

# **Equipment Reliability curtailment due to brinelling of rotating equipment**

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## **Abstract**

Industrial equipment's reliability is affected by various aspects, but the fact that over 90% of industrial equipment utilize rolling element bearings makes the reliability of bearings of crucial significance to the overall equipment reliability in industrial plants. One of the major causes of failures for rolling element bearings is brinelling. Rotating equipment are prone to the impacts of true and false brinelling, and the industrial impact of brinelling has compelled bearing manufacturers to research extensively on ways to minimize the impact of brinelling on industrial equipment. Recently, there is an upsurge of patented greases and equipment designs all done with the objective to minimize or eliminate the effect of true and false brinelling on industrial rotating equipment. This research was carried out to evaluate the measures applicable to curtail the effects of brinelling on rotating equipment reliability. Literature review was carried out to reveal measures necessary to prevent or alleviate the impact of brinelling on rotating equipment and then followed by a survey to ascertain industrial practices relevant to preventing brinelling.

## **Keywords**

False brinelling, true brinelling, fretting corrosion, indentation, rotating equipment.

## **1. Introduction**

Equipment under idle conditions such as standby capacity or storage phase are generally located under "safe" conditions all with the objectivity of delivering the equipment in perfect working condition once it is installed or called to use. But sometimes premature failure is experienced on equipment that is recently drawn from stores and installed in the plant, or when standby equipment is put into operation. Many maintenance practitioners will then wonder why "new" or "safe" equipment like these fail prematurely in the field. Equipment like electric motors, gearboxes, bearing assemblies and pumps are among the multitude of equipment termed as rotating equipment and they are prone to such failures.

Bearings constitute one of the vital components of all rotating equipment, whose primary purpose is to support the equipment and to support the rotary motion of the shafts relative to the motionless construction, and above 90% of machineries utilize rolling element bearings (Gupta and Pradhan, 2017:2085). Although inexpensive, the functional failure of bearings may result in complete failure of the equipment, thus, their critical position in industrial settings as components of high criticality is upheld as their reliability and sturdiness most times dictate the state of the equipment (Sehgal et al., 2000: 39). Operational requirements dictate that bearings are imperiled to substantial and

dynamic loading created by equipment and transferred through the constituent parts of rolling element bearings, hence, the state of the bearing is very essential in the high manufacturing volume arrangement where the total of rotating equipment contribute to the manufacturing organization, and therefore any fault in the bearing need to be recognized in time to circumvent the rise in stoppages, production cycle upsurge and ruinous failure of the equipment (Gupta and Pradhan, 2017:2085). Rolling element bearings (REBs) are broadly utilized on rotating equipment through numerous industrial sectors that embrace aerospace, manufacturing, transport and infrastructural development, and the failure of bearings compound to equipment downtime, subsequently triggering noteworthy fiscal harm and even human fatalities in some instances, e.g. locomotive derailment owing to bearing failure or airplane engine bearing seizure, with some of these failures attributed to brinelling (Singh, et al., 2014:5356). The REB is one of the uniquely regarded utmost crucial components that regulate the equipment health and its residual lifespan in contemporary manufacturing equipment (El-Thalji and Jantunen, 2015:90).

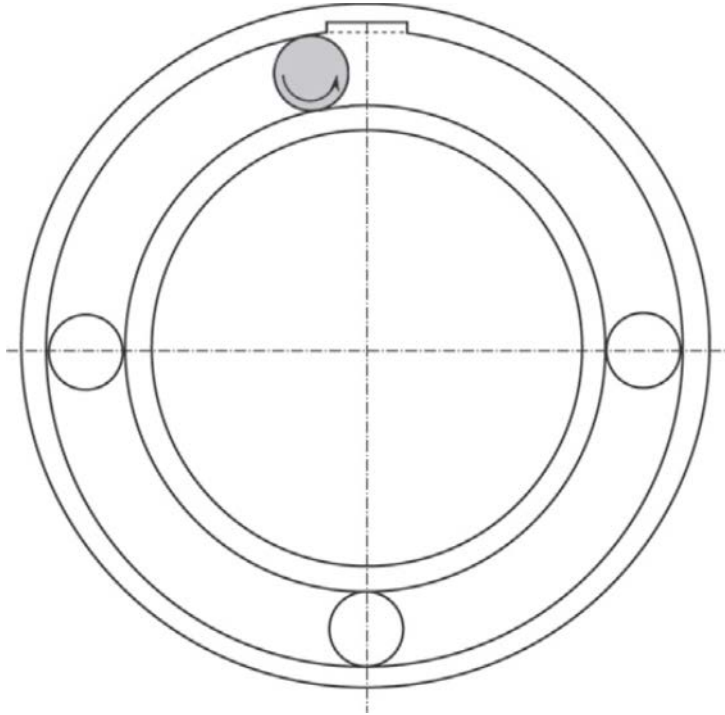


Figure 1. REB depiction with a rectangular imperfection on the outer race (Singh et al. 2015:305).

For bearings which are of the rolling element construction, over 90% of them are regarded as having grease as their primary lubricant compared to other lubricant types, accordingly enhanced appreciation and optimization of performance of friction characteristics of grease can deal an essential technique of dropping power losses in rolling bearings (De Laurentis et al., 2016:624). A majority of industrial equipment use numerous rolling element bearings, this in deed affords one of the utmost inescapable means of refining the general efficacy of mechanical structures with allied savings in green/energy and carbon discharges (De Laurentis et al., 2016:624). Presently, there happen to be extensive guiding principles for the assortment of greases for bearings application, established on far-reaching laboratory explorations and annotations from the field, signifying indiscriminate choice guidelines to satisfy the utilization circumstances, yet, currently there is privation of meticulous comprehension of the significance of distinct grease constituents in defining friction reaction subject to diverse bearing functional settings (De Laurentis et al., 2016:624). The lubricant and especially grease is part of the key components for bearings and the applicative longevity of a greased bearing is intensely affected by the grease characteristics (Lugt, 2016:467).

## 2. Brinelling of Rolling Components

Bearings and gears generally comprise the tribological constituent parts and they are open to progressively challenging usages that encompass heavy duty manufacturing equipment gearboxes, high performance internal combustion engines, long-haul locomotives and long-haul aircrafts, and because of the high performance levels demanded, concerns relating to bearing failures trends such as contact fatigue have triggered researchers to assess the maintenance and lubrication strategic aspects to curtail these concerns to warrant dependable and cost effective function (Greco et al., 2013:1583). Presently mechanical structures are projected to withstand punishing operational environments, owing to the upsurge of the tangled power and the enhanced design, and this is more so in specialized applications like space engineering, robotics and aeronautics which entail the lessening of the contact area for rolling contact bearings allowing comparative motion amongst mechanisms thereby swelling the power transmitted per unit of contact area (Massi et al., 2014:141). False brinelling and fretting corrosion are prevalent issues associated with bearings and gear mechanisms when they endure merely a slight scope of motion or structural vibrations, with the situation instigating the lubricant to be pressed out of the contact area and removing the protecting oxide layer ensuing in a speeded wear scenario that produces dents in the raceway, inhibiting the even functionality of the system (Greco et al., 2013:1584). Storage areas that are subject to slight structural vibrations therefore expose all the rotating equipment stored in them to false brinelling and fretting corrosion, and this can result in issuing already defective components for installation in the process plant. For decades, engineers have acknowledged that the bearing raceway of stationery rolling element bearings exposed to slight vibrations or oscillatory motions can be considerably dented in a quick period and this wear pattern that signifies a distinct incident of fatigue is what is termed false brinelling (Phaner-Goutorbe, et al., 1997:45).

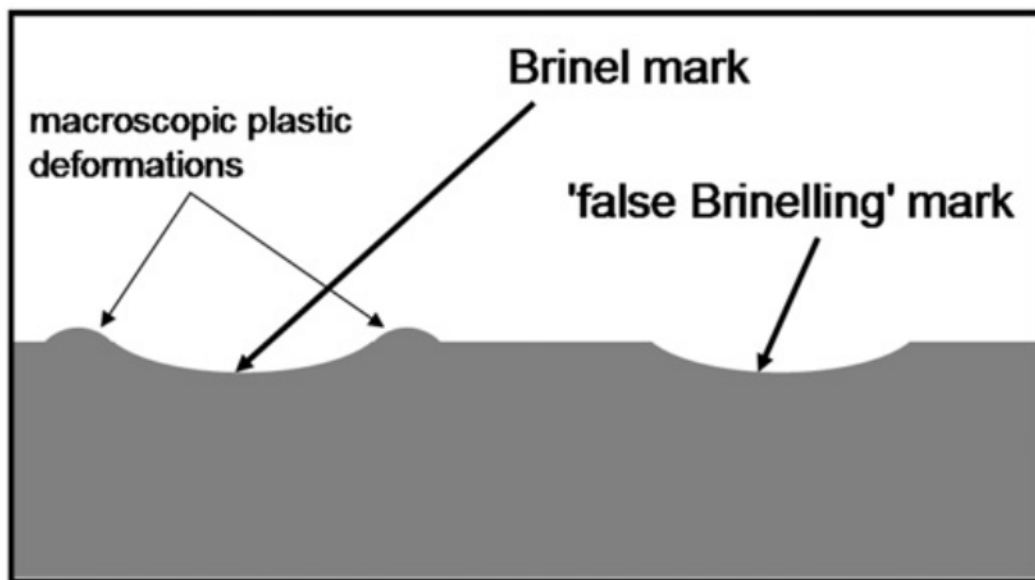


Fig. 2. Depiction of the brinelling (left) and 'false brinelling' (right) failure trends (Massi, et al., 2010:1069)

False brinelling yields fissures or cavities formed on the bearing raceways which are akin to the Brinell dent created by indentation, and it is identified to arise in quasi motionless mechanisms in a vibratory location (Phaner-Goutorbe, et al., 1997:45). Paralleled to the Brinell outcome, no macroscopic plastic distortion ensues and the indentations emanate from the detachment of the surface material instigated by oscillations of the confined contact stresses, which is as a result of the prompted vibrations by the mechanical mechanism where the bearings are mounted, and moreover by the corrosion of removed surface bits (Massi, et al., 2010:1069, Phaner-Goutorbe, et al., 1997:45). Fretting-corrosion or false brinelling is a collective destruction contrivance comprising corrosion at positions where two moving metallic planes under load, subjected to microscopic vibratory motion with typically minute amplitude and creating rubbing interaction, and this virtually occurs in all machines (Kamani, 2014:1). Failure deterioration due to fretting corrosion is identifiable by stains on the metal surface, creation of profound pitting and creation of outstandingly separated oxide debris, and with the surfaces faintly discolored, the corrosion outcome of aluminium

is white but fretting makes it to convert to black, and steel which generally corrodes to grey, becomes reddish brown (Kamani, 2014:1). This hasty conversion of the metallic surface to its oxide causes damage to the accuracy of dimensions of linked components culminating in equipment malfunction oftentimes with disastrous consequences as the pits created by fretting become points of high stress concentration (Kamani, 2014:1).

Subsequently, false brinelling fits much more to the arena of fretting and in order to avert the deterioration of these mechanical components, some lubricant is presented amid the two steel planes in interaction, that is the rolling element and the raceway, although the lubricant cannot entirely halt the wear progression, it can effectively defer the destruction (Phaner-Goutorbe, et al., 1997:45). Consequently much of the research accomplished pertaining to false brinelling complications was to develop the protecting superiority of the lubricant and this focused on the likes of corrosion inhibitors and viscosity coefficient enhancement (Phaner-Goutorbe, et al., 1997:45). The key root of false brinelling is from a design of the bearing that does not have provide a system of redistributing the lubricant without huge revolving movements of all bearing surfaces in the raceway, as the lubricant is pressed out of the loading zone during minute oscillatory movements and vibrations (Kamani, 2014:2).



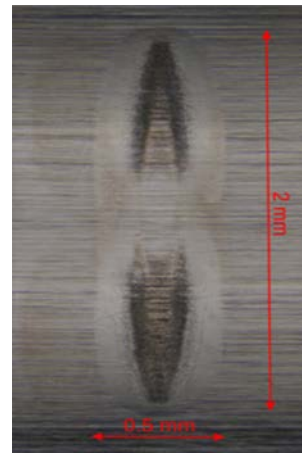
False brinelling



True brinelling



False brinelling



False brinelling

Figure 3. True and False brinelling deterioration on a bearing race-way (Massi, et al., 2010:1073).

Two kinds of fretting corrosion are distinctive and they are dependent on the environs, and these are dry fretting caused by the atmospheric oxygen attack on the metal and wet fretting which is due to the existence of electrolyte on the contact surfaces (Kamani, 2014:1, Upadhyay et al., 2013:17). The lubricant is pressed out in the middle of the interaction zone of rolling element and raceway leading to direct metal-to-metal contact that gives result to wear (Upadhyay et al., 2013:17). False brinelling does not occur during regular run phase of the equipment but during stationery phase, the bearing is exposed to vibrations due to fretting resulting in false brinelling, and the irregular

planes formed by false brinelling may create undue noise and affect untimely spalling by rolling-contact fatigue (Upadhyay et al., 2013:17).

### **3. Rolling Element Defects and Detection**

#### **3.1 Defects in Bearings**

A number of scholars have explicated the systematic principles of vibrations in bearings, and even a fit bearing produces vibrations, but the manifestation of faults steps up vibration intensities considerably (Gupta and Pradhan, 2017:2086). The bearing faults are largely categorized in two classifications and these are distributed flaws – which consist of surface coarseness, corrugation, askew races and off-size rolling components, with the chief causes being manufacturing inaccuracy, abrasive wear and inappropriate fitting; and localized flaws – which consist of pitting, cracking and spalling with a previous study showing that 90% of the entire bearing failures embroil impairment of the interior ring, exterior ring and rolling elements owing to localized flaws (Gupta and K Pradhan, 2017:2086). In essence, the wear progression development is rather intricate owing to the contribution of quite a number of wear parameters like fatigue, abrasion, adhesion and corrosion, coupled with numerous stress concentration scenarios like indentations, inclusions and debris, creating a wear progression process which diverges considerably with relevance to the surface topographical and tribological variations (Thalji and Jantunen 2015:254, Gurumoorthy and Ghosh, 2013:111).

#### **3.2 Defects Detection**

The foremost aspects that, individually or in combination, possibly will result to untimely failure of rolling element bearings in usage comprise of: improper fit, extreme preloading during installation, incorrect lubricant selection, overburdening, shock loading, extreme vibrations, extreme operating temperature, impurities due to abrasive stuff, entrance of detrimental fluids, and stray electric currents (Sehgal et al., 2000: 39). The damaging effects consequential to these aspects are brinelling, flaking, pitting, cracking, fracturing, creeping, smearing, wearing and softening (Sehgal et al., 2000: 39). The bearing raceway of a motionless rolling element bearing with exposure to slight vibrations or small oscillations will be prone to false brinelling and the surface inclines to fail prematurely as cavities are formed on the raceway. (Upadhyay et al., 2013:15)

Defects exposure in bearings is crucial for vigorous Predictive Health Monitoring (PHM) of the equipment and there are diverse techniques for the identification of these faults in the bearings which point out the imminent failures and offer additional time for maintenance planning (El-Thalji and Jantunen 2015:252). PHM targets the monitoring of the wear progression or deterioration rather than only sensing faults and many studies have been carried out to explore the aspects of bearing defects and the following areas were covered: vibration examination, oil sampling for material wear and debris evaluation, acoustic techniques, thermal checking, Shock-Pulse Measurements (SPM), and signal data analysis such as root mean square (RMS), kurtosis and Fast Fourier Transform (FFT) (Gupta and Pradhan, 2017:2085). The most extensively used bearing defects identification techniques are acoustic and vibration monitoring as they are cost effective and these mostly utilize the likes of vibration analysis in the time field, frequency field, time-frequency field, shock pulse process and acoustic production system (Gupta and Pradhan, 2017:2085).

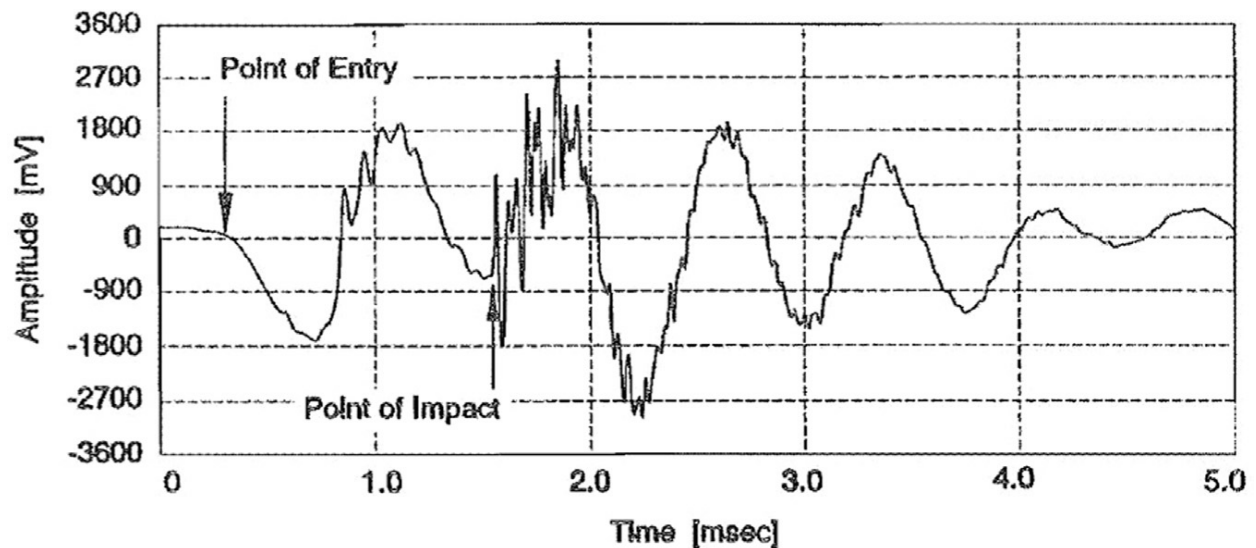


Figure 4. Ball bearing acceleration response with an outer-race fault of 3.0mm (Singh et al. 2015:305).

A comparison of the different monitoring practices for bearings is presented below.

Table 1. Comparison of defect identification techniques (Beganovic and Söffker, 2016:72)

Condition monitoring technique	Benefits	Shortcomings	On-line applicability
Vibration measurements	<ul style="list-style-type: none"> <li>usually applied in combination with Acoustic output</li> <li>economical system</li> <li>not able to detect defects criticality</li> </ul>	<ul style="list-style-type: none"> <li>Substandard outcomes in identifying of early stages of faults in gearboxes/ bearings</li> <li>Ineffective use to mechanisms turning beneath low rotational speeds</li> </ul>	No
Acoustic Emission measurements	<ul style="list-style-type: none"> <li>Convenient in slow rotational speed areas</li> <li>Capability to distinguish defects in their commencement stage</li> </ul>	<ul style="list-style-type: none"> <li>Observation for high number of samples</li> <li>Extraordinary needs on measurement sequence</li> </ul>	Yes
Oil analysis	<ul style="list-style-type: none"> <li>Can be used for on-line as well as off-line measurement</li> <li>Straight evaluation of equipment Health Status</li> </ul>	<ul style="list-style-type: none"> <li>high cost technique if used on-line</li> <li>Largely used off-line as a result of being uneconomical during on-line application</li> <li>Online application arrays necessities on secure oil systems of bearings/gearboxes</li> </ul>	Yes
Shock pulse technique	<ul style="list-style-type: none"> <li>economical method</li> <li>high accuracy identification coupled with pinpointing defects in bearings/ gearboxes</li> <li>Regularly applied in conjunction with vibration analysis</li> </ul>	<ul style="list-style-type: none"> <li>minimal sensitivity to load profile variations</li> <li>not convenient when it comes to fatigue exploration</li> </ul>	No

Vibration analysis is established on diverse signal processing approaches, and these comprise moving RMS, moving and spectral kurtosis, high-frequency resonance technique (HFRT), power spectral and cepstral analysis and these can assist in identifying the particular parts that carry a defect (Zhou, et al., 2017:191).

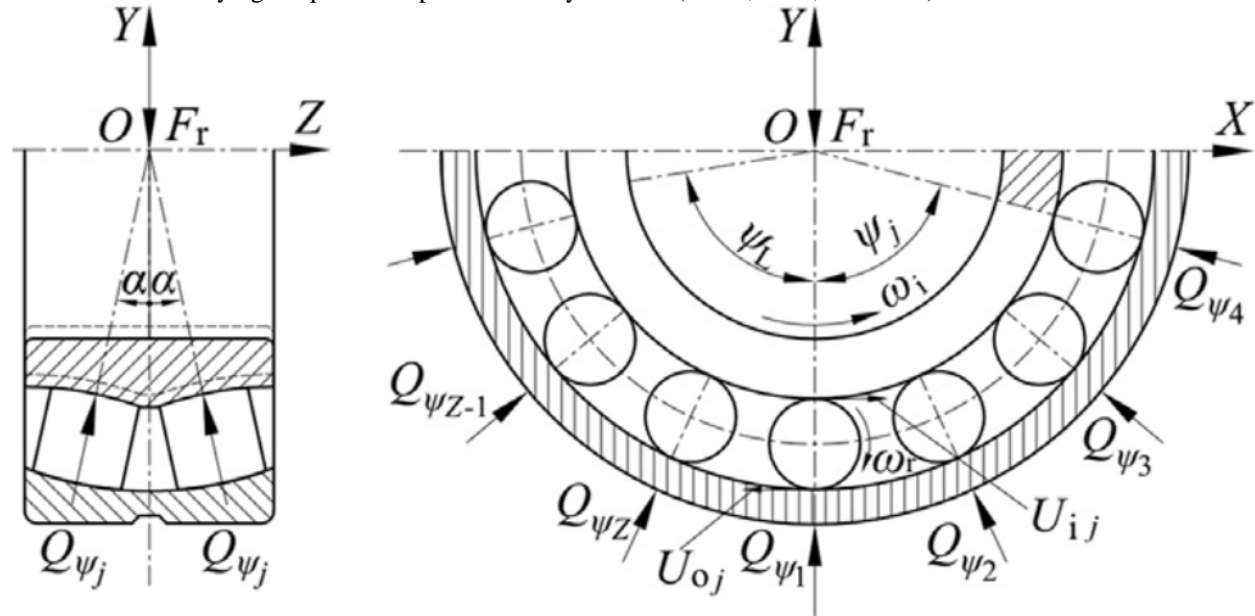


Figure 5. Depiction of Spherical Roller Bearing loading and motion evaluation (Ma, et al. 2016:116)

By possessing information of the precise loading circumstances and functional account of a specific equipment, it is feasible to forecast the possibility of failure and degree of structural destruction with a realistic prospect of success, and also the collective outcomes from oil, vibration and acoustic emission analyses can be utilized to derive effective maintenance assessments, thereby minimizing the threat of random stoppages and accompanying expenses (Zhou, et al., 2017:191).

#### 4. Prevention Methods for False Brinelling

The matter of bearing faults encompasses metallurgical engineering, tribology, and the functional setting, as well as the attention to the dynamics of loading forces, and in certain instances, a solitary occurrence may cause colossal destruction to business operations and sometimes, a compendium of incidents, inaccurate managerial resolutions, tough environmental situations, austere operating circumstances and improper maintenance performances can all lead to untimely bearing faults and breakdown (Knotek, 2016:77). Prevention of failures of rotating equipment is highly recommendable and these are some of the measures that can be taken:

1. Proper handling and storage practices that entail ensuring storage of bearings in flat, dry, clean, orderly and contamination free environment, as wet or exceedingly filthy environs are detrimental to the bearing reliability. Avoid dropping the bearings with impact on any hard surfaces. The thermal settings of the storage area should be regulated with constant temperature ranges and eliminating humid conditions. Intermittently revolve warehoused spares. Frequent rotation of rotating equipment like gearboxes and pumps should be adhered to frequently, e.g. turning the shaft a quarter of a revolution once every 30 days. Patented shaft rotators are also available in the market, e.g. SHAFT ROTATOR FOR STORED EQUIPMENT WITH ANTI-FRICTION BEARINGS - Document Number: 20110204836, Publication Date: August 25, 2011, Appl. No: 12/709477, Application Filed: February 20, 2010.
2. During transportation, please ensure that the rotating shafts are secured to avoid any shaking or vibrations during transportation. Any impacts on bearings should be avoided during transportation and proper wrapping should be applied. It is always good practice to safeguard the shaft and housing securely throughout transportation and the inner and outer rings of bearings should be packed independently during transportation
3. Ambient vibrations in storage locations ought to be curtailed, and bearings must certainly not be stored in upright positions on the shelves as false brinelling will occur. When handling bearings, they should not be dropped as true brinelling can occur as a result of mechanical indentation.



4. Proper installation is essential as fit and tolerance between the shaft and inner ring, or the housing and outer ring should be within design specification or else fretting-corrosion ensues. Loose and force fitting will likewise culminate in bearing defects and correct fits and tolerances are imperative along with use of correct fitting tools, and the use of precision fitting tools is highly recommended
5. Negative operational situations further than those allied to the surroundings like undue thrust loads, misalignment further than capacity, high humidity, chemical substances or vapour, dust, dirt, excessive heat, excessive vibrations or exposure to electrical erosion should be prevented as this can lead to reduced bearing life.
6. Installing a standby unit at a distant position from the main operational one and manually rotating the shaft of the standby unit on a frequent basis e.g. quarter turn of shaft monthly or frequently swapping the units so that both are in frequent operation, e.g. two weekly intervals. Periodic rotation of field spares in/out of service is essential.
7. Design modifications to prevent false brinelling in rotating components e.g wind turbines designs to eliminate false brinelling, modern bicycle headsets incorporating a plain bearing to provide for flexing.

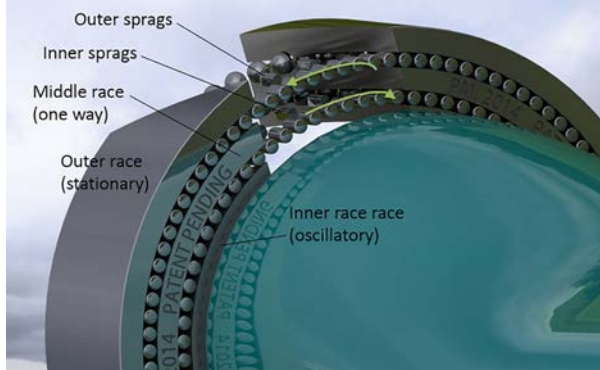


Figure 6. A patented design for wind turbine that prevents false brinelling (Source – Plymouth Machine Integration).

Further on designs to reduce or eliminating false brinelling, a patent was registered in the USA under the title “A Method to prevent brinelling wear of slot and pin assembly” under Patent Number: 8,033,782 Publication Date: October 11, 2011 Appl. No: 12/014978 and Application Filed: January 16, 2008.

8. The correct lubricant selection will go a long way in preventing bearing longevity in operation and preventing untimely failures. SKF have patented a grease that can reduce false brinelling by 50%. The correct selection of the lubricant for the application along with appropriate storage, handling and dispensing should be treated as top maintenance priorities. Lubricants possessing low viscosity, enhanced tenacity oils and greases diminish friction between contact surfaces and preclude oxidation by excluding air away from any scuffed bits. An effective lubrication management system should be characterized with effective training, color-coding, correct storage and usage, along with sanitation. SKF patented their grease in the USA with the new grease capable of reducing fretting corrosion by 50% under U.S. Class: 415/1, Patent References Cited:

3042370 July 1962 Welsh, 3407681 October 1968 Kiernan, et al., and this was reported by under the title: “SKF Grease limits fretting corrosion” by Thomas Net News on 22 December 2016.

9. Design to ensure no relative motion occurs on the surfaces at the contact zone. The surface finish is pivotal to preventing fretting corrosion as fretting generally occurs by the interaction of the astringencies of the contacting surfaces.

10. Procurement of reputable brands of bearings where you are assured of precision work during manufacture and bearings that are free of defects. Cheap counterfeit products are a recipe for disaster.

(Kamani, 2014:2-5, Knotek, 2016:78-81, Upadhyay et al., 2013:17)

## 5. Case Study

A brief survey was carried out on three manufacturing companies in South Africa, one in the pulp and paper industry, and two others in the chemical industry to ascertain their maintenance actions relevant to reducing brinelling's curtailment impact on their equipment reliability, with the following factors being surveyed: storage procedures, storage environmental control, equipment handling procedures, storage maintenance (frequent rotation), transportation procedures, standby field equipment maintenance (frequent rotation or use), Lubrication selection,



fitting and installation procedures, procurement quality control, operating environmental protection and design-out problems. The following outcome was attained.

Table 2. Brinelling Mitigation factors application

Brinelling Mitigation factor	Percentage Application by Company			Remarks
	A	B	C	
storage procedures	50%	50%	70%	Housekeeping standards- 5S followed
storage environmental control	20%	40%	30%	Thermal insulation lacking, but stores areas adequately housed
equipment handling procedures	35%	20%	65%	One point lessons on handling available and recommended equipment e.g. forklifts
storage maintenance	0%	0%	0%	No PM schedules for equipment in storage
transportation procedures	25%	30%	30%	Undocumented procedures in place
standby field equipment maintenance	0%	50%	50%	System followed in two companies but not documented
Lubrication selection	70%	80%	80%	Following tribological recommendations from suppliers
fitting and installation procedures	50%	70%	75%	Fitting equipment available, but inadequate procedures in place
procurement quality control	40%	50%	50%	Price is generally the leading factor in reaching procurement decisions
operating environmental protection	30%	40%	20%	Limited guarding in the field
design-out problems	45%	40%	20%	Not systematically applied

As a major discussion point, storage maintenance and field maintenance for standby equipment was poorly done by the companies that that were surveyed, and this signifies that a lot more effort needs to be channeled to appraise maintenance practitioners on the menace of brinelling on rotating equipment reliability.

## 6. Conclusion

Because of the essentiality of bearings to industrial processes, anything that drastically reduces the bearing life (L10) which is depicted by the overall sum of revolutions that a bearing accomplishes fittingly under prescribed environments before any failure ensues, should be curtailed in order to improve equipment reliability (Gurumoorthy and Ghosh, 2013:111). With relevance to heavy equipment, slight flaking or spalling incurred on the bearing might not be reflected as an instantaneous functional failure and the bearing lifespan may be extended with appropriate maintenance action, but it may not be so with small bearings (Gurumoorthy and Ghosh, 2013:110). This research has explored one of the phenomenon that affect industrial processes especially in the advent of using quite a number of rotating equipment. Brinelling – true and false is a phenomenon that is currently affecting industrial operations and quite a number of bearing manufacturers are involved with research in pursuit of fighting the problem of false brinelling,. These efforts are evidenced by recent patented greases like the SKF patented grease for reducing false brinelling by 50% in 2016, and designs in wind turbines to protect the equipment from false brinelling. Further studies need to be pursued to find ways to further reduce false brinelling as this failure mechanism is costing industries due to reduced equipment reliability in the event of malpractices that excludes maintaining equipment to prevent false brinelling. Bearing life need to be extended and all actions that are relevant to improve rotating equipment life need to be adhered to.

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## **Biography**

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