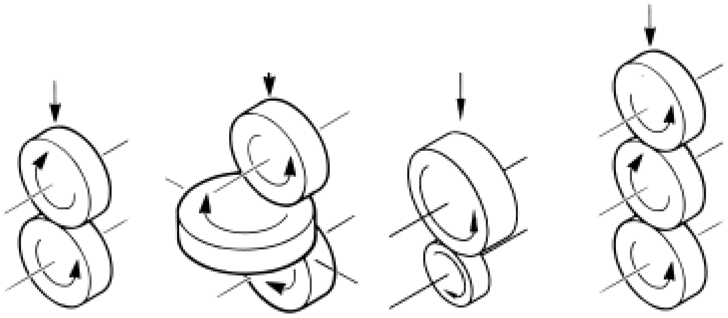
TWO ROLLER MACHINES



Torque and Power Circulation

Two roller machines fall into two basic categories, those with mechanical torque circulation (rollers back-to-back with gears in a "four-square" configuration) and those with electrical power circulation (mechanically open loop).

Mechanical torque circulation pre-dates efficient and effective electrical power circulation and Phoenix Tribology has three machines that use this technique, the TE 53 Multi-Purpose Friction and Wear Tester, the TE 55 Lubricity Test Machine and the TE 73H Two Roller Machine. With torque circulation, only a single drive motor is required, with sufficient capacity to drive the system losses only, in other words, to rotate the torque loop. It follows that the transmitted power through the tribological contact can be much higher than the motor input power with this arrangement.

Electrical power circulation first became properly feasible with the advent of the four quadrant d.c. thyristor drive, in which two identical motors are used, one driving and one absorbing, with the drives respectively drawing power from and regenerating power into the three phase supply. This works well, but is not electrically efficient. Because of phase angle effects between the supply current and the regenerating current, the supply has to have a capacity rated at the sum of the supply and regeneration current and not the difference.

In recent years, with the advent of the a.c. flux vector controller, we have ended up with a much more electrically efficient system, in which two vector controllers are supplied from a common d.c. bus, with one drawing power from and the other dumping power onto the bus. This means that the net electrical supply is limited more or less to the system losses, the difference between the driving and the regenerating power, with electrical circulation taking place entirely within the machine's power module. This system has replaced the former d.c. thyristor drive systems on all current open loop machines: the TE

54 Mini Traction Machine, the TE 72 Two Roller Machine, the TE 73S Two Roller Machine and the TE 74 Two Roller Machines.

With electrical power circulation, it will be apparent that in addition to providing the system losses, the motors used must have sufficient capacity to deliver and absorb the transmitted power and torque through the tribological contact. It follows that, unlike the circulating torque arrangement, the transmitted power through the tribological contact cannot exceed the capacity of the motors.

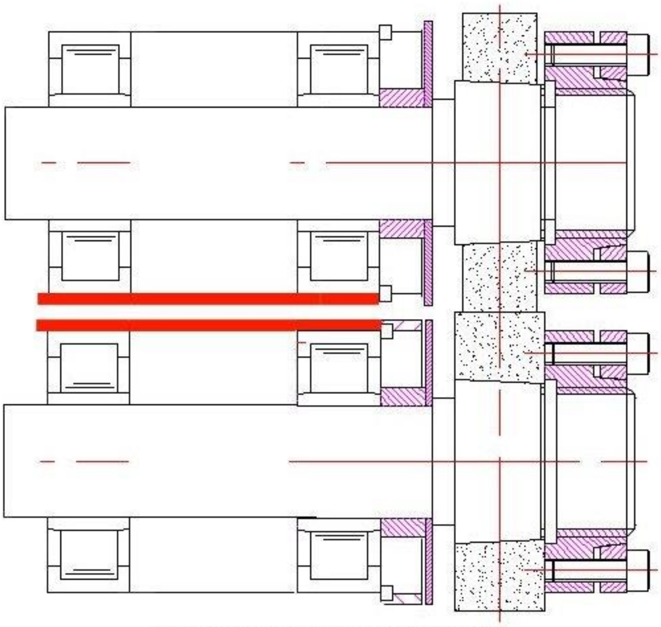
Now, it will be apparent that machines with two motors and electrical power circulation allow continuous adjustment of slide/roll ratio as the machine is running, whereas with back-to-back machines, the slide/roll ratio is fixed by the chosen gear ratio and thus cannot be adjusted while the machine is running. The preferential choice thus tends towards the flexibility of the two motor, circulating power solution. However, it will also be apparent that as the required torque or power capacity increases, usually as a result of wanting to use larger diameter discs and higher surface speeds, the size of the motors required will also increase, to a point where the twin motor solution becomes impractical. At this point, the only solution is to revert to a back-to-back gear design, but we are then left with the problem of how to achieve adjustment of the slide/roll ratio while the machine is running.

The TE 73H Two Roller Machine is a back-to-back, circulating torque design, but, uniquely, with variable slide/roll ratio at speeds up to 500 rpm. This is a large disc design, for accommodating rollers up to 300 mm in diameter, with loads up to 21 kN. Hence, assuming a traction coefficient of, say, 0.4, there is a requirement to generate a maximum torque of 1260 Nm and transmit 66 kW through the tribological contact. So, a twin motor solution would require two motors of at least 66 kW and a suitable reduction ratio drive. With the TE 73H design, the variable slide/roll ratio is achieved by using a speed modulating epicyclic gear-box as part of the torque loop. By driving the ring-gear on the output stage of the gear-box with a separate motor, a difference between input and output speed can be generated. Hence, the torsional stiffness and capacity of a four-square rig can be combined with continuously variable slide/roll ratio.

Bearing Configurations

There are two basic configurations for mounting rollers in a two roller machine, either with rollers mounted on the free end of shafts (overhung) or with the rollers mounted in the middle of shafts, supported by bearings on either side of the roller (fully supported).

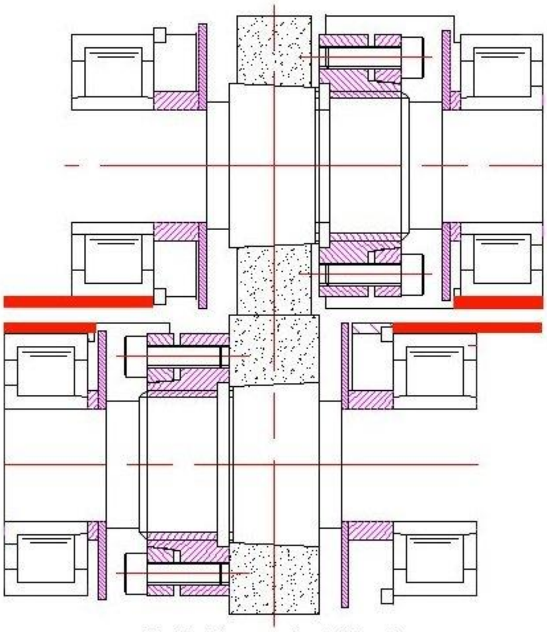
Overhung with Parallel Shafts



Overhung with Parallel Shafts

With overhung mounted rollers, the rollers may be removed and changed without disassembling the shaft. It is relatively easy to seal the shaft bearings from the test fluid.

Fully Supported Design

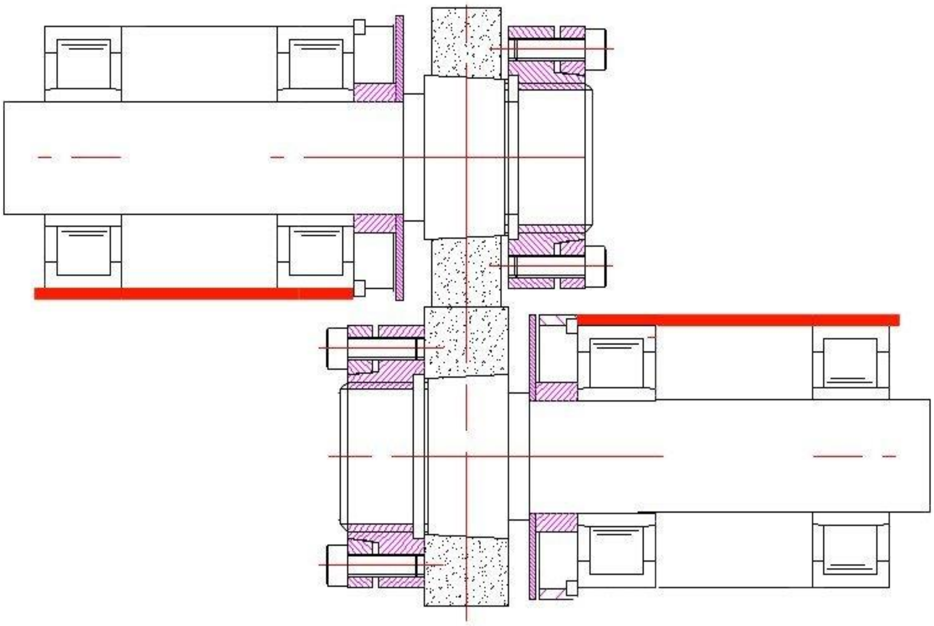


Fully Supported Shafts

With fully supported rollers, the shaft must be dis-assembled in order to change the rollers. It now becomes difficult to seal the shaft bearings from the test fluid, so one option is to run use the test fluid to lubricate the shaft bearings. This may place limits on the types of fluid that can be tested. Treating the bearings as consumable items is one potential solution.

It will be apparent that much higher loads can be achieved with the fully supported arrangement compared with the overhung arrangement.

Overhung with Opposed Shafts



Overhung with Opposed Shafts

It will be apparent that in both the above cases, in order to accommodate the spindle bearings, the centre distance between the shafts must be greater than the mean outer diameter of the bearings. Obviously, the greater the shaft centre distance, the larger the resulting test rollers; for equal sized rollers, the roller diameter must be greater than the outside diameter of the spindle bearing.

The overhung with opposed shafts arrangement overcomes this shaft centre distance limitation, allowing smaller diameter rollers to be accommodated. However, the disadvantage of this type of arrangement is that the test chamber becomes much more complicated, compared with the overhung design with parallel shafts.

Our Designs

Phoenix Tribology machines such as TE 54, TE 72 and TE 73 use the overhung roller arrangement, whereas machines such as TE 74S and TE 74H use the fully supported arrangement. In the TE 54 and TE 73 machines, the test spindles are mounted parallel to each other. In the TE 72 machines, the test spindles are mounted opposed to each other.

Both the TE 74S and the TE 74H have been optimised to give the maximum possible load with the minimum diameter roller. In the case of the TE 74S, the smallest available standard cylindrical roller bearing is used (Size 202), which has an internal diameter of 15 mm and an outside diameter of 35 mm. The dynamic load rating for this bearing is 12.5 kN. Fatigue life calculations indicate that it is acceptable to use two of these bearings mounted on either side of the test roller with a maximum applied shaft load of 12 kN, hence the TE 74S's specified load range. In order to mount two 35 mm outside diameter bearings in housings, the minimum practical shaft centre distance is 40 mm.

The TE 74H uses the smallest available spherical roller bearing (Size 22205), which has an internal diameter of 25 mm and an outside diameter of 52 mm. The dynamic load rating is 49 kN per bearing. With a specified maximum applied shaft load of 30 kN, an adequate bearing fatigue life is achieved. The minimum practical shaft centre distance could perhaps be as little as 60 mm, but in the case of the TE 74H this has been chosen as 70 mm to allow test rollers to be manufactured from standard 75 mm diameter stock material.

By contrast with the fully supported arrangement used in the TE 74 machines, with the overhung arrangement, the maximum loads permissible are correspondingly smaller. In addition to the bearing capacity and fatigue life, there are of course other considerations, of which the most significant is the rotating fatigue life of the test spindle. This is a particular issue with the overhung mounting arrangement and limits the maximum permissible shaft load.

Self-aligning Flat on Flat Rollers

In the TE 74 machines, flat on flat alignment is achieved by incorporating a spherical bearing in the pivot arm of the upper test assembly. This is a key feature of this particular design and similar solutions are not possible on any of the other machines. In order to achieve self-aligning capability, hence correct line contacts, on machines other than the TE 74 designs, it is necessary to mount one test roller on a self-aligning bearing.

In the case of the TE 54, the lower roller is mounted on a spherical bearing allowing it to rotate. The TE 54 uses an upper roller of 25 mm diameter and a lower roller of 50 mm diameter. Driving pins are used to deliver traction from the drive shaft to the "floating" roller outer. This type of arrangement applied other machines of this type.

Equal or Unequal Rollers

For rolling contact fatigue tests, it makes sense to use uneven diameter rollers. This is because the smaller roller is subjected to a higher number of contacts than the larger roller, hence failure tends to be confined to the smaller roller, which thus becomes the candidate sample.

It is of course more complicated to use rollers of different diameter, but it makes better sense experimentally.

Conclusion

There are no doubt other solutions possible, all of which may have their own strengths and weaknesses. In addition to the issue of bearing size, shaft strength and life etc, there are many other issues associated with, for example, using smaller rollers, not least their tendency to crack and fall in half during testing.

Rolling contact fatigue can be either surface propagated or pressure generated, depending on the surface roughness of the samples and conditions of lubrication. As pressure generated rolling contact fatigue is initiated below the surface, there must be sufficient thickness of material to allow this to occur. Using shaft mounted rollers that have too small a wall thickness causes problems and may give a false answer! With surface propagated rolling contact fatigue, cracks may simply migrate straight through the wall thickness and the sample fall in half.

Finally, remember that the finished test roller diameter will always be less than the stock material diameter, so, if 25 mm diameter stock material were to be specified, a finished roller diameter of 24 mm would be practical. It is important to recognise this point when specifying the shaft centre distance and finished roller diameter.