WHITE PAPER:

Service life maximisation of shafts and plain bearings in agricultural machinery

Surface treatment of shafts for protection against wear and corrosion

December 2014

The problem

One of the most common causes of failure and downtime in agricultural machinery lies in the wear of the shafts and bearings. The costs incurred by the wear can be high, not least due to the high maintenance and repair costs. According to a study conducted by the Chamber of Agriculture North Rhine-Westphalia in 2013, the farmer must take into account costs of repairs each year, which amounts to 2-5% of the purchase price of the machine. In an industry that is constantly evolving into high technology with increasing amounts of investment, this creates huge costs. Machine elements with freedom from maintenance and long service life, which are also environmentally friendly and cost effective, become a clear advantage for every farmer.

In order to optimise wear and friction values, shaft and bearing materials that harmonise perfectly with each other need to be developed. The interdependence of material pairs constitutes a major challenge for the producers of shafts and bearings. In the field of the shafts, there are various methods in surface technology to optimise their performance. Shafts that are too soft tend to wear and can even lead to material breakages at higher loads. A very rough shaft surface can rapidly wear the bearing surface. But too smooth shafts run the risk of binding, exhibiting the so-called stick-slip, which is usually noticeable by a distinctive squeak. Adhesion increases the coefficient of friction and thereby also the wear of the bearing. Abraded surfaces with a certain average roughness offer an effective antidote against this effect.Overall, there are various methods in the surface treatment of shafts that bring their respective advantages and disadvantages and must always be assessed in conjunction with the bearing material. Because the shaft and bearing always form an operational unit, it can be evaluated only in terms of the overall picture. In this sense, the present study shall first explain the different processes of the surface treatment of shafts and then examine their effects on the wear behaviour of plain bearings.

Galvanising: hot-dip and electro-galvanising

Two variants can be distinguished in the method of galvanising the shaft surfaces - hot-dip galvanising and electro-galvanising. During hot-dip galvanising, a metallic zinc coating is applied on iron or steel by immersion in molten zinc at about 450°C. Thereby a resistant alloy layer of iron and zinc, and over it a very adherent pure zinc layer are formed on the contact surface. This method is used, inter alia, for guard rails and other major components for steel structures in the construction field. The layer thickness is very high. Thus, the allowable thickness of zinc coatings for a material thickness from 0 to 1.5 mm amounts to at least 45 µm. In practice, the layer thicknesses are often well above this standard. A distinction is made between "batch galvanising" for larger components and the "small components galvanising". For small steel parts, the batch galvanising is often too expensive.In this case, the small parts are filled as bulk material in a metal basket and the metal basket is completely immersed in the molten zinc. To remove the excess zinc, the baskets are then centrifuged. This results in a rough surface. Moreover, drops and rough edges may remain on the components. Both potentially increase friction and wear. Since shafts are designed for smooth surfaces and their treatment falls into the category of the expensive small components galvanising, hot dip galvanising is usually out of the question.

In electro-galvanising, the workpieces are not immersed in molten zinc, but in a zinc electrolyte solution. Here, the workpiece to be galvanised is hung as a cathode in the solution. An electrode of pure zinc is used as an anode. In electro-galvanising, the zinc plating is proportional to the intensity and duration of the current flow, whereby - depending on the shape of the workpiece - a layer thickness distribution develops over the entire workpiece. This galvanising process has a number of advantages. It creates pure, uniform and therefore very corrosion-resistant and well-chromatable coatings. The layer thicknesses can be precisely adjusted and thus provide savings in metal. There is no need for reworking of threads, keyways, etc. A heat treatment of the base material does not occur, so that it does not lead to deformation.The actual corrosion protection develops during the electro-galvanising by the passivation of the zinc layer.

The adverse effects predominate in terms of the effects of electro-galvanising on the special requirements of the pin and housing and the shaft wear. The actual coating of an electro-galvanised shaft is relatively soft. In addition, the passivation of the layer ("white rust") creates a relatively rough surface. A relatively fast abrasion of the protective layer takes place, where the corrosion protection in the contact area of the bearing is lost. Simultaneously, the coefficient of friction increases, regardless of whether metallic or plastic plain bearings are used. Only where the bearing point is supplied with grease, the corrosion protection can be maintained.

Kommentar: I don't understand what you are trying to say here.

Nitriding:
Gas nitriding and nitrocarburisation

Two methods can be distinguished in nitriding - the gas nitriding and nitrocarburisation. However, some common conditions apply to both methods. The longer the nitriding period, the greater the nitriding hardness depth (NHD). The higher the temperature is chosen (usually temperature ranges from 350 to 630°C), the deeper the nitrogen can penetrate at the same time. Generally, however, the intrinsic hardness of the nitrided layer decreases with increasing treatment temperature.

Materials with nitrite-forming elements (e.g. chromium, molybdenum, vanadium, aluminium) have a higher nitriding hardness, but reduces the potential nitrogen penetration depth with an increasing alloy content.

In gas nitriding, nitrogen diffuses into the components in a split ammonia gas atmosphere, usually at 500-530°C. Through long treatment durations from 10 to 160 hours, a nitriding hardness depth (NHD) of 0.1 - 0.9 mm is achieved, depending on the material used. The main objectives are the improvement of component strength, wear resistance, sliding properties, temperature resistance and fatigue strength under reversed stress. The gas nitriding permits a partial treatment of the material.

In nitrocarburisation, a nitrocarburising treatment is performed at 560 - 580°C. In addition to nitrogen, carbon also diffuses into the material. The treatment time is usually 1-5 hours, with the cooling dependent on the material in water or salt bath. The nitriding hardness depth amounts to approximately 0.1 to 0.25 mm (depending on the used material). The treatment is mainly for wear and corrosion protection. The process can take place either in a salt bath (salt bath nitrocarburising) or ammonia gas (gas nitrocarburisation), whereby the current trend is predominantly towards gas nitrocarburising.

Nitriding versus electrogalvanisation

In general, nitrite-treated pins are significantly better shafts for iglidur® materials than those from untreated raw materials. A major advantage compared to galvanised finishes is that no coating is applied. Instead, the actual pin material is modified through the diffusion of nitrogen and carbon. Thus, even superficial damage - depending on the diffusion depth - cannot reduce the corrosion protection.

The differences are demonstrated in a comparative test. Both bearings were used in the same machine under identical conditions (pivoting motion, high forces, edge loads, dirt). The gliding bearing material iglidur® G was used in both cases. One pin was galvanised, for the other, the identical basic material was nitrocarburised. It becomes clear in the galvanised option: in the area of contact with the bearing, the protecting zinc layer was completely abraded. Thus the corrosion protection is lost. There is a massive corrosion of the pin. The consequence is a massive rise in the friction coefficient. The destruction of the bearing cannot be attributed to wear in the tribological sense. Instead, the material has become torn due to the shear stress. This effect was not seen with the nitrocarburised pin option.

Top: galvanised pin, bottom: the nitrocarburised pin (Source: igus® GmbH).

Nitriding has many positive characteristics. It is applicable on almost all steels. It leads to a hard-surface with a soft core. The material properties remain, since no structural change takes place. The fatigue strength enhances and the wear and corrosion behaviour improves. The treatment of bulk material is possible as a partial nitriding. Furthermore, a post-oxidation after the nitrocarburising can contribute to further improve the corrosion resistance. In conjunction with maintenance-free iglidur® plain bearings, which can be operated dry, i.e. without external lubrication by grease or oils, due to their self-lubricating properties, both nitriding methods are recommended for a low wear and corrosion protection.

Hard-chromed shafts

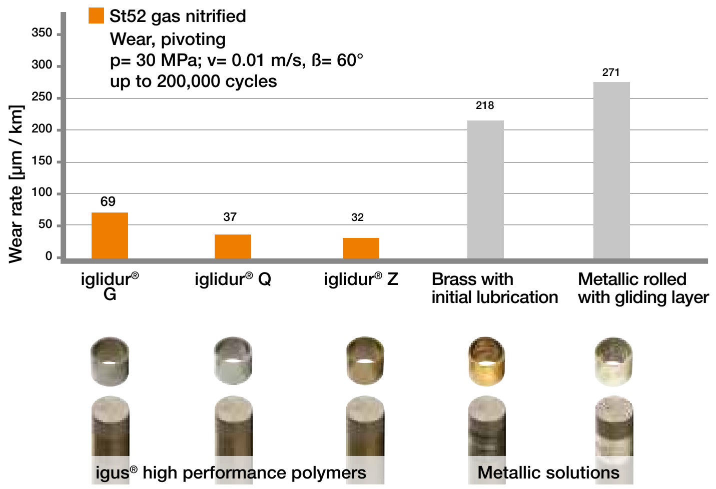
The term "hard chrome" does not refer to the actual hardness of chromium, but to the layer thickness. By hard chrome plating one indicates a layer thickness of at least 1 µm. This is, for example, so low in the case of bright chrome plating that at a hardness test, the test probe readily pierced through the thin chromium layer. In this surface treatment, a hard chrome layer is deposited by electroplating. This metallic chromium is applied by means of direct current, a suitable chemistry and an appropriate plant technology.

Common piston rods are offered for use in pin-socket connections. The thickness of the chromium layer is here, as a rule, 15-20 µm. A typical hard chrome layer contains a dense network of very fine cracks, but they are not visible to the naked eye and one cannot palpate. The cracking of chromium layers has this effect that - despite the excellent properties of chromium - a bright chrome layer alone does not provide good protection against corrosion. This develops only in conjunction with appropriate intermediate layers, usually made of nickel or an alloy of copper and nickel. The crack structure can even be advantageous for some applications, e.g., when a film of oil has to adhere better, such as in the use of a shaft as a piston rod in a hydraulic cylinder. Even in the use of plastic plain bearings, the cracking offers advantages at times, since the negative effects of a too smooth surface of the counter partner are reduced or avoided. For hard chrome plating, all steels, nickel and nickel alloys as well as cast iron, brass, copper or aluminium are suitable as materials.

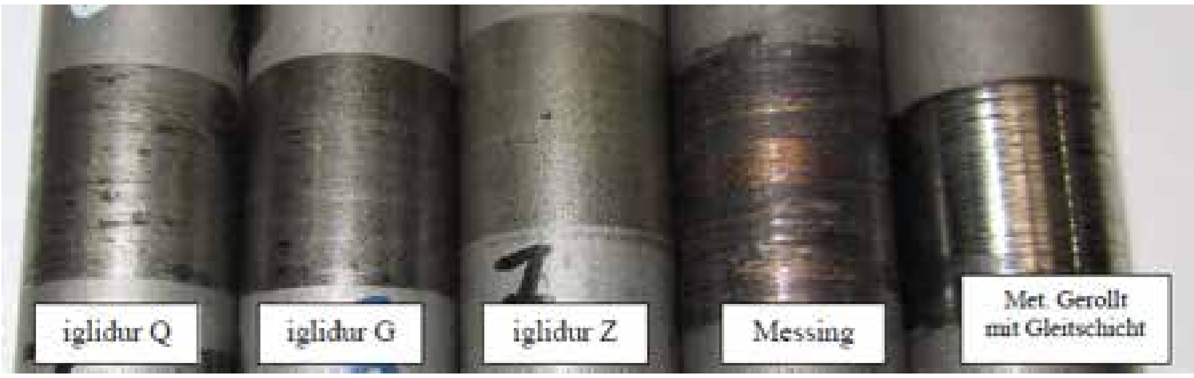
Hard chrome plated surfaces offer a very good shaft material for almost all iglidur® materials. It does not matter if the basic material is hardened or not. In conjunction with metallic plain bearings, the basic material should, however, be hardened, otherwise there is the risk of "collapse" of the chromium layer. The corrosion protection must be classified as very high. Friction and wear of the plain bearings made of tribo-polymers show excellent values in the use of hard chromed shafts. This knowledge resulted partly from the practical experiences of users of agricultural machinery, and also from the findings in the laboratory under experimental conditions.

Case study: Heavy duty tests with iglidur® materials

In the igus® dry-tech laboratory heavy duty experiments were conducted for wear behaviour with a gas-nitrided shaft of type St52. This combination of shaft material and surface treatment is a commonly used pin and socket connection in agricultural technology. Different bearing solutions were tested as shaft materials: the three iglidur® materials Q, G, and Z and an initially lubricated brass bearing and a metallic rolled bearing with sliding layer. Diameter and length of the tested bearing were 20 mm. The wear was measured in a pivoting application and a load of 1200 kg. Up to 200,000 test cycles were run at a speed of 0.01 m/s (swivel angle 60°, 30 cycles per minute) and a force of 30 MPa. However, due to the high wear, the experiments with the metallic bearings had to be abandoned after approximately 35,000 cycles. Only the iglidur® bearings were able to finish the planned 200,000 cycles.



The results speak clearly in favour of the iglidur®-materials. All three have significantly less wear than the metallic plain bearings. The shafts of the metallic bearings were greatly reduced in diameter and thus not fit for further use. It is the same thing with the bearings. The inner surface of the brass bearing is broken down and the sliding layer of the metallic rolled plain bearing is completely worn out. In contrast, no damage could be detected in the iglidur® plain bearings. When the wear rates are translated in terms of service life, the polymer bearings have approximately eight times higher potential.



Significant damages could be ascertained only in the metallic bearings (Source: igus® GmbH).

In addition to the measurement data of the shown shafts and bearings, there are countless other test results from a total of 15,000 individual experiments performed annually in the igus® laboratory. These findings are made available by igus® to its customers in two ways. For one, they are considered in the individual application consulting, two, they are stored in the company database which the customer can access via unique and user-friendly online tools, such as the one for service life prediction of plain bearings, or the selection of the ideal material for every shaft. If necessary, the company offers the laboratory itself to customers, where in addition to the usual standard tests, test stands are set up for customised trials.

Product development through persistent internal research

igus® GmbH has been developing and producing polymer plain bearings for over three decades under the brand name "iglidur®". There are now 47 different materials in over 7,000 standard dimensions (from Ø 2-240 mm) available from stock, which are tested in agricultural practice as well as in the in-house test lab, the largest in the industry, and are developed continuously. More than 135 trillion test movements are performed annually alone in the dry-tech test laboratory. The basis of all material options are iglidur® compounds made of base polymers that are optimised by specifically tailored additions of reinforcing materials and solid lubricants. In contrast to the solutions with metallic backs from other providers, in which the components are applied in layers and thus create a lubricating liner that can extrude under load, the iglidur® compounds are homogeneously mixed together in the injection-moulding production of plain bearings. iglidur® plain bearings, which are used in agricultural machinery, therefore, have extremely low friction coefficients and still allow a high surface and edge compression. They are resistant to shock and vibration. The polymers provide corrosion and media resistance. Fertiliser, liquid manure or fuel does not affect their functional reliability. The machines can therefore be used reliably even after prolonged shutdown.

Especially under agricultural conditions, where the machines are exposed to an extreme dirt accumulation, iglidur® bearings ensure optimum operation and high operating times. With the iglidur® Q2, igus® has developed a special material that is unparalleled in terms of wear and dirt resistance. Plain bearings made from the cost-effective iglidur® G are also insensitive to dust and dirt and therefore particularly suitable for agricultural machinery. However igus® comprehends its technological leadership as dynamic. To continue to offer the best quality and the most cost-effective bearing at the same time, a consisting advancement of the research and development work is needed. Since the development in the area of the shaft materials and surface treatment does not stand still, tests are especially indispensable that respond to modifications in the shafts and aim at a perfect match between the shaft and bearing.

Technology and Market Outlook

Friction and wear are highly dependent on the counter partner. The proper selection and combination of shaft is becoming increasingly important due to the individuality of the applications and the specialisation of materials. Shaft and bearing materials and their respective surface structures must be perfectly matched. Providers of bearing technology should therefore have a wide range of different types of materials in order to offer the ideal combination in each case, whether it be "soft", "hard" or "rough" shafts, or it be plastic, aluminium or chrome-plated shafts. Manufacturers who have only a single material with certain defined characteristics, will find it increasingly difficult to meet the demand of its customers and to compete in the market.

Besides their wear resistance and low maintenance, what counts particularly for plastic bearings is the freedom from lubricants. Both the environmental requirements of the authorities and the environmental awareness of consumers of agricultural products are increasing. A study of the RWTH Aachen assumes that 250,000 tonnes of oil or grease-containing machine lubricants seep into the German soil and water and evaporate into the atmosphere every year. Dry-running iglidur® plain bearings do not cause - in contrast to all metallic plain or rolling bearings - external or financial burdens for the environment or for the budget. The one who operates his farm equipment with components made of high-performance plastics, protects the farmland and money. The agricultural industry has therefore discovered for quite some time, the positive properties of self-lubricating polymer plain bearings.This trend will increase in the future and metallic bushes and recirculating ball bearing guides will be replaced by bearings made of high-performance plastics in more and more applications.

Summary

The different methods of surface treatment of shafts have a decisive influence on the properties of pin and socket connections. Suitable methods such as nitrocarburisation and hard chrome plating can significantly reduce friction and wear coefficients and lead to a much longer service life of the shaft and bearings. But, with the prerequisite of the right combination of materials, particularly in conjunction with the specific requirements and demands of each application.

Wear resistant and lubrication-free plain bearings offer a double advantage to agriculture. Less pollution of farmland and groundwater, simultaneous increase in the service life of the equipment, machinery and components. The agriculture of the future is virtually under the imperative "plough with a clean conscience without grease". Producers of agricultural machinery who heed the maxim combine technological innovation with cost savings and have a decisive competitive advantage.

Contact

If you require any further information, please do not hesitate to contact the igus® *agricultural technology* department.

Use the following options to contact:

Online contact: Uwe Sund
Tel.: +49 2203 9649 7208
usund@igus.de

Phone: +49 (0) 22 03 - 96 49 - 487
Fax: +49 (0) 22 03 - 96 49 - 487
Online contact: usund@igus.de
Online presence: http://www.igus.de/agrar
Online finder, configurators and 3D CAD: www.igus.de/online

The terms "igus, e-ketten®, e-kettensysteme®, chainflex®, readycable®, easychain®, e-chain®, e-chainsystems®, energy chain®, energy chain® system®, flizz®, readychain®, robolink®, pikchain®, triflex®, twisterchain®, invis®, drylin®, iglidur®, igubal®, xiros®, xirodur®, plastics for longer life®, CFRIP®, dryspin®, manus®, vector® are legally protected trademarks in the Federal Republic of Germany and elsewhere, where applicable.