Design a gear drive to give 18 speeds of a spindle of a milling machine. The drive from an electric Motor of 3.75 kw at 1440. The maximum and minimum speeds of the spindle are to be around 650 and 35 r.p.m respectively.

Given Data:-

$n = 18$; $P = 3.75 kW$, $N_{motor} = 1440$ rpm,

$N_{max} = 650$ r.p.m, $N_{min} = 35$ rpm.

To find :- Design the gear box

Solution.

1) selection of spindle speeds:-

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

$$\phi = 1.1875.$$

We can write, $1.06 \times \underline{(1.06 \times 1.06)} = 1.191$

$\phi = 1.06$ satisfies the requirement. Therefore the spindle speeds from R40 series, skipping 2 speeds, are given by,

35.5, 42.5, 50, 60, 71, 85, 100, 118, 140, 170, 200, 236, 280, 335, 400, 475, 560, 670 rpm.

2) Ray diagram:-

The ray diagram is constructed, as shown in fig.

Structural formula:-

2(1) 3(2) 3(6).

stage 3:-

$$\frac{N_{min}}{N_{input}} = \frac{35.5}{140}$$

$$= 0.253 > \frac{1}{4} \text{ and } I$$

$$\frac{N_{max}}{N_{input}} = \frac{280}{140} = 2.$$

Stage 2:-

$$\frac{N_{min}}{N_{input}} = \frac{140}{236}$$

$$= 0.59 > \frac{1}{4} \quad \text{and}$$

$$\frac{N_{max}}{N_{input}} = \frac{280}{236} = 1.186.$$

Stage 1:-

$$\frac{N_{min}}{N_{input}} = \frac{236}{475}$$

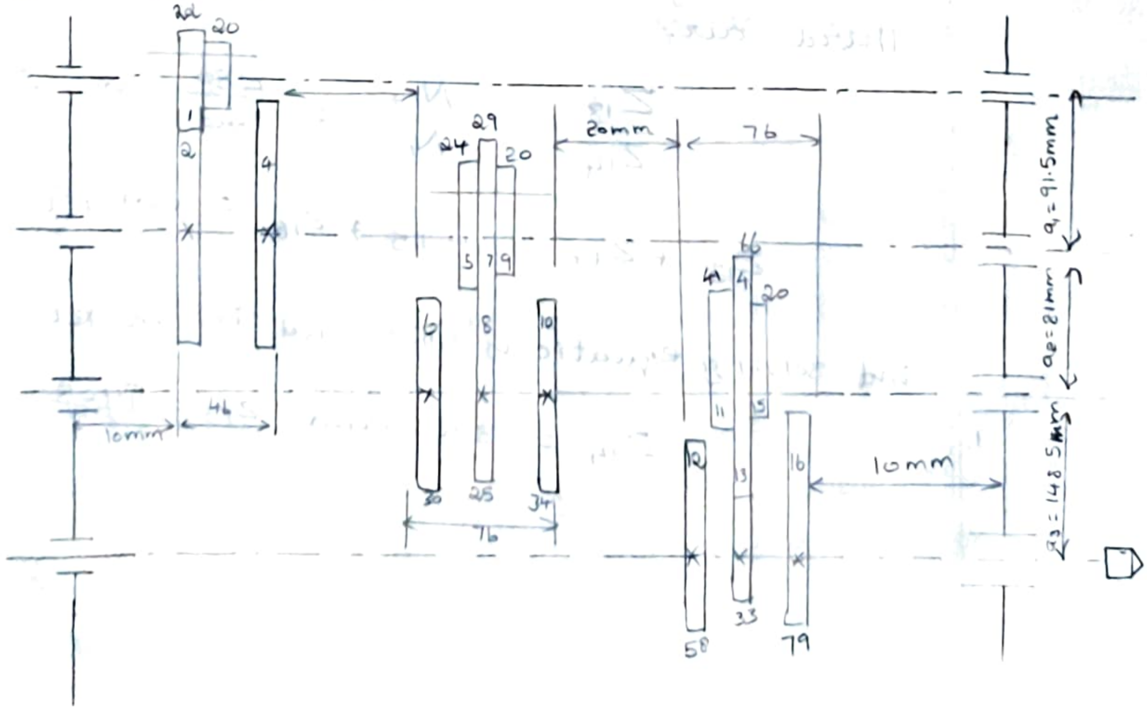
$$\Rightarrow 0.497 > \frac{1}{4} \quad \text{and}$$

$$\frac{N_{max}}{N_{input}} = \frac{280}{475} = 0.59 < 2.$$

∴ Ratio requirements are satisfied.

3) Kinematic arrangement :-

The Kinematic arrangement for the given 18 speed gear box is drawn.



4) Calculation of no of teeth on all g..

Stage 3:-

First pair:-

Consider the ray that gives maximum reduction from 140 r.p.m to 35.5 rpm

The corresponding gears are 15 and 16

Assume $Z_{15} = 20$ (driven)

$$\frac{Z_{15}}{Z_{16}} = \frac{N_{16}}{N_{15}} \text{ (or) } \frac{20}{Z_{16}} = \frac{35.5}{140}$$

$$Z_{16} = 78.87 = 79.$$

Second pair:-

Consider the other ray that gives speed reduction from 140 rpm to 100 rpm. The corresponding gears are 11 and 12.

$$\frac{Z_{11}}{Z_{12}} = \frac{N_{12}}{N_{11}} = \frac{100}{140} \text{ (or) } Z_{11} = 0.714\, Z_{12}$$

$$Z_{11} + Z_{12} = Z_{15} + Z_{16} = 20+79 = 99.$$

on solving the equations.., i) and ii), we get :,

$$Z_{12} = 57.75 = 58 \quad \text{and } Z_{11} = 99-58 = 41.$$

Third pair:-

$$\frac{Z_{13}}{Z_{14}} = \frac{N_{14}}{N_{13}} = \frac{280}{140} \text{ (or) } Z_{13} = 2 \times Z_{14}$$

$$Z_{13} + Z_{14} = Z_{15} + Z_{16} = 20+79 = 99.$$

and solving equations iii) and iv) we get.:

$$Z_{14} = 33 \quad \text{and } Z_{13} = 99-33 = 66.$$

Stage 2:-

First Pair:-

Consider the ray that gives maximum reduction from 236 to 140 rpm.

The corresponding gears are 9 and 10.

$$z_9 = 20 \text{ (driver)}$$

$$\frac{z_9}{z_{10}} = \frac{N_{10}}{N_9} \quad (\text{or}) \quad \frac{20}{z_{10}} = \frac{140}{236}$$

$$z_{10} = 33.71 \approx 34.$$

Second Pair:-

Other ray that gives speed reduction from 236 to 200 rpm. Corresponding gears are 5 and 6.

$$\frac{z_5}{z_6} = \frac{N_6}{N_5} = \frac{200}{236} \quad (\text{or}) \quad z_5 = 0.847z_6$$

$$z_5 + z_6 = z_9 + z_{10} = 20+34 = 54.$$

Third Pair:-

Consider other ray that gives the speed increase from 236 to 280 rpm. Corresponding gears are 7 and 8.

$$\frac{z_7}{z_8} = \frac{N_8}{N_7} = \frac{280}{236} \quad (\text{or}) \quad z_7 = 1.186\, z_8.$$

$$z_7 + z_8 = z_9 + z_{10} = 20+34 = 54.$$

On solving equations vii) and viii) we get,

$$z_8 = 24.69 \approx 25 \quad \text{and} \quad z_7 = 54-25 = 29.$$

Stage 1:-

First Pair:- Consider the ray that gives speed reduction from 475 to 236 rpm. Corresponding gears are 3 and 4

$$z_3 = 20 \text{ (driver)}$$

$$\frac{Z_3}{Z_4} = \frac{N_4}{N_3} \quad (or) \quad \frac{20}{Z_4} = \frac{236}{475}$$

$$Z_4 = 40.25 \approx 41.$$

Second Pair:-

Consider the other ray that gives speed reduction from 475 to 280 rpm. corresponding gears are 1 and 2.

$$\frac{Z_1}{Z_2} = \frac{N_2}{N_1} = \frac{280}{475} \quad (or) \quad Z_1 = 0.59 Z_2$$

$$Z_1 + Z_2 = Z_3 + Z_4 = 20 + 41 = 61.$$

on solving equations...,

$$Z_2 = 38.37 \approx 39 \quad \text{and}$$

$$Z_1 = 61 - 39 = 22$$

Material selection:-

Take 40 Ni 2 Cr 1 Mo 28 (hardened and Tempered).

6) Calculation of Module:-

✓ To find Torque:-

The gear 16 has the lowest speed of 35.5 rpm.

$$T_{16} = \frac{P \times 60}{2\pi N} = \frac{3.75 \times 10^3 \times 60}{2\pi \times 35.5} = 1008.73 \text{ N-m}$$

✓ To find Tangential force on gear 16:

$$F_{t16} = \frac{T}{r} = \frac{2 \times T_{16}}{Z_{16} \times m}.$$

$$\Rightarrow \frac{2 \times 1008.73 \times 10^3}{79 \times m} = \frac{25537.43}{m}$$

We know that, Module

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

$$\psi_m = b/m = 10 \quad \text{and}$$

ψ = Material constant = 100, for 40Ni 2Cr 1Mo28
from table 9.4

$$m = \sqrt{\frac{(25527.43/m)}{10 \times 100}} = \sqrt{25.537/m}$$

$$(or)\ m^2 = 25.537/m$$

Module, $m = 2.945$ mm.

The nearest higher standard Module is 3 mm.

Calculation of centre Distance:

✓ Centre distance in stage 1, $a_1 = \left(\frac{z_1+z_2}{2}\right)m$

$$\Rightarrow \left(\frac{22+39}{2}\right)3 = 91.5\ mm$$

✓ Centre distance in stage 2, $a_2 = \left(\frac{z_5+z_6}{2}\right)m$

$$\Rightarrow \left(\frac{24+30}{2}\right)3 = 81\ mm$$

✓ Centre distance in stage 3, $a_3 = \left(\frac{z_{11}+z_{12}}{2}\right)m$

$$\Rightarrow \left(\frac{41+58}{2}\right)3 = 148.5\ mm$$

8. Calculation of face width:-

$$b = \psi \times m = 10 \times 3 = 30\ mm$$

9) Calculation of length of shaft :-

Length of shaft, $L = 25+10+46+20+76+20+76+10+25$

$$\Rightarrow 110 + 18b$$

$$\Rightarrow 110 + 18 \times 30 = 650\ mm$$

10) Design of Shafts:-

1) Design of Spindle i.e., output shaft;

Maximum bending Moment, $M = \frac{F_n \times L}{4}$

Where F_n = Normal load on gear $= \frac{F_t}{\cos\alpha} = \frac{(25537.43/n_1)}{\cos\alpha}$

$$\Rightarrow \frac{25537.43/3}{\cos 20°} = 9058.79\,N.$$

$$M = \frac{9058.79 \times 650}{4} = 1.472 \times 10^6\,N\text{-}m.$$

✓ Equivalent Torque, $T_{eq} = \sqrt{M^2 + T_{16}^2}$

$$\Rightarrow 1.784 \times 10^6\,N\text{-}mm.$$

✓ Diameter of Spindle is given by:-

$$d_s = \left[\frac{16 \times T_{eq}}{\pi [\tau]}\right]^{1/3} \text{ Where } [\tau] = 55\,N/mm^2$$

$$\Rightarrow \left[\frac{16 \times 1.784 \times 10^6}{\pi \times 55}\right] = 54.87 \simeq 56\,mm$$

ii) Design of other Shafts:-

a) Diameter of Shaft 1:-

input speed = 475 rpm.

$$\text{Torque} = \frac{P \times 60}{2\pi N} = \frac{3.75 \times 10^3 \times 60}{2\pi \times 475}$$

$$\Rightarrow 75.39\,N\text{-}m$$

$$T = 0.2 \times d_s^3 \times [\tau]$$

$$75.39 \times 10^3 = 0.2 \times d_{s1}^3 \times 55$$

$$d_{s1} = 18.99\,mm \approx 19\,mm$$

Diameter of shaft 2:

min. speed = 236 rpm

$$\text{Torque} = \frac{P\times 60}{2\pi N} = \frac{3.75\times10^3\times 60}{2\pi\times 236}$$

$$\Rightarrow 151.74\ \text{N-m}.$$

$$151.74\times10^3 = 0.2\times d_{s2}^3\times 55$$

$$d_{s2} = 23.98\ \text{mm} \approx 25\ \text{mm}$$

(R40 series)

Diameter of shaft 3:

Minimum speed = 140 rpm.

$$\text{Torque} = \frac{P\times 60}{2\pi N} = \frac{3.75\times10^3\times 60}{2\pi\times 140}$$

$$\Rightarrow 255.78\ \text{N-m}.$$

$$255.78\times10^3 = 0.2\times d_{s3}^3\times 55$$

$$d_{s3} = 28.54\ \text{mm} \approx 30\ \text{mm}$$

(R40 Series.

Ray diagram for 18 speed gear box.