

## Understanding GO/NO GO Gauges
## (Fixed Limit Gauging)

One of the most frequent questions that we are asked at A.A. Jansson is, “How do I choose a plug gauge for my measurement application?” Therefore I put together this document to help everyone understand the concept of fixed limit gauging.

Keep in mind the fundamental concept of fixed limit gauging is to never accept a bad part. In order to accomplish this, the tolerance of the plug or ring will be designed to actually have the potential to reject good parts.

When this method rejects good parts that are near the extreme limits of the part tolerance the part can be rechecked with a more accurate method to determine if the part is actually in tolerance.

In the following examples I don’t want to get hung up about semantics. Some people call pin gauges, plug gauges, and others call plug gauges, pin gauges. Either way is acceptable.

Keep in mind that a Go plug has a plus tolerance and is designed to gauge the smallest acceptable hole size, and a NoGo plug has a negative tolerance, designed to gauge the largest acceptable hole size. Subsequently a Go gage should be able to pass through the hole and a NoGo plug gauge should not. This is why they call it Go/NoGo gauging. Others call it Fixed Limit Gauging.

The opposite is true for ring gages. A Go ring has a negative tolerance and is designed to gauge the largest acceptable diameter and a NoGo ring has a positive tolerance and is designed to gauge the smallest acceptable diameter. The reasons for this will become clearer as we go through a couple of examples.

It is easy to get confused between how the tolerance of the ring and plug is applied in relationship to the Go and NoGo member. Sometimes it is easier to think of the member you are measuring in terms of more or less material.

## Plug/Pin Gauge Example

1. **Dimension on part that needs to be gauged**:
   a. The tolerance is taken from the blue print.
   b. The nominal hole size on the part to gauge is 1.0000”
   c. Tolerance of the hole is +.002”/-.000”
   d. This means the hole must be manufactured somewhere between 1.0000” and 1.0020” in size.

2. **Determining Plug Gauge:**
   a. The Go plug would be intended for gauging the smallest acceptable hole size. This size would be 1.0000”
   b. The NoGo plug would be intended for gauging the largest acceptable hole size. This size would be 1.0020”
   c. We will use the 10:1 rule to help us determine the tolerance of the plug that should be used in the <u>ideal world</u>.
      i. The part tolerance spread is .002”, therefore the tolerance of the plug gauge should be approximately 10% of the overall range of the tolerance being measured. 10% of .002”=.0002”
      ii. The tolerance is split between the Go and NoGo Plug. 5% on the Go and 5% on the NoGo. 5% is .0001”
      iii. Go Plugs have a plus Tolerance
      iv. NoGo Plugs have a minus Tolerance

   EXAMPLE:

   Hole Size= 1.0000 +.002/-0.000
   Range of Tolerance=.002
   10% of Tolerance=.002 x .10= .0002”
   Apply ½ of 10% to each member=.0002”/2=.0001”
   Low Limit Plug Gage is 1.0000” +.0001” (Go Gage)
   High Limit Plug Gage is 1.0020” -.0001” (NoGo Gage)

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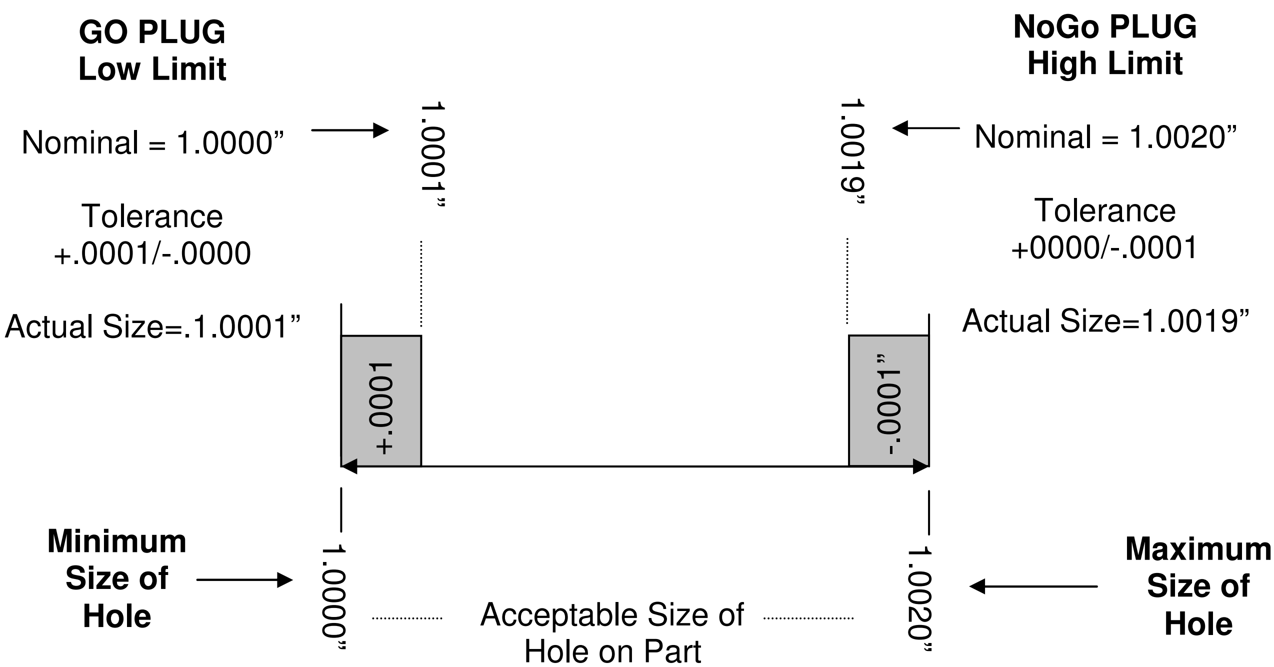
3. **Graphical Representation of Example**




4. **Ideal Gage that is required**:

The Go Plug has a nominal size of 1.0000” with a tolerance of +.0001”/-0.0000
The NoGo Plug has a nominal size of 1.002” with a tolerance of +0.0000/-.0001

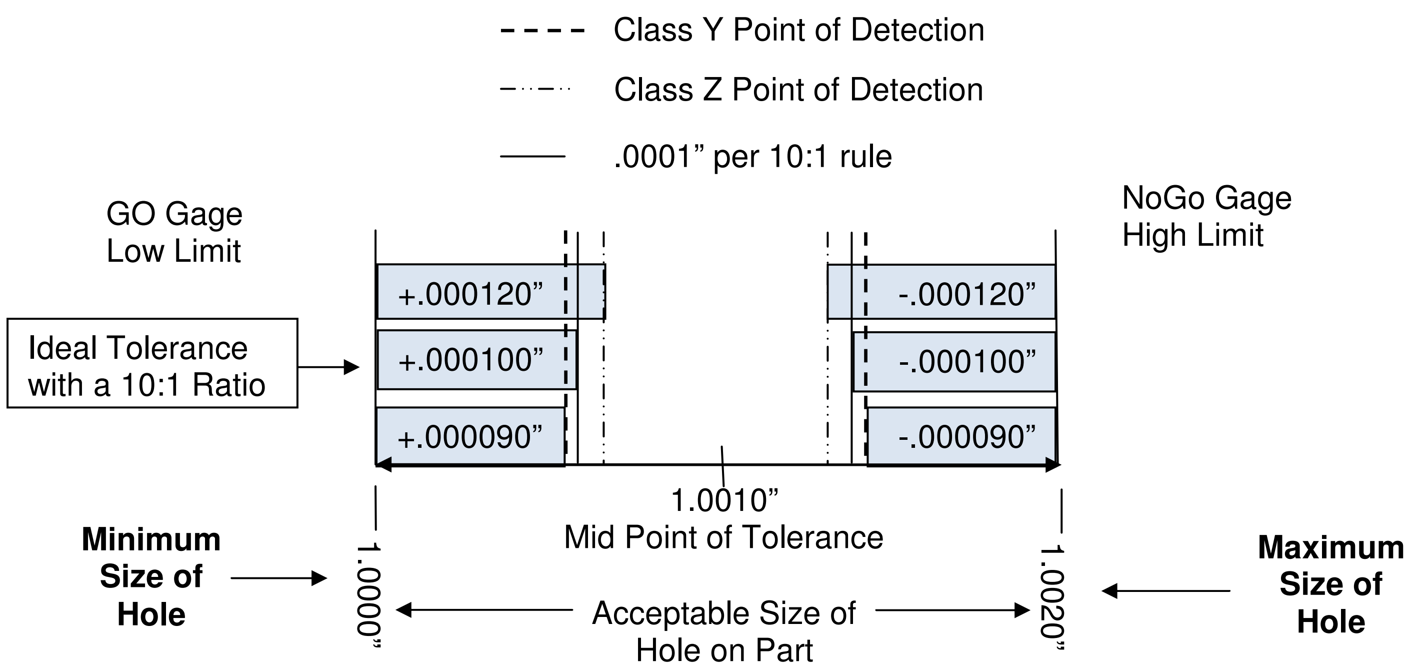
This is the ideal gage that is required to meet the 10:1 gauging concept. However one must consider cost and availability and most importantly one must consider risk. Obviously there are common sizes and grades of plug gages that are produced. Let’s first look at the standard Gage Maker Tolerance Chart for our size plug gage.

Gage Maker Tolerance for 1.0000” Plug

| | Grade | | | | | |
|---|---|---|---|---|---|---|
| Size | XXX | XX | X | Y | Z | ZZ |
| .8250”-1.5100” | .000015” | .000030” | .000060” | .000090” | .000120” | .00024” |
| Price Steel | quoted | $54 | $34 | $ 26 | $15 | $15 |

The gage in our example required a .0001” tolerance. There isn’t a grade that has a .0001” tolerance for a 1.0000” nominal size. You can spend the money to have a special gauge manufactured with a .0001" tolerance or more likely you will purchase a standard size that is close to your desired tolerance. If you look at the Gage Maker Tolerance Chart the class Y is the closest grade to our requirement.

The class Y has a tolerance of .000090". By choosing the class Y tolerance gauge we are tightening our tolerance from the ideal gauge tolerance by .000010". By tightening the gauge tolerance we are effectively creating a situation as the production begins to move away from the midpoint of the tolerance (1.001") it can deviate further from the midpoint of the tolerance before the fixed limit gauge detects the out of tolerance condition as opposed to the special gauge made to our original .0001" tolerance. If we choose the class Z tolerance gauge we are loosening our tolerance from the ideal gauge tolerance by .000020". By loosening the gauge tolerance we are effectively creating a situation that allows us to detect an out of tolerance condition sooner as the production begins to move away from the midpoint of the tolerance (1.001") Refer to graphical representation below.




At this point it is a good time to discuss risk vs. cost of scrap. As depicted in the above figure it becomes obvious that the less accurate plug gauge will detect an out of tolerance condition sooner than the more accurate gauge. And the less accurate gauge costs less.

However depending on how fast your process is running, how often you are gauging the product and the risk level associated with producing and accepting an out of spec part will help determine which gauge you might want to use.

If your risk level is high you might want to consider the less accurate gauge since it will detect the process moving out of spec sooner than the more accurate gauge. Allowing you to correct the shift in the process before the limits are exceeded.

Similarly if you are sampling parts and the process is running significantly fast you might want to use a less accurate plug gauge. For example if you are measuring 1 in 100 parts you don't want to find that the last part you measured exceeds the limit and you produced potentially 100 bad parts since your last check.

It could be said that a more accurate gauge increases your risk of accepting a bad part. With the less accurate plug gage you decrease your risk of accepting a bad part. This sounds backwards and isn't 100% true. However it isn't 100% false.

Remember in our example the part tolerance was .002" and our gauges used .0002" <u>combined</u> tolerance. The part tolerance divided by the gauge tolerance created our 10:1 relationship (.002"/.0002"=10). If we choose the class Y plug gauge the ratio would change to an approximate 11:1 (.002"/.00018 Combined gage tolerance (.000090"+.000090") =11:1 ratio). If we choose the class Z plug gauge the ratio would change to an approximate 8:1 (.002"/.00024 combined gage tolerance (.00012"+.00012")=8:1 ratio)

This is where it is important to remember the fixed limit gauging concept. You will always reject good parts when the parts are manufactured near the part limits. The question is do you want your gauge to detect and reject a defect sooner or later as your process moves away from the midpoint of the part tolerance. If you want to reduce risk you want to reject sooner. If the part isn't extremely critical you might want to reject later, and thus potentially have less scrap.

A class Y gage costs approximately 42% more than a class Z gage. If a person decides to save some money on gauging and purchase a class Z gauge with a larger tolerance they could potentially detect and reject more parts sooner as the manufacturing process nears the limit. Since the tolerance on the gauge is larger. If you are rejecting parts sooner you are reducing the possibility of a bad part being accepted, thus reducing risk. However you could potentially have more scrap depending on how frequently you are gauging the part. Some of the scrap might very well be within the part tolerance. There is a cost associated with scrap whether you actually scrap the parts or re-measure the parts with a more accurate method in order to salvage some of the scrap. This costs time and money.

There are two costs aspects that are working in opposite directions.

a. Cost of the gauge
b. Cost of scrap

The tighter the tolerance of the gauge the more it costs. However the tighter the gauge tolerance the less parts that will be rejected when the part is manufactured near the limits of the tolerance. The gauge may cost more but you would have less scrap if the process is running near the limits. You pay a little more for the more accurate gauge but you have less scrap. However as your gauge tolerance is tightened and your process is nearing the limits you risk of accepting a bad part increases.

If you run your process near the middle of the tolerance and don't let it approach the limits none of this matters. It wouldn't matter what tolerance gage you used as long as the size you're controlling doesn't reach the limits. This isn't real world. You are trying to control a process and things do change over time.

When you choose a plug gauge you have other factors to consider.

a. Form of the gauge
b. Uncertainty of the calibration of the gauge

A plug gauge has a degree of form error or out of roundness condition. A lower class or less accurate gauge will have a larger form error than a more accurate gauge. Many people purchase a plug gauge based on the diameter size and tolerance without giving any consideration to form error. The larger the form error you might reject a part sooner than a perfectly round plug gauge. This may increase your scrap but your risk of accepting a bad part probably didn't increase.

The uncertainty of the calibration is probably more critical. For our example we used a class Y gauge to gauge the low limit of 1.0000". The tolerance of the class Y gauge was +.000090". However gauges are not made perfect. The manufacturer of the gauge is just stating that the plug gauge will have a size somewhere between 1.000000 and 1.000090. If the gauge was 1.000010" it would be acceptable. Perhaps the gage isn't new and it has worn over time but is in tolerance. Different Laboratories have different measurement capabilities. Let's assume a calibration laboratory calibrated the plug and found it in tolerance with a size 1.000010" with an uncertainty of .000060" (60µin). Simply stated this means that the plug could be as small as .99995" or as big as 1.000070" Most calibration laboratories state measurement uncertainties are based upon a 95% confidence level, k=2. This means you could be gauging the go (low limit) 1.0000" hole with a plug gauge that is .999950". In essence you could be accepting out of spec parts. This has all kinds of bad implications. <u>Measurement uncertainty does matter.</u>

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5. **Ordering the Gauge**
A plug/pin gauge can be ordered in three fashions in relation to the tolerance required:

| Type | Direction of Tolerance | Example |
|---|---|---|
| + Tolerance | Applied in the + Direction | 1.0000” + .0001”/-0.0000” |
| - Tolerance | Applied in the – Direction | 1.0000” + .0000”/- .0001” |
| Bilateral/Master | Tolerance Split | 1.0000” +.00005”/-.00005” |

When you are ordering a Plug/Pin gauge the High Limit of your part tolerance is the NoGo Plug with a plus tolerance. The Low Limit of your part tolerance is the Go Plug with negative tolerance. This is the opposite for a ring gauge.

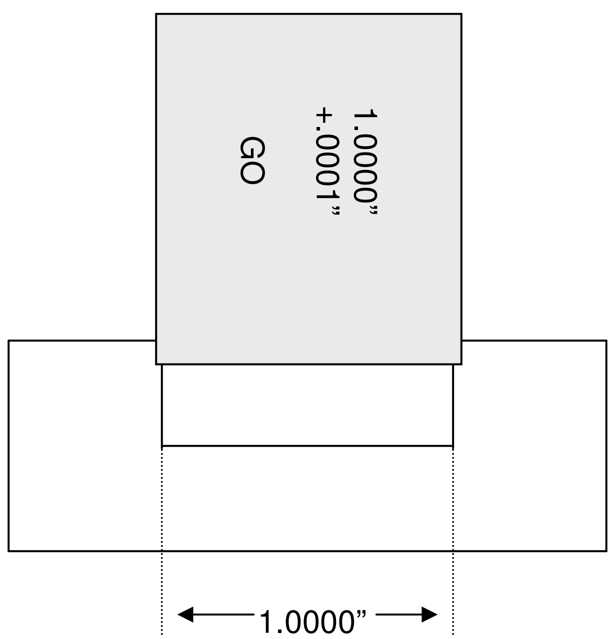
| Gauge | Low Limit | High Limit |
|---|---|---|
| Plug/Pin | + Tolerance (Go) | - Tolerance (NoGo) |
| Ring | + Tolerance (NoGo) | - Tolerance (Go) |

A Bilateral gauge or sometimes referred to as a master tolerance isn’t used for fixed limit gauging purposes. A master is ordered with a split tolerance and typically is used for setting another gage to a nominal size.

6. **Cause and Effect**:
    a. Keep in mind the fundamental concept of fixed limit gauging is to never accept a bad part. In order to accomplish this, the tolerance of the plug will be designed to actually have the potential to reject good parts.
    b. If the hole actually was 1” in diameter a Go Plug of 1.0000” with a plus tolerance would not fit into the hole and the good part would be rejected. (see figure 1)
    c. If the hole was actually 1.0020” in diameter a NoGo Plug of 1.0020” with a minus tolerance would fit into the hole and the good part would be rejected. (see figure 2)
    d. Remember a Go gauge should <u>go</u> into the hole and a NoGo gauge should <u>not go</u> into the hole.

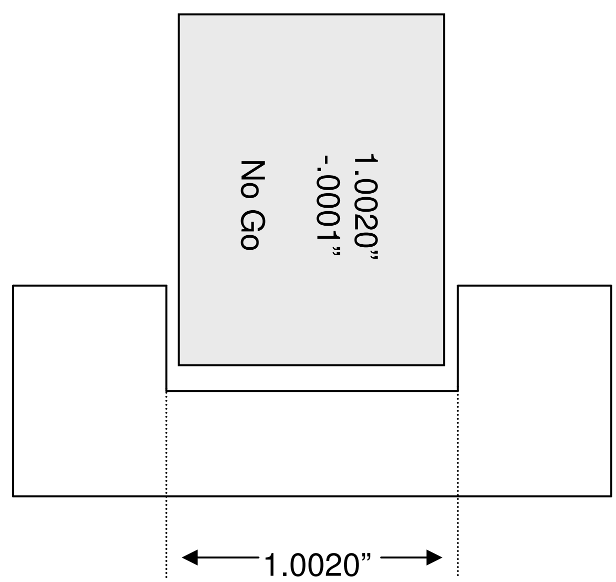
Example:

Figure 1




Actual Size of Hole
Low Limit

Figure 2




Actual Size of Hole
High Limit

7. **What happens to these rejected parts that are actually good**? The parts are typically re-measured by a more accurate method. This is done either by a more accurate plug or an alternative-measuring device. Thus reducing the amount of parts that are rejected, and the amount of scrap material. If the parts are inexpensive to produce one could make an argument to scrap the parts.



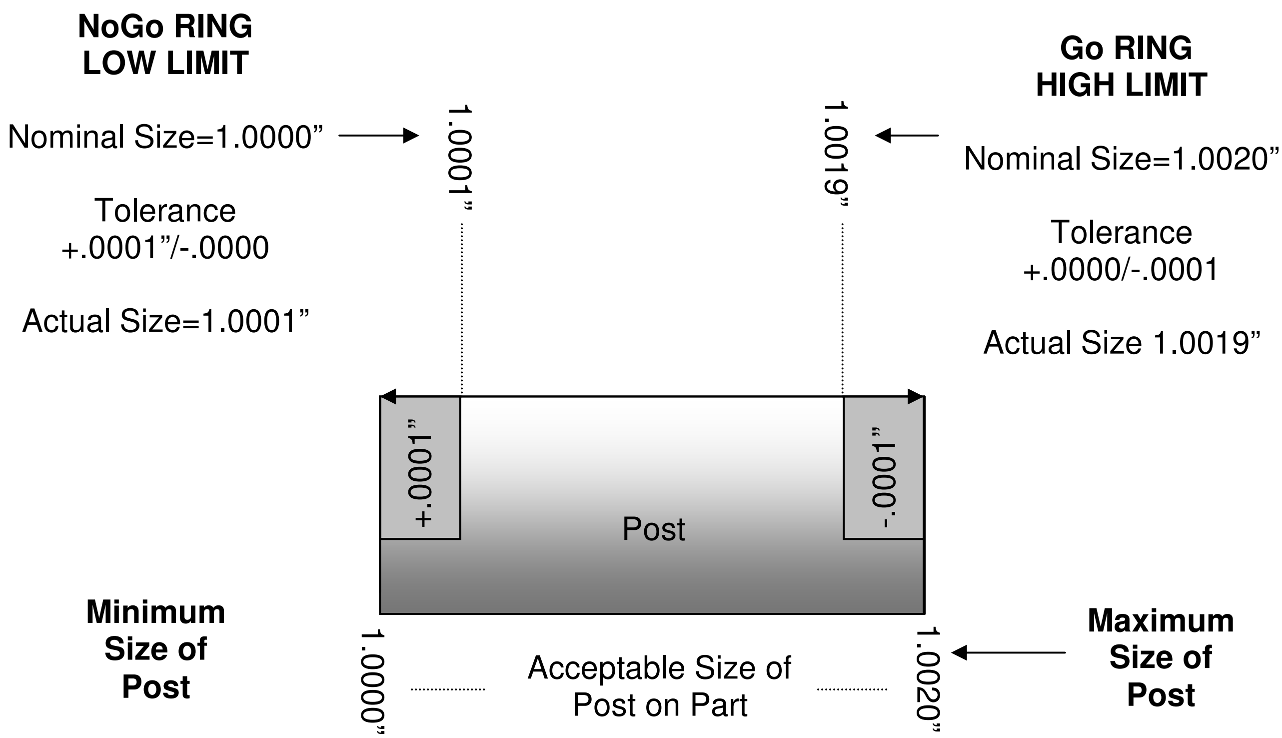
## Ring Gauge Example

1. **Dimension on part that needs to be gauged**:
    a. The tolerance is taken from the blue print.
    b. The nominal post size on part to gauge is 1.0000”
    c. Tolerance of the post is +.002”/-.000”
    d. This means the post must be manufactured somewhere between 1.0000” and 1.0020” in size.

2. **Determining Ring Gauge:**
    a. Go Ring would be intended for gauging the largest acceptable post size. This size would be 1.0020”
    b. NoGo Ring would be intended for gauging the smallest acceptable post size. This size would be 1.0000”
    c. We will use the 10:1 rule to help us determine the tolerance of the ring that should be used in the <u>ideal world</u>.
        i. The part tolerance spread is .002”, therefore the tolerance of the ring gauge should be approximately 10% of the overall range of the tolerance being measured. 10% of .002”=.0002”
        ii. The tolerance is split between the Go and NoGo Ring. 5% on the Go and 5% on the NoGo. 5% is .0001”
        iii. Go Rings have a minus Tolerance
        iv. NoGo Rings have a plus Tolerance

    EXAMPLE:
        Hole Size= 1.0000 +.002/-0.000
        Range of Tolerance=.002
        10% of Tolerance=.002 x .10= .0002”
        Apply ½ of 10% to each member=.0002”/2=.0001”
        Low Limit Ring Gage is 1.0000” +.0001” (NoGo Gage)
        High Limit Ring Gage is 1.0020” -.0001” (Go Gage)

3. **Graphical Representation of the example**




4. **Ideal Gage that is required**:

Go Ring has a nominal size of 1.0020” with a tolerance of +.0000”/-0.0001
A NoGo Ring has a nominal size of 1.0000” with a tolerance of +0.0001/-.0000

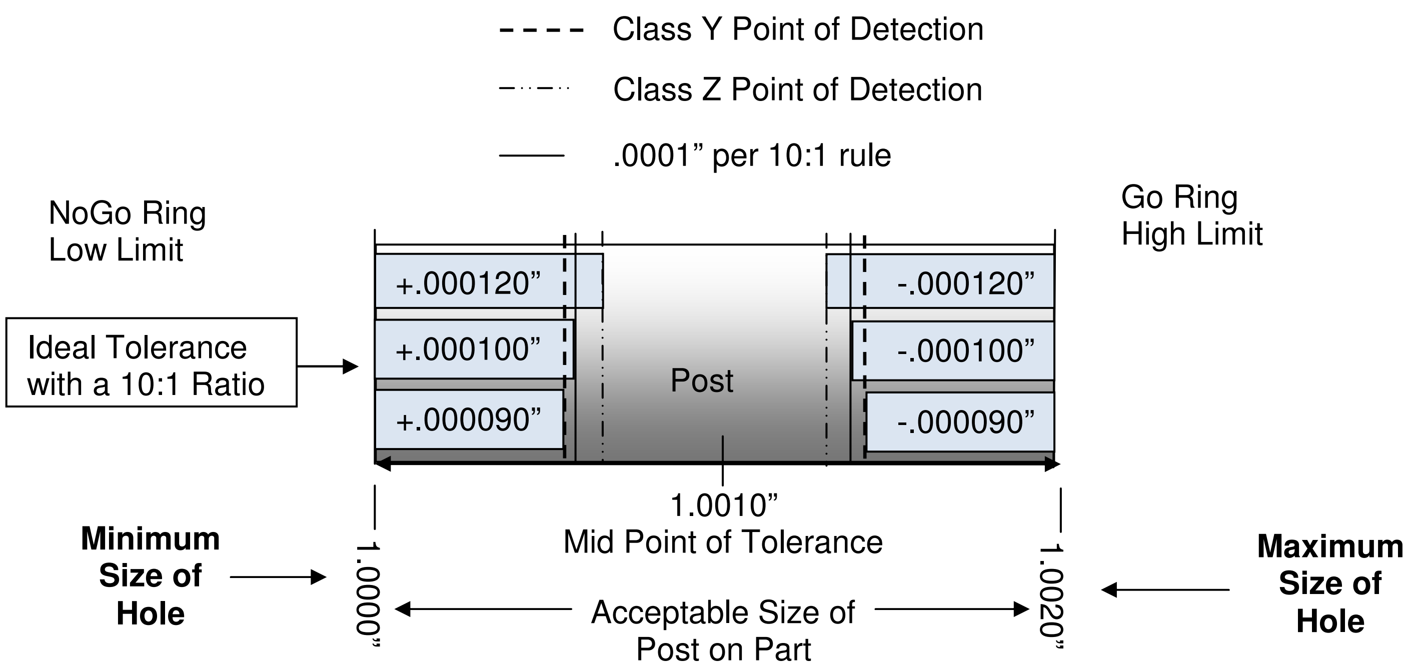
Once again this is the ideal gage that is required to meet the 10:1 Rule gauging concept. However one must consider cost and availability. Most importantly one must consider risk. There are common sizes and grades of ring gauges that are manufactured. Once again let’s refer to the Gage Makers Tolerance Chart

Gage Maker Tolerance Chart for 1.0000” Ring

| Size | XXX | XX | X | Y | Z | ZZ |
|---|---|---|---|---|---|---|
| .8250”-1.5100” | .000015” | .000030” | .000060” | .000090” | .000120” | .00024” |
| Price Steel | Quoted | $107 | $92 | $ 87 | $83 | $83 |

The gage in our example required a .0001” tolerance. There isn’t a grade that has a .0001” tolerance for a 1.0000” nominal size. You can spend the money to have a special gauge manufactured with a .0001” tolerance or more likely you will purchase a standard size that is close to your desired tolerance. If you look at the Gage Maker Tolerance Chart the class Y is the closest grade to our requirement.

The class Y has a tolerance of .000090”. By choosing the class Y tolerance gauge we are tightening our tolerance from the ideal gauge tolerance by .000010”. By tightening the gauge tolerance we are effectively creating a situation as the production begins to move away from the midpoint of the tolerance (1.001”) it can deviate further from the midpoint of the tolerance before the fixed limit gauge detects the out of tolerance condition as opposed to the special gauge made to our original .0001” tolerance. If we choose the class Z tolerance gauge we are loosening our tolerance from the ideal gauge tolerance by .000020”. By loosening the gauge tolerance we are effectively creating a situation that allows us to detect an out of tolerance condition sooner as the production begins to move away from the midpoint of the tolerance (1.001”) Refer to graphical representation below.



At this point it is a good time to discuss risk vs. cost of scrap. As depicted in the above figure it becomes obvious that the less accurate ring gauge will detect an out of tolerance condition sooner than the more accurate gauge. And the less accurate gauge costs less.

However depending on how fast your process is running, how often you are gauging the product and the risk level associated with producing and accepting an out of spec part will help determine which gauge you might want to use.

If your risk level is high you might want to consider the less accurate gauge since it will detect the process moving out of spec sooner than the more accurate gauge. Allowing you to correct the shift in the process before the limits are exceeded.

In addition if you are sampling parts and the process is running significantly fast you might want to use a less accurate ring gauge. For example if you are measuring 1 in 100 parts you don't want to find that the last part you measured exceeds the limit and you produced potentially 100 bad parts since your last check.

It could be said that a more accurate gauge increases your risk of accepting a bad part. And With the less accurate plug gage you decrease your risk of accepting a bad part. This sounds backwards and isn't 100% true. However it isn't 100% false.

Remember in our example the part tolerance was .002" and our gauges used .0002" <u>combined</u> tolerance. The part tolerance divided by the gauge tolerance created our 10:1 relationship (.002"/.0002"=10). If we choose the class Y ring gauge the ratio would change to an approximate 11:1 (.002"/.00018 Combined gage tolerance (.000090"+.000090") =11:1 ratio). If we choose the class Z ring gauge the ratio would change to an approximate 8:1 (.002"/.00024 combined gage tolerance (.00012"+.00012")=8:1 ratio)

This is where it is important to remember the fixed limit gauging concept. You will always reject good parts when the parts are manufactured near the part limits. The question is do you want your gauge to detect and reject a defect sooner or later as your process moves away from the midpoint of the part tolerance. If you want to reduce risk you want to reject sooner. If the part isn't extremely critical you might want to reject later, and thus potentially have less scrap.

In this particular situation there isn't much difference in the cost of a class Y or Z ring gauge, unlike the cost of the plug gauge. If a person decides to purchase a class Z gauge with a larger tolerance they could potentially detect and reject more parts sooner as the manufacturing process nears the limit. Since the tolerance on the gauge is larger. If you are rejecting parts sooner you are reducing the possibility of a bad part being accepted, thus reducing risk. However you could potentially have more scrap depending on how frequently you are gauging the part. Some of the scrap might very well be within the part tolerance. There is a cost associated with scrap whether you actually scrap the parts or re-measure the parts with a more accurate method in order to salvage some of the scrap. This costs time and money.

There are two costs aspects that are working in opposite directions.

a. Cost of the gauge
b. Cost of scrap

The tighter the tolerance of the gauge the more it costs. However the tighter the gauge tolerance the less parts that will be rejected when the part is manufactured near the limits of the tolerance. The gauge may cost more but you would have less scrap if the process was running near the limits. You pay a little more for the more accurate gauge but you have less scrap to deal with. However as your gauge tolerance is tightened and your process is nearing the limits you risk of accepting a bad part increases.

If you run your process near the middle of the tolerance and don't let it approach the limits none of this matters. It wouldn't matter what tolerance gage you used as long as the size you're controlling doesn't reach the limits. This isn't real world. You are trying to control a process and things do change over time.

When you choose a ring gauge you have other factors to consider.

a. Form of the gauge
b. Uncertainty of the calibration of the gauge

A ring gauge has a degree of form error or out of roundness condition. A lower class or less accurate gauge will have a larger form error than a more accurate gauge. Many people purchase a ring gauge based on the diameter size and tolerance without giving any consideration to form error. The larger the form error you might reject a part sooner than a perfectly round ring gauge. This may increase your scrap but your risk of accepting a bad part probably didn't increase.

The uncertainty of the calibration is probably more critical. For our example we used a class Y gauge to gauge the high limit of 1.002". The tolerance of the class Y gauge was -.000090". However gauges are not made perfect. The manufacturer of the gauge is just stating that the ring gauge will have a size somewhere between 1.000191" and 1.002000". If the gauge was 1.001992" it would be acceptable. Perhaps the gage isn't new and it has worn over time but is in tolerance. Different Laboratories have different measurement capabilities. Let's assume a calibration laboratory calibrated the ring and found it in tolerance with a size 1.001992" with and uncertainty of .000060" (60µin). Simply stated this means that the ring could be as small as 1.001932" or as big as 1.002052" Most calibration laboratories state measurement uncertainties are based upon a 95% confidence level, k=2. This means you could be gauging the Go (high limit) 1.0020" post with a ring gauge that is 1.002052". In essence you could be accepting out of spec parts. This has all kinds of bad implications. <u>Measurement uncertainty does matter.</u>

## 6. Ordering the Gauge

A ring gauge can be ordered in three fashions in relation to the tolerance required:

| Type | Direction of Tolerance | Example |
|---|---|---|
| + Tolerance | Applied in the + Direction | 1.0000” + .0001”/-0.0000” |
| - Tolerance | Applied in the – Direction | 1.0000” + .0000”/-0.0001” |
| Bilateral/Master | Tolerance Split | 1.0000” +.00005”/-.00005” |

When you are ordering a Ring the High Limit of your part tolerance is the Go Ring with a minus tolerance. The Low Limit of your part tolerance is the NoGo Ring with plus tolerance.

A Bilateral gauge or sometimes referred to as a master tolerance isn’t used for fixed limit gauging purposes. A master is ordered with a split tolerance and typically is used for setting another gage to a nominal size.

6. **Cause and Effect**:
   a. Keep in mind the fundamental concept of fixed limit gauging is to never accept a bad part. In order to accomplish this, the tolerance of the plug or ring will be designed to actually have the potential to reject good parts.
   b. If the post actually was 1” in diameter a NoGo Ring of 1.0000” with a plus tolerance would go over the post and the good part would be rejected. (see figure 1)
   c. If the hole was actually 1.0020” in diameter a Go Ring of 1.0020” with a minus tolerance would not pass over the post and the good part would be rejected. (see figure 2)
   d. Remember a Go gauge should <u>go</u> over the post and a NoGo gauge should <u>not go</u> over the post.

Figure 1

**NoGo Ring**
Nominal Size = 1.0000”
Tolerance = +.0001”/-.0000
Actual Size = 1.0001”

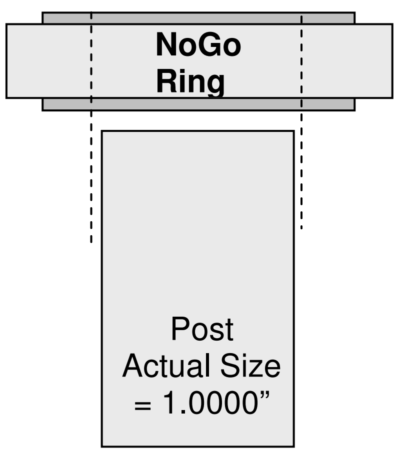
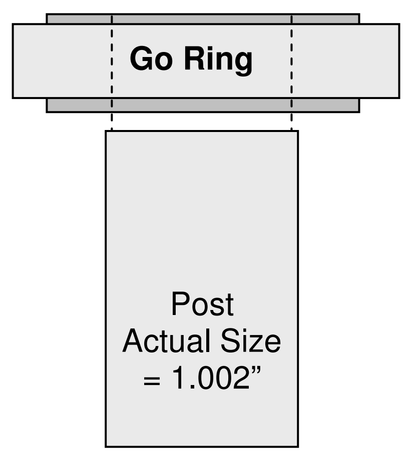



Figure 2

**Go Ring**
Nominal Size = 1.0020”
Tolerance = +.0000/-.0001”
Actual Size = 1.0019”



## 8. Temperature

Do not forget the role temperature plays in the process. Every gauge in this world is calibrated and reported at 68ºF. If the certificate doesn't state that the gauge is reported at 68°F is should report at what temperature it was when the gauge was calibrated. Sometimes the certificate will make a blanket statement that the gauge was calibrated within a given range for example 68° ±2°F.

Regardless of how the calibration is performed understand the effects of temperature. Since every calibration is referenced back to 68°F the question becomes what happens when the temperature changes?

As the temperature rises from 68°F your gauge and part will expand in size. When the temperature falls from 68°F your gauge and part will contract in size. Depending on the type of materials used they will not necessarily expand and contract at the same rate. This is something you need to consider depending on the control of the temperature in your environment.

Steel expands at 6.4ppm °F (Parts per Millionth). Tungsten Carbide expands at 2.4ppm per °F. Here is an example of the effect of temperature on a 2" plug gauge that is exactly 2 inches in size. Let's assume the plug gauge is made out of steel and the temperature is 75°F where the part is being gauged and manufactured. Since the temperature is greater than 68°F the gauge has expanded. The question is how much? We are 7°F warmer than 68°F (75-68=7). This means that our plug gage has expanded 89.6 µin (.000089"). This is as much as our tolerance in our previous example.

You multiply the (temp from 68°F) x (Size) X (Expansion Rate or CTE)

7°F x 2" x 6.4ppm= 89.6µin

The final unit is in µin since Coefficient of thermal expansion (CTE) is in parts per millionth and our temperature is in °F and our size in inches.

If the part is made out of Tungsten Carbide it would only expand at a rate of 2.4ppm per °F. This means that our part expanded 33.6µin (.0000336").

This means that there is difference of 26µin. between the expansion of the part and the gauge. Depending on the tolerances of your part this could be a significant number. The further you are away from 68°F and the larger the dimension the more significant the temperature becomes.

**Conclusion**

The 10:1 gauging rule is a recommendation and a starting point to help you decide what accuracy fixed limit gauge you should use. This 10:1 rule is not in any standards that I have read. However the concept has been around for decades and works as a good starting point. It simply states that the accuracy of your gauges should be designed to use 10% of your part tolerance.

In the final decision one must evaluate risk, cost and delivery in determining the final gauge tolerance to be used. It is always a fine balance to manufacture a quality product at the least amount of cost while managing your level of risk.

*Inspector Jansson*