Mechanical Transmission /Drives

Mechanical drives can be broadly classified as:

1. **Positive drives**: In these, the driver and the driven elements, mesh with each other (gears), or with the power transmitting elements (chains).
2. **Frictional drives**: Belts and clutches rely on friction for power transmission. There is always possibility of slip, under high speed (above 30 m/sec in belts), or due to overload, Timer belts with a toothed profile on the inside, are used for light load. The provide almost slip free transmission.

Positive drivers are suitable for low speed (below 6m/sec), high-torque applications, while frictional drives are more convenient and economical for high speed (above 15m/s), low-torque applications.

The resultant efficiency of a composite drive, will be a multiple of the efficiency of the constituent drives.

$$\eta = \eta_1 \times \eta_2 \times \eta_3$$

$$\text{Power rating of motor} = \frac{cutting\ Power\ (kW)}{\eta}$$

Example 1

A turning lath is required to machine M.S/C.I workpieces of 100 diameter with 4mm roughing cut, at 25m/min speed, at 0.5/revolution feeds. Belt is used for drive from motor to the gear box input shaft at efficiency of 90%. The gear box reduces the spindle speed, further to required value. Find

(i) The cutting power
(ii) Overall efficiency
(iii) Rating of motor

Solution

$$N = \frac{1000V}{\pi D} = \frac{1000 \times 25}{\pi \times 100} = 79.6$$

The nearest standard spindle speed is 80 R.P.M (Table 1)

In turning axial linear speed of cutting tool = Nf ;

Where

N = R.P.M and f =Feed rate/rev.

As specific power is stated in mm/sec, all related values will be converted to cm/sec .

$$\therefore Linear\ Feed\ Rate = N_f = 80 \times 0.5/10\ per\ \min$$
$$= 4cm/\min$$
$$Linear\ feed\ rate/\sec = \frac{4}{60} = 0.067\ cm/\sec$$

The 4mm cut removes material in the annular area between 100 and 92 (100-2 x 4) diameters

Material removal/sec (mm) = 0.7854 x ($10^2 – 9.2^2$) x 0.067 = 0.808

Among M.S. and C.I, hardness can be higher for C.I. Specific power for C.I. (24,BHN) is 2.51 kW/mm.sec.

$$\therefore Cutting\ power = 2.51 \times 0.808$$
$$= 2.03\,kW$$

Increase in power requirement due to worn-out tool can be 100% in rough turning

$$\therefore Max,\ cutting\ power = 2.03 \times 2 = 4.06\ kW$$
$$overall\ \eta = \eta_1\ (belt) \times \eta_2\ (gear) \times \eta_3\ (motor)$$
$$= 0.9 \times 0.7 \times 0.9 = 0.567$$
$$Rating\ of\ motor = \frac{4.06}{0.567} = 7.16\,kw$$
$$= 7.5\ (nearest\ higher\ s\tan dard\ rating)$$

Motor speed should preferably be at mean value of speeds (R.P.M)

Example 2

A machine tool spindle has six speed 355, 600, 710, 1,000, 1400 and 2,000. Select suitable speed for a 75kW motor. Draw the ray diagram for the arrangement, assuming belt drives.

Solution

Preferable electric motor speed = N_m

$$N_m = \frac{N_{\min} + N_{\max}}{2} = \frac{355 + 2000}{2}$$
$$= 1177.5$$

From table 2, it can be seen that the nearest minimum motor speed is 950 R.P.M, for six pole motors above 3.7kW.

It will be convenient to use a 2 stage transmission. The two intermediate speeds can be equal to the middle terms of the lower three speeds (355, 500, 710), i.e. 500 R.P.M., and the upper three speeds (1,000, 1,400, 2000) i.e. 1400 R.P.M. Then the intermediate shaft should have two speeds: 500 and 1400 R.P.M.

- For drawing the ray diagram (Fig.3a) draw three parallel vertical lines with suitable spacing (say 50mm). the left line will represent the input motor shaft, the middle-the intermediate shaft, and the right one-the output at the machine spindle.

- On the right, on the spindle line, mark six equidistant points with suitable spacing, say 20mm. These six points represent six spindle speeds. Write the speeds on the right of the line: the lowest speed (355) at the lowest point, and each higher speed near the next higher point, with 2000 at the uppermost point.
- Draw from the points representing speeds 500 and 1,400 R.P.M, horizontal lines towards the left, to meet the middle line for the intermediate shaft. Mark intercept points with speeds 500 and 1400 R.P.M.
- Join the point for 500 R.P.M on the intermediate shaft, with the points representing lower speeds 355 and 710 R.P.M. Similarly, join the point for 1,400 R.P.M on the intermediate shaft, with points for 1,000 and 2000 R.P.M, on the spindle shaft. We now have the ray diagram for transmission between the spindle and the intermediate shaft.
- Now, Mark a point on the left input line, representing motor R.P.M 950. It will be almost in line with the point representing 1000 R.P.M on the right (spindle) shaft line. Write the motor speed near the point.
- Join the motor speed point with the intermediate speeds points 500 and 1400, on the middle line to finish the ray diagram.

Suppose the 950 R.P.M is not immediately available. We can use the commercially popular 1410 R.P.M motor, or 700 R.P.M motor. Still, the intermediate shaft speed can remain the same. Fig. 3b shows the ray diagram for a 1,400 R.P.M, motor, while Fig. 3c shows the speed chart for a 700 R.P.M motor. Ray diagrams or speed chart are blue-prints plans for speed change to be effected.

The most important parameter in a speed chart is the transmission ratio (i). As each stage of speed change might involve a maximum of three transmission ratios. We will distinguish them by the suffices ‘h’ (higher), ‘m’ (middle), and ‘l’ (lower). Similarly, shafts involved in the changes will be distinguished by the stage suffixes for input, I, II, III etc. for the following stages; i.e

Transmission Ratio (i) = $\frac{Input\ R.P.M}{Output\ R.P.M}$

$$= \frac{N_1}{N_2}\left(or\ \frac{N_2}{N_3}, \frac{N_6}{N_5}\ etc \right)$$

Thus, for the transmission ratios between motor shaft I and intermediate shaft II in Fig. 3a are:

$$^{i}I\,II\,h = \frac{950}{1400} = 0.678\ and\ ^{i}I\,II\,1 = \frac{950}{500} = 1.9$$

Ratio for Fig.3b will be:

$$^{i}I\,II\,h = \frac{1410}{1400} = \frac{141}{140} = 1.007$$

$$^{i}I\ II\ 1 = \frac{1410}{500} = 2.82$$

Assignment:

Deduce transmission ratio for Fig. 3c as an exercise

BELT DRIVES

Belt drives are more convenient for higher speed. The transmission capacity decreases with a decrease in the angle of the arc of contact (Table 3). At speeds exceeding 10m/s, there is a slip between the belt and the pulley (Table 4). It affects the torque capacity (Table 5). V belts with 40^o included angle and thicker cross section must have higher diameter pulleys, for proper contact.

Table 5 gives d the minimum pulley diameter, and (Fig. 4) gives the groove size, margins, and angles, for various standard sections. Bigger pulley diameter depends upon the transmission ratio(i).

For V belt, the ideal center distance can be found from the following equation:

$$\text{Centre distance} = C = \frac{1.5D}{\sqrt[3]{i}}$$

$$C_{\min} = 0.55\,(d + D) + h$$

$$C_{\max} = 2(d + D)$$

The center distance (C) must be adjusted to permit usage of standard belt lengths available. Belts are specified by inside length (Li). The pitch line length (L_p), used for finding the center distance between pulley passes through the neutral axis of the belt.

$$L_p = L_i + p$$

Note: ‘V’ belts are graded in length. The grade unit is 2.5 in inside (or pitch) length. 610-1168, 5 in lengths 1219-1778, 7.5 in lengths 1905-1168, 10 in lengths 2464-4013, 12.5 in lengths 4115-6807, 15 in length 7569-9093 and 17.5 in lengths 9855-16713. Suffix 50 means the actual length is equal to the specified standard length.

B 1016-49 means that the B section (17 x 11) belt has length, one unit (50-49) less than the standard length , The unit is 2.5 for lengths 610-1168. It means the belt is shorter by 2.5, i.e.

Actual length = 1016-2.5 = 1013.5

Similarly, C 3404-52 means the C section (22 x 14) belt is 2 units (52-50) longer than the standard length 3,404.

Actual length = 3,402 + 2 x 10 (unit for length, (2,464 – 4013) = 3,422.

When more than one belt is used, the belts longer than the shortest, are stretched less. They will transmit lesser power than the shortest belts. None of the additional belts can transmit as much power as the most stretched belt.

Machine design by Berezovsky, Chernilevsky, and Petroy gives a simpler and more logical method for length variation compensation in a multi-belt drive. This method uses the coefficient ‘M’ to take care of unequal tension due to variation in belt length.

For very long center distances, it is necessary to increase the pulley diameters, to satisfy equations for maximum and minimum center distances earlier discussed.

The center distance (C) for any given belt length can be found from the following equation:

$$C = 0.25\left[L_p - 1.57(d+D) + \sqrt{\left(L_p - 1.57(d-D)^2 - 2(D-d)^2\right)}\right]$$

As V belt wedge in pulley grooves, the transmit more power than flat belts, lesser tension necessarily decreases the load on the shaft and bearings. ‘V’ belts ad more compact drive than that belts. However [higher deformation of V belts makes them less efficient 92% than flat belts (97%). Also, the shaft used for ‘V’ belt transmission should be parallel.

Standard Pulley Diameter

40,45,50,56,63,71,80,90,100,112,125,140,160,180,200,224,315,355,400,450,500,560,630,710,800,900,1,000, 1120,1250, 1,400,1600,1800,2000 (1mm=0.03937^{o})

Standard Pulley widths: 20,25,32,40,50,63,71,80,90, 100, 112, 125, 140,160, 180,200, 224, 250, 280, 315, 355, 400, 450, 500, 560, 630 (1mm = 0.03937^{o}).

Power Transmitted by ‘n’ belts (kW)

$$P_n = \eta \times \frac{NTAVM_n}{(S+I)1000}$$

where

N = R.P.M of driving pulley

T = Torque transmitted by one belt (kgm)

A = coefficient for arc of contact (α) for smaller pulley (Table 3)

$\alpha = \left[180 - 60\frac{D-d}{C} \right]$ where D and d are big and small

Pulley diameters and C the center distance, ‘A’ from Table 3

V= velocity coefficient from Table 4

M = multi-belt drive factor from Table 6b

n = No of belts

S = Service factor Table 7

I = Idler correction I from Table 8

η = Efficiency of transmission= 92% for V belts, 97% for flat belts

Example

Design belt drives between shafts I and II for a 2.2kw transmission system shown in (fig.) that would run for about 8hrs everyday.

Solution

From the Figure 3c , the motor speed = 700 R.P.M

The intermediate sped are 1,400 and 500 R.P.M and the spindle speeds are 2,000, 1400, 1000, 710, 500, and 355 R.P.M.

Assuming a single ‘V’ ; belt transmission between shafts I and II and arc of contact = 180^o ; η = 100% = 1.0 , N=700 (at motor); A = 1, V = 1, for preliminary torque computation. From Table 7, for a daily 8hrs run, service factor S = 1, for normal torque light duty drive (without idler).

From the above,

$$P_n = 2.2 = \frac{700 \times T \times 1 \times 1 \times 1}{1 \times 1000}$$

$$T = \frac{2.2 \times 1000}{700} = 3.143\, kgM$$

$$= 3{,}143\ kg\ mm$$

From Table 5 ‘A’ size belt with 6kgm torque capacity, would be suitable.

Note: Calculating pulley diameter-first, for higher transmission ratio saves time.

Transmission ratio = $i_t = I_{th} = \frac{1400}{700} = 2$

As the intermediate shaft has a higher speed (1400), it will carry the smaller pulley i.e. ϕ 90 (Table 5)

The motor shaft will have a bigger pulley.

$$\therefore\ d_1 = 90;\ D_1 = \frac{1400}{700} \times 90 = 180$$

While using stepped pulleys the sum of the small (d) and big (D) diameters should be kept equal to facilitate the usage of same belt length.

$$d_1 + D_1 = d_2 + D_2 = d_3 + D_3$$

Transmission ratio for 500 R.P.M on intermediate shaft II = $i_{1\ II\ 1}$

$$i_{(II)} = \frac{500}{700} = \frac{5}{7}$$

$$d_2 + D_2 = d_2 + \frac{7}{5} d_2 = d_1 + D_1 = 90 + 180 = 270$$

$$d_2 = \frac{270}{2.4} = 112.5\ and\ D_2 = 112.5 \times 1.4 = 157.5$$

$$C = \frac{3.5D}{\sqrt[3]{i}} = \frac{1.5 \times 157.5}{\sqrt[3]{\frac{5}{7}}} = 264.3$$

From, $C = 0.25\left[L_p - 1.57\left(d + D\right) + \sqrt{\left(L_p - 1.57(d - D)^2 - 2(D - d)^2\right)}\right]$

$$C = 264.3 = 0.25\ (L_p + 1.57(112.5 + 157.5) +$$
$$\sqrt{(L_p - 1.57(112.5+157.5)^2 - 2(157.5 - 112.5\ )^2}$$
$$= 0.25(L_p - 423.9 + \sqrt{(L_P^2 - 847.8L_p\ + 179691.21 - 4050}$$
$$= 0.25\ (L_p - 423.9 + \sqrt{(L_P^2 - 847.8L_p\ + 179641.21}$$
$$1057.2\ -\ L_p + 423.9 = \sqrt{(L_P^2 - 847.8L_p\ + 179641.21}$$
$$1481.1 - L_p = \sqrt{(L_P^2 - 847.8L_p\ + 175641.21}$$

Squaring both sides,

$$2193657.2 - 2962.2\ L_p + L_P^2 = L_P^2 - 847.8\ L_P + 175641.21$$
$$2193657.2 - 175641.21 = (-847.8 + 2962.2)\ L_p$$
$$L_p\ = \frac{1478942.4}{2114.4} = 954.4$$

From,

Inside length = $L_1 = L_p - P$

From Table 9 for A belt P = 35

$$\therefore\ \ L_i = 954.4 - 35 = 919.4$$

Reference to Table 10 shows that A914 belt can be used for the drive

Actual C = 0.25[(914+35) – 423.9 + $\sqrt{[949 - 423.9]^2 - 4050}$

= 261.5

Now, let us take other factors into account. The problem of arc of contact will be acute to the highest transmission ratio, i.e. 2.

$$\alpha\ = 180\ -\ 60\ \frac{D-d}{C}$$
$$= 180\ -\ 60\frac{180-90}{C} = 159.45^o,\ \textit{for smaller pulley}$$

From Table 3, A = 0.95 for 160° Arc

Velocity at the smaller pulley = $\frac{\pi dn}{60{,}000}$

$$= \frac{\pi \times 90 \times 1400}{60{,}000} = 6.6\ m/\sec$$

From Table 4, for 5m/sec. V=1.03

= 1.02 for 6.6m/sec

From

$$P_n = \eta \times \frac{NTAVMn}{(S+1)1000}$$
$$= \frac{0.92 \times 700 \times 3.143 \times 0.95 \times 1.02 \times 1}{(1+0)1{,}000}$$
$$= 1.96\,kW$$

The power capacity can be increased by placing idler within the belt loop, and pushing the slack side. The idler increases the arc of contact, and the power capacity. However, an idler outside the belt loop or/and on the taut side, decreases power capacity by increasing the device factor (Tables 7, 8).

Let us use flat belts for the three-stepped pulley, the statement that rubberized fabric belts can be used for 0.2-0.26 mm^2 effective tension.

From

$$d = 53 - 65\sqrt[3]{T}\ (T\ in\ Nm)$$
$$= 53 - 65\sqrt[3]{31.43} = 167.2 - 205.1$$

Nearest std. pulley diameters are 160 and 200

For ϕ 160 pulley on the intermediate shaft,

$$\text{Tensile force on belt} = \frac{T}{d/2} = \frac{3143}{160/2} = 39.28\,kg$$

$$\text{Belt cross sectional area} = \frac{39.28}{0.2} = 196.4\,mm^2$$

From , d ≥ 30 t

$$t = \frac{d}{30} = \frac{160}{30} = 5.33 = 5$$

$$Belt\ width = \frac{196.4}{5} = 39.28 = 40$$

For $i_{II\ III\ I}$ $D_3 + d_3 = D_3 - 0.71 \quad D = 337.2$

$$D_3 = \frac{387.2}{173} = 226 + d_3 = 5.75 \times 3.76 = 3$$

From

$$C = \frac{1.5D}{\sqrt[3]{i}} = \frac{1.5 \times 227.2}{\sqrt[3]{1.42}} = 303.2$$

$$= 303$$

Arc of contact – 189 – 50 $\dfrac{227.2 - 160}{303} = 166.7$

From Table 3

Linear speed at Φ 160 pulley, at 1,400 R.P.M

$$= \frac{\pi \times 360 \times 1400}{50 \times 1500} = 11.72\ m/\sec$$

From Table 4, for 11.7m/sec V = 0.98

No of belts = 1, M = 1, = 1.0, t =1 (From Table 7)

$$T = \frac{2290}{1400} = 1.57\,kg$$

$$P_n = \eta \times \frac{NT\ AV.M}{(S+I)1000}$$

$$= 0.97 \times \frac{1{,}400 \times 1{,}575 \times 0.487 \times 190 \times 1 \times 1}{(1+0)1{,}000}$$

$$= 2.02$$

It should be noted that flat belts transmit more power than 'V' belts, due to a 5% higher efficiency.

From Table 11, crown values for ϕ 160, 193.6 and 227.2 pulleys are 0.5, 0.6 and 0.6 respectively. Std. pulley width = 50.