Gears
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Chain Drive Systems

Description

In order to design, build and discuss chain drive systems it is necessary to understand the terminology and concepts associated with chain drive systems. Good designers and engineers have experience and knowledge and the ability to communicate their thoughts and ideas clearly with others. The students and teachers who participate in this unit will learn the terms and concepts necessary to design, draw and build chain drive systems, and improve their "Chain Drive literacy".

Standards Addressed

National Council of Teachers of English Standards (http://www.readwritethink.org/standards/index.html)

- Students adjust their use of spoken, written, and visual language (e.g., conventions, style, vocabulary) to communicate effectively with a variety of audiences and for different purposes.
- Students conduct research on issues and interests by generating ideas and questions, and by posing problems. They gather, evaluate, and synthesize data from a variety of sources (e.g., print and non-print texts, artifacts, people) to communicate their discoveries in ways that suit their purpose and audience.
- Students participate as knowledgeable, reflective, creative, and critical members of a variety of literacy communities.
- Students use spoken, written, and visual language to accomplish their own purposes (e.g., for learning, enjoyment, persuasion, and the exchange of information).

National Council of Mathematics Teachers

(9-12 Geometry Standards) (http://standards.nctm.org/document/appendix/geom.htm)

- Analyze properties and determine attributes of two- and three-dimensional objects
- Explore relationships (including congruence and similarity) among classes of two- and three-dimensional geometric objects, make and test conjectures about them, and solve problems involving them;

(9-12 Algebra Standards) http://standards.nctm.org/document/chapter7/alg.htm

- Understand and perform transformations such as arithmetically combining, composing, and inverting commonly used functions, using technology to perform such operations on more-complicated symbolic expressions.
- Understand the meaning of equivalent forms of expressions, equations, inequalities, and relations
- Use symbolic algebra to represent and explain mathematical relationships;

(9-12) Science and Technology Standards (from the National Science Standards web page) http://www.nap.edu/readingroom/books/nses/html/6a.html#unifying

- The abilities of design. Using math to understand and design Sprocket forms is an example of one aspect of an ability to design.

Terms to Research

Bottom Diameter	Hub Length	Pitch Diameter
Caliper Diameter	Offset Section	Roller Diameter
Catenary Curve	Outside Diameter	Roller Links
Chain Width	Pin Diameter	Tooth Form
Connecting Links	Pin Links	Tooth Profile
Hub Diameter	Pitch	Width

Materials

Pencils	Straight Edge
8-1/2 x 11" Paper	GEARS Kit
Compass	Spread Sheet Software
Protractor	CAD Software
Ruler	CADD Workstation

Objectives.

Students who participate in this unit will:

1. Sketch and illustrate the parts of a sprocket and chain drive.
2. Calculate sprocket and sprocket tooth dimensions using pitch and the number of teeth.
3. Calculate center-to-center distances for 2 or more sprockets in a chain drive.
4. Calculate and specify sprocket ratios.
5. Calculate center distances and chain length.
6. Design a 2 sprocket drive system.

Some Things to Know Before You Start

How to use Solid Works solid modeling program.
How to use and/or create a spreadsheet.
How to solve simple algebraic expression.
How to calculate Sine (sin) and cosine (cos)

Chain Drive Systems

Chain drives, gear drives and belt drive systems are all effective power transmission choices. Each offers advantages and disadvantages with respect to the other.
The advantages of chain drive systems are as follows:

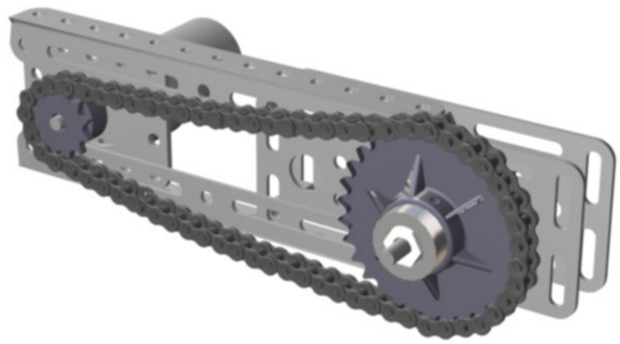


Fig. 1 GEARS-IDS Chain Drive

1. Shaft center distances are relatively unrestricted. Whereas gear drive center-to-center distances are restricted to specific dimensions for a given set of gears, the center distances between two chained sprockets can vary anywhere from 50% to 300% or more of their pitch diameters.
2. Chain Drive are relatively easy to install. Assembly tolerances are not as restrictive as those for gear drives. Chain drives are a better choice for less experienced builders working with a minimum of machine tools.
3. Chain drives can be readily redesigned and reconfigured in comparison to gear drive systems.
4. Chains perform better than gears under shock loading conditions.
5. Chain drives spread operating loads over many teeth whereas the operating loads acting on gear drives are concentrated on one or two teeth.
6. Chain drives do not require tension on the slack side (Belt drives do) thus bearing loading is reduced.
7. Chain drives require less space for a given loading and speed condition than pulleys and belts.
8. Chain drives systems are *(usually)* less costly to build and maintain than an equivalent gear drive.

While chain drives offer many advantages, there are good reasons to choose a gear drive system, particularly when:

1. Compact drive requirements demand the shortest possible distance between shaft centers.
2. High speed ratios are required.
3. High rotating speeds (RPM) are required.
4. High horsepower AND high speed loading is required.

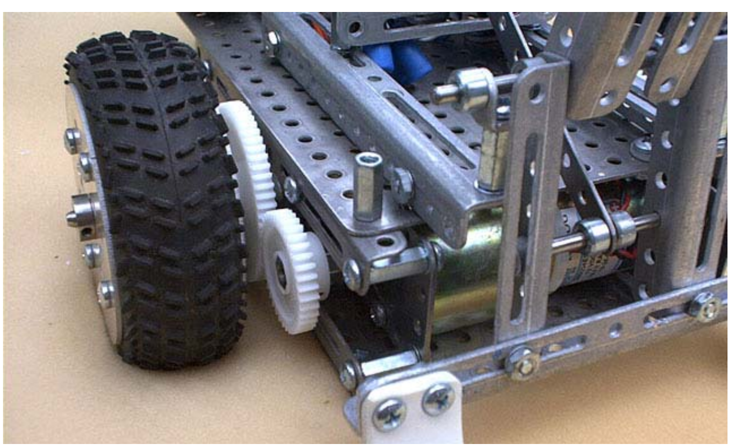


Fig. 2 Gear Drive system on a GEARS-IDS Robot

Belt and pulley systems also offer design advantages with respect to either chain or gear drives. These advantages include:

1. Belts slip, chain and gears drives do not. This is a useful advantage for drive systems that do not require positive speed ratios to be maintained. Momentary overloading loading conditions may cause a belt to slip over the pulleys whereas a chain may break or a gear tooth may shear. Belts offer built in "Clutching". Of course sustained overloading will cause premature wear and "Burned out" belts.
2. Belt drives are not as noisy as chain or gear drive systems.
3. Belt drives can operate over longer center distances than chain drives.
   Belts are better suited to extremely high-speed ratios.

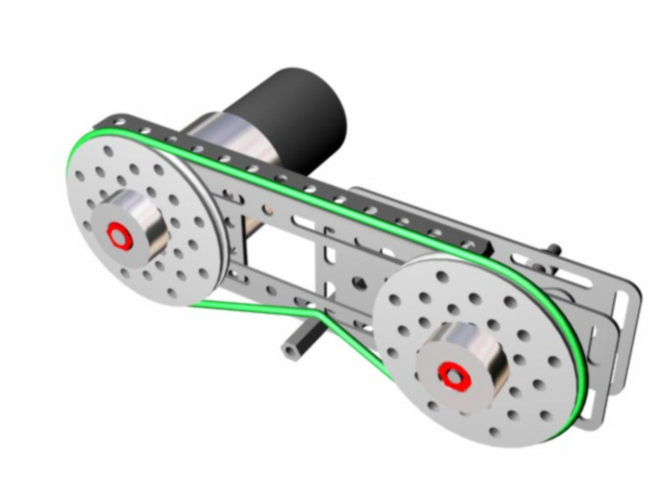


Fig.3 GEARS-IDS Pulley system

Engineering is the process of making the best decisions within the given parameters of knowledge, time, budgets and other available resources. Within a given set of constraints, the best engineers make the best decisions. Clearly, no single drive system is ideal for all applications. Experience and knowledge guide the best engineering decisions with respect to drive selection. This lesson will help young engineers gain drive system experience and knowledge by analyzing, calculating, drawing and designing chain and sprocket drive systems.

Roller Chain Construction

Roller chains are assembled using link plates, pins and rollers and connecting them in an endless chain using a connecting link.

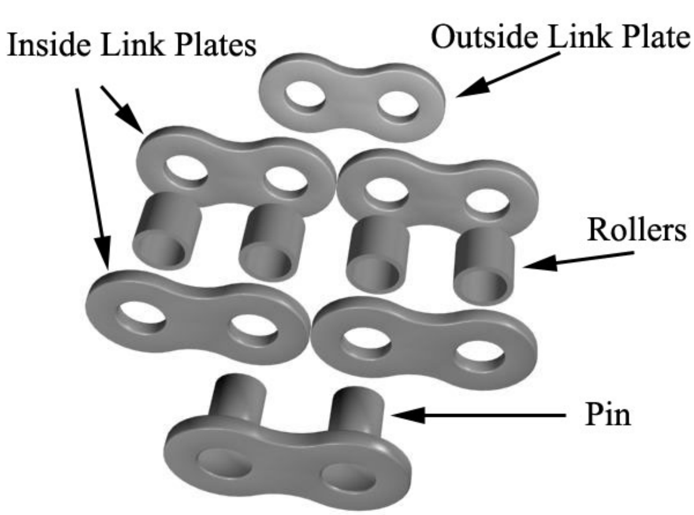


Fig. 4 Roller Chain Components

Note: The GEARS-IDS kit makes use of #25 (pitch) Nylatron plastic chain. Plastic chain does not require the use of master links to connect the chain into endless loops. Click here for directions on assembling Nylatron plastic chain.

Chain sections are made up from two separate assemblies called the Roller Link and the Pin Link.

Note: Smaller pitch chains (1/4 and less) do not have rollers.

Chain Size (Pitch)
Chains are sized according to their pitch. The center-to-center distances of the link pins determine pitch. The plastic chain used in the GEARS-IDS kit is an industry standard pitch size. The center-to-center distance of the pins is 0.250 inches. The pitch of chain drive components is specified by a 2 digit number.

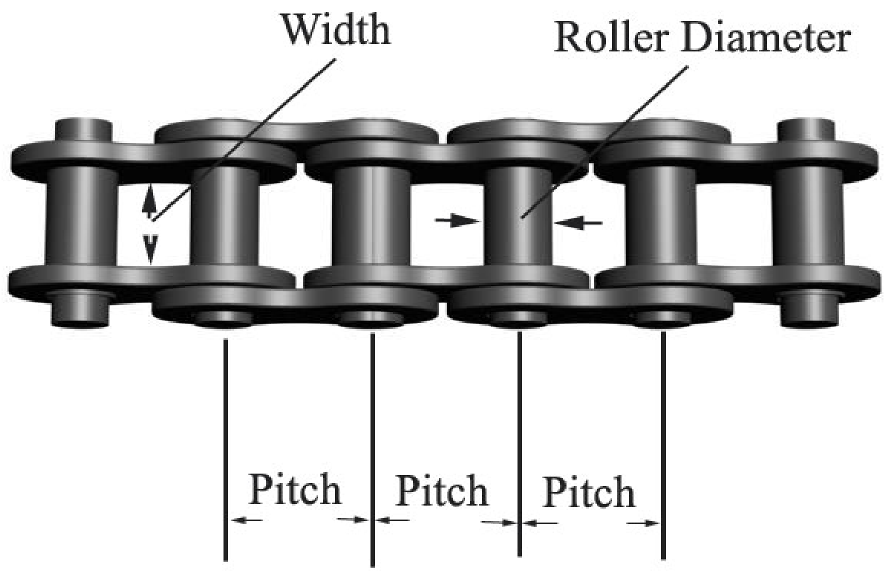


Fig. 5 Roller Chain Pitch

The first digit specifies the center –to-center distance of the chain link pins in 1/8ths of an inch, the second number specifies the chain style.

#25 chain means:
Chain pitch = 2 x 1/8 or ¼" pitch
Chain style = 5 = rollerless chain.

Chain style specifications are as follows:
0 = Standard proportion roller chain
1 = Light weight roller chain
5 = Rollerless chain

Examples:

The plastic chain in the gears kit is a #25 plastic chain

2 = 2 x 1/8" or ¼ " pitch
5 = Rollerless chain

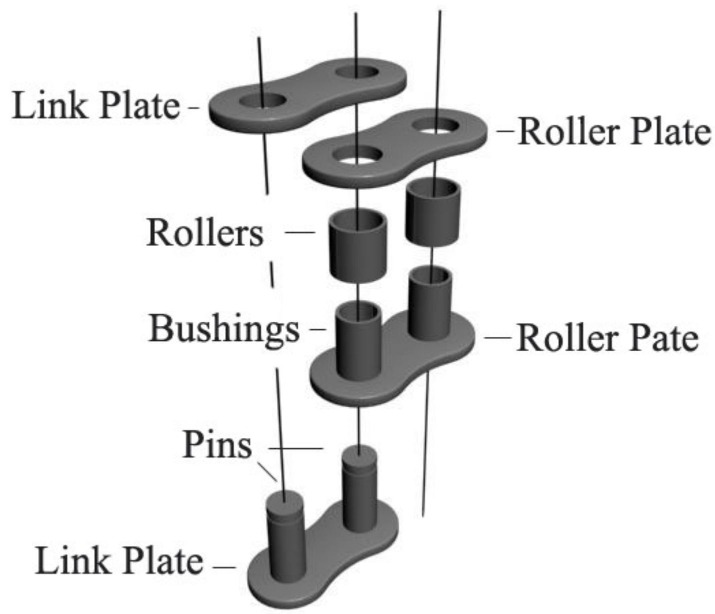


Fig. 6 Roller Links and Pin Links

Roller Links and Pin Links
Chains are made up using two types of link assemblies; Roller links (Inside links) and pin links (outside links).*(See fig 6.2.1.6).* Roller links and pin links are assembled in a continuous loop using a connecting link.

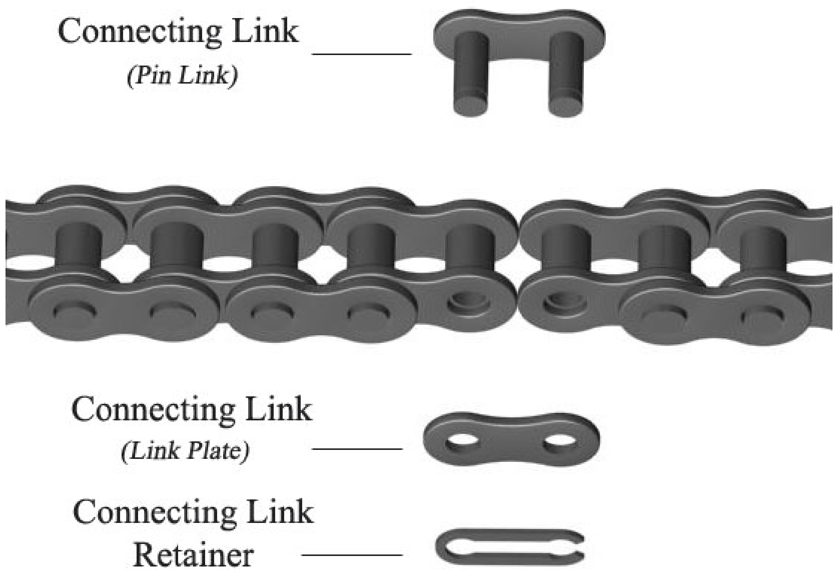


Fig.7 Connecting Link

Connecting Link
A connecting link is a special purpose pink link assembly designed for easy and rapid replacement.

Standard Chain Dimensions
The dimensions of roller chain and sprockets are governed by American National Standards Institute or ANSI. ANSI standards are used to ensure the interchangeability between chains and sprockets produced by different manufacturers.

ANSI standard chain dimensions are Pitch Proportional. That is to say that the various lengths, widths and heights of chain components are based, in some way, on the pitch of the chain. The table below provides ANSI standard dimensions for #25 and #35 chain.

ANSI Chain #	**Pitch P**	**Max Roller Dia. D_r**	**Width W**	**Pin Dia. D_p**	**Link Plate Thickness LPT**	**Roller Plate Height H_r**	**Link Plate Height H_p**
25*	¼”	0.130**	1/8”	0.0905”	0.030”	0.95 x P	0.82 x P
35*	3/8”	0.200**	3/16”	0.141”	0.050”	0.95 x P	0.82 x P

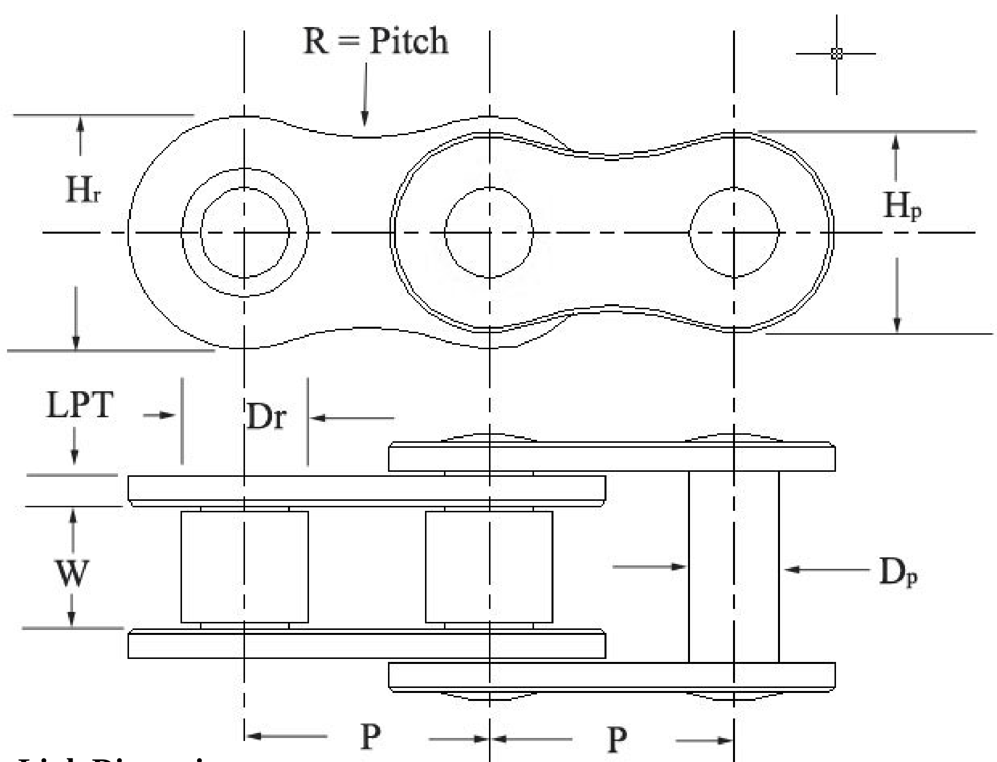


Fig .8 Chain Link Dimensions

*This pitch chain has no rollers
** Bushing Diameter (No Rollers)

Note: Small sized roller chain does not have rollers, only bushings which ride directly on the sprockets. Larger sized chain with pitches greater than 35 are assembled using Pins, Rollers and Bushings.

Ratios of Part Dimensions to Chain Pitch
The following ratios are approximate proportions for chain dimensions. Actual dimensions are available from the American Chain Association.

Chain Dimension	Symbol	Pitch Ratio
Roller Diameter	D_r	5/8 x Pitch
Chain width W	**W**	5/8 x Pitch
Pin Diameter	**P**	
Link Plate Thickness	**LPT**	
Roller Link Plate Height (Maximum)	H_r	
Pin Link Plate Height (Maximum)	H_p	

Sprocket Terms and Concepts

Common Sprocket Types
<u>(Type A without hubs)</u>
Sprockets without hubs are held onto shafts by a flange. The flange has a keyway (groove) that is cut into the bore. This keyway matches up to a similar keyway cut into the shaft. A rectangular or square "Key" is inserted into the two keyways and prevents unwanted rotation of the shaft.

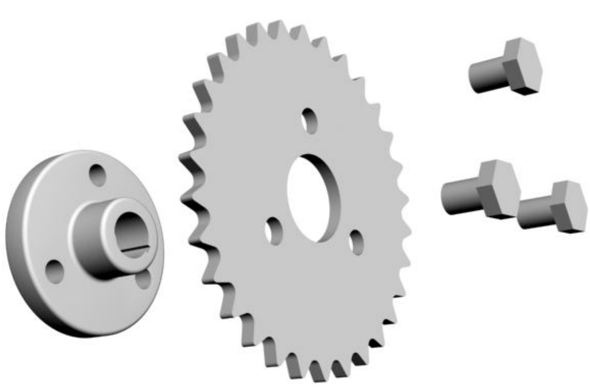


Fig. 9 Type A Sprocket ***(No Hub)***

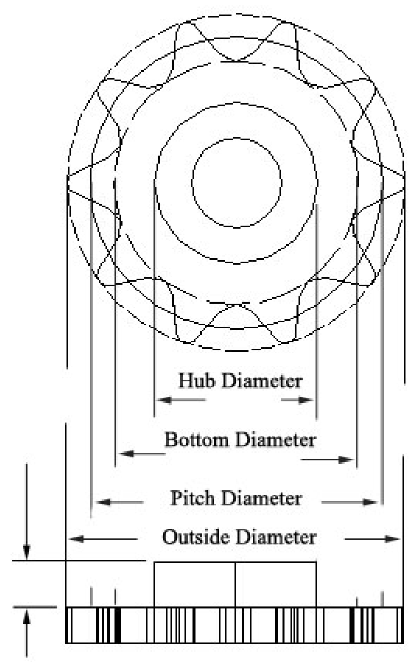


Fig 10 Sprocket Diameters

Type B With Hubs

Type B sprockets have integral hubs. The hubs can be broached (with keyways), or plain bored, with out a broached keyway. The sprockets that come as standard equipment with the GEARS-IDS kit are Nylatron Plastic sprockets with #10-24 set screws. The sprocket set screws are meant to keep the sprocket from sliding off the hex adapters or the flat portion of the motor shaft.

Fig 11 Sprocket with Integral Hub

Designing Chain Drives

Chain Pitch is determined by the forces torque and RPM acting on the shafts and sprockets. Larger pitch chain and sprockets are needed to handle higher torques and higher RPM. Consult the American Chain Association design manual to determine power and RPM ratings for specific pitch chain.

Drive Ratios

Drive ratios greater than 10:1 should not be used. In order to achieve higher ratios it is good practice to create multiple drives using two drives in series. This will be explained in more detail in the section on gears.
The drive ratio between two sprockets is specified by the relationship between the number of teeth of the Driven Sprocket to the number of teeth of the Drive Sprocket. It is therefore important to understand that power is transferred through a drive train from one sprocket to another through the tension created on the chain.

In the figure below a 12 tooth sprocket is attached to an electric motor. The 12 tooth sprocket is the Drive Sprocket (The drive sprocket is the sprocket that initiates the transfer of power). The 30 tooth sprocket is the Driven Sprocket (The Driven Sprocket receives the power from the drive sprocket).

The sprocket ratio in this case is given as 2.5:1. The Drive Sprocket must turn 2.5 revolutions before the Driven Sprocket turns 1. A simple rule to follow when determining ratios is this:

$$Ratio = \frac{DrivenSprocket}{Drivesprocket}$$

$$Ratio = \frac{30}{12} = 2.5:1$$

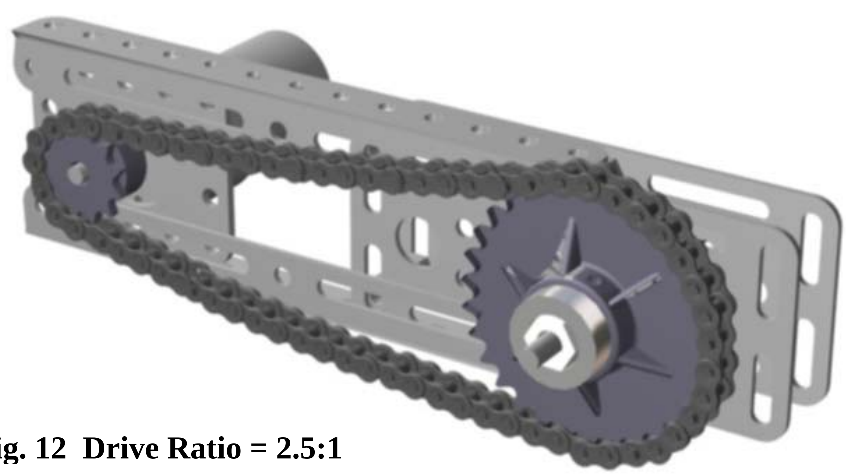
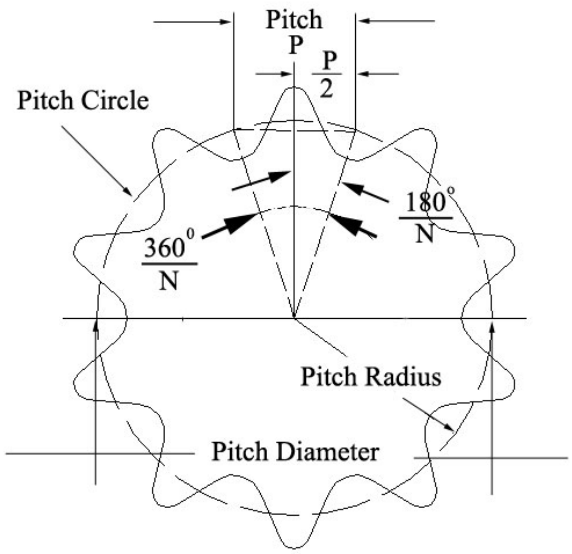


Fig. 12 Drive Ratio = 2.5:1

Calculating Sprocket Pitch Diameter
The sprocket pitch diameter is an imaginary circle through which the chain pin centers move around the sprocket. The pitch diameter is the fundamental design geometry that determines the size shape and form of the sprocket teeth dimensions.



Sprocket Pitch Diameter Calculation

$$PD = \frac{P}{\sin\left[\frac{180°}{N}\right]}$$

PD = Pitch Diameter
P = Chain Pitch in inches
N = Number of teeth on the sprocket

Example: Using the information from figure 6.2.1.13, calculate the sprocket pitch diameter.

Fig. 13 10T, #25 Pitch Sprocket, 0.809" Pitch Diameter

$PD = \frac{P}{\sin\left[\frac{180°}{N}\right]}$	**PD** = Pitch Diameter **P** = Chain Pitch in inches **N** = Number of teeth on the sprocket	**PD** = 0.809" **P** = ¼" = 0.250" **N** = 10 Teeth

Solve the equation above using the standard order of operations (PEMDAS), Parenthesis, Exponents, Multiplication, Division, Addition, Subtraction.

$$PD = \frac{P}{\sin\left[\frac{180°}{N}\right]} = \frac{0.250''}{\sin\left[\frac{180°}{10}\right]} = \frac{0.250''}{\sin 18°} = \frac{0.250''}{0.309} = 0.809''$$

Determining Chain Length if the Center Distances are Given

Chain length is measured in discreet units called links. The length of each link is the same as the pitch length. A #25 chain has a pitch length of ¼".

The chain length for a given drive is determined by:
1. The number of teeth in the drive sprocket
2. The number of teeth in the driven sprocket
3. The pitch diameter (PD) of the drive sprocket
4. The pitch diameter (PD) of the driven sprocket

The center-to-center distances between the sprockets

Chain Length Calculation
It is sometimes necessary to fix the center-to-center distance of the sprockets to accommodate existing constraints or mechanical design considerations. An example of this may be the case where a chain and sprocket assembly are fixed to a nonadjustable motor shaft and required to drive a set of meshing gears.

Chain length is a function of the number of teeth of the drive and driven sprockets as well as the center-to-center distance. Here is an example of the process required to calculate chain length given a center distance and the sprocket teeth numbers.

Note: Chain length is customarily expressed in (even numbers) of pitch units since chains can only be shortened or lengthened by multiples of their pitch units. If an odd number of pitches is required then a special link called an offset link is used.

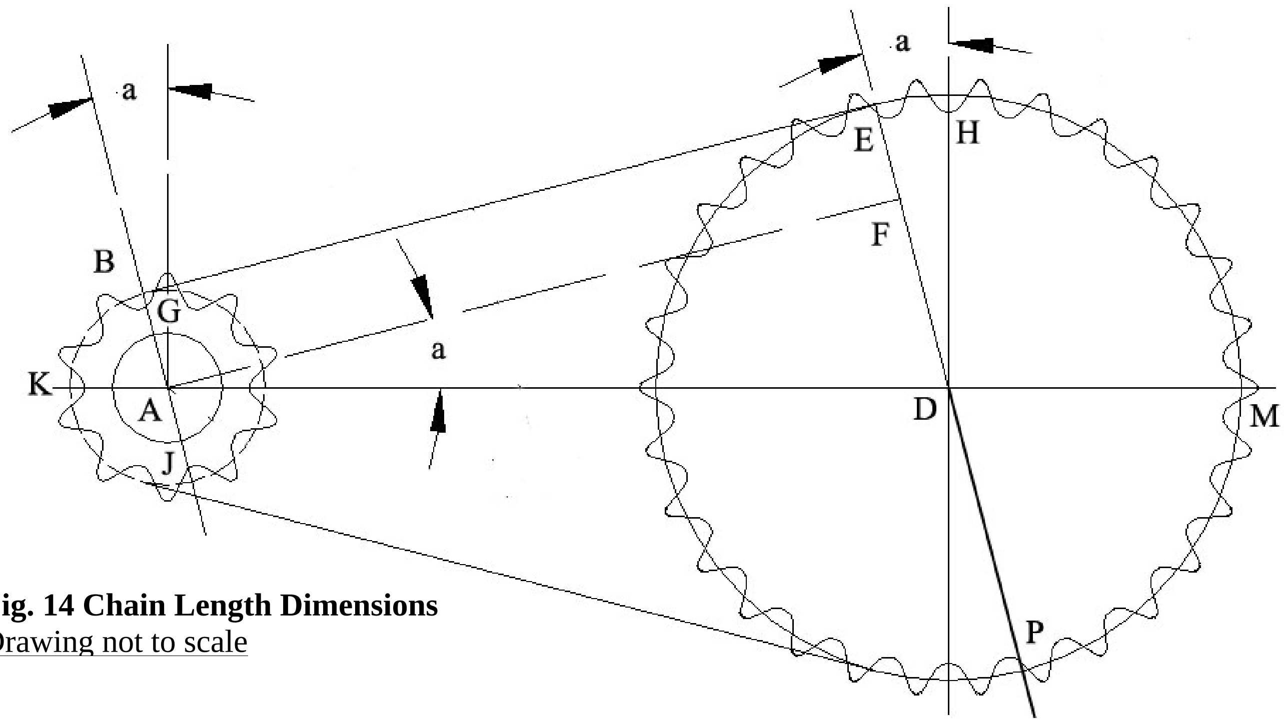


Fig. 14 Chain Length Dimensions
Drawing not to scale

Specifications:

Pitch (**P**)	= ¼” = 0.250”
PR	= Pitch Diameter x 0.5
Drive Sprocket (**n**)	= 10 Teeth
Driven Sprocket (**N**)	= 30 Teeth
Center Distance (**C**)	= 6”/0.250 = 24 (expressed in pitch units

The chain length = 2 (Tangent line length BE + arc ME + arc BK)

Procedure
1. Calculate the pitch circle radius for the drive sprocket. *(Refer to the pitch circle diameter formula on page 9)*

$$AB = \frac{P}{\sin\left[\frac{180°}{n}\right]} = \frac{0.250''}{\sin\left[\frac{180°}{10}\right]} = \frac{0.250''}{\sin 18°} = \frac{0.250''}{0.309} = 0.809'' \text{ x } ½ \ = 0.4045”$$

2. Calculate the pitch circle radius for the driven sprocket.

$$DE = \frac{P}{\sin\left[\frac{180°}{N}\right]} = \frac{0.250"}{\sin\left[\frac{180°}{30}\right]} = \frac{0.250"}{\sin 6°} = \frac{0.250"}{0.1045} = 2.392" \text{ x } ½ = 1.196"$$

3. Calculate the length of side DF
   a. Line AF is parallel to line BE and perpendicular to AB and DE
   b. Line BE is tangent to circles K and M
   c. Line DF = DE-AB
   d. Line DF = 1.196" – 0.405" = 0.791"

4. Calculate angle *a*.
   a. Triangle AFD is a right triangle
   b. Use the math mnemonic **SOHCAHTOA** to find the sine of angle *a*.

$\sin a = \frac{SideOpposite}{Hypotenuse}$ Referring to figure 6.2.1.14. We substitute $\sin a = \frac{DF}{AD}$

$$\sin a = \frac{DF}{AD} = \frac{0.791"}{6"} = 0.1318$$

To find the measure of angle a with a sine of 0.1318 we take the inverse $\sin^{-1}$

$\angle a = \sin^{-1} 0.1318 = 7.57°$

5. Calculate the length of the chain between the pitch circle tangent points, BE. *Refer to the illustration on figure 6.2.1.14.*

Since angle *a* = 7.57^{o} then we can use a calculator to find the cosine of 7.57^{o} = 0.991.

Use the math mnemonic **SOHCAHTOA** and the cosine of angle *a to find BE*

cosine of *a* = $\frac{SideAdjacent}{Hypotenuse} = \frac{AF}{AD}$ we can rewrite this algebraic statement substituting

the values we already know. Cosine a = $\frac{AF}{AD}$ = 0.991 = $\frac{AF}{6"}$ and then set the expression equal to AF = 0.991 x 6".

To express this answer in pitch units we divide the length in inches by the pitch.

$AF = \frac{0.991 * 6"}{0.250} = 23.784$ Since AF = BE then BE =23.784 pitch units

Here are the relationships we determined in the exercise above.

BE = AF = AD cosine a = C cosine a = 23.784 pitch units

6. Find the pitch lengths of chain wrapped around each of the sprockets.

Note: Each tooth on the sprocket represents a pitch unit. Therefore, if we calculate the arc lengths of chain wrapped around the sprocket in terms of teeth, we will have the arc lengths in pitch units and it will be unnecessary to convert inches to pitch units.

Half the chain wrapped around the large sprocket is represented by arc ME. Measured in pitch units (teeth) we find;

$$ME = MH + HE = \frac{N}{4} + N\frac{a}{360} = 8.13$$

Half the chain wrapped around the small sprocket is computed in a similar way, except, the arc length of angle a is subtracted from the 90 degree arc KG. Note that the chain does not wrap the small sprocket in as many degrees of arc as it does the large sprocket. Prudent chain drive designs dictate that the angle formed by the arc of the chain around a sprocket should be equal to or greater than 120 degrees.

$$KB = KG - BG = \frac{n}{4} - n\frac{a}{360} = 2.3$$

7. Using the information from the 6 preceding steps, we can find the chain length (In pitch units) for these 2 sprockets.

Let L represent the chain length in pitches. L = 2 [BE + ME + KB] =

From the calculations above we know that:

Line AD = 24 Pitch Units Line BE = 23.784 Pitch Units Arc ME = 8.13 Pitch Units	Arc KB = 2.3 Pitch Units Angle a = 7.6 Degrees

L = 2 [BE + ME + KB] = 68.4 Pitch Units

We can combine all the calculations above into a single more elegant expression of the chain length (In pitch units) between any 2 sprockets;

$$L = 2\left[C\cos a + \frac{N+n}{4} + \frac{a}{360}(N-n)\right]$$

Solving for L we find

$$L = 2\left[23.78 + \frac{30+10}{4} + \frac{7.57^\circ}{360}(30-10)\right] = 68.4$$

The calculated chain length is 68.4 pitch units. Since each pitch unit represents 1 chain link, and it is not possible to have a fractional link, we must round off the chain length to a whole number. Remember, it is best practice to use **EVEN** numbers of chain links. The (final) chain length in this example becomes 70 chain links.

Note: Do not round down. This causes the chain to be too tight and the added tension can damage sprockets, shafts and cause premature chain failure.

A length of 70 chain links will leave excessive "Play" or slack in the chain drive. This slack will have to be taken up with a spring-loaded idler sprocket or other chain-tensioning device.

The preferred method for solving this drive design is to recalculate the center to center distance of the sprocket so that the chain length results in an even and whole number of pitch units. In this case the desired chain length that will yield a center distance closest to 6" for these 2 sprockets would be 68 pitch units.

Calculating Center Distance From a Known Chain Length

This requires that we rewrite the formula in step 7 in terms of C (The required center distance). The desired chain length is 68 links or pitch units. This formula can be used to find the center distance for any given chain length and sprocket set.

C = Center Distance in Pitch Units
L = Chain Length in Links or Pitch Units
N = Number of Teeth of the Large Sprocket
N = Number of Teeth of the Small Sprocket

$$C = \frac{L - n(\frac{90-a}{180}) - N(\frac{90+a}{180})}{2\cos a}$$

$$C = \frac{L - 10(\frac{90-7.57}{180}) - 30(\frac{90+7.57}{180})}{2\cos 7.57}$$

C = 23.81 Pitch Units or 5.9525"

Summing Up The Process of Chain Length Calculation

Calculating chain length is an iterative design process. The procedure for designing and determining the center-to-center distances and chain lengths for a given chain drive system is as follows;

1. Determine the sprocket and chain pitch
2. Determine the necessary drive ratio and the number of teeth for each sprocket.
3. Determine the required center-to-center distance for a given design.
4. Calculate the chain length for the required center-to-center distance.
5. Round off the chain length to nearest (Longer) even number of pitches
6. Using the computed chain length (Even number of pitches), recalculate the center-to-center distance.

Calculating the Overall Dimensions of a Chain and Sprocket Drive
It is often necessary to integrate chain and sprocket drives systems into mechanisms where space is at a premium. Small form factors and necessity to reduce weight demand close fitting tolerances. Designers must be able to accurately calculate the specific and overall dimensions of the drive systems they create in order to ensure that they will integrate with an existing mechanism without interference. In order to generate a successful design it is necessary to calculate the following:

Minimum Center Distance
The arc of the chain engagement on the smallest sprocket should not be less than 120 degrees. For drive ratios greater than 3:1, the center distance of the sprockets should be equal to or greater than the difference of the 2 sprocket diameters. This will ensure 120 degrees of chain wrap around the smaller sprocket.

Maximum Center Distances
The American Chain Association suggests that center distances between sprockets should not exceed 80 Pitch Units (For unsupported chain drives). Excessively long center distances create catenary tensions that act to increase chain wear and result in unnecessary chain vibration. Consider supporting the chain on guides or rollers where long center distances are required.

Outside Sprocket Diameters (OD)
In order to accurately calculate the clearances for a given chain and sprocket drive, it is necessary to determine the outside diameters of the sprockets. This dimension can be approximated using the following formula:

$$OD = P(0.6 + \cot\frac{180°}{N})$$

Activities

Activity #1
Sketch and lable a chain and sprocket drive system with the following specifications:

#25 Pitch
Drive Sprocket = 24T
Driven Sprocket = 84T
Center Distance = 10”

Calculate and include the following in your sketch:

Pitch Radius of the small sprocket
Pitch Radius of the large sprocket
Center distance in pitch units
Chain Length in pitch units (Actual)
Chain Length in even numbers of pitch units.
Center-to-center distance for even pitched chain length.

Essentially this unit is a repeat of the exercises described in this unit.

Activity #2
Download and build the HMC chassis that utilizes a chain drive. Instructions for building this chassis using the GEARS kit can be obtained by clicking here.

Using the GEARS-IDS electronic controls, and PS2 transmitter and C6C receiver, construct a simple radio controlled platform that can be used to determine the speed and Tractive (pulling or pushing) forces generated by the chain and sprocket drives.

Develop experiments to evaluate tone or more of these performance characteristics:
Speed
Acceleration
Tractive Force (Pulling or pushing force)
Maneuverability
Work
Power

Activity #3 (Advanced)
Design an build a set of wheels of different diameters and tread design.

Determine the effect that different wheel designs have on the performance of the mobile chassis with respect one or more of these performance characteristics:

Speed
Acceleration
Tractive Force (Pulling or pushing force)
Maneuverability

Possible wheel modifications can include:

Plastic Jar Lids (Drilled to fit the 3" hex wheels)
Wheels from existing toys modified to fit on the chassis
Student designed and fabricated wheels using a variety of machine tools and processes

Activity #4 (Advanced)
Create a spread sheet that can be used by anyone in the class to solve problems involving chain length and center distances based on chain lengths.

You can Check your answers by **clicking here** to open and use the GEARS Chain Center Distance spread sheet.