


WHITE PAPER

# Role and Maintenance of Gearmotors in Automotive Manufacturing

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## Introduction

In this time of economic downturn, the media is never far from some story about the Automotive Industry. And no wonder, as an engine of economic activity, it is estimated that 10% of jobs in the United States are related to the use of automobiles. A recent report indicates that 877,000 US employees were involved in the automotive and auto parts sectors of the economy in 2008 and represented 5% of the US GDP.

The current economic downturn has had a dramatic impact on the automotive industry with plant closings and bankruptcy filings. This on top of the substantial pressures faced by the “Big Three” whose market share in the United States has gradually eroded over the years as foreign players began shipping then building cars in the United States. Over the last 3 decades, foreign automotive plants have sprouted in the United States. This and the economic downturn put ever more competitive pressure to every player in the automotive industry.

Throughout history, the automotive manufacturers have perhaps led globalization efforts and developed ever more efficient manufacturing techniques to leap ahead of competition. Perhaps the current economic difficulties will raise new innovations from which other industries can continue to learn and to benefit.

One area of such focus may be the use and maintenance of the gearmotors found throughout the automotive manufacturing plant and integrated tightly into the manufacturing process. This paper will review 1) the driving forces and mindset in the automotive manufacturing sector, the 2) types and applications of gearmotors in these plants and 3) approaches to maintaining and managing this equipment for trouble-free operation.

## Lean Manufacturing

It has been cited that the early success of the Japanese automakers into the United States market, first in selling and then manufacturing the cars in the United States has been the innovative manufacturing system that has provided them with the competitive edge. This manufacturing system referred to as Lean Manufacturing or Lean Production, of which examples from Toyota Production System are often cited, provide two end benefits when compared to prevalent methods in mass production— 1) produce more with less work (efficiency) and 2) produce better quality by focusing on process quality at each stage of manufacturing. The success of Lean Manufacturing perhaps can be gauged by the fact that competitors to the Japanese in the automotive industry as well as other industries have adopted many of the methods and principles from Lean Manufacturing.

Although, there are many elements to Lean Manufacturing, perhaps two elements, “Just-in-Time” inventory management and Pull processing of Lean Manufacturing, provide the spotlight on key elements of Lean Manufacturing to understand the mind-set involved in this type of environment. In “Just-in-Time” (JIT) inventory management, inventory required to do the job is kept to a minimum at the point of assembly. Usually there may be only few hours of inventory, and inventory may be replenished by in-house processes or by outside suppliers perhaps several times a day. The Pull processing is a related concept to “Just-in-Time” and involves processes upstream fulfilling needs of downstream operations on an as-required basis. In other words, an assembly station will “pull” required elements from upstream processes supplying to this station. The supplying station is making only what is required for the next station nothing more. In this system, the ultimate “puller” is the customer looking to purchase an automobile.

How can these two elements help the manufacturing process? From a value-added perspective, these two principles help dictate the work absolutely necessary to produce the end product and minimize extra (non-value added) work. By defining the necessary work, each assembly station can be loaded evenly with work, based on actual value-added needs. As a consequence, some key tangible benefits appear as follows:

Large inventory that can hide inefficiencies are eliminated, exposing these inefficiencies for improvement and/or immediate corrective action. Design changes and improvements can be implemented quicker due to less material in the supply pipeline. Excess, non-usable inventory (or waste) from model changes or design changes is reduced.

#### Manufacturing Innovation - Lean Manufacturing

The automotive industry is a highly competitive field that drives innovation in manufacturing processes. For example, Henry Ford refined the mass production assembly line for the Model T in the early part of the twentieth century, leading to the term “Fordism” which is a reference to high manufacturing efficiency and high wages as other manufacturers followed suit by adopting methods Ford had established.

In recent years, a collection of innovations originating in Japan and anointed with the term “Lean Manufacturing” has pervaded the auto manufacturing sector. Lean Manufacturing, where Toyota Production System and its various elements are cited, developed from techniques of analyzing action/work as to whether value was being added for the end customer and reducing/eliminating non-value added work or waste. From Toyota’s website, not only waste (Jpn “muda”), but two other aspects for elimination are inconsistencies (Jpn “mura”), and unreasonable requirements (Jpn “muri”). Principles developed from this process include Just-in-Time, continuous improvement (kaizen), perfect quality at each stage, lean supply chain, and others. Improvements in reducing waste from these can also help the environment. The EPA has case studies where lean manufacturing methods have helped reduce waste in various industries. See <http://www.epa.gov/lean/studies/index.htm>

**Downside of Just-in-Time?**

Just-in-Time (JIT) means making things as you need it. Manufacturing process based on this philosophy inherently leads to smaller inventory of parts for auto plants as well as first tier and possibly second tier suppliers. The approach reduces any latency of parts and creates a dynamic but steady process. With everything dependent equally on everything else any glitch in one part of the process can quickly affect the entire system. Case in point is Toyota's experience with a factory fire in Japan at a 1st tier supplier, Aisin Seiki Co., for brake valves in 1997. News reports indicated that Aisin Seiki Co. at the time supplied 99% of these brake valves used by Toyota. Aisin Seiki Co. kept only a 4-hour supply. The fire completely damaged all equipment necessary to build the brake valves. Consequently, Toyota had to stop production throughout their factories in Japan for several days, as emergency measures to find alternate production sources were conducted. At the end, Toyota lost production of around 72,000 vehicles due to the shortage of a \$5 part.

Putting extra inventory in the process may be one approach to handle glitches as insurance, but this violates the spirit of lean manufacturing, which tries to correct the root cause of any problem in the process. From another perspective, "it [JIT] removed all safety nets and focused every member of the vast production process on anticipating problems before they became serious enough to stop everything."

Storage for excess inventory is eliminated and use of floor space can be optimized. Parts stay in process and do not get lost in storage.

The focus on these two elements plus the emphasis on quality at each stage, gives authority to the assembler to shutdown the production line due to problems, leads to other consequent action for process improvement and reduction of waste—whether material or labor.

How does this compare with the prevalent mass production methods that Lean Manufacturing is displacing? In the old methods, the expectation is that problems will arise; consequently, the system is loaded with extra capacity and extra inventory. In both old and new methods the end goal is the same, to maintain production continuously. However, the mind-set of Lean Manufacturing is to improve the process and to fix the underlying problems

permanently at the root cause instead of adding extra resources to patch-up problems. A comparative analogy might be like spending money on auto insurance (possibly considered waste from a Lean Manufacturing perspective) or working to prevent accidents in the first place (continuous improvement).

Regardless of manufacturing methods, a line shutdown for any reason can be a costly proposition, maybe more so for the Lean Manufacturer where each stage is intricately connected with other stages without built-in buffers. In the Lean Manufacturing environment where automotive manufacturing flow rate or the inverse of flow rate, Takt time, can be down to no less than 50 seconds per vehicle [3], a 1-hour production line shutdown could keep 72 vehicles from being manufactured. If each of these vehicles has a factory invoice value of \$20,000, then the lost production value can be easily calculated at \$1.44 million per hour, a substantial value for a system keen on eliminating any waste. Consequently, in a Lean Production system, Maintenance and/or Manufacturing Engineering Departments have a critical role of preventing lost production time, which can quickly add up to operating losses and waste resulting from idled workers and lost vehicle production.

**Gearmotors in Manufacturing**

The manufacturing of mass-produced automobiles typically relies on conveyors and equipment to bring the parts and assemblies to a location where robots (welding) or workers (assembly) are tasked with a specific function in the elaborate dance of assembling a car or truck. The engine of this manufacturing dance could be the thousands of electric motors that keep the mechanism of the manufacturing process moving. These electric motors are often connected directly to gearboxes as gearmotors and used for driving conveyors, lifts, robot arms, etc. In the era of Lean Manufacturing, each element plays a vital role. Maintaining this equipment so the manufacturing machinery runs smoothly and efficiently is the goal of the Maintenance Department at each automotive plant. However, when things break down, maintenance will need to quickly get production restarted by replacing equipment with spares available from their stores.

When building a brand new automotive plant (sometimes called "greenfields") or upgrading an existing plant with new

equipment, a multitude of equipment builders and suppliers of conveyors, stamping presses, automated transfer vehicles and many other equipment may be involved. The equipment manufacturer may select the industrial components such as gearmotors used in the supplied equipment, but sometimes the end user may specify a particular manufacturer and product specification where possible to keep maintenance and supply of spares consistent and easier to manage. In addition, the Manufacturing Engineering department may have extensive specification documents that may dictate requirements for various components used in the equipment or plant location.

## Introduction

Can lubricants improve gearbox efficiency? This paper will explore how oil selection can affect gearbox efficiency. According to the US Energy Information Administration, the United States generated 1,006 billion kWh of electricity in 2007. (EIA) It is generally accepted that electrical motors account for about seventy percent of industrial electrical power consumption. Assuming that electric motors are all driving gearboxes, then every one percent increase in gearbox efficiency saves the equivalent yearly output of an 800 MW power plant. Small changes in efficiency can have a large aggregate impact. Unlike other efficiency-improving ideas, lubrication changes require no changes to existing equipment.

Oil churning, seal drag, and friction account for most of the losses in gearboxes. To some extent these three sources are all affected by lubrication. Seals ride on a thin oil lubricant film. Churning losses are due to the gearbox components moving through the oil sump.

## Fluid Friction

The Stribeck Curve, shown in Figure 1 (Maru), relates friction between load-bearing surfaces as a function of relative oil film thickness and lubrication regime. Relative oil film thickness is the ratio of film thickness to surface roughness. The thicker the film relative to surface roughness indicates a reduced likelihood of contact by surface asperities. Figures 2 through 4 illustrate the relationship between film thickness and surface roughness.

the output shaft through the 150:1 gear reduction. It can be seen in this example that the output torque is less than the “expected” value due to the internal losses. In using this example, the unit efficiency in can be determined as follows:

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ffi cti  
ci on  
en(μ  
tof)

$$\begin{aligned} \text{Efficiency} &= \frac{\text{Actual Output Torque}}{\text{Theoretical Output Torque}} (100) \\ &= \frac{463,166}{540,000} (100) \end{aligned}$$

Given this, it is calculated that the gearbox in this example is 85.8% efficient.

## Efficiency of Gearing Types

The term **speed reducer** is a general term used to describe a device that increases torque while, at the same time, reduces the rotational speed of the prime mover (which is usually an AC motor). This is achieved through the interaction of gears within the speed reducer. Different *gear types* can be utilized to facilitate this reduction of speed/increase of torque. Each of these gear types has distinct advantages and disadvantages associated with them and, likewise, each of these gear types have different efficiencies associated with them.

Specifically, as it relates to efficiency, two gears in mesh incur losses in efficiency due to the sliding action of one gear tooth against the corresponding gear tooth of the mating gear. This sliding

action reduces the overall efficiency of the gearset since useable power is converted to heat. It is not accurate to say that a specific gear type has a definite efficiency associated with it since factors such as reduction ratio, gear-manufacturing methods and lubricant (among others) all play a roll in the efficiency of a gearset. The following table details three common gear types along with their associated typical efficiencies:

Typical Efficiency:

It is not uncommon for speed reducers to incorporate more than one set of gears (called **stages**) to achieve the desired overall reduction ratio. In such cases, the overall efficiency of the gear train is the product of the individual efficiencies of each gear reduction stage. Say, for example, that a Sumitomo Paramax gearbox incorporates three stages of Helical Gearing. Further say that each stage has an efficiency of 98.5%. The overall gear train efficiency would be:



$$\text{Efficiency}_{1^{\text{st}} \text{ Stage}} \times \text{Efficiency}_{2^{\text{nd}} \text{ Stage}} \times \text{Efficiency}_{3^{\text{rd}} \text{ Stage}} \times 100 = \text{Total Gear Train Efficiency}$$

$$0.985 \times 0.985 \times 0.985 \times 100 \approx 95.6\%$$

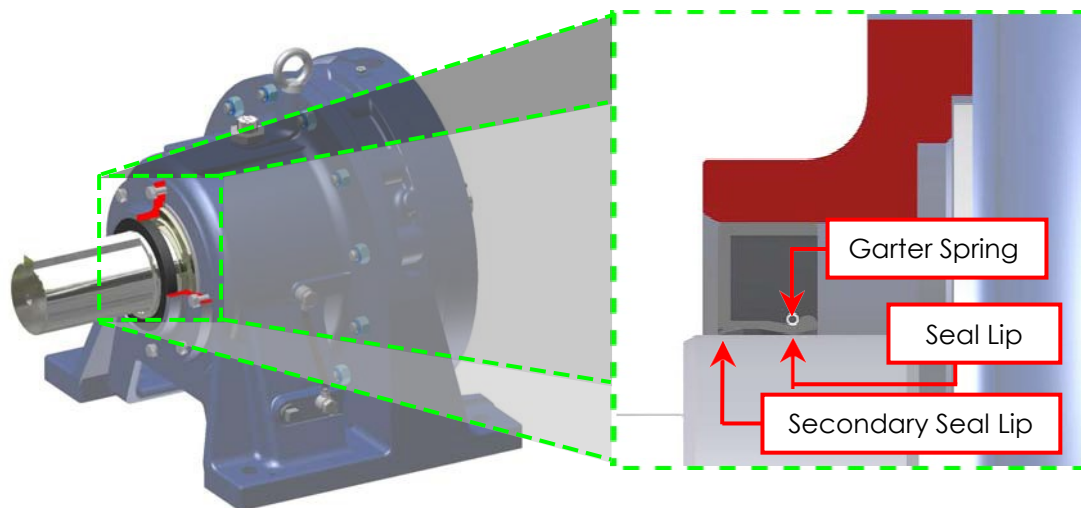
To continue this example, it is possible that a multistage gearbox utilizes different types of gearing for each of its reduction stages. A Right Angle gearbox (one where the output shaft is at a right angle to the input shaft) may utilize a Spiral Bevel gearset as its first reduction stage followed thereafter by a helical gearset as its second reduction stage. Using the typical gearing efficiencies detailed previously, the efficiency of the gear train in this example can be calculated as follows:

$$\text{Efficiency}_{1^{\text{st}} \text{ Stage}} \times \text{Efficiency}_{2^{\text{nd}} \text{ Stage}} = 0.92 \times 0.96 \times 100 = 88.0\%$$

### Oil Seals and Efficiency

Virtually all speed reducers incorporate the use of oil seals within their assemblies. These seals can be found on both the input and output shafts as well as internally within the unit. Their primary function is to retain the lubricant within the gearbox while eliminating the ingress of dirt and water into it. There exist a variety of different types of seals for a variety of different applications (i.e.: axial shaft seals) but the most common type of seals used in industrial gearboxes are Radial Shaft Seals.

The performance of a radial seal is dependant upon an interference fit that provides pressure of the seal lip against the shaft or collar surface. Through operation, the seal lip will gradually wear so, in some cases, a garter spring is incorporated into the oil seal in order to maintain adequate seal lip pressure against the shaft. Additionally, a secondary seal lip may be utilized on the seal to prevent the ingress of contaminants into the system – refer to the following section view of a Sumitomo Cyclo® speed reducer which details an oil seal cut away for clarification.

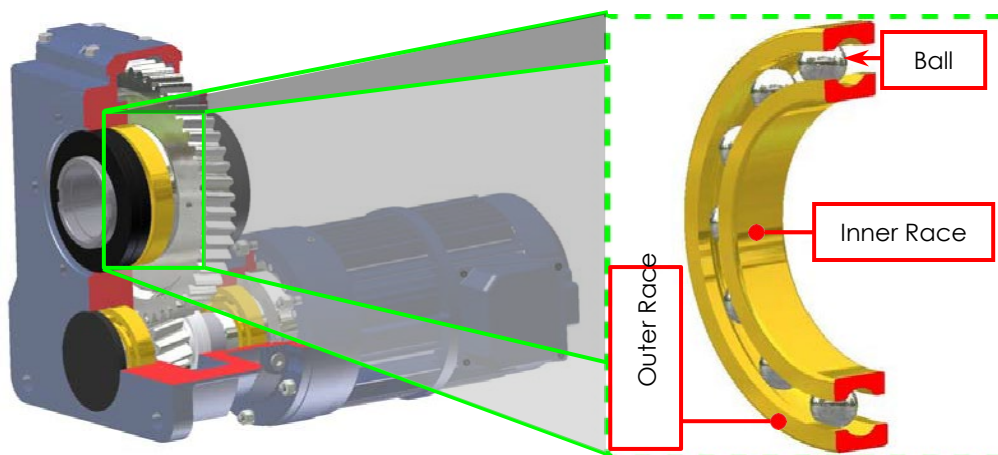


Since these seal lip(s) are riding against a rotating shaft (or collar), friction at this interface is developed, hence, an energy loss (albeit small) is realized. The amount of this energy loss due to friction is dependent upon many factors that include shaft speed, shaft diameter, and the surface finish/roughness against which

the seal lip(s) are in contact. As an example, published data indicates that an oil seal riding on a 100 mm shaft ( $\approx 4$  inches) that is rotating at 500 RPM will generate frictional losses on magnitude of 20 Watts. While it is true that this is a seemingly minuscule value, it is common for some gearbox manufacturers to incorporate more than a single seal on a given shaft as an added feature to minimize, or eliminate, the possibility of lubrication leakage. Having said that, multiple seals within a single speed reducer may develop frictional losses exceeding 100 Watts (once again, depending on seal sizes and rotational speeds).

## Bearings and Efficiency

As with the other components discussed thus far, bearings are another component common to all speed reducers. In its simplest form, a bearing is a device that allows for a smooth, low-friction, motion between two components. In the case of speed reducers, roller bearings are used to secure and support shafting and gearing within the unit. These roller bearings are intended to accept external loading (radial and axial) on the input and output shafts. Additionally, these bearings are also utilized to accommodate the internal forces generated by the gears in mesh. To accept these forces, roller bearings rely on balls (spheres) or rollers retained between an inner and outer race – refer to the following section of a Sumitomo Helical Buddybox which details a Deep Groove Ball Bearing for clarification:



As noted, a bearing is a *low-friction* device, it is not friction-free. As one race rotates about the other race, the balls (or rollers) likewise rotate/slide within the race. The rotating/sliding action of the balls (or rollers) creates friction between these bearing components thereby creating an additional avenue for energy loss.

Like oil seals and gearing, the amount of energy consumed by a bearing is dependent on many different factors. Mathematical formulas exist which can be used to calculate the **Friction Torque** of a given bearing. This value of friction torque is a function of the coefficient of friction between the rolling elements of the bearing, the bore diameter of the bearing itself and the load acting upon it and it is expressed as:

$$M = \frac{\mu F \cdot d}{2}$$

where: M = Friction Torque (in•lbs, N•m)  
 $\mu$  = Coefficient of Friction  
 F = Bearing Load (lbs, N)  
 d = Shaft Diameter (in, m)

For example, using this equation, the Friction Torque for a ball bearing of size 6211 with a 4,250 pound radial load acting upon it is approximately 5.8 inch•pounds. Whereas, for a similarly sized Tapered Roller bearing (32211) operating under the same loading conditions, the Friction Torque is calculated to be 9.8 inch•pounds. These “required” torque values may seem relatively small in comparison to the overall requirements of the system but these values are for one bearing only. Gearboxes incorporate the use of four or more bearings, each one of which has a Friction Torque associated to it.

It should be noted that some bearings contain integrated seals or shields, the purpose of which is to maintain lubricant within the bearing and/or to prevent the ingress of foreign matter into the race. Tapered Roller bearings may incorporate a Nilos Ring for the same purpose. Inclusion of such sealing devices further contributes to efficiency losses since these sealing devices are in direct contact with the rotating race(s) of the bearing.

### Effects of Lubricant on Efficiency

For internal gearing, the use of the appropriate lubricant is crucial to obtaining maximum service life and reliability of the gearbox. The function of the lubricant is two-fold: first it provides a thin film between the internal rotating components as well as the gear teeth in mesh thereby preventing direct metal-to-metal contact and, second, it provides a median in which heat - developed through normal unit operation - is dissipated.

As noted previously, the type of lubrication utilized in a gearbox plays a role in the overall efficiency of the unit. As the internal gearing moves through the lubricant, the lubricant is continuously displaced by the action of the gears striking it. This is typically known as **churning loss** since power that could otherwise be used for the application is absorbed (or required) by this action of the gearing striking, pumping or moving the lubricant. For example, a gearbox lubricated with grease would be less efficient than if it were to be lubricated with oil. Intuitively, this makes sense since grease is typically thicker than oil and it requires a greater amount of power to move the gearing through it. Imagine, for a moment, what it would be like to swim in syrup as opposed to swimming in water. Clearly, the thicker media (syrup) would require more personal power to “swim” thru.

Another avenue for loss in efficiency specifically related to gearing and lubricant is what is known as **windage loss**. As the gearing rotates through the lubricant, and then out of the sump, a certain amount of lubricant adheres to the surface of the gear itself. Since the gear is rotating, centrifugal forces cast the

lubricant adhering to the gearing into the enclosed atmosphere of the speed reducer casing. This action may serve to create a lubrication “mist” through which the gearing must pass. In essence, this mist is another barrier for the gear to pass through thereby requiring (or diverting) power which otherwise could have been utilized as usable output torque.

To quantify the effects of lubricants on speed reducer efficiency, testing has been conducted by Sumitomo Drive Technologies on a planetary gearbox of a given size and reduction ratio (4:1). This efficiency testing was conducted twice: once with the gearbox lubricated with a grease of NLGI Grade #2 (a moderately soft grease with the approximate consistency of peanut butter) and again with a grease of NLGI Grade #00 (a semi fluid grease with an approximate consistency of applesauce). Other than the lubricant, no other components within the test units were changed. Post-test results revealed that the speed reducer lubricated with the NLGI #00 grease had an efficiency of 92.1% whereas the same unit lubricated with the NLGI #2 grease was 90.9% efficient.

This is not to say, however, that oil lubrication for a gearbox is distinctly preferred over grease. Grease has the advantage in that it may provide for universal mounting of the gearbox (i.e.: output shaft vertical up or vertical down), it’s replenishment/replacement interval may be longer than a comparably sized oil lubricated unit, and grease is less likely to leak through the shaft seals of the unit.

## Conclusion

As discussed, many components incorporated into the gearbox construction and its subsequent operation influence the overall efficiency of the speed reducer itself. While the greatest loss in efficiency is typically associated with the interaction of the gears in mesh, other factors and components also serve to influence the overall efficiency of the system.

As a speed reducer manufacturer, Sumitomo Drive Technologies actively designs to minimize efficiency losses within the product through a variety of means. Utilization of high quality gearing with superior surface finish on the gear teeth combined with the incorporation of low-friction seals and bearings all serve to maximize the power efficiency of the enclosed gearing product lines.

From the point of view of the user (or potential user), perhaps one of the most important factors in selecting a unit to assure that its efficiency is being optimized for the application is unit size. In short, make sure that the gearbox is properly sized for the application. Prior to ordering the speed reducer from the manufacturer, it is imperative that the application power requirements and demands are clearly understood. Utilization of the appropriate service factor for the speed reducer must be taken into consideration and applied. If the gearbox is unnecessarily oversized – specifically, if the power capacity of the gearbox greatly exceeds the power of the applied motor combined with the application service factor, much of the motor power will be used to overcome the constant losses within the gearbox thereby leaving little additional usable power/torque for the application itself. In short, this would be a situation where the speed reducer is yielding a very low efficiency.

Conversely however, a gearbox undersized for an application runs the risk of low life expectancy due to overload conditions despite a seemingly high efficiency.

Additionally, follow the manufacturer's recommendation for the correct type of lubricant to be used within the speed reducer along with its recommended change interval. Be it oil or grease, over time all lubricants lose their effective properties and, due to this, the overall gearbox efficiency stands to decrease over time as well.

Finally, consider the method by which the gearbox is attached to the driven shaft. Is it possible to directly couple the output shaft of the reducer directly to the driven shaft? This may be preferred, from an efficiency point-of-view, since the use of belts and/or chains generates friction or possibly slippage at their interface which, in- turn, leads to additional efficiency losses.

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