TORQUING A BOLT
Why?
What Does It Do?
How Much?
What Are Variables?
What Kind of Equipment?

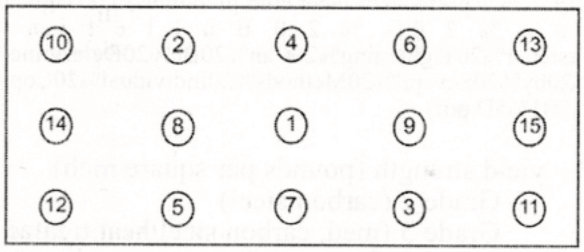
A recent query set me thinking: "What is the head bolt torque for my '35 Lafayette, flathead six, and what is the manifold bolt torque?"

My response was essentially a basic one: "Bolt torque is based, not necessarily on application, but on bolt type, threads/inch, grade of bolt and bolt diameter…." And as important as torque is the technique for tightening head bolts and manifold bolts.

Torque is measured in several units: inch-pounds (in-lbs), foot-pounds (ft-lbs), newton meter (N•m) or the unit joule per radian. The inch-pound measurement is the force in pounds along a one-inch lever. The foot-pound is the force in pounds along a one-foot long lever. It is possible to convert between the two units by multiplying or dividing by twelve. The metric measurements are a newton meter (also known as a 'moment') which is equal to the torque resulting from a force of one newton applied to a lever one meter long. The joule is a derived unit of energy or work in the International System of Units. It is equal to the energy expended in applying a force of one newton through a distance of one meter.

Too much torque – that is over-tightening a bolt – can cause the metal to crack (the metal of the parts being fastened or the bolt itself), sometimes from the direct pressure of the bolt and sometimes by the expansion of the metal. Without room for expansion, the metal can crack. Too little torque – too loose a bolt – is just as bad. Vibration between the parts, leakage of liquids or gases, and further loosening of the bolt are several of the resultant problems.

The correct method for tightening a head or manifold is often given in the owner's service manual or a text like Chiltons or Motors Manual. They offer torque values and tightening sequence. But often, especially for older cars – pre-1935 or so – the information just isn't readily available. The correct technique for tightening heads or manifolds is to apply even pressure, alternating from the center to the ends, working progressively from the center and side-to-side and toward the ends. Picture the rocker on the bottom of a chair. Begin at the center, tighten slightly, from left-to-right and right-to-left, alternately to the ends. Then go back and start all over, tightening just a little more than the first time. Continue this process in a minimum of three steps or as many as five, until the correct torque value is reached. But without a chart, how can you determine the correct torque value?



The correct sequence for tightening a compression head slowly and equally applies pressure from the center to the sides and toward the ends.

Please don't think of a bolt as merely a fastener. It is much more than just the male threads of the bolts engaging with the female threads of the nut (or tapped hole) that firmly holds the two parts together. You wouldn't realize just to look at a $^{7}/_{16}$" or a ½" bolt, but they are flexible. They stretch, they twist and they intentionally deform. And that is the secret of torquing a bolt. There is an engineering formula with which to determine torque, but frankly, for most of our work, it is not necessary – nice to know, but not necessary. (There are specialty bolts that are designed not to stretch. We will not deal with them.)

$T = K \times D \times P$: T represents (torque), K is the friction coefficient (see explanation below), D the nominal bolt diameter and P the desired tensile strength of the bolt (generally 75% of yield strength). (see below)

K – friction coefficient – the increased resistance of the bolt to its mating surface results in a higher coefficient. The less resistance due to lubrication or special finishes can reduce the coefficient factor. A lubricated bolt can require less than 50% tightening torque of a dry bolt:

Hot dipped galvanized, clean and dry = approx 0.23

Zinc plated, new, dry bolt = approx 0.22

Plain finished, new, dry = approx 0.20

Clean, rust-free with a very thin film of oil approx. 0.15 – 0.20

Additionally lubricated bolt – oil, wax, or dissimilar plating = approx. 0.10 to 0.15

High-performance lubricants or anti-seize compound = as low as 0.05

(A much more comprehensive chart of 'K'factors may be found on the Industrial Fastener Institute's website: http://www.porteousfastener.com/pfconline/PDF/Tightening%20-%20Bulletin-Fastener%20Tightening%20Can%20Be%20Determined%20by%20Several%20Methods%20Individual%20Copy%5B1%5D.pdf)

P – yield strength (pounds per square inch)

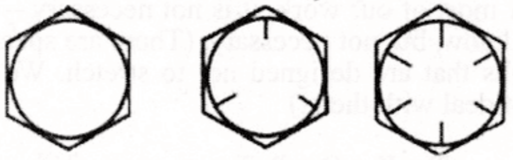
Grade 2 (carbon steel)

Grade 5 (med. carbon steel/heat treated – quenched and tempered)

Grade 8 (med. carbon alloyed steel – quenched and tempered)

Hex-headed bolts are readily identified as to grade by markings, or lack thereof, on the head of the bolt. No markings is a grade 2 bolt; 3 radial lines indicate a grade 5 tempered bolt, and 6 radial lines indicate a grade 8 hardened and tempered bolt. The torque required to 'stretch' a grade 8 bolt is much greater than that required for a grade 2 bolt.

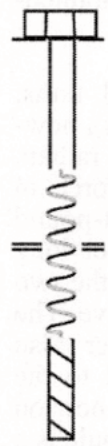
BOLT (in) YIELD (lbs) TENSILE (lbs)



GRADE 2 GRADE 5 GRADE 8

SIZE	STRENGTH	STRENGTH (75% of yield strength)
GRADE 2		
¼	1,750	1,313
5/16	2,900	2,175
3/8	4,250	3,188
7/16	5,850	4,388
½	7,800	5,850
9/16	10,000	7,500

SIZE	STRENGTH	STRENGTH (75% of yield strength)
GRADE 5		
¼	2,700	2,025
5/16	4,450	3,338
3/8	6,600	4,950
7/16	9,050	6,788
½	12,050	9,038
9/16	15,450	11,588
GRADE 8		
¼	3,800	2,850
5/16	6,300	4,725
3/8	9,300	6,975
7/16	12,750	9,563
½	17,050	12,788
9/16	21,850	16,388



As a bolt is tightened, it stretches. Essentially the bolt becomes a 'spring' and the tension of the stretched bolt against its mating surface provides the holding power. The tension created by the stretching is known as preload or 'yield'. The tightening torque (or torque-to-yield) is the suggested amount of pressure (in foot pounds or inch pounds) to be applied to the bolt to stretch it to its optimum level. Stretching beyond this point moves the material from the 'stress' phase into the 'strain' phase. Too low a torque will not provide maximum holding power; too much will over-stretch, or 'strain' the bolt, weakening, or even cracking it. It can also distort the bolt so that the elasticity is exceeded and the bolt will not return to its normal limits. The harder the bolt the more torque is required to stretch it to the desired level. (Grade 2 steel is considered, for our purposes, the softest material, and Grade 8 alloyed steel is considered the hardest. There are, of course softer materials – brass, aluminum – and harder materials – specialty and aerospace grades.) A lock washer, itself a spring, is often installed between a bolt head and tapped hole, or between the nut and the load being fastened. The lock washer exerts a pressure against the bolt head (or nut) minimizing the chance that the bolt (or nut) will work loose. Neither a lock-washer, nor a chemi-

The spring pressure of a lockwasher simulates pre-load but is not a replacement for proper torquing.

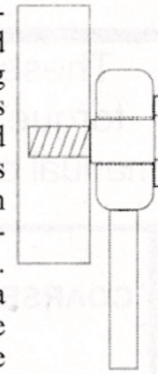
cal thread locker will replace the preload necessary for maximum holding power.

This information offered is for new bolts. Previously used bolts have been stretched; they do not fully recover, and torquing them will not necessarily provide the correct amount of stretch and therefore holding power. Rusted or otherwise corroded bolts cannot be considered (even if cleaned, wire brushed or otherwise having removed signs of corrosion) because the constituents of the steel have been altered, the steel possibly weakened, and pits, abrasions or other imperfections almost invisible to the naked eye exist, making the bolt's value questionable. Metal fatigue, in bolts 50, 60, 70 years old or oldermay have lost some of their strength.

An 'Anti-seize' compound is a semi-permanent lubricant which remains on the bolt. A 'Thread-Locker' compound acts as a lubricant to the bolt as it is tightened, but is designed to cure and dry, no longer acting as a lubricant but as an adhesive, gluing the bolt to its mating surface (the tapped hole or nut) and adding to the resistance provided by the 'stretch' of the bolt in preventing the bolt from working loose. Once a thread-locked bolt is removed, the seal is broken. The old thread locking compound must be removed - with a tap, die or wire brush - and new chemical applied.

Why is the stretching of a bolt desirable? Well, for one thing, especially in an engine or other automotive part that gets hot and then later cools, as the metal heats it expands; as it cools it contracts. This is known as cycling. Without adequate preload, each time the metal cools and contracts the bolt exerts less pressure on the two parts, allowing them, eventually, to loosen, to develop gaps, to leak, and eventually for the bolt to loosen and the parts to separate. By torquing a bolt to its optimum tensile strength (remember, tensile strength is 75% of the yield strength of the bolt) enough tension remains in the bolt as it, too, expands and contracts, keeping the fastened parts in tight contact with each other. Interestingly, although the predictable stretch and distortion of a bolt is very important, the nut is considerably less so. As long as the threads are clean, well cut and not stripped, the nut will do the job.

Up to this point we have been discussing parts which must be firmly bolted together so that they do not move. Another application is a bolt that holds two or more parts, at least one of which is designed to move. A shock absorber mounting bolt is an excellent example. Although the moveable part may have a yoke to facilitate the movement, pressure is still exerted against the bolt. The swinging motion of the moveable part tends to try to alternately loosen and tighten the bolt – if the preload is not adequate to keep the bolt from moving. In this case only a portion of the bolt is threaded. Perhaps the bolt has a shoulder – a diameter slightly larger than the threaded portion – or it may be just that the threads do not extend to the moveable part.



We indicated earlier that a new bolt is critical in determining optimum torque. But the condition of the mating surface – a nut or a tapped part – is just as important. Rust, stripped or distorted threads, or soft metal will all prevent the bolt from stretching properly. Replacing a bad nut is easy; replacing a stripped tapped part might not be as easy. If the threads are less than perfect, a couple of options exist. One is to retap the hole to a slightly larger size. This might entail re-drilling a number of holes and changing bolt size. Another option is to install a 'new hole' in the metal. A number of companies produce units that effectively put a new hole, with clean threads in place of the bad threads. One of the most popular brands is Heli-Coil®. Essentially, the bad hole is slightly enlarged, new threads tapped into the larger hole and a Heli-Coil® thread installed. The Heli-Coil® – the new 'hole' – has threads on both the outside and inside. The outside threads fit snugly into the enlarged and re-tapped hole, and the inside threads match the original damaged threads.

A Helicoil® - a 'new'thread - is screwed into an enlarged threaded hole. The crossbar shown in the illustration is broken off after installation.

IMPROVING ON DETROIT
Good or Bad? Warranted or Not?

Let us assume that you are working on your own engine. You are rebuilding it completely, or you are merely doing a valve job. But you do have the head off. Since you are putting a great deal of effort into the job, you want it to be right, or even better than just 'right.' When it comes to replacing the head bolts, you might consider new ones.

Replacing the old, used head bolts with new ones is a good idea. First of all, as discussed previously, a bolt 'stretches.' That's its job. Each time the bolt is torqued it stretches. But does it fully recover when the tension is released (when the bolt is removed)? I haven't been able to (yet) find a definitive answer to that question, but I am making an assumption that it does not. As discussed, if the bolt remains within the 'stress' range, it is likely to recover most of its original values, but over-stressing the bolt could move it to

These torque charts (in foot-pounds) may be used when specific torque values are not available in either a service manual, owners manual or repair manual such at Chiltons or Motors Auto Repair Manuals.

COARSE	STEEL (in Ft. Lbs.) SAE Grade 2			SAE Grade 5			SAE Grade 8					
	Plain	Zinc Plated	Waxed	Plain	Zinc Plated	Waxed	Plain	Zinc Plated	Waxed	Brass	Bronze	Alum.
1/4	6	6	3	9	10	5	13	14	6	5.1	5.7	3.8
5/16	12	13	6		19	21	9	27	29	13	8.9	6.7
3/8	21	23	10	33	37	17	47	52	24	16	18	12
7/16	33	37	17	53	59	27	76	83	38	26	29	19
1/2	51	56	25	82	90	41	116	127	58	35	40	26
9/16	73	81	37	118	129	59	167	184	84	47	53	35.5

FINE	STEEL (in Ft. Lbs.) SAE Grade 2			SAE Grade 5			SAE Grade 8					
	Plain	Zinc Plated	Waxed	Plain	Zinc Plated	Waxed	Plain	Zinc Plated	Waxed	Brass	Bronze	Alum.
1/4	7	7	3	10	12	5	15	16	7	6.4	7.3	4.8
5/16	13	14	6	19	21	9	27	29	13	9.7	10.9	7.2
3/8	24	26	12	38	42	19	54	59	27	18	20	13
7/16	37	41	19	60	66	30	85	93	42	27	31	20
1/2	57	63	29	92	101	46	131	144	65	37	42	27.3
9/16	82	90	41	131	144	66	186	205	93	51	58	38

the 'strain' phase which indicates a material distortion. I feel that each time a bolt is torqued, a degree of permanent distortion takes place. That means that the next time the bolt is torqued, the specified ft. lbs. might not stretch the bolt to its necessary preload. And the next time it is torqued, it will be even less. With a new bolt (or new studs) you will know that torquing to the specified ft. lbs is going to give you the correct preload for that bolt.

Let me muddy the waters a bit more. I have never seen a Motor's Manual or a Chilton's Manual call out the grade of bolt for a head. (Maybe I have just missed it, but I still haven't seen it.) I have to assume that the OEM bolt noted in the 1976 edition is a grade 5. I am basing this assumption on the 1976 Motor's Manual (grabbed at random) engine tightening specifications for a Chrysler Product and for an Oldsmobile. A head bolt is normally between $^7/_{16}$" diameter and ½" - they could be slightly smaller or slightly larger. Chrysler calls for a tightening torque of 70-95 ft. lbs, depending on application. Olds calls for 80-95 ft. lbs. Those figures fall right in the correct torque range for the Grade 5 bolts (see chart on previous page). An earlier edition, covering Chrysler 1935 to 1949, lists head bolt torque at 65 to 70, again within the Grade 5 range. It is interesting though, to read the text from the earlier edition: "*When using a torque wrench, the final tightening should be from 52 to 57 pound feet on nuts; 65 to 70 on plain head cap screws, and from 67 to 72 pounds feet on cupped head cap screws. The lower limit is for clean and oily threads and the high limit is for clean and dry threads.*"

Replacing the original head bolts with a grade higher (Grade 8, for example) or a grade lower (Grade 2 or 3) and continuing to use the specified torque as called for in the abovementioned manuals, or in the service manual, will result in too little torque resulting in inadequate holding power, or too much torque leading to premature failure. If the original head bolts are marked (see grade marking designations on page 33) be sure to use the same grade in a new bolt, and if you increase or decrease the grade, adjust the torque to fit the new grade of bolt.

It is interesting to note that the later edition of Motor's (1976) includes a complete chart of torque values for various engine parts:

"Spark Plugs Ft Lbs
Cylinder Head Bolts Ft Lbs
Intake Manifold Ft Lbs
Exhaust Manifold Ft Lbs
Rocker Arm Shaft Bracket Ft Lbs
Rocker Arm Cover Ft Lbs
Connecting Rod Cap Bolts Ft Lbs
MainBearing Cap Bolts Ft Lbs
Flywheel to Crankshaft Ft Lbs
Vibration Damper or Pulley Ft Lbs

(NOTE - footnotes for selected applications for Intake Manifold, Exhaust Manifold, Rocker Arm Shaft Bracket, and all applications of the Rocker Arm Cover are in Inch Pounds.)"

MEASURING TORQUE

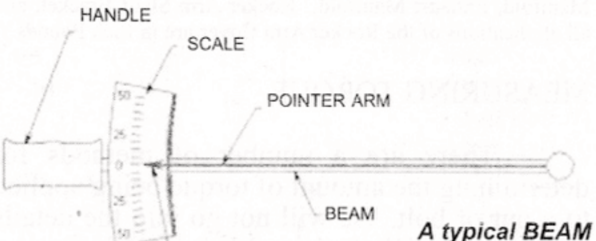
There are a number of methods for determining the amount of torque being applied to a nut or bolt. We will not go into the details of the professional or production equipment or techniques. Strain gauges and motorized electronic torque testers are connected to computers that relate the amount of torque. They are too sophisticated (and expensive) for our shops.

We are generally limited to using one of two methods: user feel or a torque wrench. In the hands of an experienced expert, user feel is pretty effective, but it takes a lot of experience and a lot of mistakes to reach that point. Normally user feel has about a 35% margin of error. Not really acceptable when working on your car. There are three basic styles of do-it-yourself torque wrenches. Torque wrenches are simply tools for measuring resistance to rotation. The first, least expensive but dependable nevertheless, is the beam wrench. The beam torque wrench was invented for automotive use by none other than a fellow named Walter P. Chrysler.

The second type of torque wrench is known as a 'clicker.'

The third type, the newest and most sophisticated, is an electronic, digital torque wrench.

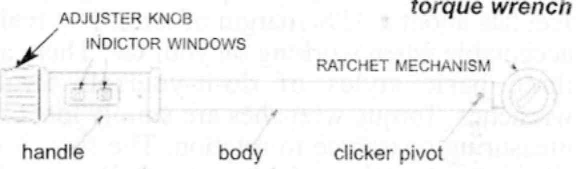
The BEAM torque wrench: The beam design is relatively simple, and is accurate for both left-hand and right-hand threading. The socket head holds two steel beams: a primary beam and an indicator or pointer beam. The primary beam deflects as the handle is pulled. The separate pointer beam remains un-deflected, and the primary beam below flexes and moves with the handle. The reading is taken at the end of the pointer, at the reading plate on the primary beam. The handle is moved until the desired reading is attained. These wrenches rarely require re-calibration. If the pointer needle is not pointing to zero when the tool is at rest, it is simply bent back until it does align. As radial pressure is applied to a nut or bolt, a lever moves indicating the amount of torque against a scale. Primitive? Perhaps, but still pretty effective and inexpensive.



A typical BEAM torque wrench

The CLICKER torque wrench: A calibrated internal clutch can be set at the desired amount of torque. When that level is reached, a clicking sound is heard, indicating that the desired torque has been reached. A dial-adjust system allows desired torque setting to be preset. Normally the clicker wrench does not have a dial or direct-read gauge.

A typical CLICKER torque wrench



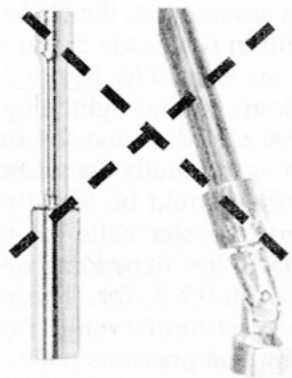
The ELECTRONIC DIGITAL torque wrench, the newest addition to the range of this handy tool, allows the user to program an exact torque value (or values) into the wrench. Most of the electronic wrenches have a digital readout window as well as an audible signal indicating that the desired torque level has been reached.

A typical ELECTRONIC torque wrench

Using a torque wrench requires a little practice to get accurate results. There are also a number of factors that can seriously affect proper torque. Whether using a beam or clicker torque wrench or an electronic wrench, smooth, steady pressure is necessary. Jerky, erratic application of pressure is liable to give inaccurate results. Most torque wrenches are designed to be pulled toward you, not pushed.

A torque wrench is essentially a holder for a socket; if the socket is a sloppy or loose fit (like a worn 12-point socket on a partially rounded-off bolt head) it will give inaccurate results. If the square end of the wrench – either $^{3}/_{8}$" or ½" – does not fit snugly into the socket, poor results may be obtained.

A torque wrench is designed to measure radial pressure. Anything that interferes with a direct, positive measurement of the pressure around the axis on a nut or bolt head can result in inaccurate readings. For example, using an extension between the wrench and the socket, unnecessarily using a deep socket, or using a swivel between the wrench and socket can all alter the actual reading, often radically.



Anything that affects the direct reading of the pressure around the axis of the bolt shaft must be eliminated for accurate results.

WHAT IS TORQUE-ANGLE?

Torquing (in foot-lbs or in inch-lbs) measures the friction between a bolt and tapped hole or nut. It is designed to provide optimum pressure between the two surfaces depending on the size and material or the bolt.

Torque-angle is a visual indication (obtained by using a torque-angle adapter or a special torque-angle wrench). It is a much more accurate indication of how much the bolt has stretched after reaching the yield point. Unfortunately, virtually no old car/truck manuals offer torque-angle information. Stick with plain old torque. It has been accurate for years and is really all we need for old old cars.

MAINTAINING A TORQUE WRENCH

A torque wrench is a delicate instrument. It must be treated with care and used only for the purpose that it is intended. Do not use it as a hammer, or a pry bar or ??? When not in use, the torque wrench should be kept dirt- and grease-free and stored in its protective case.

As indicated, a beam wrench requires no special recalibration. If the pointer does not indicate 'zero,' just bend it slightly until it points to '0'.

But the clicker and the electronic wrenches are much more sophisticated mechanisms. In order to assure an accurate reading, a clicker or an electronic torque wrench should be professionally calibrated once a year.

Dropping a wrench, or using it or exposing it to heavy work means that calibration must be done more often.

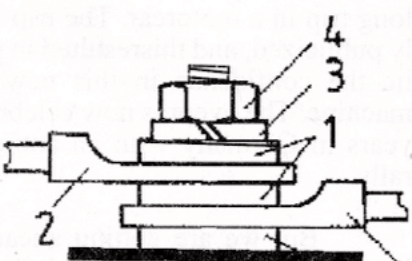
WHAT HAS TO BE TORQUED?

Torquing is imperative for any fastener that is not supposed to loosen on its own. We normally think of head bolts, head studs, manifolds, steering and other heavy mechanical fasteners. Although it doesn't often happen, even light screws - #8, #10 and #12 – should be torqued so that they do not loosen and so that too much pressure is not applied to the fastened parts. Almost no one does it, but spark plugs should be torqued when installed. In an article in our December 2011 issue on Champion spark plugs the manufacturer offers the recommended torque values for various sized plugs.

Over the years the idea has been drummed into us: "You must torque and retorque head bolts." When we work on an engine's head, we almost automatically reach for the torque wrench. But why not torque the transmission, or the wheel studs (actually a very important and ignored need for torquing), or body bolts. Small torquing tools are available for those smaller jobs – ¼" drive torque wrenches and torque screwdrivers.

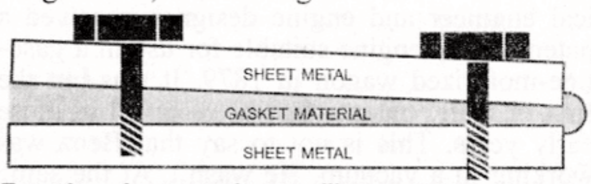
A torque screwdriver is a handy tool for measuring radial tension of screws.

Another very important, and virtually always ignored, need for torquing is on electrical connections. Loose electrical connections are probably the greatest bane of our (automotive) existence. Chances are when searching for a short or an electrical problem, you have stuck your hand behind the instrument panel, felt around and wiggled wires. Those that move - and there always seem to be one or more - are suspect. Torquing the nut and/or using lock washers will often minimize this problem.



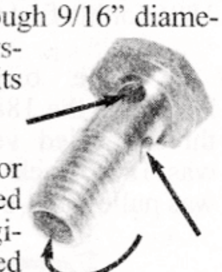
1- WASHERS, 2- ELECTRICAL LUG OR CABLE ENDS, 3- LOCK WASHER, 4- STUD NUT.

Sometimes though, we should not torque a nut or bolt. Can't think of an example? When two parts have to be joined with a gasket in between, like an oil pan or a valve cover, torquing a bolt is liable to apply too much pressure and could squeeze the gasket out, or at the very least, distort it. The cushioning of the gasket, whether a pre-cut gasket or a chemical gasket, helps it do its job – keeping liquids or gases in or out. With sheet metal it is imperative that the surfaces be dent, wrinkle and distortion free. Place the surface of the sheet metal against a piece of glass to check for flatness. The gasket or gasket material will often fill very small irregularites, but not larger ones.



Torquing sheet metal parts, like an oil pan or a valve cover, can result in too much pressure often squeezing out the gasket from between the sheet metal.

Often a special purpose bolt should not be torqued to normal specs. Although 9/16" diameter, since the bolt (Ford EGR system) is hollow and drilled, its strength is compromised.



Torquing a wheel nut or lug is critical. Since a strained bolt will not return to the original size, and the lugs are re-used regularly, over-torquing, with the resultant stretching can irrepairably damge the lug bolt. Do not overtighten.

Our cars are important to us. Why take shortcuts when, for just a couple of minutes more, we can do the job properly by applying the correct torque to a bolt, regardless of application?

S.K.

See 'Unusual Products' on two new, electronic torque wrenches from the Eastwood Company, page 21.