PRE, CHE, RIP

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The battle over whether you can use measurements of fired brass to judge peak chamber pressure is a little like the old song:

Anything you can do, I can do better. I can do anything better than you.

No you can't.

Yes I can.

No you can't

Yes I can, yes I can, yes I can!

The argument then loops back to the statement starting with "anything". Sometimes the arguments resemble a political fervor. Judging from the tone, I can easily imagine some web BBS posters red-faced, pounding their theories into the keyboard.

I now have some data that lets us evaluate the methods. I have no illusion that the facts presented here will persuade everyone, but, since they are data based, perhaps they will move the discussion in the right direction.

History

Case Head Expansion, or CHE, is a measure of how much the solid brass case head expands when the cartridge is fired. The measurement is normally taken just in front of the extractor groove. Pressure Ring Expansion, or PRE, is simply a measure of the diameter of the pressure ring that occurs just forward of the solid brass portion of the cartridge, and is not a difference.

Ken Waters helped popularize PRE with his article, "Developing Pet Loads"[i]. He called both the strain gage and the copper crusher systems real measurement systems. Regarding PRE, he said, "It must be understood that this is only a means of determining comparative pressures, with nothing more to be expected of it. With the data provided, the pressures of my handloads can be classified as moderate, normal, near maximum, maximum, or excessive—which is all that is necessary to ensure the safety of the shooter." That's a fairly modest claim, which many have embellished over the years. Unfortunately, even the original modest claim of being able to put cartridges into five categories turns out to be optimistic.

CHE is discussed in some current reloading manuals. Hodgdon[ii] indicates that .0005" expansion on a single firing indicates a maximum load. In 1958, Vernon Speer[iii] held that any measurable expansion indicated a load that is too hot.

In a related note, Ackley[iv] experimentally found that leaky or blown primers, from excessive case head expansion, begin at something below 65,000 "PSI". Since Ackley's measurement system was a copper crusher, there is no doubt that he was using the measurement units that we now call CUP, and calling them PSI, as was commonly done at that time. This pressure converts to about 80,200 PSI in the current system[v].

Test Overview

Two tests were performed. One uses matched pairs of cartridges, and micrometer measurements only, to test whether the same input pressure produces the same changes in brass dimensions. It is a test for self-consistency. The second test checks brass dimensions against the PressureTrace™ strain gage system, which has previously been shown to be more self-consistent than some published reloading data[vi,vii]. This test allows us to relate any error we find to actual PSI.

By every choice of equipment, technique, and tested loads, PRE and CHE were given all possible chances to succeed.

A Note About Brass and Geometry

This is almost an aside, but it contains an idea that we'll use later in the discussion.

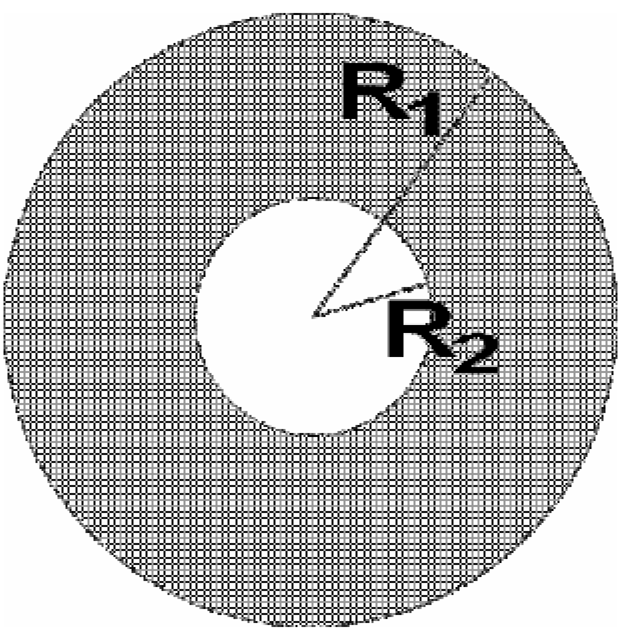

Figure 1

If you cut a cross section of a cartridge, or just look at the base, you have a primer pocket, surrounded by quite thick brass.

You'd think that as R_1 grows, R_2 would grow by the same amount. This is not the case.

The solid brass doesn't stretch forward or backward, so it can only stretch outward. If you assume that the brass maintains constant density, as it must, then it follows that the shaded area of Figure 1 must remain constant.

If you work through the math, the surprising result is that R_2, the primer pocket radius, will grow faster than R_1, sometimes by quite a bit. For the particular cartridge I used in this test, the 7.62x54R, the primer pocket grows 2.3X as fast as the outer dimension. Of course, the geometry of the 223 Remington, for example, is quite different, and the ratio would also be different.

The Main Event

28 7.62x54R cartridges were prepared, with loads from about 35,000 to 65,000 PSI. Two cartridges were prepared for each load.

Figure 2

Measurements were performed with the setup shown in Figure 2.

The micrometer is an electronic Mitutoyo blade micrometer with .00005” resolution. Since I wanted to be sure to hit exactly the same spot again and again, I clamped the micrometer to a flat granite inspection plate, and used appropriate shims to hit the desired spot on the case. The repeatability of the setup was tested, and found to be very adequate.

For the pressure ring diameter measurements, the method outlined by Ken Waters was followed.

The cartridges were fired at a barrel temperature of 80-82 degrees F. For each cartridge, the peak pressure and muzzle velocity were recorded.

Some may question whether it is appropriate to use a rimmed cartridge in this test, since they believe that rimmed cartridges are more resistant to deformation than rimless. Ackley investigated this[viii], and his experiment showed that rimmed cartridges have no practical strength advantage over rimless. Just to be conservative, I was careful to take my case head measurements away from the rim, but still over the primer pocket.

My Finnish Mosin Nagant serenely digested everything I gave it, without the least complaint or pressure sign, even though I knew I was shooting some cartridges 10,000 PSI over the limit for this rifle.

Pairs of near-identical cartridges were compared, using Interclass Correlation Coefficient. In this test, 1.00 is ideal, meaning the measurements perfectly repeated themselves. Measurement systems scoring over .90 are considered good, and systems scoring between .70 and .90 are considered marginal. Part of the calculation takes into account the variation between the cartridge pairs, with more variation giving a better chance for a high score. By choosing actual pressures with a 30,000 PSI range, I gave PRE and CHE maximum chance to score well. Usually, we are concerned about much smaller pressure ranges than this.

PRE scored .359, which is about halfway up to marginal, but better than CHE scored. In order to be able to put things into five distinct categories, the system would have to score .92 or better. With no more information that this, it is appropriate to class both systems as inadequate indicators of peak chamber pressure. But, as they say on TV: Wait! There's more!

The next test was to run a regression of KPSI vs. pressure ring diameter, and against case head expansion.

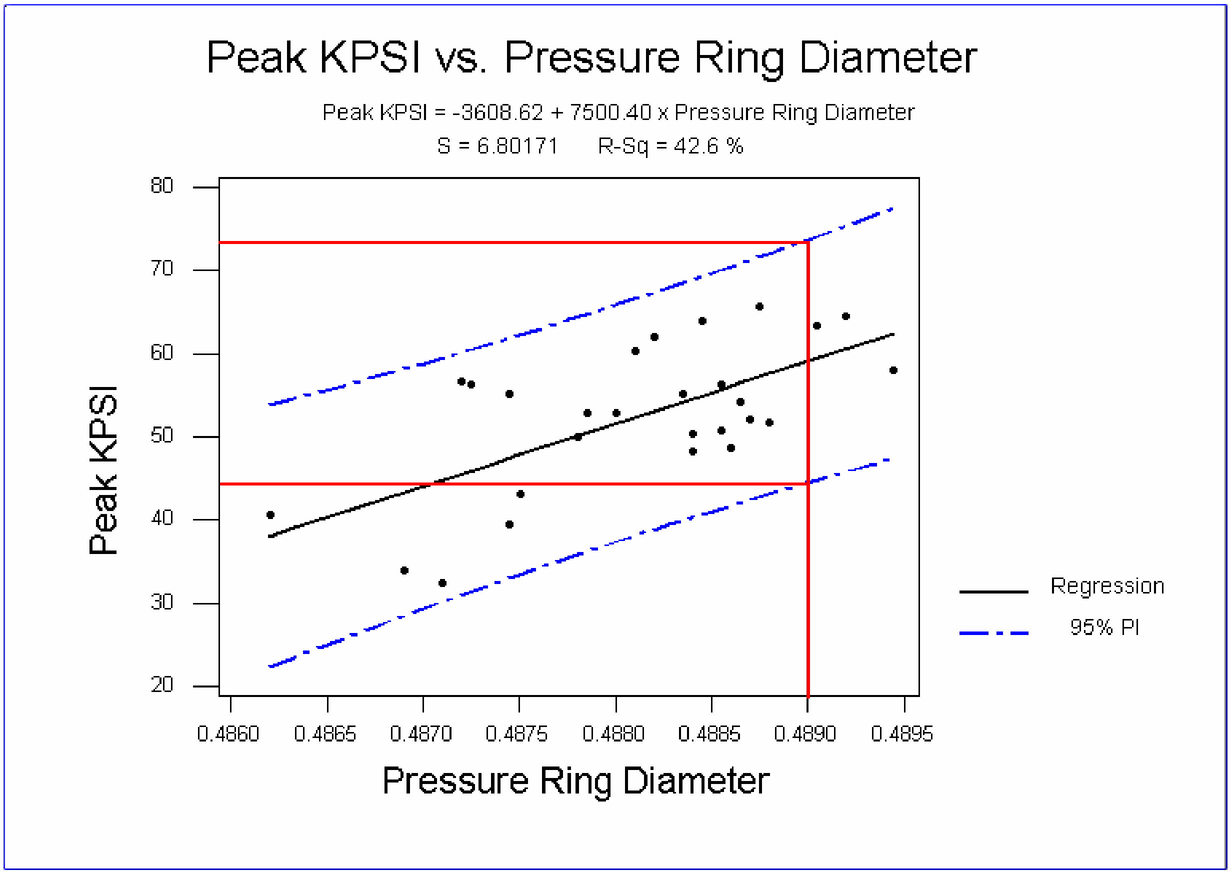

Figure 3

The statistics leave no doubt that pressure ring diameter is correlated with peak PSI. The problem is, it's not very well correlated. It explains only 42.6% of the variation, with other, unknown factors explaining the rest—over half. Another way of saying this is that the model contains more random noise than it does information[ix].

In Figure 3, the blue lines contain 95% of the data. So, with a straightedge, we can estimate error. If you pick a pressure ring diameter of .4890 in my rifle, just draw a vertical line until it reaches the first blue line. Then, draw a horizontal line over to the Peak PSI scale. The lower pressure that .4890" represents is about 44,000 PSI, a very mild load. Similarly, you can extend the vertical line up to the top blue line, and find that the higher pressure that .4890" represents is about 73,000 PSI, far "over the top". If you then say that .4890" represents 44,000 to 73,000 PSI, you'd be right 95% of the time.

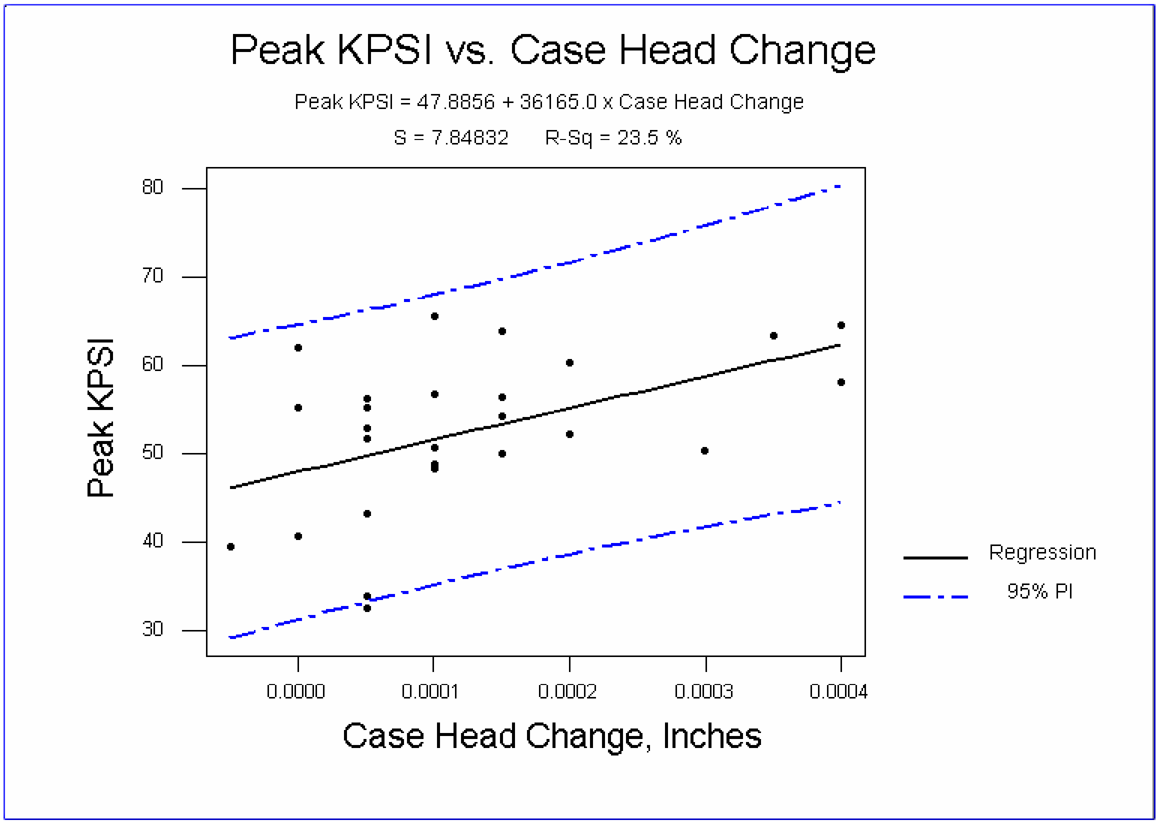

Figure 4

Figure 4 shows a similar relationship between Peak KPSI and case head growth. The relationship is real, but filled with even a higher percentage of noise than the pressure ring diameter regression. There are six data at 60,000 PSI and above. They produced growth ranging from none, to .0004".

When a system has a lot of random noise, averaging will reduce noise. Noise diminishes by the square root of the sample size. So could averaging give PRE adequate resolution? Yes, it will, if we carry it far enough. If you average the PRE measurements of 10 cartridges, it brings the random error down 3.16X, enough that a 30,000 PSI range can be divided into five distinct categories. So, in theory, it is possible to get the five categories Ken Waters sought, by averaging. However, even if you can distinguish five categories, you can't tell which of the five are OK, and which are not, without something to compare with. And there's the "hitch".

The usual suggestion is to compare with cases from fired commercial cartridges. Unfortunately, the commercial cartridges are subject to the same uncertainty we have just seen here. With a little math, it is found that you have to average about 140 commercial cartridges to get the error in that "standard" down to the point that it is comparable with the old CUP system. In addition, this requires two fairly hard to swallow assumptions:
1) The factory cartridges were loaded very close to maximum pressure. This is often not

the case. 2) All batches of brass from the same manufacturer are equally hard. I'll leave this one to the metallurgists.

Comparing to a fixed standard, such as limiting case head expansion to .0005" is fraught with even more peril. Different cases have different geometries, and different geometries produce different yield points for the same hardness of brass.

In contrast, the strain gage will get you 10.5 categories for the same range, without averaging, and 33.5 categories with a 10 shot average. Furthermore, reference to factory ammunition is needed only as a safety check, to ensure everything is working correctly.

From the second regression shown, we have a very noisy formula that relates peak KPSI to case head expansion. If we plug in the 80,200 PSI that Ackley found caused blown or leaky primers, we find a case head expansion of about .0009". From our little geometry detour, we know that will correspond to about .0021" of primer pocket growth. Since primers have a press fit between .0005" and .0045", this is enough expansion to cause about half of all new primers to fall out when installed. So our findings seem consistent with Ackley's.

σ_e is a figure of merit for a measurement system. It is the standard deviation of the random error in the system. Smaller is better. In terms of PSI, I have measured or calculated from published data the following σ_e numbers for a single cartridge test. This provides the simplest way of comparing several systems side by side.

CHE method, 7,500
PRE method, 6,800
Copper crusher method, 1827
Commercial piezoelectric, 1366
PressureTrace™ strain gauge, 667

Try It Yourself

With a slight modification, it is quite easy for anyone to replicate my experiment. You don't need any special equipment, or statistical knowledge. All you need is your usual reloading equipment, a micrometer, graph paper, and eyes.

Prepare at least 6-8 matched pairs of cartridges, spanning about four grains of powder, in half or quarter grain increments. Use the same case, powder, primer, and bullet for all. Mark each case so you can identify it.

Fire about three normal cartridges to warm your barrel. Allow plenty of cooling time between the test shots that follow, to keep the barrel as nearly constant in temperature as you can.

Fire your test cartridges in <u>random</u> order. Then, measure the pressure rings.

Set up your graph paper with grains of powder on the horizontal axis, and pressure ring diameter on the vertical axis. Mark each axis so that the range of your powder charges, and the range of your pressure ring measurements take up most of the available room. Place a dot on the graph for each cartridge.

If you get points tightly clustering around an obvious trend line, you have a repeatable system, and have a result contrary to mine. If your points are scattered, and if you have cases of lower pressures creating larger diameters, and higher pressures creating smaller diameters, you have the same conclusion as mine

Conclusions

1. CHE and PRE do provide some information, but it's mixed with a lot of random noise. The mix contains more random noise than information.

2. Both the PRE and the CHE methods do poorly at giving the same answer when comparing cases subjected to near-identical conditions.

3. A measurement system can be useful, even if it is imprecise. The problem is that PRE, the better of the two systems, can just barely distinguish a plinker load from a barrel buster. That's only two categories, and not very useful. You can average to improve precision, but it takes an impractical number of cartridges to get a questionable standard of comparison.

4. PRE and CHE always do always give an answer, but I can give you a random number table that is almost as good. That has the added advantage of not requiring a micrometer. Since firearms are typically very conservatively designed, your chances of blowing one up are slim, as long as you stick to reasonable powder choices. The illusion is that the methods work. The fact is that both methods can lead you to think that you are safe, when, in fact, you are punishing your firearm.

5. In preparing this article, I spent $200 on a flat granite plate, and the nicest used electronic blade micrometer I could find. I have other uses for these tools, which is a good thing, because their cost exceeds that of a strain gage system, and they are a poor indicator of whether my cartridges are safe.

6. Since conventional pressure signs did not develop, even at 10,000 PSI over limit, it seems that they are not a reliable indicator, either. That seems to narrow the field of safe options to three: 1) Use commercial ammunition. 2) Reload, and stick to the book loads. 3) Reload, study the books, and get a strain gage.

7. As the title of the article suggests, both the PRE and CHE methods should be retired, and "Rest In Peace".

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[i] Waters, Ken, "Developing Pet Loads", Handloader Magazine, Sept 1982, p6a
[ii] Hodgdon Powder, No. 27 Data Manual, 1998, section 5, page 3.

[iii] Ackley, P.O., Handbook for Shooters and Reloaders Vol I, 1962, page 149.
[iv] Ackley, P.O., Handbook for Shooters and Reloaders Vol II, 1966, page 70.
[v] Bramwell, Denton, "Correlating PSI and CUP", The Varmint Hunter Magazine, #46, April 2003, p66.
[vi] Bramwell, Denton, "Measurement Precision: What Tools Can You Trust?", The Varmint Hunter Magazine, #47, July 2003, p92.
[vii] For product details, see http://www.shootingsoftware.com/
[viii] Ackley, P. O., Handbook for Shooters and Reoladers Vol. I, 1962, p197-202
[ix] Some readers may note that the strain gage system used to test peak pressure has some random noise, too, so it is wrong to attribute all the error to the PRE or CHE method. That is correct. However, because the error in the PRE and CHE methods is much larger than that of the strain gage, and because of the non-linear way that standard deviations add, the contribution of the strain gage system to the total variation is very small.