Gage Block Measurement, Vertical Orientation, Dual Spherical Contact, Three Anvil Comparison

Method 1: Saddle Anvil

Pros:

- Good for measuring blocks 0.1” to 4” long.
- Point contact ensures good repeatability.
- Locates blocks for quick measurement.
- Uses only one displacement sensor.
- Measures (8) points on square gage blocks.
- Alignment of probe to lower contact is not critical.

Cons:

- Measures only one location on rectangular gage blocks.
- Deflection at the bottom contact points is quite large.

Details:

The Saddle Anvil supports the gage block on (3) balls. The measuring instrument is set so that its probe direction of travel is perpendicular to a plane that contains the top contact points of the (3) balls. One of the balls may or may not be placed directly under the probe. For stability reasons, the probe centerline should be on or inside a triangle formed by the center of the three balls. If one ball is directly under the probe, then the gage block thickness at that point is measured directly. If no ball is directly under the probe, then the measurement is affected slightly by gage block flatness and parallelism. An estimate of the uncertainty due to flatness and parallelism can be obtained by multiplying flatness and parallelism (in µin per inch) times the lateral offset distance between the probe centerline and the nearest ball. Typically the uncertainty due to flatness and parallelism is negligible.

The contact force on the top surface of the block is typically 0.5 ounces. Contact penetration for a 0.125” radius diamond tip at a force of 0.5 ounces is shown below.

Diamond Probe Contact Deformation @ 0.5 oz.	
Material	Defl (uin)
Steel	1.9
Tungsten Carbide	1.1
Chromium Carbide	1.5
Ceramic (CERA)	1.9

The contact force on the bottom of the block depends on the block size and shape. A reasonable estimate of the bottom contact force for the ball under the probe is that it is equal to half the weight of the gage block plus 0.5 ounces. The other two balls see a force approximately equal to one quarter of the gage block weight. Contact forces, penetration, and contact stress of square steel gage blocks and

0.125” ruby balls is listed below. The yield stress for steel gage blocks is 312 ksi. Contact stress should be below this value.

Square Gage Block, Steel, Saddle Anvil							
		Single Ball (under probe)			Other Two Balls		
Size	W (lbs)	0.5W+1/32	Defl (uin)	Stress (ksi)	0.25W	Defl (uin)	Stress (ksi)
0.1	0.025	0.044	3.4	98	0.006	0.9	51
1	0.247	0.155	7.9	150	0.062	4.3	110
2	0.493	0.278	11.7	182	0.123	6.8	139
3	0.740	0.401	14.9	206	0.185	8.9	159
4	0.987	0.525	17.8	225	0.247	10.8	175

The contact deflections are large, but get linearized with a two point calibration. The table below shows measurement error (Lin1 and Lin2) due to contact deflection (calibration points are 1 and 4 inches).

Square Gage Block,Steel, Saddle Anvil				
	Single Ball		Other Two Balls	
Size	Defl1 (uin)	Lin1 (uin)	Defl2 (uin)	Lin2 (uin)
0.1	3.4	-1.5	0.9	-1.4
1	7.9	0.0	4.3	0.0
2	11.7	0.5	6.8	0.3
3	14.9	0.4	8.9	0.3
4	17.8	0.0	10.8	0.0

The three tables above indicate that contact penetration correction is usually not necessary when mastering and measuring with blocks of the same material.

If the mastering and measured gage blocks are different materials, then thermal growth and contact deformation needs to be considered.

Material	CTE (ppm/°F)
Steel	6.4
Tungsten Carbide	2.5
Chromium Carbide	4.7
Ceramic (CERA)	5.5

Contact Penetration, Square Gage Block, Saddle Anvil												
	Steel			Tungsten Carbide			Chromium Carbide			CERA		
Size	W (lbs)	0.5W+1/32	Defl (uin)	W (lbs)	0.5W+1/32	Defl (uin)	W (lbs)	0.5W+1/32	Defl (uin)	W (lbs)	0.5W+1/32	Defl (uin)
1	0.247	0.155	7.9	0.461	0.262	7.4	0.205	0.134	5.9	0.188	0.125	6.8
4	0.987	0.525	17.8	1.843	0.953	17.6	0.819	0.441	13.0	0.751	0.407	15.0

Contact Penetration, Rectangular Gage Block, Saddle Anvil												
	Steel			Tungsten Carbide			Chromium Carbide			CERA		
Size	W (lbs)	0.5W+1/32	Defl (uin)	W (lbs)	0.5W+1/32	Defl (uin)	W (lbs)	0.5W+1/32	Defl (uin)	W (lbs)	0.5W+1/32	Defl (uin)
1	0.141	0.102	6.0	0.263	0.163	5.4	0.117	0.090	4.5	0.107	0.085	5.3
4	0.564	0.313	12.6	1.054	0.558	12.3	0.468	0.265	9.3	0.429	0.246	10.7

The two tables directly above indicate that contact penetration correction is not necessary when using steel and tungsten carbide blocks. Other combinations of blocks require contact penetration correction.

Diamond probe contact penetration and block thermal growth apply to all anvils and will not be repeated in the following sections.

Method 2: Bump Anvil

Pros:

- Good for measuring blocks 0.05” to 4” long.
- Point contact ensures good repeatability.
- Good for measuring 0.05” blocks which may not be perfectly flat.
- Measures multiple locations on square and rectangular gage blocks.

Cons:

- Deflection at the bottom contact point is quite large.
- Contact stress limits the size of blocks that can be measured.
- The anvil contact needs to be accurately aligned with the probe directly above it.

Details:

The Bump Anvil is designed to minimize measurement error due to curvature of thin gage blocks and to provide a means of measuring 5 points on square and rectangular gage blocks. The probe needs to be positioned directly over the Bump Anvil ruby for the best accuracy. Bump Anvil measurement error can be estimated by

$$E = 2 * a * h / b$$

Where

Error = possible error due to probe to ball misalignment
a = probe to ball misalignment
h = bump height
b = distance between the bump and where the gage block contacts the anvil

For example, if a = 0.1”, b = 0.7”, and h = 0.000050”, then E = 14 µin. In this case, “a” needs to be less than 0.014”, for E to be within 2 µin.

Contact penetration with the Bump Anvil is slightly greater, and contact stress is slightly lower, than the penetration and stress on the Saddle Anvil heavier loaded ball. Like the Saddle Anvil, Bump Anvil contact penetration correction is usually not necessary when mastering and measuring with blocks of the same material.

If the gage blocks are different materials, then contact deformation needs to be considered. The contact radius for the Bump Anvil is 0.09375”.

Contact Penetration, Square Gage Block, Bump Anvil												
	Steel			Tungsten Carbide			Chromium Carbide			CERA		
Size	W (lbs)	0.7W+1/32	Defl (uin)	W (lbs)	0.7W+1/32	Defl (uin)	W (lbs)	0.7W+1/32	Defl (uin)	W (lbs)	0.7W+1/32	Defl (uin)
0.1	0.025	0.049	3.2	0.046	0.064	2.5	0.020	0.046	2.5	0.019	0.044	3.0
1	0.247	0.204	8.3	0.461	0.354	7.9	0.205	0.175	6.2	0.188	0.163	7.1
4	0.987	0.722	19.3	1.843	1.322	19.1	0.819	0.605	14.1	0.751	0.557	16.1

Contact Penetration, Rectangular Gage Block, Bump Anvil												
	Steel			Tungsten Carbide			Chromium Carbide			CERA		
Size	W (lbs)	0.7W+1/32	Defl (uin)	W (lbs)	0.7W+1/32	Defl (uin)	W (lbs)	0.7W+1/32	Defl (uin)	W (lbs)	0.7W+1/32	Defl (uin)
0.1	0.014	0.041	2.8	0.026	0.050	2.2	0.012	0.039	2.3	0.011	0.039	2.7
1	0.141	0.130	6.1	0.263	0.216	5.7	0.117	0.113	4.6	0.107	0.106	5.3
4	0.564	0.426	13.6	1.054	0.769	13.3	0.468	0.359	9.9	0.429	0.332	11.4

The two tables directly above indicate that contact penetration correction is not necessary when using steel and tungsten carbide blocks, or blocks < 0.1”. Other combinations and sizes of blocks require contact penetration correction.

Method 3: Live Anvil

Pros:

- Good for measuring blocks of any length.
- Point contact ensures good repeatability.
- Measures multiple locations on square and rectangular gage blocks.
- Low contact forces.

Cons:

- Requires (2) displacement sensors, which may increase uncertainty.
- The anvil contact needs to be accurately aligned with the probe directly above it.

Details:

The Live Anvil is similar to the Bump Anvil except the ruby ball is connected to a displacement sensing element. Contact stress and deflection typically are not an issue with this anvil since the force values are low and constant. The lower contact needs to exert less force than the probe in order not to lift thin blocks. If dissimilar materials are used for mastering and measuring, then thermal growth and contact deflection need to be accounted for. Contact penetration for the Live Anvil contact for 0.5 ounce contact force is shown below. The contact radius for the Live Anvil is 0.09375”.

Contact Penetration, Live Anvil, 0.5 oz.	
Material	Defl (uin)
Steel	2.4
Tungsten Carbide	1.6
Chromium Carbide	2.0
Ceramic (CERA)	2.4

The Live Anvil has added uncertainty associated with the Live Anvil displacement sensor.