Chassis Alignment Basics

By Dr. Rob Tuluie, May. 23, 2005

Editor's Note--This story is part of the "Wrenching with Rob" series, in which Vintage Editor and Technical Writer Dr. Robin Tuluie discusses, in depth, technical and theoretical topics that make motorcycles function. This time the focus is on motorcycle chassis basics, in particular on how to do your own wheel and chassis alignment. Today, Rob covers parts (1) Aligning Wheels, and (2) Determining if the wheels are in one plane, in addition to a quick review of basic chassis terminology. In the next installment of "Wrenching with Rob - Chassis Alignment Basics," Rob will cover parts (3) Determining if the sprockets align, (4) Checking whether the frame and swingarm are straight, (5) measuring chassis specifications, and (6) what to do if your motorcycle isn't straight.

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As I've set out to cover a large part of motorcycle technology - more or less everything to do with motorcycle chassis technology - and I think it is quite important to clearly define all the terminology and geometry right from the start. As you will see there are not a lot of definitions, but a clear understanding of these basic terms is essential for an understanding of what's to follow.

First there are the geometrical definitions. These dynamical measurements determine how the bike behaves while being ridden.

WHEELBASE:
The distance between the centers of rotation for the front and rear wheels - that is, the distance between the front and rear axle. Typical numbers are 55 to 58 inches for mid-size and larger street sporting motorcycles, 52 to 54 inches for 250 or 500cc Gran Prix bikes and just under 50 inches for 125cc GP bikes. Choppers, as well as the infamous Bohemia motorcycle (a Czech-made, 3-seated behemoth) can easily double these numbers!

WHEEL ALIGNMENT: (1): In the most basic form it means that the front and rear wheel are in-line. That is, they point in the same direction and are not offset from each other. (2): A more constraining definition of the term also requires that both wheels are in the same plane. That is, one wheel is not vertically tilted with respect to the other. On a motorcycle that is not properly set up or has a bent frame, forks or swingarm (1) can be true without (2) being the case. This is illustrated in figure 1.

SPROCKET ALIGNMENT: Exactly the same definitions as for WHEEL ALIGNMENT, but now concerning the gearbox and rear wheel sprockets of the bike.

RAKE: The angle of inclination with respect to the vertical of the axis of rotation about which the front wheel is turned during the steering process. This is usually the angle with respect to the vertical of the steering head of the frame, but not always. For example, if eccentric bearing cups are used in the steering head to alter the angle between the steering head and the steering stem of the triple clamps, than the rake is the inclination with respect to the vertical of the steering stem. The definition of the rake via the axis of rotation is always true and even applies to non-conventional designs. Typical numbers range from about 20 to a little over 30 degrees, the former for GP-racers and dirt bikes, the latter for cruisers and most vintage bikes. Note however that a relatively well-handling motorcycles have been built (most notably by Toni Foale, a 1970s chassis specialist) with much steeper steering head angles (i.e. a much smaller rake angle).
TRAIL: The distance, as measured along the ground, of the point at which the front tire contacts the ground and the axis of rotation (see above) would contact the ground. For a conventional design this means visualizing the continuation of an imaginary line through the center of - and parallel to - the steering head tube that extends to contact the ground a few inches in front of the bike. Then, simply measure the distance between this contact point and the center-point of the tire's contact patch (vertically straight down from the front axle). Note that in an accurate measurements of trail, the wheels need to be aligned as defined above (see figure 2 below).
OFFSET: The perpendicular distance between a line drawn through the centers of the fork tubes and the steering stem center of a triple clamp. The trail is a linear function of the offset of the triple clamps: More offset will yield less trail and vice versa. However, zero offset will not yield zero trail. In that case the trail is a function of the rake and the diameter of the front tire only. The geometry is shown in figure 2. Sometimes the top and bottom triple clamps do not have the same offset. In that case the trail and wheelbase (but not the rake!) are altered. Also, if the center of the

front wheel axle is not in the center of the fork tube as viewed from the side of the bike, then this is equivalent to a change in the offset (and thereby the trail) of the bike.
CENTER-OF-GRAVITY: The center of mass of the entire motorcycle, without rider. Usually located somewhat above and behind the crankshaft of the engine. The exact location of the center of mass is an important quantity in the design of top-level racing motorcycles. The vertical projection of the center of mass onto the ground (i.e. the point at which a vertical line drawn through the center of mass hits the ground) solely determines the static weight distribution between front and rear wheels of the bike.

RIDE HEIGHT: The height of the front of the motorcycle (typically measured from one of the triple clamps) and the height of the rear of the motorcycle. Changes in spring preload, tires, rear shock location or linkage, or changes achieved by moving the forks up or down in the triple clamps all change the respective ride heights. The true purpose of changes in ride height is to affect a change in the location of the center of gravity. Every change in front or rear ride height is primarily a change of the location of the center of gravity of both rider and machine relative to the ground. Other quantities, such as the inclination and length of the swingarm, the location of the swingarm pivot and the geometry of the chain run and sprocket centers are explained as we go along the mysterious road of motorcycle chassis technology.

Now let's get started with our first wheel alignment.

The outline is as follows: (1) Align wheels. (2) Check whether the wheels are in one plane. (3) Check whether sprockets align (4) Check whether the frame and swingarm are straight. (5) Measure chassis specs. (6) What to do if your motorcycle isn't straight. Required materials: Don't fret, this really is the poor man's chassis alignment method! You'll need some string, preferable some strong, brightly colored sewing thread. Also, little hand-held lasers (often used as pointers during lectures) can be used by those that think sewing thread is just too crude, but believe me, I have used both and the thread is just as accurate. Let me just mention right form the beginning this very crucial fact: You do not need to measure any more accurately than about 0.5 mm.The reason is that a typical laser aperture is about a millimeter (that is, the 'width' of the beam), not any better than what you get from sewing thread.

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Let me just mention right form the beginning this very crucial fact: You do not need to measure any more accurately than about 0.5 mm. The reason is that the wheels on many motorcycles are out of round by this much (or more sometimes!), even brand new ones. Especially once tires are mounted on the wheels, the actual tire surface is never perfectly aligned with the rim even if the rim were perfectly true. Hence this inaccuracy is inherited in *every* motorcycle and any attempt to measure anything to do with the wheels, frame or swingarm more accurately than this is meaningless. I regard claims of measuring machines or frame straighteners that have much higher accuracy than this as misleading, not because the machines don't, but because this superfluous accuracy is wasted and hence meaningless with regard to the errors induced by the wheels and tires.

So, that said, we can all agree that our sewing thread method of alignment will be as meaningful a measurement as any multi-thousand dollar machine can provide. It should also be clear that before you start any of these measurements, check to see if your wheels are true side-to-side. A runout of 1.0 mm is okay, while 2.0 mm is already to inaccurate, besides being a major factor in any possible handling problems you might be trying to solve.

Part (1): Wheel Alignment

Begin by placing the bike on it's center stand, or better yet, support it via wood or stone blocks from both sides as per figure 3.

Put a drop line - which consists of about 2 feet of your brightly colored sewing thread with a weight (a small nut, for example) tied on one end - on the top edge of the rear tire and a little backwards so that it clears the axle and swingarm. Depending on which side of the tire you've put the string, there will be a small gap between the bottom tire edge and the string. For later reference, call this gap `a_r'. For now, adjust the blocks under your bike so that this gap is small, say less than 2 mm. This doesn't have to be accurate yet. Now you've got the bike nearly vertical. Make sure the bike is secure as you'll be doing a lot of measuring and moving around and you don't want the bike to move during this. Turn the steering wheel so it points straight ahead approximately (we'll get it perfectly straight later).

Next string some thread from the back of the rear tire around the front tire and back to the rear tire again (see figure 1 again, posted below). Make sure that the string isn't touching anything else besides the tires! If it's touching the center stand or exhaust you'll need to move the string up or down along the tire. The higher up along the tire you can get the string, the better, but typically the highest one can get is maybe eight inches off the bottom of the tire before the string hits the brake disk or bottom of the engine. At worst, you'll have to remove some parts to gain the necessary clearance. Next straighten the front wheel by adjusting gap `b' in figure 1 to be the same on the left and right side of the bike. Measure the width of your rear tire and cut a piece of wood to this length (I find that a pencil works great for this). Now stick this pencil between the strings, just behind the front tire and perpendicular to the strings. The strings should be nice and tight and hold the pencil in place. If not, tighten the strings and use a piece of duct tape to hold the pencil against the front tire.

Now go back to the rear wheel and look down along the strings: Usually one string will be closer to the front edge of the rear tire than the string on the other side. Adjust the chain adjusters (take the chain off before) to move the rear wheel so that the gap `c' is the same on both sides. If the pencil is exactly the same length as the width of the rear tire, the gap `c' will be zero on both sides. Now go back to the front wheel. Remove the pencil and check whether gap `b' is still the same on both sides. If not, turn the steering wheel ever-so-slightly to make `b' the same on both sides. Stick the pencil back in (make sure it goes in symmetrically, so that it sticks out the same amount on each side), and recheck the alignment for the rear wheel. You may have to adjust the chain tensioners just a tad now, but once you've done this you're done with Part (1). Your wheels are now in-line!

Part (2): Determining whether wheels are in one plane

Now that your wheels are aligned, be very careful not to bump into the bike. Any slight perturbation of the motorcycle can move the handle bars and throw off all your previous work.

Next we'll do an easy, preliminary check to see if the frame and swingarm of the bike are not twisted, which the most common type of damage.

With the wheels aligned, put the drop line on the rear tire just as before, and measure gap `a_r' just as before. Also measure distance `s_r' in figure 3.

If the string touches on one side of the tire on both the top and bottom, move to the other side. There should be at least a small gap now. If not, the bike is perfectly vertical, so record a_r=0. Note that the bike doesn't have to be perfectly vertical! Don't attempt to readjust the bike to get a_r=0, it will only disturb the wheel alignment. Whether a_r=0 or not, it will not affect the accuracy of the measurement we're about to take. Next go to the front wheel and record a_f and s_f there.

It helps if s_r and s_f are the same. If this is not possible for your bike (it should be, though, follow part 2 (b) below). If s_r and s_f are the same, then take the difference and divide by s_f. This gives the angle theta by which the wheels are out of plane:

theta = 57*(a_r -a_f)/s_f

(b) if s_r and s_f are not the same:

theta = 57*(a_r/s_r - a_f/s_f)

Here the coefficient 57 is just the conversion factor form radians to degrees. It also doesn't matter what units you use for a_r, a_f and s_f, as long as they are all the same (i.e. either mm, cm or in, but no mix of them). This formula is the small angle approximation for sin(theta) and tan(theta) and valid here for angles less than approximately 5 degrees, which will always be the case here.

In fact, your value of theta should be between 0.0 and 1.5 degrees. If theta=0, then both wheels are in plane and most likely your chassis is perfectly straight. If theta is less than 1.0 degree, your chassis is not quite straight, or your wheel not properly spaced (in the swingarm), or your forks or swingarm are bent. However, if theta is no more than 1 degree, the "tweak" in your chassis is minor and will most likely be acceptable, even for racebikes. Sandy Kosman

once told me that they usually don't bother to straighten a bike unless theta is greater than 1.5 degrees, and my own experience with straightening frames and building chassis has shown this to be true.

If theta is considerably larger than 1.5 degrees then either you've goofed somewhere along the line of this measurement or you've got a problem.

Now, if you're a world-class racer and really good at picking up even the slightest chassis imperfections you'll probably notice theta=0.5 degrees. However, as long as theta is about 1.0 degree the chassis will be aligned well enough for most mortals. If theta is considerably larger than 1.5 degrees then either you've goofed somewhere along the line of this measurement or you've got a problem. I suggest re-checking the entire process, including the wheel alignment, as it is easy for the strings to hang up or touch against something and throw off your entire measurement. If you still have theta considerably larger than 1.5 degrees you'll need to find out what's wrong with your bike. This will be discussed in the next installment of "Wrenching with Rob".

In addition, the next installment of "Wrenching with Rob" will continue with (3) Checking whether sprockets align (4) determining whether the frame and swingarm are straight (5) measuring chassis specifications and (6) what to do if your chassis is bent.