Chapter ...6

Shock Absorbers

In this chapter we are going to take an in-depth look at the inner workings of shock absorbers. We will look at the differences of the basic shock types. We will follow the hydraulic oil on its many journeys inside the shock absorber. We will see how to arrange the shock valvings to give various types of damping forces. We will explain those funny little oval Shock Dyno Charts you may have seen in the road test sections of several motorcycle publications.

Before we go inside the shock, let's discuss why we need damping in our suspension system and how a shock absorber supplies damping.

In the earlier chapters of this handbook we explained the need for springs in our suspension system and how a myriad of different spring forces occur while the suspension is operating. We also learned a spring will give back the same energy put into it. If we don't want that energy to have an effect on the chassis, we must devise a method of consuming that energy. The damper (or shock) takes the energy stored in the spring and dissipates it gradually by pumping oil through tiny orifices and valves. These orifices create resistance to the flow of oil and that resistance becomes the damping force. The resistance through the valves converts the spring energy into heat and eventually the heat is distributed out of the shock into the surrounding air.

The key to a successful shock absorber is to match its resistance or control force to the force generated by the spring. **Be aware that different spring rates will require different shock absorbers.** A shock suitable for a heavy spring will overpower a light spring and suspension movement will be limited. Conversely a shock suitable for a light spring will not be able to handle a heavy spring and suspension movement will be excessive.

In actual practice damping also occurs as the spring is being compressed, and not just after it. Most shocks assist the spring by resisting movement during the compression part of the bump sequence. This has a two-fold advantage. First it keeps the suspension from overrunning or floating higher than the road obstacle, minimizing suspension travel. Secondly, compression damping has the effect of adding to the spring rate so a softer spring can be used. This means the shock will have less spring force to deal with on the return stroke.

There are many philosophies among shock manufacturers as to the proper amount and proportions of damping. Some believe no compression damping combined with stiff springs and a lot of rebound damping is the answer. (Compression or bump damping is the force generated while the shock is going together or being compressed. Rebound or return damping is the force generated while the shock is being pulled open or returning to its original state.) Others favor a substantial amount of compression damping with very soft springs and very little return damping.

After exhaustive testing we have come to prefer a damping ratio somewhere in between those two extremes. Both of the above philosophies work excellently in special types of conditions, but both have problems performing the full range of suspension requirements. The "no compression" concept has the problem of stiff suspension even at very low speeds. It has the same suspension rate at all speeds. This scheme is also prone to "pumping down" of the suspension, and the stiff springs put a heavy burden on the shock absorber during the rebound stroke. The "high compression" concept has limitations of an entirely different nature. Since damping force generally varies with the speed of the damper movement, if you use a lot of compression force for normal suspension speeds, you will likely get an excessive amount of damping force at high suspension speeds. This can cause suspension "lock-up" which can lead to a trip over the handlebars. Another problem associated with the combination is not enough spring rate to deal with situations where you encounter sustained "G" forces. These are found on bankings and long corners and at the bottom of large undulating "whoops" or "sand rollers." The effect on the motorcycle is one of slowly settling into the suspension until it either bottoms the suspension or grounds out on the underside. Needless to say, there is also no suspension left to deal with any further bumps.

The amount and proportions of damping control unfortunately don't provide a complete picture of a shock's damping characteristics. We have learned that the amount of force generated by a spring is proportional to how far it is deflected. A shock absorber is quite another animal. Its forces are related to how fast it is moved. In fact **as you pass oil through a fixed orifice its resistance will increase as the square of the velocity.** Luckily a "fixed orifice" describes a primary or fundamental shock absorber. Today's shocks have an elaborate system of valves that allow us to deviate from this "force squaring with speed" phenomena. Generally the shock internals are arranged to provide individual adjustments for each of the three speed ranges or stages (low, medium, and high speed). Additionally compression and rebound will each have their own set of valve stages bringing the total of stages to six. Some shocks have an even finer adjustment capability with more than six stages. S & W shocks are capable of eight stages in adjustment.

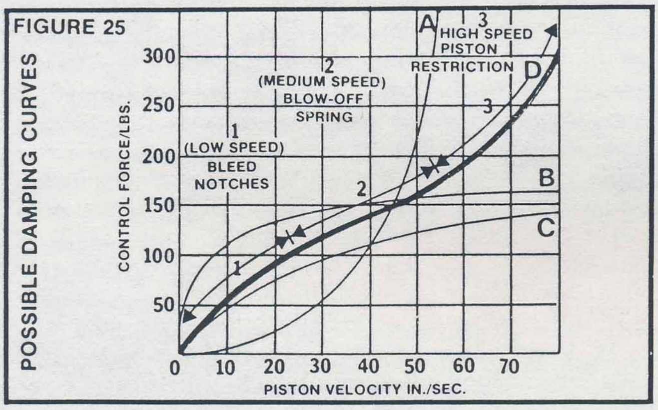
If you were to measure damping forces at various piston speeds with a Shock Dyno (more about Dynos later) and then plot those forces on a chart, you will see a **damping curve** that reveals how the shock reacts to changes in speed. **Figure 25** illustrates several variations of damping curves. The curves represent four distinct valving options. **Figure 26** illustrates those four different valving configurations. Valve type **A** correlates with damping curve **A,** Curve **B** correlates with **B** etc., etc. For simplicity we will illustrate the valve stages at the piston during the rebound stroke. The compression valving generally occurs at the basevalve and the manner in which the parts are arranged is very similar to rebound, but in miniature.

Curve **A** and valving **A** are the fundamental "fixed orifice" type. Notice the only parts creating resistance to oil flow are the holes passing through the piston. The size of these holes can be varied to change the resistance but in all cases there is little resistance until substantial piston speed is achieved. The curve demonstrates how the force builds up slowly but quickly escalates at the higher piston speeds. If you stroke this shock by hand it will feel as if there is no damping at all but in actual fact is has considerable damping at the speeds it will see when in use.

Suppose you decide valving **A** has not enough low speed damping and too much high speed damping. Valving **B** will produce damping exactly the opposite of valving **A.** In this instance we have arranged a blow-off valve to cover over the piston holes and backed it up with a spring. Now the oil cannot flow until the pressure is high enough to push open the blow-off valve. The point at which the blow-off opens is regulated by the load of the spring behind it. Once the valve is open the damping is again controlled by the size of the orifice through the piston. In valving **B** we have greatly enlarged the orifice to eliminate the excessive high speed damping. If you stroke this shock by hand it will be very difficult to move it, even though it really doesn't have as much damping as valving **A.**

Be careful about judging damping characteristics by how a shock feels when stroked by hand. The speed achieved by hand is lower than any speed the shock sees in service.

FIGURE 25



Now suppose valving **B** is too extreme and you would like damping somewhere in between valving **A** and **B.** Valving **C** is the same as valving **B** except we have added a **bleed notch** to the piston so some oil can flow before the blow-off valve is opened. Damping curve **C** shows that this change has brought the low speed damping right in between the first top options, but the damping does not rise up even as much as valving **B.**

In order to get the damping curve to continue higher than blow-off curve **B** we must arrange the valves like valving **D.** In this case the valve is exactly like valving **C** except we will use a stiffer spring to raise the blow-off pressure and reduce the size of the piston orifice to cause some further restriction at very high speed.

Valving **D** has all the necessary ingredients to gain complete control over the damping curve. Most shock manufacturers have a valve system very similar to that shown in valving **D,** sometimes the parts are arranged slightly differently like flexible spring disc shims in place of coil springs. Sometimes the entire system is a stack of spring disc shims like those found in the "De Carbon system." Whatever the system, there should be a provision to adjust each speed range independently. A typical shock system will have about ten different options for each of the adjustments, whether it is the bleeds, the blow-off valves, the spring discs, the blow-off spring, or the piston or base-pin restriction.

With that many options it is clear the damping curve can be tailored for just about any set of conditions. The pivotal difference between a good and bad shock is the amount of time and money and engineering each manufacturer has invested in learning the optimum valving combination for each application. S & W is proud of the fact that we have devoted time, money and talent to achieving the optimum application for today's motorcycles.

Now let's look at the paths the hydraulic oil takes during the compression and rebound strokes. If you read Chapter 5 of this handbook, the following text will sound familiar as the oil flow inside a shock is similar to the flow inside a front fork.

FIGURE 26

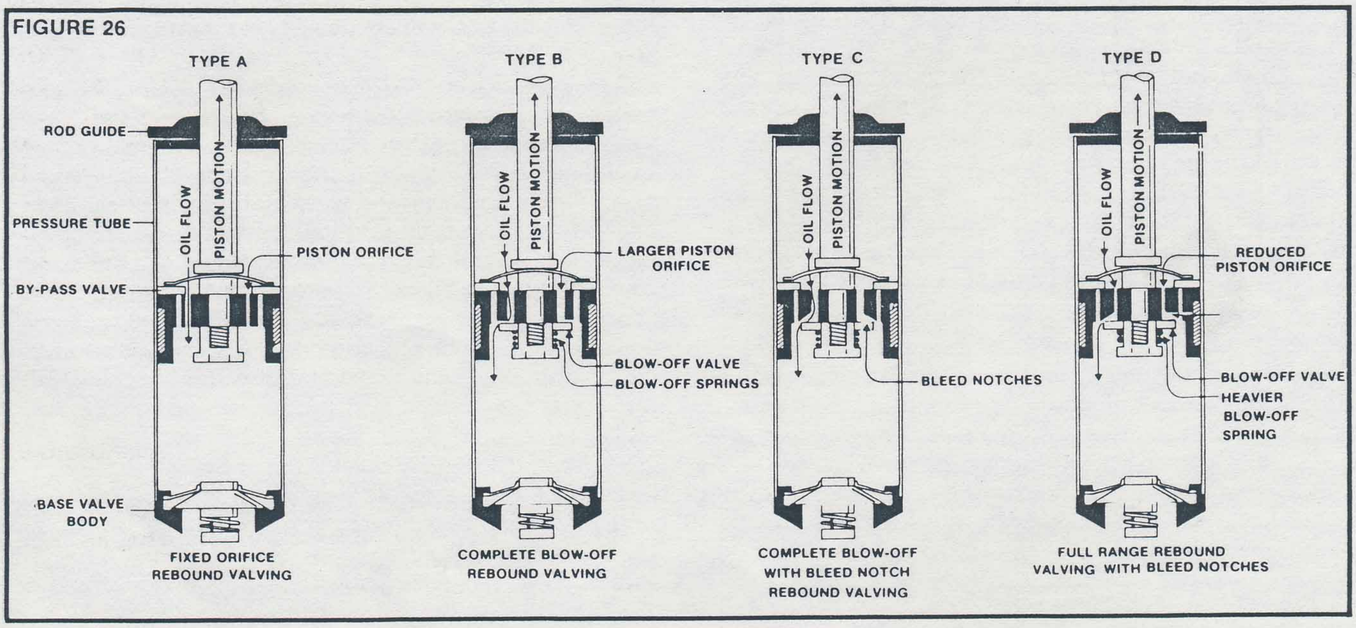


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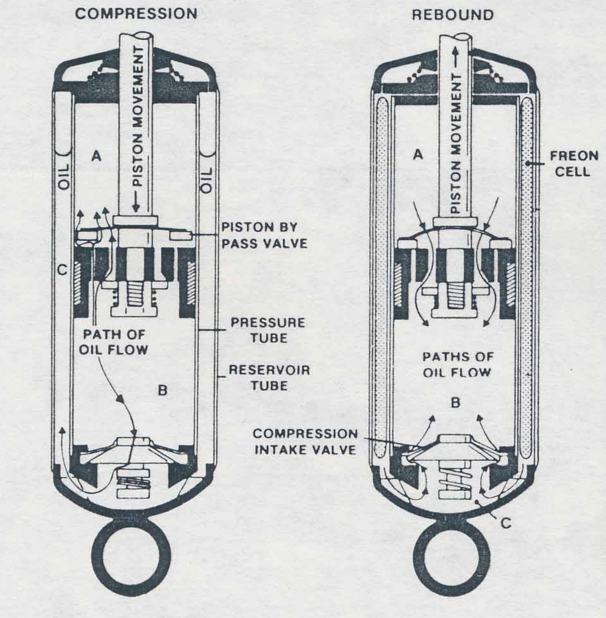
Figure 27 illustrates a conventional double tube type of shock in both compression and rebound cycles.

Compression: During the compression cycle the rod and piston move down in the pressure tube which results in a small pressure drop in the upper chamber (Chamber**A**). Simultaneously the volume of Chamber **B** is reduced causing high fluid pressure. The fluid, following the path of least resistance to correct the pressure imbalance, flows up through the piston's outer passages, unseating the piston by-pass valve, filling Chamber **A**. However, all the fluid originally in Chamber **B** cannot pass into Chamber **A** because the piston rod now displaces fluid. That volume of fluid displaced by the piston rod is forced down through the center of the compression valve and out into the reservoir (Chamber **C**). Compression control is the amount of force necessary to transfer the fluid from Chamber **B** to Chamber **A** and down through the three-stage compression valve at a given piston velocity. (Motorcycle shocks do almost all the compression control at the base valve.)

Rebound: As the piston and rod are moved closer to the top of the pressure tube, the volume of Chamber **A** is reduced and thus becomes the high pressure area. To correct the pressure imbalance, fluid flows down through the piston's three-stage rebound valve into Chamber **B.** However, the piston and rod have been withdrawn from Chamber **B,** greatly increasing its volume. Thus the volume of fluid from Chamber **A** is insufficient to fill Chamber **B.** The pressure in Chamber **B** thus falls below that in Chamber **C**, forcing the compression intake valve to unseat. Fluid then flows from Chamber **C** into Chamber **B** keeping the pressure tube full. Rebound control is the amount of force required to pass fluid through the three-stage piston valve system at a given velocity.

FIGURE 27



CONVENTIONAL DOUBLE TUBE SHOCK ABSORBER

DOUBLE TUBE FREON CELL SHOCK ABSORBER

This system is perfectly adequate for normal road use and for most automobiles but for Motocross, where high piston speeds and a lot of leaping and jumping go on, a condition can occur that causes the pressure tube to not refill itself completely. If you look at Reservoir **C** in **Figure 27** you will notice an air space above the level of the oil. Because of the gyrations a motorcycle can experience it is possible to have the oil in the reservoir traveling up into the air space while the shock is traveling down and demanding more oil at the compression intake valve. (This oil weightlessness phenomena can be caused by high piston reversal speeds alone, and it is essential the motorcycle leave the ground for this to occur.)

If the oil is not there at the precise moment, the intake valve drags in air instead. Now we have a mixture of oil and air in the pressure tube, which, unlike normal hydraulic oil, can be compressed. There will be a loss of damping while this oil-air mixture is pumped through the varied control valves. Normally the problem is only momentary and the shock automatically purges the air out of the pressure tube. However, the demands of Motocross are severe and the problem is chronic. More and more air is mixed with the oil until the fluid becomes a foam. At this point the riders all complain of the shock "going away" or "fading" or "boinging." These are all great graphic terms to describe the symptoms, but "aeration" is the name of the failure.

To combat aeration a few manufacturers have provided a diaphragm in the reservoir that isolates the air space from the oil but still accommodates changes in the oil level due to rod displacement. In **Figure 27** you will notice the right hand shock has this device, known as a **Freon Cell,** submerged in its reservoir. The freon cell is a simple plastic bag that has freon gas trapped inside. When a freon cell is incorporated the reservoir is then completely filled with hydraulic oil and the only provision for oil expansion is to compress the freon inside the cell. Because the freon is inside the plastic bag it can never mix with the oil and the oil can never migrate away from the compression valve because the shock is completely full of oil.

The freon cell looks to be ridiculously simple but in fact it is a highly engineered component and must be applied correctly. First in importance is the volume of trapped freon must be in the correct proportion to the volume of oil displaced by the rod. (About 2½ to 3 times the volume of the rod.) Additionally the cell must be positioned in the reservoir so oil can always flow easily from top to bottom. The cell material must be nylon and the gas must be freon. The reason nylon is chosen is that most plastic materials are slightly porous. This allows the encapsulated gas to leak out. Nylon has the smallest pores of the readily available plastics. Freon is chosen because it has a molecule structure too large to pass through the nylon. Air has much smaller molecules so it can pass through the nylon. Because of this a freon cell will collect air from its surroundings and once the air is mixed with the freon it acquires a molecular structure too large to pass back through the nylon bag. This process works to your advantage inside the shock reservoir.

Figure 28 illustrates a **De Carbon** Type Shock Absorber. It derives its name from that of its inventor, Dr. De Carbon. As you can see, it is quite different from the double tube type shock. The primary differences are that it has no reservoir and it has no compression base valve. The lack of a base valve is taken care of by providing both compression and rebound valving on either side of the main piston. The lack of a reservoir is overcome by an ingenious arrangement. At the bottom of the shock Dr. De Carbon has designed a floating piston with high pressure nitrogen gas behind it. As the piston rod enters the shock it displaces some hydraulic oil. This causes the oil to push on the floating piston and move it slightly to compress the nitrogen gas. The floating piston accomplishes exactly the same job as the freon cell in the double tube shock but without the need for a separate reservoir and reservoir tube. It also operates at a much higher pressure than the freon cell which is both good and bad news.

The good news is the high pressure acting on the hydraulic oil virtually eliminates the possibility of aeration. The bad news is the high pressure creates a force that pushes the piston rod out of the shock. This force is proportional to the area of the cross section of the piston rod. To keep this force to an acceptable minimum, De Carbon Shocks generally have small diameter piston rods which sometimes are not strong enough for the rigors of Motocross. Additionally as the shock gets hot the gas pressure increases, which increases the force at the piston rod. Unfortunately, the extra force on the rod comes at a time when the shock damping control is diminishing from heat. This can cause a mis-match of damping to springing, making the suspension feel "boingy."

Another drawback of De Carbon Shocks is the available piston rod stroke is generally less than that for other types. This is because of the space occupied by the floating piston and gas chamber in the bottom of the shock. Sometimes this problem is sidestepped by removing the piston and gas chamber from the main tube and placing them into a separate external housing. This housing is then connected to the main housing by a short hose. This yields excellent piston rod stroke but brings on added expense and complication.

The De Carbon System has very precise valving components which respond instantly to changes of the direction of piston travel. This is one of the real advantages of this system. Another advantage is the aforementioned natural tendency to resist aeration of the oil. Still another advantage is derived from the fact the main piston can be larger in diameter than is possible with a double tube type. This is because the piston runs right against the outer housing. This arrangement also encourages heat to dissipate slightly faster. However, only in serious professional racing are these advantages worth the additional complication and expense.

Figure 29 illustrates the simplest of the basic shock types, the **Emulsion Type.** This shock is very much like the De Carbon Shock except it has no reservoir at all and does not separate the oil from the air. These shocks are designed to operate best when the oil and air (or gas) are mixed together in an emulsion or foam. The advantage to this type of shock are lots of piston rod stroke, few parts to go wrong, and they are very inexpensive to manufacture. The disadvantages center around the requirement that the oil be in an emulsified state before they will damp correctly. This suggests that until the oil is emulsified the damping will be excessive. This also suggests the damping will be inadequate if the oil is over-emulsified. Both of these conditions happen with this type of shock unit.

From our earlier discussion we learned that air in the oil makes damping unpredictable until all the air is pumped out. The pumping out process happens at the first part of the stroke which coincides with the low speed part of the damping curve. This makes it hard to achieve precise low speed damping with an emulsion type of shock absorber. This compromise in the damping curve explains why emulsion shock absorbers work well in the terrain they are designed for, but do not adapt to other riding conditions. They are seldom used as a universal, all-around shock absorber, but they are excellent in places like desert racing where the conditions are narrowed down to go straight and fast.

We have already stated it is impossible to tell very much about shock damping by pulling them in and out by hand. In order to move the shock fast enough to make all the valving work we need a machine called a shock Dynamometer. This machine cycles the shock up and down at numerous speeds and measures electronically the damping forces. These forces are then displayed on an oscilloscope so the operator can visually see the action of that particular shock.

FIGURE 28

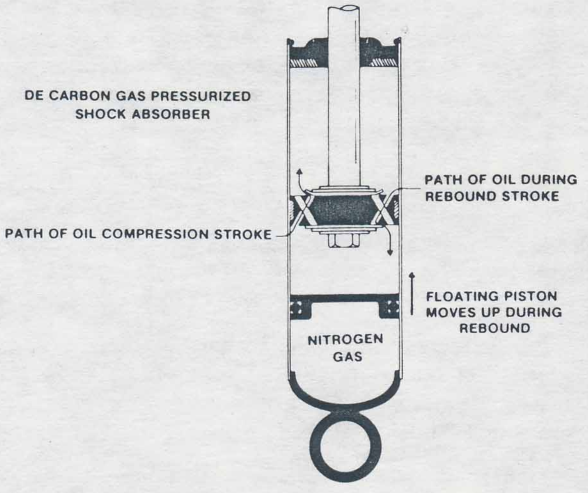


FIGURE 29

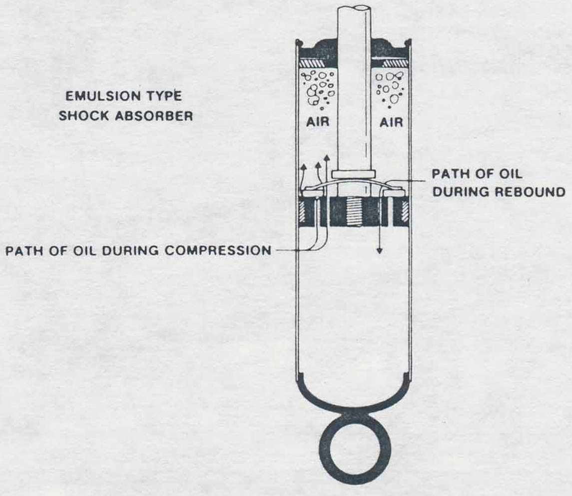


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Figure 30 illustrates a basic shock Dynamometer. The main parts start with the motor driven flywheel-crankshaft, which is attached to one end of the connecting rod. The other end of the connecting rod is hooked to the sliding ram. This arrangement converts the rotary motion of the crankshaft into the linear motion needed at the ram to stroke the shock in and out. To the upper end of the ram we connect the lower end of the shock absorber. The other end of the shock is connected to a **load cell** that is located at the top of the dyno, directly over the center of the ram.

Except for the electronics, that is all there is to a shock dyno, but before we get into the electronics we must fully understand the motion at the top of the ram. This motion is straight up and then a reversal to straight down. In order for the ram to reverse direction it must come to a momentary stop at each end of the stroke. The ram accelerates from a standstill at the bottom up to peak speed about half way up the stroke. (The exact point of peak speed is determined by the angle and length of the connecting rod) and then begins to slow down to come to a standstill at the top of the stroke. Then it begins to accelerate back down again going to peak speed about halfway down. The cycle is completed as the ram slows down to another complete stop at the bottom. Some dynos use a hydraulic drive mechanism that can vary the type of ram motion but for the most part this type of motion is universal in the industry. Familiarity with the way the ram speed varies according to its position in the stroke will help you comprehend the dyno charts.

The ram has an electro-mechanical device (a Potentiometer) hooked to it that sends a signal to the oscilloscope that follows the position of the ram. At the upper end of the machine we have the rest of the electronics in the form of a load cell. We hook the upper end of the shock to this load cell and it measures the amount of force transmitted by the piston rod as the shock is cycled. With the two electronic measurements we can now draw a chart on the oscilloscope screen.

The oscilloscope draws these charts with a high intensity illuminated dot that moves around the screen according to the signals received from the dyno. If you run the dyno with the load cell disconnected the dot will move up and down on the screen exactly as the ram does. The dot will stay right on the vertical line marked zero in **Figure 31.** If you connect the load cell and push up on it with your hand the dot will move to the left. If you pull on it, the dot will move to the right. Pushing on the load cell represents compression damping and pulling on it represents rebound damping. Now if you install a shock in the machine and turn on both signals, the dot will draw a pattern that resembles an oval in shape. As the dot moves upwards the compression damping will move it to the left and because shock damping is sensitive to the speed of the piston, the dot will move farther and farther to the left as the speed increases. As the shock slows down near the top the damping diminishes and the dot will move back closer to the zero line. At the top the direction of travel reverses and as the shock moves downward the dot moves to the right denoting rebound damping.

The oscilloscope screen is phosphorous so the dot momentarily leaves a trace on the screen which can be photographed for a permanent record of the damping forces. **Figure 31** has three traces taken at various piston speeds. To construct a damping curve a multiple exposure picture would be taken showing many traces from the slowest to the fastest dyno speeds. Then the peak forces of each speed would be transposed to a piece of graph paper and then connected with a line that would reveal a curve of the damping characteristics.

That is the basic story of shock absorbers. The reality of shock absorber design is the fine tuning inside these general boundaries.

FIGURE 30

COMPONENTS OF SHOCK ABSORBER DYNAMOMETER

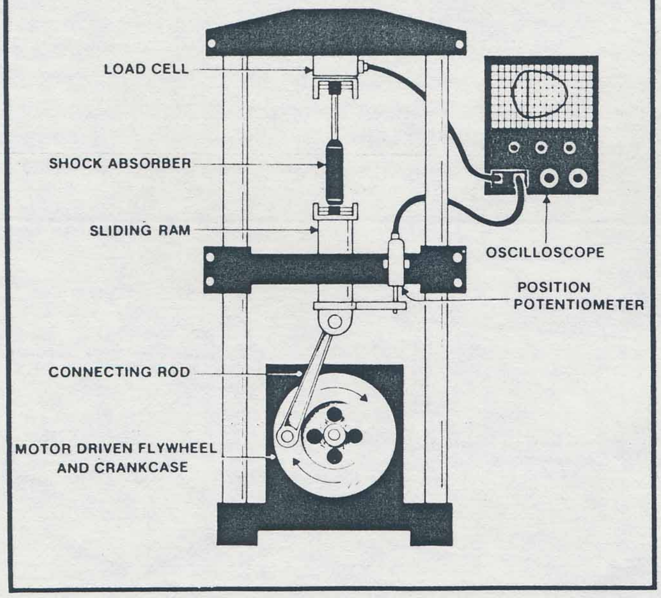
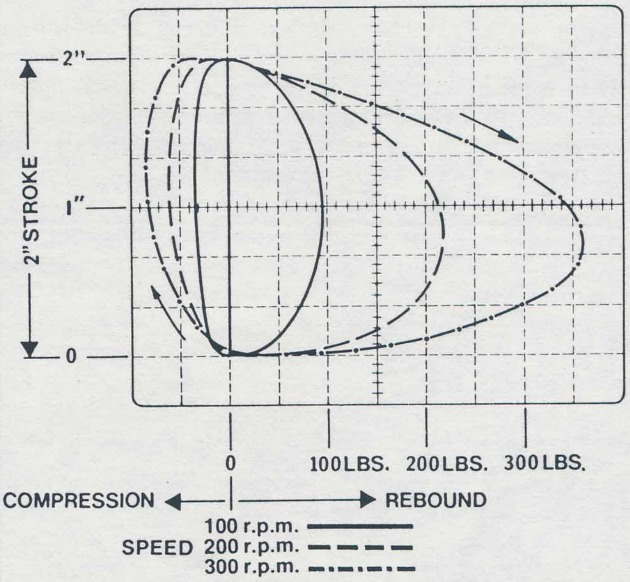


FIGURE 31



Chapter ...7
Stability and Steering

In the first six chapters of this book we explored in detail specific areas of motorcycle suspension and encouraged you to apply the concepts to your own motorcycle. Some of you may have begun experimenting and found the desired improvements rather elusive and sometimes accompanied by problems of a new nature.

This chapter will be more general, and concerned with those areas that are affected by changes to your suspension system. By understanding the interdependency of your suspension with steering geometry, weight distribution and transfer, and overall dimensions (wheelbase, height, center of gravity, etc.), it should be possible for you to better analyze your own test results. Many times a particular effect is attributed directly to a certain modification, when, in fact, the effect was caused by some accompanying change. Assumptions of this nature will cause each successive experiment to go farther and farther astray. Reality is that many factors are altered by even the simplest modifications to your suspension. Our hope is to expand your awareness to the point where you can assign the appropriate cause to any particular effect.

Geometry, weight and dimensions are fundamental in determining the handling character of each motorcycle. In fact, the choice of engine placement, steering angles and trail are the most significant differences between motorcycles on the market today. It is the careful juggling of these parts *in relation to each other* that makes the difference between a really fine handler and a motorcycle that is evil and scary. Keep in mind, however, that something as simple as moving the fork tubes up or down in the triple clamp will affect the balance of everything already mentioned. The key words above are "in relation to each other," because the final performance you feel is a combination of many contributing factors. Absolute values or rules cannot be postulated, however there are many guidelines or rules of thumb to use in your evaluations.

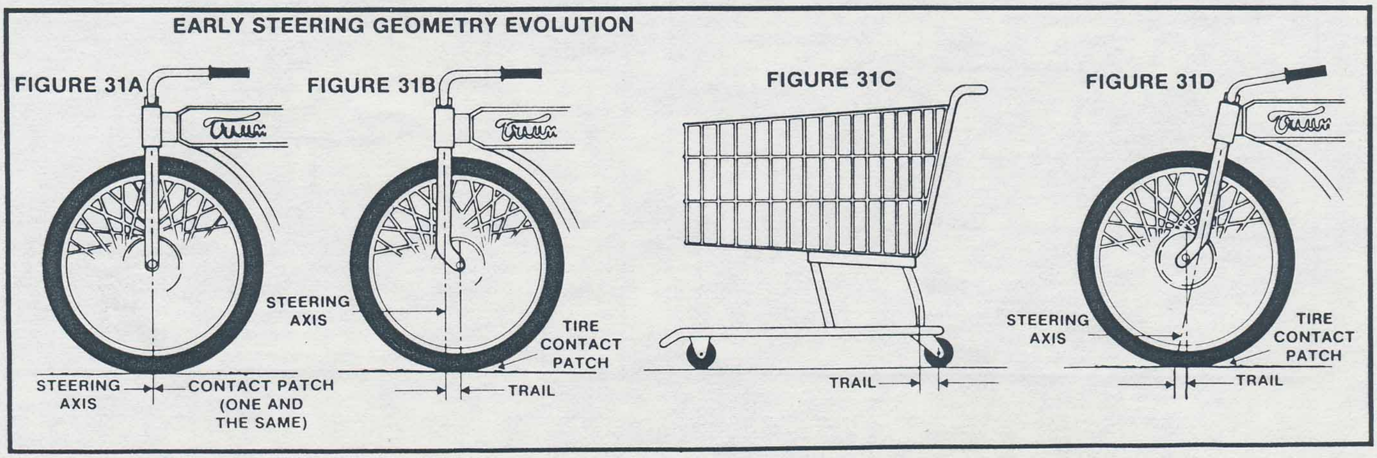
Let's begin by reviewing steering geometry. Primitive motorcycles had their steering-head angle or steering axis perpendicular to the ground and situated directly over the front axle **(figure 31A).** Immediately the first test riders complained that the handlebars had to be held very firmly to keep the slightest bump from rotating the steering to full lock. In addition, there was no feedback or feel through the handlebars to indicate how much to move the handlebars in order to turn. Stability was also absent. In order to counteract these problems, a modification was made to move the point where the tire contacts ground to a position behind the point where the steering axis intersected the ground **(figure 31B).** Now the bumps tended to push the contact patch straight back behind the steering axis and restore (or self-center) the steering. This geometry is exactly like that found on the rear wheels of shopping carts and is known as *trail* which creates castor effect **(figure 1C).** Unfortunately, early motorcycles emulated our shopping carts in other respects and sometimes developed the same side-to-side wheel wobble seen everyday in your supermarket. To eliminate the effect, the steering axis was leaned back from vertical and the axle repositioned. This change retained the wheel's self-centering castor effect, but eliminated the wheel's tendency to swing past the center point of straight-line tracking as it self-centered, thus creating a wobble. This layout gave remarkably wobble-free straight-line stability and is basically the steering geometry in use today **(figure 31D).**

(In the automotive world castor effect is achieved by leaning the kingpins back from vertical to create trail at the contact patch. The word "castor" is used to describe the number of degrees or the angle at which the kingpin is laid back. Motorcycles don't necessarily have a direct relationship between head angle and trail, therefore, "castor" as used by car people is misleading terminology. From now on we will use the term *trail* to describe the distance the tire contact patch "trails" behind the point at which the steering axis would intersect the ground.)

Head angle will be the term used to describe the angle the steering is leant back from a vertical.

You might assume that, because head angle and trail are such a panacea to stability, if some is good, more is better. Wrong. True, they do wonders for straight-line stability, but when you lean a motorcycle in a turn, the tire contact patch moves around off to the side of the tire, and trail then tends to continue turning the steering into the turn. Because that

EARLY STEERING GEOMETRY EVOLUTION



is true, the combination of head angle and trail must be held to very critical limits and in correct proportion to each other.

Take a look at **figure 32A** and you will get a better idea of how steering geometry is diagramed. Trail is the distance the center of the contact patch lies behind the steering axis and is measured in inches. To find the trail, first project one line straight down from the front axle to the ground. This will reveal the position of the contact patch. Then project another line through the center of the steering axis to the ground. Trail is the distance from the contact patch to the point the steering axis intersects the ground.

There are a number of things that determine the amount of trail on a motorcycle. Put an alternate size front tire on the bike and the ground will cross the line drawn through the axle centerline at a different place. Essentially, a larger front tire makes the ground lower, increasing the trail. A considerably smaller front tire would create a ground plane that would result in *lead* which is the opposite of trail. Remember that a change in tire diameter will change both trail and head angle because the front of the motorcycle will be either lifted or lowered. A new tire could also have a different tread pattern or cross-section or both, further confusing you.

Figure 32B illustrates what happens to the trail if you change the head angle. Notice that the head angle was reduced simply by sliding the fork tubes up in the fork crowns. Notice also that the weight of the motorcycle has been lowered and that the wheel is now closer to the engine. Once again, many alterations result from one simple modification.

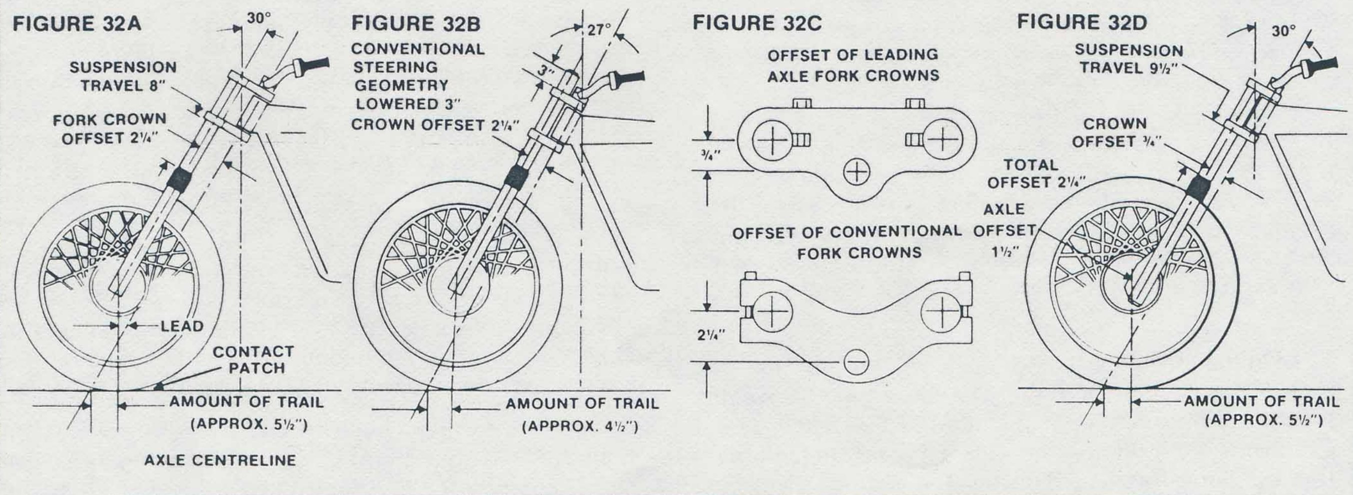
The primary components that determine trail are the fork crowns, or tripie clamps. By varying the offset of the fork crowns the trail can be adjusted without affecting too much else. **Figure 32C** illustrates how to measure fork-crown offset. One thing to take notice of in **figures 32A** and **32B** is that the amount of trail is inverse to the amount of crown offset. That is, more crown offset will produce less trail and conversely, less crown offset will produce more trail. This is often confused. Don't be misled by the offset of the leading axle crown. For this type of fork the offset is the sum of the crown offset plus the offset of the axle from the fork tube centerline. Almost always the total offset of a leading-axle configuration is identical to a standard fork's offset.

There is a common misconception that leading-axle forks work better because the steering geometry is different. Let us digress a moment to explain why we believe they are superior. There are several reasons for the more precise feel of leading axle forks. Structurally, they have considerably less flex, which makes control through the handlebars more direct. If you have taken a hard fall recently you probably recall having to align the handlebars with the front wheel after you picked yourself up. This is done by standing over the front wheel and clamping the tire between your knees. By twisting the handlebars you can put everything back in line. If you take a look at the fork tubes where they enter the fork slider you will notice that the two parts rotate in opposition when you tug on the handlebars. With a leading axle this rotation cannot happen without the fork sliders also swinging in a little arc about the axle offset. The extra arc creates resistance to rotation, thereby achieving more integrity between the handlebars and wheel.

If you look at the leading axle in **figure 32D** you'll notice that even though the steering geometry is identical to that in **figure 32A** the mass of the fork assembly is much closer to the steering axis. To the rider this means that when he swings the handlebars quickly there will be less momentum of the fork/wheel assembly. This reads out as less effort to control the steering, or more control for the same effort.

Again in **figure 32D** notice that the bottom of the fork is well below the axle. The top of the slider does not project as high above the tire, which means that for the same travel the fork crowns, frame and bearings can be closer to the axle. This results in a couple of benefits. One is that the center of gravity of the motorcycle can be placed much lower, a benefit in turning. Also, because the flexing fore and aft of the fork tubes begins right under the lower fork crown, the closer that fork crown is to the axle, the shorter the lever arm to do the bending. The result: less flex. Lastly, in this day and age of extra-long fork travel, leading axles with their lowered sliders are necessary to keep the overall height to an acceptable level.

CONVENTIONAL STEERING GEOMETRY



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So much for leading axles; let's discuss the effects of head angle and trail. It is common practice on motorcycles today to use a specific head angle for each type of event, a pretty good indication that changes in head angles will make big differences in handling. The compromise always seems to center around the amount of ease in turning or straight-line stability desired. The range of head angles begins with speedway bikes at 14-16 degrees, where you can't operate in anything less than a full-lock slide, and progresses to 32-33 degrees on desert racers where the motorcycle must continue straight ahead regardless of the size of the obstacle it just hit. In between those extremes we have flat trackers at 25-27 degrees, road bikes at 26-29 degrees and motocrossers at 29-31 degrees.

Most racers know to within half a degree the correct head angle for their particular motorcycle. The general rule is that a lot of head angle will make the motorcycle go straight, but it will not be easy to initiate a turn or to slide. Conversely, a motorcycle with less head angle will shake its head at high speed and be prone to tank slappers in the whoops, but it will slide like crazy. If you experiment with your motorcycle by sliding the forks in the crowns or by raising or lowering the rear suspension with different shock lengths, you will begin to feel the best compromise for your type of riding. Put a bubble protractor on your fork tubes when the suspension is topped out and arrive at a number that suits your style. Raising or lowering the chassis at either end by one inch will generally change the angle by almost one degree.

Suppose that after much experimenting your motorcycle cannot be made to turn or go straight, or that by the time you have achieved one handling goal the other has deteriorated enough to be dangerous. That is a good indication that something else is not quite right. The culprit might be trail. If the motorcycle seems dead stable, but when leaned over the steering tends to continue turning, it is a good bet that it has too much trail. On the other hand, if the steering wanders excessively it will show up worst in deep sand. In sand, because the tire is down in the sand opening a groove, the tire contact patch moves forward on the tire and more trail is required to counteract this phenomenon. Another culprit might be weight distribution. This affects the interaction of the tire tread with the ground and determines the amount of *traction* at that point. As a general rule, the heavier the load on them, the more traction or bite motorcycle tires have. The balance of these loads front to rear will determine whether a motorcycle will push the front tire when cornering or oversteer with the rear wheel slightly hung out. Too little weight on the front tire will cause the push and too little weight on the rear will cause the oversteer.

The difficult part is determining whether the pushing condition is caused by too much trail or too little weight. Sometimes the answer can be found by trial and error. Insufficient weight on the front tire is a common fault these days with long-travel suspension. The addition of suspension travel is invariably accomplished by extending the front forks, which raises the chassis. When the wheel is allowed to extend down farther, it also moves away from the engine, making the wheelbase longer. This makes the static weight on the front tire lower. The increase in chassis height also allows more weight transfer to the rear when accelerating, causing even less weight on the front.

If you have a front-end pushing situation only when accelerating, it indicates that the center of gravity is too high, though not necessarily too far back. If the push is there whether the throttle is on, off, or neutral, it indicates that the center of gravity is too far back. The whole subject of weight transfer will be investigated in Chapter 8, but something to consider is that weight distribution can also be altered at the rear by use of a different length swing arm. Also be aware that changes to the rear suspension, like a different shock length, affect the head angle and trail in much the same manner as changes in the front height.

Up to this point we have primarily been talking about chassis angles and dimensions measured while the motorcycle is stationary or *static*. If you have handling problems that still can't be explained, perhaps those critical angles are quite different when your motorcycle is in motion or its *dynamic* condition.

One of the compromises brought about by long-travel suspension is that under braking and acceleration the chassis is free to *pitch* (or rock) fore and aft much farther than before. We have seen that raising or lowering the chassis at one end changes the head angle and that pitching is a raising of one end and a lowering of the other. What this means is that under braking, where straight-line stability is important, the chassis nose-dives and much of the head angle goes away. When this happens it is very difficult for the rider to hold the handlebars straight ahead.

Under acceleration coming out of a turn the chassis can rock backwards, causing the forks to extend and provide an excess of head angle. This makes it difficult to maintain your line accelerating out of a turn.

So far the improvement in ride over rough terrain has more than compensated for the sacrifices in the turns caused by long-travel suspension. However, if you are not careful with the details, the sacrifices become more than is tolerable. It is important that both front and rear suspensions ride at about the same average distance into the travel when in motion. Spring-rates that are too soft, especially at one end, will allow excess pitching. Too little shock damping will also allow the chassis to pitch farther than necessary and suddenly enough to be quite a surprise to the rider. It should also be noted that some pitching is desirable in order to start a turn; if your motorcycle doesn't want to turn without first having braked hard it is a good indication that your front suspension is too stiff or your static head angle excessive.

Another dynamic condition that might be a problem is *pumping down* and *pumping up* of the suspension. This can happen at either or both ends of the motorcycle. It is caused by an improper amount of shock damping for the spring rates being used.

Pumping down is caused by an excess of return (or rebound) damping in the shock absorber. When the suspension is compressed by a bump the rebound damping is supposed to let the suspension return to its original position very gently. However, if you have an excess of rebound

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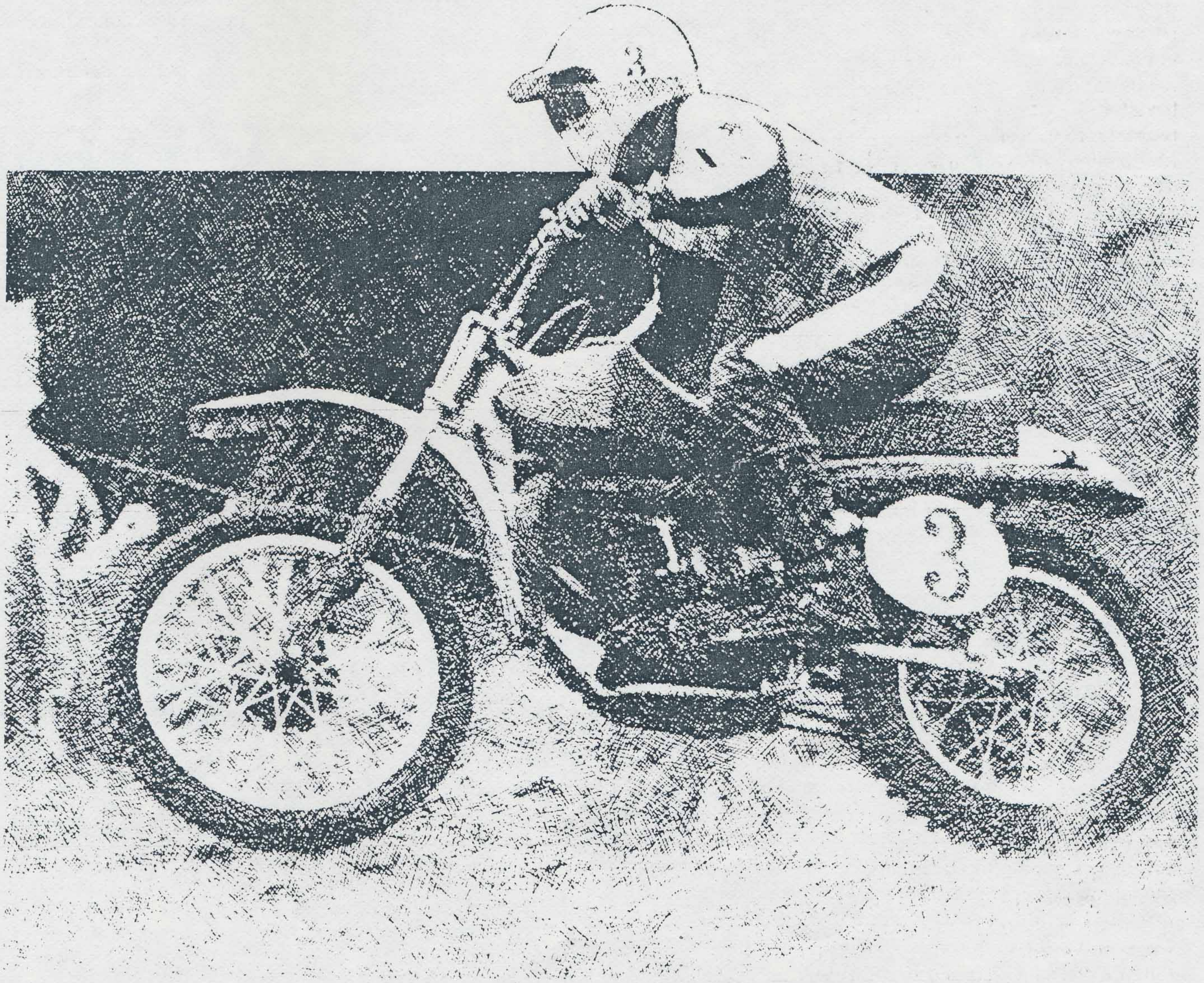
damping the suspension returns so slowly that you are likely to encounter another bump before the suspension has fully recovered. This becomes very apparent on a series of bumps or a washboard surface. The symptoms on washboards are a very harsh, chattery ride and a reduction in forward traction. This is because the suspension rides at an average (or dynamic) height a couple of inches pumped down. To the wheel this seems like a couple of inches of extra preload.

The symptoms on a series of larger bumps are much more severe. The scenario goes like this. As you traverse these bumps the suspension does not return quickly enough, so each successive bump is encountered with a progressively higher impact. The suspension is pumping down farther with each bump and there remains less and less suspension travel to soak up the bumps. Eventually the remaining travel will be inadequate and the suspension will bottom out and pitch that end of the motorcycle into the air. Unfortunately, this "always" occurs when there are still more bumps left to negotiate, which can be very stimulating to the rider.

Pumping up is the opposite of pumping down and is caused by an excess of compression damping accompanied by too little rebound damping. The suspension tends to ride in a raised up condition which is desirable for events like desert races. The softness of the ride is usually very good in a pumped-up condition except that if this condition happens in one end only it is likely that too much pitching of the chassis will occur, bringing on steering/stability problems. The same is also true of pumping down in one end.

This is why it is important to use information linking damping to spring rate, as found in the S & W catalog.

As you can see there are many things going on in your chassis at the same time. If you are getting test results that are bizarre, consider all the various gremlins presented here.



Chapter ...8
Weight Transfer & Anti-Squat

This is the final chapter in this manual. Based upon that fact, the subjects were chosen to stimulate your curiosity and, perhaps, establish a foundation for a whole new wave of experimentation to a long-neglected part of your suspension system.

The concepts are more abstract than anything presented here previously and may be slightly more difficult to grasp. However, you should not be intimidated by, or take casually, the theoretical nature of this material.

The first part of this chapter is concerned with **weight transfer.** This dynamic condition happens every time your motorcycle moves under its own power and it has a profound effect on every aspect of your motorcycle's handling behavior.

The second part of the chapter focuses on a rear suspension condition known as **anti-squat.** Anti-squat is a dynamic force in the rear suspension that can add or subtract to the downforce at the point the tire contacts the ground. This force varies with the application of engine power or the brakes and its value is determined by the geometry between the swing-arm and the chain and the ground.

The anti-squat concepts presented here are derived from research performed by Trevor Harris of Harris Dynamics in Costa Mesa, California. To the best of our knowledge, these ideas are completely original and new as applied to motorcycles and have not been published anywhere prior to this publication. We thank him for making these concepts available and for his editorial contribution.

What exactly is weight transfer and what does it do to your motorcycle? Specifically, it is the change in load at the tire contact patch as a result of acceleration of the vehicle. For a clearer understanding of this statement, follow this text using **Figure 33** through **Figure 38** as a visual guide. It would be even better if you would perform this series of tests yourself while following along with the text: Place a small box about the size and proportions of a box of kitchen matches on a smooth table, so that it is standing on end. **Figure 33** establishes the end, side and top. Now, push it across the table with your fingers at a point as close to the table as you can, as in **Figure 34**. Start slowly and gradually build up the speed as you push the box across the table. Do this at a faster and faster speed until the box tips over backwards. At this point, there is total weight transfer. All the weight that was being supported at the front of the box is now being supported at the rear of the box. **Figure 35** diagrams this condition. Now, perform this same procedure, but this time push on the topside of the box, again as close to the table as possible, as shown in **Figure 36.** Notice the box tips over much easier this time.

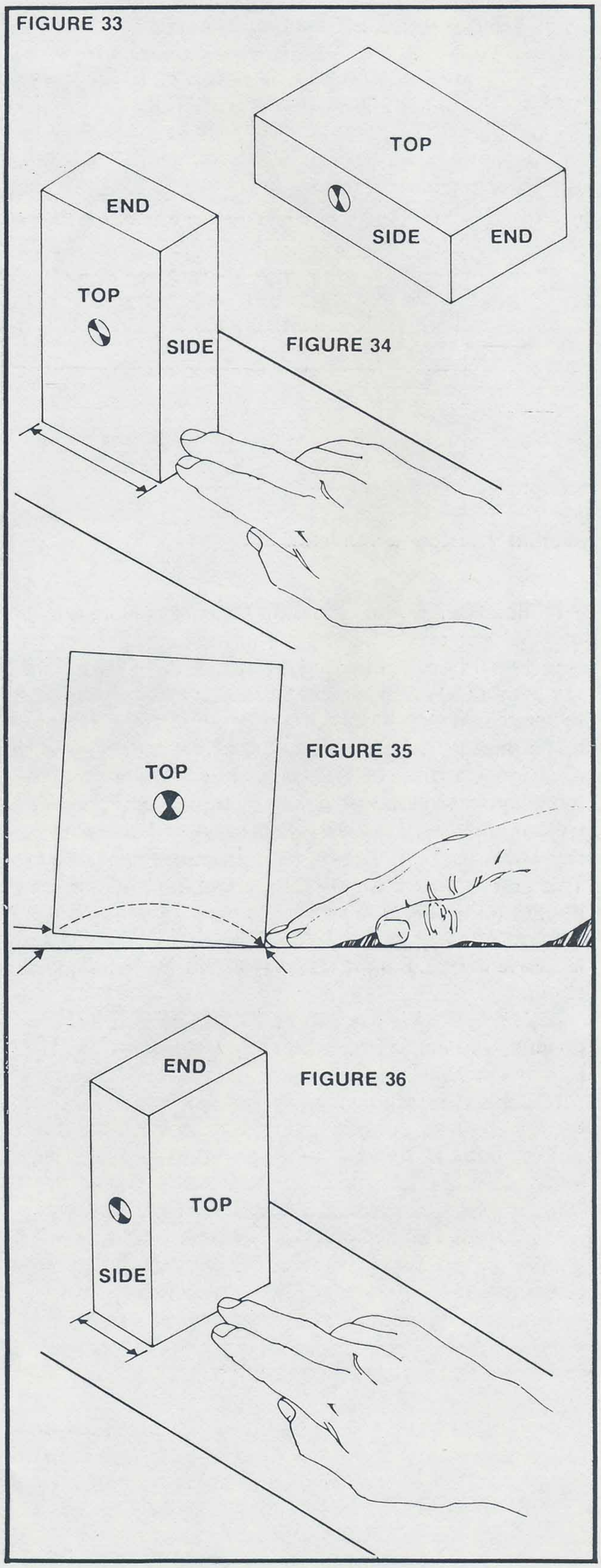


FIGURE 33

FIGURE 34

FIGURE 35

FIGURE 36

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Very carefully, climb aboard the motorcycle and assume your normal riding position. Have your friend make a mark on the masking tape where the plomb-bob intersects it. This is the center of gravity. Needless to say, this almost upside down riding position is very fatigueing so be prepared to read the plomb-bob quickly. Also, don't perform this procedure unless you have full confidence in your overhead hoist and your attachment to it.

Here are some figures taken from a Suzuki RM 370B with half a tank of gas. The rider is 175 pounds and 6'2" tall. The wheelbase is 57.5".

	WEIGHT FRONT	WEIGHT REAR	TOTAL WEIGHT	FORE & AFT C.G.	VERTICAL C.G.
BIKE ONLY	112 LBS. 46%	133 LBS. 54%	245	31.05" back FROM AXLE	21.25" FROM GROUND
BIKE/ RIDER	161 LBS. 38%	266 LBS. 62%	427	35.65" BACK FROM AXLE	30.5" FROM GROUND

Now, let's plug these figures into the formula:

$$\text{Weight Transfer} = \frac{(.71)\ (427)\ (30.5'')}{57.5''}$$

$$\text{Weight Transfer} = 160.8 \text{ pounds}$$

Notice the amount of weight transfer is just short of the original load on the front tire. This indicates the motorcycle is just on the verge of doing a wheelie. Take note of the fact that almost all of the weight transfer has taken place before the front wheel has lifted off the ground. Weight transfer, to some degree, is happening all the time as long as there is acceleration or deceleration. It is not necessary for the motorcycle to pitch or change attitude for there to be a weight transfer. Conversely, pitching of the motorcycle does not necessarily change the amount of weight transfer. This is true only if the pitching does not change the C.G. height, as is the case when the front raises and the rear lowers. However, most pitching *is* accompanied by a major increase in C.G. height, as is the case when doing a wheelstand.

If you desire to keep the front tire in contact with the ground, you can compensate by altering any of the components in the formula or you can alter the static weight distribution so that after weight transfer there is some remaining load on the front tire. If you don't want to alter the static weight, you can reduce the weight transfer which will also leave you with some remaining load at the front tire.

When you look at the formula, you will notice that the wheelbase is divided into all the other components. This means that in order to reduce weight transfer you must either lengthen the wheelbase or reduce any or all of the other components. The difficulty lies in the fact that alteration of any of the components creates compromises somewhere else in the motorcycle. The trick is to select the compromise that best suits your purpose.

Before you decide on which compromise to tolerate, let's look at the effects of weight transfer. You have seen that it alters the load at the front and rear tire contact patches. However, up to now we have just talked about weight transfer to the rear under acceleration. When the brakes are applied, exactly the same dynamic condition is produced, but in the opposite direction. The front tire load increases and the rear gets lighter; again a shuffling of the loads at the tire contact patch. The effect of these load changes is the traction between the tire and the ground varies accordingly.

In order to interpret these load changes, you must know something about the interaction of the tires and the ground. *The traction increases as the load increases.* This statement is the most important of this entire chapter and again will be important in the discussion of anti-squat. It is always true when the track surface is dirt and generally true for pavement, but not always.

With this idea firmly in mind, let's look again at the options available for reducing weight transfer. The first option is to lengthen the wheelbase. This will definitely lower the weight transfer, but the static weight distribution will be effected, depending on how the chassis is lengthened. If it is lengthened at the rear only, the static load will be less there and more in the front. If the motorcycle always tended to wheelie too easily and was generally unpredictable while turning, this modification would help considerably. But, if the motorcycle was balanced before, it probably will now experience too much loss of traction at the rear. This means the acceleration will be less (lower G force), which means even less weight transfer, further reducing traction. *The traction is contingent on the amount of weight transfer fed to it, which is contingent on the amount of acceleration fed to the C.G., which is contingent on the traction available.* This cycle of events feeds on itself in a closed-loop fashion. This is an important concept to understand and will help explain why some minute changes have a drastic effect.

If the wheelbase is lengthened at the front only, it will cause the static load to be less at the front and more in the rear. This will produce less weight transfer, but since there is now more weight in the rear, the traction will be increased which could cause faster acceleration which, in turn, could return the weight transfer back to the same level as before. But now the load on the front is less so the wheelstand problem may become worse. When attempting to turn or brake this new configuration, you will really regret the effect of not enough front tire loading.

Let's consider some of the other options in the formula that are written over the wheelbase. The first figure is the **g's** of acceleration. In order to reduce weight transfer, it is necessary to make this figure smaller and/or acceleration slower. We have never heard of a race where less acceleration is a virtue, so this option is out.

The next available option is to lower the overall weight. Since most current motocrossers are right at the minimum allowable weight, there is little that can be done in this area.

The last, and perhaps the best option of all, is to lower the C.G., since the static weight distribution does not necessarily have to be changed. One of two things to be aware of at this point is that the C.G. height (30.5") is roughly one-half of the wheelbase (57.5"). What this indicates, as far as weight transfer is concerned, is one inch of C.G. height change is equivalent to two inches of wheelbase change. This may help you decide which is the easiest part of your motorcycle to modify.

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Several points are evident from this sequence. First, the box, which obviously has no wheels or suspension, has weight transfer when it is accelerated; second, the weight transfer is increased if the acceleration is increased; and third, weight transfer varies in relation to the size of the base. (The base is broader in **Figure 34** than in **Figure 36** and the box can be moved faster without tipping over).

Now, push the box again as in **Figure 34** and make a comparison as to the ease of tipping over with the box positioned as in **Figure 37**. Notice that in the **Figure 37** configuration the box is very difficult to tip over even though the size of the base is no greater than in **Figure 34**. In this case, the center of gravity of the box is moved much lower in relation to the point being pushed on. From this it is established that the lower the center of gravity is in relation to the point of reaction, the less the weight transfer.

In **Figure 38** the box is positioned to have the broadest base and the lowest center of gravity. In this configuration, it is virtually impossible to tip the box over, which indicates a combination of broad base and low C. of G. has the least weight transfer of all.

FIGURE 37

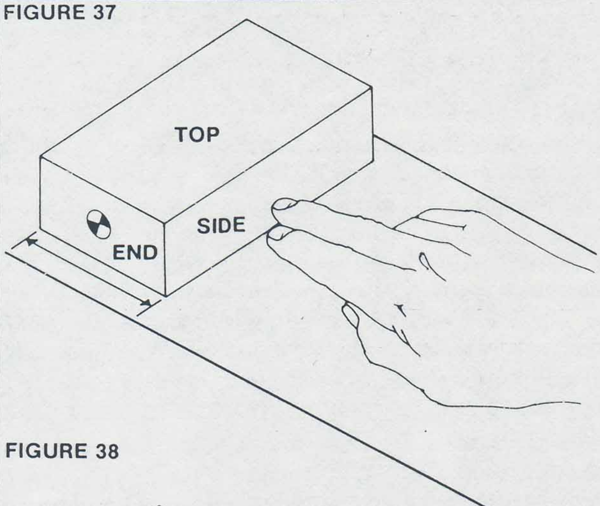
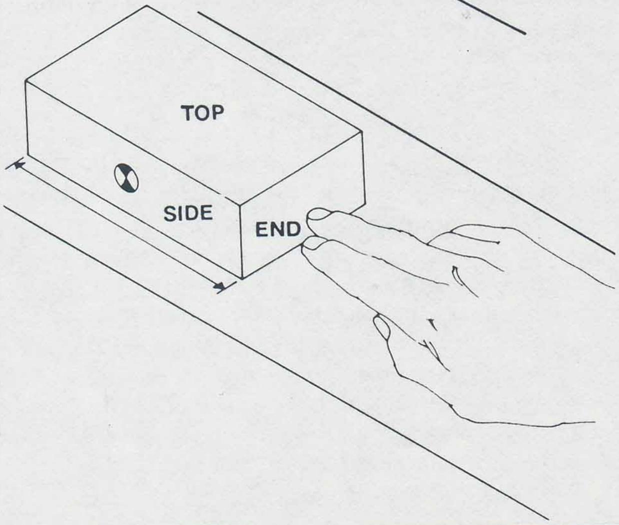


FIGURE 38



These simple tests show that several factors have a direct and predictable bearing on weight transfer, and therefore, that weight transfer is a mathematical function capable of calculation. In order to set up this calculation, we must transform the components of our box test to those of an accelerating motorcycle. Begin by substituting the motorcycle's front and rear tires for the lower corners of the box. Now, the wheelbase becomes the "base." The point where the rear tire contacts the ground is now the reaction point and corresponds with the point where you pushed on the box. The engine now provides the acceleration instead of your finger and the motorcycle/rider combination has its own center of gravity.

These components are applied to a formula:

$$\textbf{Weight Transfer} = \frac{\textbf{(g's) (Weight) (C.G. Height)}}{\textbf{Wheelbase}}$$

Weight Transfer	is the amount of weight in pounds subtracted from the load at the front tire and then added to the load at the rear tire.
g's	is the rate of acceleration of the motorcycle. (For a typical open class motocross bike, a theoretical **g** figure of .71 will just lift the front wheel off the ground with the rider sitting in an upright position).
Weight	is the total weight in pounds of the motorcycle/rider combination.
C.G. Height	is the height of the center of gravity of the motorcycle/rider combination measured in inches from the ground.
Wheelbase	is the distance in inches between the front and rear axles.

If actual figures are plugged into the formula, several additional aspects of weight transfer are revealed. These figures can be collected by placing your motorcycle on two bathroom scales, one tire on each. Then run a tie-down strap from each end of the handlebar straight out to the nearest adjacent immovable object. The tie-downs will keep the motorcycle from falling over without influencing the weight shown on the scales. Now, get on the motorcycle and have a friend take some readings at the front and rear. For your own curiosity, try several different riding positions to get a feel for the effects of body english on the weight distribution. From this procedure, you can get the total weight by adding the two readings together and then can establish the fore and aft position of the center of gravity by proportioning the two readings in relation to the wheelbase. (If the total weight is 427 pounds and the weight is distributed 161 pounds front and 266 pounds rear, the percentage of weight distribution will be 38% front and 62% rear. The fore and aft C.G. will be closer to the rear tire and, specifically, 62% of the wheelbase back from the front axle or 35.65" back for a 57.5" wheelbase).

Finding the center of gravity height is slightly more difficult, but not much. First, take a strip of masking tape and put it straight up and down on the motorcycle exactly where the calculated fore and aft C.G. is located. Now, attach the front tire to some overhead hoist or crane and raise the motorcycle until it is hanging vertically from the front only. Attach a plomb-bob to the front axle so the bob weight can swing freely across the strip of masking tape.

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Notice that no mention is made of the fore and aft position of the C.G. in the formula. This tells you the static weight can be altered without effecting the weight transfer as long as the C.G. height remains constant. However, you have already seen that altering the static weight does change the behavior of the motorcycle's handling.

If you analyze the type of "body english" necessary to make your motorcycle behave correctly, you will know whether to play with the C.G. height, the wheelbase or the static weight. If you find yourself moving forward under acceleration and backward while turning or braking, it is a good sign the wheelbase is too short. If you move around in the opposite manner, it is a sign the wheelbase is too long. If your motorcycle is already pretty short and you find it necessary to move in the same directions as if it were too long (back on acceleration and forward for turning), it's a good bet your C.G. is too low. If you have a long motorcycle and you find you still have to climb over the bars on acceleration and scoot back for turning, the C.G. is probably too high. If you always end up sitting way forward, the static weight distribution is biased too far to the rear. The converse is also true.

The best compromise between static weight distribution and weight transfer is achieved when very little "body english" is required. This is not to suggest that "body english" is inherently bad. It is a very useful tool and if your motorcycle responds to a lot of moving around, by all means do it. However, it is less fatiguing to ride a well-balanced motorcycle that allows you to sit or stand in just one spot.

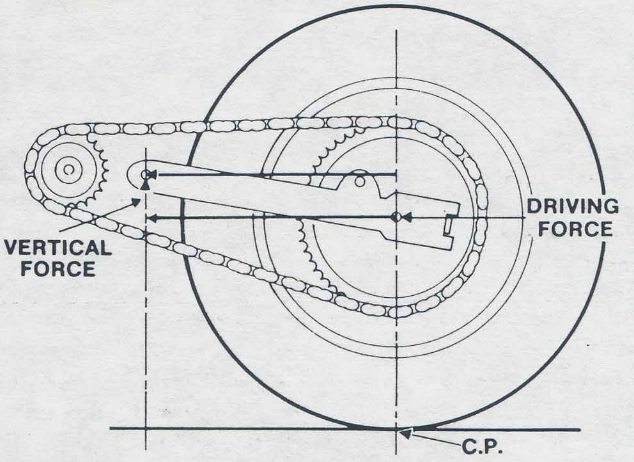
Thus far, we have been searching hypothetically for a means to reduce weight transfer. It is likely that your motorcycle probably doesn't need less weight transfer. We have used this example merely to illustrate the components that do effect weight transfer. The fact is, the optimum amount of weight transfer is the most you can use without causing any real compromises elsewhere.

ANTI SQUAT

As noted earlier, anti-squat is a force in the rear suspension that changes the load at the tire contact patch. To fully understand this dynamic phenomenon, it is necessary to go back to some fundamentals.

Figure 39 illustrates a typical motorcycle rear suspension. When power is applied to this mechanism, the rear tire claws at the ground at the contact patch (designated C.P.). This causes a reaction which propels the motorcycle forward. Since the tire revolves about frictionless bearings at the rear axle, the forward driving force is imparted to the motorcycle at the axle. The axle subsequently pushes on the end of the swing-arm in a direction that is parallel to the ground. However, the swing-arm is not parallel to the ground so the driving force, which is straight ahead, gets divided into two components: one, horizontal, and the other vertical. The vertical force becomes a portion of our mysterious anti-squat by pushing up on the chassis at the swing-arm pivot. Elementary — right? Wrong! This vertical force is only a portion of the force energized as power is applied and these other forces work in opposition and cancel part of the swing-arm vertical forces.

FIGURE 39



Before we go any further, let's make sure you understand how a force can be divided and go in two directions. Some simulations will help make this clear. Take an ordinary pencil and hold it lengthwise between the tip of your forefinger on one hand and the forefinger on the other hand (**Figure 40** illustrates the positioning of the pencil). Don't use a sharpened pencil or you will injure one of your fingers! If the pencil is sharpened, put an eraser over it. Now push on both ends of the pencil and envision the pencil as representing a swing-arm with one end being fixed and stationary, like the frame end, and the other as being free to swing in an arc, like the axle end. Maintain your pressure on each end of the pencil and swing the moveable end down out of line with the fixed end as shown in **Figure 41.** Notice the

FIGURE 40

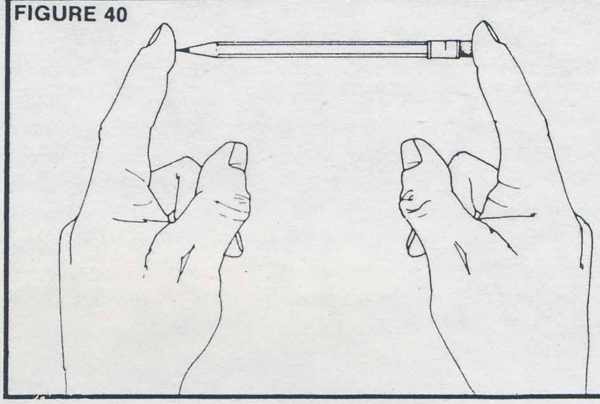
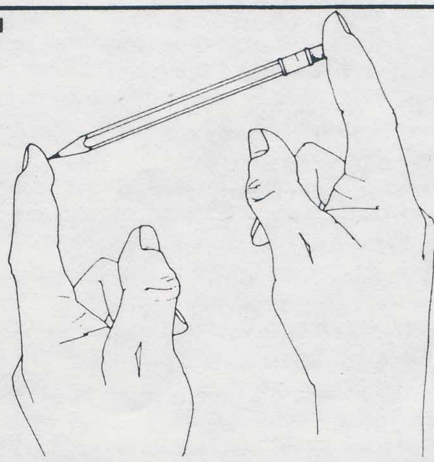


FIGURE 41



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different feel at your imaginary fixed end. Even though there is a force trying to push your finger over backwards, there is another force trying to push your finger upwards. Notice those forces trade progressively from horizontal to vertical the more the pencil is angled. This indicates the *angle* determines the distribution of the two components. Now notice the *upwards* vertical force at the stationary end of the pencil is counteracted by a *downwards* vertical force at the movable end. (For every action, there is an equal opposing reaction). This is an important point and illustrates the main benefit of anti-squat. This downwards force is translated to the motorcycle as an increase in load at the contact patch which increases the traction.

Diagramming the distribution of component forces is done as shown in **Figure 42.** In Part **A**, a rectangle is drawn around the swing-arm, having the top and bottom parallel to the ground. The length of the top and bottom represent the percentage of the original force that is horizontal. The length of the sides represents the vertical percentage. Part **B** shows what happens to the forces if the angle is increased. In this instance, the angle is 45° and all four sides are equal, forming a square. This means the horizontal force is less and the vertical force is more than before, but they are equal to each other.

FIGURE 42A

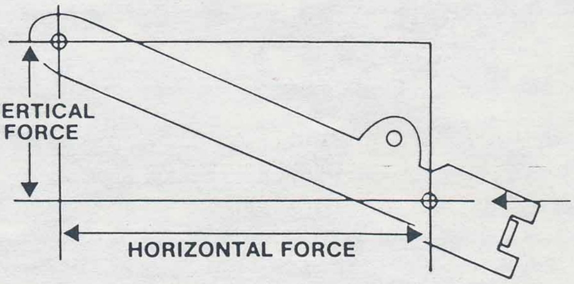
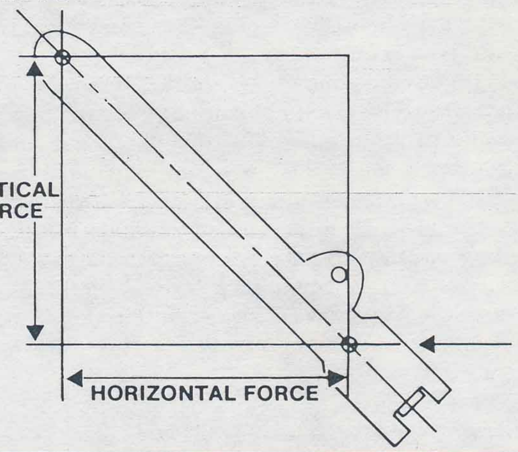
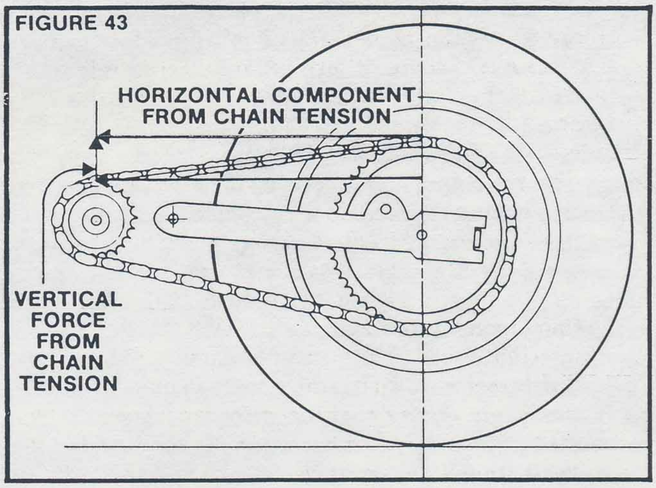


FIGURE 42B



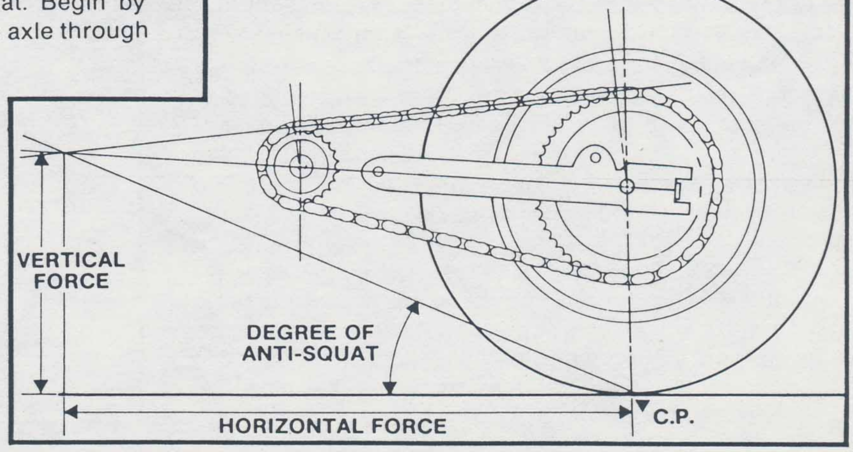
Let's get back to the real world and look at the other forces that contribute to our anti-squat forces. If you look at **Figure 39** again, you will see the chain also works at an angle in relation to the ground. We know there is a force imparted to it from the engine. However, this time the force is a pull instead of a push. Because the chain is in tension, we can look on it as just another link in our system much the same as the swing-arm, except in the case of the swing-arm we can both push and pull. The ends of this link are considered to be at the tangent points where the chain leaves the rear sprocket and enters the engine sprocket. **Figure 43** shows the component forces of the pulled chain.

FIGURE 43



The next step is to devise a system to diagram these component forces to give us their resultant force and how it relates overall to the chassis. **Figure 44** illustrates the technique for determining the relative anti-squat. Begin by drawing a straight line from the center of the axle through the swing-arm pivot and continue it out into space. Then draw a line connecting the two chain tangents and extend it into space. These two lines will cross each other somewhere ahead of the engine sprocket. From the intersection point, draw another line back down to the tire contact patch. This third line indicates the degree of anti-squat in the system. The angle between this line and the ground is the measure of the amount of anti-squat. Again, the horizontal and vertical components can be derived by drawing a rectangle around this angled line.

FIGURE 44



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If you know the driving force, you can calculate the vertical force with this simple formula:

Vertical Force $= F \times \frac{A}{B}$
F = **the driving force in pounds**
A = **the vertical component**
where: B = **the horizontal component**

The point where all three lines intersect is known as the *instantaneous force center* and is the location where the component forces act on the chassis. Watch what happens to the force center when the rear suspension is compressed **(Figure 45).** Notice the force center has moved down and forward, introducing a drastic reduction of the anti-squat angle. This shows that the anti-squat somehow varies according to the position of the suspension — a condition not conducive to promoting a stable, predictable motorcycle.

The position of the instantaneous force center and the manner in which it moves determines the effect anti-squat will have on your motorcycle. There are many ways to modify the force center characteristics. It is important to decide on the exact type of anti-squat that will be beneficial rather than a liability. Very little empirical research has been done as to the optimum anti-squat. At this point, it is conjecture and we only can make an educated guess as to the perfect compromise.

Immediately, it seems reasonable that anti-squat should not vary with suspension movement, especially if it diminishes as the suspension compresses. It should at least stay constant all through suspension travel and, perhaps, it should increase with travel. This is one trait we can put on our list of preferences.

The real question is the amount of anti-squat to start with. Our testing revealed that too much anti-squat is as bad as too little, but for different reasons. Too much anti-squat will physically lift the rear of the motorcycle when power is applied as long as the traction remains constant. If the traction is intermittent, the suspension will "relax" with every interruption of traction and tense up or "flex" as the traction is restored. To the rider, this will read out as a chatter in the rear suspension. This chatter can be caused by an irregular track surface or it can be induced by the anti-squat itself. As the anti-squat is energized by engine power, the tire is momentarily pushed against the ground with extra force which increases the traction which in turn increases the driving force which increases the anti-squat. Sound familiar? This closed-loop cycle is very similar to that discussed in weight transfer, earlier.

If the anti-squat gets too strong, the rear suspension virtually will become locked in one position. In this condition, the suspension will be unable to comply with track irregularities and will cause the entire chassis to follow the track undulations. The motorcycle will have enough of its own momentum (and perhaps upward momentum from suspension flex) so that it will not follow the ground on the downside of each bump. As the tire leaves the ground, the traction is interrupted for a moment, allowing the suspension to "relax." When the tire touches the ground again, the anti-squat is once again energized, causing the suspension to "flex." If this sequence is repeated over and over at a fast enough rate, a chatter will develop. The chatter can be so bad that intermittent daylight can be detected between the tire contact patch and the ground. However, chatter can be a problem and be felt by the rider well in advance of this extreme condition. Chatter will reduce the forward acceleration and the motorcycle will tend to wiggle from side to side.

Too little anti-squat causes the reverse effect. As power is applied, the tire is jerked away from the ground, causing a general reduction in traction. This condition is known as pro-squat and is the equivalent of negative anti-squat. Many of today's motorcycles actually have pro-squat when the suspension is fully compressed. In addition to reducing the traction, pro-squat also tends to keep the suspension compressed just at a time when you would like it to return to its original position quickly. Pro-squat has the same effect as shocks that cause "pumping down." Excessive anti-squat can do the opposite and launch your motorcycle off of jumps by quickly extending the suspension.

We believe the optimum anti-squat to be an amount somewhat less than most of today's motorcycles have when their suspension is fully extended, but only if the anti-squat does not change very much when the suspension is compressed. To take full advantage of this configuration, it might be necessary to increase the static weight and/or weight transfer to the rear tire to restore any traction lost by the reduction in anti-squat. Shock absorbers might need some redesign because those available on the market today are most likely compensating for excessive anti-squat.

In **Figure 46**, compare the effect on the instantaneous force center (I.F.C.) with that in **Figure 44**. In this case, we have lowered the swing-arm pivot in relation to the engine sprocket. This I.F.C. has moved down forward, partially achieving our goal of reduced initial anti-squat. The drawback to this modification is that pro-squat is more pronounced than ever when the suspension is compressed. This is unsatisfactory.

Study **Figure 47** to see the effect of gear ratio changes on anti-squat. Notice a smaller wheel sprocket moves the I.F.C. further forward and reduces anti-squat. Notice that a larger engine sprocket has almost the same effect.

FIGURE 45

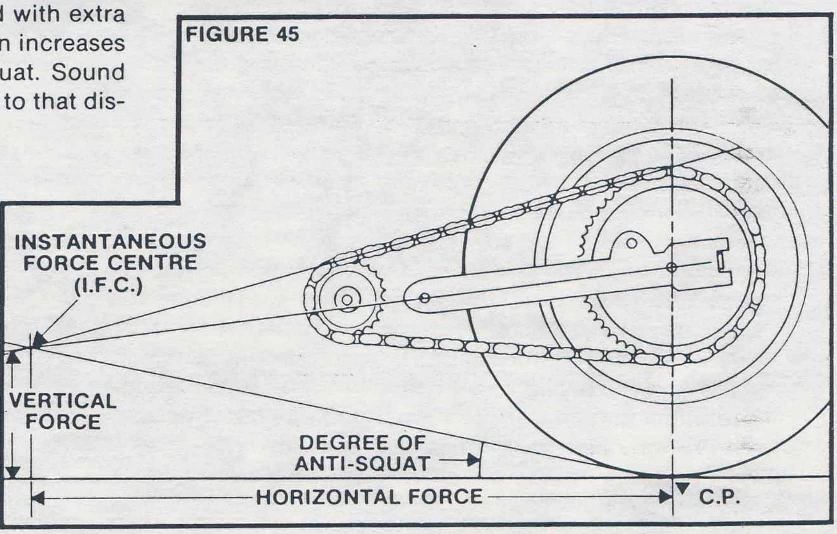

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FIGURE 46

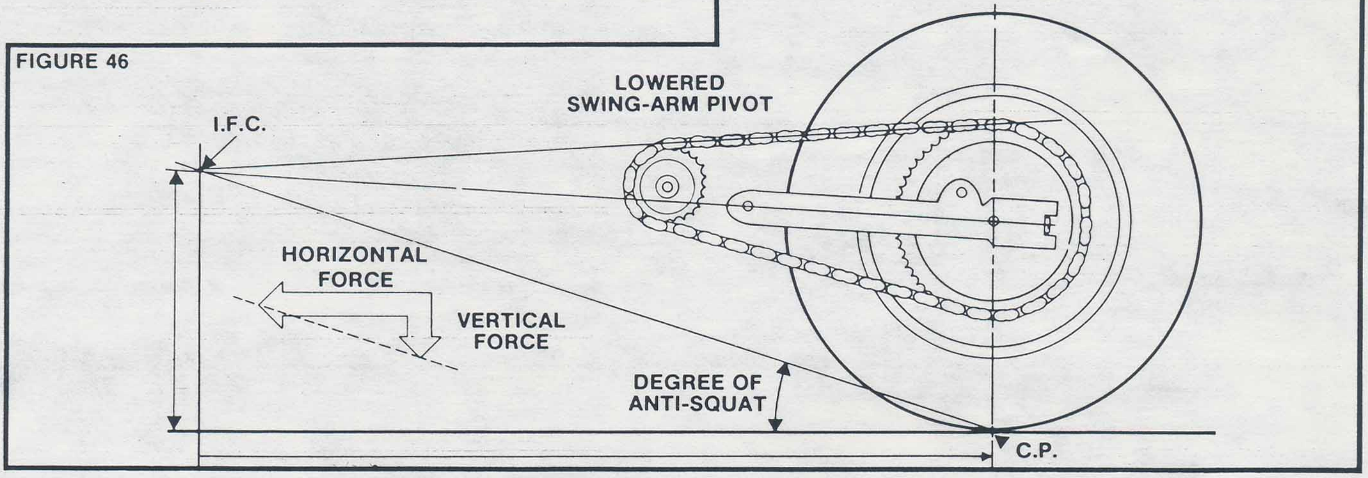


FIGURE 47

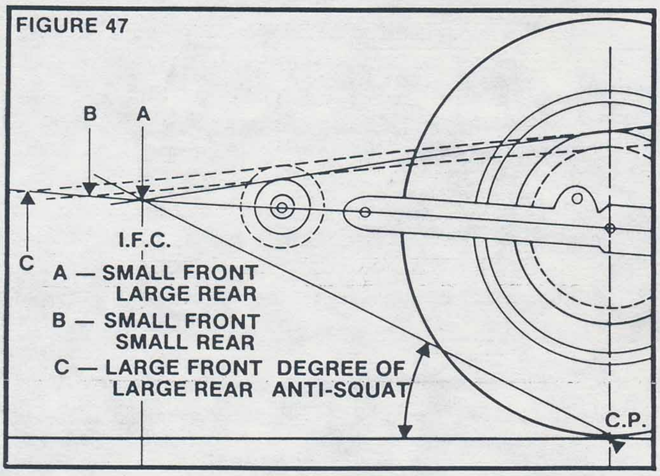
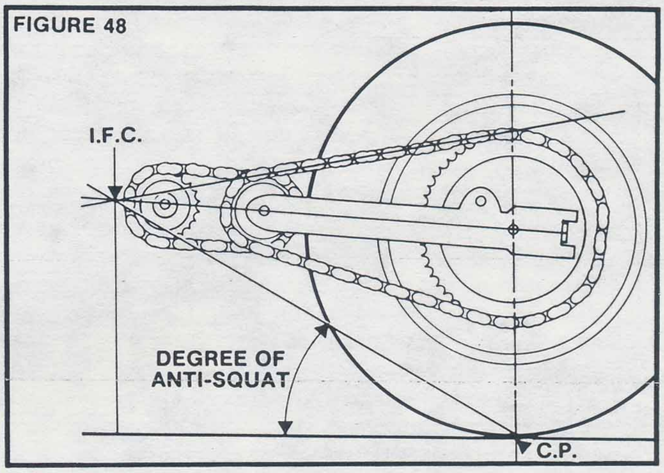


FIGURE 48



These gear-change effects can be useful for adjusting the anti-squat if you don't end up with gear ratios that are unusable. Some motorcycles have provision for altering the primary drive ratio (the gear ratio between the engine and transmission) to counteract any unfavorable final drive ratios. In any case, be aware that gear ratio changes also change the amount of anti-squat. Again, be aware that gear ratio changes don't solve the problem of pro-squat when the suspension is compressed.

Juggling the relationships of the swing-arm pivot and angle to the sprocket sizes and angle can bring the initial anti-squat to a more favorable amount and can reduce slightly the amount of anti-squat change due to suspension travel. But, in order to have any dramatic effect other methods are necessary. **Figure 48** diagrams an arrangement where the chain reacts on the chassis from a secondary sprocket mounted concentric to the swing-arm pivot. This configuration reduces the anti-squat change quite a bit but still falls short of the goal of no anti-squat change. Notice the only chain angle we are now concerned with is the second or final drive chain. This is because it is the one connecting, or acting as a link between, the sprung and unsprung parts of the chassis. For our anti-squat purposes, we will always consider the last fixed sprocket on the chassis as the point the chain is acting and the chain angle will be drawn through that point.

■ NOTE: For a topped-out suspension, or a rigid frame, none of the anti-squat forces discussed in these earlier paragraphs will apply.

The concentric sprocket design is the goal of most manufacturers today, as evidenced by all their efforts to position the countershaft sprocket and the swing-arm pivot as close together as possible. A few actually have made jack-shaft concentric arrangements, as shown in **Figure 48** and some are now designing extra long swing-arms that pivot right at the engine sprocket. Still, this design leaves something to be desired.

Figure 49A shows another approach to the problem. This time, two swing-arms are used in conjunction with a short upright to form a parallelogram that gives the effect of one very long swing-arm. If the arms are parallel to each other and exactly the same length, the effective swing-arm is the same as if there was just one central swing-arm. However, if the arms are not parallel **Figure 49B**, they assume an instantaneous center of their own and anti-squat diagrams must be drawn using this new instantaneous center as if it were the swing-arm pivot. This arrangement geometrically solves many problems like chain tension and braking torque, but still does not completely solve anti-squat change. Further, the double-link system pays a penalty in complication and extra weight.

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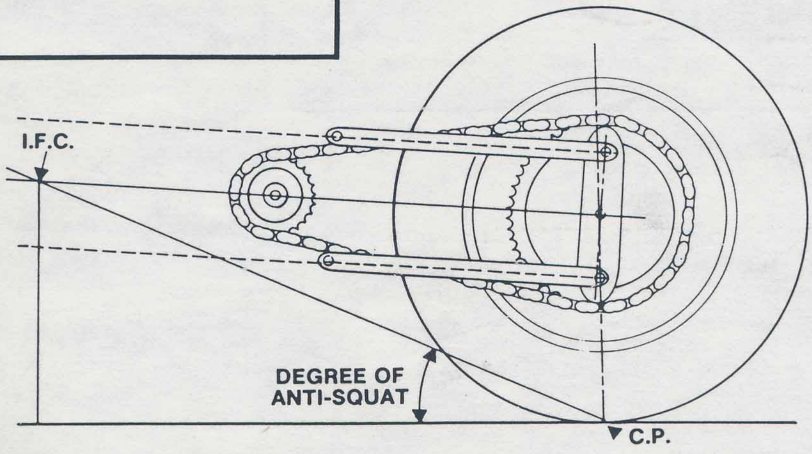


FIGURE 49A

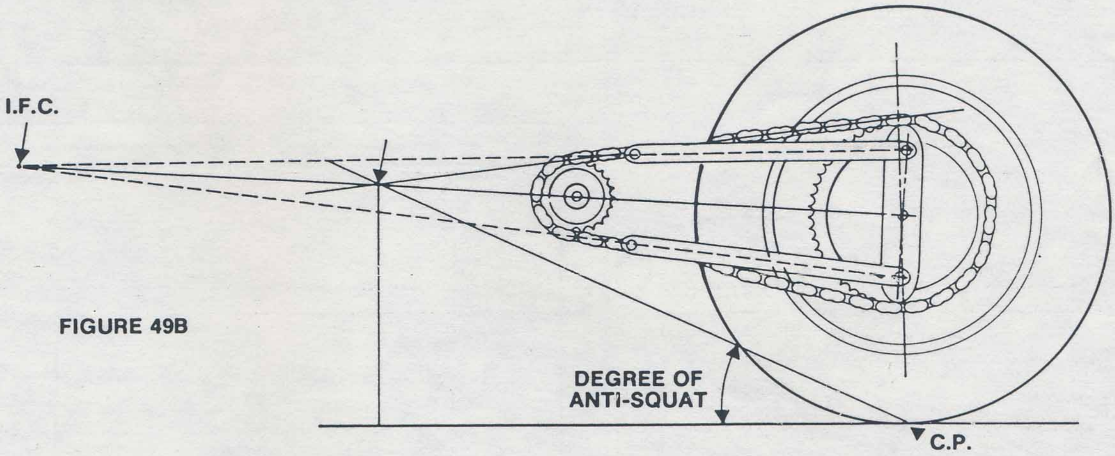
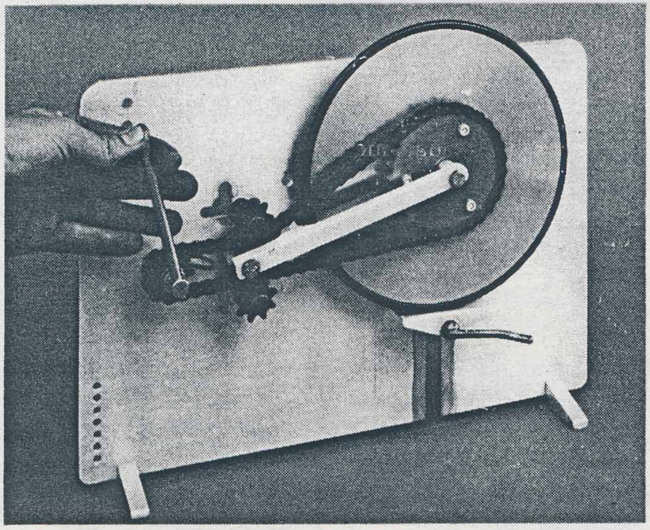


FIGURE 49B

The most promising approach to anti-squat change is one developed by Trevor Harris. **Figure 50** is a photograph of a test fixture built by him to prove or disprove his theories. As you can see, it is a miniature motorcycle rear suspension with the positions of all the components completely adjustable. With this fixture, any combination can be tried and by measuring the torque required to rotate the engine sprocket, the traction between the tire and its support platform can be computed. This fixture confirmed beyond a doubt that anti-squat has a substantial effect on traction and the methods of diagramming anti-squat geometry presented here are accurate and realistic, not merely theoretical mumbo jumbo.

FIGURE 50



After determining the factors that influenced anti-squat, Trevor tried many variations in an attempt to minimize anti-squat change. The system with the best compromise of complication to effectiveness turned out to be a pair of idler sprockets that redirect the angle of the chain. **Figure 51** diagrams the new configuration both extended **(A)** and compressed **(B)**. Notice the top idler has no effect until the suspension is compressed. Notice the position fore and aft of the top idler changes its effectiveness. The farther back the greater the effect, but complications of chain length and swing-arm interference make installation more and more difficult on today's motorcycles. The bottom idler has two functions: One to improve the chain geometry during braking; the other to give up chain length as the top idler consumes chain length. This system does not solve the anti-squat change problem, but it does reduce anti-squat change more than any of the others. Additionally, it lends itself to an infinite number of variations which should provide the answers concerning anti-squat.

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FIGURE 51A

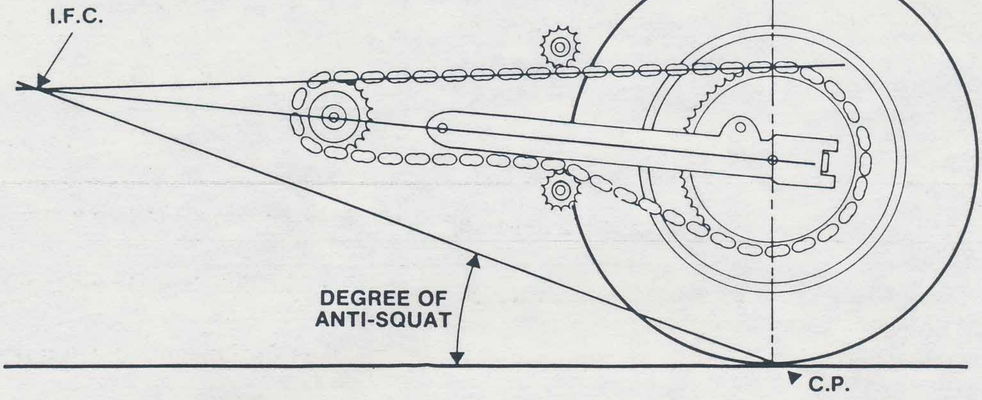


FIGURE 51B

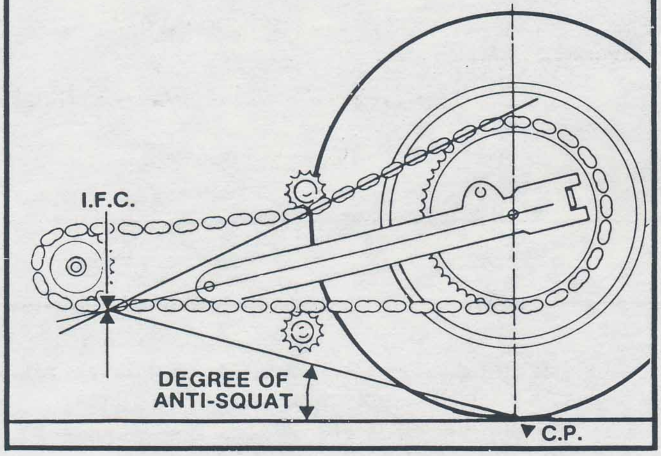
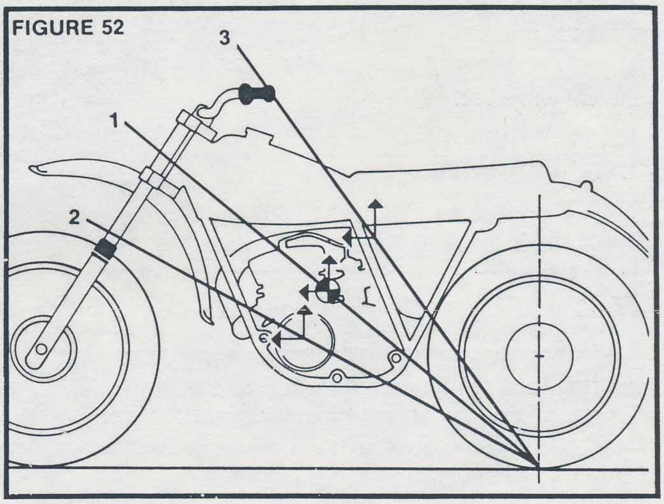


FIGURE 52



The chain idler system has been tested in competition in a flat track application with success that includes a win. The riders (one a former national champion) report a definite change immediately in the feel of the motorcycle when the idlers are installed. Further proof that anti-squat should not be ignored. These preliminary tests are just the tip of the development iceberg. Designs do exist that provide just about any anti-squat characteristics imaginable; however, the question of optimum anti-squat still haunts us.

Another look at the instantaneous force centers (I.F.C.) in the various diagrams reveals that as it moves up and down it almost always moves fore and aft as well.

There is another relationship to the I.F.C. that should be considered besides the anti-squat angle it prescribes. **Figure 52** shows a motorcycle with its center of gravity indicated. The center of gravity is the point where if you were to lift the motorcycle from that point, everything would be in equilibrium, or balanced. If you lift the motorcycle on either side of the center of gravity, the motorcycle will rotate until the center of gravity hangs directly under the lifting force.

In **Figure 52** three hypothetical optional I.F.C.'s are shown. How they differ is in their relationship to the center of gravity. The first option has the I.F.C. coincident with the center of gravity. This option will lift the chassis straight up. Option two has the I.F.C. ahead and below of the center of gravity. This configuration will tend to cause the chassis to rock clockwise for an instant. This rocking force gets more pronounced the greater the moment arm from the center of gravity. (The moment arm is a perpendicular line drawn from the anti-squat angle line to the center of gravity).

Option three will cause the chassis to rock in a counter-clockwise direction. The effective differences between options two and three is that the second option will tend to induce or promote wheelies whereas option three will tend to cancel wheelies for an instant. Notice also that any I.F.C., whether fore of aft of the center of gravity, whose anti-squat angle or force vector intersects the center of gravity will not impart a rocking motion to the chassis.

As is the case with the optimum anti-squat, the question of the optimum I.F.C. to center of gravity relationship is still very much unanswered. It is hoped that the information presented here will encourage further experimentation to resolve these questions. When that is done, we can all look forward to improved motorcycles and better motorcycling.

Glossary ...

ACCELERATION — The rate of change of velocity, or how quickly an object speeds up.

ACTIVE COILS — The working coils in a spring that are free to move.

AERATION — The condition when air bubbles are present throughout a liquid.

AIR SPRING — A device that uses air's natural ability to be compressed.

ANTI-DIVE — A system to resist a vehicle's nose-down pitch when braking.

ANTI-SQUAT — A system to resist a vehicle's nose-up pitch when accelerating.

BASE PIN — The restriction in a conventional shock absorber that gives compression damping.

BASE VALVE — The particular valve that gives damping in the compression direction, and free-flow in the rebound direction.

BLEED NOTCH — The small aperture in a shock valve that gives damping at slow piston speeds.

BODY ENGLISH — Instinctive use of body weight for control while riding.

BOTTOMING OUT — The condition when all suspension travel has been used up.

BOYLE'S LAW — A gas law stating that at a steady temperature, Pressure X Volume = a Constant.

CENTRE OF GRAVITY — The point in a mass where all the weights within the mass are equally balanced. Abbreviated to C.G. and shown on diagrams by the symbol ⊕

CHROME SILICON AND CHROME VANADIUM — Alloying elements in steel that give strength and toughness.

COIL BIND — The condition when a spring coil bears against the next coil.

COMPONENTS OF A FORCE — Parts of a force that act in specific directions.

COMPRESSION DAMPING — The resistance of a shock absorber to being pushed together at a given speed.

COMPRESSION RATIO — The ratio between the starting volume and the final volume when a piston moves in a cylinder.

CONTACT PATCH — The print of a tire on the ground.

DAMPING FORCE — The force required to move a shock absorber at any given speed.

DE CARBON — Name of leading authority on shock absorber design. Holder of many patents.

DECELERATION — The rate of slowing down of an object.

DEFLECTION — Movement of a part under load.

DIMINISHING RATE — Suspension where wheel rate decreases as the wheel moves up.

DIVE — Downward movement of the front of a vehicle (nose dive) caused by pitch.

DOWN FORCE — Total load at, for example, the tire contact patch.

DROOP — Suspension movement in the down direction. Wheel moves away from fender.

DYNAMIC — A system that's moving.

DYNAMOMETER — (Shock Dyno) A test machine for working a shock and measuring the loads it produces.

EMULSION — A dispersion of tiny air or gas bubbles throughout a liquid.

ENERGY — A body's ability to do work.

EXTENSION DAMPING — (Rebound or return damping) The resistance of a shock absorber to being pulled open at a given speed.

FADE — An unwanted reduction in damping control caused by heat.

FLOATING PISTON — Device to separate oil from gas in a De Carbon shock.

FORCE — An influence (as a push or pull) that causes motion or a change in motion.

FREE LENGTH — Natural length of a spring when no load is applied.

FREON CELL — Plastic bag with Freon gas trapped inside.

"g" — The acceleration due to gravity. (Or, what you feel in a banked turn.)

GEOMETRY — Descriptive term for the lengths and angles used in a chassis design.

G.V.W. — Gross Vehicle Weight. (For example, motorcycle, with fuel and oil, plus rider, passenger and luggage.)

HEAD ANGLE — Angle the steering axis leans back from vertical.

INSTANTANEOUS FORCE CENTRE — Location where component forces act on the chassis (I.F.C.)

LEVERAGE RATIO — (Of a rear suspension) Rear wheel travel divided by the shock travel.

(LEVERAGE RATIO)^2 — The leverage ratio multiplied by itself.

LOAD CELL — Device which produces an electric signal when loads are applied.

MASS — For motorcycles, think of mass as weight.

MEAN DIAMETER — The inside diameter of a spring plus one wire diameter.

MECHANICAL ADVANTAGE — (Of a rear suspension) Numerically, the same as leverage ratio

MECHANICAL PRELOAD — The amount either in pounds or inches, a spring is compressed when fitted to an extended shock absorber.

MOMENTUM — The momentum of a body is its mass multiplied by its velocity.

MUSIC WIRE — A good quality wire used for small springs.

ORIFICE — A passage, of exact and pre-determined size, for metering shock absorber fluid.

OSCILLOSCOPE — Electronic device for displaying information on a cathode ray tube.

Glossary ...

OVERSTRESS — The condition in a spring when the wire size cannot carry the loads applied.

PITCH — Rotation, or rocking of a vehicle in a vertical plane.

POLAR MOMENT OF INERTIA — A measure of the reluctance of a vehicle to rotate about its centre of gravity.

POTENTIOMETER — Device to sense movement and give an electric signal.

PRELOAD — See definitions of "mechanical" and "static" preload.

PRESSURE TUBE — The precision working cylinder in a conventional shock absorber.

PRIMARY SPRING — The long spring of a dual spring system.

PROGRESSIVE RATE SPRING — A one-piece spring with a rate that smoothly increases as the spring is compressed.

PUMPING DOWN — The condition (like a ratchet effect) when the ride height of a motorcycle progressively lowers over a series of bumps.

PUMPING UP — The condition when the ride height rises over a series of bumps.

REACTION — The push or pull that acts in opposition to (and is equal to) a force.

REBOUND — The extension or return direction of the shocks or suspension.

RISING RATE GEOMETRY — A suspension where the wheel rate rises with bump travel.

SEAL FRICTION — Mechanical drag of the seal on a rod or tube.

SECONDARY SPRING — The short spring of a dual spring system.

SHOCK ABSORBER — A hydraulic device used to resist movement or damp vibrations by pumping oil through orifices.

SPRING COMBINATION — Two (sometimes three) springs stacked together.

SPRING RATE — The amount of force required to deflect a spring a given distance.

STATIC PRELOAD — The mechanical preload plus the additional amount the spring compresses when it is supporting the chassis while at rest.

STATIC WEIGHT — Total of the weights at the front and rear tire contact patches with the motorcycle stationary.

TANGENT — Line touching an arc of a circle. (Example, a chain makes a tangent to a sprocket).

TORSION — A turning effect about a point.

TRAIL — Distance between the point where the steering axis intersects the ground and the centre of the contact patch.

UNSPRUNG MASS — Weight of the wheel, tire, brakes and suspension parts, etc.

VELOCITY — Speed.

WEIGHT TRANSFER — When braking, this is the amount of load subtracted from the rear wheel and added to the front.

WHEELBASE — The distance from front to rear axles.

WHEEL RATE — The amount of force required to deflect a wheel vertically by a given distance.

S & W Engineered Products wishes to thank **Motorcyclist Magazine** for their kind permission to reprint major sections of our Suspension Engineering Handbook which first appeared in **Motorcyclist** as a series in 1978. Their courtesy and cooperation was of tremendous value to our staff.

AUTHOR: BRUCE BURNESS

CONSULTANT ENGINEER/DESIGNER: MARTIN WAIDE

LAY-OUT AND ILLUSTRATIONS BY ROGER SAURIOL

Spring rate Selection

The use of the table and chart on this page will give an estimated rear suspension spring rate for all types of riding. Several variables have to be considered, and turned into a "correction factor" by using the small table (below, at right) which shows both off-road and street riding parameters. Total up the appropriate correction factors (plus cancels minus) and apply this factor to a particular box at the top of the main chart, which carries the description of your type of riding.

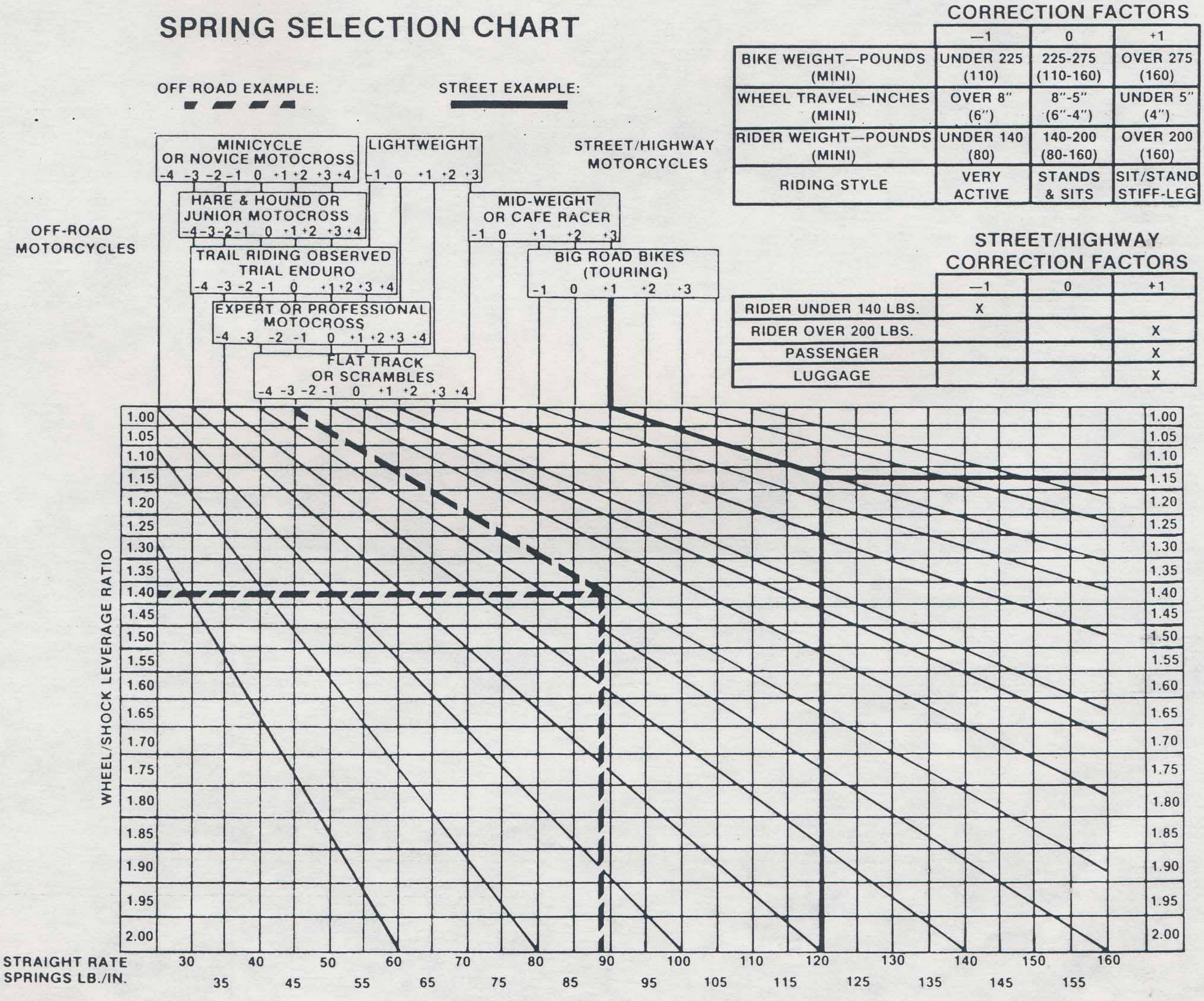
You will note that the leverage ratio of the suspension must be known. Draw a line horizontally across the chart for your particular leverage ratio. Refer to Page 9 for a method of obtaining this ratio for your bike's measurements if you don't already know it.

Follow the angled line down from your selected correction factor at the top of the chart until it crosses your horizontal leverage ratio line. Then follow vertically downwards to the spring rate scale, and read off the spring rate in lbs./in.

The resulting spring rate is a best estimate and your personal preference may eventually be for a rate slightly different from the one recommended. Here are two actual examples in the use of the table and chart.

Off-Road Example: First refer to the small table. A 280 lb. Bultaco (+1) with 8 inches of rear wheel travel (—1) has a 140 lb. rider (—1) with a riding style standing and sitting (0). Totaling the correction factors, +1, —1, —1, and 0, the result is —1. Transfer this factor to the main chart, and knowing that the rider is an expert at motocross, and that the Bultaco has a leverage ratio of 1.41:1, the chart shows a recommended Spring rate of 88 lb./in.

Street Example: Again refer to the small table. Take a Honda GL-1000 being ridden by a rider of over 200 lbs. (+1) but with no passenger (0) and no luggage (0). The resulting correction factor is +1, +0, +0, = +1. Transfer this to the main chart and knowing that the GL-1000 is a big road bike with a leverage ratio of 1.15, the recommended spring is 120 lb./in.


SPRING SELECTION CHART

OFF-ROAD CORRECTION FACTORS

	—1	0	+1
BIKE WEIGHT—POUNDS (MINI)	UNDER 225 (110)	225-275 (110-160)	OVER 275 (160)
WHEEL TRAVEL—INCHES (MINI)	OVER 8" (6")	8"-5" (6"-4")	UNDER 5" (4")
RIDER WEIGHT—POUNDS (MINI)	UNDER 140 (80)	140-200 (80-160)	OVER 200 (160)
RIDING STYLE	VERY ACTIVE	STANDS & SITS	SIT/STAND STIFF-LEG

STREET/HIGHWAY CORRECTION FACTORS

	—1	0	+1
RIDER UNDER 140 LBS.	X		
RIDER OVER 200 LBS.			X
PASSENGER			X
LUGGAGE			X

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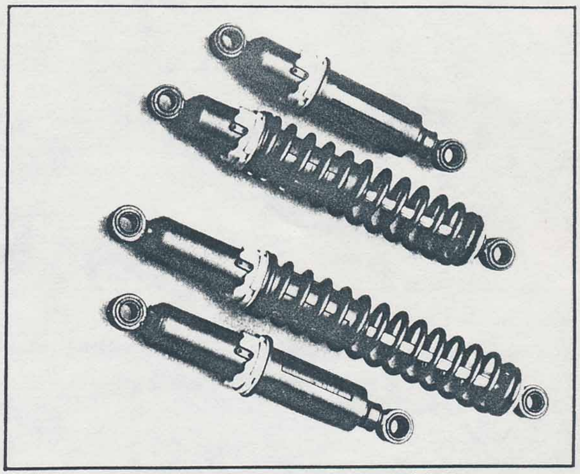
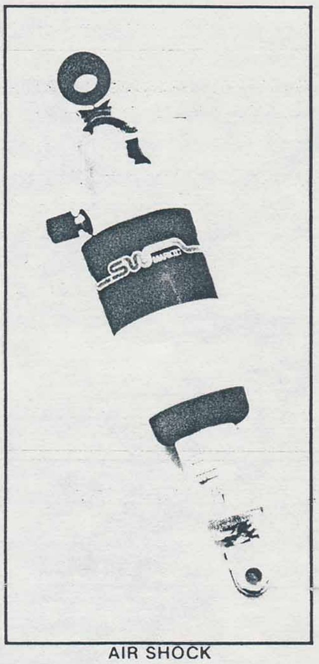
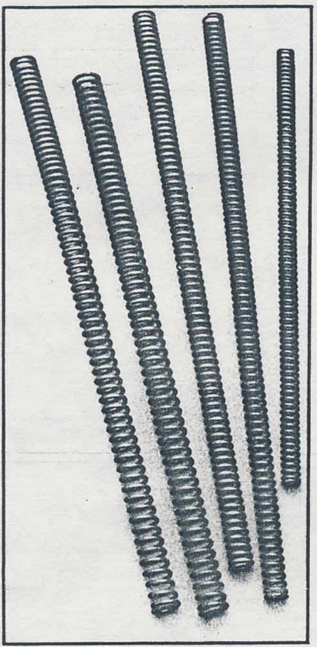


FREON GAS LONG TRAVEL SHOCKS

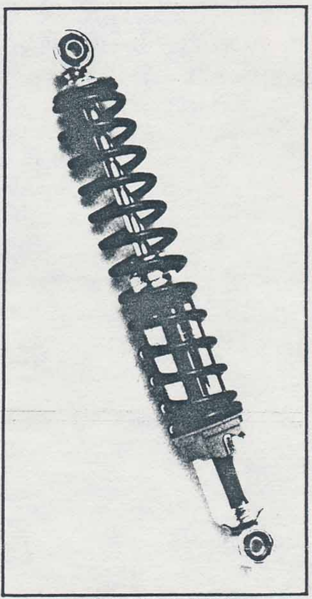


AIR SHOCK

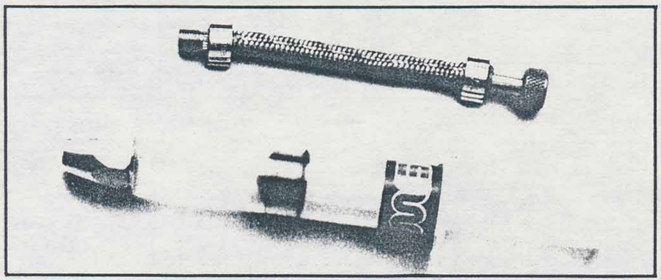


FORK SPRINGS

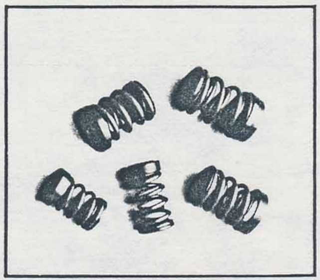
MOTOCROSS
DUAL SPRING SHOCK



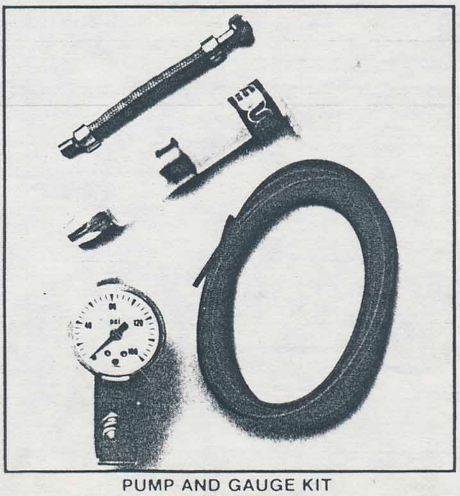
FREON GAS TOURING
SHOCK (CHROME)



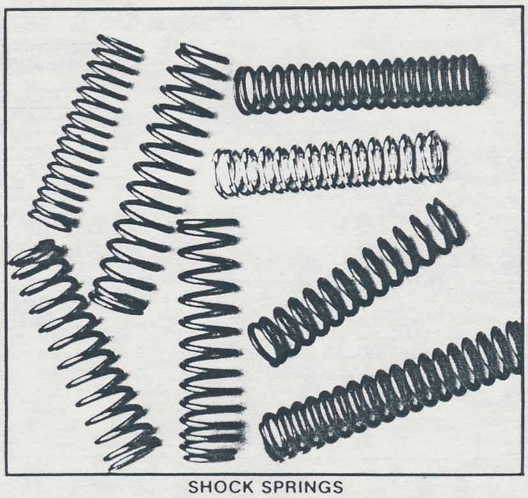
MINI-PUMP KIT



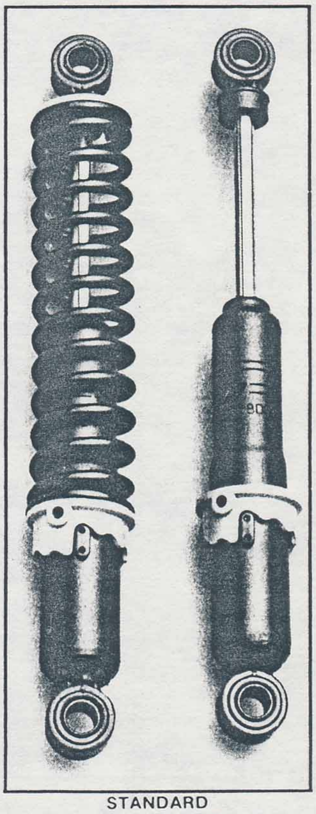
COMPETITION
VALVE SPRING KITS



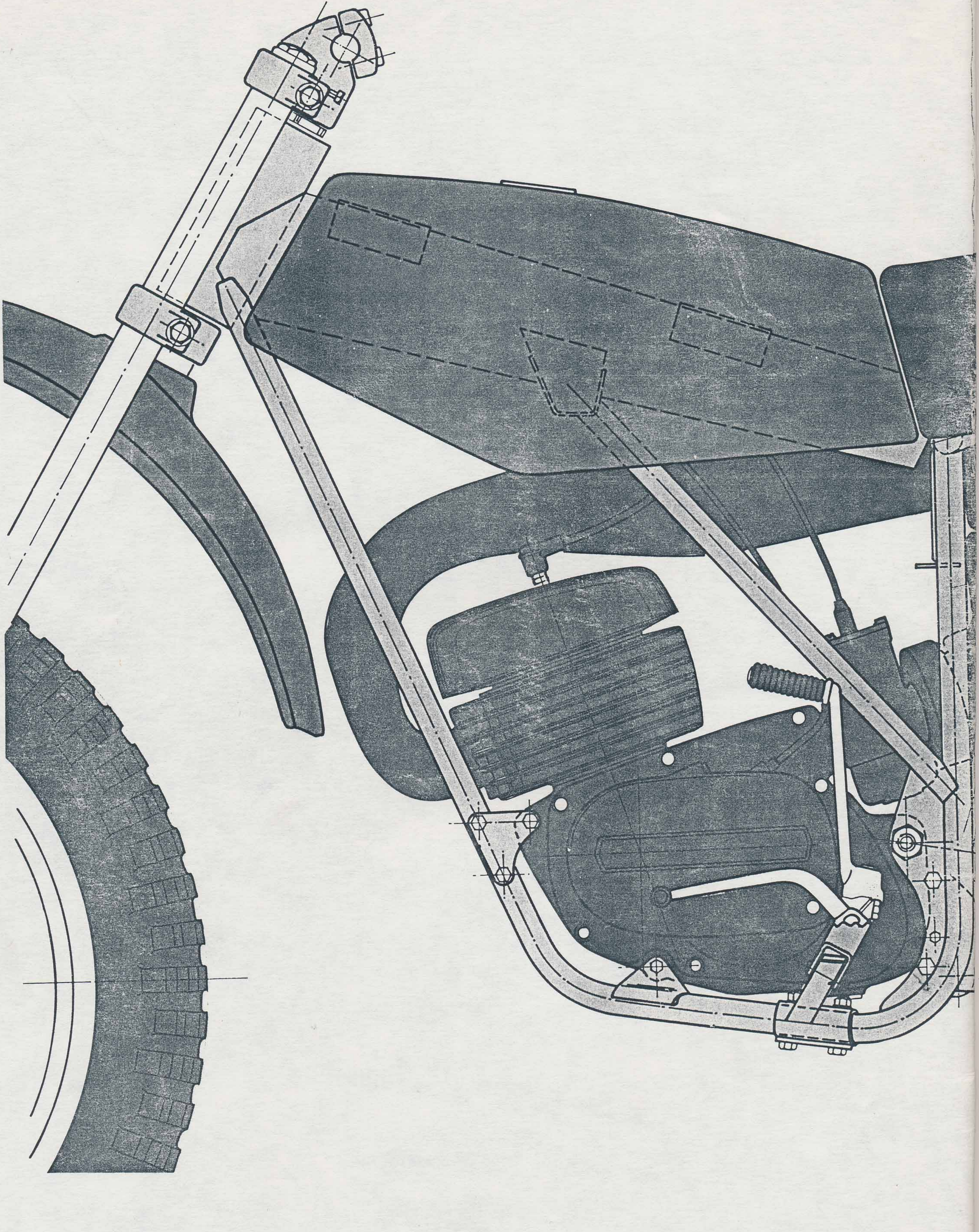
PUMP AND GAUGE KIT
FOR AIR SHOCK



SHOCK SPRINGS



STANDARD
HYDRAULIC SHOCKS



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