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UNIT - IV

Gear Boxes

Introduction:

Machine tools like lathe, milling machines etc require a wide range of Spindle Speeds. Because a machine tool is adoptable for cutting different types of metals having different properties using varying grades of cutting tools on work pieces of different diameters.

Thus the Pression of Variable Spindle Speed is necessary in order to meet different requirements. The Various methods using for obtaining different Speeds of machine tool Speedle are as follows.

1, By using a gear box mechanism.
2, By using a Cone Pulley arrangement
3, By using a vertical Speed electric motor and
4, By hydraulic operations

Requirements of a Speed Boxes;

A Speed gear Box Should have the following requirements.

1, It Should Provide the designed Sources of Spindle Speed.
2, It Should transmit the requireds amount of Power to the Spindle.

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3, It Should Provide Smooth Silent operations of the transmission

4, It Should have Spindle Constructions.

5, Mechanism of Speed Gear boxes Should be easily accessible So that it is easier to Carry at Preventive maintenance.

Methods of Changing Speed in Gear Boxes:

The two important methods widely used are:

1) Sliding mesh gear box and
2) Constant mesh gear Box.

Preferred Numbers:

Preferred numbers are the Connectionally rounted off Values derived from Geometric Series. denoted as

R_5, R_{10}, R_{20}, R_{40} and R_{80} Series.

Example:

Machine tool Spindle Speeds under R_{20} Series is given by 100, 112, 125 140, 160, 180 and 200 rpm.

(from PSG Data Book Page no 7.20).

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Standard Step ratio :

Step ratio or Series Ratio of Progression Ratio :

When the Spindle Speeds are arranged in geometric Progression, then the ratio b/w the two adjacent Speeds is known as Step ratio or Progression ratio, It is denoted by ϕ.

If n is the number of Steps of Speed. If $N_1, N_2, N_3, \ldots N_n$ are the Spindle Speeds arranged in geometric Progression than

$$\frac{N_2}{N_1} = \frac{N_3}{N_2} = \frac{N_4}{N_3} = \ldots \frac{N_n}{N_{n-1}} = \text{Constant} = \phi$$

$$\frac{N_n}{N_1} = \phi^{n-1} \quad \text{or} \quad \frac{N_{max}}{N_{min}} = \phi^{n-1}$$

Permissible deviation $= \pm 10(\phi - 1)$

— x — x — x —

Problem :

Find the Progression ratio for a 12 Speed gear box having Speeds b/w 100 and 355 rpm, Also finding the Spindle Speed.

Given Data

$n = 12$, $N_{min} = 100$ rpm, $N_{max} = 355$ rpm

Progression ratio $\phi = ?$

Spindle Speed $= ?$

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$$\frac{N_{max}}{N_{min}} = \phi^{n-1}$$

$$\frac{355}{100} = \phi^{12-1}$$

$$\phi = (3.55)^{1/11} = 1.122$$

Spindle Speeds:

Since the Calculated $\phi = 1.12$ is a Standard Step ratio for R 20 Series There fore the Spindle Speeds from R20 Series are

100, 112, 125, 140, 160, 180, 200, 224, 230, 280, 315, 355

Structural formula:

n = number of Speeds available at the Spindle

$P_1, P_2, P_3 \ldots$ = Stagenumbers in the gearbox.

x_1, x_2, x_3 = Characteristic of the Stage

Then the Structural formula is given as

$$n = P_1(x_1) \cdot P_2(x_2) \cdot P_3(x_3) \cdot P_4(x_4)$$

1st Stage 2nd Stage 3rd Stage 4th Stage

$x = 1$, $x_2 = P_1$, $x_3 = P_1, P_2$, $x_4 = P_1 P_2, P_3$

Kinematic Layout (or) kinematic arrangement

The kinematic Layout Shows the arrangement of gears is a gear box the kinematic Layout Provides the following informations required for gear box design.

The number of Speeds available at the Spindle is at the driven Shaft.

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The Structural formula for the kinematic arrangement of gear box is given by

$$n = P_1(x_1), P_2(x_2)$$

$P_1 = 3$ (is in Stage 1, there are 3 Speed available)

$P_2 = 3$ (is in Stage 2, There are 3 Speed available)

$x_1 = 1$, $x_2 = P_1 = 3$

Structural formula $z = 3(1)\,3(3)$

n = number of Speeds available at the design

$= P_1 P_2 = 3 \times 3 = 9$

Ray diagram or Speed diagram:

The ray diagram is a Graphical representation of the drive arrangement is general form, In other words the ray diagram is a Graphical representation of the Structural formula.

It Provide the following data on the drive

The number of Stages (a Stage is a Set of gear trains arranged on two Construction Shafts.

The number of Speeds in each Stage. The order of kinematic arrangement of the Stages.

The total number of Speeds available at the Spindle.

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Procedure :

In this diagram Shafts are Shown by Vertical equidistances and parallel Lines.

The Speeds are plotted Vertical on Longarithmics Scale with Log ϕ as a unit.

The ray diagram for 9 Speed gear box having the formula

$$Z = 3(1) \cdot 3(3)$$

Basic Rules for optimum Gear Box Design:

The basic rules to be followed while designing the gear boxes are as follows.

1, The transmission ratio i in a gear box is Limitted by

$$\frac{1}{4} \leq i \leq 2$$

In other words

$$i_{min} = \frac{N_{min}}{N_{input}} \geq 1/4 \text{ and}$$

$$i_{max} \frac{N_{max}}{N_{input}} \leq 2$$

2, For Stable operation the Speed ratio at any Stage Should not be greater than 8.

In other words $\frac{N_{max}}{N_{min}} \leq 8$

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3, In all stages except in the first stage

$N_{max} \geq N_{input} > N_{min}$

4, The sum of teeth of matting gears in a gear stage must be the same for same module in a sliding gear

5, The minimum number of teeth an smallest gear in drive should be greater than or equal to 17

6, The minimum difference b/w the number of teeth of adjacent gears must be 4.

— x — x —

Problem:

The minimum and maximum speeds of a six speed gear box are to be 160 and 500 rpm. Construct the kinematic arrangement and the ray diagram of the gear box.

Given Data:

$n = 6$, $N_{min} = 160$ rpm

$N_{max} = 500$ rpm

To find Construction of the kinematic arrangement and the ray diagram

Solution:

Selection of spindle speed

$$\frac{N_{max}}{N_{min}} = \phi^{n-1}$$

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$\frac{500}{160} = \phi^{6-1}$ or $\phi = 1.256$

We find $\phi = 1.256$ is not a standard ratio. So let us whether multiplies of standard ratio 1:12 at 1:06 come close 1.25.

We can write:

$1.12 \times 1.12 = 1.254$

$\phi = 1.12$ satifies the requirement. Therefore the spindle speeds from R20 series skipping one speed are given by

160, 200, 250, 315, 400 and 500 rpm

Structural formula.

For 6 speeds the preferred structural formula $= 3(1)\ 2(3)$ 1st and 2nd stage.

Ray diagram:

Since there are 3 shafts in kinematics layout, draw 3 vertical equidistant lines to represent shafts

Since there 6 spindle speeds draw 6 horizontal equidistant lines to represent speeds. Then mark the speeds on the horizontal lines

From the structural formula it is clear that there are two stages. In the speed stage is 2(3), 2 represents no. of speeds available in the stage.

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The locate the input speed point from the preceding shaft (in shaft 2) The follows requirements should be met That is

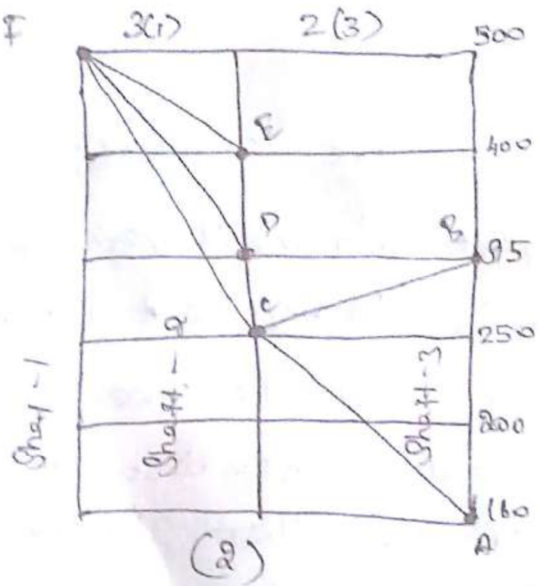
$$\frac{n}{n_{input}} \geq \frac{1}{4p} \text{ and } \frac{n_{max}}{n_{input}} \leq 2$$

Locate point c and the input speed of 250

$$\frac{N_{max}}{N_{input}} = \frac{160}{250} \geq \frac{1}{4p} \text{ and}$$

$$\frac{N_{max}}{N_{input}} = \frac{315}{230} \leq 2$$

Thus the requirements are satisfied note that the above conditions are met for other input speeds.



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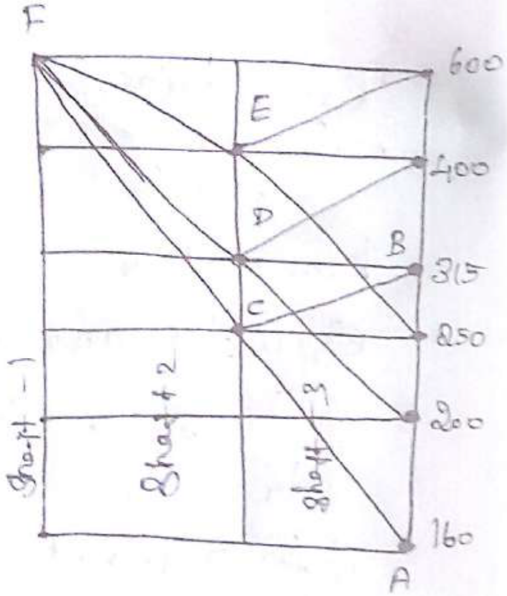

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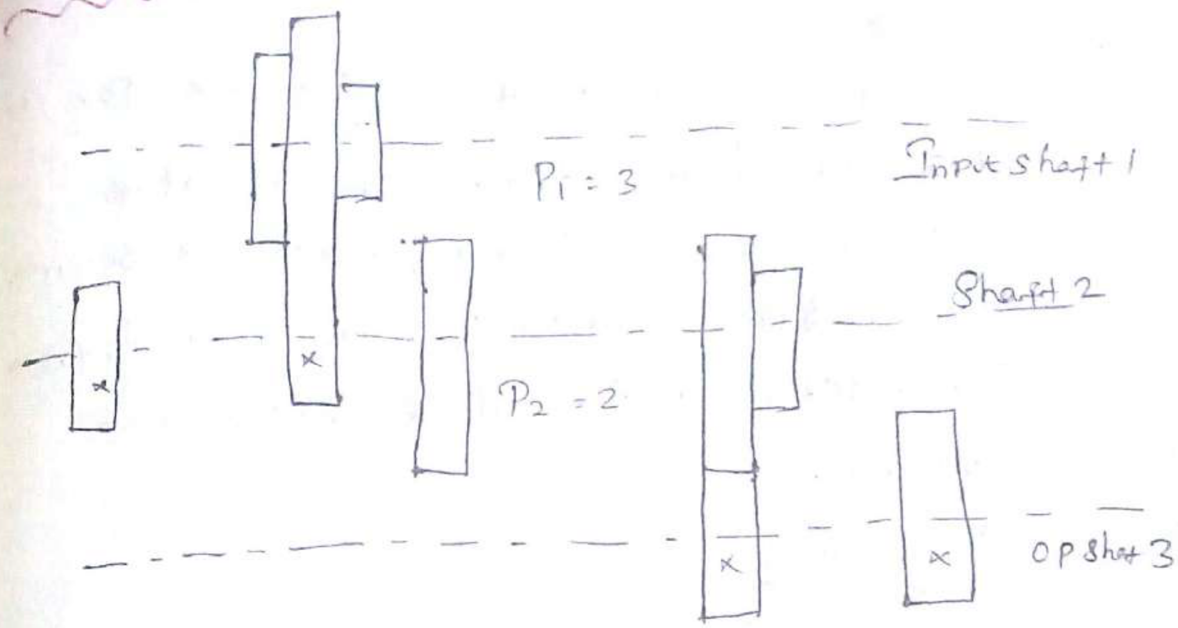
Kinematic arrangement for 6 Speed Gear Box



Over Lapping Speed Gear Box

If the engagement of two different set of gears provide the same speed than the gear box is known as over lapping speed box.

Design Procedure for Gear Box:

1. Selection of Spindle Speeds
2. Contract the ray diagram.
3. Construct the kinematic arrangement.
4. Calculate the no. of teeth on all Gears.
5. Select the material.
6. Calculate the module.
7. Callculat the Centre distance.
8. Calculation of face width.
9. Calculation of distance b/w bearings in length of Shafts.
10. Design Shafts

— x — x — x —

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Problem:

Design a 12 Speed Gear Box for an all geared head Stock of a lathe, maximum and minimum Speed are 600rpm, and 25 rpm. respectively, The drive is from an electric motor giving 2.25kw at 1440rpm.

Given data:

$n = 12$

$N_{max} = 600rpm$

$N_{min} = 25rpm$

$P = 225kw$

$N_{input} = 1440rpm.$

To find

Design 12 - Speed Gear Box

Solution:

1) Selection of Spindle Speed:

$$Q^{n-1} = \frac{N_{max}}{N_{min}}$$

$$Q^{12-1} = \frac{600}{25}$$

$$Q = 1.315$$

We Can write $1.06 \times 1.06 \times 1.06 \times 1.06 = 1.338$

$Q = 1.06$ Satisfies the requirement, There fore the Spindle Speeds from R40 Series. Skipping fours Speeds are given as

25, 33.5, 45, 60, 80, 106, 140, 190, 250

335, 450 and 600rpm.

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Ray diagram.

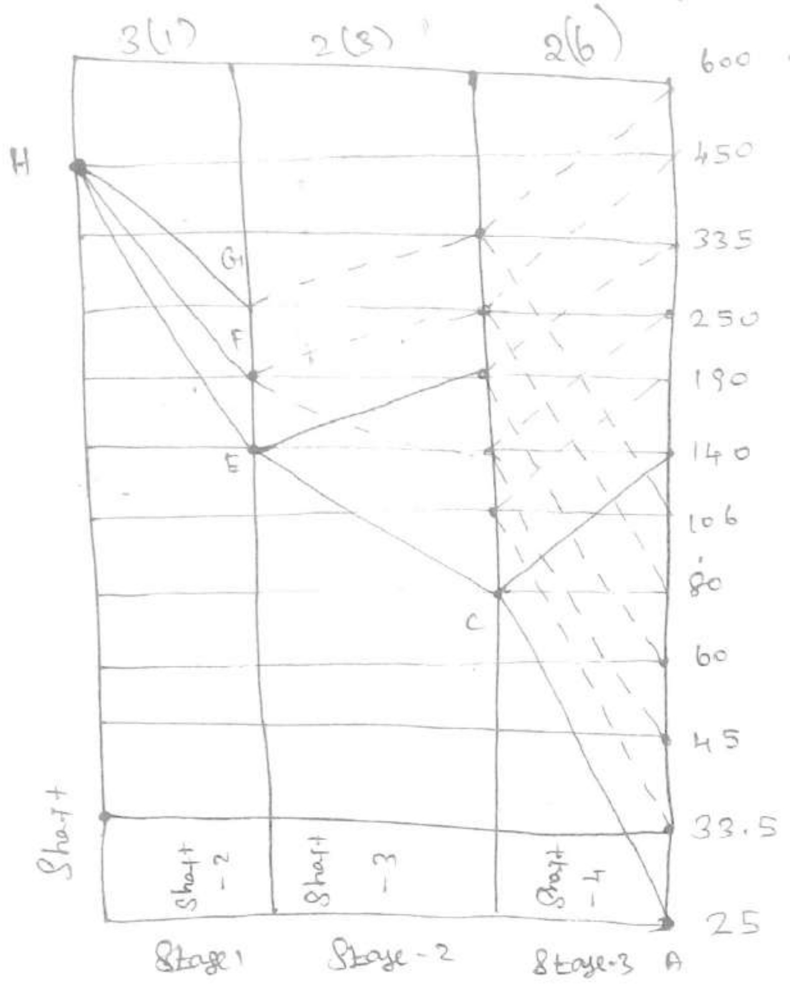
Structural formula 3(1) 2(3) 2(6)

Stage (3)

$$\frac{N_{min}}{N_{input}} = \frac{25}{80}$$

$$= 0.3 > \frac{1}{4}$$

Ray diagram for 12 Speed Gear Box.



$$\frac{N_{max}}{N_{input}} = \frac{140}{80}$$

$$= 1.75 < 2$$

Stage 2 $\frac{N_{max}}{N_{input}} = \frac{80}{140} = 0.57 > \frac{1}{4}$ and

$$\frac{N_{max}}{N_{input}} = \frac{190}{140} = 1.36 < 2$$

Stage -1 $\frac{N_{min}}{N_{input}} = \frac{140}{450} = 0.311 > \frac{1}{4}$

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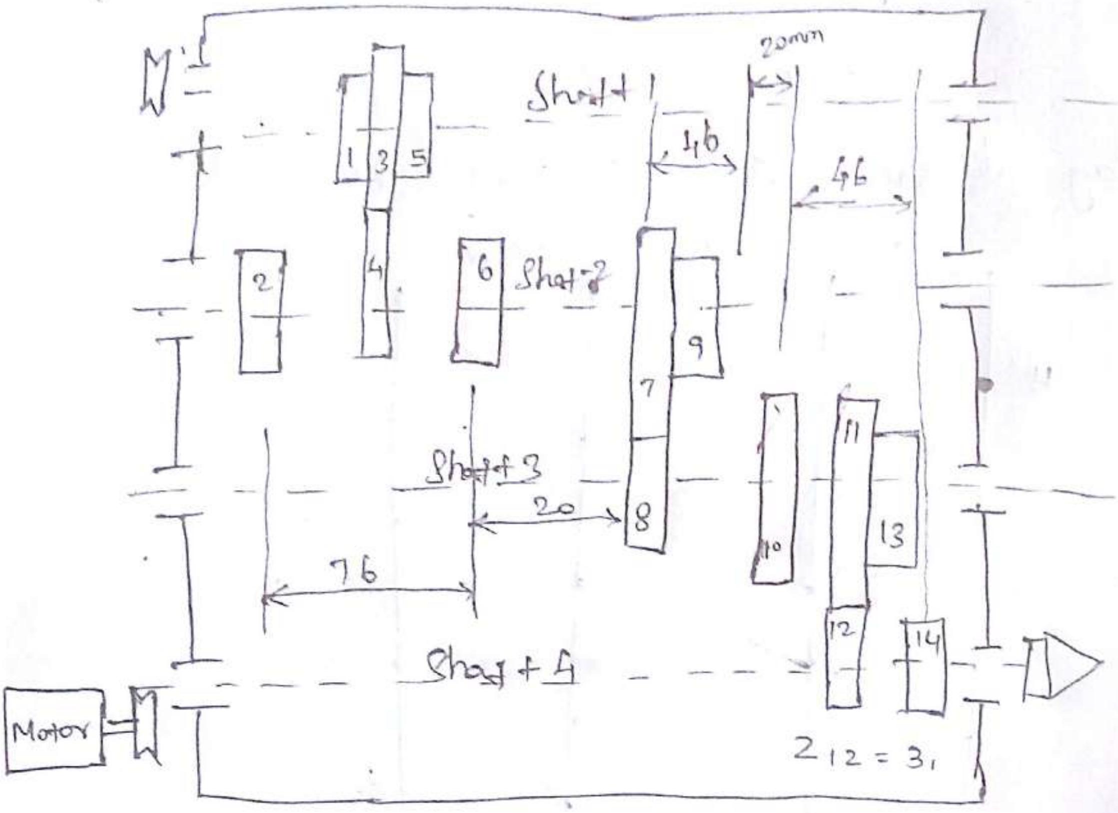
$$\frac{N_{max}}{N_{input}} = \frac{250}{450} = 0.56 < 2$$

Ratio requirements are satisfied

3, Kinematic arrangement :



4, Calculation of number of teeth on all gears :

The number of teeth in all gear are Calculated as below.

Stage 3:

First ~~gear~~ Pair

Consider the ray that gear maximum reduction is from 80rpm to 25rpm. The Corresponding gears are 13 and 14 Shaft 4

We know that $Z_{min} \geq 17$ Therefore $Z_3 = 2,$

$$\frac{Z_{13}}{Z_{14}} = \frac{N_{14}}{N_{13}} \text{ or } \frac{20}{Z_{14}} = \frac{25}{80} = N_{14} = 64$$

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Second Pair:

Consider the other ray that given speed in crease from 80 rpm to 140 rpm. The Corresponding gears are 11 and 12

$$\frac{N_{11}}{N_{12}} = \frac{N_{12}}{N_{11}} = \frac{140}{80} \text{ or } Z_1 = 1.75 Z_{12}$$

$$Z_1 + Z_{12} = Z_{13} + Z_{14} = 20 + 64 = 84$$

Solving equ (i) and (ii)

$$Z_{12} = 30.5 = 31 \text{ and } = 84 - 31 = 53$$

Stage : 2

First Pair

$$\frac{Z_9}{Z_{10}} = \frac{N_{10}}{N_9} \text{ or } \frac{20}{Z_{10}} = \frac{80}{140}$$

$$Z_{10} = 35$$

Second Pair

$$\frac{Z_7}{Z_8} = \frac{N_8}{N_7} = \frac{190}{140} \text{ (or) } Z_1 = 1.357 Z_8$$

$$Z_1 + Z_2 = Z_9 + Z_{10} = 201 + 35$$

Solving Equation (iii) and iv

$$Z_0 = 23.3 \text{ and } Z_1 = 55 - 24$$

Stage : 1

$$Z_{12} = 20$$

$$\frac{Z_1}{Z_8} = \frac{N_6}{N_5}$$

$$\frac{Z_0}{Z_8} = \frac{140}{450}$$

$$Z_8 = 64 \cdot 28 = 66$$

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Second Pair

$$\frac{Z_3}{Z_4} = \frac{N_4}{N_3} = \frac{190}{450} \text{ (or) } Z_3 = 0.422\,Z$$

$$Z_3 + Z_4 = Z_5 + Z_6 = 20 + 65 = 85$$

Solving Equation

$$Z_4 = 59.77 = 60$$

$$Z_3 = 85 - 60 = 25$$

Thired Pair

$$\frac{Z_1}{Z_2} = \frac{N_2}{N_1} = \frac{250}{450}$$

$$Z_1 = 0.55 Z_2$$

$$Z_1 + Z_2 = Z_3 + Z_4 = 60 + 25 = 85$$

On Solve to equation

$$Z_2 = 54.66 = 55 \text{ and } Z_1 = 85 - 55 = 30$$

5, Material Selection C45

6, Calculation of Module.

To find torque

$$T_{16} = \frac{P \times 60}{2\pi N} = \frac{2.25 \times 10^3 \times 60}{2\pi \times 25} = 859.44 \text{ Nm}$$

To find tangential force.

$$F_t = \frac{T}{r} = \frac{2 \times T_{16}}{Z\,m}$$

$$T = F \times r \text{ and } r = \frac{Z \times m}{2}$$

$$= \frac{2 \times 859.44 \times 10^3}{64 \cdot m} = \frac{26851.5}{m}$$

We know that module

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$$m = \sqrt{F_t / \psi_m \times m}$$

$$\psi_m = b/m = 10$$

m = material Constant = 30

30 for C45 from table

$$m = \sqrt{\frac{26857.3/m}{10 \times 30}}$$

$$= \sqrt{\frac{89.5252}{m}}$$

$$m^2 = 89.52/m$$

$$m = 4.47$$

Table 5.8 nearest higher Standard module = 5mm

7, Cancalation of Centre distance

Centre distance stage 1 $a_1 = \left(\frac{Z_1 + Z_2}{2}\right)m$

$$= \frac{30 + 55}{2} \times 5 = 222.5mm$$

Centre distance stage 2 $a_2 = \left(\frac{Z_7 + Z_8}{2}\right)m$

$$= \left(\frac{31 + 24}{2}\right) 0.5 = 137.5mm$$

Centre distance stage 3 $a_3 = \left(\frac{Z_1 + Z_2}{2}\right)m$

$$= \left(\frac{53 + 30}{2}\right) 5 = 200mm$$

8, Calculate of face width

$$b = \psi \times m = 10 \times 5 = 50mm$$

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9, Calculation of length of shaft is distance b/w to bearing

$L = 25 + 10 + 76 + 20 + 4b + 20 + 4b + 10 + 25$

$= 110 + 15b$

$= 110 + (15 \times 50) = 86mm$

10, Design of Shaft

Design of Spindle output Shaft

$$m = \frac{F_n \times L}{4}$$

$$F_n = \text{Natural Load} = \frac{E}{\cos\alpha_1}$$

$$= \frac{26857/m}{\cos\alpha} = \frac{268575/5}{\cos 2}$$

$= 3716.23N$

$$\text{Max. bending Moment } M = \frac{5706.23 \times 860}{4}$$

$= 12.29 \times 10^6 \, N\text{-mm}$

To find equal Torque

$$T_{eq} = \sqrt{m_2^2 + T_{14}^2} = \sqrt{(12.29 + 10^2)^2 + (859.44 \times 10^3)}$$

$= 1.5 \times 10^6 \, N.mm$

Dia of the Spindle is given

$$d_s = \left(\frac{16 \times T_{eq}}{\pi \times Z}\right)^{1/3}$$

$Z = 30 \, N/mm^2$ from table

$$= \left(\frac{16 \times 1.5 \times 10^6}{\pi \times 30}\right) = 63.58 \, mm$$

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Rounded of Value of the dia using

R_4 Radius is 67mm

Design of other Shafts

Dia of Shaft (1)

Input Speed = 450rpm

$$\text{Torque} = \frac{P \times 60}{2\pi N} = \frac{2.25 \times 10^3 \times 60}{2\pi \times 450}$$

$$= 47.746 \text{mm}$$

$$T = 0.2 d^3 (z)$$

$$47.746 \times 10^3 = 0.2 d^3 \, 30$$

$$d_2 = 19.96 \text{mm} = 20\text{mm} \ (R_4 \text{ Series})$$

Dia of Shaft (2):

Min Speed = 140rpm

$$\text{Torque} = \frac{P \times 60}{2\pi N} = \frac{2.25 \times 10^5 \times 60}{2\pi \times 140}$$

$$= 153.47 \text{ Nm}$$

$$T = 0.2 d^3 (\pi)$$

$$153.47 \times 10^3 = 0.2 d_a^3 \times 30$$

$$= 29.46 \text{mm}$$

$$= 30 \text{mm} \ R_4 \text{ Series}$$

Dia of Shaft (3)

min Speed = 80rpm

$$\text{Torque} = \frac{P \times 60}{2\pi N} = \frac{225 \times 10^3 \times 60}{2\pi \, 80}$$

$$= 268.57 \text{N-m}$$

$$268.57 \times 10^3 = 0.2 \times d_1^2 \times 30$$

$$d_1 = 35.5 \text{mm}$$

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Speed Reducers:

Since mechanisms are operated at moderately high Speeds and Some of with very low Speeds. But the input Speed Supplies to the above machines by the motor will be Some Standard high value.

Type of Speed Reducers:

a) Single Reduction Speed Reducers
b) Multi Reduction Speed Reducers

Torque Convertor:

This is a mechanism designed to get a mechanical advantage or gear ratio by hydraulic transmission. Torque Convertor in automobile transmission gives a maximum gear ratio during Starting from rest. As the Speed increased this transmission gradually decreses the gear ratio.

Torque Convertor Consists of

1) An impeller which is a the driving member Connected to the engine
2) The turbine which is the driving member Connected to the Propeller Shaft

—— x —— x —— x —— x —— x ——

—— x —— x —— x —— x ——