Compression Ratios And Cylinder Pressure Testing In N-Series Tractors

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Compression ratios, compression testing and cylinder pressures often seem to be sources of confusion. Ford maintenance literature itself has contributed to this with some of the figures in an often reproduced table (see Table 1) for the 8N engine. It is hoped that the following will help clarify matters.

When we see a published compression ratio (CR) for an engine, this figure is usually a so-called "static" CR. It is simply the ratio of "swept volume" of one cylinder to its combustion chamber volume when the piston is at Top Dead Center (TDC). The swept volume is the area of the cylinder bore multiplied by stroke length. In the 8N, for instance, the swept volume of one cylinder is about 30 cubic inches. Although static CR is a useful number, as we will see it is not quite the same as the effective CR under cranking or running conditions. Further, you can't get directly from static CR to an equivalent pressure reading when doing a compression check. Let's see why.

Atmospheric pressure on an average day at sea level and 60 degrees F is 760mm or 29.9 inches of mercury, equivalent to about 14.7 PSI. This is known as Standard Temperature and Pressure, or STP. It seems reasonable that the published 8N compression ratio of 6.2:1 therefore should yield a maximum cylinder pressure of about 91 PSI (6.2 X 14.7). However, compression of a gas also raises its temperature, which increases the maximum cylinder pressure. Based on textbook data, the increase is equal to $\mathbf{CR^{0.28}}$ (i.e., compression ratio raised to the 0.28th power). Thus, our pressure of 91 PSI for a static CR of 6.2:1 should be raised by a multiplier of 1.67 to a value of about 152 PSI. Why don't we see such values on a compression test even in a good engine? There are several reasons, but two of the main ones are as follows.

1) First, the intake valve does not actually close at Bottom Dead Center (BDC), the downward limit of piston travel on the intake stroke. Instead, this occurs several rotational degrees later when the piston is already partway up the cylinder on the compression stroke. (How far varies with how "hot" or "mild" the cam profile is.) At normal engine running speeds there is enough air-fuel flow and inertia to partially overcome this. But at cranking speeds the lower flow rate means that pressure does not increase much until the intake valve closes. In other words, the CR when cranking is effectively less than the specified static figure, and resulting cylinder pressure is lower.

2) The compression tester itself has a certain volume that must be filled to register peak pressure. This in effect increases the combustion chamber volume, also reducing the compression ratio by some amount and reducing the peak pressure read on the gauge. Keep in mind also that most compression testers are not exactly precision instruments. An accuracy of $\pm$ 5 to 10 percent is probably the best we'll usually see.

A useful rule of thumb states that cylinder pressure in an engine in good condition with a mild or "street-type" cam should range (at sea level or a little above) from 17 to 20 times the specified compression ratio. If we take the average of 18.5 and apply it to the 6.2:1 CR of the 8N engine, we arrive at a rounded value of 115 PSI. This is what Ford specifies as nominal for this engine in new condition at a cranking speed of 120 RPM.

Similarly, if we apply the same rule to the 134-inch OHV engine introduced in the NAA with a CR of 6.6:1, we arrive at a nominal cylinder pressure of 122 PSI for an engine in like-new condition.

Now let's consider the often reproduced compression table published by Ford for the 8N engine (see Table 1 below). It seems somebody goofed. The barometric pressure figures are not in Lbs as labeled, they're in inches of mercury. Further, minimum acceptable pressure numbers should go down with increasing altitude, not up. Atmospheric pressure is inversely proportional to altitude and drops about 0.5 lbs/sq.in., or 3.4%, for each 1,000 feet increase in altitude. (It's not quite linear, but close from sea level to about 20,000 feet.) Therefore, cylinder pressures should go down in the same proportion.

COMPRESSION			
Compression Ratio 6.2 to 1			
Cranking Speed 120 RPM (all spark plugs removed)			**W. O. T.**
Altitude	**Cylinder Compression**	**Barometric Pressure**	**Min. Press.**
Sea Level	115 Lbs.	29.92 Lbs. (Approx.) at 60^0 F	86.8
1000 Ft.	111 Lbs.	28.8 Lbs. (Approx.) at 60^0 F	90.
2000 Ft.	108 Lbs.	27.7 Lbs. (Approx.) at 60^0 F	92.7
3000 Ft.	104 Lbs.	26.7 Lbs. (Approx.) at 60^0 F	96.
4000 Ft.	99 Lbs.	25.7 Lbs. (Approx.) at 60^0 F	100.9
5000 Ft.	94 Lbs.	24.7 Lbs. (Approx.) at 60^0 F	106.2
6000 Ft.	90 Lbs.	23.8 Lbs. (Approx.) at 60^0 F	111.
7000 Ft.	87 Lbs.	22.9 Lbs. (Approx.) at 60^0 F	114.8
8000 Ft.	81 Lbs.	22.1 Lbs. (Approx.) at 60^0 F	123.3
9000 Ft.	78 Lbs.	21.2 Lbs. (Approx.) at 60^0 F	128.1
10000 Ft.	74 Lbs.	20.4 Lbs. (Approx.) at 60^0 F	135.

Table 1. Original Ford 8N Compression Specs (from Ford service literature–see text)

If we start with the specified figure of 115 PSI at sea level, the cylinder pressure at 5,000 feet should be about 95 PSI. At 10,000 feet it should be around 75 PSI. These figures are consistent with those shown in the Cylinder Compression column of the Ford table, which does indeed show the drop in pressure with increasing altitude.

It's in the Min. Press. column where the trouble begins. It appears that the pressure differentials related to altitude may have been added instead of subtracted. Based on the sea level figures, Ford's stated minimum acceptable pressure is about 75% of the nominal or "new-engine" value. Using this factor, minimum pressure at 5,000 feet should be not less than about 71 PSI, and at 10,000 feet about 56 PSI. (Values for other altitudes are shown in Table 2.)

The W.O.T. notation means Wide Open Throttle. Compression tests should be done with the carburetor throttle plate open to assure unrestricted air flow into the cylinder being tested. If not, readings may be erroneously low. Ford also specifies that all plugs should be removed to reduce the load on the starter and provide for maximum cranking speed. It's also a good idea to shut the fuel valve and drain the carb during these tests; we don't want volatile fuel mixture flying around.

Table 2 below lists corrected figures for minimum acceptable cylinder pressures for the 120 cubic inch flathead engine (8N, etc) at increasing altitudes. It also includes derived figures for the later 134 cubic inch OHV engine (NAA and Hundred series) based on the slightly higher compression ratio and Ford criteria for minimum acceptable pressures. Pressure figures have been rounded to the nearest whole number, since fractions of a pound in this case are not at all significant.

COMPRESSION TEST SPECIFICATIONS					
Cranking Speed 120 RPM (all spark plugs removed, W.O.T.)					
Atmospheric Conditions		**120 CI Eng. (8N, etc.) CR 6.2 to 1**		**134 CI OHV Eng. (NAA, etc.) CR 6.6 to 1**	
Altitude	**Barometer (in. Hg at 60^0 F)**	**Std. Cylinder Compression**	**Min. Press.**	**Std. Cylinder Compression**	**Min. Press.**
Sea Level	29.9	115 Lbs.	87 Lbs.	122 Lbs.	92 Lbs.
1000 Ft.	28.8	111 Lbs.	84 Lbs.	118 Lbs.	89 Lbs.
2000 Ft.	27.7	108 Lbs.	81 Lbs.	114 Lbs.	86 Lbs.
3000 Ft.	26.7	104 Lbs.	78 Lbs.	110 Lbs.	83 Lbs.
4000 Ft.	25.7	99 Lbs.	74 Lbs.	106 Lbs.	80 Lbs.
5000 Ft.	24.7	95 Lbs.	71 Lbs.	101 Lbs.	76 Lbs.
6000 Ft.	23.8	91 Lbs.	68 Lbs.	97 Lbs.	73 Lbs.
7000 Ft.	22.9	87 Lbs.	65 Lbs.	93 Lbs.	70 Lbs.
8000 Ft.	22.1	83 Lbs.	62 Lbs.	89 Lbs.	67 Lbs.
9000 Ft.	21.2	79 Lbs.	59 Lbs.	85 Lbs.	64 Lbs.
10000 Ft.	20.4	75 Lbs.	56 Lbs.	80 Lbs.	60 Lbs.

Table 2. Corrected Cylinder Pressures For 8N and Added Data For NAA Tractors

Finally, let's consider what a typical compression test might reveal. First, it is well to remember that these numbers are guidelines. Variations of a few pounds in either direction are usually not significant. The main value of a compression test is that it is a relatively easy way to gain some idea about the condition of an engine's rings, cylinder bores, and valves without tearing the engine down. Obviously this can be useful when you're considering purchase of an old tractor.

If the pressure on all cylinders is fairly uniform and not too low, this is usually a sign of an engine with only normal wear. A pressure variation of 8 to 10 percent from the lowest to the highest cylinder is usually considered acceptable. If abnormally and uniformly low, it usually means an overhaul is needed due to out-of-limits wear, but it could also mean that the rings might be stuck due to a buildup of varnish. If pressure is abnormally low on only one cylinder, it often indicates a burned and/or warped valve, also meaning a teardown is in order. It could also indicate a blown head gasket in an otherwise reasonably sound engine. These are not all of the possibilities but are fairly representative.

Compression tests can be even more meaningful when supplemented by other diagnostics. As a first step, for example, it is always wise to "read" the sparkplugs and make notes on their condition and the cylinder from which each plug came. Heavy carbon deposits on plugs (usually indicating an excessively rich fuel mixture from a misadjusted carburetor) may point to similar buildups in combustion chambers which can skew compression readings. Similarly, heavy oil-fouling adds support for a diagnosis of worn cylinder bores and/or piston rings suggested by low compression readings. *(Note: An illustrated article on reading sparkplugs appears elsewhere in the How-To section.)* Taken together, these diagnostics provide valuable insight into an engine's condition short of a teardown and indicate when an overhaul may be needed.