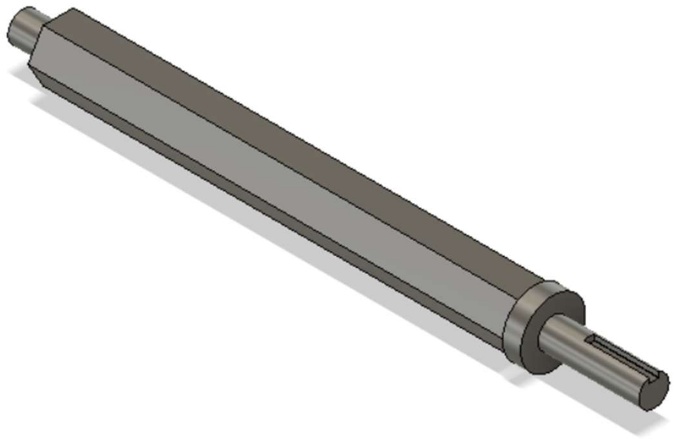
Factor of safety fs = 3

Maximum shear strength = Ssy/fs = 10.8 N/mm2

Diameter of shaft,

Maximum shear strength = $\frac{16}{\pi d^3} * \sqrt{(k_b M_b)^2 + (k_t M_t)^2}$

Diameter = 10.8 mm = 15 mm



Force calculations

By experimentation, the force required to cut the flesh of the jackfruit by 1 blade is 10 N

Torque of 1 blade = F * r = 10 * 50 = 500Nmm
Torque required for 8 blades = 0.5 * 8 = 4 Nm
Considering one complete rotation of the blade in 2 sec,
Angular velocity (omega) = 3.142 rad/s
Required power for both shafts = Torque * omega = 12.5 watt
Considering mechanical efficiency,

Required power = 25 watt
Required RPM = 30

Motor Selection

Required power = 25 watt
Required RPM = 30

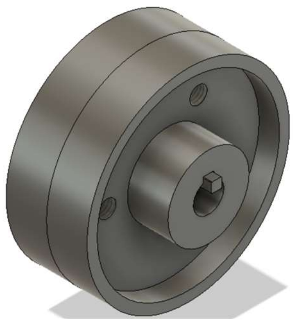
Selected motor - PM6015-PL73020
Voltage = 90 V
RPM = 120
Motor power = 0.03 HP = 25 watt

Bearing selection

	Blade shaft
Bearing	SKF 6002
Type	Deep groove
d	15
D	32
B	9
Shaft step	17

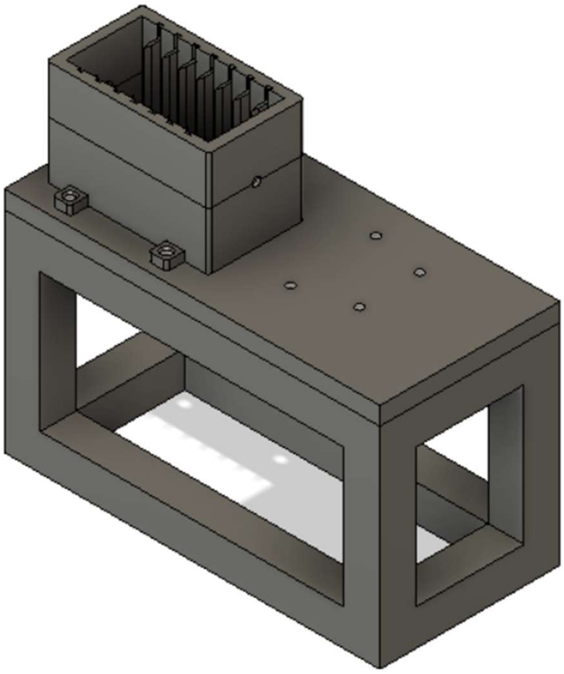
Flange Design

Shaft diameter	d	20	mm
Hub OD	dh	40	mm
Hub Length	L	30	mm
Bolts PCD	D	60	mm
Flange Thickness	t	10	mm
Rim thickness	t1	5	mm
Spigot, Recess Diameter	dr	30	mm
Flange OD	Do	90	mm
Number of bolts	N	3	-



Slicing box casing

Casing is manufactured by Aluminium die casting and is attached onto a welded structure made of C50.



Gearbox design

Spur gear design
Required reduction = 120 to 30 RPM = 4:1

Transmitted torque = 25 watt
$N_p = 120\ RPM$
$N_g = 30\ RPM$
Selecting number of teeth for required speed ratio,
$Z_p = 20$
$Z_g = 80$

Material for Pinion – C 50
Material for Gear – 35 Ni 1 Cr 60
$(S_{ut})_p = 700\ MPa$
$(S_{ut})_g = 800\ MPa$
$BHN_p = 241$
$BHN_g = 277$

$f_s = 1.5$
Bending stress,
$$\sigma_{bp} = \frac{(S_{ut})_p}{3} = 233.33$$
$$\sigma_{bg} = \frac{(S_{ut})_g}{3} = 266.66$$

Lewis form factor,
$$Y_p = 0.484 - \frac{2.865}{Zp} = 0.3405$$
$$Y_g = 0.484 - \frac{2.865}{Zg} = 0.4481$$

$$\sigma_{bp} * Y_p < \sigma_{bg} * Y_g$$

Design for Pinion –

Beam strength of pinion,
$$F_b = \sigma_{bp} * Y_p * m * b = 794.5\ MPa$$

Ratio factor,
$$Q = \frac{2Z_g}{Z_p + Z_g} = 1.6$$

Load stress factor,
$$K = 0.16 \left(\frac{BHN}{100}\right)^2 = 0.929$$

Wear strength of pinion,
$$F_w = d_p * K * Q * b = 297.37\ MPa$$

Service factor, $k_a = 1.25$
Load concentration factor, $k_m = 1.1$

Theoretical tangential force,

$$F_t = \frac{P}{V} = 198.94\ MPa$$

Maximum tangential force,

$$F_{t_{max}} = k_a\, k_m\, F_t = 273.55\ MPa$$

Preliminary estimation by velocity factor,

$$k_v = \frac{6}{6+v} = \frac{6}{6+0.125m}$$

Effective load,

$$F_{eff} = \frac{F_{t_{max}}}{k_v}$$

Design according to wear strength of pinion,

$$F_b = f_s * F_{eff}$$

Solving for module,

m = 1.24

Corrected module,

m = 2

Precise estimation by Buckingham equation,

Velocity, v = 0.125 m = 0.25

Deformation factor, C = 2.32

Dynamic force,

$$F_d = \frac{21\,V\left(bC + F_{t_{max}}\right)}{21\,V + \sqrt{bC + F_{t_{max}}}} = 51.4\ MPa$$

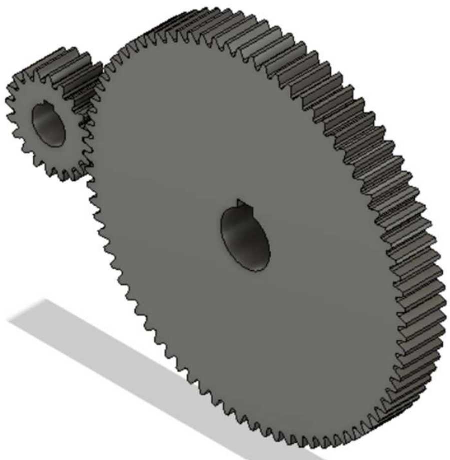
$$F_{eff} = F_d + F_{t_{max}} = 188.17\ MPa$$

$$F_w = 1189.12\ MPa$$

Available factor of safety $f_s = \frac{F_w}{F_{eff}} = 6.3$

Pinion and gear dimensions,

	Pinion	Gear
Material	C 50	35 Ni 1 Cr 60
S_{ut}	700	800
BHN	241	277
N	120	30
Z	20	80
Module	2	2
PCD	40	160
Addendum	2	2
Dedendum	2.5	2.5
Face width	20	20



Tangential force $F_t = \frac{P}{V} = 100\ N$
Radial force $F_r = F_t * tan\emptyset = 36.4\ N$

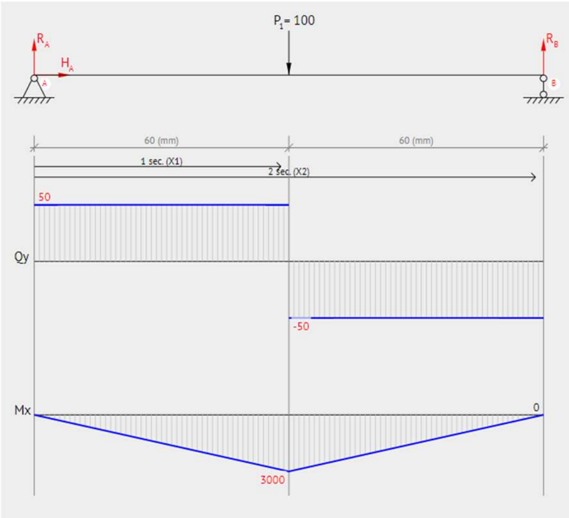
Shaft design
Length = 120 mm

Material – Al 46000
$S_{yt} = 150\ MPa$

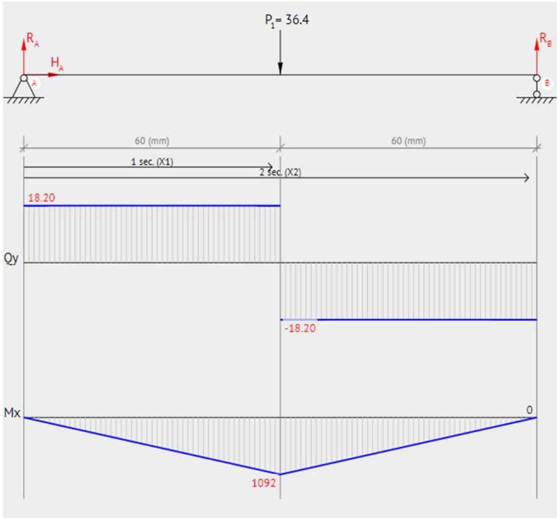
$S_{sy} = 75\ MPa$

$f_s = 1.5$

Forces in horizontal plane,



Forces in vertical plane,



Mb = 3000 + 1092 = 4092 Nmm

$$\text{Mt} = \frac{60 * 10e6 * kW}{2\,\pi\,n}$$

$$\tau_{max} = 0.75 * 0.3 * S_{yt}$$

$$d^3 = \frac{16}{\pi * \tau_{max}} * \sqrt{(k_b\,M_b)^2 + (k_t\,M_t)^2}$$

Material – Al 46000

$S_{yt} = 150\ MPa$

$S_{ut} = 75\ MPa$

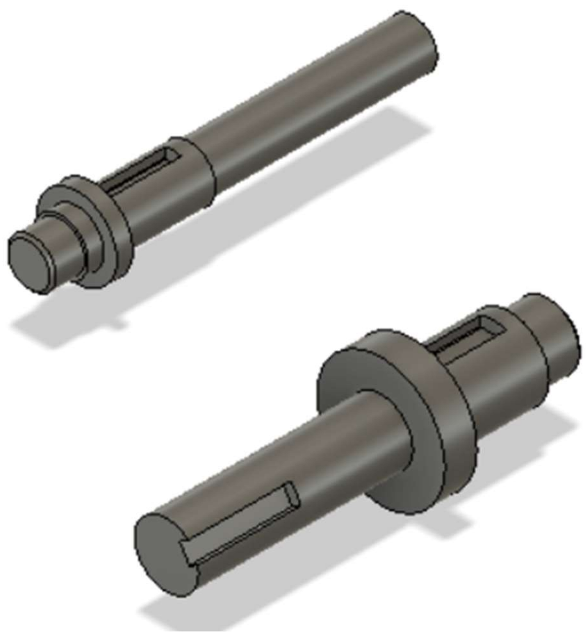
Shaft for pinion,

d = 14.81 = 15 mm

Shaft for gear,

d = 17.16 = 20 mm

Steps of 17 mm and 25 mm have been provided to the respective shafts along with the keyways for the mounting of gears.



Parallel keys selection

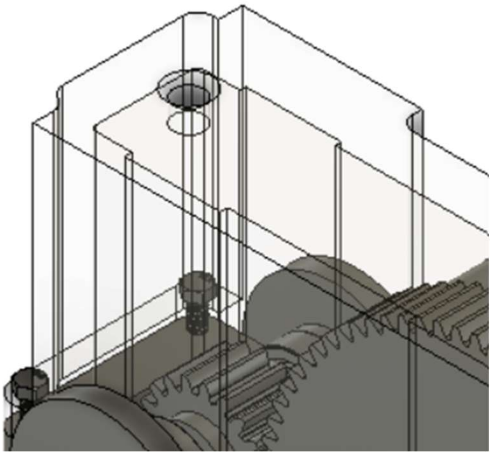
	Pinion	Gear
Type	Parallel key	Parallel key
Cross section	5 x 5	7 x 8
Length	25	25
Radius of fillet	0.25	0.35

Bearing selection

	Pinion	Gear
Bearing	SKF 6002	SKF 6004
Type	Deep groove	Deep groove
d	15	20
D	32	42
B	9	12
Shaft step	17	25

Lubrication

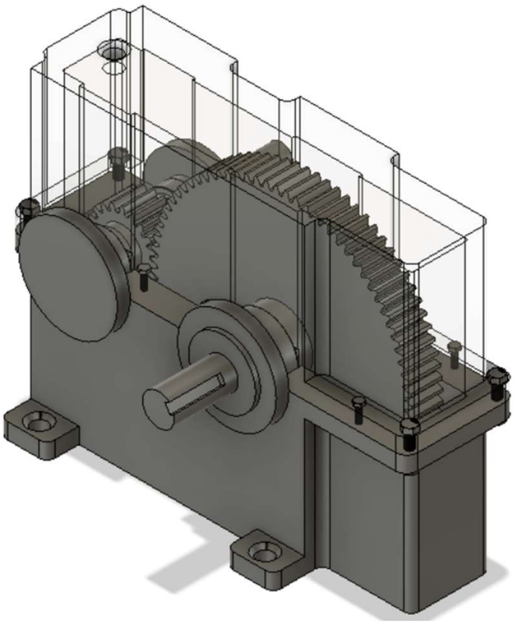
Splash type lubrication, casing to be partially filled with lubricant in order to submerge half of the gear faces. Lubricant – SAE 40 W



Tolerances and Fits

Mating parts	Fit	
Pinion – pinion shaft	Light press fit	H7/n6
Gear – gear shaft	Light press fit	H7/n6
Coupling - Shaft	Press fit	H7/r6
Key – Keyway	Light press fit	H7/n6
Bearing - shaft	Easy running fit	H8/e8
Oil seal - shaft	Slide running fit	H8/c11

Gearbox



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