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Tractor Systems & controls

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Module 1. Tractor Mechanics

Lesson 1. Determination of Centre of Gravity of wheeled and track type tractors

A tractor, in Indian context, can be defined as a wheeled, self propelled vehicle used as power source for towing agricultural implements or for driving threshers, pump sets or performing similar agricultural operations. Most Indian agricultural tractors fall in the category of general purpose tractors. For the purpose of understanding, the tractor can be divided into tractor engine and tractor system. The tractor engine on Indian agricultural tractors is the usual multi cylinder compression Ignition engine producing high torque at low speed. It is the tractor systems that make the agricultural tractor different from any other automobile designed for running on the roads.

The tractor systems include study of tractor mechanic, traction, transmission system, steering system, brakes, hydraulics and location of the controls.

Tractors mechanics present a very complex picture towards understanding of the design behind agricultural tractor. Some of the parameters that make the understanding of tractor mechanics difficult are listed as follows:-

1. Location of the center of gravity.
2. Traction produced by the traction devices.
3. Surface condition and slope of surface on which tractor is used.
4. Type of hitch system.
5. Load characteristics of the implement being used.
6. Power take off- both stationary as well as tractive.
7. Varied operational conditions.
8. Response of the tractor to dynamic forces.

Before going in to study the tractor mechanics, some assumptions that can be made to make the study less complex are listed as follows:-

1. Tractor is a four wheeled general purpose tractor with rear wheel drive.
2. The tractor has a uniform forward motion on a level surface.
3. The point of pull is mid way between the traction wheel and the line of pull is parallel to the direction of motion of the tractor.
4. The soil reaction is vertical and passing through the centre of the axle.
5. The traction force at the point to contact of traction wheel and ground surface is tangent to the traction wheel.

6. The rolling resistance is initially neglected.
7. All minor forces are neglected.

Location of Centre of Gravity

Importance: - The location of the centre of gravity determines the weight distribution on the wheels. Height of the centre of gravity above the ground is important especially during working on slopes or during high speed turns. Distance in front of the rear axle helps in improving pull exerted by the tractor.

In this context, it is important that the centre of gravity should be as low as possible leading to low ground clearance. But, since the tractor is supposed to move over, many times standing crop, a low ground clearance can cause a lot of problem. Distance in front of the rear axle increases the wheel base of the tractor. Longer wheel base means larger turning radius. But in the case of agricultural tractors, shortest possible turning radius is required, which is contrary to the location of the centre of gravity.

In general, it is a tendency while designing a tractor that the centre of gravity be as low as possible from stability point of view. On the other hand the tendency to have high ground clearance especially for use of tractors in growing crops, leads to the center of gravity being raised. Therefore a trade- off has to be struck to keep the center of gravity low and have high clearance over the crops, while designing the agricultural tractors.

As a thumb rule, the rear-wheel drive tractors usually have 55-80% of weight on the rear wheels. In case of all wheel drive tractors, the center of gravity is located ahead of the center of the tractor. For the track type tractors, the centre of gravity is located ahead of the middle plane of the tracks so that uniform soil pressure can be obtained under normal pull and load.

Determination of location of center of gravity

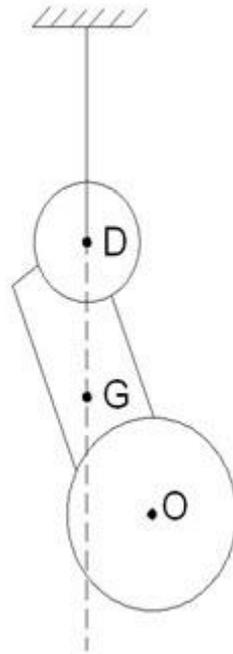
For accurate analysis of the mechanics of a tractor, it is important to determine the location of the center of gravity. A tractor consists of many fixed and movable parts. The fixed parts may include various assemblies such as the engine, gearbox, radiator, front axle, rear axle etc. on the other hand the movable parts include oil in the sump, air cleaner oil, coolant in the radiator, the operator changing his position, location of center of gravity, the affect of movable components is neglected.

It is important to use the three reference planes to determine the location of center of gravity. Since the tractors are approximately symmetrical about the longitudinal vertical plane passing through the mid points of the front and rear axle, it is assumed that the center of gravity will be on this plane.

Following methods can be used to determine the location of the center of gravity:-

Suspension Method I

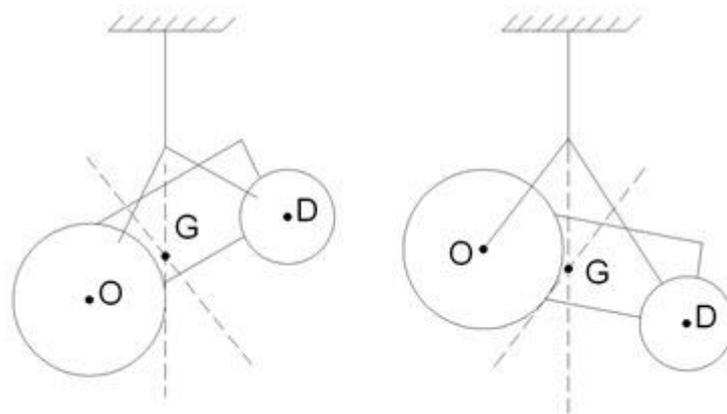
As shown in fig1.1(a), if a tractor is initially suspended from a point on, say the front axle using a crane hoist taking care that the front axle and rear axle are horizontal, then the center of gravity will be on the vertical plane passing.



through the point of suspension. If this can be repeated using another point of suspension, another vertical plane is derived. The point of inter section of these planes is the center of gravity of the tractor.

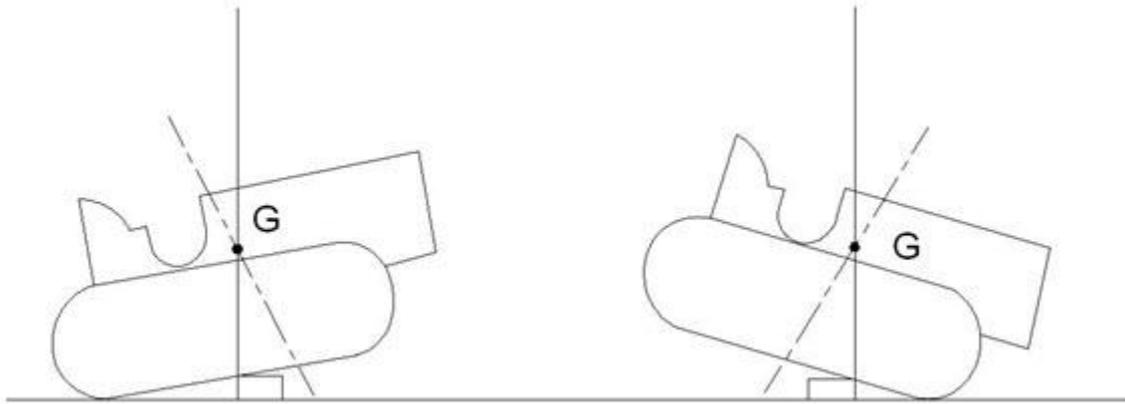
Suspension Method II

If a tractor is suspended (as shown in fig 1.2) using ropes (or chains) in such a way that one side is longer than the other. The tractor is suspended twice in such a way that one side is longer than the other. The tractor is suspended twice in such ways that in one case the longer side is attached to the rear axle and reverse in the second case. The intersection of the two vertical planes got in that case gives the location of the center of gravity of the tractor.



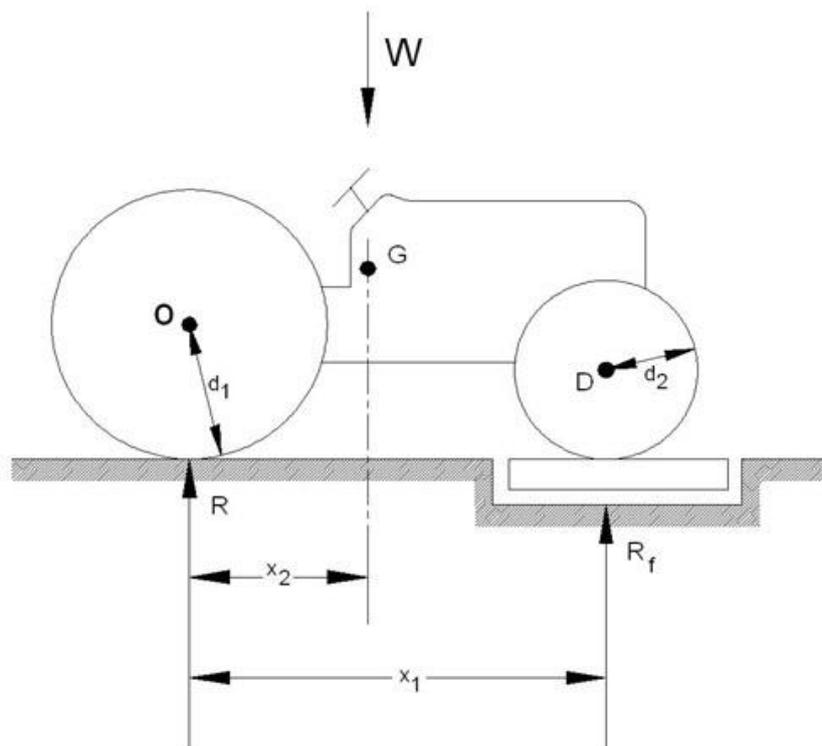
Balancing Method

The balancing method can be used to determine the location of center of gravity of track type tractors. In this case, a large block of wood of length equal to the overall width of the tractor and height of nearly 15 cm is used as shown in fig 1.3. It is balanced on the block while driving forward and then while driving in the reverse. The two vertical planes so got give the location of the center of gravity of the track type tractor.



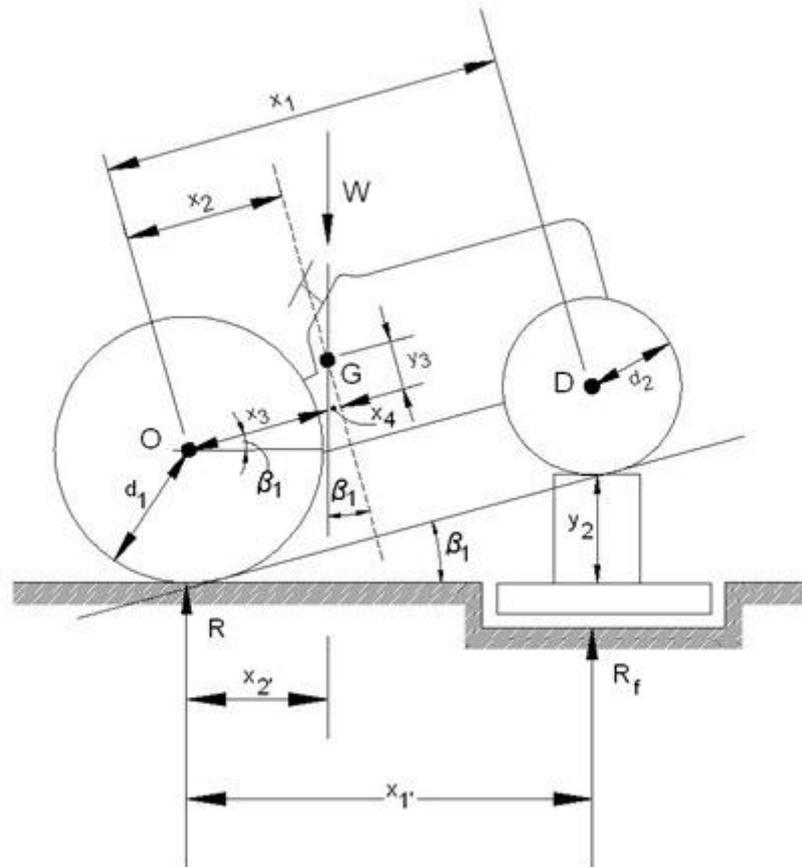
Weighing Method

The weighing method of finding the location of the center of gravity can be used in the laboratories. A weighing scale can be used to measure the total weight of the tractor and the reactions acting on the two wheels (fig 1.4(a) and (b)).



The weighing method of finding the center of gravity is easily applied. A vertical plane containing the center of gravity can be determined by the following equation:

$$x_2 = \frac{R_f x_1}{w} \tag{8}$$



If the front wheel of the tractor are raised a distance y_2 and R_f' determined, another plane containing the center of gravity may be obtained from the same equation (fig.14.6):

$$X_2' = \frac{R_f' x_2'}{w}$$

The intersection of these two planes will locate the center of gravity G. This location can be satisfactorily indicated by chalking the lines of the planes on the side of the tractor.

It should be pointed out that x_1' can be determined approximately by:

$$X_1' \approx x_1 \cos \beta_1 \tag{9}$$

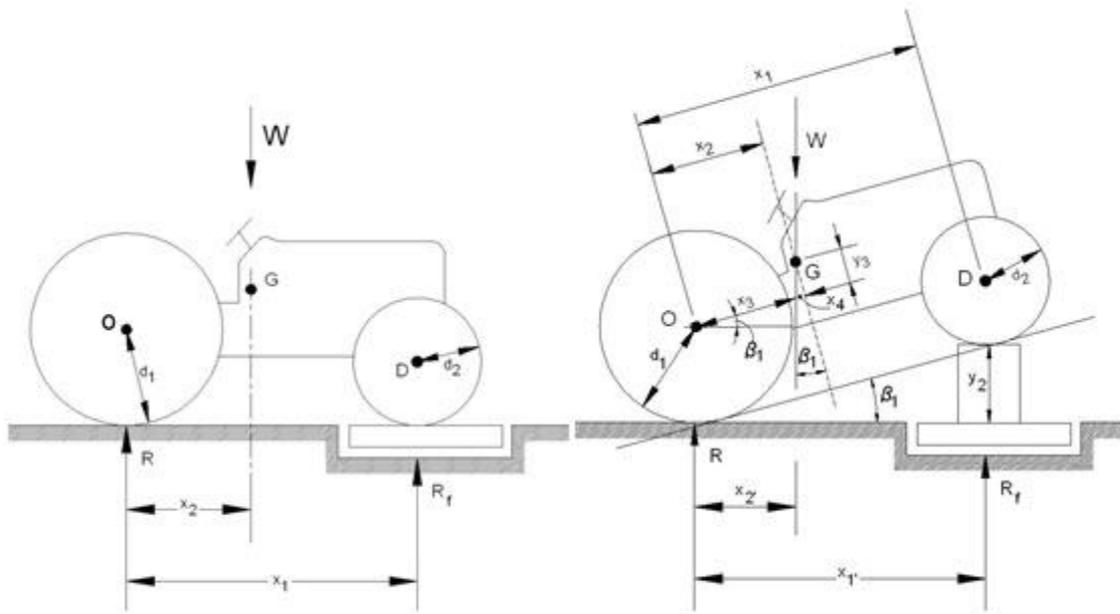
The error involved in using equation 9 is small and, in fact, is justified, considering weighing errors such as the effect of the tire tread and increased deformation of the rear tire when the tractor is tipped etc.



Lesson 2. Calculation of location of Centre of Gravity of a wheeled rear wheel drive tractor

As discussed in the previous lesson, weighing method can be applied for determining the location of the centre of gravity in laboratory conditions.

From the Fig.s 2.1 and 2.2, the various parameters can be determined.



Following parameters are measured before taking the tractor to a weighing balance:

- Wheelbase of the tractor
- Radius of front and rear wheels
- Height of the centres of front and rear wheels from the ground

When on the weighing balance, the parameters noted are:

- Total weight of the tractor
- Weight coming on the front and rear tyres.

These parameters are also measured when the front wheels are lifted by a height 'h'.

From Fig. 2.1

$$Wx_2 - R_f x_1 = 0$$

$$\text{or } x_2 = \frac{R_f x_1}{W} \dots\dots\dots(1)$$

so, a vertical transverse plane containing C.G. can be determine by the equation (1)
the front wheel of the tractor are raised distance Y_2 and R'_f is determined by weighing.

From Fig.1.2

$$Wx'_2 - R'_f X'_1 = 0$$

$$X'_2 = \frac{R'_f x'_1}{W}$$

From fig. 1.2

$$\tan \beta_1 = x_4 / y_3 \quad (2)$$

and $\tan \beta_1 = (x_2 - x_3) / y_3 \quad (3)$

or $y_3 = (x_2 - x_3) / \tan \beta_1$

and $\cos \beta_1 = x_2' / x_3 \quad (4)$

or $x_3 = x_2' / \cos \beta_1$

$$y_3 = \frac{x_2 - (x_2' / \cos \beta_1)}{\tan \beta_1} \quad (5)$$

Hence the height of CG from the ground is given by

$$h = \frac{d_r}{2} + y_3$$

where d_r is the diameter of the rear wheel.

Some assumptions while doing this analysis were:

1. The displacement of the point of contact of rear wheel on the ground as the front wheels are lifted is negligible.
2. There is no deformation of the pneumatic tyre at the point of contact i.e. height of centre of rear wheel is same as the radius of the rear wheel.



Lesson 3. Determination and importance of Moment of Inertia of a tractor

Moments Of Inertia

Moment of inertia is the property of a distribution of mass in space that measures its resistance to rotational acceleration about an axis. The Newton's first law can be extended in the terms that the inertia of a body that is rotating about an axis shall remain rotating unless acting upon by an external torque.

The moment of the inertia force on a particle around an axis multiplies the mass of the particle by the square of its distance to the axis, and forms a parameter called the moment of inertia. The moments of inertia of individual particles sum to define the moments of inertia of a body rotating about an axis.

Moment of inertia appears in Newton's second law for the rotation of a rigid body, which states that the torque necessary to accelerate rotation is proportional to the moment of inertia of the body. Thus, the greater the moment of inertia the torque needed for the same acceleration.

The moment of inertia of an object is defined by the distribution of mass around an axis. It depends not only on the total mass of the object, but also on the square of the perpendicular distance from the axis to each each elements of mass. This means the moment of inertia increases rapidly as masses are distributed more distant from the axis.

Mass Moments of Inertia Determination: If the rotational motion of a tractor is being considered, it is necessary to know its mass moment of inertia about the axis of rotation in question. The tractor may rotate about any one of its three axes: longitudinal, transverse, and vertical. There are more sophisticated methods for determining the mass moment of inertia than the one presented here which is quite basic.

If a tractor is suspended from a hoist, as in fig.14.3, the tractor plus the sling will be a compound pendulum which will oscillate with a frequency of:

$$f = \frac{(W_r/I_0)^{1/2}}{2\pi} \quad (1)$$

where I_0 = the mass moment of inertia about the pivot

f = the frequency in cps

W = the weight in lb

r = the radius in feet from the center of gravity to the pivot point of the sling holding the tractor.

From equation 1 everything can be measured except I_0 which can then be computed. The moment of inertia with respect to the center of gravity, I_{CG} , can then be computed as follows:

$$I_{CG} = I_0 - Wr^2/g \quad (2)$$

If English units of measurement are used, the dimensions of I will be in ft lb sec².

It is, of course, possible, but not practical, to compute the mass moment of inertia thus:

$$I = \sum_{i=1}^n m_i r_i^2 \quad (3)$$

If, however, it is to study the dynamic behavior of a tractor still in the drawing-board stage, it will be necessary to make an estimate of I by use of equation 3.

The pendulum method as described below can be readily used for determining the mass moment of inertia with respect to the transverse and longitudinal axes.

If a tractor in a cradle is suspended from a hoist (Fig. 2.1), the tractor plus the cradle will behave as a compound pendulum which will oscillate with a frequency of

$$f_0 = \frac{1}{2\pi} \left(\frac{W_r}{I_0} \right)^{0.5} \quad \dots\dots\dots (4)$$

Also the M.I. of cradle alone its axis of rotation is given by:

$$I_c = \frac{W_c}{4\pi^2} \frac{k}{f_1^2} \quad \dots\dots\dots (5)$$

The M.I of tractor plus cradle about the axis of rotation is given by:

$$I_0 = \frac{W}{4\pi^2} \frac{r}{f_0^2} \quad \dots\dots\dots (6)$$

The radius of gyration 'r' is given by:

$$r = \frac{K W_c + (H-Y) W_t}{(W_c + W_t)} \quad \dots\dots\dots (7)$$

Finally the required M.I of tractor about its C.G. is

$$I_{C.G} = I_0 - I_c - \frac{W_t}{g} (H - Y)^2 \quad \dots\dots\dots (8)$$

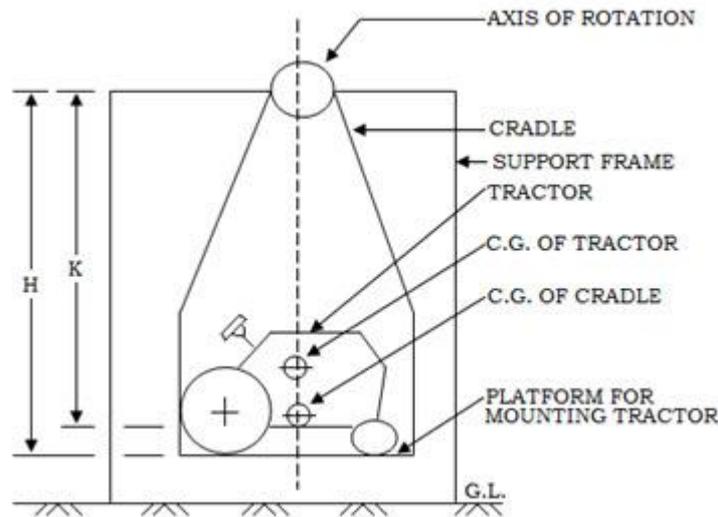


Fig. 2.1 Tractor mounted on cradle for determination of moment of inertia

Where:

- M.I = Moment of inertia, Kg-cm-sec²
 W = Weight of tractor + weight of cradle = $W_t + W_c$, Kgf
 r = Distance of C.G. of cradle plus tractor from axis of rotation, cm
 I_o = Mass moment of inertia of tractor and cradle about the axis of rotation of cradle, Kg-cm-sec²
 f_o = Frequency of oscillations of tractor plus cradle, cycles/sec
 f_1 = Frequency of oscillations of cradle, cycles/sec
 I_c = Moment of inertia of cradle about axis of rotation, Kg-cm-sec²
 $I_{c.g.}$ = Moment of inertia of tractor about the required axis through its centre of gravity, Kg-cm- sec²
 X, Y = Location of centre of gravity of tractor in horizontal and vertical directions and from rear wheel axle and ground level respectively, cm
 H = Height of axis of rotation above platform, cm
 K = Height of axis of rotation above centre of gravity of cradle, cm



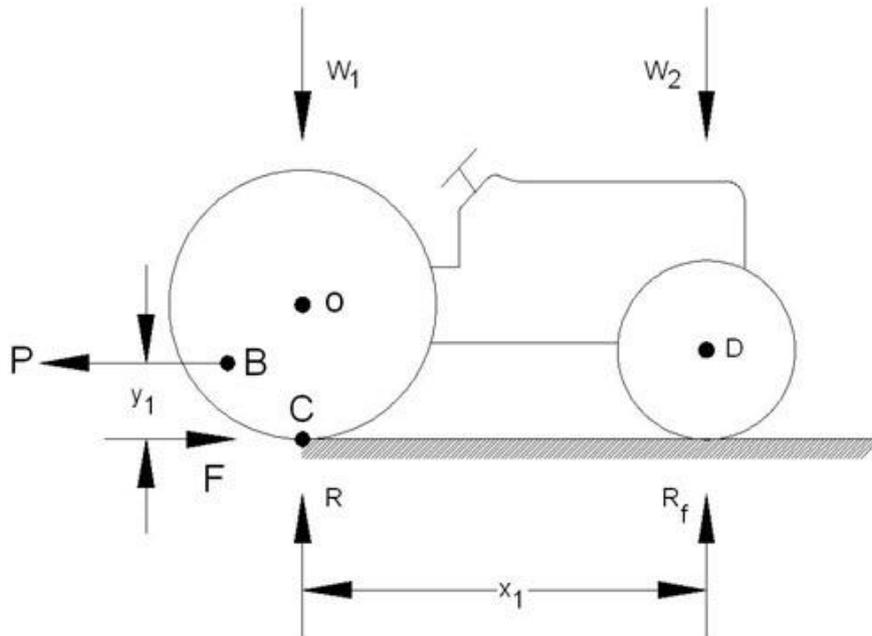
Lesson 4. Analysis of tractor in static conditions

Analysis of a tractor:- Level surface and horizontal pull

Analysis of the tractor is done to measure the weight transfer coefficient due to pull exerted by a tractor while pulling an implement.

Fig. represents the various forces present on a tractor operating on a level horizontal surface with pull being horizontal and parallel to the direction of motion.

On the basis of the assumptions listed above, gravitation may be conveniently and satisfactorily represented as shown in fig.1 by the weight W_1 , supported by the rear wheels, and the weight W_2 , supported by the front wheels, when the drawbar pull is zero. Likewise, the soil reaction can, for the purpose of this approximate analysis, be resolved into three components R_1 , R_2 , and F .



If the tractor is considered as free body, the algebraic sum of all forces acting parallel to the motion must equal zero:

$$F - P = 0 \quad (1)$$

Likewise, the algebraic sum of all forces acting perpendicular to the direction of motion must equal zero:

$$R_1 + R_2 - W_1 - W_2 = 0 \quad (2)$$

The algebraic sum of the moments about any given axis must equal zero. The problem is greatly simplified by summing moments about C , the intersection of the soil reactions R_1 and F (fig.1). The line of action of force W_1 also passes through this axis. The moment equation is:

$$W_2 x_1 - Py_1 - R_2 x_1 = 0 \quad (3)$$

From these three equations the values of the soil reaction may be readily calculated in terms of the tractor's weight and the drawbar pull.

Solving equation 3 for R_2 :

$$R_2 = W_2 - \frac{Py_1}{x_1} \quad (4)$$

And equation 2 for R_1 :

$$R_1 = W_1 + W_2 - R_2 \quad (5)$$

Substituting the values of R_2 from equation 4 for R_2 in equation 5:

$$R_1 = W_1 + \frac{Py_1}{x_1} \quad (6)$$

The stability of a tractor is, to a great extent, determined by R_2 and the tractive capacity by R_1 .

The term expresses the change in soil reactions R_1 and R_2 , resulting from the drawbar pull P . The soil reaction R_1 , supporting the rear wheels, increases as P increases and the soil reaction R_2 decreases. This relationship is true until P becomes large enough to cause to become equal to W_2 , which in turn causes R_2 to become zero. Any further increase in P will cause the front wheels to leave the ground.

Whether the tractor will become unstable and tend to turn over backward will depend on a number of factors, such as the location of the center of gravity of the tractor and the location of the hitch points to the tractor and to the implements being pulled. These factors are discussed later.

Although there is no actual shift of weight, this change in soil reactions R_1 and R_2 is commonly known as weight transfer.

If zero is substituted for R_2 in equation 4 and the equation is solved for P , an expression is obtained for the value of the drawbar pull P at which the soil reaction against the front wheel becomes zero.

$$P = \frac{W_2 x_1}{y_1} \quad (7)$$



Lesson 5. Tractor as a spring mass system

The Indian tractor is a frameless wheeled self propelled vehicle used as a source of power for operating mainly agricultural machinery, special equipment and towing trolleys. There is also no suspension system.

The suspension system is a set of devices that effect the undercarriage and the wheels. It is there to absorb the shocks from the field where the tractor is operating from reaching the operator.

The wheeled agricultural tractors are mounted on pneumatic rubber tyres. These air-filled tyres act as a system for absorbing the shocks. These act as spring-mass system having six degrees of freedom as shown in Fig. 5.1. The six degrees of freedom include vibration along the three principal axes, and can rotate about these three axes (longitudinal, vertical and transverse).

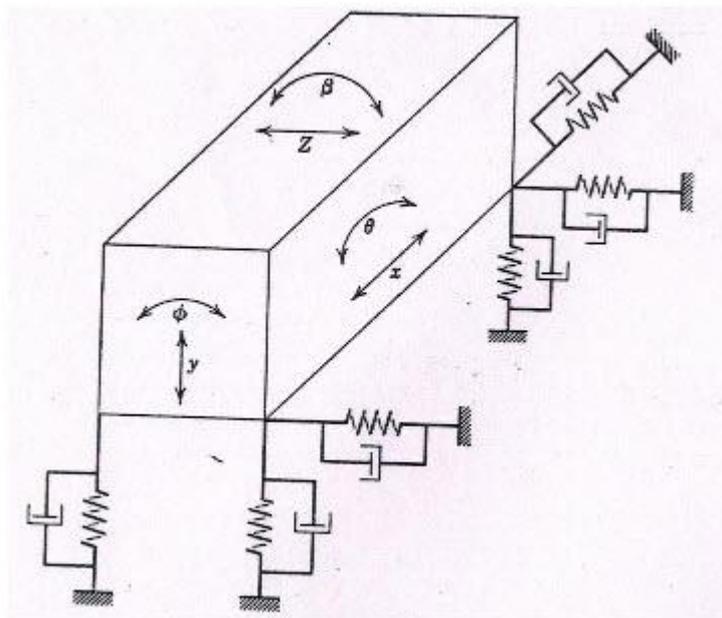


Fig 5.1

The motion terms generally related to the vehicles are: roll, pitch and yaw.

To vibrate or rotate along one of the three degrees of freedom, the tractor needs to be disturbed accordingly. Under normal conditions, the disturbances do not excite the tractor in the ' x ', ' β ' and ' z ' directions.

The disturbances ' Φ ' is called roll, ' θ ' is called yaw and ' y ' is called pitch.

A tractor as shown in Fig 5.2 can be represented as in Fig 5.3 as a system suspended on springs and dampers on the front and rear side. The displacement X_f and X_r at the front wheel and rear wheel respectively, causes the disturbance in the tractor. The various parameters associated with the analysis are as listed below:

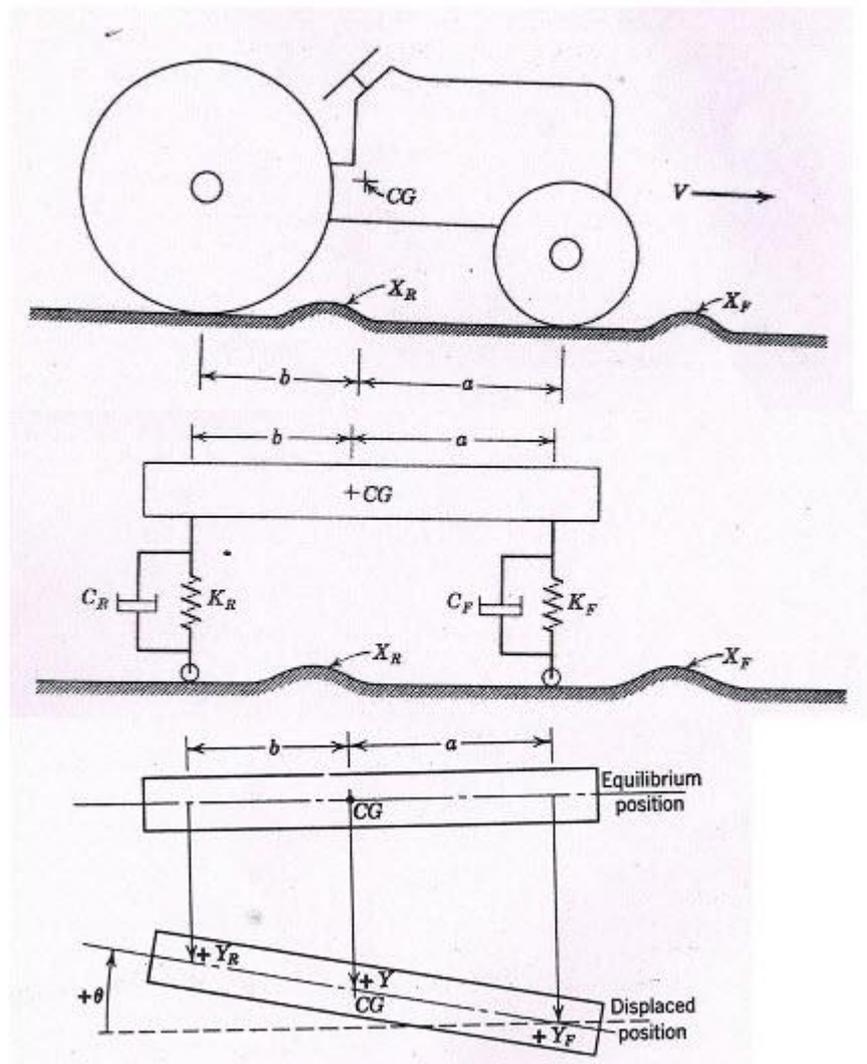


Fig 5.2

- m Mass of the tractor
- I_θ Mass moment of inertia about transverse axis passing through the CG
- Y Vertical displacement of the CG due to the disturbance
- Y_f Vertical displacement of front tyre
- Y_r Vertical displacement of rear tyre
- K_f Spring constant of front tyre
- K_r Spring constant of rear tyre
- C_f Damping constant at front tyre
- C_r Damping constant at rear tyre
- a,b Describe the location of the CG
- w_y Natural frequency along y coordinates
- w_q Natural frequency along q coordinates

From Fig. 5.3 the following relationships can be obtained:

$$Y_F = Y + a\theta \tag{1}$$

$$Y_R = Y + b\theta \tag{2}$$

The equation of motion in the y-direction is

$$m\ddot{Y} + \sum F_Y = 0$$

$$\text{Where } \ddot{Y} = d^2Y/dt^2, \quad \dot{Y} = dy/dt, \quad \text{etc.}$$

Or

$$m\ddot{Y} + C_F(\dot{Y}_F - \dot{X}_F) + C_R(\dot{Y}_R - \dot{X}_R) + K_F(Y_F - X_F) + K_R(Y_R - X_R) = 0 \quad (3)$$

$$\text{also } I_\theta \ddot{\theta} + \sum T_\theta = 0$$

or

$$I_\theta \ddot{\theta} + aC_F(\dot{Y}_F - \dot{X}_F) - bC_R(\dot{Y}_R - \dot{X}_R) + aK_F(Y_F - X_F) - bK_R(Y_R - X_R) = 0 \quad (4)$$

Substituting equations 1 and 2 into 3 and 4,

$$\ddot{Y} + K_1 \dot{Y} + K_2 \dot{\theta} + K_3 Y + K_4 \theta = F_y/m \quad (5)$$

$$\text{and } \ddot{\theta} + K_5 \dot{Y} + K_6 \dot{\theta} + K_7 Y + K_8 \theta = F_\theta/I_\theta \quad (6)$$

where

$$K_1 = (C_F + C_R)/m$$

$$K_2 = (C_F a - C_R b)/m$$

$$K_3 = (K_F + K_R)/m$$

$$K_4 = (K_F a - K_R b)/m$$

$$K_5 = (C_F a - C_R b)/I_\theta$$

$$K_6 = (C_F a^2 + C_R b^2)/I_\theta$$

$$K_7 = (K_F a - K_R b)/I_\theta$$

$$K_8 = (K_F a^2 + K_R b^2)/I_\theta$$

and F_Y and F_θ are linear combinations of \dot{X}_F , X_F , \dot{X}_R , and X_R .

The undamped natural frequencies of this system can be determined by letting equations 5 and 6 be equal to zero (equilibrium condition), and by letting the damping equal zero or .

Hence,

$$\ddot{Y} + K_3 Y + K_4 \theta = 0 \quad (7)$$

$$\ddot{\theta} + K_7 Y + K_8 \theta = 0 \quad (8)$$

In free vibration the natural modes will be:

$$Y = A_Y \sin \omega t \quad (9)$$

And $\theta = A_\theta \sin \omega t \quad (10)$

Where A_Y and A_θ are the amplitudes of free vibration.

If these values are substituted into 7 and 8, there results:

$$(K_3 - \omega^2)A_Y + K_4 A_\theta = 0 \quad (11)$$

$$K_7 A_Y + (K_8 - \omega^2 A_\theta) = 0 \quad (12)$$

Since A_Y and A_θ are constants, they can be eliminated from equations 11 and 12 thus:

Therefore, the two natural undamped frequencies of this system are:

$$\omega_{1,2}^2 = \frac{(K_3 + K_8) \pm \sqrt{(K_3 + K_8)^2 - 4(K_3 K_8 + K_4 K_7)}}{2} \quad (13)$$

The frequencies previously determined do not consider viscous damping in the tires. The values determined are the result of either the front or the rear tires striking a bump to set the tractor in motion (vibrating) as it moves on a smooth surface.



Module 2. Traction

Lesson 6. Traction and related definitions, mechanics of a rigid wheel (traction and towed)

A pneumatic tyre which is flexible has a smaller contact area on concrete surface than it does on soft ground. A rule of thumb which can be used for estimation of tire contact area is given below-

$$A = bl$$

Where:

A = Tire contact area

b = Section width of tire

l = Contact length of tire

experimentally it has found that it is

$$A = 0.78 bl$$

Traction testing machine

The traction testing device, is a soil bin based that can be used to conduct controlled experiments.. With this tires of varying diameters widths can be tested. The system is designed will provide variable vertical load up to get varying pull force. The device can be operated in a draft control or a slip control mode. The simplest device for a traction test of a wheeled device requires supporting the moving wheel, which apply the required torque, and measuring the developed force . However, there are various ways by which this can be carried out , with varying levels of complexity. Some devices can be operated only in soilbins, whereas, others are operated in the field.

Tire testing procedure

The tire test consisted of several runs and for a given run, vertical load on the tire is varied to get pull force under controlled slip using load cell type of sensors. The slip control mode may include zero slip to higher slip levels using single wheel tyre tester. In this type of machine torque and speed can also be measured by installing the required sensors to estimate traction performance parameters.

Traction Terminology

Traction.

The process by which a tractor develops tractive force and overcomes motion resistance to produce desired motion.

Tractive force

The force developed on the tractor interface by the traction device as a result of applied torque from the power source.

Motion resistance

Any force imposing resistance against desired motion.

Rolling resistance

Motion resistance that arises from deformations in the soil and the traction device

Sinkage

The depth to which the traction device penetrate into the soil measured normal to the original, undisturbed surface.

Slip

It is an indication of how the speed of the traction device differs from the forward speed of the tractor. It can be defined as the percentage travel reduction and given as

$$S = [1 - V_a/V_t] 100$$

Coff

Traction efficiency

The efficiency of the tractive device is converting the axle input power into output power, the term tractive efficiency (TE) has been defined as

$$TE = \text{Output power} / \text{Input power} \times 100$$

Basically tractive efficiency is converting the axle torque into net traction .

Traction prediction equation

Dimensional analysis is the best technique used to develop the prediction models for traction forces of pneumatic wheel type of tractor in tillage operation. Soil-wheel interaction was considered in developing the prediction models. Based on the Buckingham Pi Theorem, the number of dimensionless and independent quantities required to fully express the relationship between the variables were determined. Total number of factors can be listed as below table1-

Table 1 : the effective factors of soil and tractor

Effective factors	Definition	Symbol	Unit	MLT
Soil engineering properties	Cone index	CI	N/m ²	ML ⁻¹ T ⁻²
Tractor parameters	Tyre breadth	B	m	M ⁰ L ¹ T ⁰
	Tyre diameter	D	m	M ⁰ L ¹ T ⁰
	Tyre rolling radius	R	m	M ⁰ L ¹ T ⁰
	Tractor weight	W	N	MLT ⁻²
Operational parameters	Tractive force	F	N	MLT ⁻²
	Towed force	F _T	N	MLT ⁻²
	Pull	F _P	N	MLT ⁻²
	Slip	S	-	

The factors listed above in table 1, can be written as-

$$F, F_T, F_P = f (CI, B, D, R, W, S)$$

According to Buckingham's theory, the number of invariants and repetitive invariants were 9 and 2 respectively, so 7 constant pi-values are obtained. In this, two repetitive invariants - weight (W) and breadth(B) are used. Using the dimensional analysis with considering the two repeating variables, the π numbers can be written as -

$$\Pi_1, \Pi_2, \Pi_3 = f (\Pi_4, \Pi_5, \Pi_6, \Pi_7)$$

Equating the exponents of two sides of each π number and by Solving these we obtained an equations for a₁, b₁, ..., , with seven dimensionless parameters in the form as mentioned below-

$$\Pi_1 = F (W)^{a_1} (B)^{b_1} = M^0 L^0 T^0$$

$$\Pi_2 = F_T (W)^{a_2} (B)^{b_2} = M^0 L^0 T^0$$

$$\Pi_3 = F_P (W)^{a_3} (B)^{b_3} = M^0 L^0 T^0$$

$$\Pi_4 = CI(W)^{a_4} (B)^{b_4} = M^0 L^0 T^0$$

$$\Pi_5 = D (W)^{a_5} (B)^{b_5} = M^0 L^0 T^0$$

$$\Pi_6 = R(W)^{a_6} (B)^{b_6} = M^0 L^0 T^0$$

$$\Pi_7 = S(W)^{a_7} (B)^{b_7} = M^0 L^0 T^0$$

The combination of extracted π numbers can be written as a functional equation in the form of:

$$\Pi_1 = F/W$$

$$\Pi_2 = F_T/W$$

$$\Pi_3 = F_P/W$$

$$\Pi_4 = B^2CI/W$$

$$\Pi_5 = D/B$$

$$\Pi_6 = R/B$$

$$\Pi_7 = S$$

It can also be written as -

$$F/W, F_T/W, F_P/W = B \cdot D \cdot CI/W, D/B, R/B, S$$

TOWED WHEEL

A towed wheel is an unpowered wheel and axle torque is considered to be zero. The towed force of a towed pneumatic tire is generally dependent upon load, size and inflation pressure, as well as soil strength. Hence the towed force can be predicted from-

$$F_T/W = 1.2/C_n + 0.04$$

Where

F_T = towed force of wheel

W = dynamic wheel load

B = unloaded tire width

D = unloaded tire diameter.

C_n = wheel numeric

$$C_n = B D CI/W$$

CI = cone index

DRIVING WHEEL

The variations of driving wheel performance is based on the consideration that the normal tire inflation pressures in agricultural tyres produce tire deflections of approximately 20 per cent. Therefore, traction prediction equation can be given as for net pull, slip, and load -

$$F_P/W = 0.75(1 - e^{-C_n S}) - (1.2/C_n + 0.04)$$

Where,

F_p = wheel pull

W = dynamic wheel load

e = base of natural logarithms

$C_n = CIBD/W$

CI , B , D and S as stated before.



Lesson 8. Traction aids

A number of factors influence the development of traction force by a traction device, which in our case usually is a pneumatic tyre. These factors include area of contact on the soil by the traction device, rolling resistance, tyre inflation pressure, etc. In addition to this a lot of aids can be used for enhancing the traction developed.

Effect of Inflation pressure

Inflation pressure affects the traction as is evident from the Newton Mohr expression. The tyre thrust can be increased if the area of contact on the ground surface is increased specially in case of soils which are cohesive in nature. Hence, as the tyre pressure is decreased, the contact area increases, and traction can be increased, and vice versa. However, the tyres can get cracked or can get damaged due to low pressure.

Tread Pattern and Design

Tyre tread pattern and design is also important for enhancing the traction. The tyre tread pattern depends upon:

- Tractive efficiency
- Soil compaction
- Slip
- Tyre inflation pressure
- Direction of motion
- Normal load on the tyre

Tracks

Tracks have been used as a traction aid in loose ground surface. This is not only used in loose soil in field conditions but also in icy and snowy conditions. This helps in traction by reducing the bearing pressure. These also tend to be a costly option, although a quite a efficient one.

Tyre Chains.

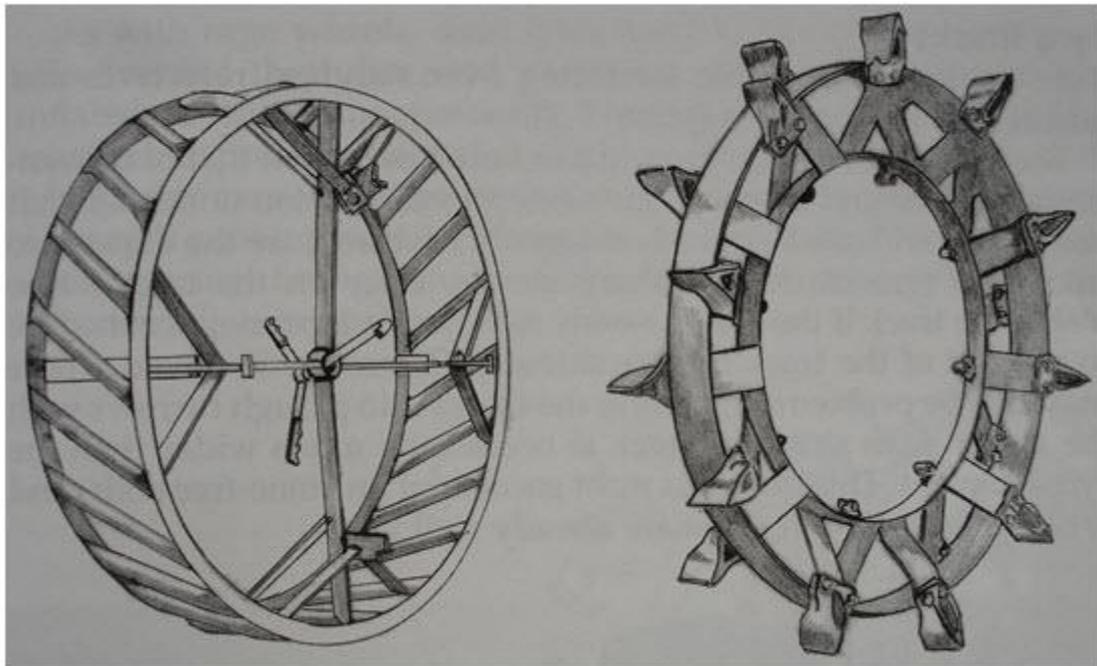
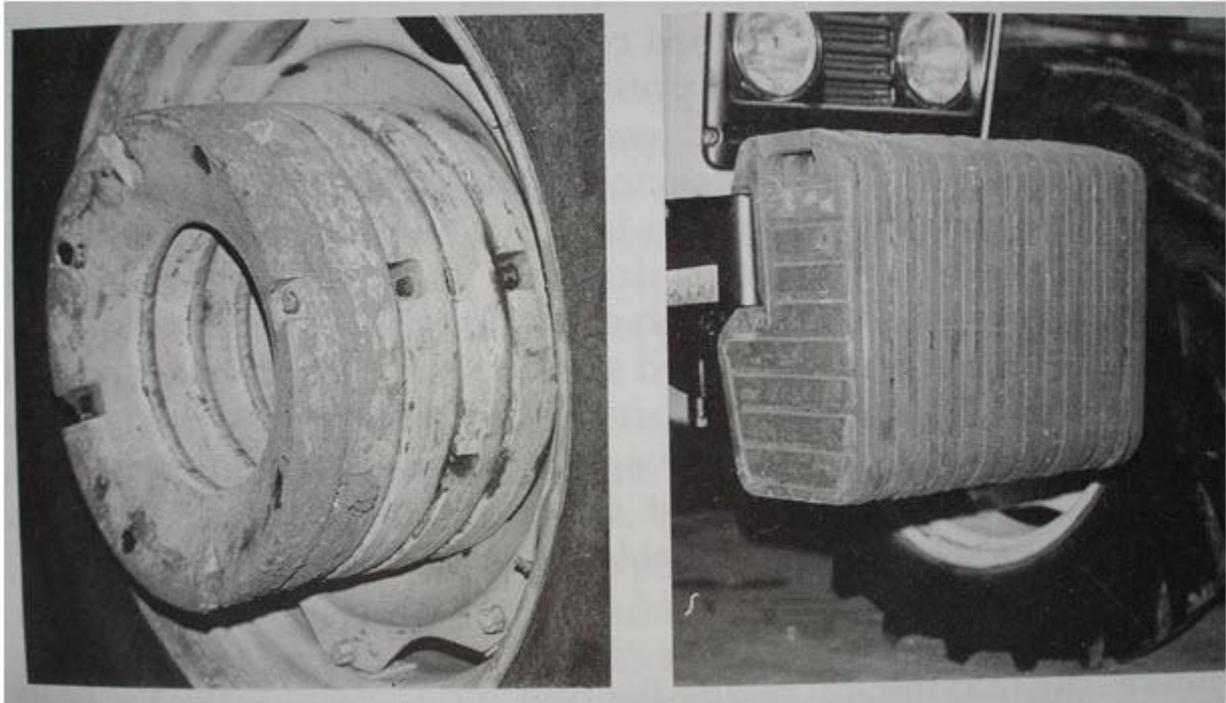
Tyre chains are used around the tyre and helps in improving traction by increasing adhesion in slushy conditions.

Ballasting

The normal load on traction wheels can be increased by putting water or air inside the pneumatic tyre-tube. Filling water in the tube is water ballasting, and filling sand in the tube is sand ballasting. Generally the tube is filled upto maximum of 75% by the ballasting material and rest with the air at the rated air pressure.

Additional weights

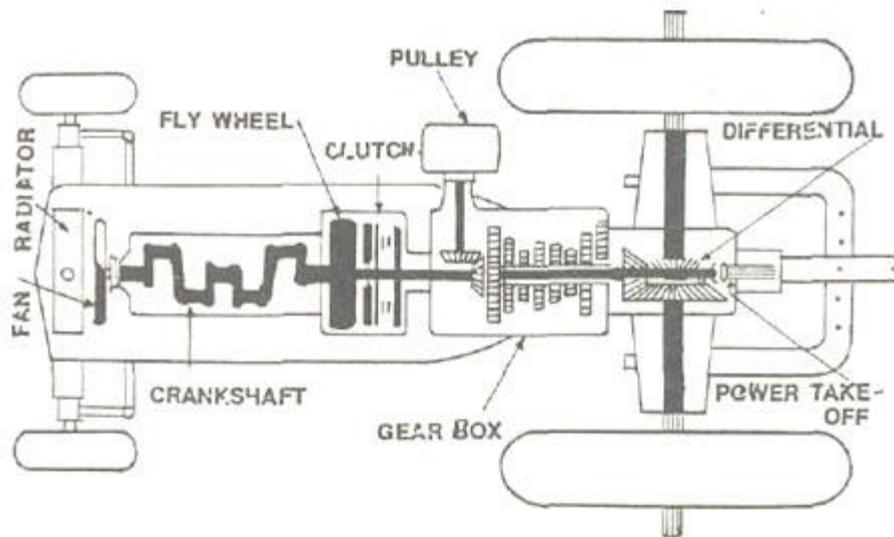
Additional weights are also used



Module 3. Introduction to Transmission System

Lesson 9. Introduction to transmission systems in four wheeled tractors

The transmission system is basically the drive line of any automobile or a tractor in our case. This system consists of components that are used to transmit the torque developed by the prime-mover or the engine to the driving wheels and to vary the torque and direction of rotation of the ground wheels. The main drive line units are shown schematically in the Fig. 9.1.



POWER TRANSMISSION SYSTEM

A power transmission system usually consists of the following parts:

1. Clutch - The device that connects or disconnects two torque transmitting devices.
2. Transmission - A device for transmitting power at a multiplicity of speed and torque.
3. P.T.O. Drive - The parts that transmit torque from the engine to the PTO spline on the rear of the tractor.
4. Differential - The device, usually in the axle housing, that allows the two wheels on an axle to rotate at different speeds.
5. Brake - The device, usually in the axle housing, that stops the motion of the tractor.
6. Axle - The shaft and connecting parts that transmits torque from the differential or final gear reduction, to the wheels.

Engine - Crankshaft - flywheel - clutch - transmission box - differential - final drives - axle - drive wheels.

A power transmission system for a tractor has two functions:

1. To disconnect the engine from the road wheels when desired.

2. To transmit the torque in a smooth manner without shocks and jerks.
3. To reduce the engine speed as desired based on tyre size and forward speed required.
4. To change the axis of rotation of power to align it as per the orientation of the drive wheels.
5. To change engine torque and speed into the torque and speed required by the wheel for different task required of a tractor.
6. To provide for auxillary power outlet in the form of Power Take Off for powering the implements and also for stationary machinery.

Mathematically:

$$T_e N_e (\text{eff}) = T_w N_w = \text{Constant}$$

Where,

T_e = torque at engine

N_e = rpm of engine

T_w = torque at drive wheels

N_w = rpm of drive wheels

Eff = efficiency of the power transmission system.

A classification of tractor transmissions can be made as follows:

1. Selective-gear, fixed-ratio
2. Selective-gear, fixed ratio plus one planetary
3. Planetary gears in series
4. Hydrodynamic
5. Hydro static

Variations of these classifications exist. All transmissions convert the engine torque and speed into a more useful combination of torque and speed at the drive wheels.

Because the maximum speed of a tractor is regulated by a governor, the potential maximum drawbar power of the tractor is nearly constant regardless of the forward speed, except for the lowest speeds when the maximum power is limited by traction.

The greatest difference between transmission for farm tractors and those for highway vehicles is that in the tractor most of the gears may be used continuously under full load. Automobile transmissions would fail if they were run in low gear at full power for any length of time.

Module 4. Clutch System

Lesson 10. Working principles of Clutch and its Construction and clutch materials

Clutch System

Requirement of Clutch

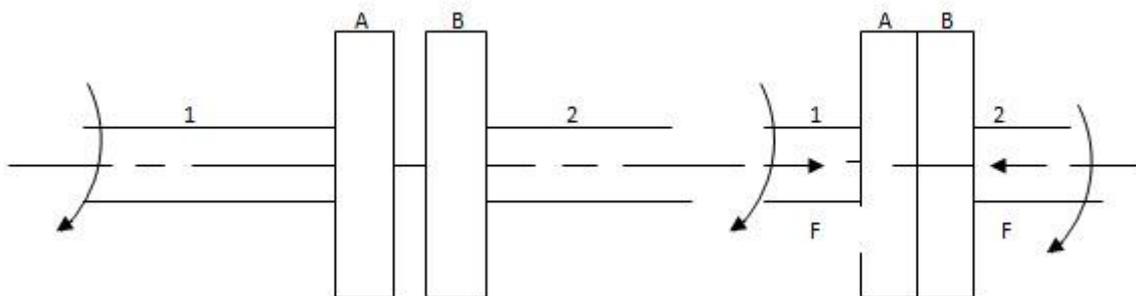
A clutch is required to connect the rotational power from the flywheel of the engine to the gearbox especially at the time of selection of proper gear, specially at the time of starting, or moving the tractor from position of rest.

The clutch used in automobiles can be classified as follows:

- Friction type clutchCone clutch
 - Plate type friction clutchWet type clutch
 - Dry type clutch
 - Single plate clutch
 - Axial spring type single plate clutch
 - Diaphragm type single plate clutch
 - Multi plate clutch
 - Wet type clutch
 - Cone clutch
 - Liquid clutch

The agricultural tractors mostly use axial spring

Clutch, as the name suggests, uses a clutching force (axial force) to transmit the rotational motion from one shaft to another. Most tractor clutches are frictional clutches.



To transmit power from shaft 1 to shaft 2, the flat discs are forced together with a force (axial force), F . The friction between the discs, A and B , causes the rotational motion of shaft 1 to be transmitted to shaft 2.

The torque that this system can transmit is given by

$$T = \mu FR$$

Where μ = coefficient of friction between the two discs A and B

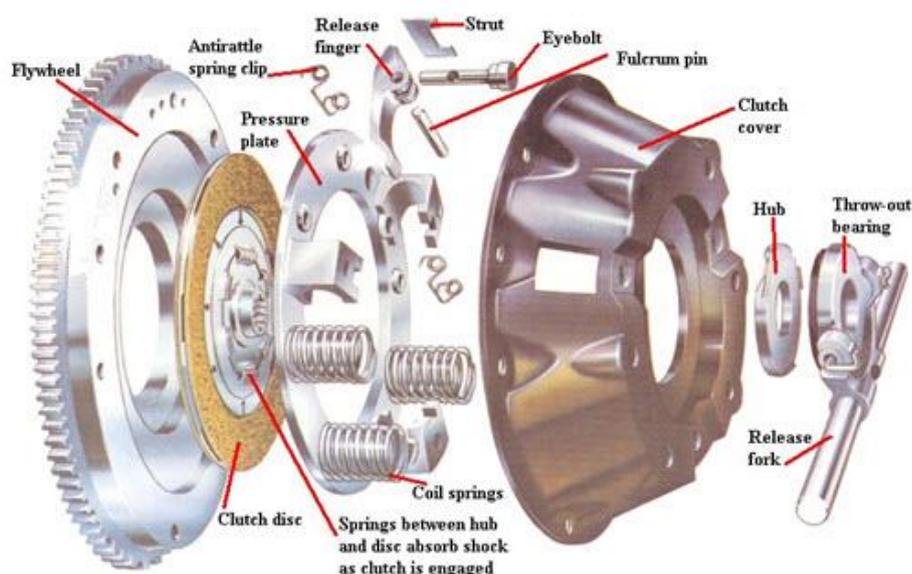
F = Axial force with which the two discs are put together.

R = mean effective radius of the friction surface of the discs.

Requirements of a good clutch

1. The clutch should be able to transmit 1.25 to 1.50 times the maximum engine torque.
2. The clutch material should have good coefficient of friction.
3. Lot of heat is generated due to the relative motion between the flywheel, pressure plate and clutch plate during clutch operation. This heat needs to be quickly dissipated, otherwise high temperature can damage clutch components.
4. The clutch should have low moment of inertia, otherwise the clutch will keep spinning at high speed even during gear changing.
5. Vibration and Jerk absorption. The clutch should be able to take up sudden jerks encountered when the clutch plate comes in contact with the rotating flywheel.
6. The clutch should be dynamically balanced or it will lead to vibrations at high speeds.
7. The operation of the clutch pedal should be easy for the operator and not tiresome, especially for operating for long durations.

Main components of a Single Plate Axial Spring type friction clutch



1. **Flywheel:** It is connected to the engine crankshaft and is used to store the energy.
2. **Clutch Plate:** It consists of a steel disc with the centre splined. Frictional material is mounted (riveted) around the circumference of the steel disc.
3. **Pressure Plate:** The pressure plate pushes the clutch plate onto the flywheel due to spring pressure so that the clutch plate on one side and the flywheel on the other.
4. **Axial Springs:** Axial springs provide the clamping force due to which the power can be transmitted from the flywheel to the clutch plate.
5. **Clutch cover:**It is not only covers the clutch components, but also provides motion from the flywheel to the pressure plate.
6. **Clutch release system:**it consists of those components which are required for engaging -disengaging the power transmission to the clutch plate.

Clutch Facing Material

While selecting material for clutch facing, it is to be kept in mind that the material should have high coefficient of friction, low heat generation and quick dissipation of generated heat. These qualities are counter to each other. Hence a tradeoff has to be reached. Most common materials that can be used are as follows:

- | | | |
|-----------------|---|--|
| Leather | - | Coefficient of friction of dry leather on iron is 0.27 |
| Cork | - | Coefficient of friction on dry steel is 0.32 |
| Fabric | - | Coefficient of friction on dry steel is 0.4, but these cannot be used at high temperature. |
| Asbestos | - | Coefficient of friction on dry steel is 0.2, has good anti-heat properties, but is harmful for human health. |
| Ferodo Material | - | This material is based on asbestos and has a coefficient of friction 0.35. |

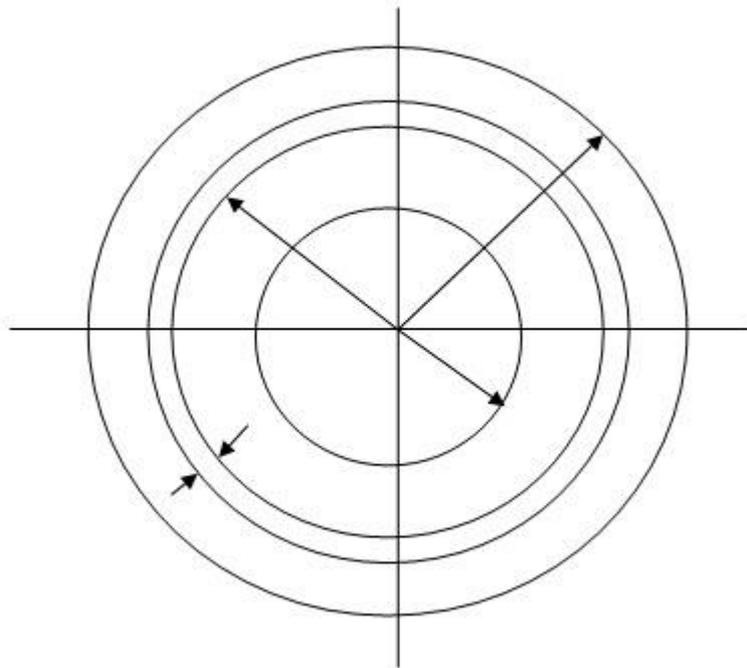


Lesson 11. Analysis of Clutch - uniform wear, uniform pressure

Analysis of Torque Transmission

In the figure, the frictional surface has an outer radius, r_o , inner radius r_i .

Assume an elemental surface area of thickness dr at a radius of r from the centre. If p is the pressure exerted while putting the two discs A and B together.



r_o - radius of outer end of the clutch facing

r_i - radius of inner edge of clutch facing

dr - thickness of the elemental element of clutch facing at a distance of r from the centre

Total axial force, $df = p.dA$

$$df = p.2\pi r.dr$$

$$F = 2\pi$$

The torque that can be transmitted

$$\begin{aligned} T &= \int_{r_i}^{r_o} u. 2\pi. pr^2. dr \\ &= 2\pi u \int_{r_i}^{r_o} pr^2. dr \end{aligned}$$

Case I : If pressure is constant i.e. $p=k$

$$\Rightarrow F = 2\pi p \int_{r_i}^{r_o} r \, dr = 2\pi p \left(\frac{r_o^2 - r_i^2}{2} \right)$$

$$= \pi p (r_o^2 - r_i^2)$$

$$T = 2\pi u p \int_{r_i}^{r_o} r^2 \, dr = 2\pi u p \left(\frac{r_o^3 - r_i^3}{3} \right)$$

$$= u \cdot \pi p (r_o^2 - r_i^2) \cdot \frac{2}{3} \left(\frac{r_o^3 - r_i^3}{r_o^2 - r_i^2} \right)$$

$$\Rightarrow R = \frac{2}{3} \left(\frac{r_o^3 - r_i^3}{r_o^2 - r_i^2} \right), \text{ the mean effective radius if pressure is constant}$$

Case II: if wear is constant i.e. $p \cdot r = \text{constant}$

$$\Rightarrow F = 2\pi r_i \int_{r_i}^{r_o} dr = 2\pi r_i (r_o - r_i)$$

$$\Rightarrow T = 2\pi u r_i \int_{r_i}^{r_o} r \, dr = 2\pi u r_i \left(\frac{r_o^2 - r_i^2}{2} \right)$$

$$= u \cdot 2\pi r_i (r_o - r_i) \cdot \left(\frac{r_o + r_i}{2} \right)$$

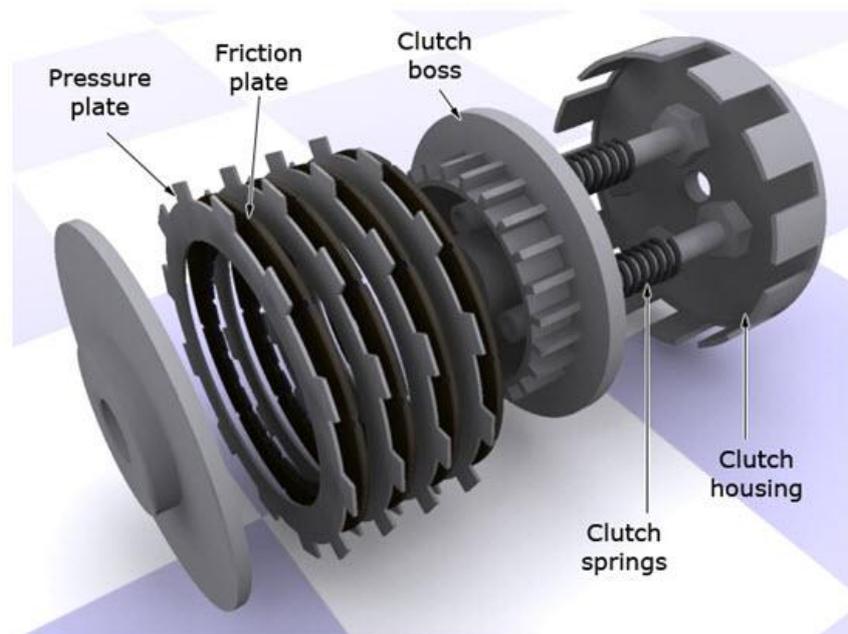
$$\Rightarrow R = \left(\frac{r_o + r_i}{2} \right), \text{ the mean effective radius if wear is constant.}$$



Lesson 12. Calculations of number of clutch plates.

Multi Plate Clutch

A multi plate clutch is an extension of a single plate clutch where the number of friction surfaces is increased. Due to this increase in number of frictional surfaces, the area which transmits torque is increased which in turn increases the capacity of the clutch to transmit torque. This type of clutch finds its application in case of heavy torque transmission or where there is limitation of space available.



Method of working

The construction of the pressure plates and the clutch plates is such that the pressure plates have teeth at its outer periphery, or it is grooved from outside. This is done so that the teeth on the pressure plates mesh with the corresponding grooves on the flywheel. The clutch plates are grooved on the inside periphery to sit on the splines of the clutch shaft.

The pressure plates are meshed in the grooves on the flywheel and are free to move away from or towards the flywheel depending on whether the clutch pedal is released or pressed. When the clutch pedal is pressed, the axial force binding the clutch plates is removed, stopping the power being transmitted by the clutch.

The number of clutch plates to be used is decided by the total surface area of the clutch plate in contact with the flywheel or pressure plate driving the clutch plates.

Mathematically the torque transmitted by the clutch as discussed in lesson 10, is given by:

$$T = \mu FR$$

This relation holds for single contact surface.

For a single plate clutch with two contact surfaces, the torque transmitted is

$$T = 2uFR$$

For a clutch with 'n' number of plates, the torque transmitted is given by:

$$T = 2nuFR$$

Numerical:

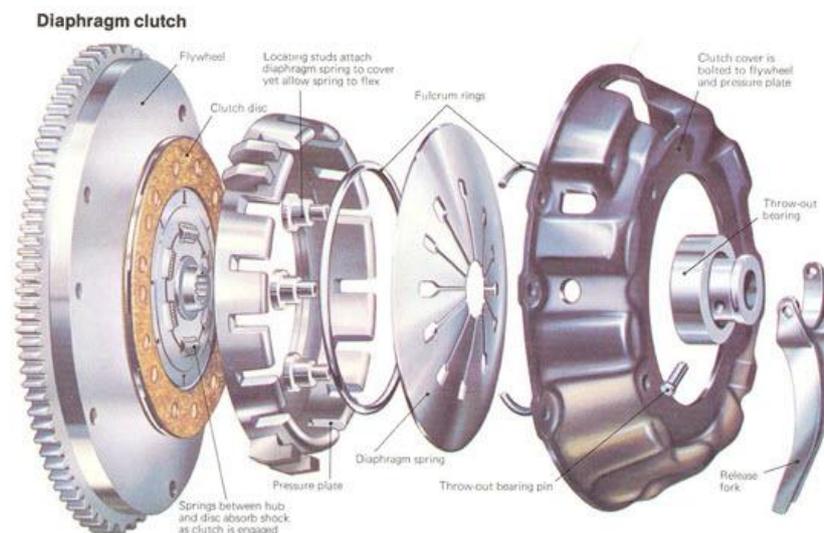
An automobile whose engine develops

Diaphragm type clutch

The construction of this type of clutch is similar to that of the single plate type clutch described earlier except that in this case the axial force is exerted by a curved diaphragm instead of a series of axial springs.

The axial spring type clutch has got axial springs for exerting the axial force for clutching together the clutch plate to the flywheel. These springs are of compressive type, i.e. compressive force needs to be applied to disengage the clutch plate. Each of these axial springs need huge amount of force to be pressed. When these are combined, the force required for disengagement increases multifold.

In the free condition, the diaphragm spring is conical in shape, but when assembled, it is constrained to an approximate flat condition due to which the force is exerted on the pressure plate.



Lesson 13. Hydraulic drives

In case of automatic transmission, there is no clutch that engages or disengages the engine power to the transmission. This is done with the use of a hydraulic torque converter. This is also called a fluid coupling.

The main components of a torque converter are:

- Pump
- Turbine
- Stator
- Transmission fluid

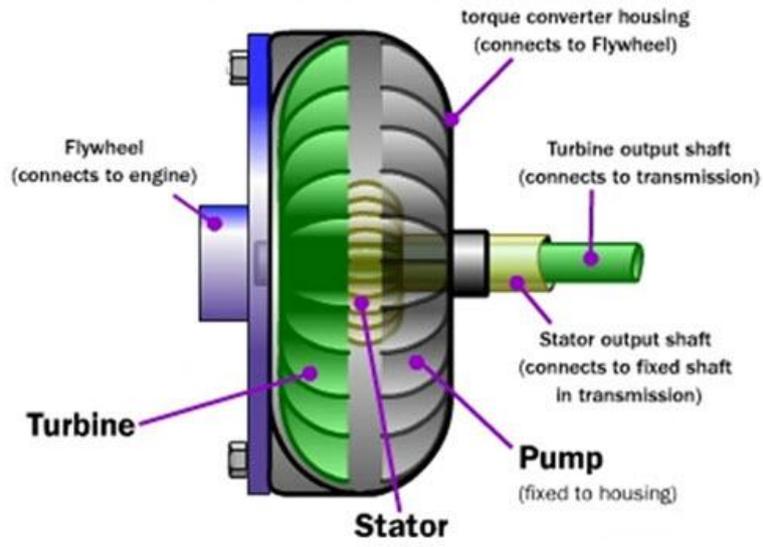
The pump and the turbine are bowl shaped with fins on the inside. These are assembled facing each other with the transmission oil inside. The pump and the turbine are fitted to the flywheel in such a way that the pump is fixed to the flywheel and rotates along with the flywheel whenever the engine is turning. The turbine is fitted between the flywheel and the pump but is free to rotate of the flywheel or the pump.

The fins on the inside of the pump are given a direction in such a way that the when the pump rotates, the oil inside is imparted kinetic energy like in a centrifugal pump. When this oil goes into the turbine, it strikes the fins of the turbine in such a way that it transfers the kinetic energy to the turbine.

This turbine is connected to the out shaft which rotates along with the turbine, and serves as the input to the transmission. As the oil moves from the pump portion to the turbine component and it imparts its kinetic energy to the turbine, there is a change in direction of the oil. Now when this goes back to the pump side, the pump has to impart an additional force to change the direction of oil and increase the kinetic energy of this oil. This action regarding the changing the direction of the oil, leads to unnecessary wastage of energy.

For this reason a stator is provided. The stator is placed in the very center of the torque converter. Its job is to redirect the fluid returning from the turbine before it hits the pump again. This dramatically increases the efficiency of the torque converter.

The stator has a blade design that almost completely reverses the direction of the fluid. A one-way clutch connects the stator to a fixed shaft in the transmission. Because of this arrangement, the stator cannot spin with the fluid -- it can spin only in the opposite direction, forcing the fluid to change direction as it hits the stator blades. This helps in increasing the torque being output this effect only happens when the engine is turning much faster than the transmission.



Module 5. Gear Box

Lesson 14. Working principle of speed reduction and torque transmission

Transmission System

While moving the vehicle/tractor in the field or for transportation purposes, there is a large variation of torque and speed requirements. The requirement of a transmission system are as listed below:

1. To reduce the rpm from the engine before it reaches the wheel.
2. To change the direction to rotation by providing a reverse gear.
3. To provide the required torque or speed depending on the field requirement or the operation being performed.
4. To provide a neutral position, where-in the power from the engine can be disconnected from the power train.

All these purposes are fulfilled using series of gears. There are various types of gears that are used for tractor and automotive applications. The Fig 14.1 shows the different types of gears used on tractors

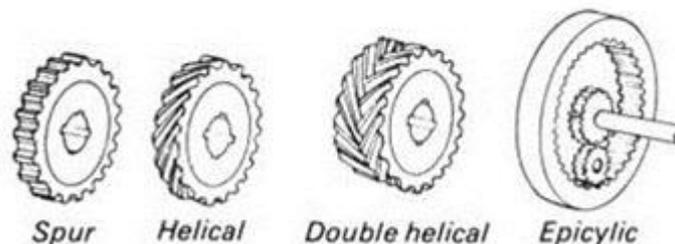


Fig 14.1 Types of Gears

Various types of gearing are used on a motor vehicle. The gearboxes employ one or more of the following:

- 1- Spur, teeth parallel to axis, used on sliding mesh.
- 2- Helical, teeth inclined to axis to form helix.
- 3- Double helical, two sets of opposing helical teeth.
- 4- Epicyclic or planetary, spur or helical gears rotating about centers which are not stationary.

Principle behind Gear Box

Consider following three cases in which there are a pair of gears in each case. The gear A is the driver and gear B is the driven.

In case I, the gear A (driver) is larger than gear B (driven), this case there is an increase in rpm of the driven as compared to the driver based on the following relation.

$$\phi_A n_A = \phi_B \cdot n_B$$

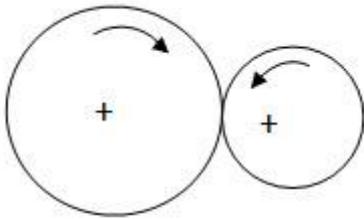
$$\Rightarrow n_b = \frac{\phi_A}{\phi_B} \cdot n_A$$

Where ϕ_A = diameter of gear A

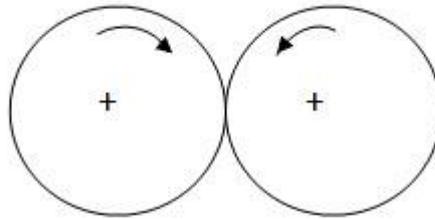
ϕ_B = diameter of gear B

n_A = rpm of gear A

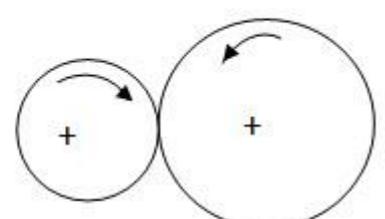
n_B = rpm of gear B



Case I



Case II

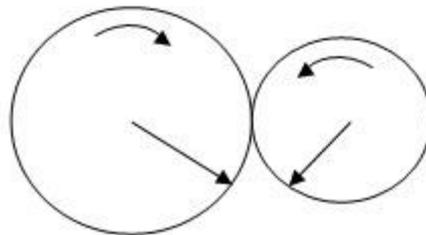


Case III

In case II, ϕ_A is equal to ϕ_B meaning that there is no change in the output speed as compared to the input speed.

In case III, ϕ_A is smaller than ϕ_B , leading to reduction of output rpm as compared to the input rpm.

Study of Torque output



When the driver gear A drives the gear B with a torque, the torque exerted by gear A is given by

$$T_A = F \times r_A$$

Where r_A is radius of gear A.

F is the force that the gear A exerts.

Going back to the earlier figures the torque generated in gear B will be given by

$$T_B = F \times r_B$$

In case of Case I,

$T_A > T_B$ because $r_A > r_B$

In case II,

$T_A = T_B$ ($r_A > r_B$)

In case III,

$T_A < T_B$ because ($r_A < r_B$)

Therefore from the analysis of the three cases for both torque and speed, it can be stated that in a combination of gears where speed is increasing, torque reduces and vice-versa.

In case of automobiles, the starting torque is higher as compared to the cruising torque. The requirement of torque and speed keeps on changing with the driving conditions. In case of tractors this requirement and combination of speed and torque changes with the operation being performed. Providing for these requirements helps in running the engine and the machine for best tractor- machine system efficiency and returns the best fuel efficiency.

The speed ratios provided by tractor transmissions can be arbitrarily divided into low speed gears and transport gears. Low speed gears provide high torque at low speeds. These are required for performing operations such as tillage, crop planting and harvesting operations. The transport gears are used specifically for transportation purposes specially when there are good road conditions.

The gear box can also be classified based on arrangement of shafts between which the gears are mounted:

- i) Parallel shafts (spur gears, helical gears, etc.)
- ii) Shafts at an angle in the same plane (bevel gears)
- iii) Shaft an angle not in the same plane (worm, hypoid gears)



Lesson 15. Types and construction details of gear boxes

Since the torque requirement for doing the various agricultural operations is continuously varying, there is a constant need for changing the set of gears involved in transmission of the engine power to the wheels. There are a number of ways in which gears can be combined to alter the torque being supplied to the tractor wheels. A series of gears are often combined together in a Gear Box in an orderly manner.

The automobile transmission gear boxes can be classified into different categories based on the method in which the gears are meshed and speed ratios selected. Gear boxes used for transmission systems are classified into:

- Sliding Mesh Gear Box
- Constant Mesh Gear Box
- Synchromesh Gear Box

The main components of the gear box are:

- Gear Box housing
- Gear shafts
- Gears
- Bearings

The gear box housing is the outer casing, usually made of cast iron, that houses the various shafts and gears inside. It also contains the gear box oil (SAE 90) for lubrication of the gears.

There are three types of shafts inside the gear box:

- Input shaft (also called primary shaft or clutch shaft)
- Counter shaft (also called lay shaft or auxiliary shaft)
- Main shaft (also called secondary shaft or out shaft)

The gears on these respective shafts are called by the name of the shaft i.e. input pinion, counter shaft gear, main shaft gear.

On the primary shaft is only one gear (helical type). The primary shaft takes the rotational power from the clutch. The clutch plate is mounted on one end of this shaft, the one side which is splined. The helical gear on the primary shaft is inside the gear box housing and is meshed to another helical gear on the counter shaft. All the gears on the counter shaft are fixed to the counter shaft and rotate along with the shaft.

While construction and working of primary and counter shafts in case of all the three types of gear boxes is similar, the construction and working of the main shaft gears. The main shaft is

splined, but the main shaft gears sit on the main shaft in different ways depending on which gear box these are on. The construction and working of the gear boxes is described hereunder:

Sliding Mesh Gear Box

This is the oldest and the simplest of automotive gear boxes. As the name suggests, the selected main shaft gear is slid over the main shaft to mesh with corresponding gear on the counter shaft. While the main shaft is splined, the main shaft gears are splined from inside, such that there is a positive motion between the main shaft and the main shaft gears.

At any given time, only one set (pair) of main shaft and countershaft gear are in mesh with each other. In case two pairs get meshed, they will tend to rotate the main shaft at different speeds, leading to breakage of either the main shaft or the meshed gears.

When a particular gear is to be meshed, it is slid over the main shaft by its collar and is made to mesh with the corresponding counter shaft gear.

Fig 15.1 shows the various components of a sliding mesh gear box. The gears 4, 5 and 6 on the main shaft can be slid to mesh with the corresponding gears on the counter shaft. The gear 4 is 1st gear, gear 5 is 2nd gear and gear 6 is the 3rd gear. For the 4th gear, the primary and the secondary shafts are coupled together implying that there is no speed reduction at the gear box in the 4th gear.

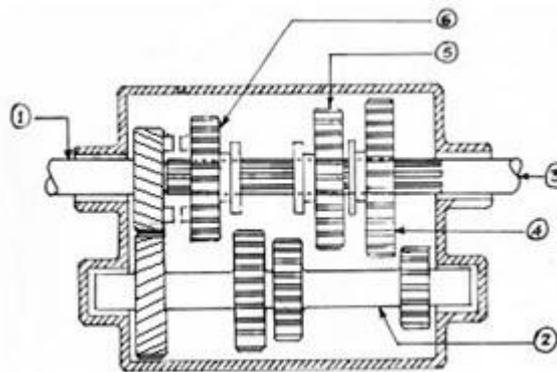


Fig 15.1 Cross-sectional view of a Sliding Mesh Gear Box

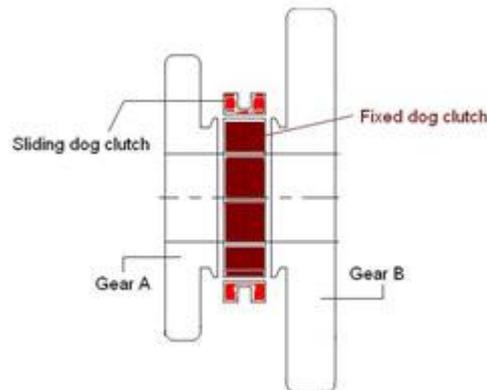
1. Input drive gear
2. Counter shaft
3. Main shaft
4. Ist gear
5. IInd gear
6. IIIrd gear

During the neutral position, none of the main shaft gears are engaged to the counter shaft gears. Depending on the speed-torque requirement, the gears of main shaft is slid to mesh with the respective gear on the counter shaft.

Constant Mesh Gear Box

In case of constant mesh type of gear box all the gears of main shaft are constantly meshed to the corresponding gears on the counter shaft as shown in the figure below:

Similar to the sliding mesh gear box, the main shaft is splined in this case too. But since all the gears on the main shaft are meshed, these are free to rotate on the splined main shaft. To transmit power an arrangement of fixed dog clutch and sliding dog clutch is used. The arrangement is shown as in the fig 15.2 below.



As mentioned before, the main shaft gears are free to rotate on the main shaft. The fixed dog clutch, placed between two gears is splined from inside in such a way that its rotation is associated with the main shaft i.e. when the fixed dog clutch rotates, the main shaft rotates and vice versa.

During the neutral position, the sliding dog sits on the fixed dog clutch (as shown in Fig 15.2). Now when the gear A is to be meshed, the sliding dog clutch is moved to the left so that it locks the movement of the gear to that of the fixed dog clutch. Now the gear is meshed to the corresponding gear of the counter shaft. When this gear gets locked to the fixed dog clutch, the power from the gear is transmitted to the main shaft through the fixed dog clutch. All this while the other gears continue to rotate freely on the main shaft without any interference.

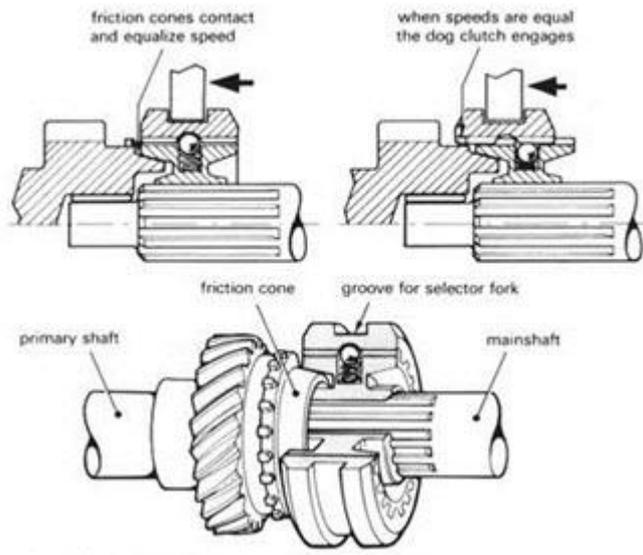
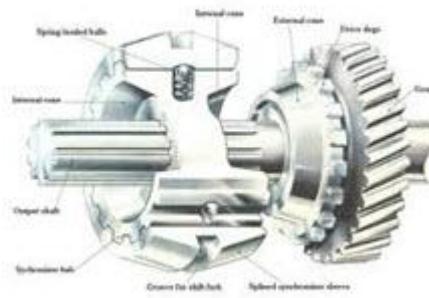
In this case all the gears on the main shaft are meshed to the corresponding gears of the counter shaft. These gears are of helical type. The advantages the helical gears offer as compared to spur gears is that in case of helical gears the contact starts with a point contact thus there is less noise and it also has more area of the gear teeth in contact leading to stronger gears and higher amount of torque that can be transmitted.

While engaging the gears from neutral position, when the clutch is engaged, all the gears on main and counter shafts are rotating, but all the sliding dog clutches are in neutral position. Now to engage the gear, the clutch is disengaged, but the gears are still rotating because of their momentum, the selected sliding dog clutch is moved as per requirement towards the gear that is to be engaged. As the relative motion between the gear and the dog clutches reduces, the sliding dog clutch engages with the selected gear and the clutch can be gradually engaged.

In case of the constant mesh gear box, the clutch has to be pressed twice while moving from one gear to another. This is done in such a way that the clutch is pressed once for moving from the gear to neutral position and the second time for moving from neutral to other gear. This process of pressing the clutch twice is called double de-clutching.

Synchromesh Gear Box

Synchromesh is an advancement over the constant mesh gear box. A synchronizing unit is provided to assisting in the gear changing.



Lesson 16. Working principle of gear change and gear shifting

In a gear box arrangement is provided on the top for gear changing mechanism. This includes gear changing lever, gear changing spindles, gear forks etc. The Fig 16.1 shows various components which go in to form the gear housing and the gear changing mechanism.

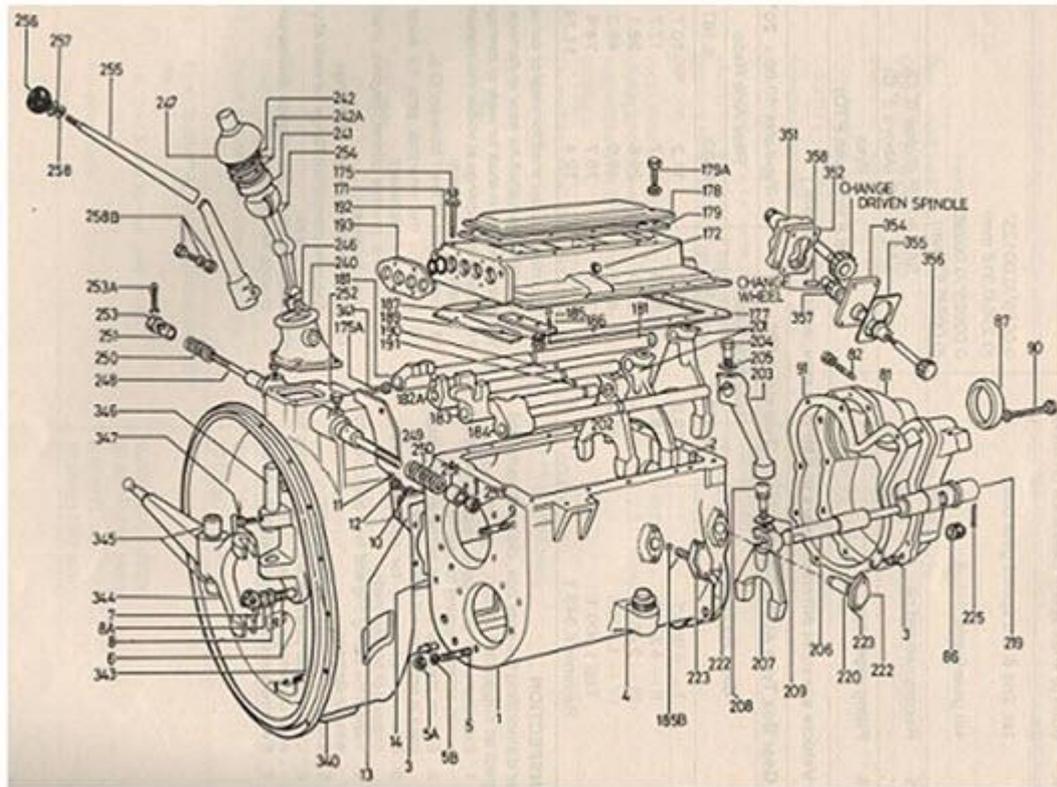


Fig 16.1 Exploded view of the gear box along with the gear selector mechanism

As discussed in the previous lesson, either the gear (in case of sliding mesh gear box) or the sliding dog collar (in case of constant mesh and synchromesh gear box) are slid (pulled or pushed) using the gear changing lever while selecting the appropriate gear (speed-ratio).

The gear lever is provided to the operator, who has the control of the system. There is swivel pin at the lower end of the gear shifting lever. This swivel pin moves within the box shaped cavity provided at the selector rod jaws. Movement of the gear lever also moves the swivel pin to select the selector rod out of the 3-4 rods provided in the gear selector cover. Fig 16.2 (a) and (b) shows two views of the gear selector mechanism, showing the various components involved in the gear changing mechanism

Each of the gear selector rods has a gear selector fork. This fork is sitting on the collar shaped gear (or sliding dog clutch as the case may be). When the selector rod is moved, the fork pushes or pulls the collar of the gear for meshing as required.

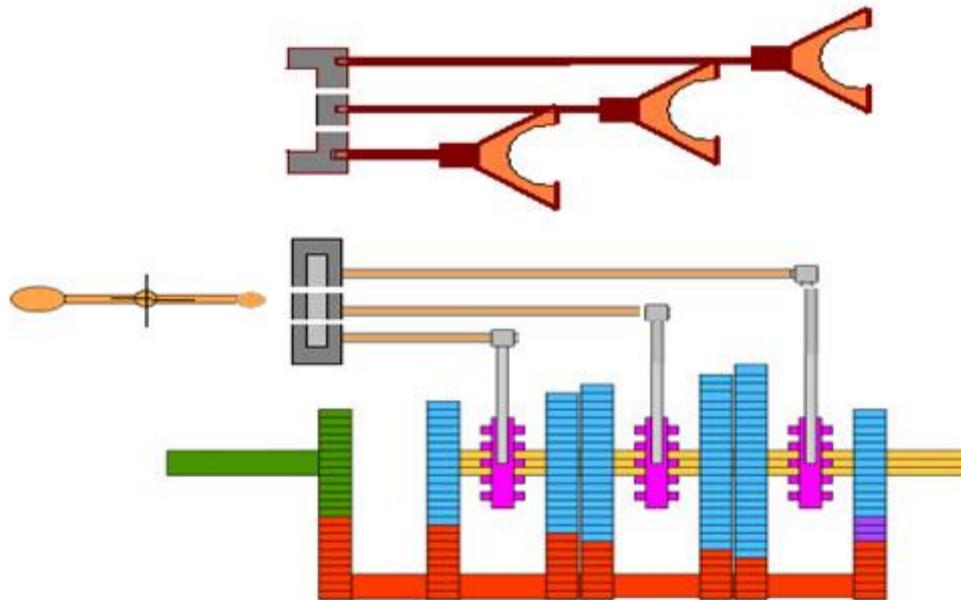
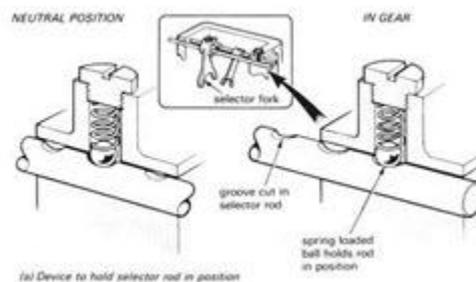


Fig 16.2 Arrangement showing the different components involved in gear changing mechanism which the

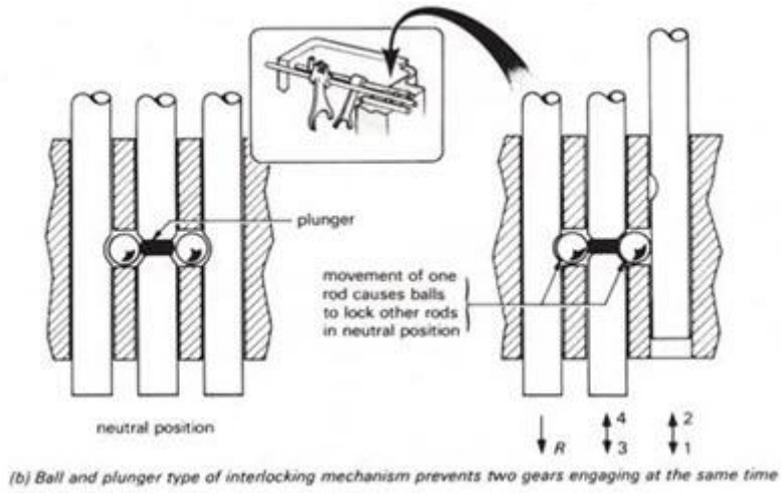
1- Selector detent-

Holds the gears and selectors in position and so prevent gear engagement or disengagement due to vibration. The figure shows a typical arrangement suitable for a layout having the selector fork locked to the rod.



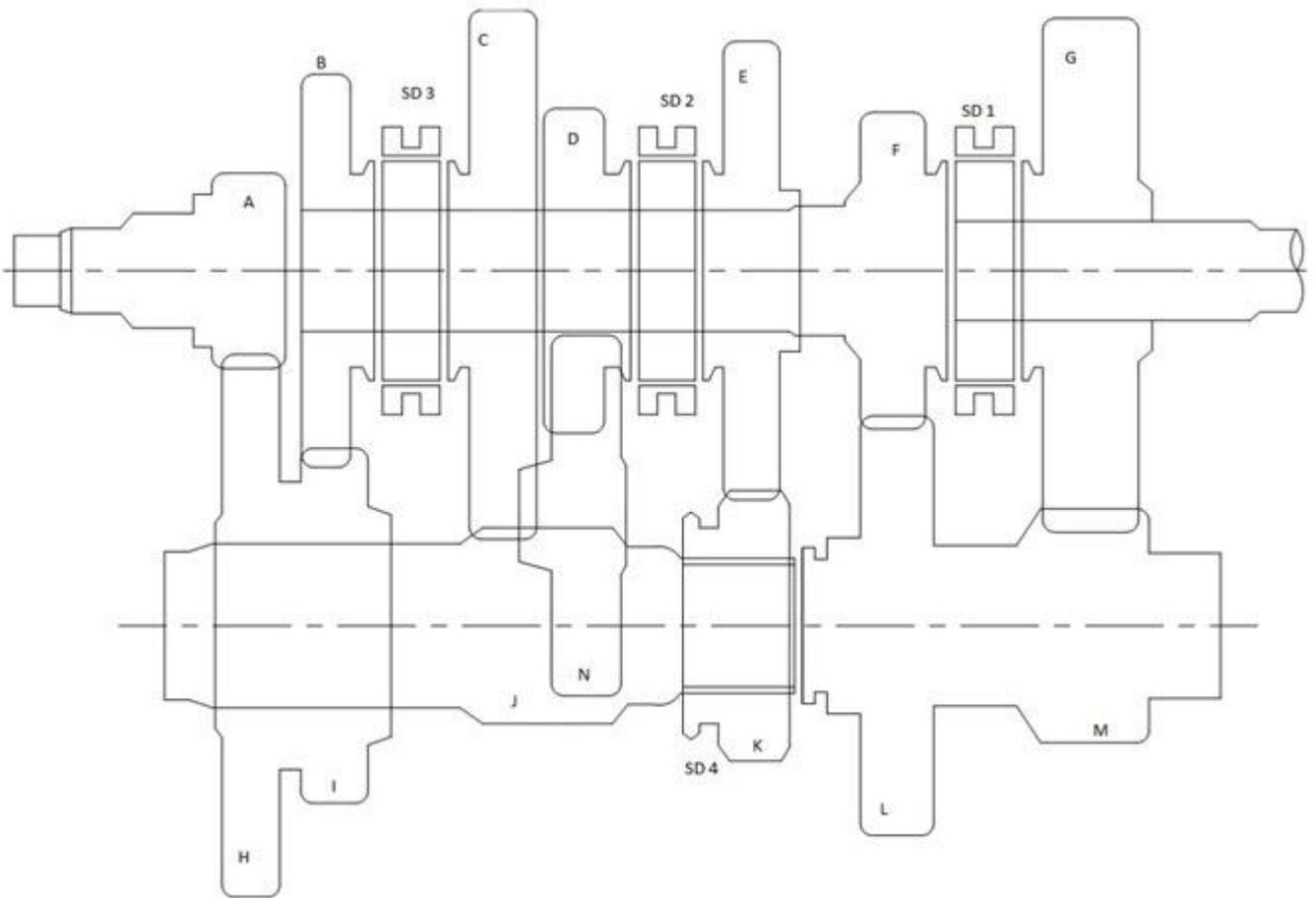
2-Interlock mechanism-

Prevents two gears engaging simultaneously; if this occurs the gearbox will lock up and shaft rotation will be impossible. Although the interlock device takes a number of different forms, the arrangement shown in the figure is one of the most common.



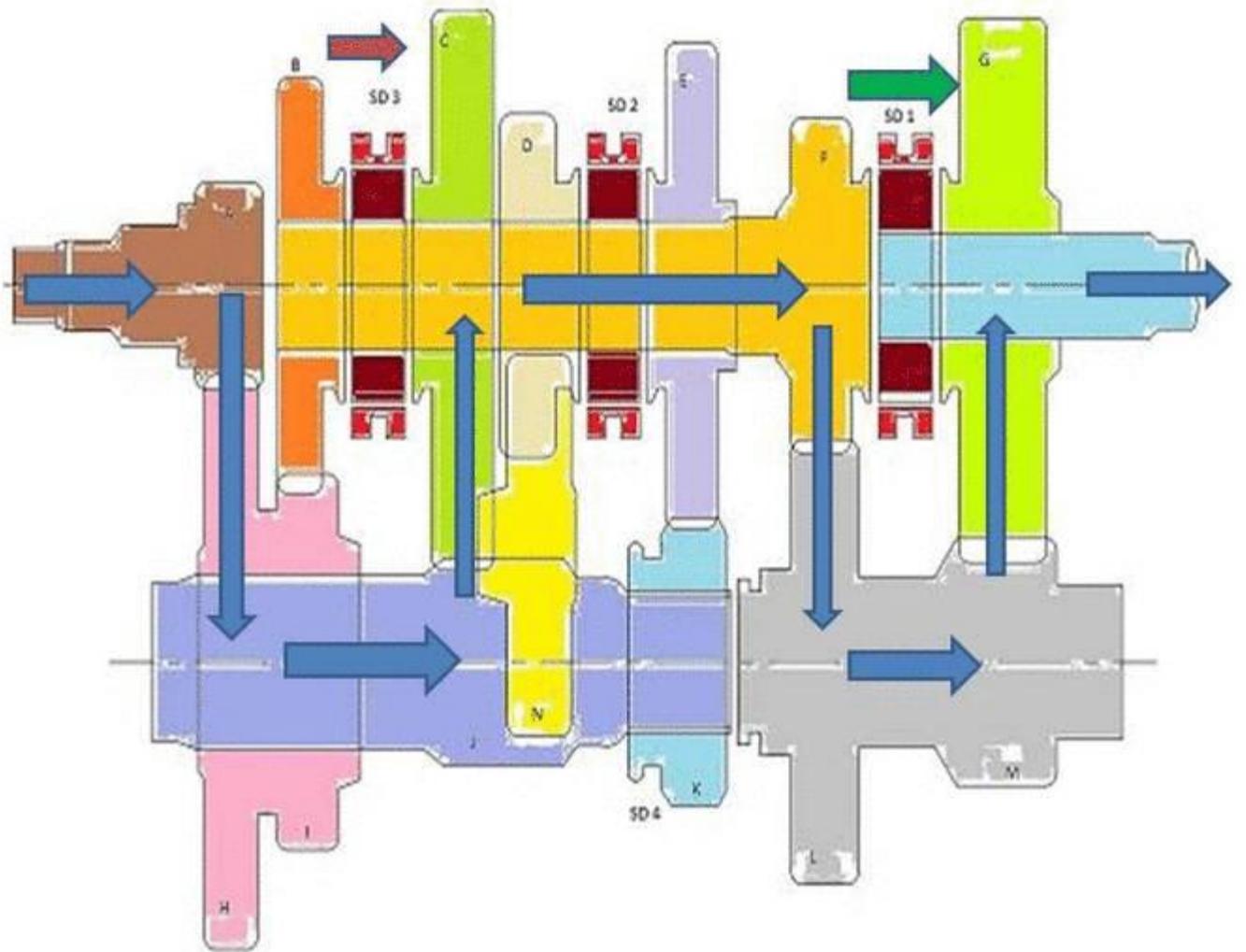
Lesson 17. Calculation of speed ratio

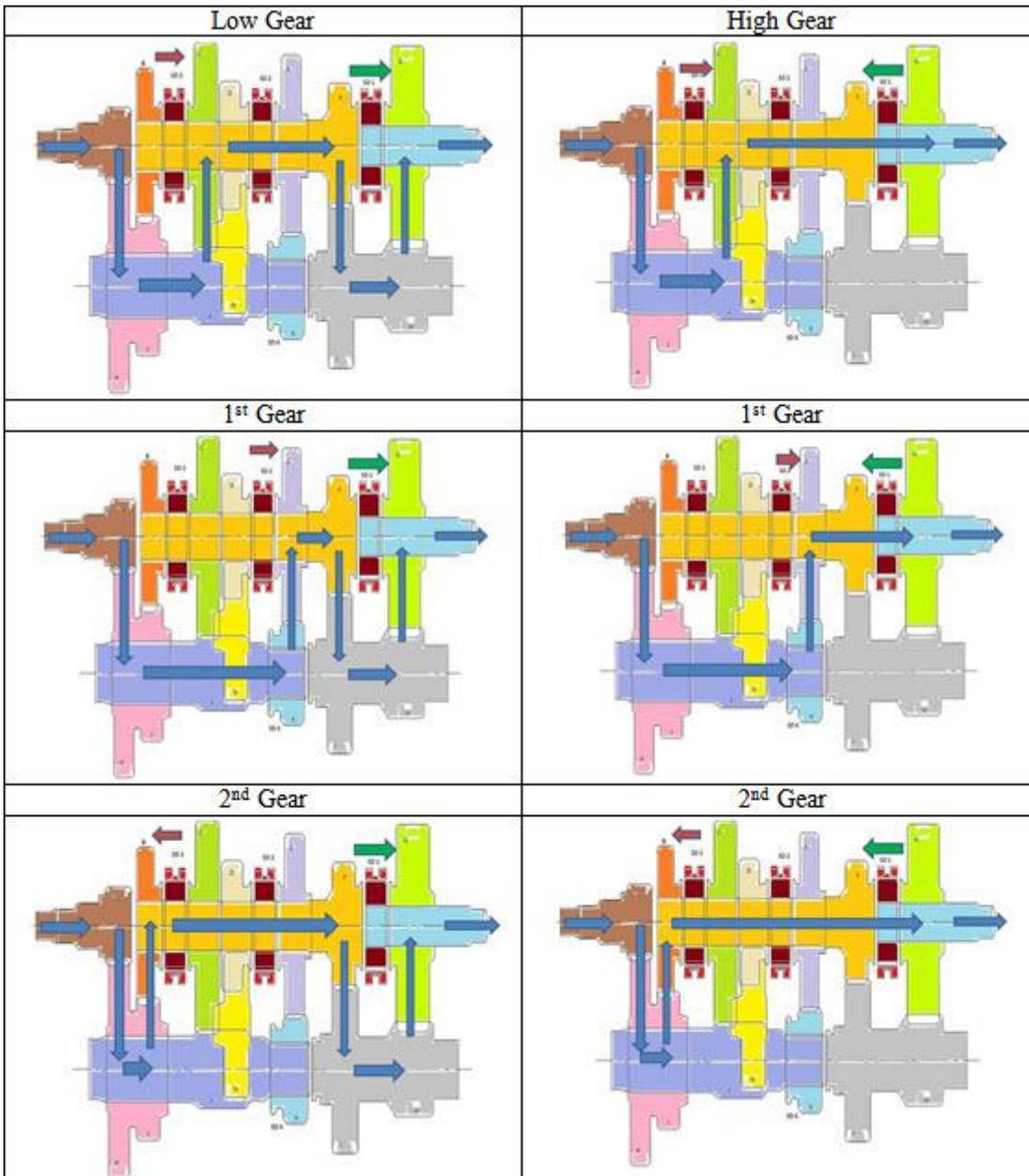
Fig 17.1 shows a typical constant mesh gear box in an agricultural tractor. This gear box has 8+2 gear ratios i.e. 8 forward speed gear ratios and 2 reverse speed gear ratios.

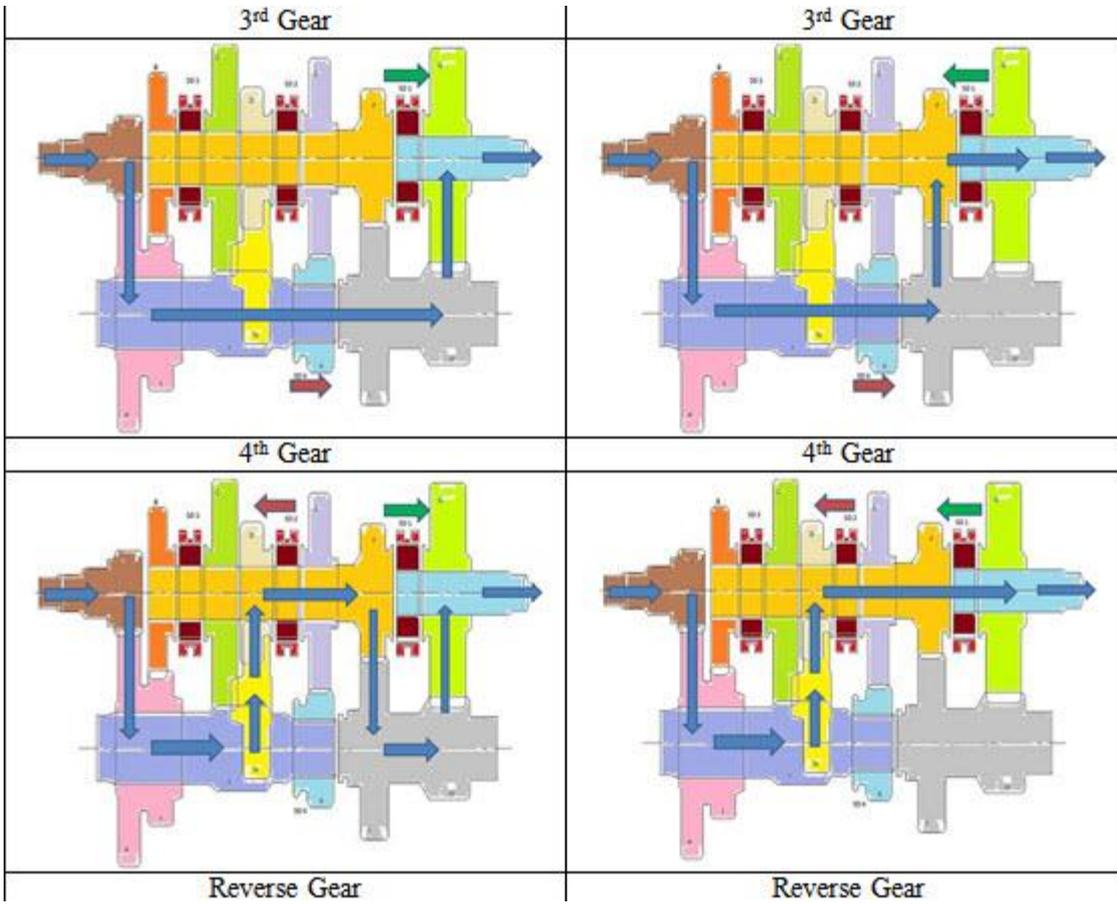


In this gear there are 5 shafts and a number of gears. There are also four sliding dog clutches - 3 on the upper shaft axis and 1 on the lower shaft.

Gear meshing







Module 6. Differential and Final drive

Lesson 18. Working principle of differential system and its construction

When an automobile travels around a corner, the distance traveled by the outside wheels is greater than that traveled by the inside wheels. If the wheels are mounted on dead axles so that they turn independently of each other, like the front wheels of an ordinary passenger vehicle, they will turn at different speeds to compensate for the difference in travel. But, if the wheels are driven positively by the engine, a device is necessary which will permit them to revolve at different speeds without interfering with the propulsion system. To accomplish this purpose a system of gears called the differential is provided.

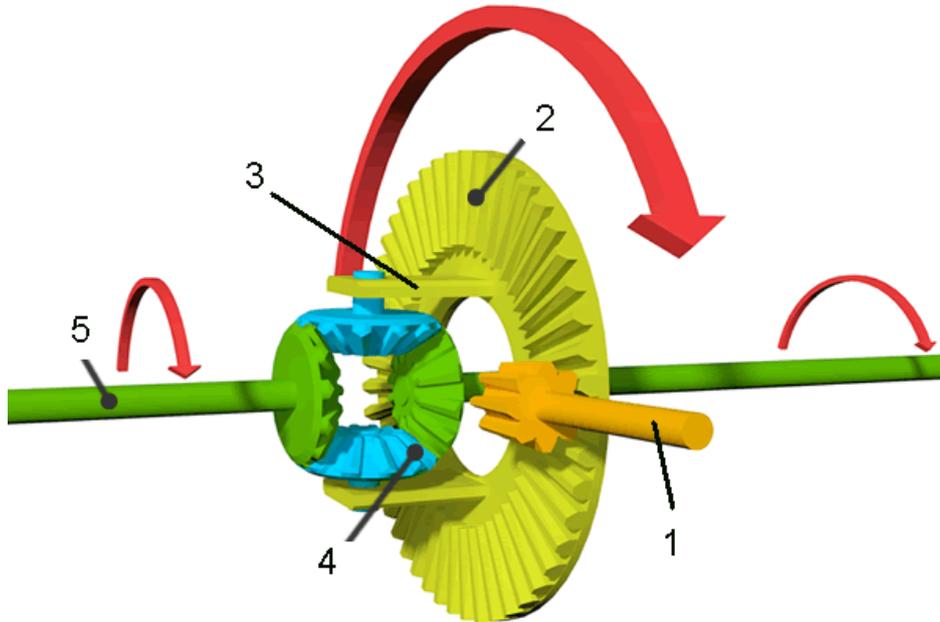
The driving axle is one of the cross members which supports the load of the tractor, and has the driving wheels at its ends. The driving axle consists of a housing, a differential, two axle shafts (half axles), and final drives (if required).

The differential is an important component of the driving axle. The main functions performed by the differential system are:

1. Further reduces the rotations coming from the gear box before the same are passed on to the rear axles.
2. Changes the direction of axis of rotation of the power by 90° i.e. from being longitudinal to transverse direction.
3. To distribute power equally to both the rear driving axles when the tractor is moving in straight ahead direction.
4. To distribute the power as per requirement to the driving axles during turning i.e. more rotations are required by the outer wheel as compared to the inner wheel - during turns.

The main components of the differential (Fig. 18.1) are:

1. Input pinion gear
2. Crown wheel gear
3. Differential cage
4. Differential star
5. Differential axle (sun) gear



Action	Results	Crown wheel	Sun Gears	Star Gear
One wheel jacked and rotated, Gear engaged	Engine rotates	Rotates	Only jacked side rotates	All rotate
Two wheels jacked and one rotated	Other wheel will rotate in opposite direction	Does not rotate	Both rotate	All rotate
Tractor moving in straight ahead position	Both wheels rotate with same speed	Rotates with the cage	Both rotate with the cage	Do not rotate independently but with the cage
Tractor turning left or right	Turning side rotates with slow speed. Other wheel rotates faster	Rotates	Turning side rotates slower, other side rotates faster	All rotate
Diff locked (side dog coupling engaged with crown-wheel)	Both wheels rotate with same speed	Rotates with the cage	Both gears rotate with same speed (with the cage)	Do not rotate independently but with the cage

Module 7. Brakes

Lesson 20. Brake System - necessity, working principle, functional components, brake lining material.

BRAKES

The braking system is an important system in the tractors used to slow down or stop the tractor motion. It is also used to prevent the tractor from moving when it is stationary. During field operations it helps in taking sharp turns by applying differential brakes on the two rear wheels.

The brakes use the frictional force to reduce the motion of the wheels. Friction is used to convert the kinetic energy into heat.

The brake arrangement serves to intentionally offer resistance to the movement of the tractor. Most common are the friction brakes. These are essentially heat devices that change the kinetic energy of the moving vehicle into heat, by virtue of friction between a rotating component and a stationary component which are mechanically moved so that they come in contact with the rotating component. The stationary are lined with a hard wearing friction material. When this material is moved into contact with the rotating component, braking takes place.

Brake is used to stop or slow down the motion of a tractor. It is mounted on the driving axle and operated by two independent pedals. Each pedal can be operated independently to assist the turning of tractor during the fieldwork or locked together by means of a lock.

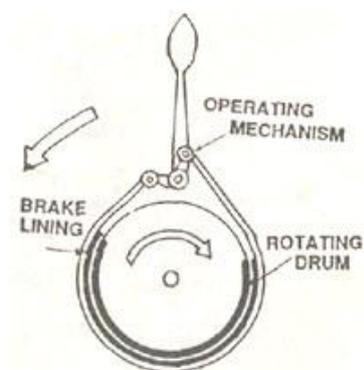
Principle of operation: Brake works on the principle of friction. When a moving element is brought into contact with a stationary element, the motion of the moving element is affected. This is due to frictional force, which acts in opposite direction of the motion and converts the kinetic energy into heat energy.

Classification of brake: Brake can be classified as:

- (1) Mechanical brake and
- (2) Hydraulic brake.

Mechanical brake can be:

- (a) Internal expanding shoe type
- (b) External contracting shoe type and
- (c) Disc type.



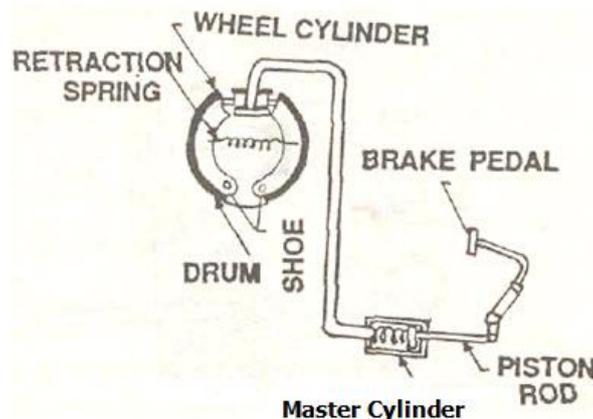
Internal expanding shoe type: Two brake shoes made of frictional material fitted on the inside of the brake drum are held away from the drum by means of springs. One end of each shoe is fulcrum whereas the other is free to move by the action of a cam which in turn applies

force on the shoes. The movement of the cam is caused by the brake pedal through the linkage. The drum is mounted on the rear axle whereas the shoe assembly is stationary and mounted on the back plate.

External contracting shoe type: This type of brake system is normally available on crawler tractors. The brake band directly surrounds the drum mounted on the drive axle. When the pedal is depressed, the band tightens the drum

Disc brake: Two actuating discs have holes drilled in each disc in which steel balls are placed. When the brake pedal is depressed, the links help to move the two discs in opposite directions. This brings the steel balls to shallow part of the holes drilled in the disc. As a result, the two discs are expanded and braking discs are pressed in between the discs and the stationary housing. The braking discs are directly mounted on the differential shaft, which ultimately transfers the traveling effect to the differential shaft.

Hydraulic brake: Hydraulic brake system is based on the principle of pascal's law. The brake fluid, which is usually a mixture of glycerin and alcohol, is filled in the master cylinder. When the pedal is depressed, the piston of the master cylinder is forced into the cylinder and the entire system turns to a pressure system. Immediately, the piston of the wheel cylinder slides outward which moves the brake shoes to stop the rotating drum. When the pedal is released, the return spring of the master cylinder moves the piston back to its



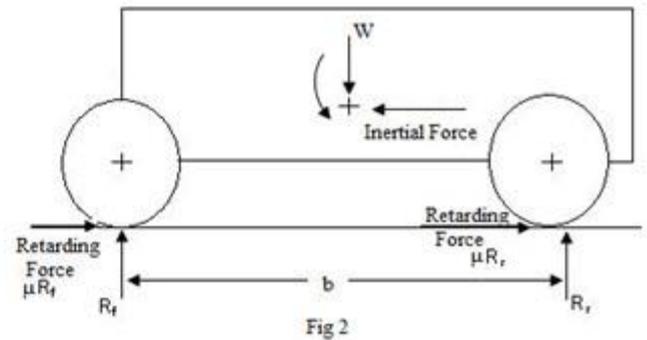
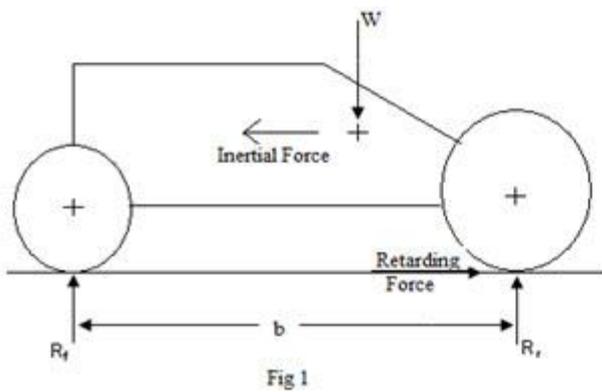
Braking Efficiency:

High braking efficiency is required as on many occasions the brakes are required to stop the vehicle in emergency. However higher brake efficiency not only leads to stopping in a shorter time, may also cause injury to the driver operator due to high decelerating forces and dislodging of loads in the trolley. Higher braking efficiency also causes rapid wear of the brakes and there is more risk of losing control of the vehicle. Braking efficiencies of the order of 50-80% enable to stop within reasonable distance. However the stopping distance varies with the type of road conditions and condition of the tyres.

Braking distance generally refers to the distance a vehicle will travel from the point when the brakes are fully applied to when it comes to a complete stop. It is primarily affected by the original speed of the vehicle and the coefficient of friction between the tires and the road surface. Braking distance also includes the reaction time to when the driver feels the need to stop the vehicle and the response time

Lesson 21. Calculation of braking effort.

Weight Transfer:



The figure 2 shows a body moving towards the left with an inertial force. Brake is applied, which produces a retarding force at the road surface. This retarding force at the road surface causes an overturning couple on the body due to which weight transfer takes place from the rear to the front wheels.

In figure 3, the body is coming down a gradient of angle ϕ when the brakes are applied.

W = Weight of the vehicle

R_f = Normal reaction on the front wheel

R_r = Normal reaction on the rear wheel

b = Wheelbase

h = Height of CG from the surface of the road

∞ = Retarding force due to braking

μ = Coefficient of friction between the wheels and the road surface

μR_f = Braking force on the front wheels

μR_r = Braking force on the rear wheels

When brakes are applied on all the wheels

$$R_f + R_r = W \cos \phi \quad -1$$

$$\mu R_f + \mu R_r = W \sin \phi + \frac{W}{g} \cdot \infty \quad -2$$

g

In case of equilibrium $\sum M=0$ at point B

$$W \cdot \infty \cdot h + W \sin \phi \cdot h + W \cos \phi \cdot x - R_f \cdot b$$

g

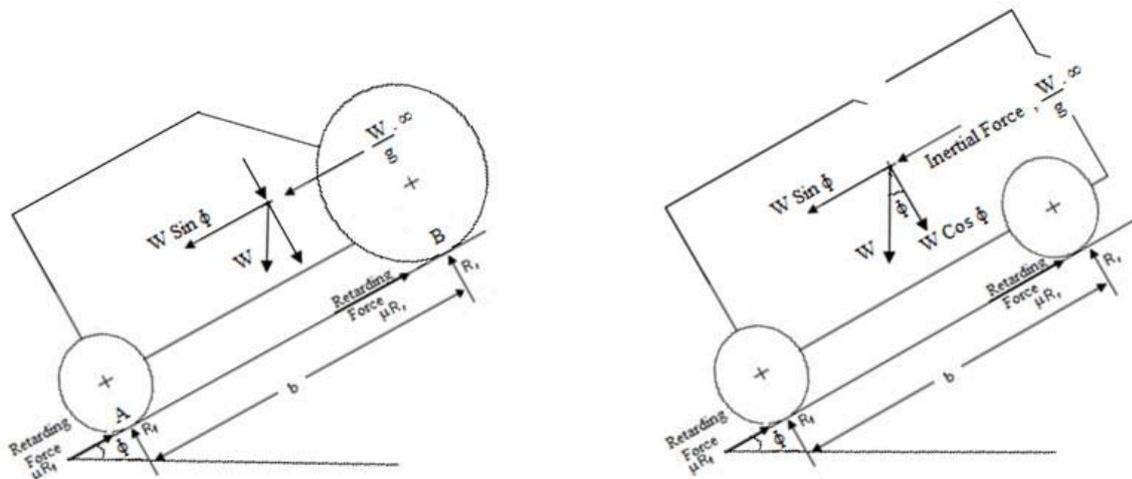


Fig 3

From equation 1 and 2

$$M W \cos \phi = W \sin \phi + W \cdot \infty$$

g

$$\infty = \mu \cdot \cos \phi - \sin \phi \tag{4}$$

g

From equation 3 and 4

$$R_f = \frac{W(x + \mu h) \cdot \cos \phi}{b}$$

$$R_r = \frac{W(b - x - \mu h) \cdot \cos \phi}{b}$$

Case of Indian Agricultural Tractors

While most of the automobiles have an all wheel braking but most of the Indian Agricultural Tractors, being rear wheel drive, have braking only in the rear wheels.

The weight transfer in case of tractors with braking in the rear wheels only is analyzed as follows:

$$R_f + R_r = W \cos \phi \tag{5}$$

$$\mu R_r = W \sin \phi + \frac{W}{g} \cdot \omega \quad -6$$

Taking moments about point A

$$R_r \cdot b + W \cdot h \cdot \sin \phi + \frac{W}{g} \cdot \omega \cdot h - W(b-x) \cos \phi = 0 \quad -7$$

From equation 6 and 7

$$\omega = \frac{\mu(b-x) \cos \phi - \sin \phi}{g(b + \mu h)}$$

$$R_r = \frac{W(b-x) \cos \phi}{(b + \mu h)}$$

$$R_r = \frac{W(x + \mu h) \cos \phi}{(b + \mu h)}$$

In case the body (or the tractor) is moving up the slope, the angle of the slope may be taken as negative and the derived expression can be used.



Lesson 22. Brake actuation methods

Classification of Brakes

The brakes used on automobiles can be classified in a number of ways. Some of these classifications are mentioned here under:

1. Purpose

Brakes can be classified on the basis of the purpose for which they are on the automobile:

- a. Primary Brakes:** These are used as the main brakes to stop the motion of the automobile.
- b. Secondary Brakes:** These are used as parking brakes to maintain the status of the automobile specially when parked on slopes or on even surfaces.

2. Location

The brakes can be located at the wheels or on the drive shaft of the transmission. The location of brakes on the transmission shaft not only gives the convenience of location and provides for equal braking effort on the braking wheels but locating these on the wheels provides dual advantage of having higher surface area for brake application and the greater area provides for better heat dissipation.

3. Construction

The brakes are classified into:

- a. Internal expanding shoe brakes**
- b. External contracting shoe brakes**
- c. Disc brakes**

The internal expanding shoe brakes are also called the drum brakes and explained later. These types of brakes are most commonly used in tractors. But the new-age tractors are also coming with disc brakes.

The external contracting shoe brakes are external to the wheel and can be seen in case of railways.

4. Method of Actuation

The method of actuation decides as to how the braking effort from the point of application brake pedal, reaches tree brakes.

- a. Mechanical Actuation-** Most common in tractors.
- b. Hydraulic Actuation-** used in tractors with higher HP and motor cars.

- c. **Electric Actuation-** use eddy currents for application of brakes.
- d. **Vacuum Actuation-** applied in railways.
- e. **Pneumatic Actuation-** applied in heavy vehicles and special purpose machines.



Module 8. Steering system

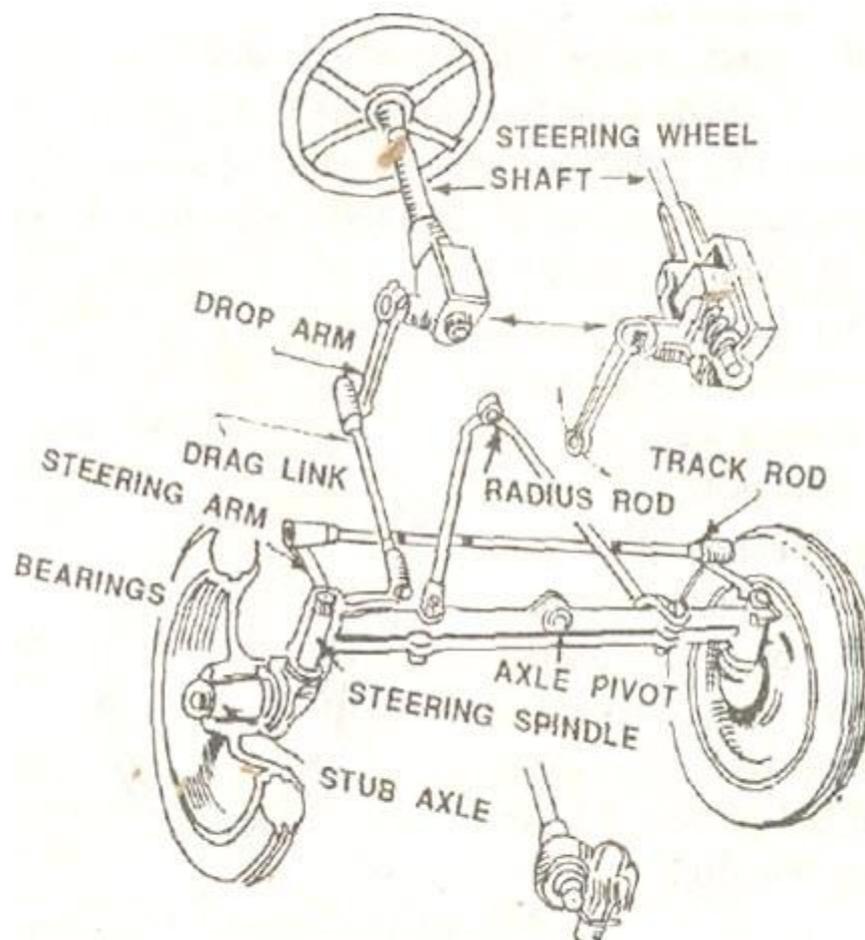
Lesson 23. Steering system : Necessity. Steering Geometry

Steering System

The steering system is required to control the direction of motion of the vehicle (tractor in our case). This is done through a series of links used to convert the rotation of the steering wheel into change of angle of the axis of the steering wheels. Another function of the steering system is to provide directional stability. The motion of the vehicle being steered needs to become straight ahead when the force on the steering wheel is removed. The design of the steering system should be such that it should cause minimum wear of the tyres of the wheels.

The steering system can be classified into front wheel steering, rear wheel steering or all wheel steering.

The system, governing the angular movement of front wheels of a tractor is called steering system. This system steering wheel minimizes the efforts of the operator in turning the front wheel with the application of leverages. The different components of the system are:



**Steering
system**

- steering wheel
- steering shaft
- steering gear
- pitman arm (drop arm)
- drag link
- steering arm
- tie rod and
- king pin.

When the operator turns the steering wheel, the motion is transmitted through the steering shaft to tire angular motion of the pitman arm, through a set of gears. The angular movement of the pitman arm is further transmitted to the steering arm through the drag link and tie rods. Steering arms are keyed to the respective king pins which are integral part of the stub axle on which wheels are mounted. The movement of the steering arm affects the angular movement of the front wheel. In another design, instead of one pitman arm and drag link, two pitman arms and drag links are used and the use of tie rod is avoided to connect both steering arms.

TRACTOR TYRE AND FRONT AXLE

The tyres are available in many sizes with the ply ratings as 4, 6 or 8. The ply rating of tyres indicates the comparative strength of tyres. The higher the rating, the stronger are the tyres. The tyres size 12–38 means, that the sectional diameter of tyres is 12" and it is mounted on a rim of 38" diameter. The inflation pressure in the rear wheels of the tractor varies between **0.8 to 1.5 kg/cm²**. The inflation pressure of the front wheel varies from **1.5 to 2.5 kg/cm²**. Useful life of the pneumatic tyres under normal operating condition may be about 6000 working hours for drawbar work.

FRONT AXLE AND STEERING MECHANISM

Front Axle

The front axles are generally dead axles. The front wheel hubs rotate on anti friction bearing of tapered - roller type on the steering spindle which are an integral part of steering knuckle. To permit the wheels to be turned by the steering gear, the steering spindle and steering knuckle assemblies are hinged at the end of the axle. The pin that forms the pivot of this hinge is known as Kingpin or steering knuckle pin.

FRONT WHEEL ALIGNMENT

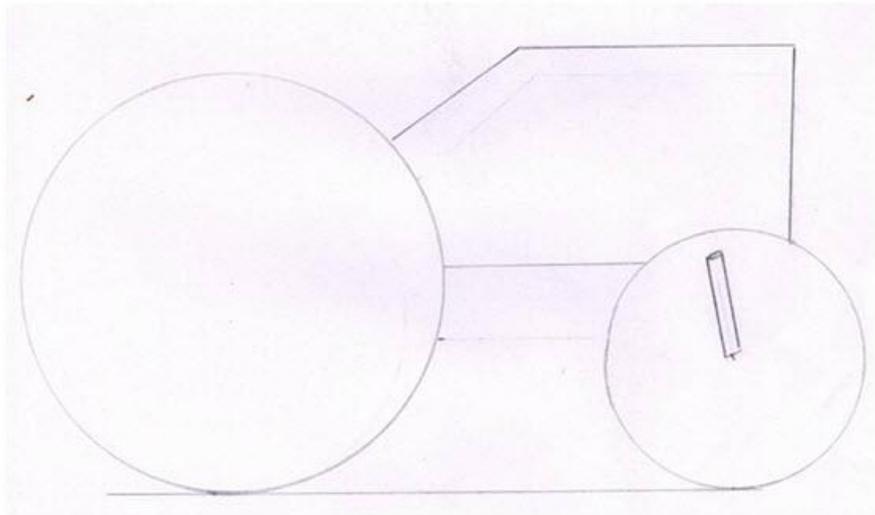
The front wheels must be in correct alignment in order to ensure easy steering, to give directional stability of the vehicle and to minimize tyre wear. Front wheel alignment is obtained through accurately setting of the following factors:

- Caster
- Camber
- Kingpin inclination
- Toe-in
- Toe-out

CASTER

Caster angle is the tilt of the kingpin or ball joint centre line from the vertical towards either the front (negative caster) or rear (positive caster) of the vehicle.

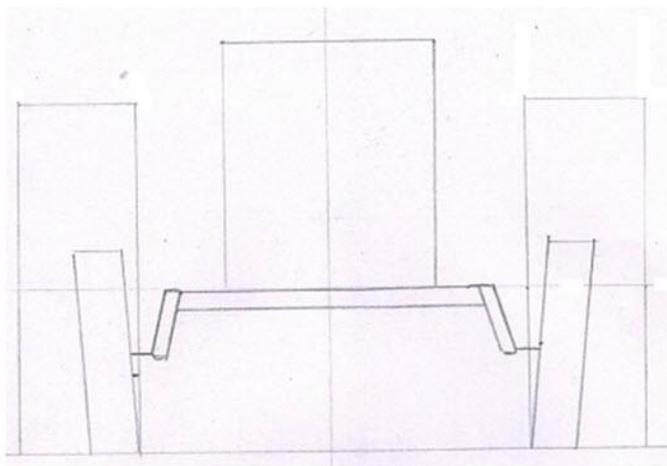
The caster angle produces a trailing effect and hence gives the directional stability. In correct caster can produce difficulties like hard steering, pulling to one side when brakes are applied. The caster angle ranges from 2-8° negative.



CAMBER

Camber angle is the inclination between the centre line of the tire and the vertical line. The outward inclination is called positive camber and the inward inclination is the negative camber. The purpose of the camber is to prevent the top of wheels from tilting inward much due to excessive load or play in the king-pin and wheel bearing. Unequal camber in the wheels causes the vehicles to roll in the direction of wheel having the greater camber which upsets directional stability and tends to scuff the tread on the opposite tire, excessive camber prevents the tire from having correct contact with the road which causes it to wear only on the side directly beneath the load.

Camber angle is less than 1 degree.



KING-PIN INCLINATION

King-pin inclination is the inward tilt of the king-pin or ball joint centre line from the vertical. King-pin inclination in combination with camber provides directional stability. whereas the king-pin inclination and camber combine to give centre-point steering of the tire on the road

and to bring upward thrust on the stub axle more nearly through the centre of the king-pin. The combined camber angle and king-pin inclination is called the included angle.

King-pin inclination ranges from 4-8°.

TOE-IN

Front wheels are usually drawn in slightly in front so that the distance between the back-ends (y) is slightly more than the distance between front-ends (x). The difference between these distances is called toe in. Wheels are toed-in to offset the tendency for them to roll outward due to camber and to play in the steering linkage.

Toe-in is usually 2-4 mm.

TOE-OUT

When a vehicle takes a turn, the inside wheel moves faster than the outer wheel because the former has to negotiate an arc with shorter radius than the latter. This action causes the wheels to out-out on turns because of difference in their turning angles.

STEERING SYSTEM

The function of a steering system is to convert the rotary movement of the steering wheel in driver's hand into the angular turn of the front wheels on road. Further, the steering system should provide mechanical advantage over front wheel steering knuckles, offering driver easy turning of front wheels with minimum effort in any desired direction.

There are two types of steering:

- Mechanical Steering
- Hydraulic Steering

MECHANICAL STEERING (ACKERMAN-TYPE)

When driver turns the steering wheel, motion is transmitted down through the steering tube to the steering gear. The steering tube revolves inside the steering column. The steering gear changes the direction of motion and increase the turning force applied by driver of the steering wheel in accordance with gear ratio. The gear rotates the steering arm (pitman arm) which transfers the motion to the steering knuckles through the steering gear connecting rod, tie-rod and knuckle arms. This type of linkage is called the relay steering linkage.

The king-pin torque (T) required to turn the wheel under a vertical load (W) can be calculated by the following equation:

$$T = W.f \left(\frac{I_0}{A} + e^2 \right)^{1/2} \quad (1)$$

Where,

f = effective friction coefficient

I_0 = polar moment of inertia of tire print, m^4

e = Kingpin-offse, t m

A = tire print area, m^2

This equation assumes a uniform tire print pressure. If the exact shape of the tire print is unknown, an approximation can be made by assuming it to be circular with diameter equal to the nominal tire width, b , then

$$\frac{I_0}{A} = \frac{\pi}{32} d^4 \times \frac{4}{\pi d^2} = \frac{d^2}{8} = \frac{b^2}{8}$$

So equation (1) becomes

$$T = W.f \left(\frac{b^2}{8} + e^2 \right)^{1/2} \quad (2)$$

The change in steering torque as a function of king-pin offset is shown by the curve given below:

The curve shows that an optimum king-pin offset e , exists for a minimum value of torque, T . Also the optimum offset varies with the different surface conditions. A small king-pin offset or even centre point steering in which the offset e approaches zero is better suited for heavily loaded tires in loose soil where rolling resistance is high. If the steered wheel is also powered or is equipped with brakes, a small or zero offset is also advisable to reduce feedback of forces into the steering system.

The curve below shows that generally accepted typical effective coefficient of friction for rubber tires on dry concrete as a function of the king-pin offset to tire width ratio.

Importance of wheel alignment

- 1. Improve Handling:** - This helps in controlling the vehicle. Improper handling can be due to vehicle pulling on one side, vibration of the steering wheel.
- 2. Improves tyre life and performance:** - Proper rolling tyre contact on road and prevention of slipping of the tyres due to improper alignment results in better tyre life.
- 3. Helps in identifying problems:** - Improper alignment could be a symptom of something wrong in the vehicle. A check on this can lead to correction in the fault in the vehicle.
- 4. Ensures Safety:** - By keeping the system in order by removing the defective parts, enhances the vehicle systems, especially the suspension system, leading to better safety.
- 5. Improves fuel efficiency:** - By enhancing the performance of various systems, leads to better fuel efficiency from the vehicle.



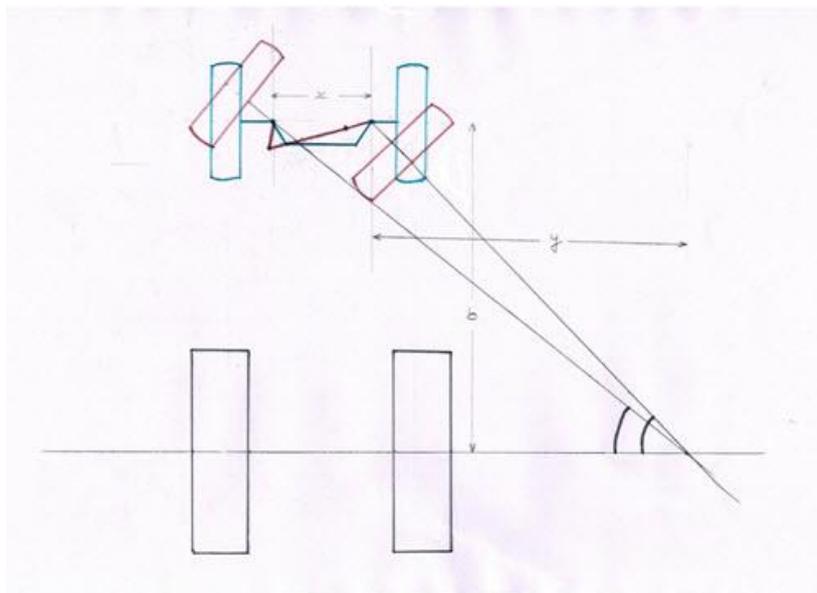
Lesson 24. Analysis of steering-Turning radius. Ackerman Steering

Analysis of Steering angle

For perfect steering, all wheels need to be rolling perfectly without scuffing. Under normal turning conditions, both the front steering wheels point in the same direction, often resulting in scrubbing and not a perfect rolling. During turning, the outer wheels move around a track which has larger turning radius as compared to the inner wheel.

The steering proposed by Erasmus Darwin in 1758 was patented by Rudolf Ackerman in 1817 is called Ackerman steering and is described below.

Fig. 24.1 shows the various linkages for going in a straight ahead situation. Fig 24.1 also shows the position of linkage for turning towards the right (lock position). For perfect steering in the locked position, the axes of all the wheels should appear to be meeting at one point, which is called the instantaneous turning centre.



From Fig 24.1,

$$\tan \phi = \frac{\text{wheelbase, } b}{x+y} \quad - (1)$$

$$\tan \theta = \frac{\text{wheelbase, } b}{y} \quad - (2)$$

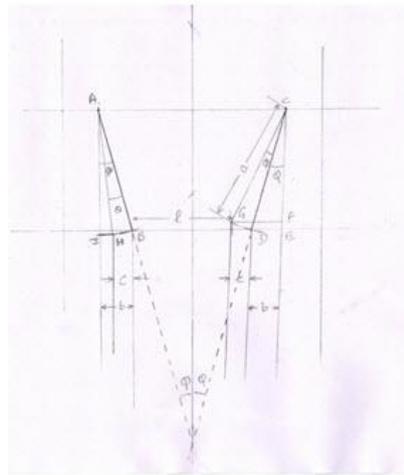
θ - angle of inside lock

ϕ - angle of outside lock

Subtracting (2) from (1)

$$\cot \phi - \cot \theta = x/b \quad - (3)$$

Ackerman steering



The Fig 24.2 has been derived from Fig 24.1.

AB and CD are the steering links from the two stub axles, each having a length of 'a'.

BD is the tie rod of length 'l' between the two steering links.

The steering links AB and CD make an angle 'φ' each with the lateral line about which the steering is symmetrical.

Now when the steering is turned to the right extreme, lock position, the steering link CD turns left by an angle 'φ' and the link AB correspondingly turns left by an angle 'θ'.

From the Fig 24.2,

In triangle CDE

$$\sin \phi = b/a \quad - (4)$$

In triangle CFG

$$\sin (\phi + \phi) = (b+c)/a \quad - (5)$$

In triangle AHJ

$$\sin (\phi - \theta) = (b-c)/a \quad - (6)$$

Adding (5) and (6)

$$\begin{aligned} \sin (\phi + \phi) + \sin (\phi - \theta) &= (b+c)/a + (b-c)/a \\ &= 2(b/a) = 2(\sin \phi) \quad - (7) \end{aligned}$$

This relation for Ackerman steering holds for three cases i.e. when moving straight ahead, lock position to the right and lock position to the left.

Lesson 25. Steering linkage. Types of steering gear (steering box)

One of the important human interface system in the automobile is the steering gear. The steering gear is a device for converting the rotary motion of the steering wheel into straight line motion of the linkage. The steering gears are enclosed in a box, called the steering gear box. The steering wheel is connected directly to the steering linkage it would require a great effort to move the front wheels. Therefore to assist the driver, a reduction system is used.

The different types of steering gears are as follows:

1. Worm and sector steering gear.
2. Worm and roller steering gear.
3. Cam and double lever steering gear.
4. Worm and ball bearing nut steering gear.
5. Cam and roller steering gear.
6. Cam and peg steering gear.
7. Recirculating ball nut steering gear.
8. Rack and pinion steering gear.

Recirculating ball steering gear

This is the most common steering gear in Indian tractors. In this the lower end of the steering column has a worm. A box type nut is clamped on this worm which has numerous ball bearings circulating between the worm and the nut. As the steering wheel on top of the steering column is turned, the nut moves up and down. This movement of the nut is sensed by the sector of the pitman which is connected to the nut. The movement of the nut is transferred into the rotational motion of the pitman. Drop arms are mounted on this pitman shafts. The blow-up figure of a recirculating ball steering box is as shown in Fig 25.1.

Worm and Roller Type Steering Box

In case of worm and roller steering, the worm at the lower end of the steering column is in the form of a cam. There is a roller which follows the shape of the worm. The roller is a part of the pitman. As the roller follows the cam when the steering column is turned, the motion is transferred to the pitman and to the drop arms. An exploded view of the worm and nut steering is given in Fig. 25.2

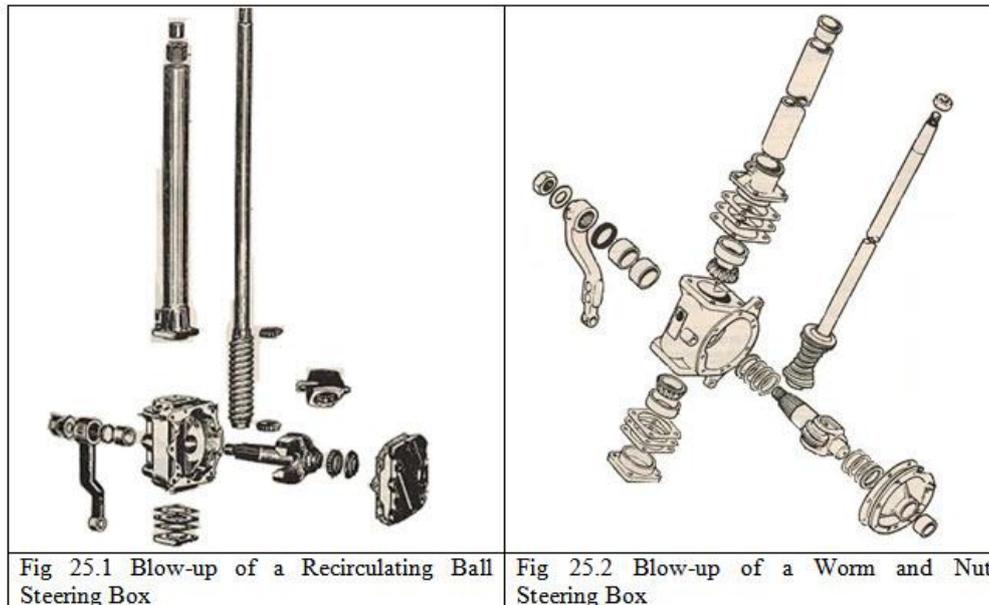


Fig 25.1 Blow-up of a Recirculating Ball Steering Box

Fig 25.2 Blow-up of a Worm and Nut Steering Box

Worm and Sector Type Steering Box

In this type of steering box, the steering worm of the steering column rotates a steering gear sector which is meshed with the worm. The gear sector in turn rotates the pitman on which it is mounted. The pitman is further connected to the steering linkage for steering the wheels. The Fig 25.3 shows the method in which the worm and sector steering is used to convert the rotation of steering column into rotation of pitman.

Rack and Pinion Type Steering Box

In a rack and **pinion steering gear**, a **pinion** is attached at the end of the **steering shaft**. When the steering wheel is turned, the pinion gear spins, moving the rack - left or right, depending on which way the steering is turned. The rack forms the part of the tie rod with steering spindle at its ends which push or pull the steering links for steering the wheels. **Fig 25.4 shows the arrangement for a rack and pinion steering box**

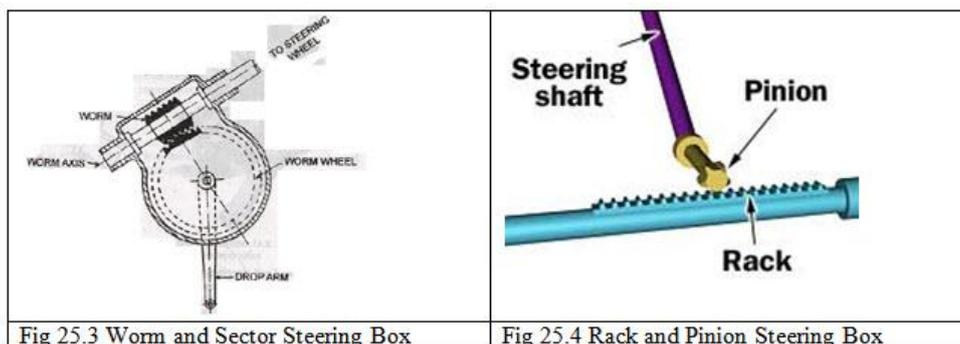


Fig 25.3 Worm and Sector Steering Box

Fig 25.4 Rack and Pinion Steering Box

The recirculating ball mechanism has the advantage of a much greater mechanical advantage, so that it was found on heavier vehicles while the rack and pinion was originally limited to smaller and lighter ones.

Lesson 26. Hydraulic steering

POWER STEERING

Tractors having 30 KW or more power generally will have power steering. This is based on two basic fluid power types: There are

- Hydromechanical systems
- Full hydraulic systems, commonly called hydrostatic power steering

Hydromechanical systems

The term "hydrostatic" means those systems requiring no mechanical linkage between the driver's steering wheel and the steered wheels. In this system fluid under pressure is used not only power the load but also to provide hydraulic feedback from load and to transmit manual effort to the load when the power source is unavailable. The two most important advantages of the hydrostatic system are

- Flexibility of installation
- Lower cost

The most distinguishing feature common to hydrostatic steering systems is the use of a positive displacement flow metering or measuring device coupled to the steering wheel shaft. Hydrostatic systems can be categorized by the manner in which this metering device operates in the control loop. At least four basic types can be identified as given below:-

TYPE-1

The metering unit is mechanically linked to steering shaft and control valve and is hydraulically connected in series to the actuator. It provides the remote monitoring of actuator position at the control valve location, known as position feedback. An input error between the steering shaft and the metering unit is measured and translated into control valve displacement by suitable mechanical means. The subsequent response of the actuator - metering unit to the directed flow cancels the error, thus returning the control valve to the null position.

Type-2

The metering unit is rigidly coupled to the steering shaft and hydraulically connected in series with actuator, but in parallel with the control valve pilot chambers. Here the metering unit functions as a transducer to convert steering wheel rotation and input torque into flow and pressure to displace the control valve. The resulting flow of high pressure oil again passes through the metering unit before entering the actuator. The incremental activator motion, which continues after the steering wheel stops, hydraulically recenters the control valve.

TYPE-3

The metering unit is mechanically linked to the steering shaft and control valve as in type 1 but is hydraulically connected to a separate feedback displacement device, which in turn is linked to the output motion. This permits the control circuit to be isolated from the power circuit.

TYPE-4

The metering unit is rigidly attached to the steering shaft and hydraulically connected to the control valve as in Type 2, but it is hydraulically coupled to a separate feedback device as in type 3. This is a simpler, lower cost arrangement than type 3 but introduces an operational factor.

Parameters that influence power requirements are:

1. Tire loading
2. Road surface and soil conditions
3. Tire inflation pressure
4. Tire sizes and tread patterns
5. King-pin inclination
6. Caster angle
7. Camber angle
8. King-pin offset
9. Toe-in and toe-out
10. Tread setting
11. Travel speed
12. Steering rates
13. System efficiency
14. Front end type
15. Tractive and braking force
16. Chassis type

Heaviest steering loads with Ackerman-type steering usually occur with a stationary tractor on dry and clean concretes. This condition provides a convenient standard for calculating maximum power requirements.

On Ackerman - type tractors, tire loading is the most significant variables affecting power requirements. Tire load ranges from minimum needed for longitudinal stability to a maximum usually dictated by tire load rating. If excessive steering force is provided, tires may be twisted from the rims or structural damage inflicted on linkage or chassis members if the tires become lodged. To avoid this possibility, it has been recommended that power steering forces be limited to about 110% of the maximum design condition.

ACTUATORS FOR POWER STEERING

The location of the actuator in the linkage will determine the mechanical efficiency between the output member and the tire print. Overall efficiencies of manual steering gears and their associated linkage are generally in the range of 40-70% depending upon the types of antifriction means employed. typical efficiencies for actuators usually fall between 80-90% with the cylinder types being some what higher than the rotary rack and pinion or vane types (Fig. below).

Actuator output travel (stroke or angular rotation) is governed to some extent by steering geometry limitations; however, it has been recommended that a stroke bore ratio for cylinders between 5 and 8 be selected, if possible, to maintain adequate column strength and a favourable servo-value amplification to linkage deflection relationship.

If the steering is to be powered from the pressure, a desired load pressure can be chosen from the following equation.

$$D = \left[\frac{4aT}{\pi sp E_a E_l} + d^2 \right]^{1/2}$$

Where,

D = piston diameter, mm

a = lock-to-lock steering angle, radius

T = required king-pin torque, N-mm

S = piston stroke, mm

p = effective pressure at piston face, MPa

E_a = overall actuator efficiency

E_l = linkage efficiency

d = piston rod diameter, mm

In terms of displacement, the equation becomes:

$$V = \frac{aT}{p E_a E_l}$$

Where,

v = acuator displacement, mm³

The appropriate multipliers must be applied to accommodate multiple actuators and/or number of torque loads involved. If the effects of king-pin inclination, cater and camber are significant, a modified value of aT should be determined and substituted. The effect of caster and camber are usually small. However, large king-pin inclination angles produce a significant lifting actin to the axle which adds to the king-pin torque when going into a turn.

It will be noticed that the energy required for steering an articulated frame, tractor is about 3.5 times that for an Ackerman-steer type tractor with the same axle load. These values will normally provide acceptable performance for all but stationary steering under maximum load condition.

POWER STEERING PUMP

The power source for a steering system can be either a separate pump, the central hydraulic system pump or a combination of both. High quality, fixed clearance gear or vane pumps are used for pressures upto 10.3 MPa. The majority of open centre steering pumps, both on farm tractors and on trucks and automobiles are of this type.

Most commercial power steering pumps are designed to be belt or gear driven and have speed capabilities above the engine speed typical on farm tractors. Unless the pump is to be driven directly off the crank shaft the higher permissible speeds should be exploited to reduce size and cost. Common maximum pump speeds are from 3000-5000 rpm. The required pump flow is given by

$$Q = 0.006 \frac{v}{t}$$

Where,

Q = pump flow rate, lit/min

v = actuator total displacement volume, cm³

t = desired steering time from lock-to-lock turn, s

A steering wheel rate of less than one revolution per second is seldom satisfactory and more than twice is rarely desired. A steering time t of 2-4s, lock-to-lock is typical.

With flow rate, Q, and time, t, the pump displacement can be computed.

The power requirement of the pump is

$$P = \frac{v_1 \Delta p \cdot n}{E}, \text{ N - m/s}$$

$$= \frac{v_1 \Delta p \cdot n}{10^9 E}, \text{ kw}$$

Where

Δp = pressure rise through pump, Pa

E = overall pump efficiency

n = revolutions/s

v_1 = displacement volume, cm³



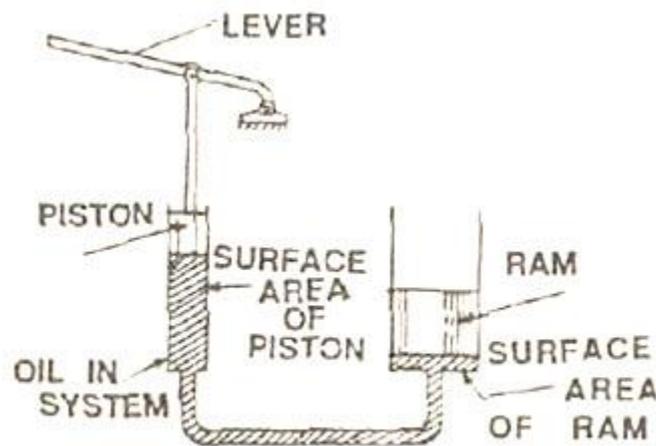
Module 9. Hydraulics

Lesson 27. HYDRAULIC SYSTEM

It is a mechanism in a tractor to raise, hold or lower of mounted or semi-mounted equipments by hydraulic means. All tractors are equipped with hydraulic control system for operating three-point hitch of the tractor.

Working principle: The working principle of hydraulic system is based on pascal's law. This law states that the pressure applied to an enclosed fluid is transmitted equally in all directions. Small force acting on small area can produce higher force on a surface of larger area

BASIC COMPONENTS OF HYDRAULIC SYSTEM

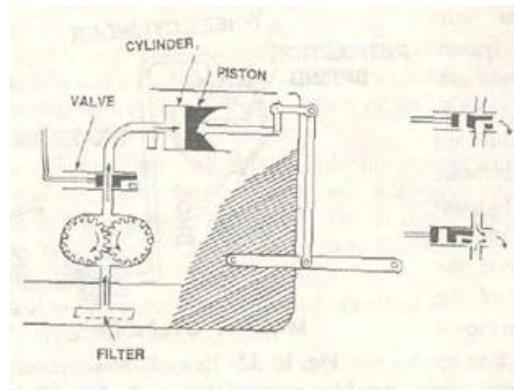


Pascal law

The basic components are:

- (i) Hydraulic pump
- (ii) Hydraulic cylinder and piston
- (iii) Hydraulic tank
- (iv) Control valve
- (v) Safety valve
- (vi) Hose pipe and fittings and
- (vii) Lifting arms.

Operation: The hydraulic pump draws up oil from the oil reservoir and sends it to the control valve under high pressure. From the control valve, the oil goes to the hydraulic cylinder to operate the piston, which in turn, raises the lifting arms. The lifting arms are attached with implements. The hydraulic pump is operated by suitable gears, connected with engine.



Schematic diagram of hydraulic system

There are two types of arrangements for storing hydraulic oil in the system:

- (i) There is a common oil reservoir for hydraulic system and the transmission system in some tractors,
- (ii) There is a special tank for hydraulic oil. It is separate from the transmission chamber.

Hydraulic pump: There are several types of hydraulic pump, such as gear pump, plunger pump, vane pump, and screw pump. Gear pump is widely used in tractors. Gear pump can flow a bigger amount of oil, compared to plunger pump. The oil pressure in the pump varies from **150 to 200 kg/cm²**.**Schema**

Hydraulic cylinder: It is a bigger size cylinder, fitted with a piston and a connecting rod. It is also called ram cylinder. The connecting rod transmits power from the piston to the lifting arms. Piston moves in the hydraulic cylinder and causes reciprocating motion in the cylinder. The lifting arms are raised by the hydraulic pressure while raising the implement but it is lowered by its own weight.

Hydraulic tank: Hydraulic tank is used for storing hydraulic oil for the system. In some tractors, transmission chamber itself works as a hydraulic tank and same oil is used for transmission system as well as hydraulic system. In some tractors, separate tank is there for hydraulic oil.

Control valve: Control valve is a type of valve, which controls the movement of hydraulic oil to have desired direction, magnitude and speed of lifting. Thus the control valve is to perform three functions:

- (1) to change the direction of lifting
- (2) to change the power of lifting and
- (3) to change the speed of lifting.

Oil filter: It is small filter, located at a convenient position in the passage of the oil.

TYPES OF HYDRAULIC SYSTEM

There are three important methods in hydraulic control system:

- (i) Position control
- (ii) Draft control
- (iii) Mixed control.

Position control: In this system, constant depth of ploughing is maintained by automatic adjustment of draft of tractor. In this system the control valve can be operated directly by the driver to raise lower or hold an implement, mounted on the linkage at any chosen height.

Draft control: In this system, the working depth of any implement can be controlled continuously without the need for a depth wheel on the implement. The hydraulic control valve reacts to changes in the loading in either the top or lower links which arc due to changes in the draft or pull required by the implement. If any implement goes too deep its draft increases. This increase is sensed through the top link or lower links. The control system then raises the implement until the draft is back to the present level and the implement is at the original depth again using the draft control system.

HITCH AND CONTROL BOARD OF TRACTOR HITCH

For the efficient and safe tractor operation, implements are to be hitched properly.

Implements can be of Trailed, Semi-mounted and Mounted type.

Implements can be hitched in two ways:

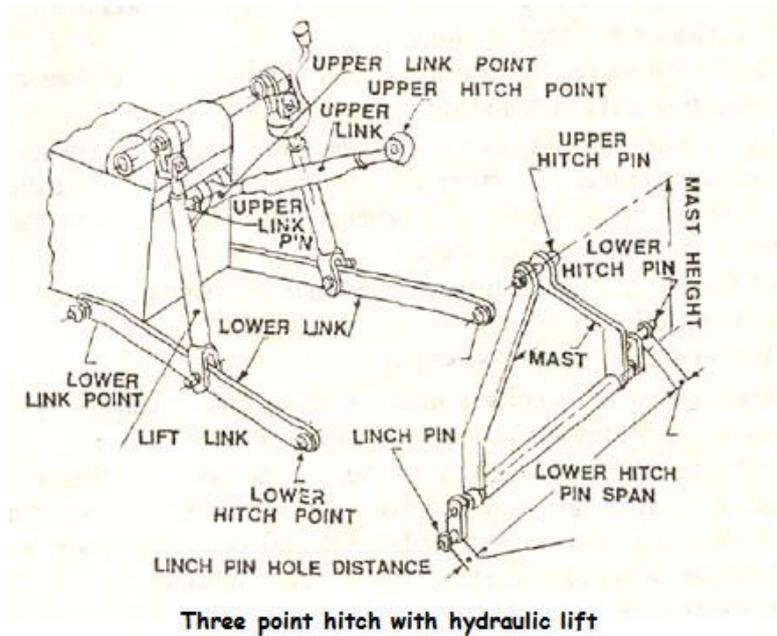
- (a) Drawbar hitch and
- (b) Three point linkage.

Drawbar hitch: Drawbar is a device by which the pulling power of the tractor is transmitted to the trailing implements. It consists of a crossbar with suitable holes, attached to the lower hitch links. It is fitted at the rear part of the tractor.

Three-point linkage: It is a combination of three links, one is upper link and two are lower links, the links articulated to the tractor and the implements at their ends in order to connect the implement to the tractor.

Advantage of three-point linkage:

- (1) Easy control of working implements
- (2) Quick setting of implements
- (3) Automatic hydraulic control of implements such as position control, draft control etc.
- (4) Good balancing of attached implements.



Implement control: The tractor with a built in lift system is connected to the implement through a specific type of mechanical linkage termed as three point linkage and the system is known as mounted system. The implement is connected to the tractor hydraulic system at two bottom links and one top link. Both the bottom links are connected to two lift arms through lift links. The lift arms are directly mounted on a rockshaft, which is further connected to the piston rod. Any movement of the piston is transferred to the bottom links. The top link is used for connecting the third hitch point of the implement and is adjustable for maintaining the implement level and suction angle. Load sensing for the draft control can also be done through the top link, which is spring loaded. In some tractors the lower links are spring loaded for draft sensing. Depending upon the soil condition and type of operation, the mounted implement can be controlled either by position control or draft control.

Weight transfer: Rear part of the tractor is heavier than the front part to get higher tractive efficiency. However, sufficient weight on the front axle is also required to facilitate easy steering and to compensate the effect due to weight transfer. When the load is pulled, the tendency of front axle is to become light by losing some weight and the same adds to the rear axle. The higher the pull, the greater is the weight transfer. Mathematically this can be represented by:

$$\text{weight transfer} = \frac{\text{pull} \times \text{hitch height}}{\text{wheel base}}$$

where the line of pull is always assumed to be parallel to the ground.



Module 10. Power Transmission

Lesson 30. Tractor power outlets-study of P.T.O. and standards

A tractor is used for not only pulling the implements for tillage operations, sowing of various crops, etc., but also used to power stationary equipment for doing operations such as threshing of crops, pumping water from tube-wells, etc. A power outlet is generally provided at the rear of the tractors. The power outlet is known as Power Take Off (PTO). The PTO has been provided on tractors for quite some time. In India the PTO is usually on the rear side, but in developed countries, a front PTO is also provided for driving front mounted machines.

Power to the PTO shaft comes from the gear box. The counter shaft of the gear box is usually extended out to the rear side to act as the PTO outlet.

Standardization of the speed of the PTO is important so that the equipment can be designed around the given speed. For example, the threshers are supposed to run at a particular peripheral velocity of the threshing cylinder. The pulley arrangements are made with the standard PTO speed in mind.

Prior to 1958, the standard PTO speed was 536 rpm. Later this speed was changed to 540 rpm and another speed was added to the standards i.e. 1000 rpm. The splines provided over the PTO out shaft are also different for avoiding accidental attachment of implement of different speed setting. Fig 30.1 shows the cut section of the PTO out shaft alongwith the shape and type of splines on the shaft for a setting of 540 rpm.

Fig. 30.2 shows the cut section of the PTO out shaft alongwith the shape and type of splines for a setting of 1000 rpm. In case of 540 rpm, the shaft has 6 splines, while for the 1000 rpm shaft, the number of splines are 21.

Setting of speed

This setting of the rpm speed is generally for $\frac{3}{4}$ setting of the hand accelerator of the tractor. For a tractor engine having a peak torque at a given rpm of the engine, usually called the rated speed of the engine. The rated speed of the engine at which it develops the best torque is generally got at the said $\frac{3}{4}$ setting of the accelerator. This is highlighted in the below example.

For example a diesel engine of a, say, 35 hp tractor, develops around 150 Nm @ nearly 1700 rpm of the engine. The maximum rpm of the engine usually settle at 2200 rpm. The best torque is usually at when the accelerator is pulled down to $\frac{3}{4}$ setting. This 1700 rpm is input to the gear box. The speed reduction at the primary to counter shaft is such that for this rated engine speed, the counter shaft rotates at 540 rpm. This rpm is then extended out at the rear side and is the PTO.

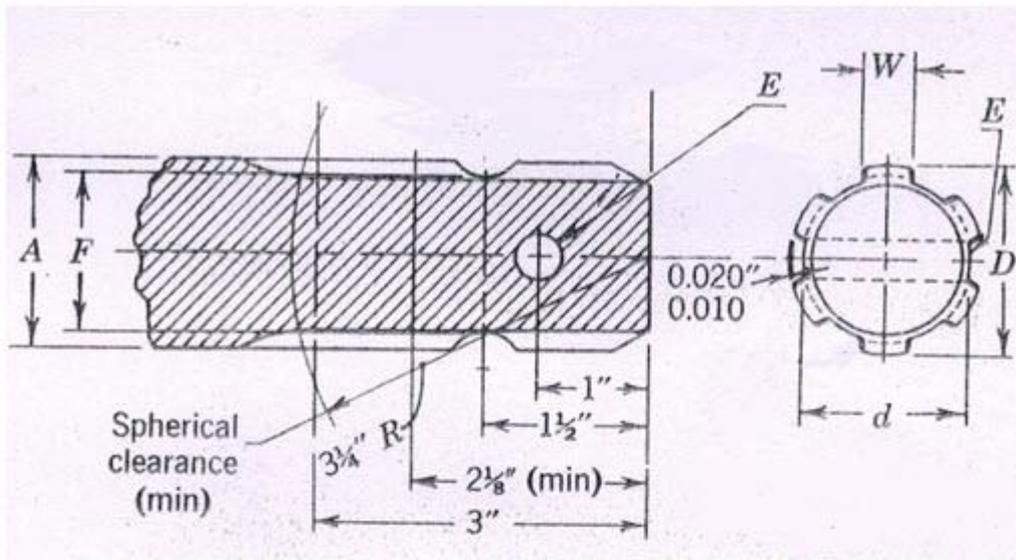
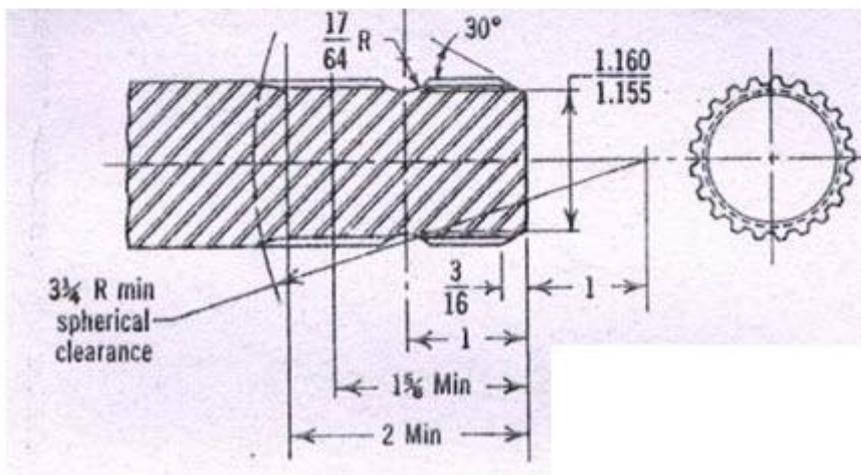


Fig 30.1 Figure of the PTO shaft showing the splines in case of shaft of 540 rpm



Module 11. Human Factors

Lesson 31 & 32. HUMAN FACTORS IN TRACTOR DESIGN

The design of modern tractor includes following human factors consideration:

1. Riding comfort
2. Visibility
3. Location and arrangement of controls
4. Ease of operating controls
5. Design for thermal control, and
6. Sound Control

These factors when properly incorporated in design, allow the operator to perform many complex with

1. Efficiency
2. Safety, and
3. Minimum of fatigue

Operator Exposure to Environmental factors

Tractors are used under varied geographical and climatological conditions. Environmental factors to which operator is directly exposed are

1. Temperature
2. Humidity
3. Wind
4. Thermal radiation
5. Dust, and
6. Chemical

Design of a suitable enclosure for the tractor operator minimizes the effects of above factors. Table 1 defines comfort and bearable zones for humans.

Table1. Environmental Zones for Selected parameters

Environmental Parameter	Comfort Zone		Bearable Zone	
	Lower Limit	Upper Limit	Lower Limit	Upper Limit
Temperature, °C	18	24	-1	38
Humidity, %RH	30	70	10	90
Ventilation, m ³ /min	0.37	0.57	0.14	1.4
Ultraviolet radiation	Unknown		Unknown	

Thermal Comfort: Is defined as the state of mind that expresses satisfaction with the thermal environment.

The value of a roof on a tractor was investigated and found that the shade reduces the black bulb temperature 3.3° to 5.5°C on a hot summer day in Midwest conditions.

The thermodynamics process of heat exchange between man and his environment can be described by general heat balance equation:

$S(\text{Storage}) = M(\text{metabolism}) - E(\text{evaporation}) \pm R(\text{radiation}) \pm C(\text{convection}) - W$ (work accomplished)

S is the amount of heat gained or lost. If the body is in a state of thermal balance, S becomes zero. Positive values of storage will cause the mean body temperature to rise; negative values will cause it to fall. It is most convenient to express the above terms as energy per unit of body surface (W/m^2 or $kcal/h-m^2$). The metabolic rate for a tractor driver will be in the range of 60 to 150 $kcal/h-m^2$. Average body surface area of a man will be $2m^2$ resulting in 120-300 $kcal/h$.

Extension research has been devoted to develop indexes to evaluate thermal comfort. An empirical index- effective temperature (ET) was developed. The new ET scale is based on a simple model of human physiological response. Most individuals will be comfortable when the ET is between 23.9 and 26.7°C.

Operator Exposure to noise

It has been observed that 40 hours of exposure per week to sound levels of 90 dBA or greater will produce permanent hearing loss. Noise-induced hearing loss does not occur in a sudden manner unless the noise exposure is extremely severe. Table 2 shows the acceptable levels presently in existence.

Average noise levels for all tractors tested at Nebraska Tractor Test Lab without cab at 75% pull was 95.17 dB(A) at the operator's site. Tractors tested with cabs averaged 91.4 dB(A). Tractors tested in 1975 with cabs at 75% pull averaged 88.04 dB(A) with the lowest reported being 80 dB(A). The average noise level for tractors without cabs at 75% pull averaged 96.0dB(A), with the lowest reported being 89.5dB(A).

Table 2. Occupational safety and health noise criteria.

Duration/day h	Sound level dB(A)
8	90
6	92
4	95
3	97
2	100
1 ½	102
1	105
1/2	110
¼ or less	115

Acoustic noise is sound. The sound is characterized by frequency, amplitude and phase. The frequency range of the human ear extends from as low as 16 Hz to as high as 20,000 Hz. From a practical stand point, however, few adults can perceive sound above 11,000 Hz.

The simplest vibration is a pure tone which consists of a sinusoid with the frequency:

$$F = \frac{1}{T}$$

Where, T = period, S

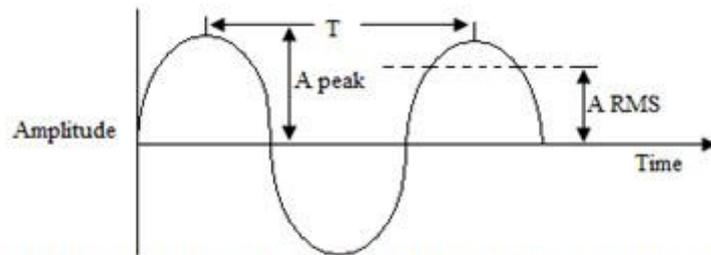


Fig.1.A Sinusoidal vibration with peak and the RMS value of the signal

The magnitude is most commonly expressed as the RMS (root mean square) value because of its direct relation with the energy content of the signal in linear systems. For a simple, pure tone

$$A_{\text{rms}} = \frac{1}{\sqrt{2}} A_{\text{peak}}$$

Airborne sound is a variation in the normal atmospheric pressure. Most sound measuring instruments are calibrated to read RMS airborne sound pressures on a logarithmic scale in decibels. Sound pressure can be expressed as a sound pressure level (SPL) relative to a reference sound pressure for airborne sounds this reference sound pressure is 0.00002 N/m^2 .

Mathematically,

$$\text{SPL} = 20 \log \frac{P}{P_0} \text{ dB}$$

and

$$\text{SPL} = 20 \log \frac{P}{0.00002}$$

Where,

SPL = Sound pressure level, decibels

P = measured RMS Sound pressure, N/m^2

P_0 = reference sound pressure, N/m^2

log = logarithm to the base 10

Fig.2. Shows some typical values for sound pressure levels. A doubling of sound pressure occurs with each increase of 6 dB.

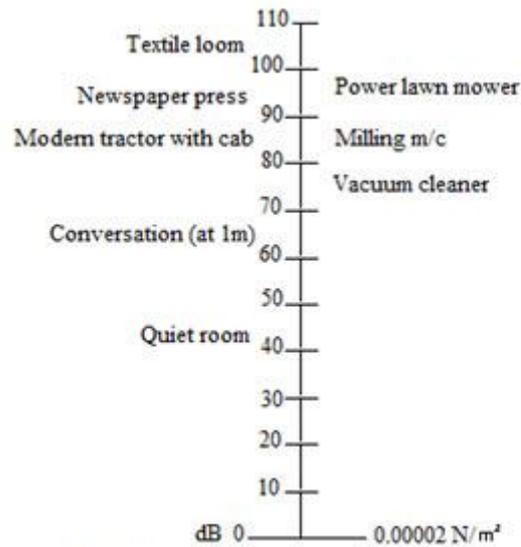


Fig.2. Typical airborne sound levels

General purpose sound measuring instruments are normally equipped with three frequency weighting scales A, B, and C. These scales approximate the ear's response characteristics at different sound levels. Nebraska tractor test data are reported in decibels, using the A weightage scale and written as dB(A).

Operator exposure to vibration

Exposure of the human body to vibrations can result in biological, mechanical, physiological and psychological effects. Ride vibration intensities are normally positively correlated with ground speed and often become intolerable as speed is increased. A survey has revealed that about 76% of the tractor drivers had stomach complaints.

Care should, therefore, be taken in designing tractors and particularly tractor seat, to reduce vibration and shocks to a minimum by appropriate suspension and shock absorption and to arrange the tractor controls in a manner to insure a comfortable posture and minimum effort.

These effects are caused by low-frequency vertical vibration, that is, frequencies upto 20 Hz. This low-frequency vibration results in whole body excitation. Enggs (1973) observed the 4 to 8 Hz range as being critical. In this range resonance occurs in parts of the human body producing discomfort.

Low frequency vertical vibration is present during normal field operations. Amplitude of vibration is, in part, dependent on roughness of the field. The undamped natural frequencies of wheat tractors commonly lie in the 3 to 10 Hz range.

Higher frequency vibration (30 Hz and up) results in part-body vibration, although it is not important with regard to whole-body vibration, it is the source of foot and hand-arm excitation. The higher frequency vibrations can be present at the steering wheel, gear shift levers, control levers and floor panels.

Quite frequently, vibration levels are expressed in decibels. A convenient reference level for vibration is 1 m/s² RMS. It is mathematically expressed as

$$VAL = 20 \log V/1 \text{ , dB ref. } 1 \text{ m/s}^2$$

Where,

VAL = Vibration acceleration level, dB

V = measured RMS acceleration, m/s²

$$V = \frac{1}{\sqrt{2}} (W^2 A)$$

W = frequency of vibration, rad/s

A = peak amplitude, m

The operation – Machine Interface

Every time a person operates a tractor, the sensing, decision making and muscular powers of the operator are joined to an engineering system. The operator uses sound, sight and feel to interpret inputs and to interface with the control-instrumentation components to achieve the desired output of the tractor. Human engineering data defining acceptable ranges for environmental factors, noise and vibration must be incorporated in the design to ensure operator safety and comfort.

Safety, comfort and convenience should be considered in the design, location and construction of the operator's work place. The work place should be located on the machine so that visibility in the driving position is good without requiring the operator to work in an awkward, tiring position. Levers, pedals and instruments should be conveniently located and work place should fit both tall and short operators. In addition, the operator should be able to change his working position easily and the work area should be free of sharp edges and obstructions such as transmission cases.

Two functional conditions in design of the workplace for a tractor operator are visibility and clearance. Primary visibility or "entire window observation" for a tractor requires provisions so that the operator can look in any direction. Near ground vision to the front and rear of the operator is important. Far vision in all directions is necessary. Secondary visibility is needed to monitor instruments or lights inside the workplace or cab.

Clearance at various levels is necessary to provide access to and from the workplace. Proper workplace dimensions in relation to the seat are important for ease in grasping and operating controls.

Sound control in operator enclosures

Reduced noise levels have in part been achieved by incorporating sound control measures in the operator enclosures. This design approach includes isolation mounts for the cab and suitable insulating materials for ceiling, walls, and floor.

Sound reaching the operator is structure-borne, airborne, or a combination of both. Structure-borne sound results from vibrations transmitted from the vehicle through the cab attaching points. Air-borne sound is transmitted through air and enters the operator area through holes or through the enclosure walls.

The floor of the cab is treated with a barrier material, normally polyvinyl chloride (PVC). A rubber material then overlies the barrier. Surface areas above the floor are treated with noise absorption materials that are effective in the 125 to 2000 Hz range. The predominant noise in tractor and other off-highway equipment is in the frequency range of 125 to 500 Hz.

Through design and development efforts, sound levels have been reduced to 80 dBA inside operator enclosures.

Thermal comfort in operator enclosures

Operator enclosure design must include cab pressurization, filtration, air movement, heating, cooling and window defrosting. These factors must be considered in order to provide clean air and proper velocity, temperature and air humidity for human thermal comfort. Design parameters to meet a wide range of climatic conditions are given in Table below.

Table. Design parameters for maintaining thermal environment in a tractor cab.

	Parameter	Rating or Capacity
1	Heating	8.2 KW at 66°C and water flow 11.4 h/min
2	Cooling	7.0 KW at 33°C and 60% relative humidity
3	Air movement	Three-speed blower rated at 0.235 m ³ /s at 50 Pa
4	Cab pressurization	50-100 Pa above outside of cab
5	Fresh air filter	1.92 m ² pleated paper, self cleaning

Cab pressurization is necessary to prevent dust from entering the closure.



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