Calipers

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Introduction

This document looks at old-style calipers and related tools. Today, the word "calipers" denotes dial, electronic, or vernier (DEV) calipers (also called slide calipers) used for length measurements. A couple of generations ago, the term instead referred to old-style machinist calipers. Though DEV calipers are useful, you may find old-style calipers still have a place in the shop and DIY projects. From here on, the word "calipers" will refer to these old-style calipers. You'll often see them misspelled as "callipers".

The latest version of this document is https://someonesdad1.github.io/hobbyutil/shop/Calipers.pdf.

Notation

Calipers = old-style calipers (spring bow, firm or lock joint, or wing dividers)
DEV calipers = dial, electronic, or vernier calipers
DIY = do-it-yourself
Drawings are third-angle projections
[*abc:n:m*] = reference [*abc*], page *n* (page *m* in a PDF)
Any pictures with "Starrett" in the corner were provided courtesy of The L. S. Starrett Company.

Types

Figure 1 shows a few of the different styles of calipers available. Caliper size is determined by the distance from the pivot to the tip of a leg, not the overall length of the device.

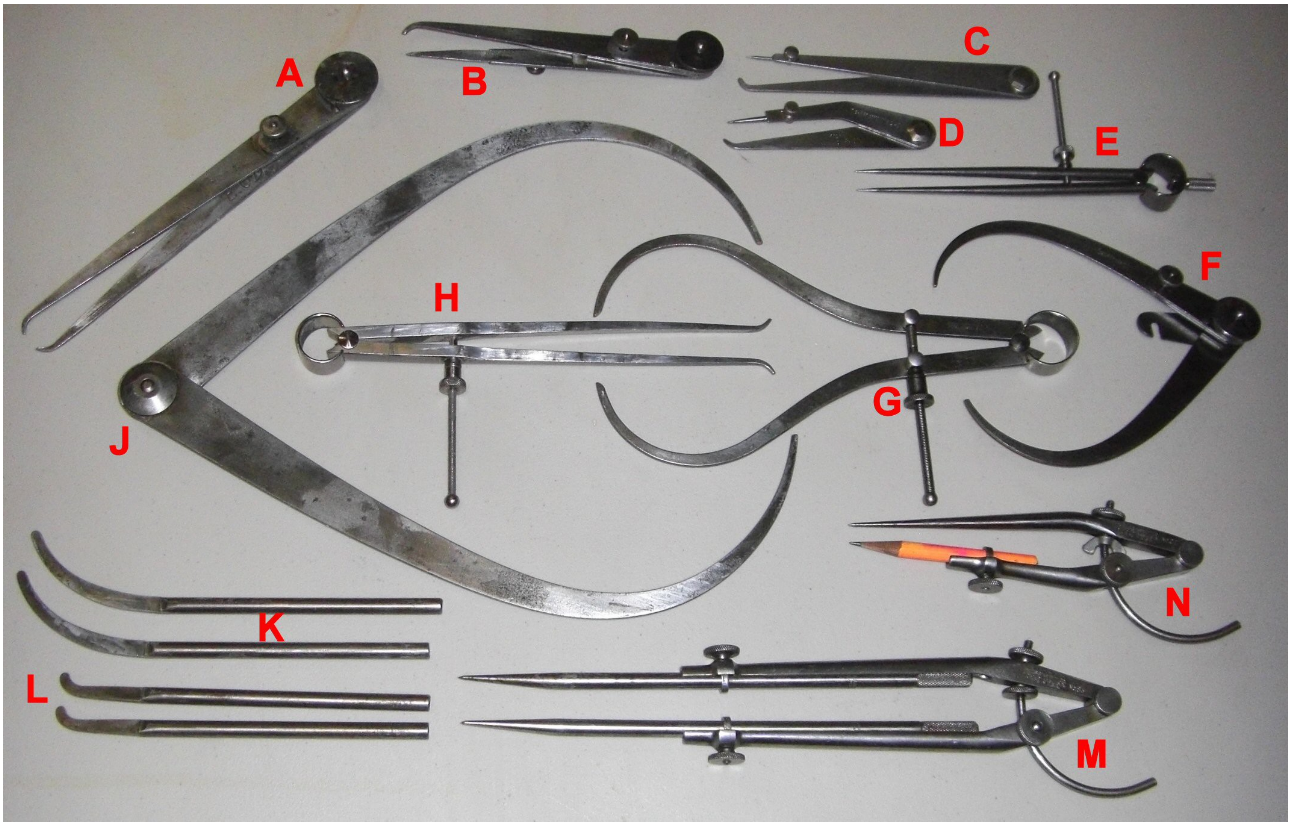


Figure 1

Key	Description
A	8 inch inside lock joint calipers (Starrett model 39)
B	6 inch lock joint hermaphrodite calipers (Starrett model 42, old style)
C	6 inch firm joint hermaphrodite calipers (Lufkin, model unknown)
D	4 inch firm joint bent-leg hermaphrodite calipers (Starrett 242)
E	6 inch toolmaker's-style spring bow dividers with solid nut (Starrett 277)
F	6 inch outside transfer calipers (Starrett 36) (short transfer leg visible)
G	8 inch Yankee-style spring bow calipers with solid nut (Athol Machine, model unknown)
H	8 inch Fay-style spring bow calipers with split nut (Starrett 74)
J	12 inch firm joint calipers (Starrett 26)
K	Outside caliper legs for Starrett 85 wing dividers
L	Inside caliper legs for Starrett 85 wing dividers
M	12 inch wing dividers (Starrett 85) with eccentrically-ground points
N	6 inch wing dividers ("carpenter's dividers", Starrett 92)

Spring bow calipers: These are the most common type (E, G, and H) and are probably what most people think about when the term "calipers" is used. The two legs have a pivot with a round spring that holds the legs against the pivot. The adjustment nut is used to change the position of the caliper legs. A split nut allows you to slide the nut on the thread for rough positioning of the calipers' legs, then final adjustment when the nut seats in the cone (desirable if you work with calipers a lot).

Firm joint and lock joint calipers: These are made from flat stock and the legs pivot about a joint that has a suitable amount of friction to hold the setting. Their advantages are speed of adjustment and wide range. Firm joint calipers are at C, D, and J in Figure 1. Lock joint calipers can be locked in position and have a fine adjust. Samples are at A, B, and F in Figure 1. Firm joint calipers can be closed slightly by knocking the leg against a piece of wood; they can be opened slightly by holding them vertically with the joint down and knocking the joint on a piece of wood. Close work can be done with firm joint calipers by an experienced user, but some people prefer calipers with a fine adjustment screw.

Wing dividers: The legs attach at a hinge and an arc of metal (which looks like a wing, hence the name) is used to clamp the legs at a desired opening (M and N in Figure 1). This is a style often used by blacksmiths, carpenters, sheet metal workers, and similar trades.

Choosing a caliper type can depend on how they feel in your hand, how fast you need to get the measurement, weight, the sizes you need to measure, and how you like to work with them. Here's a table to help with selection of caliper types (*L* = pivot to tip of leg distance, size ranges given are typical, not inclusive):

Type	Advantages	Disadvantages
Spring bow	♦ Simple construction, lightweight ♦ Inexpensive ♦ Resistant to accidental changes of size ♦ Choice of split or solid nut ♦ Built-in fine adjustment ♦ Reliable and robust ♦ Measure dimensions up to about *L* ♦ Found in *L* = 2 to 18 inch sizes	♦ Slow to adjust to size (faster with a split nut). ♦ Measuring range will be smaller than firm/lock joint calipers of the same size.
Firm joint and lock joint	♦ Allow fast adjustment to size. ♦ Will measure larger dimensions than spring bow calipers of the same size (measure up to about 1.8 *L*). ♦ Versatile: inside calipers can be used for both inside and (restricted) outside measurements. ♦ Some models have a fine adjustment. ♦ You can make your own. ♦ Found in *L* = 4 to 36 inch sizes	♦ Easy to bump and change the setting unless the joint is locked. ♦ May be tedious to adjust to the correct feel without a fine adjust. ♦ Heavier than similarly-sized spring bow calipers. ♦ Lock joint calipers are about three times the cost of firm joint calipers. ♦ The fine adjust may not be as good as spring bow calipers.
Wing dividers	♦ Quick to adjust to size. ♦ Fine adjust is desirable. ♦ Robust to stand up to rough and heavy use. ♦ Don't take up much room in a toolbox. ♦ Optional caliper legs and centering balls give a versatile tool. ♦ Used as log scribers for building log houses. ♦ Found in *L* = 6 to 12 inch sizes	♦ Often only found as dividers, not calipers. ♦ A bit heavy for precise metalworking. ♦ Can be expensive with optional legs and centering balls.

Here's a relative cost comparison for Starrett's different calipers (taken from suggested retail prices from Starrett's web site on May 2016) for 6 inch outside calipers:

Type	Relative cost
Firm joint	1
Yankee, solid nut	1.1
Yankee, split nut	1.2
Firm joint hermaphrodite	1.3
Toolmaker's	2.3
Lock joint transfer	3.1
Lock joint hermaphrodite	3.4

An important feature of calipers is that they are more robust than DEV calipers. My DEV calipers stay at my toolbox over the rubber mat; I know from experience that when they get dropped on my shop's concrete floor, they can be ruined. But I take old-style calipers anywhere I need to, as I don't worry about them getting wet, dirty, or dropped because they are easily cleaned and hard to damage.

There are a variety of specialty types of calipers not covered in this document.

Recommendations

If you have never used calipers before, consider starting with the $10 Harbor Freight set (part number 94447) of 6 inch calipers. This set will give you inside and outside Yankee-style spring bow calipers and dividers and you'll be able to learn about their basic use.

I recommend getting at least one pair of hermaphrodite calipers as they will see a lot of use for measuring and marking lines from edges and shoulders.

Buy new calipers if you wish, but there are many used brand-name calipers for sale (see *Buying used calipers*).

I recommend getting the smallest calipers consistent with the sizes you typically work on. Calipers above 12 inches can be clumsy and heavy, particularly firm/lock joint types.

The caliper style (spring bow, lock joint, or firm joint) depends on your tastes. For careful metalworking tasks, I use spring bow calipers because once set, they are difficult to knock out of adjustment.

If you use spring bow calipers or dividers a lot, you may prefer a split nut to let you set the calipers quickly. With a solid nut, you'll find yourself manually compressing the legs and adjusting the nut with the palm of your other hand for more speed.

For general fabrication work (i.e., non-machinist work), wing dividers and trammels are good choices because of their versatility and they store compactly in a toolbox.

History and patents

Firm joint calipers have been known from antiquity, being shown in drawings of Roman workers' tools. They are relatively easy to construct for oneself, although a more sophisticated joint than a rivet or bolt may be needed for a good tool (look up US patent 672424 for how Starrett's firm joint is made; also see here).

Lock joint calipers appeared commercially around 1895 with a patent by Laroy Starrett and Charles Fay (these two people had a significant influence on caliper design and L. Starrett started the Starrett company). Starrett also patented a firm-joint design with a fine adjust in 1901 (US672424.

The spring bow design first appeared in the early 1700's [*jd*]. The latter half of the 1800's saw the refinement of the metal spring bow caliper design. The basic designs were in place by about 1900 and are still in use today. The most important patent was probably Bullard's of 1886 (US335740), as it shows pretty much how most spring bow calipers are made.

If you're interested in details, here are a few US patents you can look up:

30009	229283	357487	672313	822397	1109467
37531	269754	402876	672424	887068	1194182
49337	319215	409828	689781	924073	1269336
75827	334764	411537	720773	988588	1562464
173802	335740	432578	732463	996591	1731954
179793	337531	539759	793850	1001219	

Details

Spring bow calipers

There are three different styles made: Yankee (G in Figure 1) made from flat stock, Fay (H in Figure 1) made from rectangular stock, and toolmaker's (E in Figure 1) made from round stock.

I've never been able to distinguish the different styles operationally as they all have about the same feel when gauging. What is important to me is smooth and easy adjustability. Old calipers with heavy springs and worn knurling on the nut are hard to adjust, especially with oily fingers. Look for an aggressive knurl (I've never liked Starrett's rope knurling because it's not as effective as flat knurling; Starrett changed to a flat knurl around the 1960's and it works better). I like Fay style calipers in 4, 6, and 8 inches for doing inside work, particularly for boring on the lathe.

Common sizes are 2, 3, 4, 5, 6, and 8 inches (this is the length of the pivot center to leg tip; it also indicates the approximate maximum measuring size of the calipers).

These are simple tools and things rarely function incorrectly as long as they're kept clean and lubricated. A common problem with older calipers is the knurling on the adjustment nut gets worn or disappears after long use. See *Adjustment nuts* for some tips.

Here's a picture of some Starrett toolmaker calipers' tips in new condition. You can do this shaping in your shop with a file because the tips aren't hardened. On calipers I do close work with, I'll smooth the tips with fine sandpaper or a stone after filing.

Figure 2

The two primary rules for using calipers are 1) use a light touch so the calipers or the work are not elastically deformed and 2) make sure the calipers are in the same plane as the diameter being measured for outside diameters and perpendicular to the plane of the diameter being measured for inside diameters. You can work to 0.001 inch levels with care, but this will take substantially more experience than using DEV calipers.

The width of the thumb nut can make a difference in the operation of the calipers. The following picture is of two 4 inch Starrett toolmaker's calipers. The ones painted orange have a nut knurl width of twice the ones painted yellow. The nuts are the same diameter, yet the wider one is substantially easier to operate as the narrow one (even though the narrow calipers' threaded rod has about a 54 threads per inch thread whereas the wide one's is 40 threads per inch).

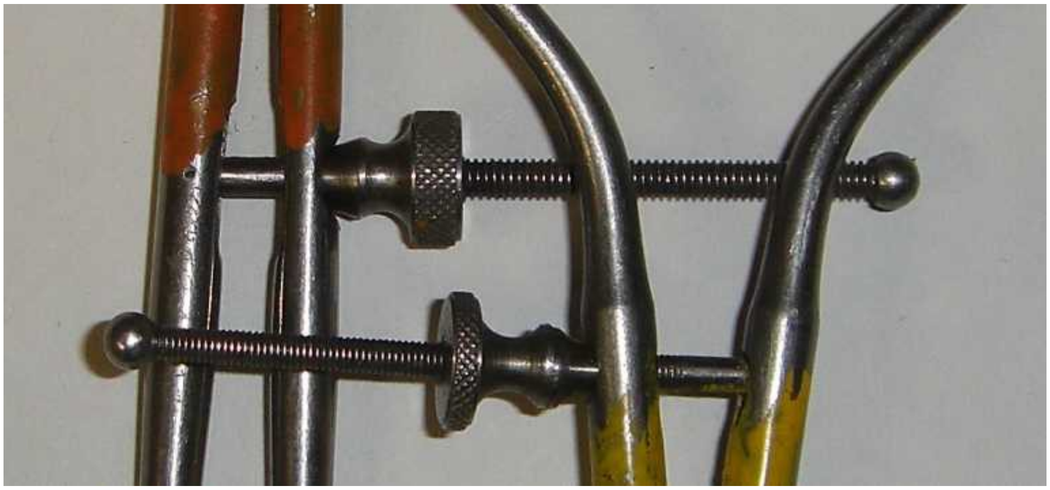


Figure 3

Look carefully at this seemingly minor detail, as most of the cheap calipers I've seen use thin-looking nuts too -- and these may bug you if you use the calipers a lot.

Minimum adjustment

The distance of the pivot to the tips *a* divided by the distance of the pivot to the adjustment thread *b* gives the ratio of the calipers' adjustment. Since the threaded rod has a pitch of *p*, one rotation of the adjustment nut moves the legs a distance *p* at the threaded rod. Thus, the tips will move a distance of $a\,p/b$. If you turn the nut a fraction β of a turn where β is the minimum practical rotation, then $a\,p\,\beta/b$ is the minimum you can move the tips. Since β will be around 1/32 or 1/64, you'll find many calipers have minimum adjustments of around 0.001 to 0.002 inches.

Split nut

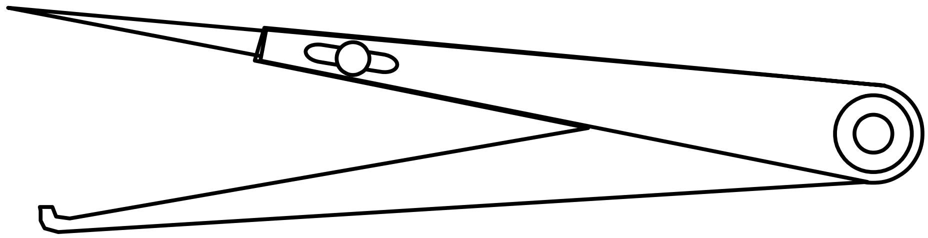
A solid nut refers to a plain thumbscrew for adjusting the caliper, such as those shown in Figure 3. A split nut refers to a nut that can be slid quickly along the threaded shaft to the desired position, giving faster operation of the calipers. Starrett patented a split nut design in 1905 in US793850. Starrett's design works OK and you'll be pleased with faster operation of the calipers when you have a lot of work to do.

A few years ago I bought a box of some used calipers because I wanted a few that were in the box. The rest got given away or put to menial duty. One old Fay style of 6 inch outside calipers made by Brown & Sharpe got tossed onto the cart of tools in the garage for working on cars. One day I needed some outside calipers, so I grabbed these B&S ones. While using them, I noticed that it looked like they had a split nut, something that's hard to see in the dark garage when I'm not wearing my reading glasses.

I pushed and pulled the nut, expected it to act like Starrett's, but it slid along the thread without opening the clamshell. After a bit I marveled at the wonderful design and realized these were the best spring bow calipers I've ever used for fast operation. I'd manually close the legs to close to what I wanted to measure, then finish by turning the nut for the final adjustment. I was stunned, as I had no idea such wonderful calipers had been made. They have an 1897 patent date stamped on them, so they could be a century old. The adjustment thread is 36 tpi (pitch is 0.028 inches) and the magnification ratio is 5.6/1.5 = 3.1, so one revolution of the nut moves the tips 3.1(0.028) or 0.086 inches. Since 1/64th is about the minimum nut movement, the minimum adjustable change is about 0.0013 inches. These became my go-to calipers.

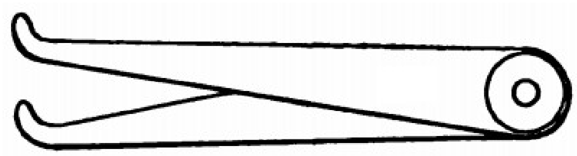
Hermaphrodite calipers

These calipers will scribe or measure from an edge or shoulder:



B, C, and D in Figure 1 show hermaphrodite calipers, which have one bent leg and a scribing tip. Styles C and D have firm joints and style B has a lock joint. Style D has a bent pin leg which keeps the scriber more perpendicular to the work surface during use.

Hermaphrodite calipers are the machinist's analog to the woodworker's marking gauge. They are called jenny calipers in the U.K. and were called compass calipers in the 1800's. They are sometimes called "odd-leg" calipers, but older usage means this style:



They are useful for e.g. setting blade height on the table saw.

Starrett made the model 42 lock-joint hermaphrodite calipers shown at B in Figure 1 for many years with the scribing leg made from a piece of flat stock, but then changed the design to a pin leg like the calipers shown at C and D. A bent leg from welding rod can be made to turn the hermaphrodite calipers into inside, outside, or odd-leg calipers (with such a leg, the calipers C in Figure 1 will measure 0 to more than 3.5 inch outside diameters and 0.8 to 10 inch inside diameters).

The flat leg is mechanically stronger and won't slip as easily, allowing you to press the point into e.g. a piece of wood. The flat leg design also allows you to scribe closely to a shoulder, where the clamp screw for a pin won't let the calipers close. The flat leg's length of adjustment is less than a pin, meaning it's not as versatile over fillets.

Well-designed and made hermaphrodite calipers have the sharp tip nestle behind the bent leg when closed to prevent you from stabbing yourself when carrying the calipers in a pocket.

Hermaphrodite calipers can be set from the end of a machinist's rule to 0.01 inches or 1/4 mm. I keep a pair of hermaphrodite calipers at the lathe, as they are useful to mark locations from the end of the work or a shoulder. I probably use hermaphrodite calipers more than any other type in the shop.

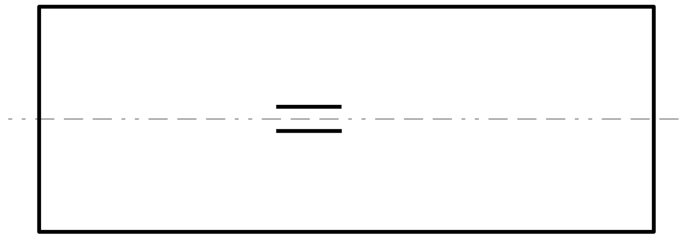
Be cautious when using hermaphrodite calipers to scribe lines on wood, as varying grain hardness can cause the scribed line to vary (this can happen with marking gauges too). I use a sharp pencil in wing dividers instead for marking such woods.

Another use for hermaphrodite calipers is to pick dimensions off something when referenced to an edge or shoulder, particularly over a feature that precludes the use of a rule.

Examples of use

Unit conversions: Use a machinist rule with inch and metric markings or convert between fractions and decimals.

Center of a board: Set the hermaphrodite calipers to the approximate half-width dimension and scribe one line from each side. You can split the distance between the two lines with your eye to find the center (this method is also used with a pencil and a combination square blade set to the approximate half-width):



In a pinch, drive a nail through a stick for indexing on the edge and use a pencil mark in the same way. With a tape measure, judge the center by eye, make a pencil dot near there at a convenient reading on the tape, then make another dot indexed from the other edge at the same reading. Mark the midpoint between the dots by eye. Another method with a tape measure is to pull the tape across the width, then tilt until it reads an even number; mark the center at half the number. For short board widths, this latter method can suffer from a cosine error because the tip indexes at a slightly different point than the edge of the tape (follow up with the first method as a check if you're worried about this).

Center of bar stock

Set hermaphrodite calipers to the approximate radius of the inscribed circle of the profile and make four marks about 90° apart:

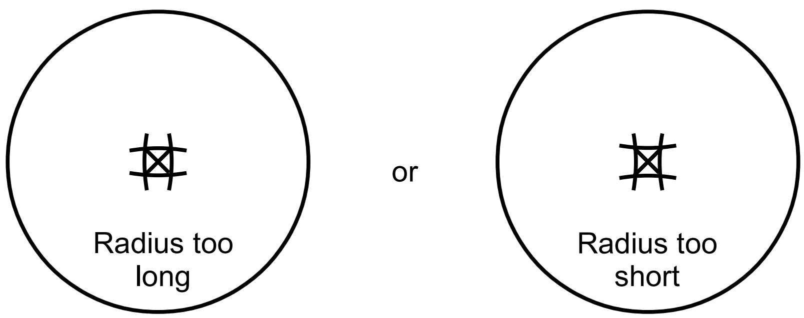


Figure 4

It doesn't matter if the calipers' setting is too long or short because you can visually interpolate the center. If the resulting approximate square is large, scribe the diagonals to find the center.

I use this method a lot because it's fast and I don't have find my center head and put it on the combination square blade.

Locating holes for screws: Hermaphrodite calipers are convenient for locating screws and holes on work. For example, given a desired hole location on the front of a board, you can locate the hole on the back side using a square to transfer the hole's location on a line on the back, then the calipers' setting can mark the hole's location from the edge. Make a light pencil line that's easily erased. When making boxes with butt joints and Torx wood screws, I'll lock some hermaphrodite calipers at half the stock thickness and use them to locate holes from and edge. There's no unsightly pencil marking gauge line.

Dividers

Dividers are adjustable points that can be used to

- ♦ Make uniformly-spaced marks
- ♦ Divide a dimension into an integer number of equal smaller lengths
- ♦ Pick dimensions off an object
- ♦ Make geometrical constructions

Spring bow dividers are probably the most commonly-used type in the shop (6 inch toolmaker's dividers are shown at E in Figure 1), but firm and lock joint types have been made and wing dividers are also popular.

Dividers are named for the process of dividing a length into an integer number of equal subdivisions. The approximately-needed subdivision length is set on the dividers, then the required number of divisions are stepped off on the length to be divided. If there is an error at the end, the dividers are appropriately adjusted and the check is repeated until the error is negligible. This division method also works approximately on curves where the radius of curvature is substantially larger than the divider setting (i.e., the curve is easily rectified). A related technique in drafting (called the "draftsman's method) is under "Dividing a line" here and can be generalized to divide a line into any desired proportions.

A machinist's rule is often used with dividers to set the point separation. The best way to do this is to index one point in one division on the rule, then set the other point at the desired reading. It's **critical** to remember to account for the offset unless you use a drafting-style rule with a zero mark or an open-style scale. Expensive mistakes will teach you to check the set dimension by putting one point at the rule end and reading the setting of the other point.

Some vernier calipers (e.g., the Starrett model 122) contain small marks that can be used to set and check divider settings. These can let you work to near 0.001 inch (0.02 mm) levels. A diagonal scale can also be used to set dividers and is something you can make yourself.

With a 10X loupe, good lighting, and sharp dividers, you can see 0.001 inch differences between a mark on some metal (sheet aluminum is good for this) and a point on the dividers. This lets you construct an accurate metal story stick for a project.

Dividers are made from high-carbon steel; the points are hardened and tempered to help them keep their sharpness. Keep your divider points sharp by honing them on a stone. Handle dividers carefully in the shop if you work on concrete floors, as dropping them on their tips can damage them. I like to have a rubber mat under my feet when using tools like DEV calipers and dividers in case I accidentally drop them. I slip a chunk of rubber fuel hose around the dividers' tips to protect them in storage and avoid poking myself. Dividers are precision tools that should be handled carefully.

There are specialty dividers that have multiple legs connected by linkages that can divide up a distance into a desired number of equal lengths or a desired proportion. The Alvin 719A is one such example.

For practical shop/DIY tasks, the usual 6 inch or so machinist dividers won't be able to handle all the work you'll want to do, so you may want to supplement your machinist dividers with some trammels for larger work.

You can use dividers on a circle's circumference to divide it into a specified number of equal-sized parts. This is commonly done for equally-spaced bolts on a bolt circle. If the diameter of the bolt circle is D and you want n bolt holes, set the dividers to the length $D\sqrt{\frac{1}{2}(1-\cos\frac{2\pi}{n})}$ and step this distance off around the circumference. Make sure your trig calculations are done with radians in this formula or change the 2π to 360° if you want to use degrees.

Proportional dividers

Proportional dividers are used to change a dimension by a desired proportion. A common use is to enlarge or reduce dimensions of objects. The principle is the geometrical similarity of vertical angles, such as two identical sticks with points at each end joined at a pivot. The pivot placement determines the ratio ρ of the separation of the end points *a* and *b* from similar triangles:

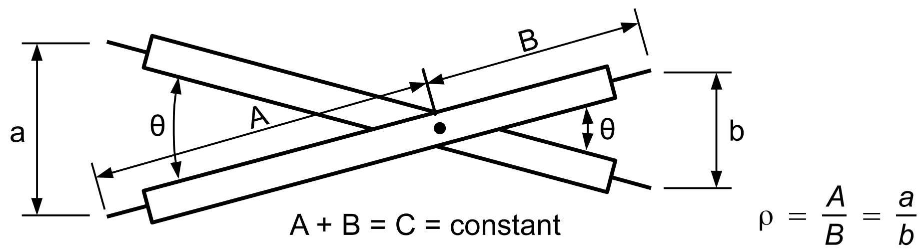


Figure 5

Since the interior vertical angles θ are equal, we have

$$\frac{a/2}{A} = \sin\frac{\theta}{2} = \frac{b/2}{B} \qquad \text{or} \qquad \rho = \frac{A}{B} = \frac{a}{b}$$

Typical usage is to set dimension *a* to something on an object or drawing, then use dimension *b* for the corresponding proportional dimension. If you need a special ratio *ρ* for a task, it's not difficult to construct some proportional dividers; the ratio is controlled by placement of the pivot point.

There are two types of commercial proportional dividers, artist's and technical. Artist's dividers are inexpensive, made from wood or plastic, and contain fixed holes for fixed proportions (I won't discuss these further, as they aren't terribly useful for shop/engineering work because of fixed ratios and they're relatively flimsy). Technical proportional dividers are constructed from metal and have a continuously-adjustable pivot. When the pivot is properly positioned to the desired ratio, the pivot is tightened in position and the dividers act as firm joint dividers.

There are two types of these technical proportional dividers: sliding pivot and geared pivot.

Sliding pivot: This type is the least expensive and most common:

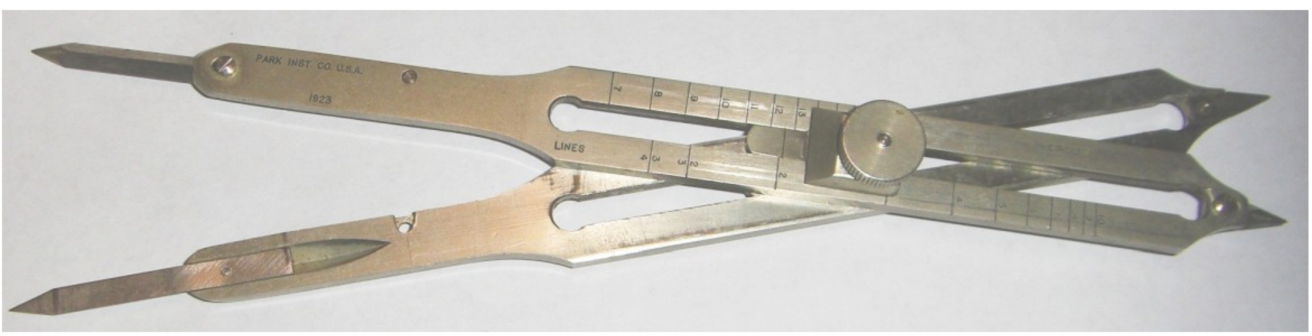


Figure 6

The knob is loosened and the pivot can be slid to a desired ratio (the legs are superimposed and held in position by a pin on the top leg meshing with a slot on the bottom leg, just behind the slot milled for the tip). Most commonly the ratio is given on a LINES scale which contains marks to divide a line into an integer number of equal parts. Some dividers also have a CIRCLES scale which let you divide the circumference of a circle into an equal number of parts (for example, machinists can use such a tool to lay out a given number of bolt holes equally around a circle). For precise use, you'll need to iteratively set the ratio desired by using a machinist's rule.

Decimal proportional dividers: This type of dividers have a pivot that can be adjusted to a desired position using a pinion gear that mates with a rack on one of the legs (see Figure 7 below). The gearing makes it easier to make small changes in the dividers' ratio. Decimal proportional dividers have a linear scale with a vertical that allows setting the dividers' ratio to nearly 3 significant figures. Keuffel and Esser (K&E) called this type of dividers "universal proportional dividers":

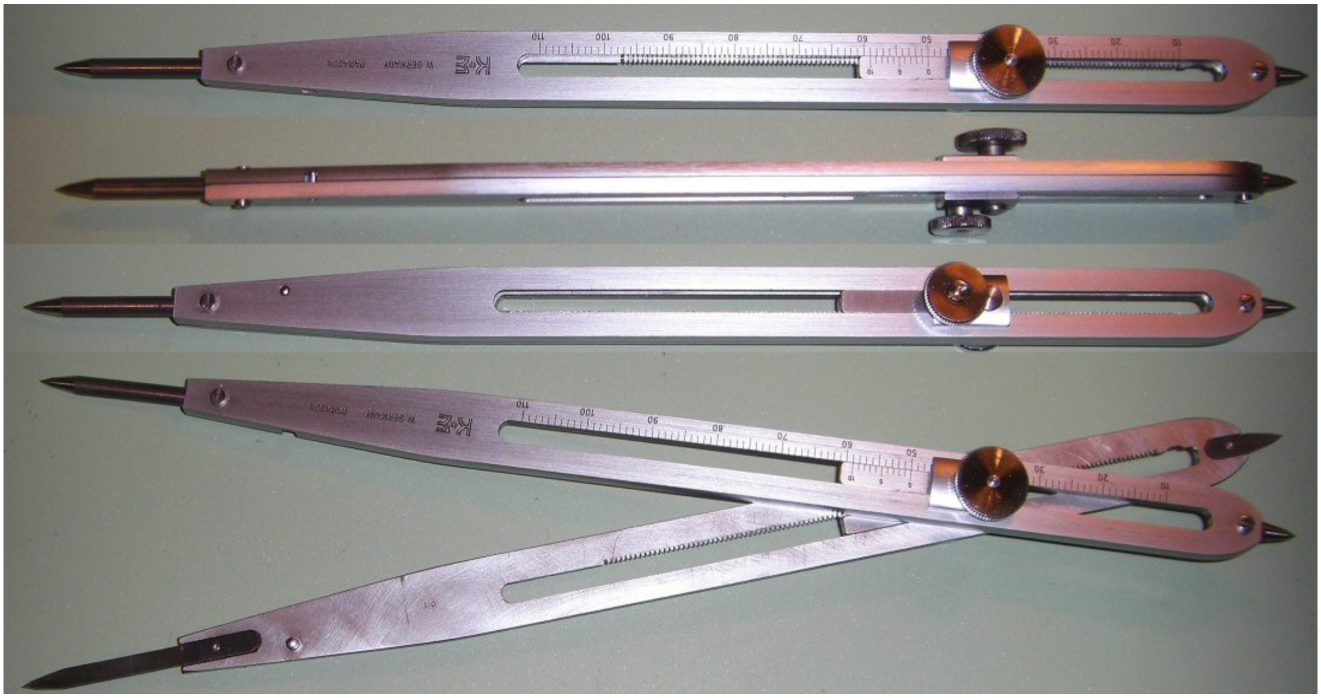


Figure 7

The dividers shown in Figure 7 are 10 inch K&E proportional dividers; they are similar to the model 440X dividers shown in a 1936 K&E catalog on page 113. It appears K&E made decimal proportional dividers from about 1900 to at least until the 1960's, as they were popular with engineering and drafting folks (properly made, they are elegant and precise tools). K&E also made decimal proportional dividers with "dog leg" points, which had points with right angle bends.

With the ratio set to maximum (minimum scale reading), these dividers are firm joint dividers and can work with dimensions up to about 12 inches or a bit larger.

A pinion gear on the bottom knob meshes with the rack on the leg, allowing fine adjustment of the pivot. The pivot has a vernier to read the linear scale on the leg, which goes from 10 to 110, corresponding to integer settings of 100 to 1100. The dividers shown in the picture can be set to actual readings of 174 to 1017, giving 844 distinct ratio settings from 0.094 to 1.034. The scale does not read out the dividers' ratio directly because a ratio scale would be nonlinear. With a little care, you can set the vernier to the midpoint between one vernier step, effectively doubling the number of settings, but this doesn't result in any practical increase in the resolution of the dividers.

The formula for setting a specific ratio ρ on the divider's scale is

$$2000 \frac{\rho}{1+\rho} \tag{1}$$

(Remember to divide this number by 10 to equal the number shown on the dividers' scale; K&E probably did this to avoid printing decimal points in the table on the back of the box, which helped save space.)

This formula is derived from Figure 5 above by noting that the pivot's distance from the left end in terms of the overall length of the dividers' leg is A/(A + B) and dividing through by B. The factor of 1000 is used to convert the scale reading using the vernier to an integer and the remaining factor of 2 is because the overall scale length is exactly half the length of the dividers. Since *ρ* is a function of *A* and *B*, you can see that the scale for *ρ* can't be linear by differentiating by either *A* or *B*, as neither derivative will be a constant.

The strong advantage of these dividers are that you set the desired ratio using the vernier scale and **there's no iteration**. For convenience, K&E put a table of various settings versus ratios on the back of the storage box:

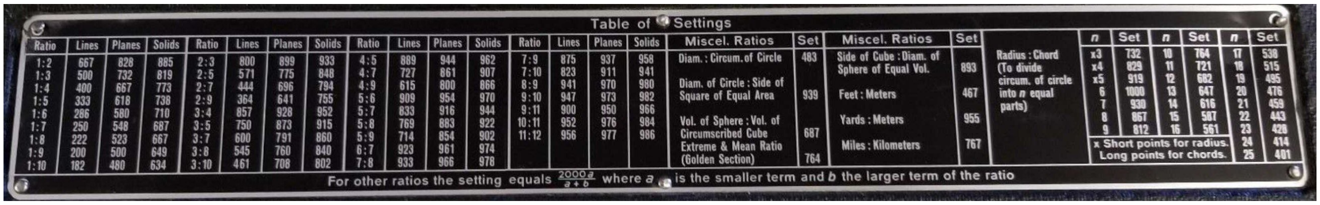


Table of Settings

Ratio	Lines	Planes	Solids	Ratio	Lines	Planes	Solids	Ratio	Lines	Planes	Solids	Ratio	Lines	Planes	Solids
1:2	667	828	885	2:3	800	899	933	4:5	889	944	962	7:9	875	937	958
1:3	500	732	819	2:5	571	775	848	4:7	727	861	907	7:10	823	911	941
1:4	400	667	773	2:7	444	696	794	4:9	615	800	866	8:9	941	970	980
1:5	333	618	738	2:9	364	641	755	5:6	909	954	970	9:10	947	973	982
1:6	286	580	710	3:4	857	928	952	5:7	833	916	944	9:11	900	950	966
1:7	250	548	687	3:5	750	873	915	5:8	769	883	922	10:11	952	976	984
1:8	222	523	667	3:7	600	791	860	5:9	714	854	902	11:12	956	977	986
1:9	200	500	649	3:8	545	760	840	6:7	923	961	974				
1:10	182	480	634	3:10	461	708	802	7:8	933	966	978				

Miscel. Ratios	Set	Miscel. Ratios	Set
Diam. : Circum. of Circle	483	Side of Cube : Diam. of Sphere of Equal Vol.	893
Diam. of Circle : Side of Square of Equal Area	939	Feet : Meters	467
Vol. of Sphere : Vol. of Circumscribed Cube	687	Yards : Meters	955
Extreme & Mean Ratio (Golden Section)	764	Miles : Kilometers	767

Radius : Chord (To divide circum. of circle into *n* equal parts)

n	Set	*n*	Set	*n*	Set
x3	732	10	764	17	538
x4	829	11	721	18	515
x5	919	12	682	19	495
6	1000	13	647	20	476
7	930	14	616	21	459
8	867	15	587	22	443
9	812	16	561	23	428
				24	414
				25	401

x Short points for radius. Long points for chords.

For other ratios the setting equals $\frac{2000a}{a+b}$ where a is the smaller term and b the larger term of the ratio

To divide a circle's circumference into n equal parts, use $\rho = 2\sin(\pi/n)$ in formula (1) (use radians). This is the ratio of the chord length to the circle's radius. When n is less than 6, subtract the setting from 2000.

Use: 1) superimpose the legs so that the pin on one leg is located in its matching slot in the other leg, 2) set the pivot to the desired ratio. With decimal dividers, you're ready to use them, but sliding pivot models will typically need some checking and iterative adjustments to get the ratio you desire.

These decimal proportional dividers are useful for scaling drawings and photographs. They're also useful for picking distances off a map in units different than those given on the map's scale. You'll find them useful with various drafting scales to let you graphically pick off dimensions in desired units.

Truthfully, I've found that I'll often simply scale a drawing by measuring a feature with a drafting rule and multiplying the value by the ration stored in my calculator. I use my programmable calculator so that I just enter the measured number and press the R/S key to get the scaled number. For lots of measurements, this is faster than using proportional dividers. However, the proportional dividers can, with care, make it a bit harder to make a mistake. For critical work where a mistake is expensive, the proportional dividers can be a good method of checking a calculation done with a calculator.

You can also do proportional work with a sector, an ancient instrument based on proportions of triangles. They are not hard to construct for shop work; look them up on the web.

Geared drafting dividers

For drafting use and picking dimensions off things, geared dividers are the tool of choice:

Figure 8

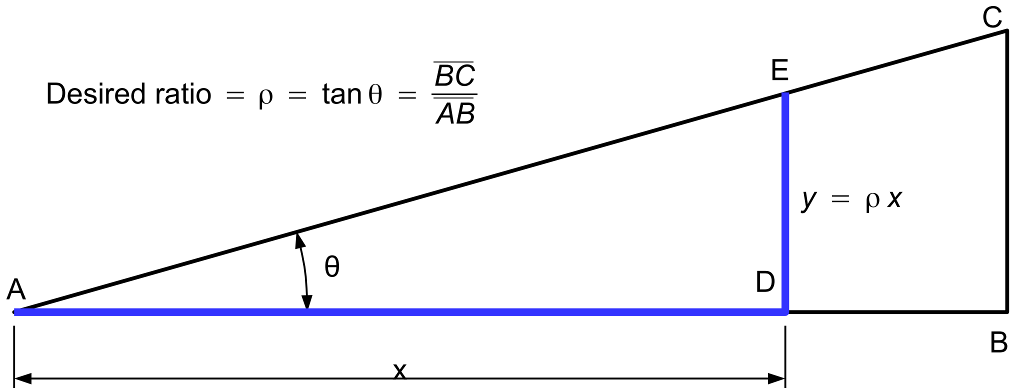
Their biggest advantages are 1) speed and 2) they can be operated with one hand. There are other styles available that can be operated with one hand, but the type shown in the picture are usually found in drafting sets (navigators also use them). I use the ones in the figure constantly at my drafting table.

Fixed-ratio work

Today, the easiest way to do occasional proportional work is with a calculator, dividers, and a rule.

Measure on the scale and use the calculator to calculate the scaled dimension. For repeated work, the following graphical method can be handy.

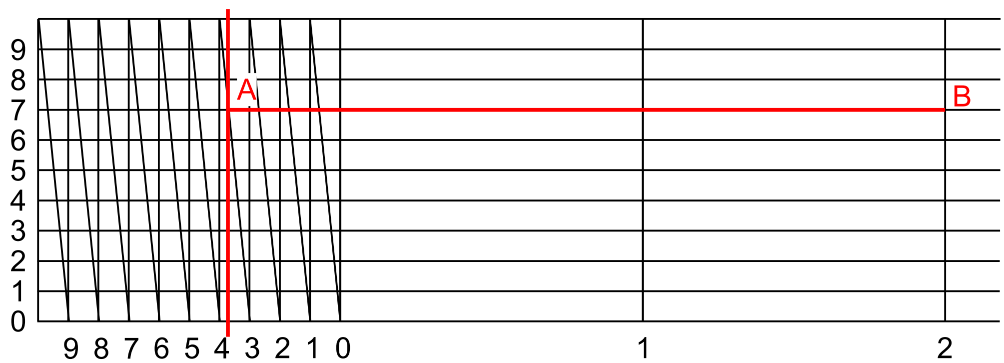
Lay out a triangle on graph paper with an angle θ whose tangent is the desired ratio *ρ*:



Set your dividers to a dimension *x* on the drawing and put one point at point A on the triangle. Hold the other point at D, set the dividers to the distance *y* such that ED is perpendicular to AB. This gives the desired scaled value without measurement or converting to numbers.

Diagonal scale

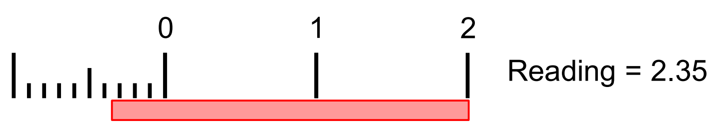
A diagonal scale used to be common on carpenter's squares for setting dividers to the nearest 0.01 inch:



This is an open scale with auxiliary slanted lines at one end to help you get another significant figure. In the diagram, the reading AB's most significant figure is 2; the next significant figure is 3. The angled line's intersection at A with the horizontal line gives you the third significant figure of 7. Thus, the reading is 2.37. Using dividers, you'd set one end on the 2 line and slide them up and down until the other point crosses one of the angled lines.

Open scale

It's straightforward to make an open scale using dividers and a machinist's rule (this is how people made scales by hand for millenia and you'll still see them on architect's scales based on fractions of an inch). Here's the basic design:



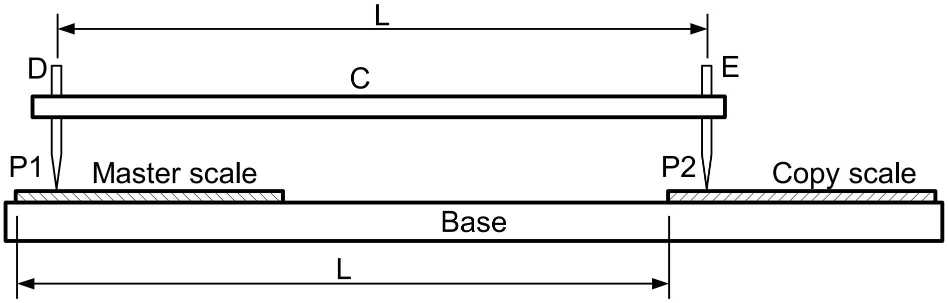
Here's how I like to graduate sticks of wood in the shop. I prefer a close grain hardwood like cherry or maple and make sure the edge to be graduated is flat and smooth. I use trammels and dividers for this task, as the first marks on the beam are made with the trammels set to a longer length.

Here's an example. Suppose I want to lay out an inch open scale on a 50 inch piece of wood. I'll first set the trammels carefully to 10 inches from a machinist's rule (use a magnifier loupe to ensure the points are in the graduations), locate the zero mark, then step off 10, 20, etc. inch marks. Each of these marks provides a reference mark for further subdividing, lowering cumulative error. Next, I'll set my 6 inch dividers to 5 inches carefully from the rule. I check that two of these settings exactly equal each of the 10 inch segments. Then the marks are made for the 5, 10, 15, etc. inch marks. Finally, I'd set the dividers to a 1 inch separation, again checking that the 5 inch increments are proper by stepping off five 1 inch segments, then mark the 1 inch marks.

Here, "marking" means pressing the dividers point in just far enough to make a visible mark that will index a sharp pencil point and let me draw a line across the wood with a double square. Put the pencil point in the mark, bring the square up to the pencil, and draw the line. Done with care and consistency, you should see accuracies on the order of 0.01 inches on wood, better on metal.

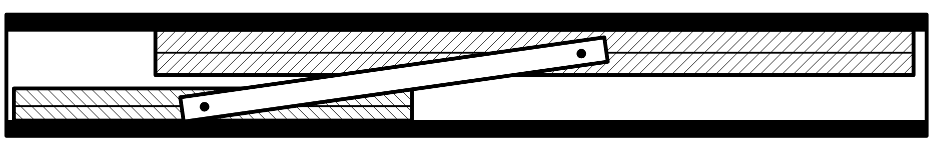
The small divisions on the end scale is set off with 2 inch dividers. A small pair of screw-adjust drafting dividers is excellent for this task.

Bunsen's method: [*st:26:51*] This method of copying a scale is obvious once you see it[1] and can let you construct a variety of scales to suit your needs. You must have a good machinist's rule with etched or scribed graduations that will index the scriber point. Trammels are the obvious tool for this task. The idea is



A master scale is used to scribe marks on the copy scale by scribers D and E that are fixed in the scribe bar C. The two scribers are located at a fixed distance L apart and the two scales are rigidly fixed to the base. Shim the lower scale so that there's no cosine error.

Looking down in plan view, note the trammels can be at an angle if there's e.g. a center line on the scales to make the marks:



The heavy black edges are stops used to align the scales. Other improvements will be obvious on reflection.

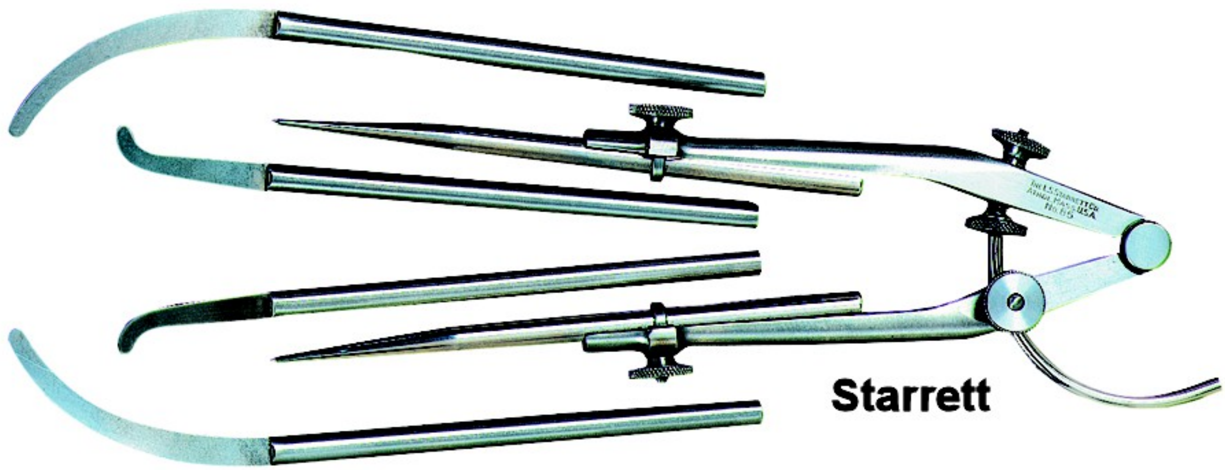
Wing dividers

For general DIY tasks, wing dividers like the Starrett 85 models can be a good choice because of their flexibility when used with various legs. The auxiliary legs and a pencil let you make dividers, inside calipers, outside calipers, a compass, odd leg calipers, and hermaphrodite calipers. Making auxiliary writing stick holders can let you use Sharpie markers, crayons, chalk, soapstone, etc. for marking flexibility.

Interestingly, the model 85 design is nearly unchanged since Laroy Starrett's 1889 patent drawing US411527. Starrett's two innovations in the patent were 1) the locking nut and spring between the legs and 2) making the wing (the circular arc piece, giving the calipers their name) from round stock and clamping it with a stud with a round hole through it. Here are the 85D dividers with the auxiliary

1 It's due to Bunsen of Bunsen burner fame, developed around 1854.

inside and outside diameter gauging legs:



The Starrett website calls them "Carpenter's and Sheet Metal Workers Improved Extension Divider with caliper legs" and makes them in different sizes (the #26 catalog from 1938 called them "Improved Extension Divider"). The 85A model is 7 inches (the 85C model is the same and includes caliper legs), the 85B is 9 inches (85D includes caliper legs), and the 85E is 12 inches (85F includes caliper legs). Starrett also made the model 90 wing dividers which were made from drawn bronze and nickel-plated, probably for marine environments to avoid rust; they were similar to the model 85 but didn't have the leg offset near the fine adjust knob. The model 92 dividers are made the same way except have one permanent leg with a point. The model 92 has been made in 6, 7, 8, and 9 inch sizes, while the model 85 has been made in the 7, 9, and 12 inch sizes. Note these are nominal sizes, as my model 92 dividers measure 4.5 inches from pivot to end of leg, the 12 inch model 85 dividers measure 7.6 inches, and the old smaller model 85 with the wing nut measure 5.0 inches (they have no stamped Starrett name on them, but they were clearly Starrett's design).

These dividers can be opened to a maximum angle of about 105°. With such an opening, here are the approximate maximum measuring capacities of this tool in the 12 inch size with the optional legs (mm values are rounded to the nearest 5 mm):

	Inches	**mm**
Inside diameters		
Small legs	21.3	540
Medium legs	24.0	610
Large legs (from model 59)	27.9	710
Outside diameters (in-plane, approximate)		
Medium legs	14	355
Large legs (from model 59)	16.5	420
Outside dimension (out-of-plane)		
Medium legs	20.6	520
Large legs (from model 59)	23.3	590
Hermaphrodite calipers	22.9	580
Scribed circle diameter (largest point & long pencil)	46.0	1170
Dividers (longest points)	25.0	635

A useful feature of these dividers (and the Starrett 59F trammels) is that the clamps will accept a standard pencil, so you can also use these dividers as a compass. The rods are 0.289 inches in diameter. Six-sided standard pencils are 1/4 inch across the flats, making them $\frac{1}{4}\frac{2}{\sqrt{3}} = 0.289$ inches across the points.

Ream the clamp hole tip: You can ream out the standard clamps on the Starrett 85 wing dividers (and other similar Starrett tools) with a 5/16 inch diameter reamer, as their holes are around 0.30

inches in diameter. The dividers will then be able to take 5/16 inch diameter stock to make various attachments.

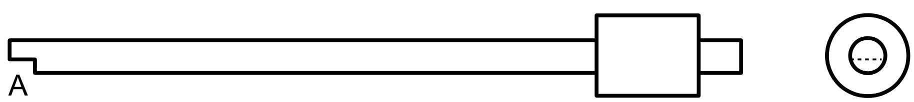
Old wing dividers can have the knurling on their knobs worn off. It's not difficult to make some replacements from aluminum bar stock on a lathe (the thread is 8-32):

Figure 9

They're not as attractive as Starrett's knobs, but they work quite a bit better.

There are vendors who sell the Starrett 85 wing dividers with a two-vial bubble level assembly on the end so that they can be used for scribing log cuts when making log homes. The levels help you hold the dividers consistently. Veritas sells some dividers aimed at scribing logs when building log houses. The tool comes with good documentation and appears to be about a 6 inch tool, meaning it can scribe circles up to about 12 inches in diameter.

If you have wing dividers but you don't have a bent leg to make hermaphrodite calipers, make a piece that clamps onto the leg with a set screw (or is held on permanently with a small spring pin):



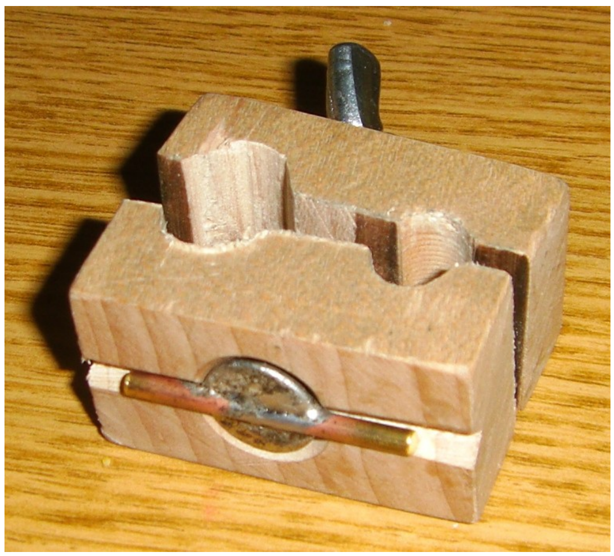
The step will let you index on the surface of the work and the rod indexes on the side of the work. Instead of the extra piece, you can just file a step on the end of the rod, shown at A, but the larger diameter piece will be more robust for rough work.

Few manufacturers make wing dividers with a fine adjust anymore -- and you'll want the fine adjust once you've tried it. C. S. Osborne makes the 6, 8, 10, and 12 inch 106-X dividers (X is the length in inches), typically for around $50, but these don't have replaceable legs, so they can only be used as dividers. Cheap dividers of the following style are easily found for $10 to $30:

While these should work fine for routine task, a picky worker will eventually want a better model with a fine adjust. A search for "wing divider" on ebay will turn up numerous suitable models by Pexto, Johnson, Sargent, Osborne, Stanley and other makers. A few have the replaceable leg(s) like the Starrett 85 or 92 (Millers Falls, Sargent, and Osborne once made knockoffs of the Starrett 85 or 92).

Writing stick holder

A piece of scrap wood can make a holder for a variety of marking tools:

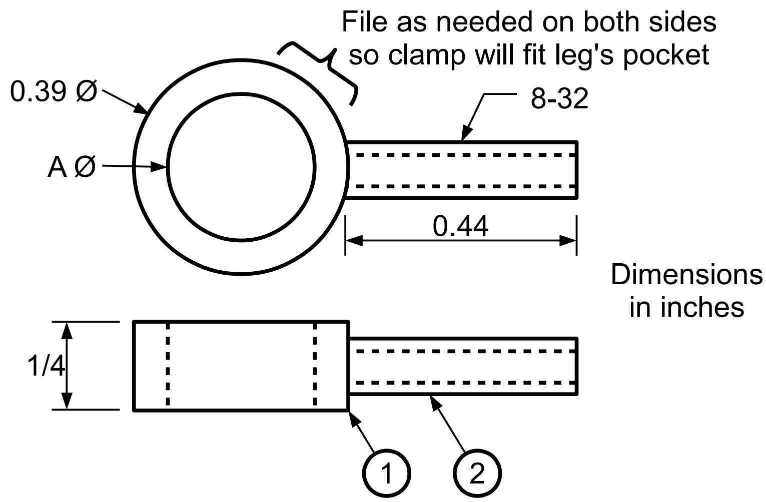


With the long points made for the Starrett 59F trammels, this lets me scribe circles over 52 inches (1.3 m) in diameter with the 12 inch Starrett wing dividers:

Leg clamps

I ream out the standard leg clamps of the Starrett 85 and 92 wing dividers with a 5/16 inch diameter reamer to let them hold 5/16 inch stock (this makes it easier to make special tooling because 5/16 inch diameter stock is easily available). This usually means removing around 0.012 inches of material.

However, on one old pair of these dividers (a 5 inch size with the wing nut as shown in Starrett's 1889 patent US411537), the reaming broke the 8-32 threaded portion, so I had to make a new one. Here are the dimensions of the part:



On the old dividers, diameter A was 0.307 and 0.309 inches on the two parts. The 0.39 inch outside diameter is for these old dividers and the forged pocket is 3/8 inches in diameter. The more modern model 85 and 92 dividers I've measured have pocket diameters of 7/16 inches.

To make the new leg clamp, I turned some 1/2 inch bar stock to 0.39 inches diameter and reamed it out to 5/16 inches in diameter, then parted it off 0.2 inches long. I drilled and tapped it transversely for an 8-32 thread, then silver soldered in a chunk of thread from a machine screw with the head cut off. I filed out the excess solder and removed some of the side material to get things to seat in the pocket.

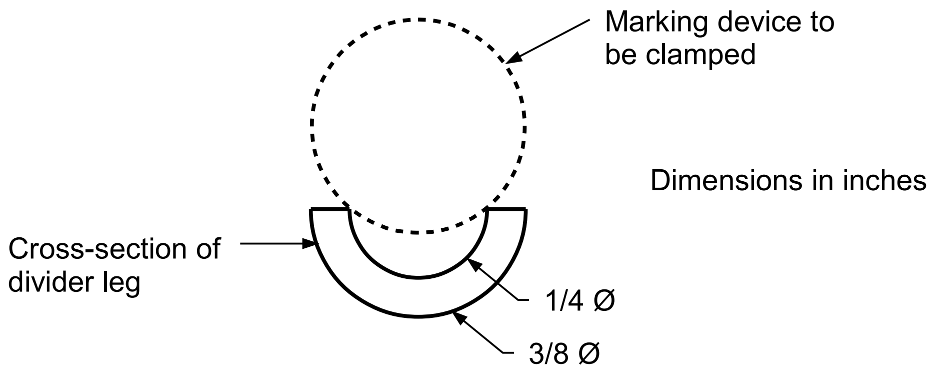
To get these rings to fit into the 3/8 inch leg pocket on the older dividers, the material has to be filed to size, but this takes only a couple of minutes.

If you have a lathe, this is a straightforward fabrication method, so it's handy to make leg clamps to hold other sizes of marking devices besides a pencil. The two I use the most in the shop are for Sharpie markers, the regular size and the ultra-fine point size. Here are the suggested clamp ring inside (ID) and outside (OD) diameters for Sharpie fine point and ultra-fine point pens, gotten from measurements from a number of pens around the house:

	Fine point		**Ultra-fine point**	
	inch	**mm**	**inch**	**mm**
ID	0.49	12.4	0.44	11.2
OD	0.63	16	0.57	14.5

Starrett seems to make the wall thickness of these clamps in the modern dividers about 1/16 inches (1.6 mm).

Here's the view down the axis of the marking device (applies to the Starrett model 85 and 92 dividers' legs I've measured):



You can make the leg clamps for special pens out of e.g. brass to denote that they are for a non-standard size.

Trammels

Trammels are a pair of trams on a beam. A tram is a single tool that holds a point, calipering jaw, or pencil and clamps to a beam.

For general shop and DIY work, I recommend the Starrett model 59 trammels ($89 Jan 2020) or similar less expensive models from other vendors. The model 59 trammels will clamp to beams from ¾ to 1½ inch thick and clamp points from 3/16 to 5/16 inches in diameter. Without the beam, they store compactly in a toolbox. The 59F set ($322 Jan 2020), though expensive, is one of the most versatile layout tools for shop and DIY work. The auxiliary legs from this set can also be held in the Starrett 85 wing dividers.

Starrett also sells the cast iron 50A and 50B trammel heads. The 50A ($150 Jan 2020) has a fine adjustment screw; the 50B ($125 Jan 2020) does not. Both come with a pencil holder. These clamp on beams from ⅜ to ¾ inches thick. I haven't used them so I can't comment on them. You can find knock-offs of this design on the web for under $20.

You can search the web and find a variety of trammels. Lee Valley Tools sells a number of different trammels; I like the design of the 05N3005 Veritas beam compass for $80 (Jan 2020), but I haven't tried one and can't comment on its use (I'd want to sharpen the points to a finer taper). Their 05N5005 trammel points for $30 (Jan 2020) are also a nice design (the 9/16 inch spec implies they are made from 9/16 inch stock). If you have a lathe, a nice copy could be made from some 3/4" brass bar stock; the through hole looks to be about ¼ inch, which allows them to be held on a piece of ¼ inch bar stock. The thumb screw thread looks like it could be 5/16 UNC.

Drafting trammels have been made in many styles, but are light duty tools not suited for rough duty in a shop. They're fine for occasional use and you may be able to find some at a garage sale.

Woodworkers often make light-duty models from wood; search the web for ideas.

Starrett 89 universal divider and beam compass

Starrett made the model 89 Universal Divider and Beam Compass in the first half of the 20th century, which essentially is a small trammel set with a bent leg and 4 inch beam [*leo:6*] (the beam has a flat so the trams won't rotate). I have found them almost indispensable for scribing small circles and arcs in metalworking tasks, especially because the cone point allows scribing from the center of existing holes. I made an auxiliary cone point that lets me scribe from circle centers up to about 3/4 inch.

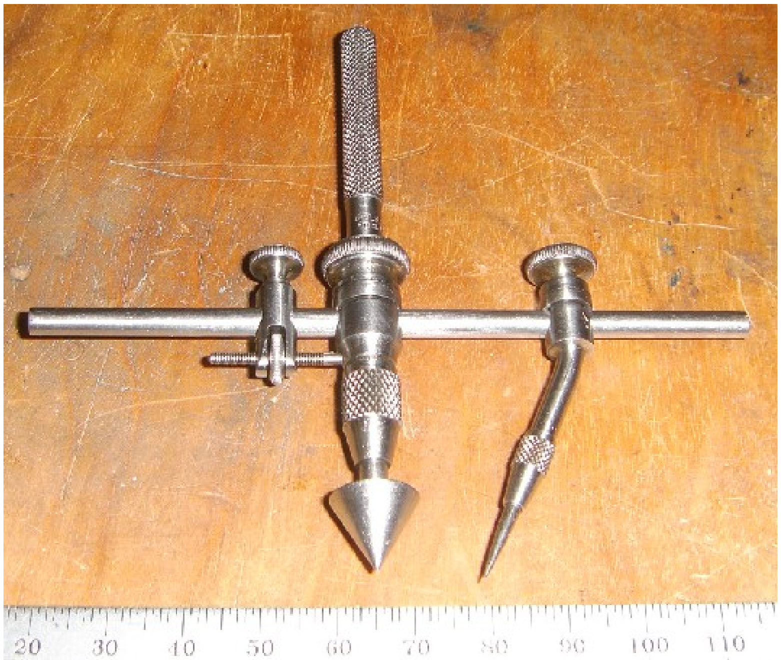
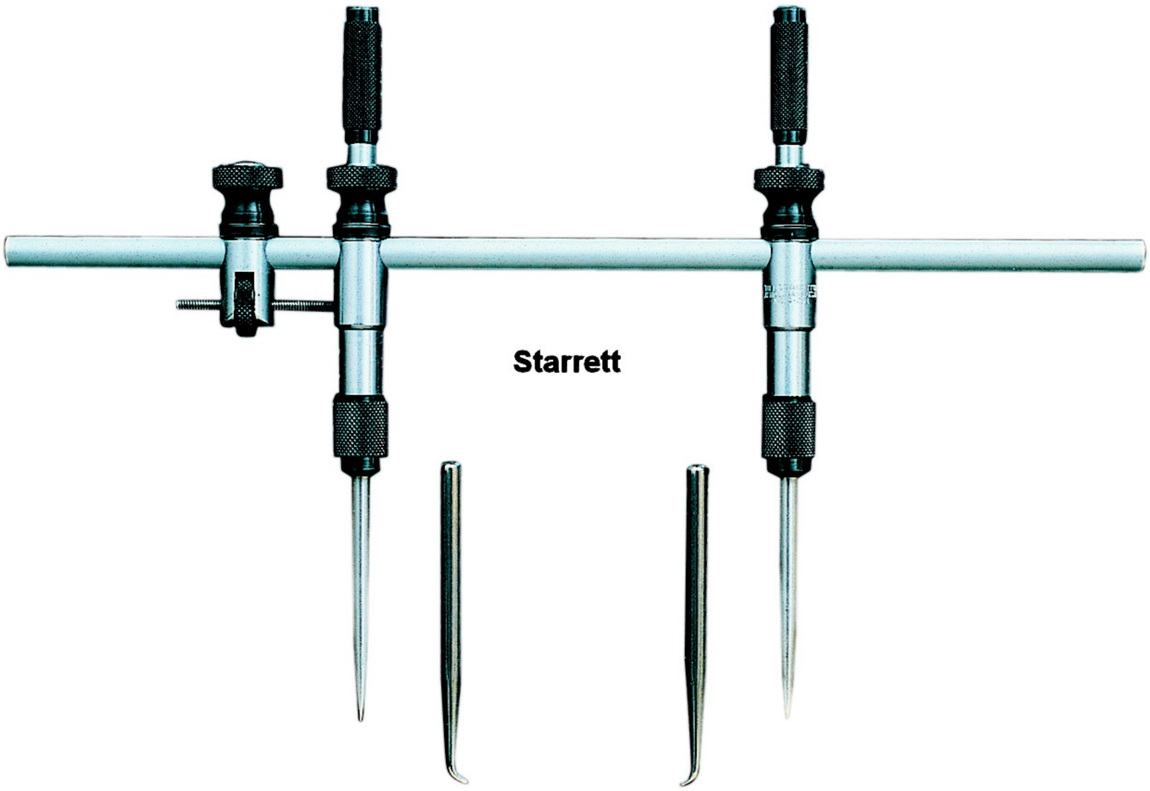


Figure 10

Dimensions in inches of these trammels: beam diameter 0.159, beam diameter over flat 0.144, body diameter 0.363, overall length from top of knurled handle to bottom of cone point 3.5, 0.085 pin diameter, diameter of cone 0.465, diameter of cone's shaft 0.149, adjustment length 0.6, diameter of knurled handle 0.23.

Starrett C251

Starrett still makes the model 251 trammels for machine shop use:



These are rigid trammels with a 5/16" steel beam (the beam has a flat so the trams won't rotate). Currently (Jan 2020) Starrett sells three models with different beam lengths for around $220. Caliper legs let you use them as calipers, along with an optional set of balls used to scribe circles using existing holes for the center. There's also a holder for 2 mm drafting leads (you'd occasionally see a draftsman using them in the old days, although most draftsmen bought much less expensive drafting trammels). The diameter of the points and calipering legs is 0.193 inches. [*tmbr3:122*] describes a method for grinding the flat on a beam for these trammels to make an extension beam.

Brown and Sharpe made a knock-off of these Starrett trammels. The Starrett 251 trammels are unchanged from the 1938 Starrett catalog and the design probably dates to the early 1900's. The 1938 catalog shows three additional points for these trammels: one that will hold 2 mm pencil leads, a needle point, and an inking pen for drafting.

Many machinists make trammels of their own design. [*tmbr3:123*] shows a picture of trammels that appear to be a copy of the Starrett C251 design (and notes that Lautard wrote an article in Jan 1985 in *Home Shop Machinist* about making one). [*tmbr3:127*] shows how to make a pencil lead holder for these trammels. Standard drafting leads are 2 mm diameter and there have been many lead holders made for these leads -- you might be able to modify one to make a handy holder for your trammels.

Here are some auxiliary legs made from ¼ inch square brass stock that hold dial indicator points:

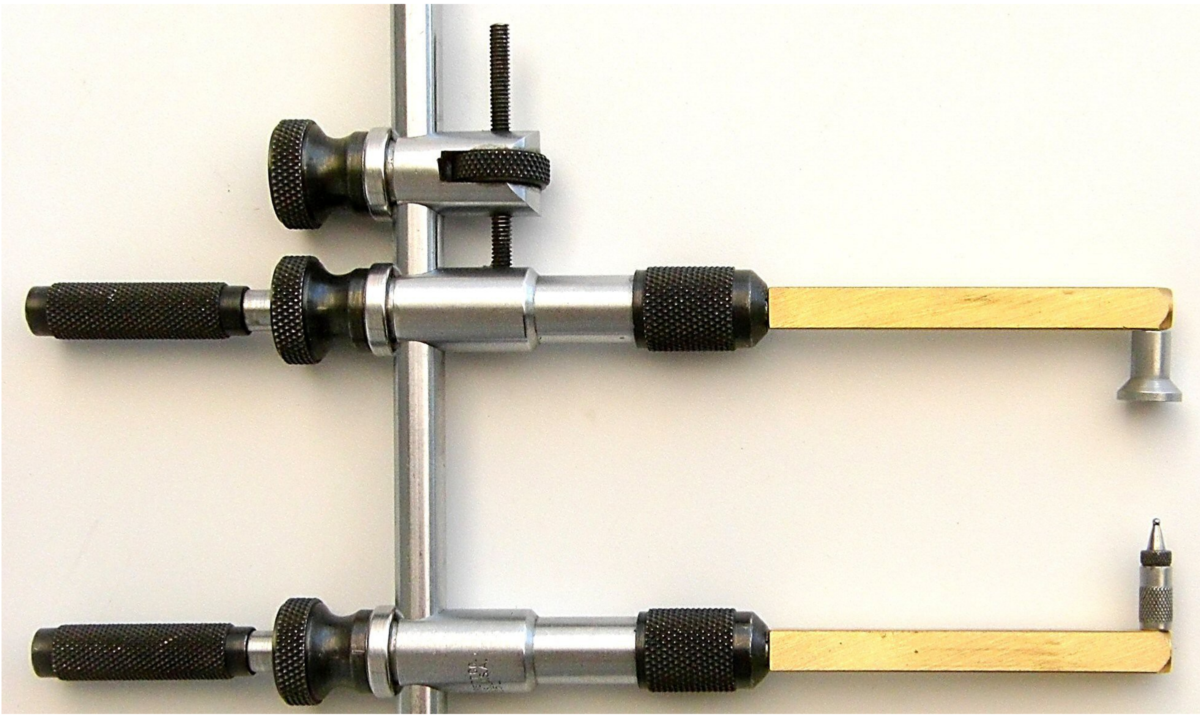


Figure 11

These are useful for oddball gauging tasks.

The Starrett 2 mm pencil lead holder is shown in the following picture with an X-acto knife with its aluminum handle turned down to fit the C251 trammels:

The knife blade gets used for cutting out gaskets, cardboard, etc.

Trammels stored with the points can lead to you getting stuck. Slip a piece of rubber fuel hose over them to protect you.

Homemade ball points

Buy some wooden balls of various diameters and install a Rosan threaded insert in them. Then make a 0.295 to 0.3 inch diameter shaft, thread the end to fit the insert, and you have an inexpensive ball to scribe from hole centers with your trammels or wing dividers. They work well and you can't argue with the price.

Instead of a ball, you could also make a set of tapered frustums of different sizes:

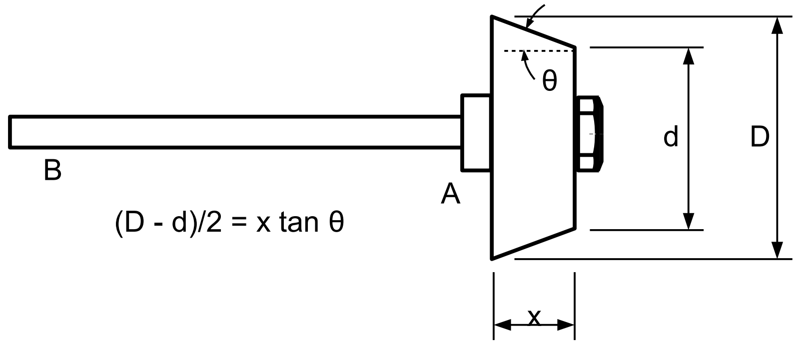


Figure 12

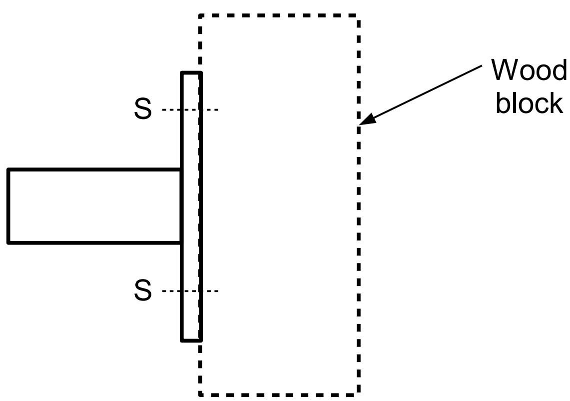
Cut out various disk sizes from e.g. plywood and mount the pieces on a spindle of the correct diameter with a nut and washer to hold the frustum in place. The spindle can be held in the lathe chuck to turn the taper to make the frustum.

To make the spindle, start with 5/16 inch diameter bar stock and turn it down to 0.295 to 0.3 inches in diameter if you'll use this in stock Starrett 85 wing dividers (use 5/16 inch bar stock directly if you reamed out your Starrett 85 leg clamps). The Starrett 59 trammels will take 5/16 inch diameter bar stock.

Solder or pin a shoulder piece or washer (a ⅛ spring pin is fast and cheap) at A and thread the end for a nut and washer. For convenience in tightening the nut, make the piece at A from some hex stock or file two flats on it so it can be held with a wrench. Drill a ⅛ inch cross hole at B for a piece of ⅛ rod to use as a tommy bar for tightening (or file a hex on the end of the rod or file wrench flats on the piece at A).

Douglas fir "2 by" material is common and cheap in the US and lets dimension x in Figure 12 be 1.5 inches. If you want the gauge to fit in holes that differ in diameter by up to an inch, the angle θ must be $\tan^{-1}\frac{0.5}{1.5} = 18.4°$. Thus, a set of frustums to span 2 to 10 inches will take 8 separate frustums.

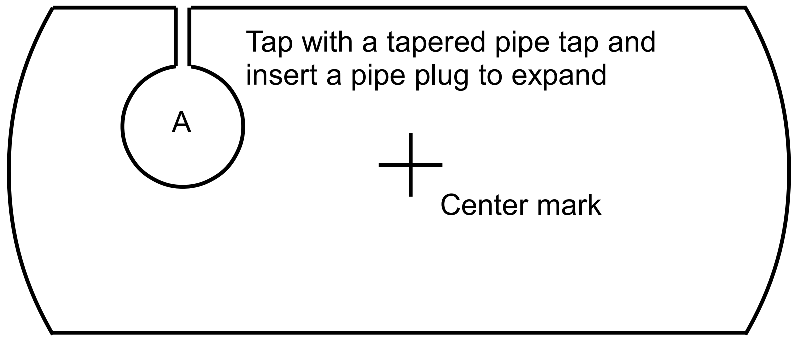
I made my holder with part A made from ¾ inch diameter stock, machined concentric with the bar stock after being pinned to the shaft with a ⅛ spring pin . Part A fits into a snug-fitting hole bored in the wood frustum and locates the spindle center concentrically with the outer diameter of the frustum. I use the following fixture in the lathe to hold the raw wood stock to bore the ¾ inch hole:



Sheet metal screws S hold the wood block in place for boring. A 5/16 inch diameter hole is first drilled through the block for the threaded 5/16 inch stock. The fixture's spindle is 1 inch diameter aluminum, held in the lathe's collet. After the ¾ inch hole is bored, the wood piece can be put on the spindle and the frustum's taper can be turned concentric with the bar's axis.

This fixture is handy around the lathe for producing wooden parts.

For larger holes, use a piece of scrap wood and cut it so that it's a tight press fit into the hole. Then mark the center point and use regular dividers or trammels.



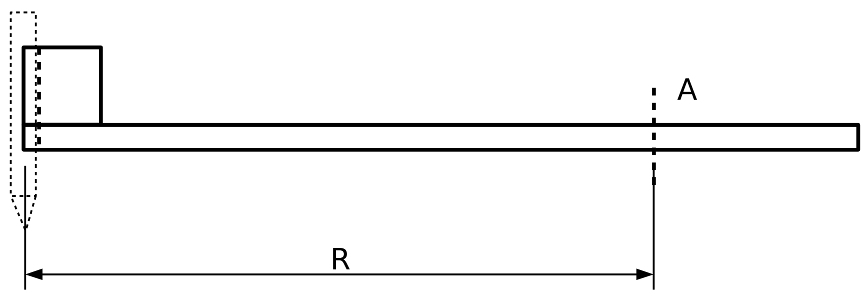
If the wood is a fine-grain hardwood, you can drill a pilot hole at A and tap the wood with a tapered pipe tap (½ NPT could be a suitable size). Then cut a slot with a bandsaw to the edge and thread in a pipe plug to expand the wood to a tight fit in the hole.

All of these methods are approximate for locating the center in an existing hole.

Makeshift arc scribing tool

A makeshift arc scribing tool can be made by driving a couple of nails through a board at the right distance, then using a hammer to bend them to the exact size needed. If you need to scribe metal, use hardened concrete nails and grind the tips to a sharp point. Hardened Torx wood screws also work well for a makeshift tool, as the point is already sharp.

Drill a 0.3 inch diameter through hole near the end of the board and cut into the hole with a thin saw. Then use a screw to clamp the hole onto a pencil to give you a compass to draw an arc. Here's another design:



A Torx-head wood screw is inserted at A to get the desired radius. A pencil is held in a vee cut into the end of the beam; the glued-on block gives more support for the pencil (if desired, hold the pencil in place with a rubber band). Size the vee so that a tape measure lets you quickly mark the desired arc radius R for the screw at A.

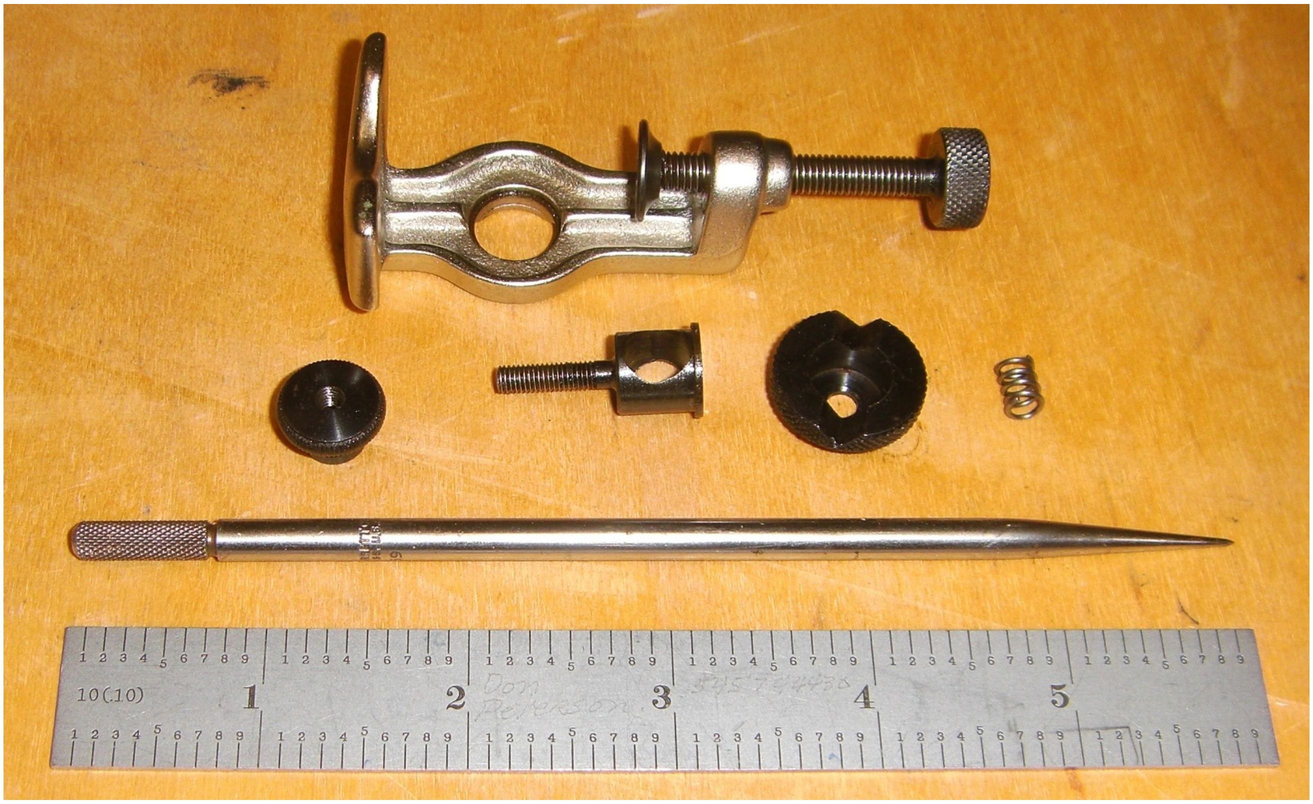
If you need adjustability, you can use two pieces of wood and clamp them together in the same fashion as an adjustable measuring stick. If you need to do this often enough, it's worth making or buying a set of trammels.

Starrett 59 trammels

In this section, I'll show the Starrett model 59 trammels, as I feel they are the best bang for the buck. You can buy cheaper trammels, but these Starrett tools will easily give a lifetime of service.

These are made from cast steel and will clamp to a board from ¾ to 1½ inches thick (this means you can clamp them to standard US "2 by" lumber). The 6 inch long points are about 0.214 inches in diameter. The points are eccentrically ground, which lets you rotate the point in the holder for fine adjustments.

I found these trammels on ebay for $32 delivered. They had a little rust on arrival, which was wirebrushed off and all parts were lubricated with Vaseline (the rule is 6 inches long and graduated in 0.1 inch units):



The clamp body is cast steel and nickel plated (the currently-manufactured part appears to be a black crackle paint finish, which is cheaper to produce). The clamp screw head and clamp pad are 0.55 inches in diameter and the screw/pad is 1.6 inches long, made from a 0.22 inch diameter by 28 tpi thread. The clamp adjustment means the tram can clamp to a beam of 3/4 to 1½ inches (actual dimensions are about 0.05 inch wider).

The depth of the bottom portion of the clamp is about 0.7 inches.

The parts in the second row are, from the left, the clamping thumb nut, the clamping screw, the clamping face, and a compression spring. The thread on the clamping screw is 0.15 inches in diameter with 40 tpi. The cross hole is elliptically-shaped with major and minor diameters of 0.36 and 0.33 inches, respectively (the part is made from ½ inch diameter bar stock). The knurled outside diameter of the clamping face is 0.82 inches and it's 0.34 inches thick. The point is 6 inches long, 0.214 inches in diameter; the knurl is 0.20 inches in diameter and ¾ inches long. The offset point allows the rod to be turned in the holder, giving a fine adjustment range of ⅛ inch.

The cross hole in the clamping screw allows clamping the point accessories from the Starrett 85 wing dividers, which are 0.289 inches in diameter.

Here are the trammels clamped to a piece of scrap wood marked in inches:

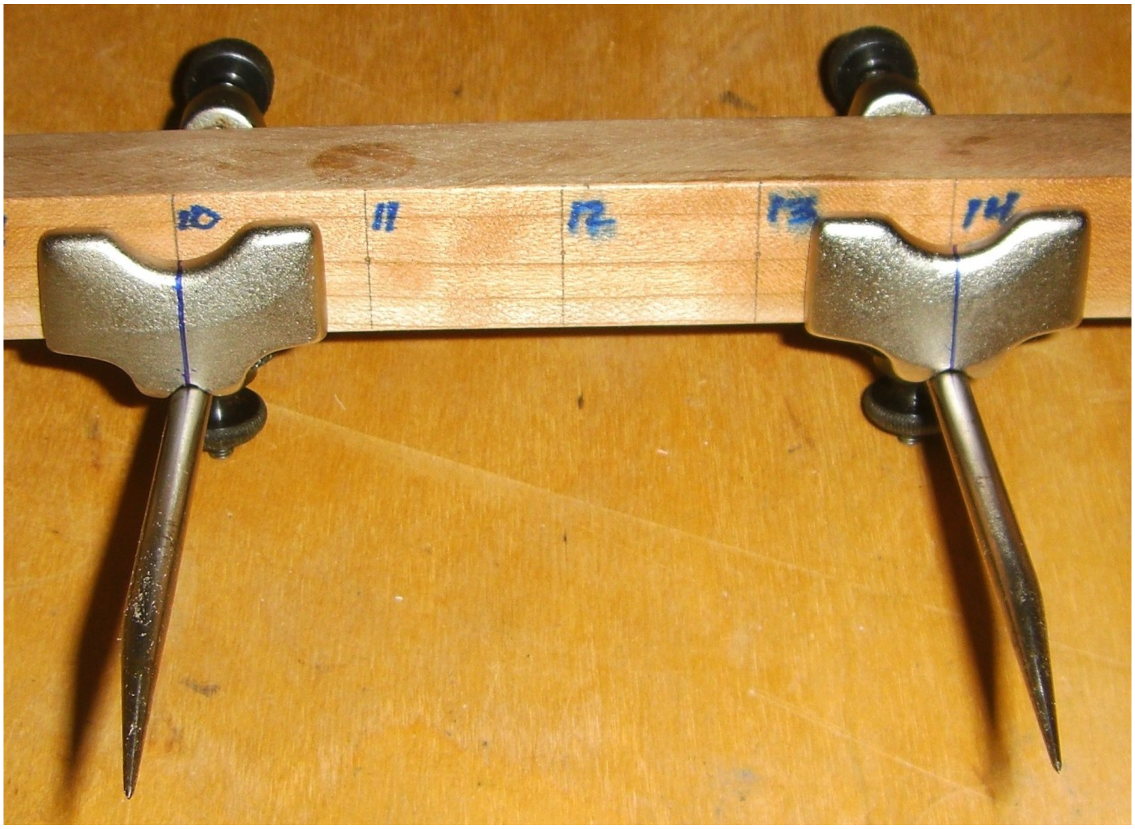
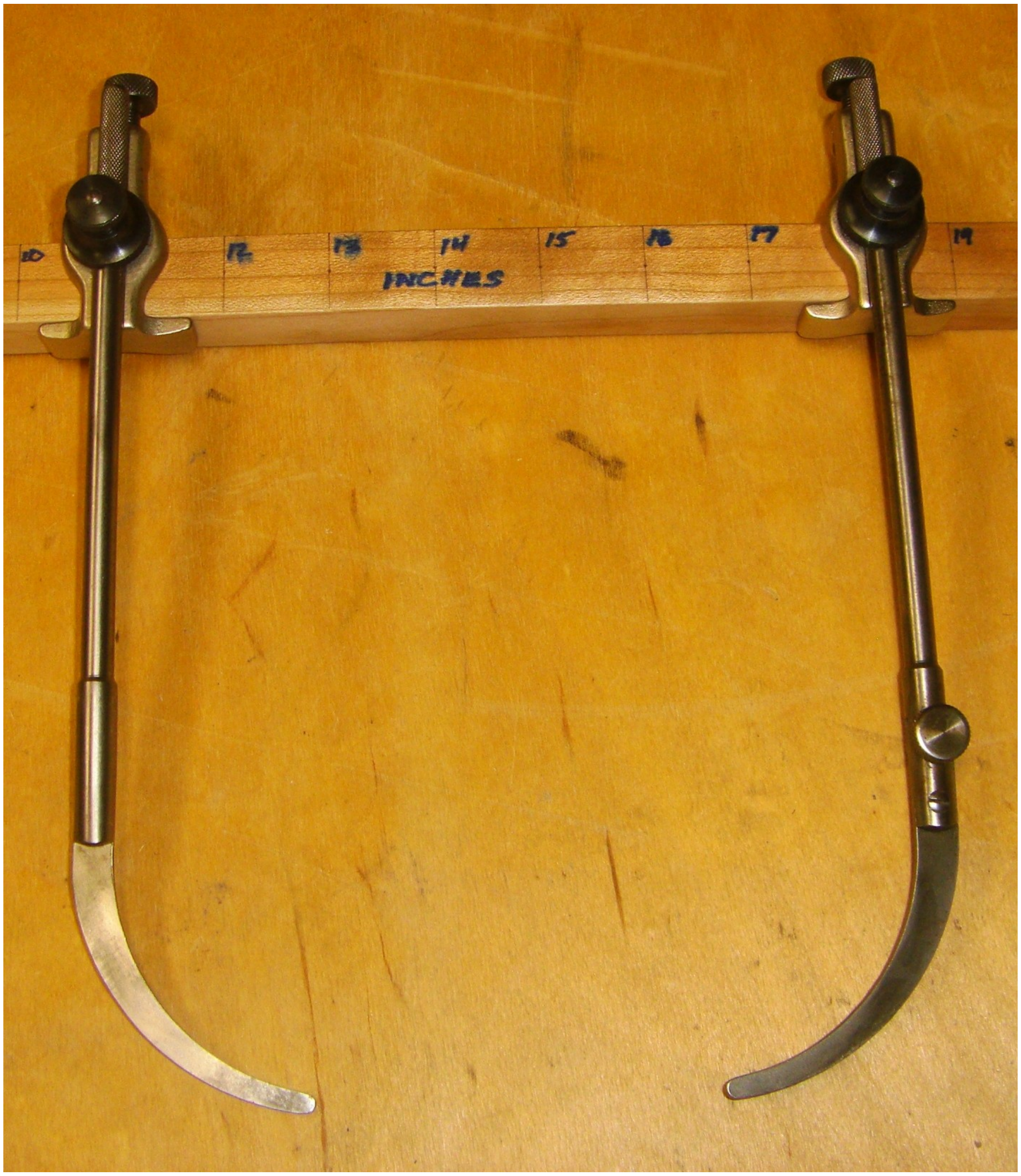


Figure 13

The blue Sharpie lines on the bottom allow indexing to the marks on the beam. You can see the eccentrically-ground points; loosening the clamp screw lets you rotate the points for a ⅛ inch fine adjustment range. It's simple and effective.

Here's the trammels with some outside gauging legs:



The knob on the right leg turns an eccentric which allows for a fine adjustment to size.

I wanted a smaller bent tip for making hermaphrodite calipers, so I made the following leg:

This was made in perhaps 10 minutes (including looking for the stock) from a bent piece of 3/16 inch diameter ground tool steel stock in the scrap bin by cutting off with a hacksaw and filing the tip. Interesting, one of the trams clamps it just fine, but the other one won't.

Make your own

You can search the web for e.g. "home made trammels" and you'll find a variety of ideas.

https://www.homemadetools.net/ might have some suitable ideas. A reasonably simple design for woodworking is https://www.woodgears.ca/measure/compass.html. Extruded aluminum tee track can be used to make some useful trammels.

Many machinists make their own trammels. Some articles on making trammels are: *Projects in Metal*, June 1991, page 12; *Home Shop Machinist*, March 1986, page 27; *More Proven Shop Tips*, Taunton Press, 1990, page 3.

If you have a metal lathe, I'd suggest copying Starrett's C251 trammel design, as it's quite rigid and useful for metalworking tasks. For other shop/DIY tasks, the Starrett 59 or a copy is a good design.

Transfer calipers

Starrett started selling transfer calipers in the late 1800's and still sells them as models 36 and 37 (Brown & Sharpe made transfer calipers too).

These are lock joint calipers that have an extra leg that can be locked at a particular setting; a nut can then be loosened, allowing the main leg to be moved to clear an obstruction (the calipers at F in Figure 1 show this transfer leg). The main leg can then be returned to the measured setting and a rule used to measure the actual dimension. The benefit is that the desired dimension is gotten directly without having to do a subtraction. This reduces the chance of an error, lowers or removes the loss of significance, and speeds things up.

Here are some 6 inch outside transfer calipers measuring the thickness of a boss on a pressure cooker lid:

I used some Starrett 6 inch model 36 outside transfer calipers and set the opening to be firmly in contact with the bottom of the pan, clearing the rim which was about an inch high. I locked the locking nut, then unscrewed the transfer leg lock nut, swung the leg out of the way, removed the calipers from the pan, and pushed the leg back into position on the locking transfer leg, tightening the transfer leg lock nut. This transfer leg lock nut goes into a recess which positions the leg back at the original locked position. A quick reading on a rule gave me the desired thickness.

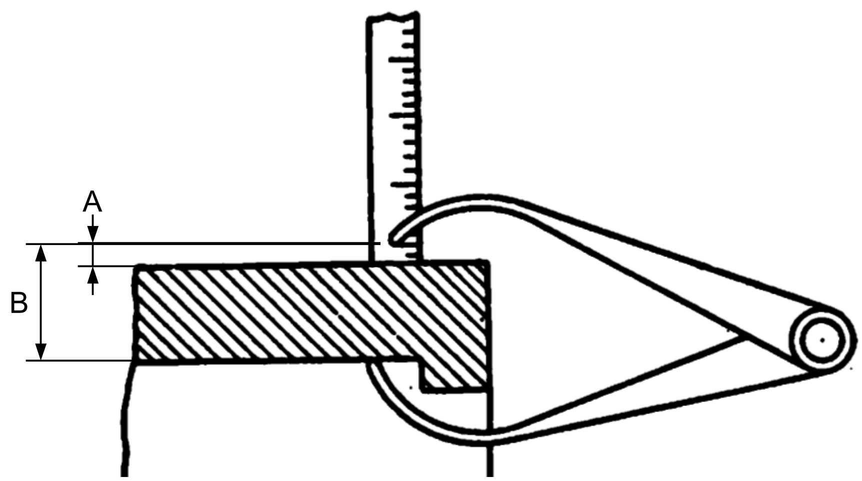
A busy fabricator who works on a variety of tasks will probably find transfer calipers speed his work.

I occasionally need an outside transfer measurement, but inside transfer measurements are rare for me (two examples are measuring an o-ring groove in a bore or measuring a tube's inside diameter while getting around a burr caused by a pipe cutter).

Woodworkers use a caliper (called double calipers) that can let you gauge a dimension without removing the calipers:

Figure 14

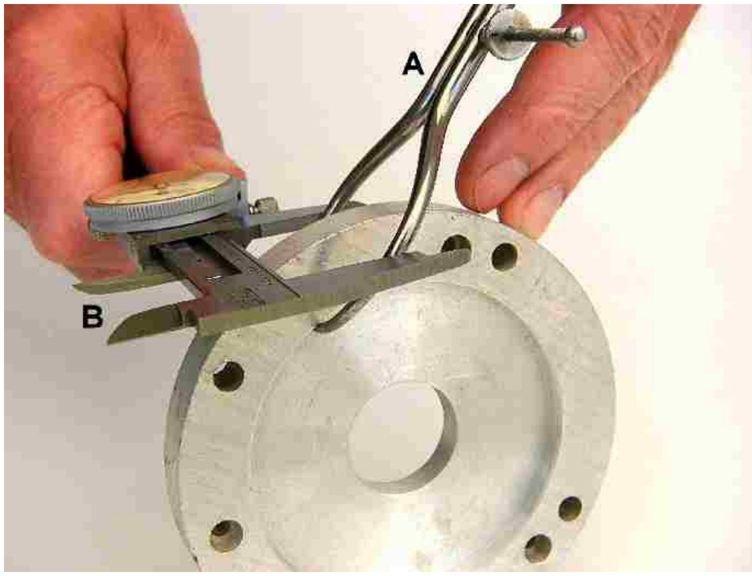
The method shown in the following picture can be used to measure a wall thickness over an obstruction with regular calipers:



The calipers are removed from the work without changing their setting, then the jaw opening B is measured and the offset A is subtracted. If you only need such types of measurements occasionally, it doesn't make sense to spend the money for transfer calipers, which are expensive. For small dimensions, there's a potential for loss of measurement significance if B is large. A height gauge on a surface plate can improve the measurement uncertainty in such cases.

Tip: When making a measurement this way, I like to use spring bow calipers and set the reading on the rule to a major division mark, such as 1 inch. Then when I measure the caliper opening, I just have to do an easy mental subtraction. This is faster than going to your toolbox to find the transfer calipers. Transfer calipers can be useful when you want to make a more fussy measurement.

Another method uses DEV calipers:



Outside calipers A are set to measure the desired dimension, then DEV calipers B are used to measure the outside dimension *D* over caliper A's legs. Calipers A are removed from the work and the DEV calipers are used to set A to the measured dimension *D* again. Now caliper A's gap can be measured with a rule, giving the gauged thickness.

Some people recommend measuring across the legs with calipers A closed, then subtracting this measurement from the first measurement. This is wrong unless you're certain both measurements are at the identical points on the legs (and they won't be, unless you e.g. weld tooling balls to the legs).

Drafting compass

You may be able to find an old drafting compass (you'll want it to have a screw adjust) at a garage sale or a pawn shop for a few dollars. These can make a light-duty tool for the shop or toolbox, but they won't stand up to heavy-duty shop use. The tips and leads are 2 mm diameter. By making some bent tips, you can make some impromptu inside and outside calipers, along with hermaphrodite calipers.

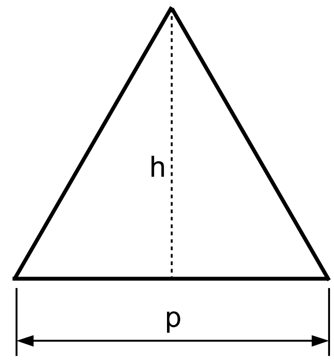
This is a good choice for someone who's on a tight budget.

A disadvantage of many such compasses are that their setting can be accidentally changed if you spring them or bump the adjustment screw. Some models have a locking feature to prevent this.

Thread calipers

A few generations ago, routine thread turning on the lathe was done with thread calipers and a rule because vee threads are often cut on the lathe. Duckbill thread calipers (see Figure 15 below) are useful for this because they can 1) gauge the major diameter of a thread and 2) measure to the root diameter of an external thread, telling you when the thread is cut to the correct depth.

After turning the major diameter to size, the thread is cut. The depth of cut for a 60° vee thread with pitch *p* is calculated from the geometry of equilateral triangles:



The double depth *DD* of a vee thread is 2h because each side of the thread has a height *h*. We have

$$\frac{p/2}{h} = \tan 30° = \frac{1}{\sqrt{3}} \quad \text{or} \quad DD = \sqrt{3}\,p \tag{2}$$

Given the major diameter *D* of the thread, you cut the thread until the thread calipers tell you the root diameter of the thread is $D - \sqrt{3}\,p$. Since full external vee threads are rarely made because their sharp exterior can cause cuts, a small constant like 0.01 or 0.02 inches can be subtracted off both the major diameter and the double depth to eliminate these sharp edges (and suitable adjustments for the needed pitch diameter, if appropriate).

Since the compound feed is typically set at 29° off the normal to the rotation axis, you'd multiply this by the reciprocal of the cosine of 29° to get how much you need to feed the compound in to cut the full thread. The cosine of 29° is nicely approximated by 7/8. You'd thus feed the compound in by

$$\frac{8}{7}\sqrt{3}\,p = 1.98\,p$$

This lets you cut most of the thread with the compound feed, then allows you to start checking near the end of cutting with the thread calipers. You can calculate this in your head by doubling the pitch *p*, then subtracting 1/100th of the resulting value. Example: For 16 threads per inch, the pitch is 0.0625; doubling this gives 0.125, so subtract 0.125/100 or 0.00125 to get 0.124.

Today, threading for interchangeable parts can involve more complicated tools and gauging (e.g., for National Form threads), such as thread wires or micrometers that can measure the pitch diameter of a thread. But a lot of routine one-off shop work can be done with vee threads, thread calipers, and a rule.

There are three types of thread calipers (see [*leo:7*] for drawings of these three types of calipers):

- ♦ The **duck-bill** style (Figure 15) allows you to measure major diameters over existing threads as well as measure root diameters because the tips are sharpened. Starrett made Yankee-style model 80 thread calipers and Fay-style model 76, either with solid or split nuts. The duck-bill style is also handy for general-purpose gauging of outside dimensions. For outside dimensions up to 1 inch, the duckbill calipers' setting can be quickly estimated with Starrett 169 taper gauges to nearly 0.001 inch levels; these tools can be used in places where you wouldn't want to use a micrometer (e.g., dirty or wet locations).
- ♦ **Scissor-bill thread calipers** can be made by filing a taper on the tips on some spring bow outside calipers so that they can measure down into the root of a thread. Starrett made the model 179 calipers in this style. They can gauge the root diameter of a thread with the plane of the calipers orthogonal to the thread axis, which can sometimes be more convenient than duck-bill calipers, which need to be oriented so that the plane of the calipers' legs contains the thread axis, meaning you'll have to pull the tailstock away from the work when working on the lathe. I also use them for measuring depths of o-ring grooves.
- ♦ Inside spring bow calipers can be filed to sharp points to let you measure the root diameter of

inside threads. Starrett made the model 184 calipers in this style.

Figure 15

The 5-inch duck-bill thread calipers in Figure 15 were made by Stevens. They appear ho-hum in the picture, but they are beautifully machined and precisely made. My grandfather probably acquired these around 1910 when he became a machinist and he showed me how to cut a thread on his lathe with them and a rule 50 years later.

You can use outside thread calipers to find tap drills for machine and wood screws. Set them to the root diameter of the thread, then use them to find a drill a bit larger than the setting. A convenience is that no measurement is needed. For wood screws, I usually use my DEV calipers to measure the root diameter directly, but I need to use thread calipers on small screws because the DEV caliper jaws are too wide to index on the thread's root.

Scissorbills

In the *Thread calipers* section, I mentioned the scissorbill style of thread calipers. While they can be useful for gauging the root diameter of a thread, they find other uses and can still double as general-purpose outside calipers.

An advantage is that they are easy to make from existing outside calipers. I had some 4 inch Yankee outside calipers and some easy filing of the tips at an angle gave the needed shape:

The calipers' leg was clamped in a parallel clamp which in turn was clamped in a vise (copper and aluminum soft jaws are in place). If you look closely, you can see the filing marks at the tip causing the tip taper. You'll also see filing swarf sticking to the caliper tip because there's a magnet in the aluminum soft jaw that's pressed against the parallel clamp.

Final shaping of the tip can be done on a sharpening stone. You want the tip to be sharp enough to get to the root of a vee thread.

These calipers will get into grooves that other tools can't. For example, I recently used them to gauge the hole diameter for a rubber grommet -- no other measuring tool I own could have done this because the slot in the grommet was so thin.

Frog leg calipers

In the first half of the 20th century, Starrett made the model 444 double calipers (the 8 inch model is shown with the legs positioned for inside diameter measurements):

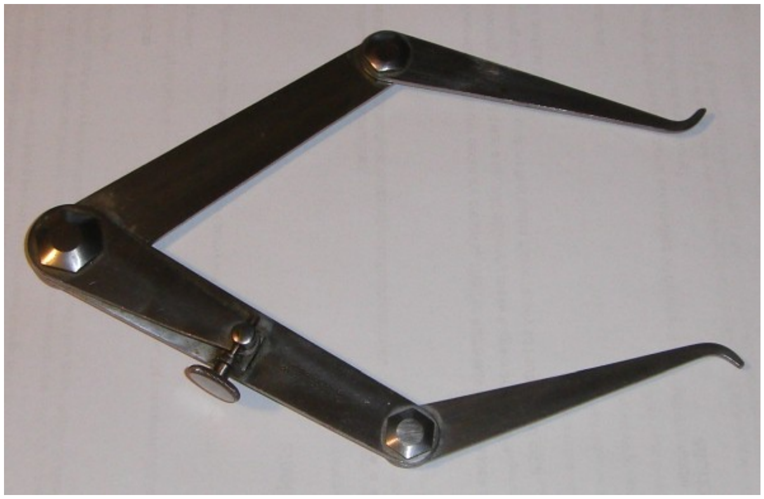


Figure 16

They look black because there was no reflected light, but they have Starrett's beautiful ground finish.

My wife calls these "frog leg calipers" and I think that's a pretty descriptive name. The basic idea wasn't new (see Bundy's 1865 patent US49337 for an interesting design). Starrett's contribution was the fine adjustment covered in Starrett's 1901 patent US672424. Unfortunately, they are rare and hard to find.

Here's a picture showing them in-hand:

The following picture shows the calipers in position to measure an inside diameter of 9 inches:

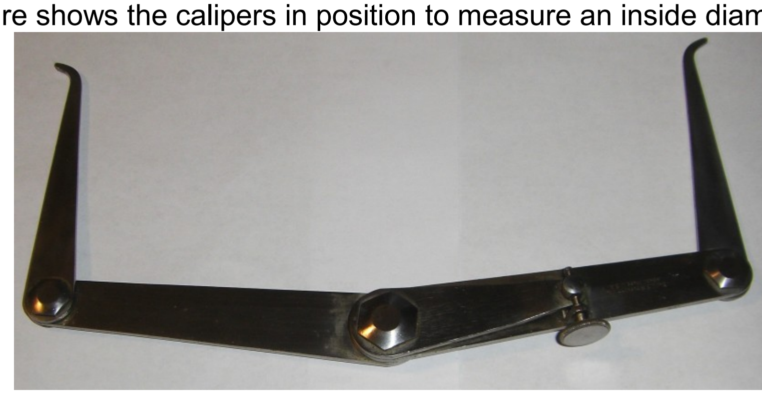


Figure 17

Inside measurements can be made from about 0.7 to 16 inches, although when the two big legs are in line, you lose fine adjust ability, so they are effectively plain firm-joint calipers. If you allow the legs to overlap, you can measure inside diameters to under 0.4 inches.

Double calipers have smaller legs that pivot on firm joints in addition to the large legs with the firm joint. This allows adjustment to either inside or outside measuring positions. These calipers can measure (in-plane) the diameter of round objects a bit larger than 8 inches (the adjusting screw may interfere around 8 inches and larger) and over 15 inch widths (out-of-plane measurements, e.g., of a board). No other type of calipers has this range (without removable parts, such as the Starrett 85F wing dividers) nor folds up so nicely for compact storage.

In the following picture, the legs are adjusted to make outside diameter measurements:

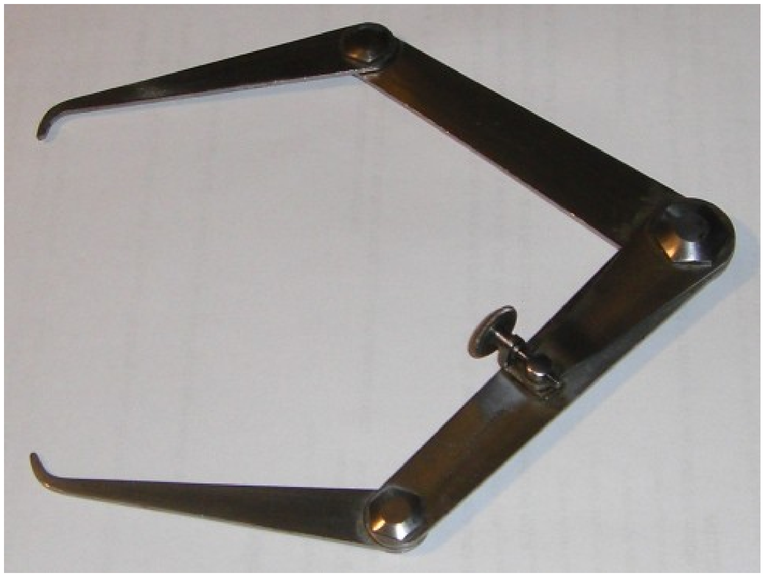


Figure 18

These calipers can be folded up and slipped into a pocket; the folded length is 5 inches and their mass is 161 g.

The model 444 double calipers have the following advantages over plain firm joint calipers:

- ♦ They fold up compactly for storage in a toolbox or tool apron pocket[2].
- ♦ The fine adjust works much better (and with more range) than on Starrett's lock joint design, giving better speed, range, and a slightly better feel.
- ♦ They can measure inside and outside dimensions (inside firm joint calipers can measure both inside and restricted outside dimensions, but these double calipers can measure over wider ranges).
- ♦ They have wide measuring ranges for their size, particularly for inside dimensions.
- ♦ They can measure in a bore while boring on the lathe by setting the small legs parallel; for suitable bore sizes, this may mean you don't have to withdraw the boring bar from the bore.

My favorite advantage of these calipers is that they fold up and slip into a pocket. With these

2 If these are in your carry-on luggage, the TSA will inspect you because they look like a folded knife on x-ray.

calipers, a machinist's rule, tape measure, and my Lufkin 6 inch hermaphrodite calipers, I can do a surprising amount of work in the shop and around the home.

Starrett model 44 calipers

Starrett also made the model 44 double calipers:

These let you measure inside and outside dimensions and make hermaphrodite calipers, odd leg calipers, and dividers. A few machine shop books from a century ago show and discuss the model 44 calipers.

I have not used the model 44 calipers, but I'd worry that I'd stick myself with the points accidentally during use. Still, they provide quite a bit of measurement and layout flexibility. These calipers appear on places like ebay regularly, so they're not rare, despite what sellers say.

Principles

I find it most useful to think of calipers as adjustable gaps or widths. They aren't really measuring tools, but rather comparison tools, enabling you to say things like "dimension 1 is greater than, less than, or equal to dimension 2". They are also transfer tools, letting you gauge a dimension on a workpiece, then e.g. transferring this dimension to a cutting tool without converting the setting to a numerical dimension.

The use of calipers appears simple, but you'll find they require more practice than DEV calipers to get accurate and consistent measurements. The plane of the calipers' legs needs to be oriented properly with respect to the diameter or linear dimension being gauged (a consequence of Abbe's Principle). For outside diameters, the plane of the legs needs to contain the diameter being measured. For inside diameters, the plane of the legs must be perpendicular to the plane of the circle being measured and, at the same time, contain the perpendicular to this plane through the center of the circle.

You'll read in many places that calipers should not be applied to moving work because the caliper tips can be drawn over the work and give an incorrect reading. I consider it a guideline and recommend you do some experimentation to find out when it's important. For example, in woodworking on the lathe, it's common to gauge rough sizes with calipers when the work is turning.

I've had occasions when turning smaller diameter metal parts that I couldn't tell the difference between the gauged dimension when the part was rotating versus when it was stationary. If someone argues that gauging moving work will wear the calipers out, they're your calipers, the wear will be small, and any long-term wear is quickly fixed with some simple welding and/or filing.

The caliper legs must touch the work lightly to avoid elastic deformation of either the calipers or the work. This is subjective and is a reason why calipers take more skill than DEV calipers. A corollary of this rule is that you must duplicate this feel when transferring the caliper setting to a machine or other calipers.

An experienced caliper user will continuously move the calipers and adjustment screw, "hunting" for the correct feel. For outside measurements, you'll hunt for the minimum diameter where the plane of the caliper legs is perpendicular to the work and the tips just brush the work. For inside measurements, you'll hunt for the maximum diameter while adjusting in two distinct planes (inside measurements are somewhat more difficult than outside measurements). You will need more practice than you think to master these tools.

Comparing sizes

Calipers are useful for comparing two dimensions. For example, if you have two shafts, you can quickly use some outside calipers to say whether the shaft diameters are equal or not and, if not, which one is smaller.

Note calipers cannot measure out-of-roundness (look up e.g. the Reuleaux triangle), but they are practical tools to get a feel for how much something might be out of round.

Calipers are often used in a decision context; for example:

- ♦ I set some calipers to a needed dimension and search for some stock that is larger or smaller than that dimension.
- ♦ Outside calipers can be used to gauge the thickness uniformity of material. Set them to the nominal size and slide them around to feel the thickness variations. They drag more where the material is thicker and you wobble them back and forth to visually see the gap for thinner material. It doesn't quantify the variations, but it's fast. Inside calipers can be used similarly to look for diameter variations or out-of-roundness of inside dimensions.

  The reason these old-style calipers are useful for gauging uniformity in this way is because they are slightly flexible. If you tried this same uniformity checking method with a micrometer, its rigidity would not allow it to be moved around the material as easily (i.e., they'd jam in place over a thicker section).
- ♦ I set some inside calipers to a bore diameter, transfer that measurement to some outside calipers, then turn a shaft to fit that bore. The converse of fitting a bore to a given shaft is also done. Surprisingly close work can be done only with calipers, but you'll speed things up quite a bit using micrometers, telescoping gauges, DEV calipers, etc. because you'll be able to quantify how much material to remove.
- ♦ I set some inside calipers to a gap, then go to my shop and cut a board to this dimension. I'll often do this by setting the table saw's fence distance from the blade directly from the calipers, removing the need to convert the calipers' setting to a dimension. Here, the decision is where to sent the saw's fence. Similarly, the calipers can be used to file an inside dimension to a desired size to fit a mating piece. Thus, calipers are adjustable ungraduated gauges.
- ♦ My son and I used a variety of calipers numerous times on his 1972 Chevy Nova project car. Some homemade 24 inch outside calipers measured the distance between the centerlines of the holes on the custom engine mounting blocks to ensure the engine would fit in the car. 24 inch Starrett model 39 inside lock-joint calipers were used to check chassis and body heights above the driveway to look for a bent frame or body (after establishing the driveway was reasonably flat). Some 8 and 10 inch model 39 calipers were used many times for checking hose diameters, wrench sizes, thicknesses, etc. Small inside and outside spring bow calipers

were used to compare exhaust system components and decide that some shims were needed to get good fits. Some 2 inch inside toolmaker's calipers were used to file an aluminum plate's oblong hole to get a close fit to the transmission's shaft to adapt to the 1972 shifting linkage to the GM LS1 transmission. Calipers G in Figure 1 let me get the size of the crankshaft pulley shaft (a ground surface the pulley is pressed onto) and bore a hole in a homemade tool that fit this shaft tightly for aligning the front main oil seal.

Converting to a measured dimension

When possible, avoid converting caliper settings to dimensions to reduce errors and speed work. When a numerical dimension is needed, the most commonly-used tools are rules and tape measures. A machinist's rule is the recommended tool for this conversion, as tape measures are only for approximate work. Younger eyes can work routinely to perhaps 0.01 inch (0.25 mm) resolutions and you can do better with a magnifier like a jeweler's loupe. With good lighting and a 5X to 10X loupe, you'll find you can work to 0.005 inch (0.1 mm) levels and even less, although this will require practice, care, and a rule with fine division lines.

With my older eyes, if I'm working in inches, I'll use a scale with 0.1 inch divisions and interpolate to the nearest 0.01 inches. This is easier for me than trying to read finer divisions and is adequate for most work. Though I can read calipers and a rule with a good light and a jeweler's loupe to better resolutions, I'll use DEV calipers or a micrometer if I need to do closer work.

An important detail is to have good lighting for reading where the caliper legs are on a scale. Poor lighting or shadows can lead to making reading mistakes.

For inside caliper measurements, DEV calipers or micrometers can be convenient for converting inside caliper settings to a dimension -- I prefer this to using the DEV calipers for direct measurement. The requirement is that you duplicate the feel of the two measurements. I use this method with 6 inch inside calipers and my dial calipers on the lathe for boring tasks and can work routinely to around 0.003 inch levels or a bit less.

For outside measurements, taper gauges such as the Starrett 269 can be used for quantifying dimensions up to 1 inch. With care and practice, you can measure outside dimensions to perhaps 0.002 inches or so. Duckbill thread calipers are particularly convenient for this (make sure the sharp edges of the tips are parallel).

When comparing two outside dimensions with calipers, you can use feeler gauges to quantify small differences. It works, but it's clumsy and a micrometer is the preferred tool.

See here for some handy gauges you can make on a lathe to use with calipers.

You'll find through experimentation and calculation that practical measurements with calipers can ignore cosine errors for dimensions above roughly 10 mm.

Buying used calipers

Since modern caliper designs have been manufactured for more than a century, there are many used calipers for sale. If you know what you're looking for and are willing to shop around, you can find good used calipers for reasonable prices. Garage sales and flea markets may be good sources. If the seller has the word "antique" in the name avoid them, as antique dealers usually add ridiculous markups. On-line sellers usually know nothing about calipers, describe them incorrectly, sometimes don't mention that the calipers are damaged, don't give the size, and many list them at inflated prices (you'll see many of the over-priced calipers remain unsold for months in a row on ebay).

It's a buyer-beware situation -- but there are so many available, you can afford to wait to find a good deal. On ebay, you can use a search term like "calipers -digital -dial" in the "Metalworking Inspection & Measurement" category and the "Joint Calipers & Dividers" subcategory. There are typically hundreds of listings.

I feel used calipers should cost from $5 to $50, depending on brand, type, size, and condition, with most in the $5-$25 range for brand-name calipers in good condition. If you want machinist-style calipers (and you do if you'll use them for shop work), beware that some sellers represent drafting tools as machinist calipers, but drafting tools won't stand up long to shop work. Buying calipers from overseas sellers may mean the shipping costs exceed the caliper cost.

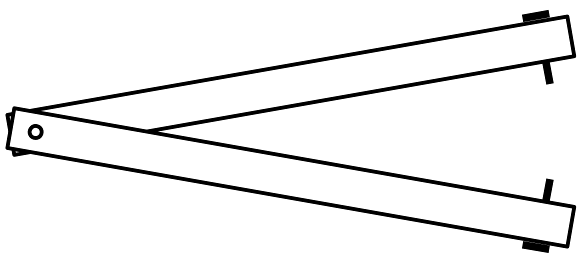
I won't buy from someone online who doesn't use proper lighting to take pictures. I've seen numerous cases where poor lighting was masking a defect, so buyer beware. I also won't buy from someone not intelligent enough to take an in-focus picture.

Used calipers are often sold as part of an estate sale, so may have been sitting in a toolbox rusting. Moderate surface rust is easily removed with a motorized wire wheel, so rust shouldn't scare you off as long as the price is reasonable. However, extensive rusting can lead to pitting and may ruin the functionality, so inspect the tool carefully before buying (or ensure you can return the tool and be willing to eat the shipping cost).

Make some calipers

Wooden firm joint calipers

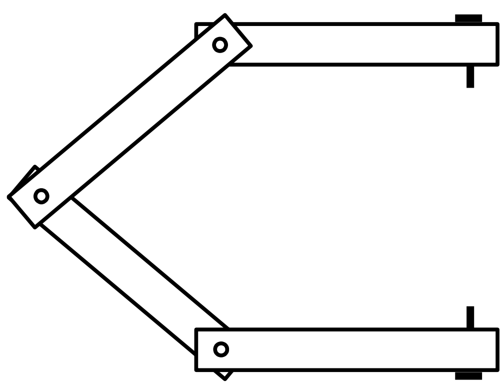
Firm joint calipers can be made with a 1/4 inch bolt, nylon lock nut, washers, and two nails. While simple to make from scrap materials, you'll find they can do useful work -- and they can double as a bevel for gauging angles too (round off the joined ends and countersink the nail heads). Here's the basic design :



Drive a nail through a tight hole and file the tip round (you may want to angle the nails slightly so that they naturally meet at their tips. Join the sticks at the other end with the bolt so they pivot; adjust the nylon lock nut to get the desired friction.

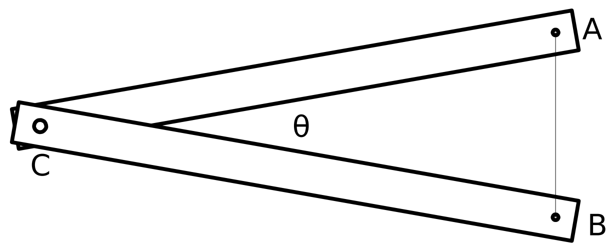
Note they can measure inside and restricted outside dimensions.

For more measuring flexibility, make them double calipers with two more firm joints:



Note the layout to put the measuring pins in the same plane.

If distances AC and BC are identical and equal to *r*, you can measure the chord AB and calculate the angle θ:

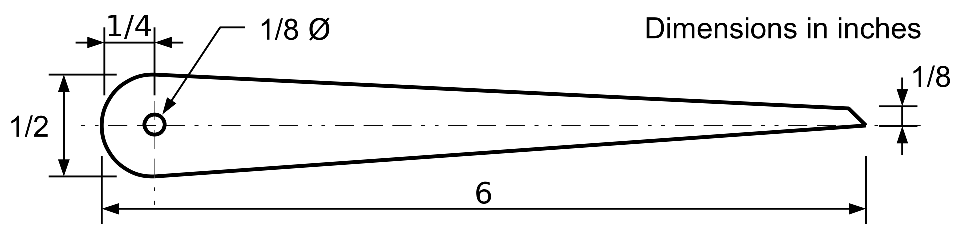


The formula is $\theta = \sin^{-1}\frac{\overline{AB}}{2\,r}$. Calibrate them with a square (see here for more details).

Metal firm joint calipers

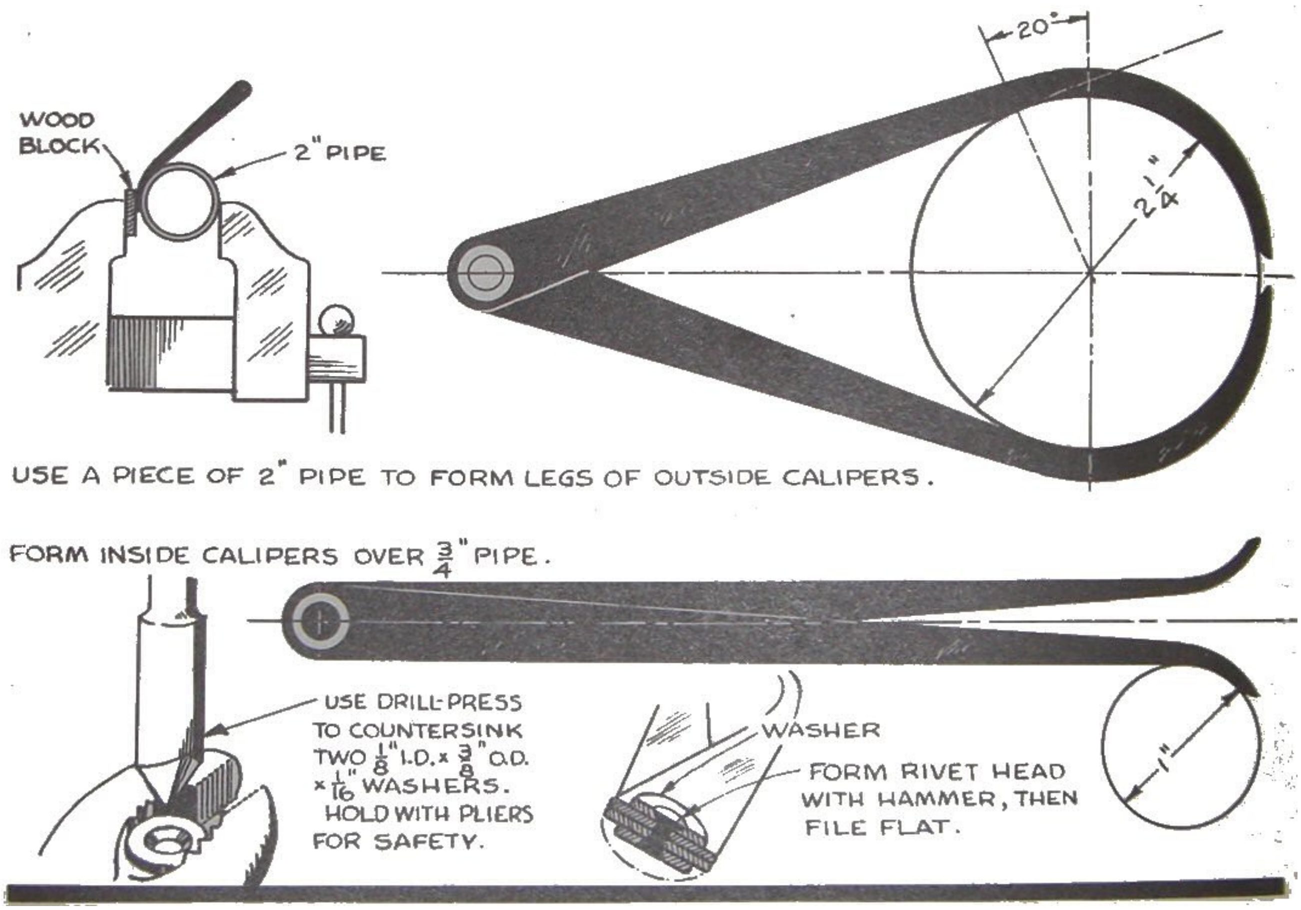
Firm joint calipers can be made with elementary tools: bench, vise, hack saw, files, drill, and hammer [*fos*]. The book recommended 0.048 inch thick steel, but anything close should be fine. Sheet aluminum can be used and makes for a lighter caliper, although easier to bend.

Here's the drawing for the legs (scale as needed to a different size)



A nice feature of aluminum sheet is that it can quickly be cut out on a wood-cutting band saw.

Here's the remainder of the fabrication (taken from the book):



Cut the legs out. Stack them and drill the ⅛ inch diameter hole for a rivet. Put a ⅛ inch rivet in the hole for alignment and clamp the tips together. Hold the legs in a vise (use wood to protect the metal) and file the legs to shape.

To make the outside legs, flip one of the legs, then bend them around a piece of 2 inch pipe. Use a plastic-tip hammer or a piece of wood to protect the metal. Flatten the legs after bending. For inside legs, form them over a piece of 3/4 inch pipe or use a suitable socket from a socket set.

Flip the leg that was flipped and join the legs together by riveting a ⅛ steel rivet into the countersunk holes of the rivets. If you used aluminum, you'll probably want to use a pure soft aluminum rivet. Or, see the next section on how to make a copper rivet from copper wire.

To form the rivets, use a suitable hammer and back the rivet up on a heavy chunk of metal. An anvil is the ideal tool for this, but a suitable chunk of bar stock or heavy steel tubing works too. I use a piece of 4 inch square hot rolled steel about 10 inches long for this, as it weighs about 45 pounds.

Be careful when upsetting the rivet -- if you deform the head too much, the caliper's joint will be too tight. Once the joint friction is what you want (I like to lubricate it with silicone oil), you stop hammering and file the rivet flush on both sides. You may want to delay the final filing for a while until you're sure you got the right joint firmness.

File the tips to a suitable shape (see Figure 2).

Making a copper rivet

To make a copper rivet from solid 8 AWG copper wire, use the following fixture. Clamp two pieces of flat steel together with a card stock shim between them. Then drill a #30 hole through the two blocks with the hole centerline along the center of the card. The picture shows a countersink, used to make a flat head rivet:

Put the copper wire in between the blocks and clamp them in the vise. This will hold the wire, allowing you to pound on the top exposed metal to deform it into the countersink.

Uses

Here's a selection of things that can be done with calipers, trammels, and dividers.

- ♦ Fit a board to an uneven wall using hermaphrodite calipers. Look up log scribing on the web for similar techniques. Use a pencil in a washer in a pinch.
- ♦ Tune up your table saw (adjust the slots parallel to the blade and the fence parallel to the slots). You can easily do this with 8 inch inside calipers rather than buying expensive tools with dial indicators.
- ♦ Chip a square hole. Lay the hole out on the stock, then drill out most of the material with a drill. Use a diamond-point chisel to remove the remaining material. A narrow pillar file can finish the job. Small inside spring bow calipers work nicely for gauging the size.
- ♦ Reuse glued PVC fittings. Chuck the fitting on a lathe, set the compound so that you bore a 2° included angle taper, and bore out the glued fitting. I've been able to reuse an $80 PVC filter for my irrigation pump twice in the last few decades after rebuilding the plumbing.
- ♦ Scribe a pipe penetration: I needed to cut a hole in some 12 inch diameter PVC irrigation pipe for a piece of 3.5 inch diameter pipe. I used wing dividers with a pencil set up as hermaphrodite calipers to do this to scribe the large pipes contour on the small pipe. This let the small pipe connect to the large pipe with no obstruction of flow (both pipes were encased in concrete to hold them together and make a seal).
- ♦ I made an 8 inch diameter wooden rotary table and used dividers to graduate the angles. A vernier allows setting the angle in 1° increments.
- ♦ I had a hammer with a broken wooden handle. I used small 2 inch inside calipers to measure the tapered hole in the hammer head and constructed a new hammer handle from wood. Once the handle was approximately cut to rectangular size on the band saw, about 10 minutes of shaping with a shoe rasp gave a tight fit after the wedge was driven in.
- ♦ Much lathe work can be done with calipers to e.g. fit a shaft to a given hole or vice versa. DEV calipers and micrometers speed the task up by telling you how much to take off, but if you're not in a hurry, old-style calipers and a rule can do a lot of work (machinists from a century or more ago knew this well).
- ♦ Duck bill thread calipers and Starrett's model 269 taper gauges can allow you to measure

outside diameters from 0.1 to 1 inch to nearly 0.001 resolution. Cheaper taper gauges (e.g. for welders) can be found on the web. These are robust tools that can be used in adverse conditions where you wouldn't want to take DEV calipers.

- ♦ Out-of-roundness can be qualitatively explored with calipers. Since there are planar curves of constant width that are not round (e.g., a Reuleaux triangle), it's not a fool-proof technique -- but it's quite practical in the shop. The same holds true for exploring thickness variations with outside calipers, as they won't jam on a high spot like a micrometer will.
- ♦ Make a tight-fitting board for a hole by measuring the width with calipers and using them to set the fence to blade tooth distance. This transfer method doesn't require converting the caliper setting to a numerical dimension, reducing the chance of an error.
- ♦ Close work with old-style calipers can be done with rattle measurements, both in the roll and pitch directions (imagine an airplane flying down a cylinder). In the early 1900's, workers routinely machined shrink fits on railroad axles and wheels using the method. The 1945 edition of [*amh*] discusses the method on page 721; it's on page 328 of the 1914 edition along with a discussion of the pitch rattle measurement on page 329 and roll rattle on page 330.

Caliper maintenance

Used calipers can be cleaned and lubricated to keep them operating well. Simple problems can often be fixed. The calipers' joint, tips, and smooth operation should be your first priorities. Calipers that are kept clean, lubricated, and are not abused should last indefinitely.

All the used calipers I have acquired over the years have been dirty/rusty and in need of cleaning and lubrication. The easiest calipers to service are the spring bow types. Older firm and lock joint calipers always need disassembly, cleaning, and lubrication. Lock joint calipers require more work to disassemble and, perhaps surprisingly, firm joint calipers can be the most challenging to disassemble, especially when the grease has hardened and there's rust in the joint.

Disassembly

Take photos or make sketches while you're taking things apart so you can put things back together correctly. Because they look simple, you may think this step is unnecessary, but experience will teach you otherwise. At the least, the photos/sketches will help you get things assembled faster.

The threaded balls on lock joint and spring bow calipers can be removed using the non-serrated portion of the jaws of needlenose pliers.

Spring bow calipers: Remove the threaded ball and thumb nut. Some calipers can be disassembled by hand at this point; others need to have the bow expanded with needlenose pliers to get the spring off (large and heavy-duty calipers might need a special tool made to do this). Once the calipers are in pieces, they can be cleaned, lubricated, and reassembled. The threaded rod is held to the leg by a pin, but there's no real need to disassemble it.

Firm joint calipers: These usually have a hex nut or screw that is used to adjust joint tension. Remove this nut/screw and you should be able to take the calipers apart. There are usually one or two thin washers (brass or a fiber-bearing plastic) between the legs and leg parts. Fits are very close on commercial calipers to minimize play, so take things apart and reassemble carefully. Apply a few drops of silicone oil to the joint and let it soak before disassembling (a lubricant may change the friction, but the adjustment can nullify the change)..

I've used two methods to get firm joint calipers apart:

1. (This is the preferred method) Unscrew the screw a mm or two and set the opposite leg on a flat surface with the nut overhanging the edge. Then tapping with a brass or plastic hammer can be used to drive the pieces apart. I prefer this method because the forces are axial and the fine threads can take them (I've never damaged any calipers this way).
2. I use a chip carving knife and a brass hammer to gently try to pry the legs and nut apart. It is

not difficult to unknowingly damage one of the washers when doing this, so go slowly and inspect things closely with a loupe under a bright light. Pry gently at numerous points around the circumference; don't try to do it all at one point.

If you decide you don't want to take the firm joint calipers apart, one thing to try is to immerse the whole joint in some oil to rejuvenate the lubrication. This doesn't deal with any existing rust, but it may slow future rust down. The washers in the joint won't be damaged by oil nor will the joint's operation.

Lock joint calipers: I'm aware of only two designs: the CoastBilt style and Starrett's 1895 design. I've not worked on CoastBilt calipers, but the pictures I've seen suggest they should be easy to take apart. Starrett's design is covered in *Appendix: Starrett lock joint calipers*.

Cleaning

Quick clean/lube: You can remove greasy dirt by using a carburetor spray without disassembling the calipers. A wire brush can help get the gunk out of the threads of the adjustment and the thumb nut. Follow with Vaseline lubrication and use a hair dryer to melt the Vaseline so it wicks into joints and crevices (silicone oil also works). This can work well enough on spring bow calipers that you won't need to disassemble them. Try this method first, as it may be sufficient.

Old calipers may have a patina and scratches/dings from long use that could be valued by antique collectors. Consider this before cleaning some old calipers, particularly ones from the 1800's.

Most used calipers I've purchased used have had rust on them. A light coating of rust is quickly removed with a worn wire wheel or steel wool, although rust stains will be harder. Be careful with large calipers and a motorized wire wheel because if you feed it to the wheel in the wrong way, the calipers can be grabbed and bent in the blink of an eye (this is especially true for firm and lock joint calipers). Aggressive motorized wire brushing can also damage a nicely ground finish.

If the rust has caused pitting, there's no easy way to fix this. Fortunately, pitting usually only affects the appearance, not the function. Badly rusted calipers may not function properly and should be disposed of, as they're likely not worth fixing.

I purchased two pairs of Starrett lock joint calipers (12 inch inside and outside) and the seller had used electrolytic rust removal on them. It worked, but it ruined the beautiful finish of the calipers. It didn't affect functionality or damage the precision-turned frustums necessary for smooth operation.

All the used firm joint and lock joint calipers I've taken apart had rusted joints in need of cleaning and lubrication. These can be cleaned by rubbing them on 400 grit sandpaper on a flat surface or on a fine sharpening stone (used calipers often show this work has been done before). Another tool is a narrow Cratex rubberized abrasive in the shape of a narrow cylinder with a gradual tapered (tree-type) point. This tool can hand-scrub the rust off without damaging the nice finish on the legs (but the scratch pattern will be altered).

You can use sandpaper to restore the finish of calipers. Straight portions of legs aren't too hard to do with the sandpaper against a block of wood, but getting around pins, studs, etc. will be problematic and the scratch pattern probably won't lay consistently like new calipers. You'll want to use 400 grit sandpaper or finer.

The hex nuts on Starrett and Lufkin firm joint calipers aren't very tall. Use a socket to turn them and hold the calipers in a vise so you can press firmly on the socket to seat it; otherwise, the socket can slip and ding up the hex. Turn the socket's chamfer off on a lathe if you can.

After cleaning, I apply Vaseline as a lubricant and rust protectant, so I have a thin film on my fingers which I wipe over the surface of the calipers. This does a good job of rust protection, is cheap, and is easy to renew periodically. An alternative lubricant for the joint is a molybdenum disulfide spray. This sprays on wet, but the solvent dries and leaves a dry lubricant. For firm joint calipers, I like to use silicone oil.

For calipers that will get used outside, I spray them with an acrylic spray to protect them from rust. You can make a suitable solution by dissolving Plexiglas chips in acetone, then brushing it on. Or just buy a can of clear acrylic spray (I like a matte finish).

Fixing

- ♦ Bent tips
  - ♦ Probably made from low carbon steel, so can be bent back to shape. You may want to anneal dividers' tips to avoid breaking them before bending.
  - ♦ Grab in vise with brass soft-jaws.
  - ♦ Inside firm/lock joint calipers have tips bent out-of-plane so they will touch when closed.
- ♦ Shaping and sharpening the tips
  - ♦ Dividers: hold the leg wrapped in cardboard so you can turn it while grinding. Do final sharpening on a stone by hand. You want them as sharp and even as possible.
  - ♦ To get a smooth feel, file to shape and polish with sandpaper.
  - ♦ Special tips can be filed as needed.
  - ♦ If you need a special tip, it's not difficult to weld on some new material and shape it as needed. For example, you could turn some outside calipers into duckbill thread calipers this way. See here for an example of making a new tip by welding.
- ♦ Ball: I make replacement balls from aluminum, as they are easy to shape with a file on a lathe. Pick a tap drill to give a 50% thread or a bit larger, then just force it onto the threaded rod enough to jam into place. This won't hurt the steel threads, but lets you take it off and replace it later if needed. You can make a proper part from steel if you have a bottoming tap, but calipers' threads are usually some oddball size.
- ♦ Pivot: straightforward lathe work; it will likely be hardened and tempered.
- ♦ Spring bow: can be made from spring steel and given a spring temper, but it's probably easier (and less time) to just buy another pair of calipers.
- ♦ Adjustment nut on spring bow calipers
  - ♦ Knurling wears off on old calipers. Use a fine needle file to file the knurled impressions to make the nut sharp again. This is finicky and slow work, but can restore the nut to useful functionality. The nuts on old calipers can have their knurling completely worn off.
  - ♦ I'll sometimes make a new nut from aluminum and give it an aggressive knurl.
  - ♦ You can make new nuts, but the thread may be an oddball size you won't have a tap for. Even if it's a common size, the pitch diameter may be different than modern threads and none of the taps you have will work well.
- ♦ Starrett 85 wing dividers, 92 carpenter's dividers
  - ♦ Lock nuts:
    - ♦ It's common to be missing one of the lock nuts. They are an 8-32 thread.
    - ♦ I make the outside fine adjust nut and the wing clamp nut from 3/4 inch diameter stock (aluminum works fine) and make them 1/4 inch thick and 0.4 inches thick, respectively. I give them an aggressive knurl to make them easier to turn, as I've never liked Starrett's rope knurling.
    - ♦ The inside fine adjust nut is made from 5/8 inch diameter stock and 0.2 inches thick.
  - ♦ A split die can be handy to clean out the threads, as they are often filthy and dinged up.
  - ♦ A fine adjust spring can be made from 0.036 inch diameter wire, 3/4 inch long, and with a 0.196 inch inside diameter. The pitch is 0.1 inches and there are nominally 7 or so turns. Flatten the ends by bending and grinding.
  - ♦ New divider points or accessories can be made from 5/16" diameter bar stock; you need to turn it to 0.295-0.300 inch diameter to fit the clamping rings. Don't bore the rings out as you won't be able to hold a standard pencil.
  - ♦ Make a new clamp ring (8-32 thread) with a 0.47 inch diameter hole and you can clamp a Sharpie fine point marker.

Adjustment nuts

On spring bow calipers and lock joint calipers, you'll find that the knurling on the adjustment nuts is important. You don't want the knurling to be so sharp that it abrades your fingers, but it should be aggressive enough to give you a good grip on the nut. Essentially all of the calipers I own have a knurl that I don't consider aggressive enough (except for the Starrett calipers made in the 1960's or later). Also, the nut diameters tend to be too small for my tastes.

Making a new solid nut with a lathe should be an easy fix. However, the screw threads are often an oddball size, especially on old calipers. Making a new split nut as shown in the drawing on split nuts would require making special tooling.

I thought it would be easy to make a new solid nut for the Athol calipers show at G in Figure 1. I had measured the thread OD with DEV calipers and it was 0.187 inches and the threads per inch was 32, so it was a 10-32 thread. After making a new nut and tapping it, it wouldn't thread onto the caliper's threads. The thread's pitch diameter is larger than that produced by a standard tap[3]. This could be fixed if I had a split die to resize the threads, but I don't -- and this isn't a high-priority task.

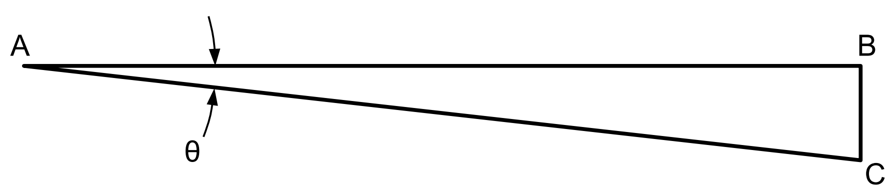
Knurl wear: On old calipers, the knurl on the nut gets worn down and becomes less effective, making the calipers harder to operate. Starrett used a bead ("rope") knurl on many of their calipers and though it looks nice, it wears more quickly, making the nut harder to turn. I've seen century-old calipers with nuts that had all of the knurling worn off. Caliper nuts with poor or no knurling can be hard to use, especially with greasy fingers.

One way to fix a worn flat knurl on solid or split nuts is to get a machinist's triangular file (not a saw-sharpening triangular file) and carefully file the knurl's grooves. This is finicky work for a fine knurl and will require a magnifier, good lighting, a small fine needle file, and a way to hold the nut steady while you file. It takes patience -- but it works well.

Appendix: Technical details

Cosine errors

A cosine error is where a small angle offset causes you to measure something different than you thought you were measuring. Example: pull a tape measure across a table to measure the width, then move the tape slightly so that it is not measuring the actual width, but a slightly slanted width. The measured slant width will be proportional to the reciprocal of the cosine (i.e., the secant) of the small angle. In the figure, you think you're measuring AB, but in actuality you're measuring AC.



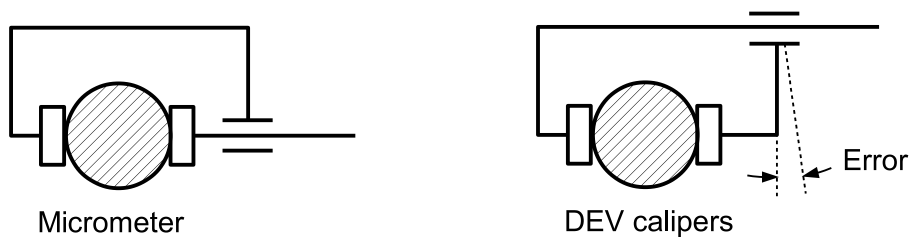
The relationship is $AB = AC \cos\theta$ and θ is usually an angle near zero. Since the cosine of a zero angle is unity, you can see that the cosine or secant of small angles will be numbers close to unity.

Abbe's principle

Abbe's principle is that a measuring scale should be coincident with the thing being measured.

Micrometers and DEV calipers give good examples of devices that do and do not, respectively, conform to Abbe's principle. [*ocw*] advises using stick figures and arrows to schematically illustrate things:

3 I've run into this a number of times on threads a century old, which may mean slightly different standards were in use then.



Conforms to
Abbe's principle

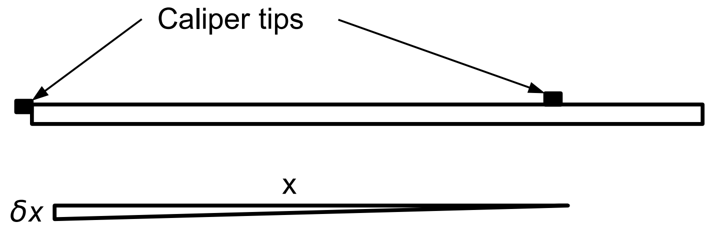
Does not conform
to Abbe's principle

The stick figure for DEV calipers shows that you can make a measurement error if you clamp the jaws too aggressively onto the part being measured because the fit of the jaws over the slide can't be without clearance.

In contrast, a micrometer more nearly conforms to Abbe's principle and it's easier to get more precise measurements. Of course, the micrometer can be made to not conform to Abbe's principle by screwing down the thimble hard enough to spring the micrometer's frame, causing an error.

Old-style inside caliper measurements essentially conform to Abbe's principle when used with a rule if you can position your eyes to eliminate parallax errors and ensure one of the tips is aligned properly with the end of the rule.

Here's a sketch of the positioning of some outside spring-bow caliper tips on a machinist's scale:



Let's calculate the magnitude of the cosine error. Suppose the measured value on the scale is *x* and the left tip is δx below the plane of the top scale, as shown in the lower triangle illustrating the geometry. The actual caliper opening distance *X* is the hypotenuse of the right triangle:

$$X = \sqrt{x^2 + (\delta x)^2} = x\sqrt{1 + \left(\frac{\delta x}{x}\right)^2}$$

Since the second term will be small, we get

$$X \approx x\left[1 + \frac{1}{2}\left(\frac{\delta x}{x}\right)^2\right]$$

As an example, suppose the measured distance *x* is 50 mm and the tip offset δx is 0.5 mm. Then the correction factor X/x is 1.0005 or 50 parts per million, which is ignorable in measurements with rules. If *x* was 5 mm, the correction factor is 1 part out of 200, still a pretty small correction. For a 0.5 mm tip offset, the correction is 0.1% when the length is 10 mm.

> **Conclusion**: cosine-type errors are negligible for the usual measurements with calipers and a machinist's rule.

However, parallax errors may not be negligible. Parallax errors are caused by a violation of Abbe's principle where the end of the object is not in contact with the scale -- if you move your head, the scale's reading changes.

Errors

It is humbling to realize how many errors can be made when trying to make a "simple" measurement:

- ♦ Cosine errors
- ♦ Parallax errors
- ♦ Accidentally changing caliper setting
- ♦ Springing the calipers or work (too much measuring force)
- ♦ Out of plane (another type of cosine error)
- ♦ Wrong number from scale
  - ♦ Off by one
  - ♦ Poor lighting
  - ♦ Bias
  - ♦ Didn't put on your glasses
  - ♦ Poor scale design or scale error
- ♦ Arithmetic error

Violation of Abbe's principle also leads to parallax error, caused by the caliper tip and scale not being coincident; if you move your head, the measured reading changes. The goal is to keep your eye on a perpendicular to the rule surface that passes through the caliper's tip.

I've learned that I can reduce arithmetic errors if I deal with measurements in integers. For many practical tasks around the home and shop, this can be done if you use mm for your distance units and try to design to integer values.

Here are some ideas for defenses against such errors.

- ♦ Don't convert to a dimension -- use a transfer measurement instead.
- ♦ Double check before cutting (measure twice, cut once). Use a different measurement method than the first measurement.
- ♦ Remeasure in different units.
- ♦ Have someone check your measurements.
- ♦ Confirm with a different measuring tool or method.

You'll find you're a creature of habit and will often make the same error if you choose the same measurement method. Probably the best defense is to ask another person to make the measurement, but if another person isn't available, the most practical check is with a different measuring tool. In particular, for me, an off-by-one error is easy to make when I get distracted by trying to get the last few digits of the measurement and make a mistake on the first digit.

With my older eyes, it's easy to make a 1 cm or 1 inch error in cutting some work to length, especially in DIY projects that have poor lighting. I use my inside lock joint calipers or adjustable measuring sticks as a "second opinion" in such cases by setting the calipers to the required length. After marking the cut, the overall length is verified with the calipers before making the cut. It's just as easy to use a piece of scrap and mark the needed length on the scrap (a type of story board), then use this mark to check the layout on the work before cutting.

Another defense against these types of errors is to make simple wooden "rules" from handy scrap. I make these with a pencil and tape measure so that they have relatively large distances between the graduations, such as 1 cm or 1 inch. Such tools are used to verify the first significant figure of a measurement. You may think such things are unnecessary, but an expensive and embarrassing error can make you a believer.

Appendix: Starrett lock joint calipers

An 1895 patent [*p1895*] by Starrett and Fay resulted in Starrett's lock joint caliper design, which has been in production since then. If you acquire a used pair of calipers using this type of joint, it is virtually certain they will need disassembly, cleaning, and lubrication. I have serviced a few tens of these used pairs of calipers with this joint and every one of them had significant rust and lack of lubrication. They all worked well after cleaning and lubrication.

This section discusses how to service these calipers. These techniques cover the following Starrett caliper model numbers 42, 36, 37, 38, and 39. Transfer calipers (36 and 37) will have one more leg than the other models, but the construction and operation are similar to the other models.

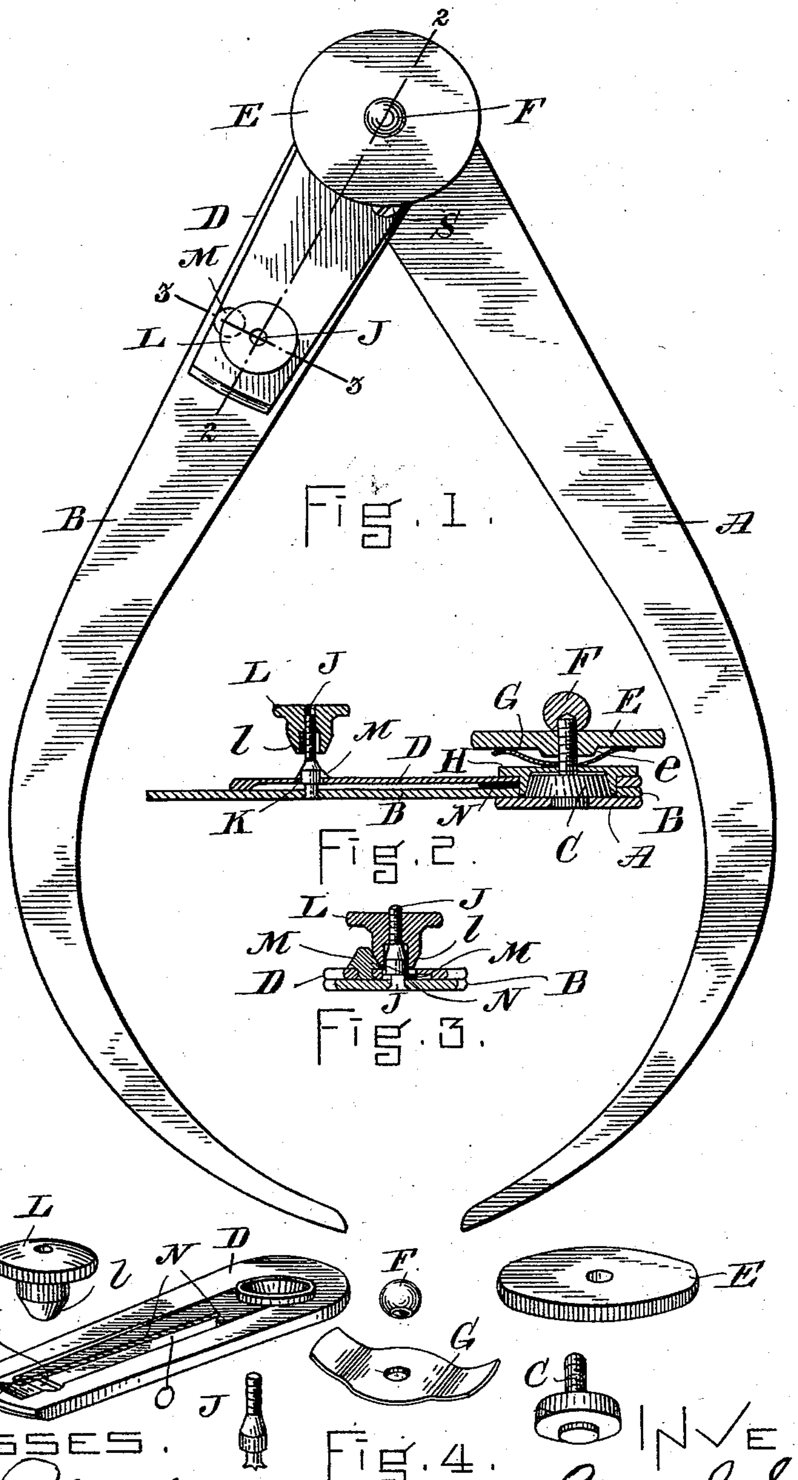
The 1895 patent drawing shows the construction:

(No Model.)

L. S. STARRETT & C. P. FAY.

CALIPERS AND DIVIDERS.

No. 539,759. Patented May 21, 1895.



WITNESSES.

G. Henry Marsh.

Samuel P. Thrasher.

INVENTORS.

Larry S. Starrett,

Charles P. Fay,

by N. A. Spencer, Atty.

Figure 19

It's easy to test if these calipers need service. Tighten the lock nut E and loosen the fine adjust thumb screw L. Push the legs A and B together. If leg D does not move relative to leg B, then the calipers need service.

To disassemble:

- ♦ Apply a drop of penetrating oil to screw S to help ensure it can be removed. I've seen them rusted, but I've not had one be difficult to remove. Make sure you have a screwdriver that fits the slot correctly (Brownell's sells slotted screwdriver bit sets for gunsmiths or learn to hollow-grind your own) so you don't look like an amateur by dinging up the screw slot.
- ♦ Unscrew the ball F protecting the lock nut thread. I use the unserrated part of the jaws of needlenose pliers for this.
- ♦ Remove fine adjust thumb nut L.
- ♦ Remove lock nut E and spring e.
- ♦ Larger calipers may have a washer with flats on it fitting over a square portion of the threaded shaft on C (this washer is not shown in the patent drawing). Remove this washer.
- ♦ The legs may now be pulled apart. You may need a knife blade to gently separate them; tap it gently in, going around in a circle.
- ♦ Remove the small slotted screw S that threads into leg B and goes through the hole in short leg D.
- ♦ Separate the short fine adjust leg D from the caliper leg B. The inside surfaces of these parts are virtually always without lubrication and are rusted. The fine adjust leaf spring N may press against the fine adjust stud J, making it hard to remove the fine adjust leg. You can unscrew leg D from the stud to avoid damaging the stud's threads (or you may be able to compress the spring with fine-tipped needlenose pliers).
- ♦ Clean and lubricate all parts (I use Vaseline or silicone oil), then reassemble. Note it's OK to lubricate the frustums[4], as they will still lock up when the lock nut E is tightened.

It's not uncommon to find the threaded studs bent; these can be judiciously bent back into position. If the threads are dinged, it may be challenging to find a suitable repair tool, as the threads can be oddball sizes. A thread file could be handy or a small 3-cornered file may be used. The best tool is probably a split die, but good luck in finding one of the proper size.

To reassemble the fine adjust leg to the caliper leg, compress the leaf spring with needlenose pliers, then slip over the stud. Align the frustum piece with the hole in the leg and, if you're lucky, the parts will snap together with thumb pressure. There may be a step at the bottom of the stud preventing the parts from snapping together; if so, the leaf spring can be pushed away with a suitable tool like an awl point. Once the parts B and D are flush together, install the fine adjust nut L and screw it down so that the fine adjust leg D is centered in the caliper leg B. Then install the slotted screw S, being careful to not strip the threads. Tighten this screw so it is snug, then unscrew it about 1/4 of a turn, as the two legs need to move with respect to each other.

These calipers will rust easily in humid environments. You can protect them from this by coating the legs with e.g. an acrylic spray.

Inspect the tapered frustums that provide the joint's friction. If the joint doesn't operate smoothly, you might want to lap these tapered surfaces to get a smoother fit. This can be done with some suitable valve-grinding compound and relative movement. There must be adequate material to lap off; otherwise, the legs will rub against each other (then the calipers are not worth fixing).

I coat the under side of leg D heavily with Vaseline, making sure it's coating everything because this is the most common location for rusted parts. I also thoroughly cover the frustums and metal surrounding them, as rust can destroy the joint's smoothness. All other parts get a coating of

---

4 A frustum is a part of a right cone that has been cut by planes perpendicular to the cone's longitudinal axis. The male frustum is shown in the patent drawing Figure 19 as C in Fig 2.

Vaseline from my fingers, then I'll heat the calipers with a hair dryer or set them out in the sun to make sure the Vaseline wicks into all areas to protect against rust. I then mentally make a note to inspect and service all these calipers again in a few years.

A quickie maintenance tip is to run a bead of Vaseline along the short leg D and set the calipers out in the hot summer sun. The Vaseline will melt and will wick in between the legs, lubricating things. In winter, use a hair dryer to warm the metal.

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p1885 Fay, US patent 319215: Early spring caliper patent.

p1886a Bullard, US patent 335740: Figure 2 shows one of the most commonly-used spring bow caliper joint designs.

p1886b Fay, US patent 334764: Early split nut design.

p1889 Starrett, US patent 411527: Wing dividers with fine adjust and replaceable legs. The Starrett model 85 calipers are still made this way, nearly unchanged from the patent drawings.

p1895 Fay & Starrett, US patent 539759: Tapered lock-joint caliper with fine adjust. Used on Starrett model 36, 37, 38, 39, and 42 calipers.

p1901 Starrett, US patent 672424: Fine adjust for firm joint calipers. Also shows Starrett's firm joint design.

p1903 Ball, US patent 720773: Bow spring outside transfer calipers. You could make these from some Yankee calipers.

p1905 Starrett & Simpson, US patent 793850: Split nut for calipers. This became the de facto split nut design. This design was apparently in figure 132 of [*vdv*], meaning it was being used in production years before this patent.

p1925 A. Nelson, US patent 1562464: Hermaphrodite calipers with fine adjust and square groove on leg for indexing on edge, 1925.

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