



PHOTOGRAPHY: DALE BOLLER

# CHAINS

BY GORDON JENNINGS

● Folklore's famous caveat concerning chains and weak links takes on special meaning for the poor motorcyclist, who usually is painfully aware that his bike's weakest link is nothing other than that collection comprising its drive chain. And experienced riders aren't even worried about weak links, because they know a chain can be in an acute state of failure and ready for retirement long before any of its links are ready to part. An exceptionally ham-fisted rider may occasionally succeed in snapping a good-quality, still-serviceable chain, but that kind of thing is comparatively rare. For most of us the major problem is simply chain wear, and it is a problem that has assumed large proportions in recent years.

Old-timers, who have been buying and riding performance bikes for maybe 20 years, will recall a time when they were getting not less than 10,000 miles of service from a rear chain. They may wonder why their new Superbike can't go more than half that distance without gnawing its chain to a frazzle. Were chains really better back in 1954? Not really. There is every reason to believe that today's motorcycle drive chains are the best we've ever had. The problem is that these chains have been only incrementally improved over those available two decades ago, while surrounding events have conspired to make vastly harsher demands on them.

At least one of these demands has increased for reasons entirely independent of what we are pleased to consider progress in motorcycle technology. Better roads systems and upward revisions in statutory speed limits encourage cruising speeds about 15 per cent higher than those typical of 1954, and the result is a disproportionate increase in the rate of chain wear. This shortening of chains' service life would therefore have occurred even if motorcycle development had been frozen at the 1954 level.

Some small part of the accelerated rate of wear at higher cruising speeds possibly is due to increased chain velocity, which produces larger centrifugal loadings on the chain as it passes around the sprockets. But of far greater consequence is the enormous increase in the amount of power that must be transmitted across the chain to sustain those higher cruising

speeds. In the steady-state cruising mode, loads on the chain result from the tug-of-war between the engine and aerodynamic drag. Because an unfaired bike and its upright rider bash such a large, messy hole in the air, that 15 per cent increase in cruising speed can translate into a 30 per cent boost in the power required to overcome drag. This inevitably shortens the chain's service life.

Other factors contribute to the higher incident of chain problems so many people seem to be having these days; for those we may thank most of the manufacturers for the lines of development they have chosen to follow. The factor most frequently mentioned is simply available horsepower, which has in all displacement classes risen extremely sharply in recent years. Some of today's 250s are delivering as much horsepower to their chains as the 500s of a decade past, and the modern Superbike has the kind of muscle old-timers dreamed about but never thought they'd get. That added power doesn't mean much when a bike is humming along at a steady, say, 65 mph, because if 20 horsepower is required to hold that speed then that's all the chain is being asked to handle—even though double or triple that power is to be had from the engine at wide open throttle. Naturally there will be times when the rider applies a lot more of the available power, as when squirting around big trucks in the face of on-coming traffic. People also use the extra power we're getting with modern bikes as a convenience, in hauling lots of luggage and chubby companions on long trips and breezing up grades steep enough to slow any big bike of the past to a canter. It is in such ways that the current crop of machines come to devour their drive chains in markedly fewer miles than once was the case.

A final straw is the widespread use of too-small sprockets at the transmission's output shaft, which works in two separate ways to help destroy chain. First, there is an increase in the tensile load placed on the chain as sprocket sizes are reduced. Second, there is the fact that sprocket's teeth do not impart uniform velocity to the chain. As far as the chain is concerned, sprockets are not circles but poly-

gons, with flats that produce an uneven, angular displacement of its links. The result is that the chain is pulled along in a series of sharp tugs, with the fluctuations increasing in amplitude as the number of teeth is reduced.

It is significant that load ratings for chains are based on 19-tooth sprockets, and that designers are supposed to adjust those ratings up or down according to the number of teeth on the sprocket to be used in a particular application. The nominal load rating is improved by 10 per cent with a 21-tooth sprocket, but falls below the nominal by 12 per cent when a 17-tooth sprocket is employed. These nominal load ratings are a reflection of what may be expected of a chain in terms of service life, and it is a bit disheartening to note that the 15-tooth transmission shaft sprocket you see on bikes like Kawasaki's Z-1 drops the chain's rating to only 76 per cent of nominal.

Some of that reduction in a chain's rated load capacity is due to the kind of polygon-effect speed fluctuations described earlier. Most of it probably is the result of the very great differences in tensile loads with sprockets of varying sizes. You can see this effect at work by considering a hypothetical example of chain drive in which the torque being applied to sprocket is 100 pounds-feet,  $\frac{5}{8}$ -inch pitch (the distance between rollers) chain is used, and tension readings are taken with 20- and 15-tooth drive sprockets. The pitch diameter of a 20-tooth sprocket is 4 inches, and the load on the chain calculates out as 600 pounds. With the smaller, 15-tooth sprocket the pull on the chain is increased to 800 pounds, which means that the chain is being stressed 33 per cent higher in transmitting the same amount of power.

What we have presented thus far adds up to a compelling reason for employing far larger transmission output shaft sprockets than are commonly being used today. Unfortunately there is more to the story yet to be told. Designers must give some thought to sheer bulk, and it is extremely difficult to find room for a large "countershaft" sprocket when the engine, clutch and gearbox all have been squeezed together inside a casing not much larger than a breadbox. Moreover,



# Basics

increasing the size of the transmission sprocket from 15- to 20-teeth requires that the rear wheel sprocket be enlarged by the same, 33 per cent amount. That is to say, if the bike has a 15/35 gearbox/rear wheel sprocket combination, changing to a 20-tooth transmission sprocket would necessitate accommodating a 47-tooth sprocket on the rear wheel to keep the same overall reduction ratio. The other approach would be to use a smaller rear wheel sprocket in combination with a big transmission sprocket and compensate for this with a higher primary drive ratio. But of course that would lead to a bigger torque multiplication between the engine and transmission, producing substantially the same high loadings on the chain and overworking the clutch as well. It all adds up to a beggar's choice for the design engineer—who is naturally inclined to heap the worst of the burden on the chain. If it develops that the chain sags under its load then there always is the hope that its maker or some other chain supplier will be equal to the challenge. That failing, it still is better to have one's customers cursing about "cheap junk chain" than to have them mired in clutch or gearbox problems.

Chain manufacturers sometimes also get the blame for troubles caused by faulty sprockets. We tend to think of sprockets as being too simple to design badly, and there once was a magazine story describing how you could make your own sprockets by drilling a ring of roller-size holes in an aluminum plate, cutting between the holes with a saw and then filing the nubs into teeth. Make a sprocket like that, or buy its near-equivalent from some incompetent specialty equipment manufacturer, and you'll have yourself a genuine chain-eater. Correctly-designed sprockets have teeth of a shape easily as complex as those on a gear, and even the gaps between the teeth are important. You may think that the chain's rollers pull down tightly into those gaps. They don't. When the sprocket has been properly designed the rollers touch down only briefly in the bottoms of the pockets between the teeth, and at a point halfway around the sprocket. The rollers are picked up high on the forward (relative to rotation) faces of the sprocket teeth as the chain moves into mesh, move progressively lower farther around until they center in the pockets at the halfway point, and then climb up the teeth's trailing faces until they pull clear to join the tangential line of the chain away from the sprocket. You will appreciate that the

sprocket's teeth and pockets must be very intricately shaped before all this happens according to plan.

To further complicate the sprocket designer's job provision also must be made to accommodate a reasonable amount of wear in the chain. Wear has the effect of increasing the chain's pitch (the distance between the rollers' centers) and that changes the effective pitch diameter of the sprocket. Under load, the chain wedges itself up on the sprocket teeth's working faces and a worn chain climbs higher than one that is new. Thus, the teeth should have the tallest working face that can be provided consistent with other tooth-form considerations, which include a lot of pressure-angle esoterica and the strength of the material from which the sprocket is made. Material strength is not terribly important with a new chain, but one that is worn climbs high on the teeth and will bend them over at their tips if the chain is too badly worn. It should be understood that this bending can occur even if the chain is adjusted fairly tight, for the rollers' urge to space themselves evenly around the teeth's working faces simply will not be denied. So a badly worn chain will ruin the best of sprockets—and a sprocket that is damaged, its teeth hooked over, will quickly destroy a new chain. The lesson in this is that you should replace chains before they have elongated enough to ruin your bike's expensive sprockets.

Those pockets between the sprocket's teeth represent, in part, nothing more than fillets to prevent stress concentrations around the teeth's bases. But the pockets' shape is important for another reason: to prevent packing with grit or mud. If a motorcycle's chain and sprockets were enclosed, or working in a completely clean environment, the pocket radii could be made to match the chain's roller diameter, and that would provide the greatest separation between a tooth's working faces and the strongest sprocket teeth with any given material. However, few motorcycles have enclosed drives, so sprockets must have pockets shaped to resist clogging. The usual approach is to enlarge the pockets, giving them radii somewhat bigger than that of the chain rollers, which provides an avenue of escape in front of and behind the rollers. In very muddy terrain the ordinary measures may prove inadequate to prevent packing—which has the effect of both overtightening the chain and lifting it out of mesh with the sprocket teeth—and other techniques may need to be em-

ployed. One of these took the form of scalloped reliefs cut into the sides of the pockets, but not up on the teeth, of the sprockets used on ISDT MZs. Bultaco compensates for the overtightening effect with an over-long chain and a spring-loaded tensioner to control the slack. These countermeasures intended for muddy conditions should also be of interest to the southwest's desert rats. The sand wash commandos frequently buy and use aluminum sprockets made by accessory equipment manufacturers, and a survey of the examples of these sprockets in our shop indicates that certain of them do have very tight roller pockets. That unquestionably makes their teeth stronger, and in fact may be necessary in aluminum sprockets. But it also renders them liable to pack with grit—and you have already seen that that is a bad thing.

Grit may be a problem for sprockets;



it is a disaster for chains, and in this area there are no trick countermeasures and none appears to be in sight. Drive chains are now fairly well standardized in design, and future progress seems to rest firmly with either those who can find ways to wrap them in enclosures or with industry's metallurgists. With one unpromising exception all of the chain used on motorcycles is of the roller variety, which is rather more complex in construction than a cursory inspection of the stuff might suggest.

Roller chain is made up of pin links and roller links. The latter type consists of tubular bushings joined together by side plates. The pin links bridge between the roller links, with the pins inside the roller link bushings and their ends held firmly by the pin/link side plates—which overlap the roller link side plates. The roller link bushings are a tight press fit in their side plates but the rollers themselves, which also are short tubular pieces, are a slipfit over the bushings and are given enough end clearance between the plates to enable the rollers to turn. All of the pins are very slightly reduced in diameter at their ends, to hold the correct distance between the pin link side plates, and the pin ends are punched like rivets when the chain is made to hold the plates in place. All, that is, except for the master link (if any) which has a loose plate on one side secured by a spring clip.

Chain failure only rarely takes the form of links snapping, but that can happen if the load applied exceeds the chain's tensile strength. With the breaking point of good quality  $\frac{3}{8}$ " pitch chain being between 6000 and 8000 pounds it is not likely that horsepower alone would ever pull it apart. Besides, the rear tire will spin long before there is enough pull on the chain to break it. Still, chains are broken, and when they are it almost invariably is a consequence of severe impact loadings—such as occur when there is a lot of slack in the chain and it is snatched hard by a sloppy gear-change, up or down. Under those conditions there may be an instantaneous loading high enough to pull a pin right out through the end of its sideplate, which is the form tension failures usually take.

Wear in roller chain seldom involves the rollers themselves to any significant extent, as the bearing surface between roller and bushing is relatively large and such wear as may take place does little to impair the chain's primary functions. That cannot be said for wear in the joint between pin and bushing, where "chain

stretch" has its origins. The chain links are supposed to be spaced a very specific distance apart to fit the sprockets and wear in the pin/bushing joint upsets that spacing. The limit for wear is established by what is tolerable at the sprockets, and for most motorcycles this seems to be an accumulated elongation of 2 to 2.5 per cent. For  $\frac{3}{8}$ " pitch chain that represents between .0125- and .0156-inch of slack per pin/bushing joint. Of course you do not have to check the minute amount of slack in a single link; you check the whole chain. Lay the chain out straight on the floor, push on its ends to bring the links together and measure its length. Then give it a pull and measure again. A  $\frac{3}{8}$ " pitch chain that is about 63 inches in length overall has reached the 2 per cent wear limit when it shows 1.26 inches of end-play. We provide these percentage limits for the benefit of those who don't have factory-direct advice on the subject regarding their bikes. As noted before, the limits really are set by a bike's sprockets, and the factory's recommendations should be followed because they know more about those sprockets than any of us private citizens.

There isn't much to know about chain care. Just keep saying to yourself, "lubricate and adjust." Your owner's manual will tell you most of what you have to know about adjustment, which usually involves fiddling around until you get about 5/8" of vertical play in the chain midway between the sprockets. But sometimes the manuals don't mention that the chain also should be checked with the bike loaded so that the swing arm is level, which is necessary because the axle moves in a smaller arc than the distance between the sprockets. Set the adjustment with the bike up on its center stand and the swing arm angled down and the chain may be too tight when the suspension is loaded and the swing arm aimed straight back. You should keep the chain in adjustment if you want maximum service life from a chain, because excessive slack allows the links to lash around and beat themselves to death against the sprockets. But don't pull the adjustment up too tight. If you do it will promptly loosen again as the pins respond to the excessive tension by wearing away.

Keeping a chain lubricated is an endless aggravation for anyone who knows what he's trying to accomplish. First off, you are faced with an impossible choice between kinds of lubricants. Unless you use a thin oil none of it will penetrate down inside the links where it is needed,

yet thin oils are easily thrown off the chain. A very thick oil is less likely to paint a racing stripe up the back of your new jacket, but it's almost impossible to make the stuff penetrate inside the links. Some of the people who compound lubricants for chains have come up with a fair compromise by diluting what seems to be 50-weight oil with a volatile solvent. The solvent thins the oil enough to let it creep into the chain's crevices, and then evaporates to leave a thick oil that will stay on the chain. Anti-suff compounds like molybdenum disulfide and/or graphite may also be added. We like the chain oils in aerosol cans, because that makes them easy to apply and near-constant application of lubricant is the most important factor in getting the best mileage out of a chain. You should understand that the amount of oil is not terribly important: the chain will hold very little oil—excess gets whipped off immediately—and it goes dry very rapidly. So squirt a little oil on your bike's chain every chance you get and it will last about three times as long as one that is neglected.

A final word on the subject of lubrication: put the oil where it will do the most good. From what you have learned about chain it should (but may not) be obvious that the oil should be dribbled on the chain's side plates and not in the middle of the rollers. The oil is needed between the pins and bushings, bushings and rollers, and where the side-plates overlap. Oil applied to the side-plates will find its way into all the places it's needed, if it is thin enough to flow—which is a good reason for oiling chain *after* riding your bike, while the links are warm and oil will have the best opportunity for penetration. And this approach will also give the excess oil a chance to drip-off the chain before you set off on the next day's ride.

Given religious neglect, chains can be ruined before they wear out—even if the wearing proceeds quite rapidly. A chain that has been run loose and dry may, for example, develop kinks caused by galling between the overlapped ends of the side plates. Sustained high-speed cruising with the chain out of adjustment will sometimes generate so much threshing of links against sprockets that the rollers split and drop off, and almost anything can happen to chain that has been cleaned with "Gunk." Washing chain with this or any other powerful cleaner tends to carry grit, and some of the water used to remove grit loosened by the cleaner, right down inside the links. The

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water then causes rusting which tends to weld the links together, while the grit mixes with oil to form a depressingly effective lapping compound. It is even possible to have a chain maladjusted without having it too tight or hanging slack, and we are not talking about the false adjustment you can get with sprockets having pitch circles eccentric to their shafts. If you adjust the chain and end up with the rear wheel misaligned the sprocket also will be misaligned and that will bias the chain pull toward one side of the links, concentrating the wear at the ends of the pins and bushings on that side. This load concentration produces rapid, lopsided wear and the chain just can't be expected to last very long, so alignment has an importance beyond for handling.

Some chains are capable of getting into trouble all by themselves. Poorly fitted pins will separate from the side plates; mistakes in heat-treatment can leave the chain too soft, meaning that wear will proceed extremely rapidly, or too hard and brittle in which case the chain will shatter like a wine glass. Good chain is expensive stuff, and it is not always, nor even often, found fitted as standard on new motorcycles—so you should consider buying non-standard, premium-quality replacement chain for your bike when the original wears out. There may be better chain than that made by Renold but if there is we haven't found it. You may be tempted by the price of the split-roller chain made for low-speed industrial applications but it's not equal to the demands made by motorcycles.

Trick chain, like the double-row kind and the Hy-Vo toothed steel belt made by Morse, may offer some hope for extended, low-aggravation service in the future, but there probably is less to be gained in that direction than in simply placing the chain and sprockets in a housing. With the chain tightly enclosed grit and mud are excluded, and it becomes possible to lubricate adequately without spraying oil on everything in sight. There is every reason to expect that the service life of chain would be extended by at least 300 per cent with an enclosure, and there certainly is nothing left to be done with the chain itself that has the potential for a similar degree of improvement.

All of which raises, as a side issue, the matter of shaft drives. BMWs have had shaft-driven rear wheels for decades, and there are persistent rumors of Honda doing likewise with a new, big-displacement tourer. Indeed, if you listen to the BMW Faithful you would think that all of the world's better motorcycles will soon have to be shaft-driven, because chains are nasty things and unreliable, etc., etc. *ad infinitum, ad nauseum*. The facts are a bit less clear-cut.

Shaft drives certainly are reliable, unless badly engineered, but when you have

said that much you're fresh out of good things to say about them. Shaft drives also are—as compared to chains and sprockets—complicated, heavy and expensive. With shaft drive there is the choice of positioning the engine in the frame with a fore-and-aft crankshaft orientation (like BMWs and the big Moto Guzzi) and have one right-angle kink in the drive at the rear wheel, or to mount the engine transversely (as in a chain-driven bike) and insert another set of bevel gears in the drive train. Here the designer is faced with a genuine beggar's choice: if he opts for the transverse engine layout he avoids the torque reactions that sometimes make BMWs and Moto Guzzis handle peculiarly—but the drive train has to make two right-angle turns, which gets into a lot of gears, shafts and bearings; placing the engine in-line with the chassis eliminates one set of bevel gears, requires an extra pair of transfer gears to offset the drive so that the shaft will clear the bike's rear wheel, and brings on the muted curse of torque reactions. But for all of that the reason most manufacturers will have for retaining chain drives even on their biggest tourers simply is expense. All those shafts and spiral-bevel gears are costly, and with the price markup normal to manufactured products the end result is a motorcycle only the affluent could possibly afford.

There also is the possibility that shaft-driven motorcycles are something that only a minority of motorcyclists feel inclined to buy—at any price. The hot-blooded enthusiast may not want to pay the price in weight even if he has the price in dollars. Further, sporting riders will give a thought to the difficulty of changing overall drive ratios in shaft-driven motorcycles, and to the loss of mechanical efficiency incurred with all those gears—which is easily twice as high as the loss across a chain and sprockets.

In short, far from being the answer to everything shaft drive is an answer to just one thing: reliability. So we're going to have those pesky chains with us for a long time to come, and we might as well learn to live with this messy, jangling, none-too-reliable (but in all other ways marvelous) form of power transmission. We can all keep reminding ourselves, while we adjust and oil and replace ruined riding jackets, that the chain and sprocket drive is light, efficient, and offers the convenience of fast and inexpensive ratio changes to suit a particular sporting application. It's a first-rate drive system for all but the long-distance touring riders, and it would work fairly well for them if enclosed in a grit-proof, oil retaining casing. Shaft drive, as a cure for chain problems, is in many ways worse than the disease. If all the world's motorcycles were shaft driven and somebody had just invented the chain, sporting riders would see it as being on balance a great leap forward. ©

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