Manufacture of Test Rollers

Background Considerations

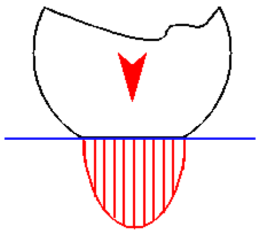
Stock Material

Before choosing the size of roller, ensure that suitable sized stock material is available, bearing in mind that the finished roller diameter will always be less than the stock material diameter, so, for example, it is not possible to manufacture a 75 mm diameter roller from 75 mm bar stock, but it is of course possible to manufacture a 75 mm diameter roller from 3 inch (76.2 mm) bar stock.

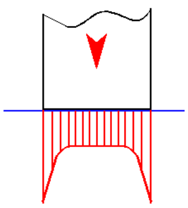
Elliptical versus Line Contact

Alignment issues are substantially eliminated (apart from skew and spin) if one roller is crowned. A crowned roller on a flat roller will produce an elliptical hertzian contact and will achieve a given hertzian contact pressure at much lower loads than the equivalent line contact, thus requiring lower torque and power. As a simple approximation, an elliptical contact will require about a fifth of the load and torque of a 10 mm wide line contact, thus significantly reducing both the required size of machine and the frictional energy input to the contact. Furthermore, the peak stress in the elliptical contact will be closer to the surface than with a line contact.

Although the pressure distribution in the direction of rolling is broadly similar for a line contact and an elliptical contact, the pressure distribution laterally is very different.



For an elliptical contact, the calculated peak pressure is central with an elliptical pressure distribution.



By contrast, with a line contact, although the nominal peak pressure appears over the middle section of the contact, geometric stress concentrations occur at either side of the contact, resulting in peak stresses far in excess of the nominal, calculated, peak pressure. The basic problem with calculating the maximum hertzian contact pressure for a line contact is that it is assumed that the contact is of infinite width and that the discontinuities at either end of the line contact can be ignored. Of course, in practical applications, geometric stress concentrations can be ameliorated by careful blending of the edges, as with cylindrical roller bearings.

Entrainment, Side Leakage and Discharge of Fluids and Particles

The entrainment and discharge of fluids and particles is frequently treated as a two dimensional problem and the assumption is thus that there is no material difference between an elliptical contact and a line contact. This is not the case.

The shape of the inlet to an elliptical contact allows fluid and particles to be displaced to either side of the inlet and thus flow past, as opposed to through, the contact. However, fluid and particles that have been successfully entrained within an elasto-hydrodynamic contact, will be constrained to discharge from the rear of the contact, with flow perpendicular to the plane of rolling contained by the pressure "horse-shoe". The pressure gradient outside the "horse-shoe" acts in such a way to eject particles and fluid from the side of the contact. This can lead to the rather unexpected situation, when running with a very shallow crown radius roller, of the asperities in the middle of the contact being satisfactorily separated by an EHD lubricant film, whereas the asperities immediately outside the "horse-shoe", lacking EHD separation, make contact.

With a line contact, the usual assumption is that one is dealing with a contact of infinite width, allowing no flow or pressure variation in an axial direction. This cannot be the case with a contact of finite width, with a stress concentration at either end of the contact. In this case, the pressure may act to cause flow in the direction of the centre of the contact, with the stress concentrations limiting discharge from either end of the contact.

Dry Contacts - Saturation

A dry rolling-sliding contact is made up of zones of adhesion and micro-slip and the transition to full sliding is termed "saturation".

Line Contact　　　　　　　　Elliptical Contact

With an elliptical contact, the adhesion patch progressively decreases in size until it eventually disappears. It gets smaller and smaller in two dimensions, heading towards a singularity. With the elliptical contact, the decrease in the lemon-shaped adhesion zone with increasing creep will be asymptotic, but not so, with a line contact and certainly not so if one takes into account the geometric stress concentration at either end of a finite width line contact.

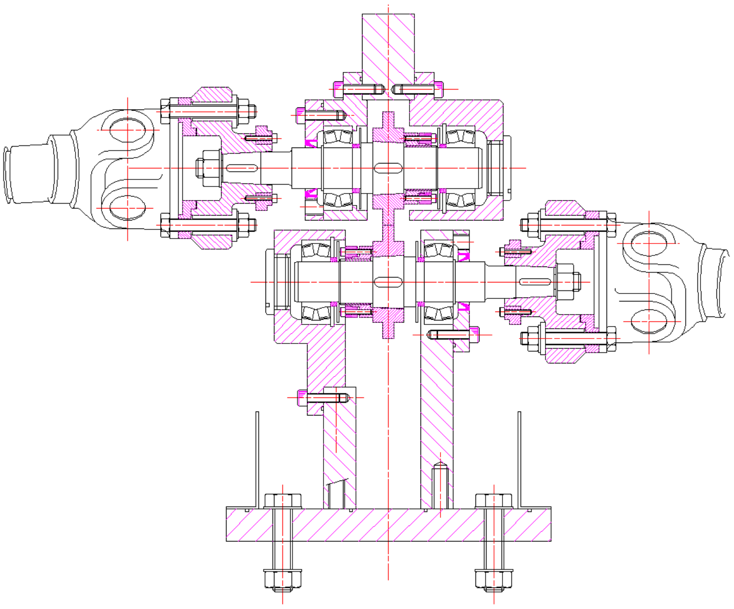
Now consider what happens if we have a line contact? The contact patch is rectangular and it will get smaller in one dimension only and this decrease will be essentially linear. Now think what happens at the moment when the patch is on the point of disappearing! It approaches a line, not a singularity! There is a step change at this point as opposed to a gradual change as seen with an elliptical contact and this may provide the mechanism to promote "chattering", which is common in line contacts as in spur gears. With an elliptical contact, the transition to gross slip will be smooth and potentially reversible, whereas with a line contact the transition will be somewhat more violent and not reversible. It probably does not matter what two roller machine one uses, a line contact is going to behave in this way and it will be different from an elliptical contact.

Roller Design

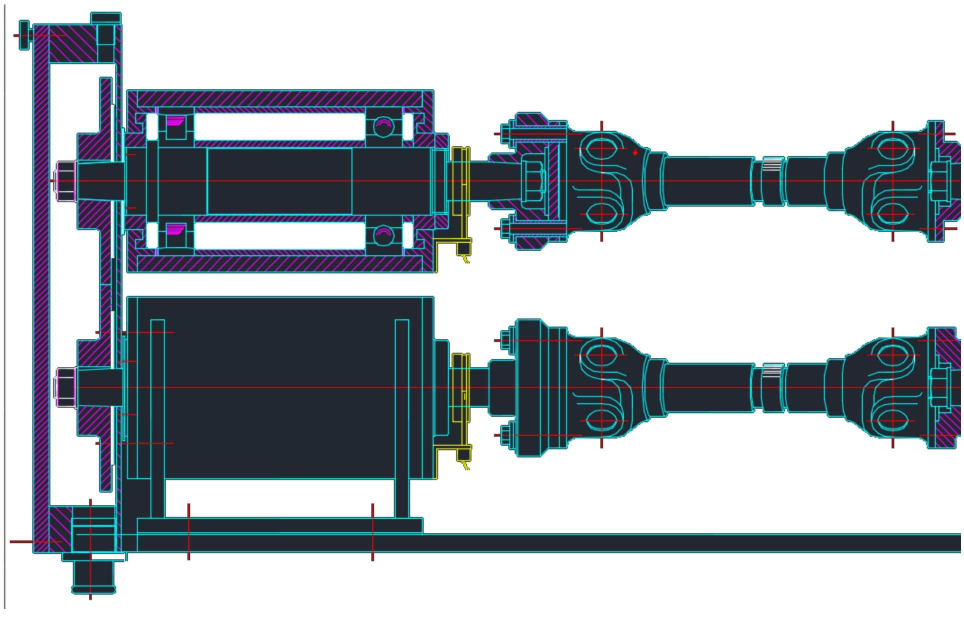
Rollers must be manufactured in accordance with the relevant engineering drawings with tapered bores ground to match the shaft tapers. This is achieved by using the plug gauge supplied with the machine.

Roller Centre Line

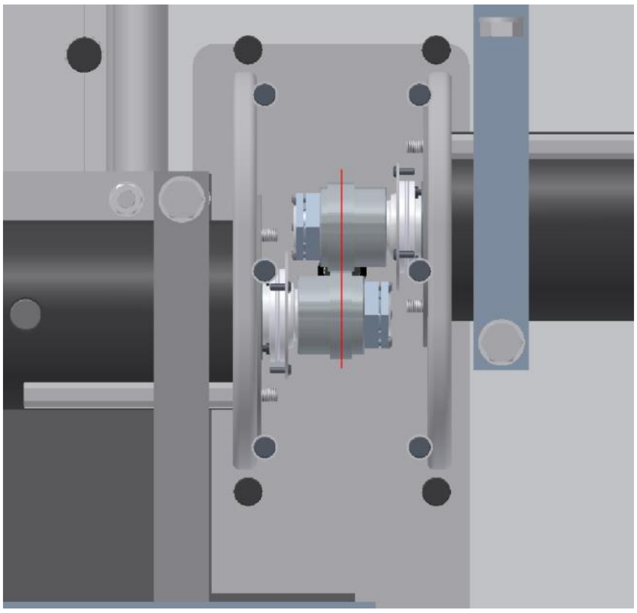
The contact centre-line of the roller will depend on the machine configuration. With a fully supported bearing arrangement, as per TE 74 designs, the roller contact will ideally align with the middle of the shaft taper.



With an overhung bearing arrangement, with shafts mounted parallel to each other, as per TE 53, TE 54 and TE 73 designs, the contact centre-line should be as close to the bearing housing as possible, to minimize the over-hung load on the roller bearing.

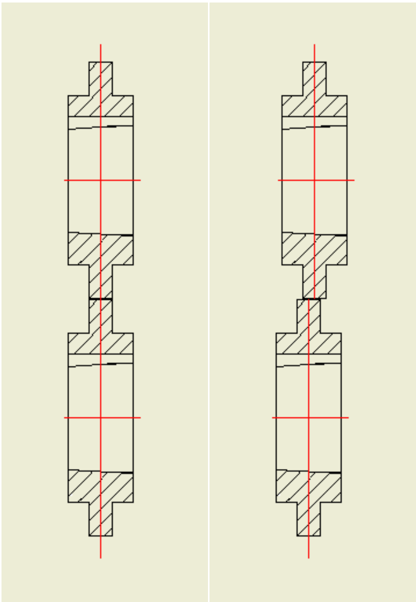


With an overhung bearing arrangement with shafts axially displaced and facing each other, as per TE 72 machines, moving the contact centre-line to be as close as possible to one bearing housing will simply exacerbate the problem at the other bearing housing. In this case, the roller contact will ideally align with the middle of the shaft taper. This is the limiting factor with regard to the maximum permissible load with this type of arrangement.

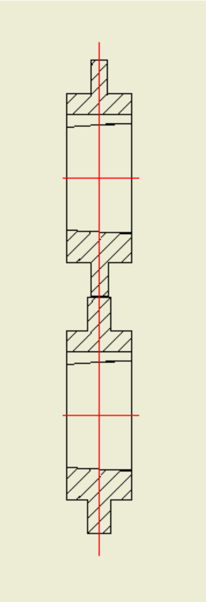


Width for Line Contact

If a line contact is required, note that with equal roller widths, care will be required if edge running is to be avoided.

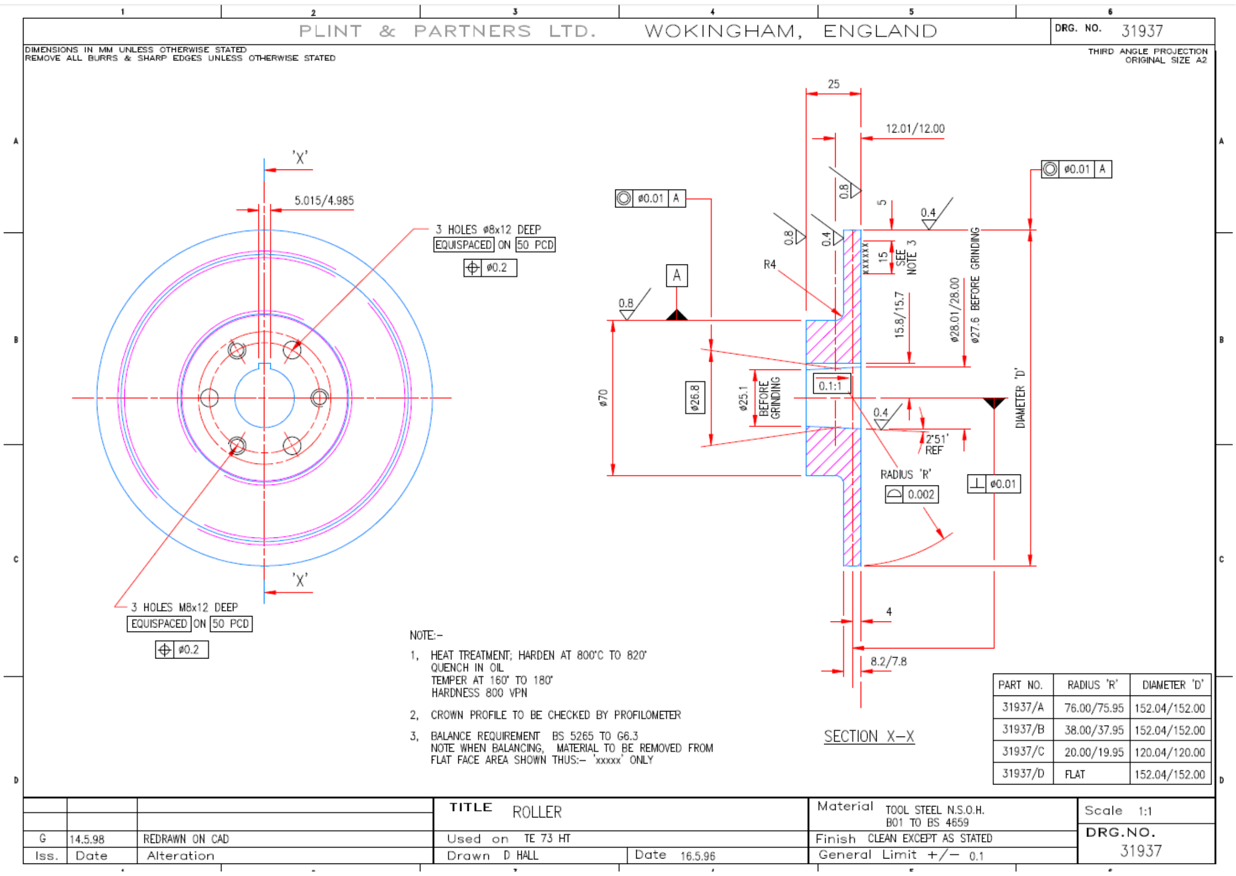


This will require careful adjustment of axial alignment and precise manufacture of roller tapers. One solution is to accept edge running but to confine it to one roller only, by making the rollers of different widths, for example a 10 mm wide roller running on a 12 mm wide roller. If the rollers are of different hardness materials, the wider roller should be the harder, in other words, avoid edge running with the harder material roller, as it will cut into the softer material.



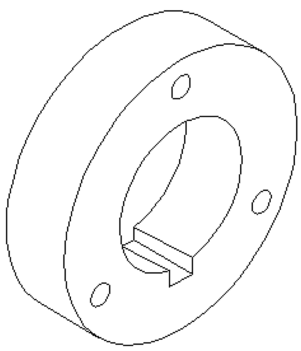
Crowned Roller

Alignment issues are substantially eliminated (apart from skew and spin) if one roller is crowned. A crowned roller on a flat roller will produce an elliptical hertzian contact and will achieve a given hertzian contact pressure at much lower loads than the equivalent line contact, thus requiring lower torque and power. As a simple approximation, an elliptical contact will require about a fifth of the load and torque of a 10 mm wide line contact, thus significantly reducing both the required size of machine and the frictional energy input to the contact. Furthermore, the peak stress in the elliptical contact will be closer to the surface than with a line contact.



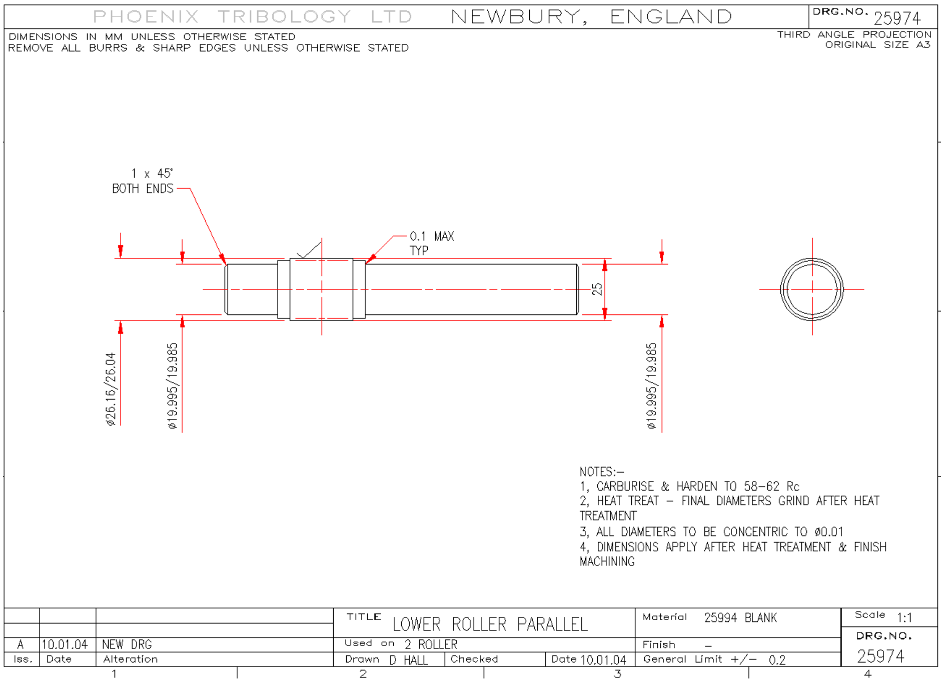
A typical design of crowned roller for an overhung bearing arrangement machine (TE 72 and TE 73) is shown above. The crowned radius may be anything achievable within the grinding process, however, the most common choice is to make the crown radius equal half the disc diameter. If two such crowned radius rollers are loaded against each other, the resulting hertzian contact will be circular as opposed to elliptical, in other words, the equivalent of running two balls of the same diameter as the rollers together in contact.

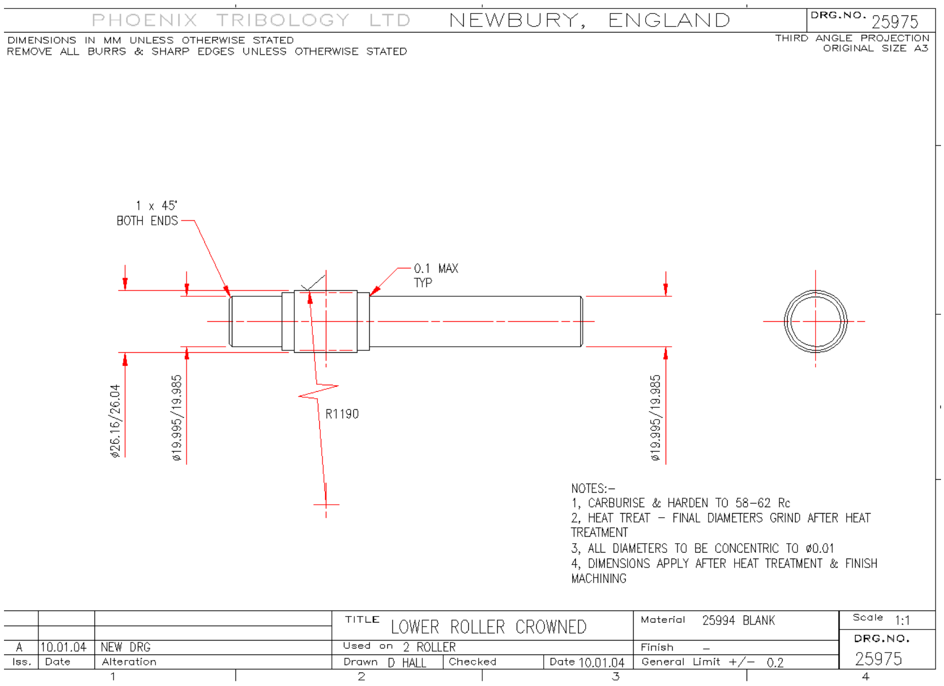
Small Diameter Rollers



A limiting factor with small diameter rollers is the roller wall thickness, which typically should not be less than approximately 10 mm. Hard rollers in particular are liable to fail by radial cracking, initiated at the sharp edges in the key-way. For tests at low traction, it may be possible to use rollers without key-ways, but clearly there will be a risk of shaft damage through fretting, should a roller come loose.

For rollers where the diameter approaches the diameter of the supporting shaft, the solution is to use a combined, single piece, roller and shafts.





Large Diameter Rollers for High Speed Operation

Basic Requirements

Test rollers are essentially just flywheels, in other words, energy storage devices. With the flywheel, unlike many other energy storage systems, the energy is instantly available, which is why they are hazardous devices. There are two reasons for minimizing the inertia of test rollers:

1. To minimize the stored energy.
2. To minimize the flywheel inertia and thus maximize the natural frequency of the system, to avoid torsional vibration.

For a disc radius r and thickness t, the stored energy can be calculated as follows:

Moment of inertia	I	=	$\rho \times \pi \times r^4 \times t / 2$
Energy stored	E	=	$I \times \omega^2 / 2$
Where:	ω	=	$2 \times \pi \times N / 60$
Where:	N	=	Rotational speed in rpm

When calculating the inertia of a stepped roller, this can be done by dividing the roller into cylindrical components, calculating their respective moment of inertia, then summing the total.

To calculate the torsional stiffness and natural frequency of the system, we would need to have detailed information with regard to all other elements in the drive train. However, as a general rule of thumb, if one end of the drive train unavoidably has high inertia, for example, because it is a motor armature or a large diameter gear, the best solution is to minimize the inertia at the other end of the drive train, in other words, at the test rollers. If there are issues with torsional vibrations, these can be addressed by introducing a slipping element into the design such as a clutch or, alternatively, some form of torsional damping.

It follows that for high speed applications with large diameter rollers, the width of the roller web should be minimized.

Balancing

Balancing, where necessary, should be specified to be in accordance with BS ISO 1940-1:2003 to Balance Grade G6,3, with a half-key fitted.

Deciding when balancing is necessary is frequently done by trial and error, with practical determination of residual out-of-balance forces. Past experience proved it necessary to balance 150 mm diameter discs to Drawing Number 31937 for operations at speeds up to 3,000 rpm on TE 73 and 6,000 rpm on TE 103, the stored energy being respectively 168.5 J and 674.1 J.

			Disc Material Density:	7800	kg/m3			
Roller	Comment	Hub Radius	Hub Length	Disc Radius	Dics Length	Total Inertia	Speed	Energy
		(including shaft)	(excluding disc length)	(including shaft)				
		mm	mm	mm	mm	kgm2	rpm	J
31937	Original	35	17	75	8	0.003414345	3000	168.5
31937	Original	35	17	75	8	0.003414345	6000	674.1
31937	Non-stepped	0	0	75	25	0.009692947	3000	478.5
31937	Non-stepped	0	0	75	25	0.009692947	6000	1913.8
35013	Original	0	0	60	30	0.004764277	3000	235.2
35013	Original	0	0	60	30	0.004764277	6000	940.7
35013	Stepped	25	20	60	10	0.001683825	3000	83.1
35013	Stepped	25	20	60	10	0.001683825	6000	332.5
35013	Stepped	25	18	60	12	0.001991871	3000	98.3
35013	Stepped	25	18	60	12	0.001991871	6000	393.3

As a general rule of thumb, we should set the following stored energy limits:

Maximum permissible stored energy:

Unbalanced Rollers: 100 J

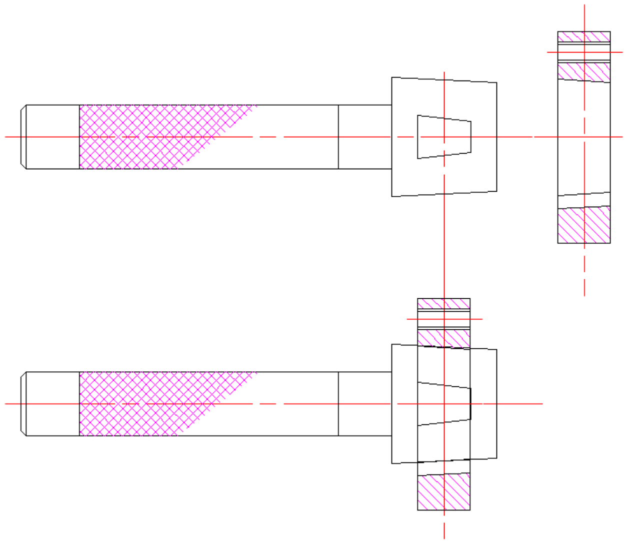
Balanced Rollers: 1000 J

For stepped rollers with a 30 mm wide by 40 mm diameter hub, this would give the following:

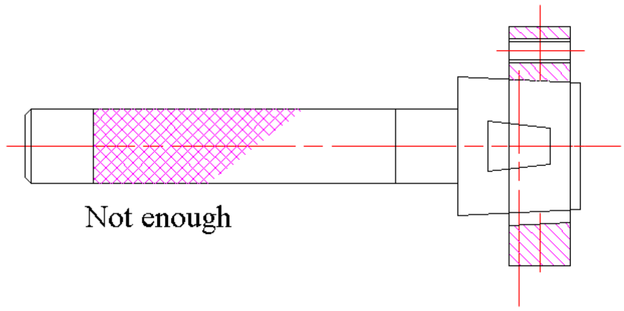
		Disc Material Density:	7800	kg/m3				
Roller	Hub Radius	Hub Length	Disc Radius	Dics Length	Total Inertia	Speed	Energy	
	(including shaft)	(excluding disc length)	(including shaft)					
	mm	mm	mm	mm	kgm2	rpm	J	
Stepped	20	20	25	10	8.70786E-05	6000	17.2	Unbalanced
Stepped	20	18	25	12	9.27306E-05	6000	18.3	Unbalanced
Stepped	20	20	30	10	0.000138468	6000	27.3	Unbalanced
Stepped	20	18	30	12	0.000154398	6000	30.5	Unbalanced
Stepped	20	20	35	10	0.000223096	6000	44.0	Unbalanced
Stepped	20	18	35	12	0.000255951	6000	50.5	Unbalanced
Stepped	20	20	40	10	0.000352909	6000	69.7	Unbalanced
Stepped	20	18	40	12	0.000411728	6000	81.3	Unbalanced
Stepped	20	20	45	10	0.000541695	5800	99.9	Unbalanced
Stepped	20	20	45	10	0.000541695	6000	107.0	Balanced
Stepped	20	18	45	12	0.00063827	5340	99.8	Unbalanced
Stepped	20	18	45	12	0.00063827	6000	126.0	Balanced
Stepped	20	20	50	10	0.000805075	4760	100.0	Unbalanced
Stepped	20	20	50	10	0.000805075	6000	159.0	Balanced
Stepped	20	18	50	12	0.000954326	4370	100.0	Unbalanced
Stepped	20	18	50	12	0.000954326	6000	188.4	Balanced
Stepped	20	20	60	10	0.001627305	3345	99.9	Unbalanced
Stepped	20	20	60	10	0.001627305	6000	321.3	Balanced
Stepped	20	18	60	12	0.001941002	3060	99.7	Unbalanced
Stepped	20	18	60	12	0.001941002	6000	383.2	Balanced
Stepped	20	20	75	10	0.003916391	2155	99.8	Unbalanced
Stepped	20	20	75	10	0.003916391	6000	773.3	Balanced
Stepped	20	18	75	12	0.004687906	1970	99.8	Unbalanced
Stepped	20	18	75	12	0.004687906	6000	925.6	Balanced

Tapers

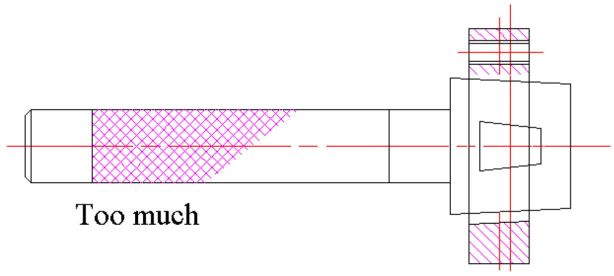
Plug gauges will be required for all tapered shaft mounting rollers.



In addition to using the plug gauges to ensure that the tapers match, the gauges are also used to check the axial position of the roller on the shaft. The roller should fit onto the gauge so that it covers the gauge notch, as shown above.



If the roller does not fit far enough onto the gauge, further grinding is required.



If too much material is removed, the roller must be scrapped

Pullers

All rollers will require holes for three legged pullers as standard.

A G P 6th December 2015