

7 – Bearings

Bearings and bushings of ZYTEL® nylon resin and DELRIN® acetal resin are used in numerous commercial applications. ZYTEL® is uniquely suited to abrasive atmospheres such as in cement plants and in factories where dust is a constant problem. Bearings of ZYTEL® have been used successfully under diverse environmental conditions including the presence of various oils, greases, chemicals, reagents and proprietary compositions, many of which are harmful to other types of plastic materials.

Bearings of DELRIN® acetal resin offer the unique characteristic of no “Slip-stick”, or the static friction coefficient being equal or lower than dynamic. Typical applications are hemispherical bearings for auto ball-joints; food mixer housing-bearing combinations; wear surfaces on integral gear-spring-cam units for adding machines; clock bushings and many others. The extensive use of DELRIN® acetal resin as a bearing material has developed because of its combination of low coefficient of friction with self-lubricating properties, good mechanical properties and dimensional stability in many chemical media.

The performance of bearings depends on a number of factors:

Shaft Hardness and Finish

If a metal shaft runs in a bearing of DELRIN® acetal resin or ZYTEL® nylon resin, the most important parameter is the surface hardness of the shaft. For unlubricated bearings of DELRIN® acetal resin or ZYTEL® nylon resin on metal, the metal should be as hard and smooth as consistent with bearing-life requirements and bearing cost. Common centreless ground shafts of steel are acceptable, but increased hardness and finish will improve bearing life.

The actual wear performance will change with the speed and load and the type of mating surface material.

Soft steel or stainless steel, as well as all non-ferrous metals do not run well with plastic bearings, even those with a so-called “self-lubricating” filler. It is only a question of load, speed and time until wear increases rapidly, leading to premature failure.

Shaft hardness becomes more important with higher PV-values and/or the expected service life. A highly polished surface does not improve wear behaviour if the hardness is insufficient.

There are nevertheless a great number of bearing applications which perform satisfactorily against soft metals running at low speed and load, such as bearings for clocks and counter mechanisms. DELRIN® acetal resin generally performs better than other plastics against soft metals. If a bearing fails, it is, however, most important to carefully check the hardness of the metal shaft surface since it may account partially for unsatisfactory performance.

Bearing Surface

The influence of mating surface on wear rate between DELRIN® acetal resin and various materials is shown in Fig. 7.01. A dramatic reduction in wear can be seen as material hardness increases between curves 1, 2 and 3. The most dramatic differences can be seen in curve 4 where DELRIN® acetal resin is matched with ZYTEL® 101 nylon.

The wear performance of DELRIN® 500, DELRIN® 900F and DELRIN® 500CL are illustrated in Fig. 7.02 against mild steel.

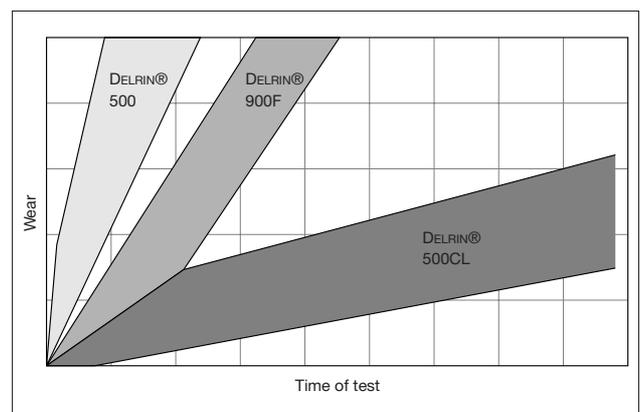


Fig. 7.02 **Wear of DELRIN® 500 against mild steel***

* Thrust washer test; non-lubricated; P, 0,04 MPa; V, 0,95 m/s.
NOTE: DELRIN® 900 F was previously coded DELRIN® 8010.

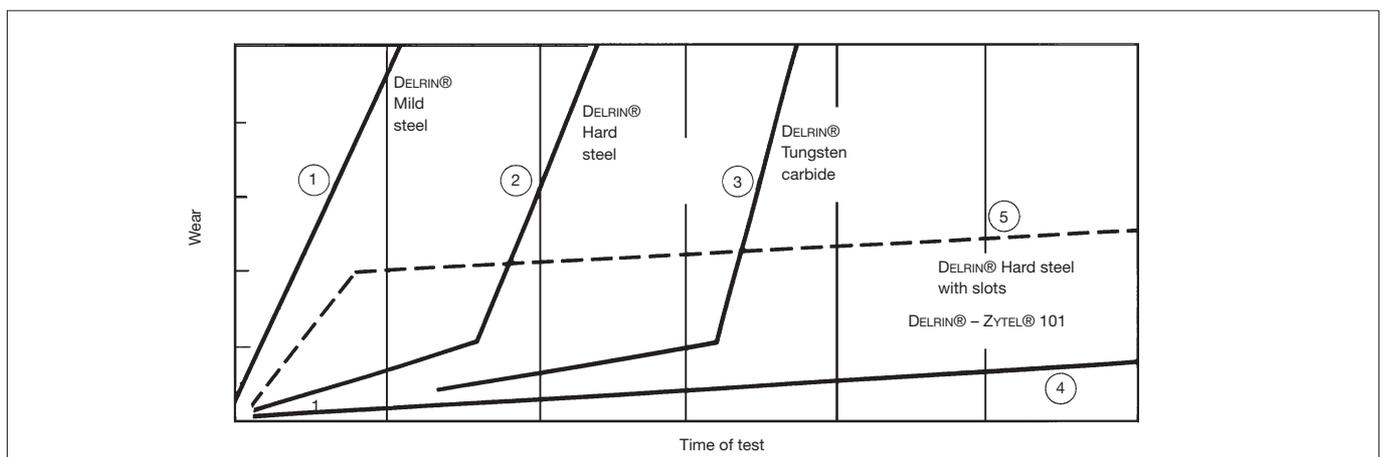


Fig. 7.01 **Wear of DELRIN® 500 against various materials***

*Thrust washer test non-lubricated; P, 2 MPa; V, 50 mm/s; AISI 1080 carbon steel.

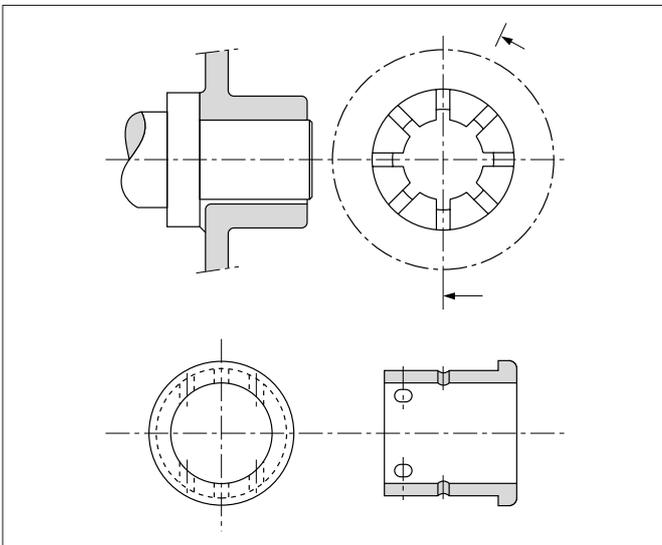


Fig. 7.03 **Typical slotted bearings**

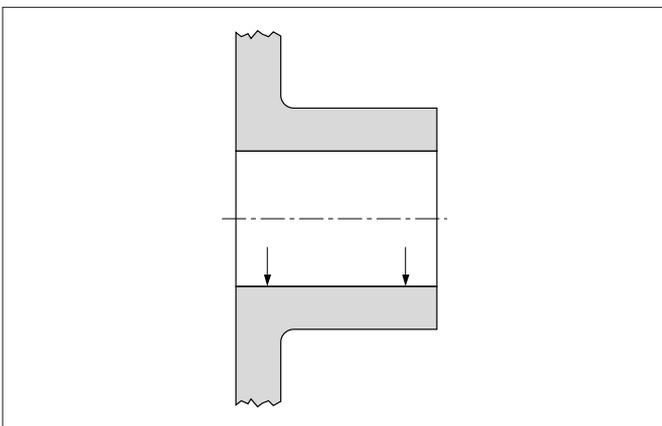


Fig. 7.04 **Bearing for low pressure loads**

Comparable data have also been obtained to show the suitability of DELRIN® acetal resin with aluminum and brass. When loads and operating speeds are low, as in clocks and hand-operated window crank drives, anodized aluminium and hard brass can be used as bearing surfaces with DELRIN® acetal resin.

The actual wear performance of specific resins will vary depending upon load, speed, mating surface, lubrication and clearance. Wear data can be found in the product modules.

A bearing surface should always be provided with interruptions to allow wear debris to be picked up and, as much as possible to be removed from the rubbing surface. This can be achieved by means of longitudinal slots or simply by radial holes depending on the design possibilities.

Extensive tests have proven beyond any doubt that maintenance of a clean rubbing surface increases service life considerably (Fig. 7.01, curve 5). Axial grooves shown in Fig. 7.03 may constitute the single most useful design improvement to a plastic bushing or bearing.

Since significant increases in service life will be dependent on the volume of abrasive particles removed from the wear interface, the following design guidelines should be helpful:

- 1) use of a minimum of three grooves;
- 2) make them as deep as technically feasible;
- 3) keep width at about 10 per cent of shaft diameter;
- 4) use through-holes where wall is too thin for grooves.

Another important factor is that the pressure load on the bearing is distributed equally over the axial length. In a design according Fig. 7.04 this is doubtful. An improved approach is shown in Fig. 7.05.

Accuracy

A determining factor, is the geometric shape of the bearing bore. A simple sleeve moulded for the purpose of being press-fitted into a metal frame as shown on Fig. 7.06 may be sufficiently accurate.

Most plastic bearings are, however, part of a whole unit or combined with other components. Fig. 7.07 shows three typical examples where it becomes difficult or even quite impossible to mould a perfect round and/or cylindrical bore due to part geometry affecting uniform mould shrinkage.

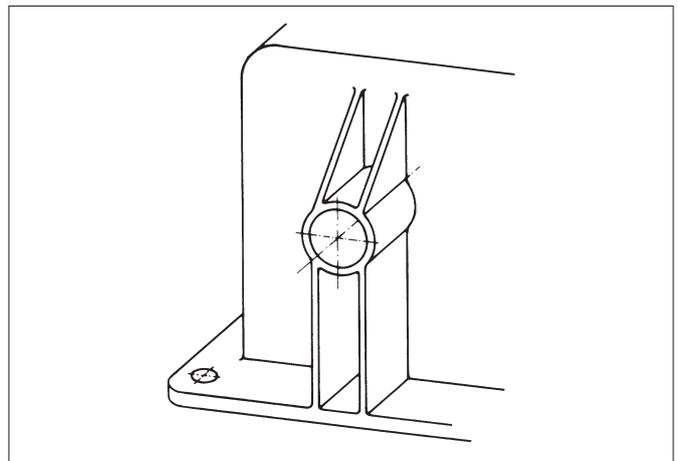


Fig. 7.05 **Bearing for high pressure loads**

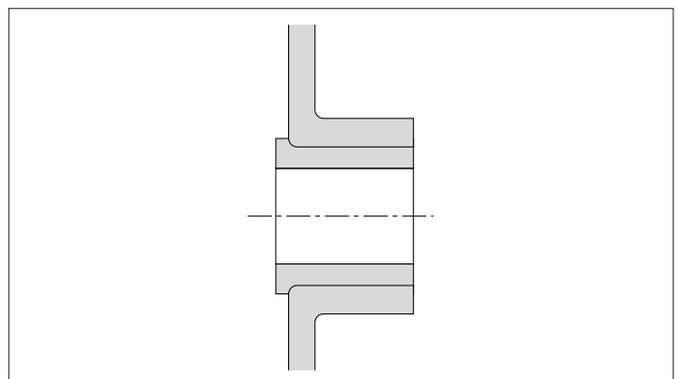


Fig. 7.06 **Press-fitted sleeve bearing**

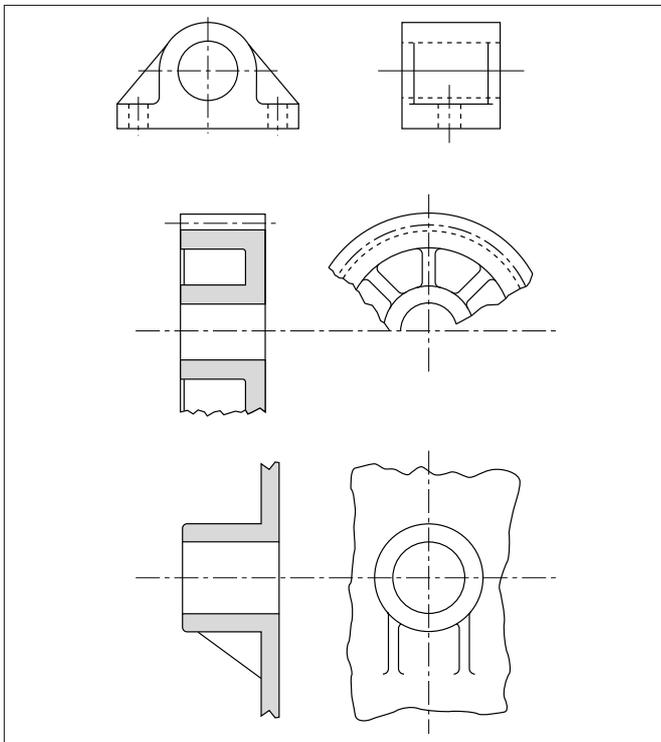


Fig. 7.07 Typical designs for integral bearings

Thus, the load is carried by only a portion of the surface, causing high local specific pressure and immediate initial wear. With high PV value bearings, this may prove to be disastrous because the wear debris is moved around continuously, thus accelerating wear and shortening service life. On low PV value bearings or ones which are operated only occasionally, this may be of no importance. High performance bearings are often post-machined in order to obtain a perfect cylindrical and round bore, which improves performance significantly.

Bearing Clearance

Plastic bearings generally require larger running clearances than metal bearings, due primarily to the much higher coefficient of linear thermal expansion of the plastic material. The designer must also take into consideration the fact that post-moulding shrinkage can reduce the diameter of the bearing after it is in service, and particularly if the service temperature is elevated. Post-moulding shrinkage can be minimized by proper moulding conditions. The engineer should include in his specifications a limit on post-moulding shrinkage. This can be checked on a Q/C basis by exposing the part for approximately one hour to a temperature approximately 28°C above the maximum use temperature, or 17°C below the melting point, whichever is lower.

Bearing clearances, when not carefully checked and controlled, are the most frequent causes of bearing failures. Bearing diametral clearance should never be allowed to go below 0,2-0,4% of the shaft diameter for DELRIN® acetal and 0,3-0,5% for ZYTEL® nylon resin.

Where the application requires closer running or sliding clearance, split bearing inserts of DELRIN® acetal resin or ZYTEL® nylon resin have been used extensively. Here, the dimensional effect of the environment on bearing clearance need be considered only on the wall thickness rather than on the diameter.

Lubrication

The main reason for using bearings of DELRIN® acetal resin and/or ZYTEL® nylon resin is to achieve good wear performance under completely dry running conditions (for instance in the food industry), or with initial lubrication (speed reducer bearings of all kinds in closed housings, like appliances).

Continuously lubricated bearings are rarely encountered in the products where plastics are used and are not discussed here.

Initial lubrication should always be provided. It not only facilitates the run-in period but increases total service life. Unless special steps are taken to retain the lubricant, it will have a limited effectiveness in time, after which the bearing must be considered as dry running. Consequently, an initially lubricated bearing where the lubricant cannot be retained cannot sustain a higher load but it will last longer and show better wear behaviour. Initial lubrication is particularly helpful in running against soft metals.

Protection against Dirt Penetration

Bearings in DELRIN® acetal resins, ZYTEL® nylon resins and RYNITE® thermoplastic polyester resins, although more tolerant than metals, work more satisfactorily when they are protected against penetration of dust, dirt and water. The benefit of initial lubrication may be lost completely by the action of dirt particles penetrating between the rubbing surfaces, thus forming an abrasive paste with the lubricant. Bearings running at a high PV-value should therefore be protected by means of felt rings or rubber seals which in addition to keeping out dirt, retain the lubricant. To say that plastic bearings are not affected by dirt is absolutely wrong. Wear debris from the metal shaft as well as dirt particles can be embedded into the plastic bearings and substantially reduce service life.

It is not always practical to protect a bearing efficiently in the described way. This does not necessarily mean that plastic bearings will not function in adverse environments. The designer must be aware of these problems and make allowances with regard to bearing pressure, velocity and service life. Successful applications of this nature can be found in conveyors, chains and textile machine bearings, for example.

In environments where dust and dirt must be tolerated, ZYTEL® nylon resin is the preferred material. In such applications, it may prove beneficial to eliminate initial lubrication.

To summarize then, important design considerations affecting the performance and life of bearings in DELRIN® acetal resin, ZYTEL® nylon resin and RYNITE® thermoplastic polyester are:

- Surface hardness and finish of the metal shaft
- Geometric accuracy of bearing bore
- Correct clearance
- Grooves or holes in the sliding surface
- Initial lubrication
- Means to protect the bearing against dirt penetration and to retain the lubricant.

Thermal Conditions

- Bearing clearance changes with temperature and so can influence the allowable load. Furthermore plastics soften at elevated temperatures. Therefore the maximum surface temperature caused by friction and external influences should not exceed 70-80°C in case of bearings made in DELRIN® and 80-100°C for ZYTEL® if good performance and long service life are to be expected.

Calculation of Bearings

A plastic bearing subjected to a continuously but slowly increasing load and/or speed reaches a point where it fails due to excessive temperature rise. This limit is defined as the maximum PV value, and it is often used to compare various plastic materials as far as wear behaviour is concerned. The surface temperature in a bearing is not only a function of load, speed and coefficient of friction, but also of heat dissipation. The latter depends very much on the overall concept of the testing device, for which no international standards exists. The comparison of such values is therefore pointless unless they are determined under exactly the same conditions. Even if this is the case, they are of no great help to designers for the following reasons:

- A bearing running close to the PV limit thus determined usually has so much wear that the value can only be applied in very special cases.
- PV limits of plastic materials measured under specific lab conditions may, for many reasons, prove to be completely different or even reversed in practical applications.
- Many so-called “special bearing compositions” with fillers show higher PV limits than the base resin. This result is merely due to the fact that blended fillers reduce the coefficient of friction, thus generating less heat and allowing the bearing to run at a higher PV value. This fact does not guarantee less wear. Tests have shown that most unfilled resins have better wear behaviour than the same resins with fillers. This is significant because it is a widespread but erroneous belief that a low coefficient of friction also means better wear resistance. DELRIN® AF acetal resin is an exception, as both lower friction and wear result from the addition of TEFLON® fibres. Filled resins may prove to be preferable for very specific applications where a low coefficient of friction is essential. For instance, highly loaded bearings running for very short periods at a time and for which a limited service life is expected.

The coefficient of friction is not a material constant but rather a response of the bearing surface to a dynamic event. The coefficient of friction data in Table 7.01 shows a comparison of DELRIN® acetal resin and ZYTEL® nylon resin against steel, etc., at a specific set of conditions. A low non-lubricated coefficient of friction can mean lower horsepower and smoother performance to the designer. Table 7.01 also illustrates the low stick-slip design possibilities with DELRIN® acetal resin with the static coefficient of friction lower than the dynamic, and particularly when running against ZYTEL® nylon resin.

The diagram in Fig. 7.08 suggests reasonable PV values which take into account the mating material and the degree of post machining.

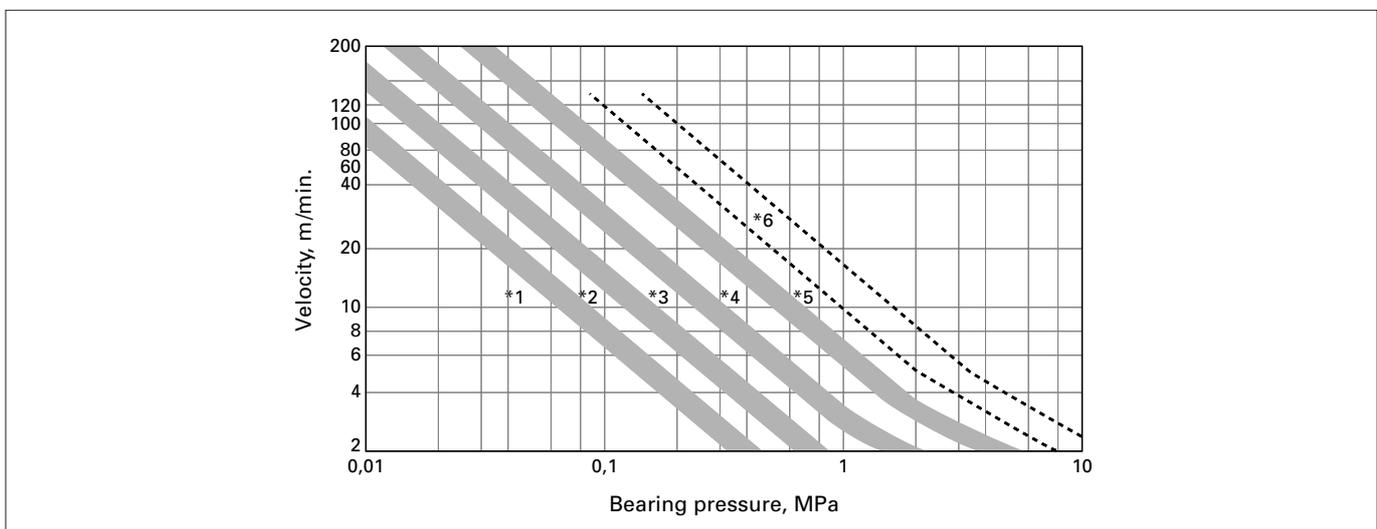


Fig. 7.08 Bearing pressure versus velocity

* See Table 7.02 for guide to the proper curve to use.

It does not include, however, severe running conditions at higher temperatures or the presence of dirt, dust, textile particles or other abrasive materials.

Table 7.02 shows how to choose the proper curve in Fig. 7.08. This guide is based on the assumption that the design, bearing clearance, bore accuracy, processing assembly and load distribution are correct.

Table 7.01 **Coefficient of friction***

	Static	Dynamic
DELIN® acetal resin on steel		
DELIN® 100, 500, 900	0,20	0,35
DELIN® 500F, 900F	–	0,20
DELIN® 500CL	0,10	0,20
DELIN® AF	0,08	0,14
DELIN® on DELIN®		
DELIN® 500/DELIN® 500	0,30	0,40
DELIN® on ZYTEL®		
DELIN® 500/ZYTEL® 101L	0,10	0,20
ZYTEL® on ZYTEL®		
Max.	0,46	0,19
Min.	0,36	0,11
ZYTEL® on Steel		
Max.	0,74	0,43
Min.	0,31	0,17
RYNITE® on RYNITE®		
Max.		0,27
Min.		0,17
RYNITE® on Steel		
Max.		0,20
Min.		0,17
HYTREL® 4056 on Steel	0,32	0,29
HYTREL® 5556 on Steel	0,22	0,18
HYTREL® 6346 on Steel	0,30	0,21
HYTREL® 7246 on Steel	0,23	0,16
PC on Steel	0,50	–
ABS on Steel	0,50	–
PBT on Steel	0,40	–
PBT on PBT	0,40	

* Data on ZYTEL® nylon resin and DELIN® acetal resin determined via the Thrust Washer test, non-lubricated, 23°C; pressure 2,1 MPa; velocity 3 m/min.
Data on RYNITE® thermoplastic polyester determined in accordance with ASTM D1894.

Table 7.02 **Guide to curves in Fig. 7.08 to determine maximum allowable PV-values**

Shaft	Bore	
	Moulded	Machined
Hardened and ground steel – Chrome plated		
R _c >50, ZYTEL®	3	4
Stainless steel – Anodized aluminum		
R _c 30-35, DELIN®	2-3	
DELIN® on steel R _c >70, dry		5
DELIN® on steel, R _c >70, lubricated, DELIN® AF	6	
Soft steel – Ground stainless steel	2	2-3
Cold drawn steel unmachined	1-2	2
Non ferrous metals – Diecast alloys	1 or less	–

Definitions

The parameters velocity and bearing pressure in Fig. 7.08 are defined as follows (see also Fig. 7.09):

Projected bearing surface $f = d \times \ell$ (mm²)

Specific bearing pressure $p = \frac{P}{d \times \ell}$ (MPa)

Peripheral speed $v = \frac{d \times n \times \pi}{1000}$ (m/min)

PV value $PV = p \cdot v$ (MPa · m/min)

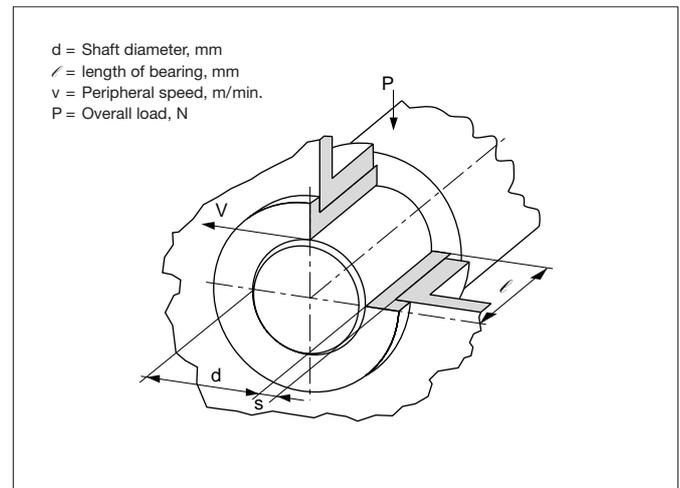


Fig. 7.09 **Definitions of bearing dimensions**

Table 7.03 **Max. PV values without lubrication**

Material	MPa · m/min
ZYTEL® 101	6
DELIN® 100/500	10
DELIN® 500CL	15
DELIN® 500AF	25
HYTREL® 5556/5526	2

Design Examples

Gear Bearings

Fig. 7.10 shows some solutions used in precision mechanics, especially regarding bearings for gears. In the case of high grade industrial drives like time switches and regulator clocks, the hardened and ground shafts are generally held fast in the platens, as shown in Fig. 7.10 A.

Should the core become too long as related to its diameter, the bore can be made conical as shown and provided with an additional bushing. This solution is only to be utilised when the hub cannot be shortened. Should the wheel and the journal be moulded integrally, the bearing bores should be deep drawn or at least precision stamped (Fig. 7.10 B).

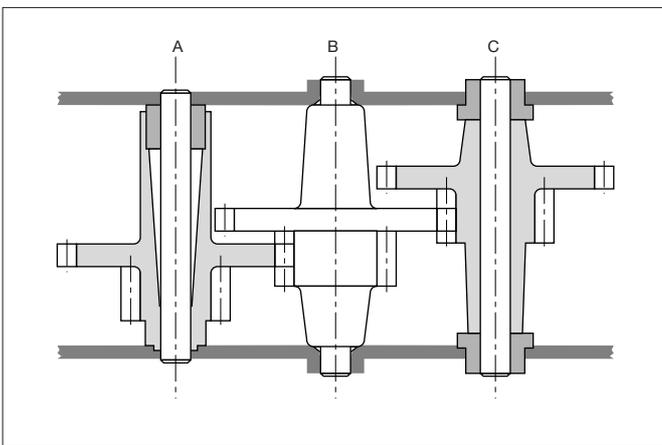


Fig. 7.10 **Bearings for gears**

Normally stamped holes have a rough surface and cause too much wear on the journal even at low PV-values. Should the shaft rotate together with the gear, it can be moulded-in or pressed-in as shown in Fig. 7.10 C.

In this case the platens are provided with additional bearing bushings as shown in Fig. 7.11. Whichever design is to be preferred for a particular application will depend first of all on economic factors, the required service life and the overall design of the device.

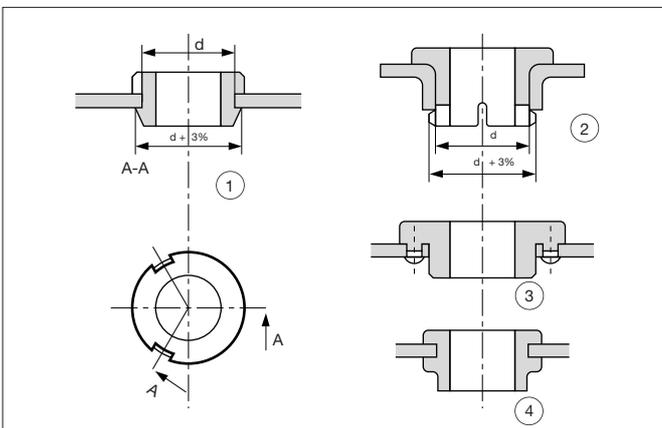


Fig. 7.11 **Securing plastic bearings**

Self-Aligning Bearings

Use of the plastics as engineering materials often allow an integration of several different functions in a part without higher costs. The designer has a wide variety of new design possibilities which allow ingenious and simple solutions. Fig. 7.12-7.19 show only a few examples to illustrate this fact.

Fig. 7.12: Mounting flange of a small motor with a flexible suspension of the bearing. The bearing becomes self-aligning to a limited extent.

Fig. 7.13: Self-aligning bushing with cooling slits, snapped directly into the mounting flange. The latter is itself secured in the sheet metal housing by mean of 3 snap heads.

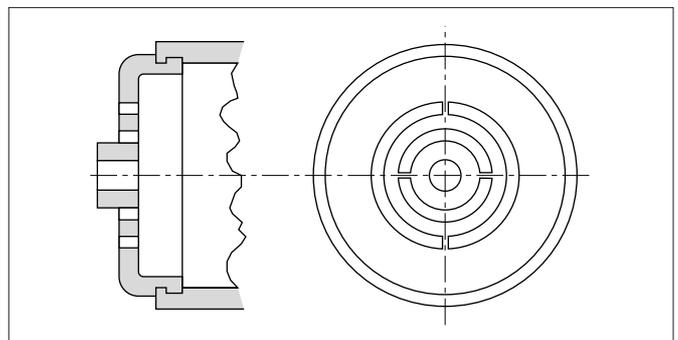


Fig. 7.12 **Bearing for a small motor**

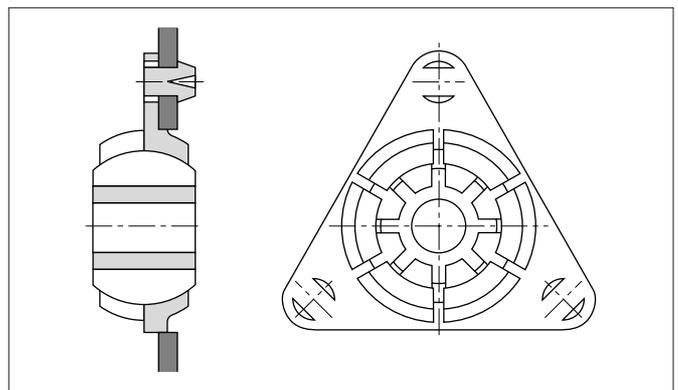


Fig. 7.13 **Self-aligning bushing**

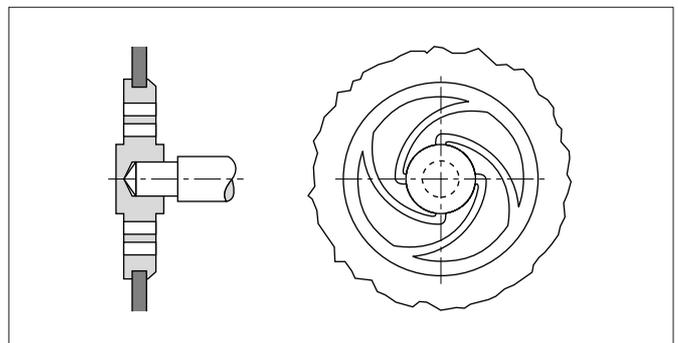


Fig. 7.14 **Elastically suspended bearing**

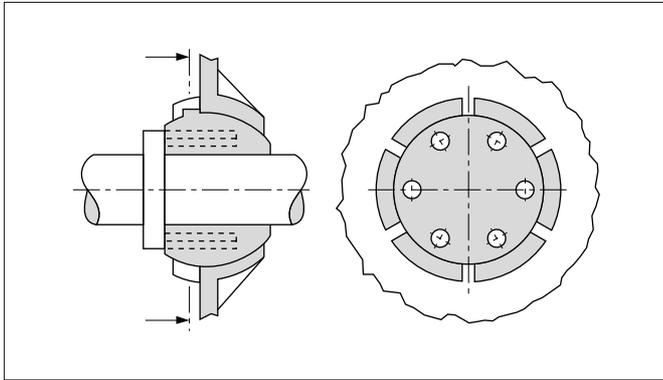


Fig. 7.15 **Self-aligning radial bearing**

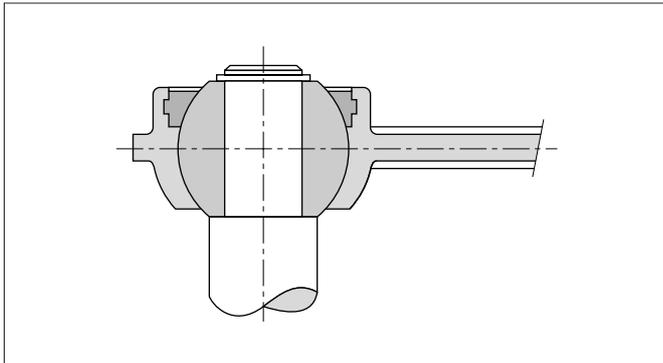


Fig. 7.16 **Spherical bearing, snap fitted**

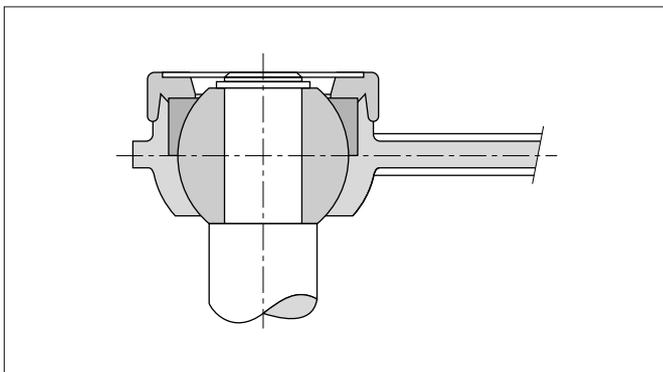


Fig. 7.17 **Spherical bearing, spin welded**

Fig. 7.14: Small bearing elastically suspended, snapped into metal sheet.

Fig. 7.15: Self-aligning and radial bearing. The lug preventing rotation should be noted.

Fig. 7.16: Connecting rod spherical bearing made of DELRIN® with snapped-in securing ring. The ball made of nylon ensures good bearing properties with low wear even when completely dry.

Fig. 7.17: Similar design, but with spin welded securing ring for high axial loads.

In order to safeguard the clarity of the illustrations, the axial grooves are not shown in these examples. Naturally they are to be provided in each case.

Testing Guidelines

In order to obtain comparative wear results of various plastic materials a trial cavity is often made and used for moulding the same bearing in many different plastics. This procedure has shown to give false and misleading results if the test part is a radial bearing. Due to differences in mould shrinkages among various plastic materials, bore accuracy and especially bearing clearances are far from being identical, thus producing erroneous wear rates. Such tests should consequently always be carried out with thrust bearings which eliminate any influence of clearance.

It must be kept in mind, however, that comparative results obtained under lab conditions are by no means always reproducible on practical applications. Final conclusions can only be drawn from tests carried out with moulded parts representative of production parts working as closely as possible to the expected conditions.

Accelerated tests at higher PV values are useless because the surface temperature may be much higher than under real conditions, causing premature failure. On the other hand, a bearing which operates only occasionally or for short periods at a time can be tested on a continuous run, provided that the temperature stays within the end-use limit.

Successful bearing design takes into account the aforementioned information, couples it with adequate end-use testing and provides for adequate Q/C methods.

Conclusion

Application of plastics as bearing materials is more limited by the admissible wear than by admissible PV-values. Bearings operation on the borderline of the admissible PV-value usually show high wear so that only a short service life can be expected. Certain plastics can be more highly loaded owing to their high melting point, but will also show excessive and inadmissible wear near the borderline of the maximum PV-values. It is therefore a mistake to give too much importance to maximal PV shown in the literature or to try to compare various plastics on this basis.

As this work emphasizes a bearing of plastics is only as good as it was designed and made, it is therefore the task of the designer to keep in mind all the factors influencing wear right from the beginning.

It should also not be forgotten that the use of plastic bearings has its natural limits and that consequently it is useless to expect performance from them of which they are not capable.

