Total Cost of Ownership White Paper

"Lube for Life"® Bearing Assemblies

October 2002

Total Cost of Ownership – Understanding "Lube for Life"® Bearing Assemblies

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Overview

In today's challenging industrial equipment market with increasing off-shore competition, the need to address parity between equipment designs is driving the need for functionality based cost cutting measures. Such thinking requires a more advanced understanding of cost drivers. Specifically, the need to view costs beyond mere unit cost analysis (simple *per piece* analysis) becomes a critical component to effective cost containment. Being able to look beyond unit or component level costs necessitates an evaluation that takes into account system or assembly costs. It is with the mindset of total cost of ownership that "Lube for Life" bearing assemblies are becoming increasingly of interest. The potential to increase equipment functionality while lowering the total cost of ownership for bearing assemblies is one of the single largest driving factors pushing OEM's to greaseless bearing designs. The question evaluated during this white paper is whether or not bearing selection criterion is visible and of interest to today's rental yard owners, service and maintenance managers.

Rental Yard Analysis

Multiple rental yards around North America were contacted by the Polygon PolyLube™ self-lubricating composite bearing team in an effort to better understand the role bearing design, bearing maintenance issues, and bearing related warranty claims played for both the rental yard proprietor and the end users themselves. Six questions were asked of each rental site interviewed.

Six Bearing Maintenance Related Questions:

1. What functionality enhancements would you like to see from equipment suppliers?

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Most users identified the broad concepts of improved equipment durability and an extension of maintenance cycles as their most desired improvements from equipment suppliers. While bearings were not specifically referenced in this lead-in question, the two most common requested enhancements are both positively impacted when an OEM incorporates greaseless bearing designs. In particular, the ability to extend maintenance cycles is accomplished easily and immediately with greaseless bearing systems.

2. What are the most common maintenance requirements for your equipment?

The most common maintenance requirement was bearing greasing. This was very prevalent in the construction equipment user group – in particular the skid steer, mini-excavator, telehandler and excavator user community. By an almost 5:1 relationship, bearing greasing or actual replacement of the bearing itself was identified as being a driver for maintenance once equipment was returned to the rental yard. This was commonly because the bearing joints had been improperly maintained during the usage cycle.

3. Is bearing maintenance (greasing or oiling) a common maintenance item?

Every rental yard that was interviewed identified bearing maintenance as a common maintenance item; the second most common maintenance item was replacement of fluids (hydraulic fluid, etc.).

4. If yes, what type of bearing maintenance do you have to do?

Two types of bearing maintenance were most common: first, having to purge the bearing assembly of grease or oil and get a newly packed bearing with fresh grease in place. The second most common bearing maintenance was actual replacement of the bearing itself due to corrosion, simple wear, or

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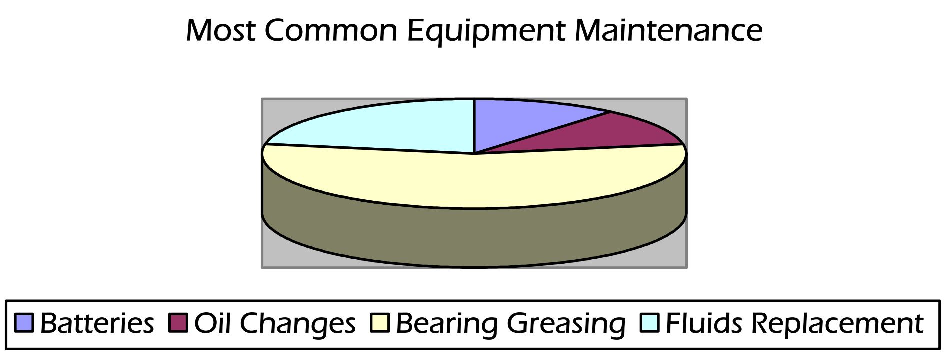
improper maintenance. In many cases, the pin is so heavily damaged that the pin itself must also be replaced.

5. How much time does this take?

Answers concerning actual time requirements for bearing maintenance varied greatly: some older scissor lift models required over 15 minutes per grease cycle; most backhoe users reported that bearing maintenance was typically a 30 minute investment. One agricultural equipment user shared that bearing maintenance can take as much as one hour per day of work.

6. Have you ever seen bearing failure or damage that results in a maintenance issue? A warranty claim?

Responses to this question ranged: while most rental yard personnel had to replace bearings, they were considered a standard maintenance item and rarely related to warranty issues. The focal point of their interest in bearing systems was on reduced and more simplistic maintenance.



What Greased Bearings Mean to Rental Yards and End Users

Said one rental store employee, "… greasing a small scissor lift with 19 zerks may take as long as 15 minutes … our concern is when a customer takes a piece of equipment for an extended period of time … do they perform the routine maintenance

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that is required … most of the time it [bearing greasing] requires daily attention." Most maintenance managers interviewed identified bearings as a very real maintenance concern, both in terms of what they had to monitor for unit replacement (actual replacement of the physical bearing as the bearing wore out) as well as actual labor and material costs for the act of greasing the bearing itself. Said one maintenance manager from a rental service in Indianapolis, Indiana: "anything that reduces maintenance is ideal in today's environment."

Two rental yard employees in East Chicago, Illinois (a territory account manager and a district service manager for an equipment rental agency with annual sales of $2.3 billion and 6,000 employees at over 500 locations) shared with Polygon that greaseless bearing systems are needed in today's user community. A common example of the problem seen in fleet management is proper maintenance of bearings for steering linkages. These are one of the most prone service areas and often need repairs that could have been prevented with proper bearing maintenance.

Most problems are related to user abuse, negligence and environmental exposure of the equipment in plant or field service. Typically, once a piece of equipment is rented it might not return back to the rental yard for months or up to a year. There is generally minimal maintenance ever done while the equipment is in the field. This is not a common requirement of the rental contract unless it is stated under the conditions of use. With these kinds of user patterns, today's OEM designer must introduce equipment designs that focus on a genuine reduction in required maintenance – both for the good of the user as well as the total cost of ownership for the rental yards.

During the course of the various field interviews, it became obvious that equipment maintenance is a sensitive issue. Said one interviewee: "the rental house is supposed to abide by the maintenance schedules listed by the manufacturer's recommendations … most of the time this is highly abused and ignored by all."

What Drives Greaseless Bearing Design?

The lessons learned by those OEM's who today use greaseless bearing designs is of value to share with other equipment manufacturers who may be contemplating the

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use of a similar product. Four primary reasons commonly drive successful OEM conversions from greased bearings to PolyLube greaseless bearings:

1. Lowered total cost of ownership (TCO).
   TCO drives many OEM's conversion from greased bearing systems to self-lubricated bearing designs. To the rental yard owner, TCO is a visible concept. The long term benefit of simply removing greasing as a necessary maintenance function means that the rental yard owner can lower his labor costs, as well as eliminate the cost of the actual grease materials themselves. Over a one year period of time, the cost for maintaining a greased bearing system on a piece of construction equipment can be significant.
2. Limit user-controlled warranty claims.
   Traditional users of self-lubricating bearing materials have been the scissor lift industry, tail-gate manufacturers, and utility truck (also known as cherry pickers) OEM's. Each of these equipment manufacturers have identified self-lubricating bearings as a very real means for the OEM to control warranty claims. Within the scheme of user-controlled features, a greaseless bearing system easily and cost-effectively eliminates the potential for the user to damage his equipment due to improper maintenance. Greaseless bearing systems are easy to introduce, cost-effective, and simply put allow the OEM to take bearing maintenance off of the list of work-hour related user maintenance.
3. Design more "eco-friendly" equipment systems (ISO14001).
   A missed value of greaseless bearing systems is the compliance greaseless bearings have with ISO14001. Already, rental yards in some parts of the European Union can receive a tax credit for migrating from conventional greases and oils to recycled lubricant packages. This migration will only accelerate in the coming years: in the near future it is realistic to assume that compliance with ISO14001 will require equipment designs that increasingly incorporate materials and systems that reduce reliance on non-recycled materials. Greaseless bearings easily fit within the expected confines of future ISO14001 in that they completely eliminate any regulated materials related to

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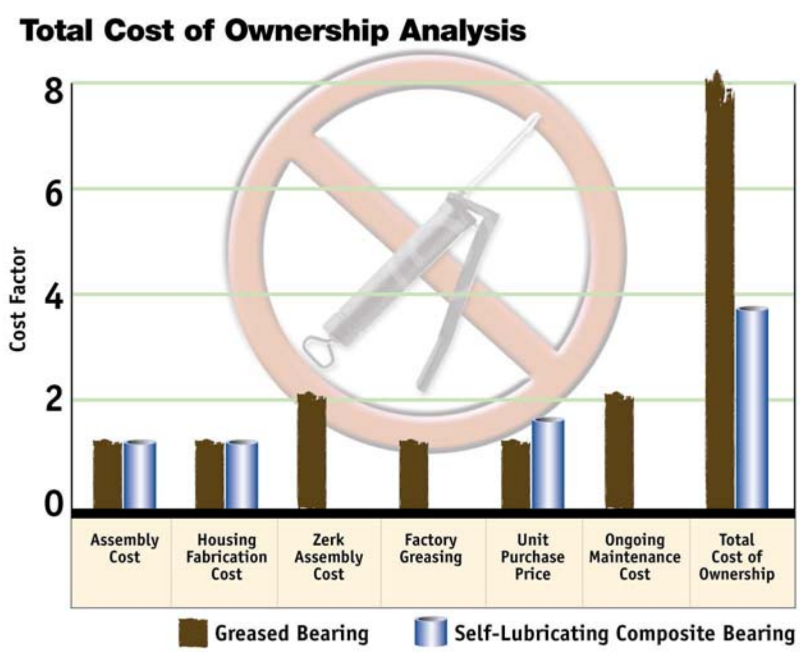
greasing bearing joints. With the environmental costs already in place for getting rid of used grease and oil, the opportunity to "Go Greaseless" has never made more sense.

Understanding Total Cost of Ownership (TCO)

Total Cost of Ownership is a metric that takes into account both the unit cost of the bearing assembly as well as two additional costs: total manufacturing costs for purchased items and actual labor for supporting either bearing design selection. Secondly, TCO includes soft costs related to ongoing equipment maintenance (a cost born by the user / rental yard owner immediately but by the equipment manufacturer long term as the rental fleets begin to incorporate competitive equipment that uses greaseless bearing systems). For the purposes of this analysis, TCO will include the following items: the cost of assembling the bearing into the bearing assembly / housing, the cost of fabricating the housing itself, any costs for the greased bearing sub-components (called out in the below graph as "Zerk Assembly Cost"), factory greasing, the unit purchase price, and ongoing maintenance cost.



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What a bearing actually costs goes beyond just the unit purchase price. As an example, in the case of conventional greased bronze bearings, the total cost of the bearing assembly requires an incorporation of costs for sub-assembly items such as grease zerks. Depending on the type of zerk used in the equipment design, the cost of a grease zerk can range from under $0.50 to several dollars. Most bearing systems that require grease zerks also incorporate pin fabrication that is costly primarily because of the CNC time required to drill and tap the respective grease path.

Another cost that must always go into the evaluation of bearing materials is the cost of pin selection, but also the cost of pin replacement related to premature bearing failure due to wear or ability to ingest contamination (embeddability). The cost of pin materials then must be evaluated from two perspectives: first, the cost for selecting a pin for greased versus greaseless bearings and second, the anticipated life of each respective pin material in relation to the bearing that has been selected.

For both issues, it is critical to look at the warranty period the OEM provides to the rental yard. Within the warranty period, replacing the bearings is costly, but can be reasonably accomplished. On the other hand, replacing the pin as a result of bearing failure is a cost that can be up to 10x the cost of the bearing material itself. With this in mind, a proper viewpoint of TCO incorporates not just bearing cost, not just pin cost, but the cumulative cost of keeping any bearing selection in the field in a properly maintained fashion.

For metal-backed bearings that require greasing, strict shafting requirements are generally needed for metal backed bearings. They require precision shafting in order to function and be designed correctly. Generally standard bearing sizing is set up using turned, ground and polished shafting. The cost of these finishes sometimes prohibits their reasonable use. A PolyLube composite self-lubricating bearing utilizes a fibrous network lubricating system that can tolerate rougher shaft textures and surface imperfections. Often, low cost cold roll steel is used without any sacrifice in composite bearing design life. Bearing loads, application surface speed and other conditions play

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an important part in shaft material selections. Polygon should always be consulted for further information on proper shaft requirements.

Impacting the Design Engineering Community

Similar to other technologies that have initially had a seeming disassociation between their unit cost and offered feature / benefits, greaseless bearings have had to go through a number of revisions in order to provide the combination of unit cost and performance that is possible today. An excellent example of this improved synergy between bearing unit cost and feature / benefit improvements is the PolyLube MRP bearing, co-developed with DuPont Advanced Fiber Systems. This new bearing offers dramatic cost improvements over legacy-era composite bearings while introducing a design life more in tune with the actual operator hours today's equipment is designed for.

No engineer in today's OEM market-place would question the increasing pressure to add functionality enhancements to new equipment designs. In fact, the trend in agriculture and equipment designs is not only to introduce continual functionality enhancements, but to incorporate more and more ergonomic designs that reflect similar changes to tried and true consumer goods. Just as the toothbrush of yesterday is certainly not the toothbrush of today, so too the excavator of today does not aesthetically nor functionally represent the excavator of yesterday.

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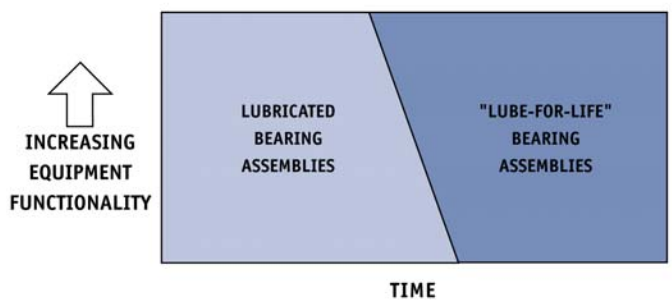
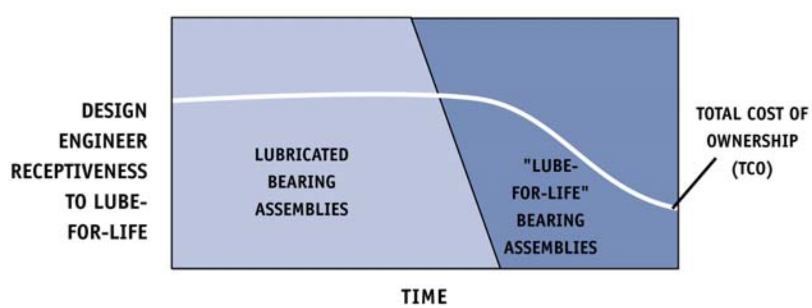
The schematics below illustrate the relationship between time and incorporation of greased versus greaseless bearing systems. While this relationship may be obvious, an associated relationship also advances: as the concept of TCO is embraced by more design engineers, the validation of this concept becomes more concrete and obvious to everyone involved in bearing selection. What may be obvious, but can be easily missed, is that as design engineer receptiveness increases to the concept of greaseless bearings, the cost for bearing assemblies begins to dramatically decrease. This is a reflection on designs that can begin to incorporate more historical knowledge on replacement life of bearing materials, similar information on pin selections, and a better knowledge of how greaseless bearings reduce maintenance and expand market share.



INCREASED EQUIPMENT FUNCTIONALITY



<u>What Is Self-Lubrication?</u>

A composite self-lubricating bearing is a high load capacity bearing material utilizing a PTFE wear liner (not a PTFE surface treatment, but an actual PTFE continuous filament layer) that has a continuous fiberglass backing. The continuous fiberglass backing results in a bearing that can handle static compressive loads of

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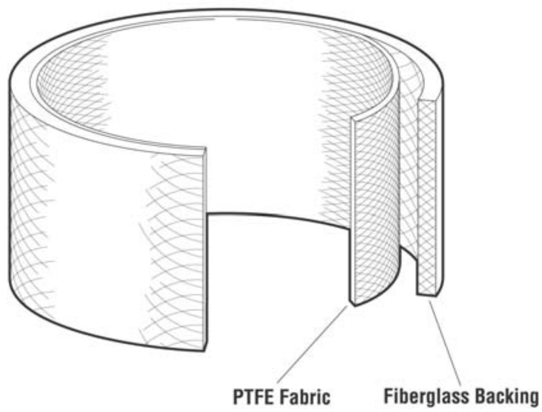
60,000 PSI and dynamic compressive loads of 30,000 PSI without the need for external lubrication. Where applicable, these bearings put an end to problems such as shaft scoring and galling, bearing assembly corrosion, and lubricant and fittings maintenance. They have high shock load capabilities as a result of the fatigue resistant resin matrix and the fiberglass reinforcement.



The structure of a properly designed self-lubricating bearing utilizes a high strength continuous fiberglass backing with a low friction, highly embeddable wear surface composed of high tenacity PTFE filaments.

The high performance composite backing and the process it is manufactured by are no less important than the woven wear liner. During the manufacturing of these composite bearings, the resin will work itself into the liner. As the bearing and liner are completely cured, the liner and the bearing backing become one, effectively ensuring that liner separation will not occur during cycling.

In addition to their probable reliance on external lubrication, metallic bearing materials have two primary limitations that potentially effect equipment users: first, corrosion of the bearing and as a result the bearing retention method, as well as the housing itself, and second, susceptibility to impact fatigue failure.

With respect to the corrosion problem, metallic bearings can, especially during oscillatory cycling, begin to corrode. Corrosion problems are made much worse by bearing systems that rely not only on secondary lubrication but on a full purge and cycling of the bearing assembly in order to properly circulate the lubrication media. As the bearing corrodes, the possibility exists for the pin to come in intimate contact with the housing material. When this intimate contact takes place, serious failure can result for the bearing assembly in question.

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A corrosion problem can be an especially sensitive point when seen in light of many construction and agriculture equipment applications. The desire to have an inherently non-corrosive bearing is obvious to any customer who may need to leave their equipment at a work-site for days during inclement weather. Most self-lubricating composite bearings can operate in unsealed environments, further expanding the usefulness of a composite bearing versus a greased metal bearing design.

In order to address the second problem with metallic bearings, impact fatigue, it is again best to review possible application environments for most equipment users. Metallic materials exhibit a measure of impact fatigue in room-temperature environments; however, as environmental factors change so does the retention of these properties. During repeated cycling – especially during temperature variations (cold being especially detrimental to impact fatigue) – an all metal bearing construction can exhibit very limited performance capabilities. This stands in contrast to composite bearings: composite bearings have dimensional and performance consistency from ±350°F.

Composite self-lubricating bearings rely heavily on the self-lubricating wear surface. In the form that PTFE is commonly used in self-lubricating composite bearings, the wear surface actually consists of super-tenacity continuous PTFE filaments. This stands in contrast with other wear liners that may simply suspend a PTFE dispersion or short fiber PTFE reinforcement in a thermoplastic resin matrix. Such systems, while properly called self-lubricating, are subject to cold flow under oscillatory cycling and can perform inadequately in many equipment applications. In contrast to the dispersion or short fiber techniques, the PTFE super-filaments allow for placement of the filaments exactly where required for maximization of self-lubrication. In addition, the placement of the PTFE fibers can result in a wear liner architecture more able to

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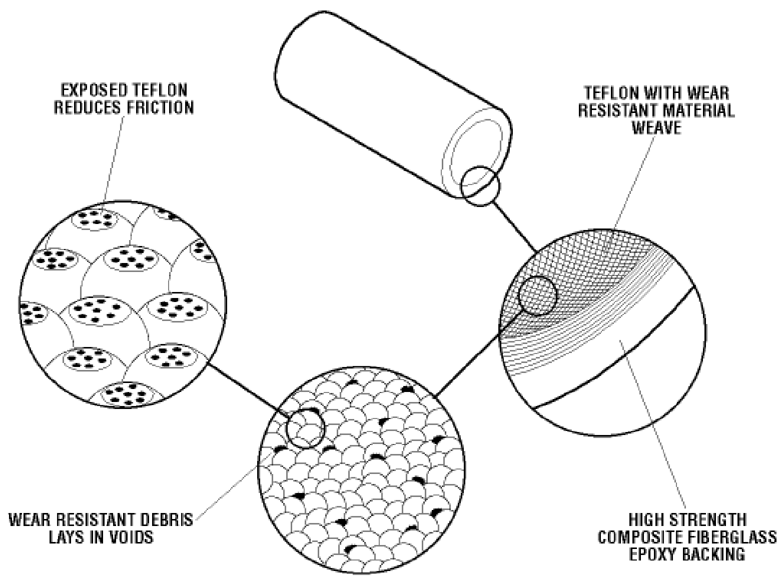
handle external contamination, minimize breakaway friction, and lower start-up torque for the bearing assembly.

Self-lubrication occurs in what is commonly referred to as the film-transfer process. PTFE molecules are easily sheared and compacted into the surface of the mating pin, actually filling in surface voids. As the pin begins to oscillate, temperature builds on the ID of the bearing. This heat begins to actually soften the PTFE molecules. This softening allows the PTFE to begin to smear and fill in the previously mentioned macroscopic voids in the pin's surface. Since PTFE has a melting point in excess of 600ºF, the film transfer process only acts as a mechanism for spreading the PTFE – no degradation of the performance (lubricity) innate with PTFE takes place.



The above schematic represents a typical PolyLube™ self-lubricating composite bearing. The high strength composite fiberglass, epoxy resin backing with the PTFE wear-resistant liner combine to make an ideal product for the industrial equipment industry.

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