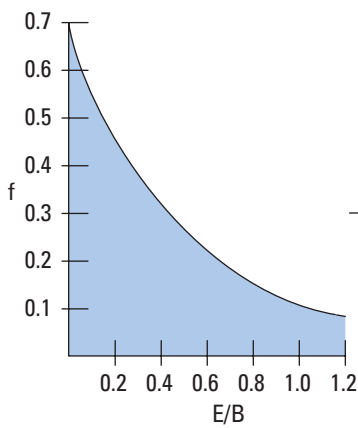# Sizing and Application—

Ackerman Type Steering

Step One:
Kingpin Torque

Typical values based
on rubber tired vehicles on
dry concrete.
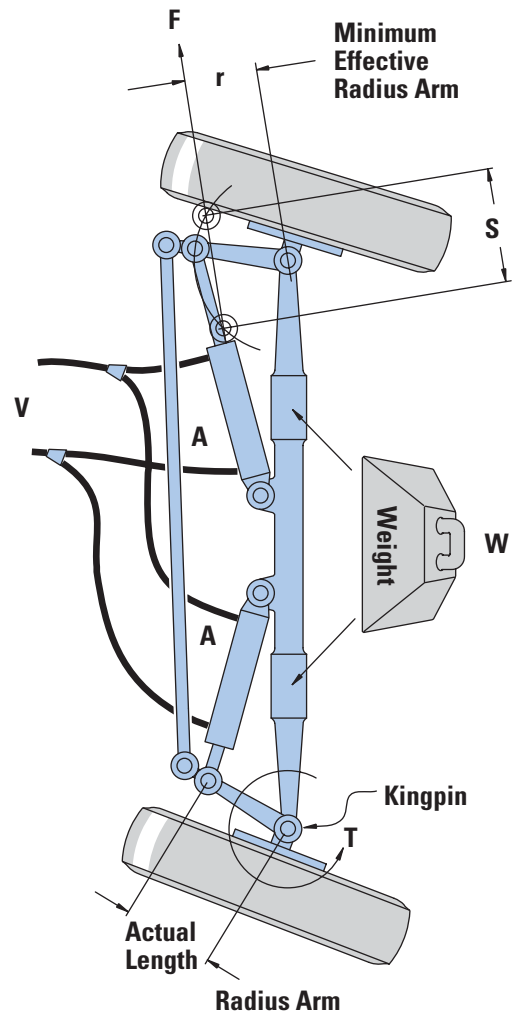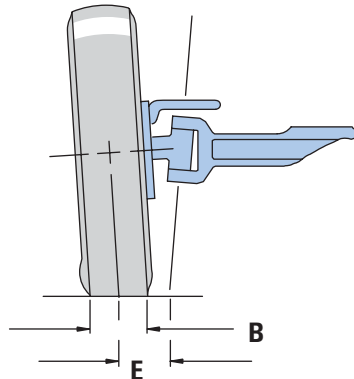
$$T = w \bullet f \sqrt{\frac{B^2}{8} + E^2}$$

T = Total Kingpin Torque required to steer axle.

W = Vehicle Weight supported by the steered axle.

f = Coefficient of friction (dimensionless). Based on 0.7 as a Maximum. Determine from chart at left.

B = Nominal width of the tire print (see diagram above).

E = Kingpin Eccentric (use nominal tire width).

Sizing and Application

Ackerman Type Steering Continued

Step Two:
Force Required

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

F = Force required for the axle.

T = Kingpin torque as determined in Step 1.
The value calculated in Step 1 is the total torque for the axle. If the steered axle is power driven, double this value to approximate the additional dynamic loads.

r = Effective radius arm about the kingpin axis at which the cylinder force is applied. The effective radius is the minimum distance from kingpin to the axis of the cylinder … not the actual length of the arm.

Cylinder Area

$$A = \frac{F}{P}$$

A = Cylinder area for the axle cylinder set.

F = Force required

P = Hydraulic pressure

For vehicle with a steered axle that can never be overloaded use 80% of the steering circuit relief valve setting. For manually loaded vehicles use 60%. For vehicles that can be severely overloaded use 30%.
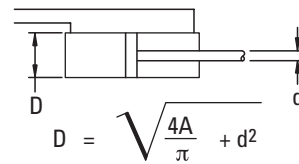
Cylinder Diameter

Once the required cylinder
set area is determined, the cylinder diameter can be calculated.

D = Inside diameter of cylinder.
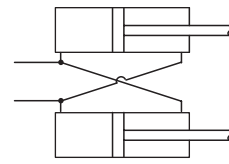
d = Rod diameter as required.

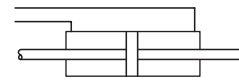**Differential Cylinder**

$$D = \sqrt{\frac{4A}{\pi} + d^2}$$

Note: $\left(\frac{d}{D}\right)^2 \leqslant .15$
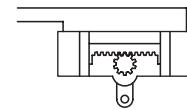
Cross Connected Cylinder

$$D = \sqrt{\frac{2A}{\pi} + \frac{d^2}{2}}$$

Balanced Cylinder

$$D = \sqrt{\frac{4A}{\pi} + d^2}$$

Opposed Cylinder

$$D = \sqrt{\frac{4A}{\pi}}$$

Cylinder Stroke

S = Stroke Length

The cylinder stroke is determined by axle geometry. That is, the required stroke is a function of the radius arm and the total angle through which the arm turns.

Differential Cylinder (Large Volume)	$V = S \times \frac{\pi}{4} \times D^2$
Differential Cylinder (Small Volume or Balanced Cylinder)	$V = S \times \frac{\pi}{4} \left(D^2 - d^2\right)$
Cross Connected Cylinder	$V = S \times \frac{\pi}{4} \left(2D^2 - d^2\right)$
Cylinder Volume	$V = \text{Volume} \quad V = S \times A$

The volume of oil required to move cylinder rod(s) through the entire stroke.

Sizing and Application

Ackerman Type Steering Continued

Step Three:

Selecting Steering Unit Displacement

Before proceeding further, a decision must be made as to the number of steering wheel revolutions desired for the application to steer the axle from full one side to the other. Depending on vehicle usage, this will vary, normally 2 1/2 to 5 1/2 with 4 being a good typical value

$$\text{Displ.} = \frac{V}{N}$$

V = Volume full stroke

N = number of steering wheel revolutions lock to lock

Once this calculation is complete, select the closest standard steering unit displacement from the catalog information.

Now the number of steering wheel revolutions should be recalculated.

$$N = \frac{V}{\text{displ.}}$$

displ. = Steering unit displacement per revolution.

Note: for different cylinder applications, the cylinder volume will be different for right and left turns and the value N will vary accordingly.

Step Four:

Calculating Required Pump Flow

Pump sizing is important to assure adequate power for steering under all operating conditions. The required pump flow can be calculated by the following equation.

$Q_P =$ Rmax. x displ.

Q_P (L/min): Required pump flow.

Rmax = Max. steering wheel input of steering control unit (SCU).

displ. = Displacement of steering control unit per revolution.

Before proceeding to evaluation required pump flow the maximum required steering wheel speed must be determined. Typically 120 revolutions per minute (RPM) is used for Rmax.

- It is important at engine low idle condition that the maximum steering wheel speed should be more than 60 rpm.

- For engine normal idle condition, maximum steering wheel speed should be more than 100 rpm if possible.

- When using open center SCU connected with pump directly, maximum pump flow should be less than 1.4 times of SCU rated flow. Higher flow into SCU increases pressure-loss of the steering system. If higher flow is unavoidable, install a flow divider valve into the system or use a load sensing system.

System Design Process

STEP I Calculate approximate Kingpin torque (KT)

1.1 Determine coefficient of friction:
Select the coefficient of friction (mu) from Chart 1 after calculating E/B. (Kingpin offset/nominal tire width). See Diagram 1.
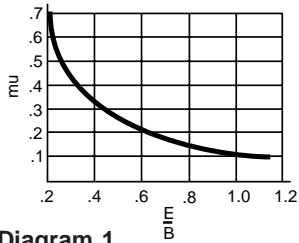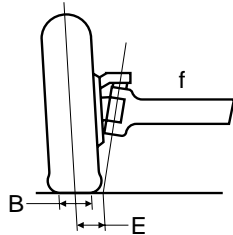
Chart 1 (Rubber tires on dry concrete)

Diagram 1

1.2 Calculate Kingpin torque:

$$\textbf{KT} = W\,(mu)\,\sqrt{\frac{B^2}{8} + E^2}$$

NOTE: If steered axle wheels are driven (powered), double KT.

Where:
- **KT =** Kingpin torque in inch-pounds
- **W =** Weight on steered axle in pounds (Use maximum overloaded weight anticipated.)
- **mu =** Coefficient of friction
- **B =** Nominal Tire width (inches)
- **E =** Kingpin offset (inches) at the intersection with the ground

STEP II Select steering unit

For small garden tractor-type vehicles, select an HGF — for larger vehicles select HGA or HGB. The purpose of this is to establish what pressure to use in Step IV.
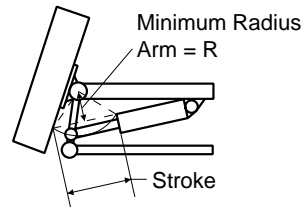
STEP III Calculate approximate cylinder force (CF)

$$\textbf{CF} = \frac{KT}{R}$$

Where:
- **KT =** Kingpin torque (inch-pounds)
- **R =** Minimum radius arm (inches) (see Diagram 2)

Diagram 2

STEP IV Calculate cylinder area (CA)

$$\textbf{CA} = \frac{CF}{P}$$

Where:
- **CF =** Cylinder force (pounds)
- **P =** Pressure (psi) (This is the pressure rating of the steering unit chosen.)

Select the next *larger* common cylinder bore size available. If one cylinder is used, use the *rod end area* only and, if two are used, use the *rod end area plus* the *head end area* to select the cylinder (Step VI).

STEP V Determine cylinder stroke

Calculate using diagram 2 as a guide and the desired vehicle turning circle.

STEP VI Calculate swept volume (SV) of the cylinder(s)

6.1. One balanced cylinder, double acting

- **SV =** (Bore area - rod area) x cylinder stroke

$$\textbf{SV} = \frac{\pi}{4}\,[B^2 - R^2]\,x\,S$$

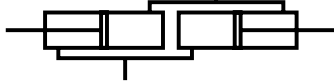**6.2. One unbalanced cylinder, double acting**

a. Head side

$$\textbf{SV} = \frac{\pi\,x\,B^2}{4}\,x\,S$$

b. Rod side
Same as 6.1 above

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System Design Process

6.3. Two unbalanced cylinders, double acting

$$SV = \frac{\pi \times S}{4}(2B^2 - R^2)$$

Where:
- **SV** = Swept volume (volume of oil to move cylinder full stroke) in cubic inches
- **B** = Bore diameter (inches)
- **R** = Rod diameter (inches)
- **S** = Cylinder stroke (inches)

STEP VII Calculate Hydraguide™ displacement (HD)

$$HD = \frac{SV}{n}$$

Where:
- **SV** = Swept volume in cubic inches from Step VI
- **n** = Number of steering wheel turns lock-to-lock (from one end of cylinder stroke to the other). This ranges from 3 to 6 depending on the type of vehicle.

When one single rod cylinder is used, calculate n for each direction because it will be different. Select the next closest displacement. If desired, recalculate n as follows:

$$n = \frac{SV}{\text{Displacement of selected Hydraguide™}}$$

STEP VIII Calculate minimum pump flow (Q)

$$Q = \frac{HD \times SS \times 60}{231}$$

Where:
- **Q** = Pump flow (gallons/minutes/revolutions)
- **HD** = Hydraguide displacement (cubic inches)
- **SS** = Steering speed (revolutions/seconds) (Ideal speed of steer = 120 rpms.)

Steering Speed

The minimum normally considered is 1 rev/sec (60 rpm). An example would be an articulated vehicle. This depends on the safety considerations for avoidance of obstacles under minimum *and* maximum flow conditions during all speed possibilities of the vehicle.

1.5 rev/sec (90 rpm) is common, and 2 rev/sec (120 rpm) is considered about the maximum input speed achievable by an average person.

If the steering wheel speed becomes greater than the pump flow, a dramatic increase in steering wheel effort is felt.

STEP IX Measure maximum steering pressure on prototype vehicle

Compare this pressure with the pressure rating of the Hydraguide. If it is higher, return to the last part of Step III and recalculate through Step IX again.

STEP X Select a relief valve setting

The cracking pressure of the relief valve, which is usually defined as the pressure when the relief valve starts to open and discharge flow to the return line, should be greater than the maximum pressure measured on the vehicle.

The full flow pressure of the relief valve, which is defined as the pressure when maximum flow is going over the relief valve, must not exceed the pressure rating on the steering unit.

NOTE:
Reversing units used with balanced area cylinders.

HGF Series
Open Center
Closed Center
Power Beyond

Operating Parameters:
1800 PSI
8 GPM
3.3 to 9.9 cu. in.

Typical Systems:
Turf, Material Handling, General Purpose, and Light Agricultural Vehicles.

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