Garlock SEALING TECHNOLOGIES®
an EnPro Industries company

Garlock Klozure® HIGH-PERFORMANCE DYNAMIC SEALS
an EnPro Industries company

Improved Life for Dynamic Seals in Wind Turbine Applications

By

Elizabeth Chitren - Product Engineer, Klozure Dynamic Seals, Palmyra, NY

Jim Drago, P.E. - Manager, Engineering, Garlock Sealing Technologies, Palmyra, NY

Presented at WindPower 2005 Conference and Exhibition
May 15-18, 2005
Denver, Colorado

Updated March 14, 2008

Abstract

The wind power industry desires components that will last 20 years. Contact type rubber lip seals cannot offer this life. Non-contacting isolator seals made of PTFE or metal can offer this possibility since there are no contacting parts. This paper presents the background, working parameters, typical applications and pros and cons of rubber lip and isolator seals. Laboratory data shows the decrease of power consumption when isolators are used. Field data shows the increase in life offered by isolators over rubber lip seals.

Introduction

Seals are components thought little of, until leaks occur causing costly down time and repairs. Dynamic seals for rotating shafts, found in the gearbox, generator, pitch and yaw systems of a wind turbine, play important roles by retaining lubricant for bearings and excluding contaminants that will destroy bearings. Seals also protect the remote environments that are the homes of many wind farms. Good seals and sealing practices protect these environments from unwanted lubricant leakage and spills.

Low cost components, such as seals, can have major effects on the duration between the repair of major components such as turbine gearboxes, generators, auxiliary motors, and gears. Rubber lip seals have traditionally been used to protect these costly components. It has been assumed that rubber lip seals will perform the service cycles required.

The wind industry's goal has been to attain 20 years of service before major maintenance is required. Traditional rubber lip seals rub on a rotating shaft to achieve the required seal. The normal life progression of a lip seal is to wear, leak, then be replaced. Non-contacting isolators do not depend on rubbing contact to contain lubricant and keep out destructive contaminants. With no wearing parts they can theoretically last forever.

This paper sets forth:

- The background on rubber lip seals and isolators
- A comparison of rubber lip seal and isolator attributes and performance
- Power consumption of rubber lip seals versus isolators
- Field experiences and life expectations
- New developments in the field of large diameter isolators

Background Information on Rubber Lip Seals and Isolator Seals

The purpose of a sealing system in a wind turbine is to prevent the damage of bearing elements. To prevent bearing damage, the sealing system must eliminate cross-contamination between the system lubricant and the external environment. Simply, the purpose of the sealing system is to prevent both lubrication egress and contamination ingress. Traditionally, this system has been a lip seal running on a shaft. However, new technologies have made labyrinth isolator seals a possibility in these hostile environments.

Lip Seal Background

To effectively protect the bearings in a wind turbine, a leak-tight sealing system must be established. Creating an effective seal requires attention to three components: the lip seal, the system lubricant, and the rotating shaft's surface. The lip seal incorporates interacting design features to attain an effective seal. Figure 1 and Table 1 identify these design features.

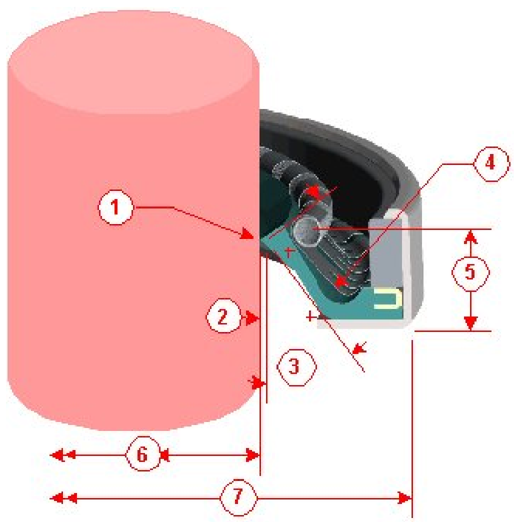


Figure 1 – Lip Seal Design Features

Table 1	
1	The seal surface is the interface between the lip seal and the shaft-sealing surface. This is where the main seal is formed.
2	The lip angle on the lubricant side is engineered to develop hydrodynamic pressure to facilitate sealing.
3	The lip angle on the environmental side is used to control the amount of lubrication allowed under the lip.
4	The seal hinge location controls the lip deflection and aids in the loading of the lip seal on the shaft.
5	The spring position controls the amount and location of the lip load relative to the shaft-sealing surface.
6	The internal diametric interference between the lip and the shaft interacts with the spring to create the seal force on the sealing surface.
7	The external diametric interference between the outside diameter and the housing prevents leakage around the outside of the seal.
Collectively these features act to create an effective seal	

Shaft Seal Surface and Its Affect on Performance

The performance of the seal can be compromised by the condition of the shaft-sealing surface. Seal manufacturers as well as organizations such as the Rubber Manufacturers Association (RMA) publish specifications for this surface. Imperfections on any surface will always exist. Accepted specifications mitigate imperfections by specifying surface roughness (expressed as average height in micro-inches, Ra), surface lay (texture) and machining methods. An example of the imperfections on a machined surface is shown in Figure 2.

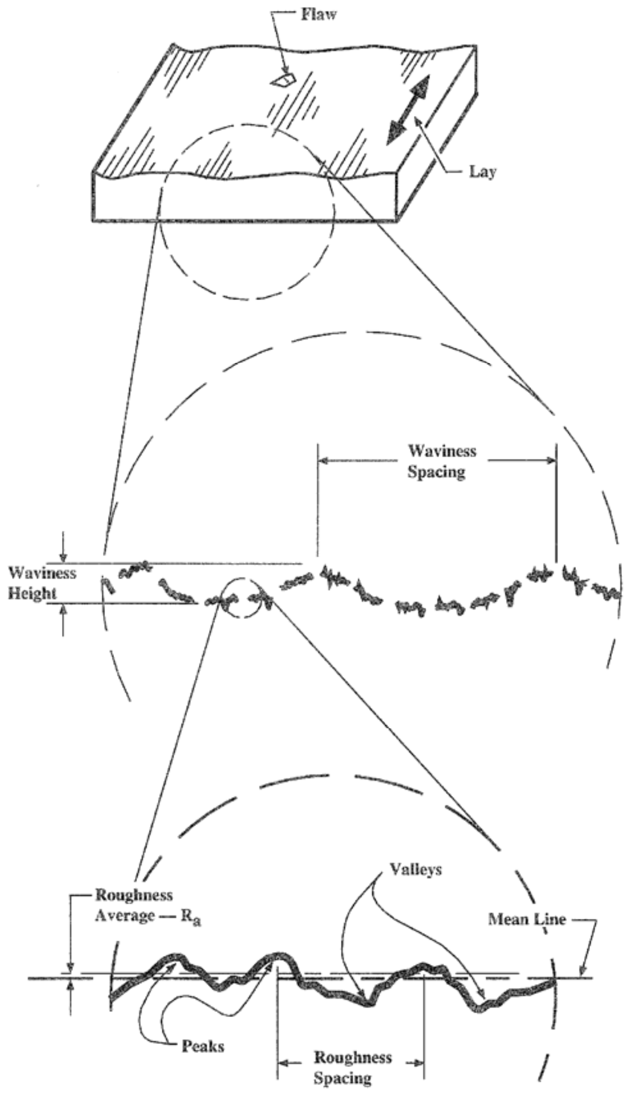
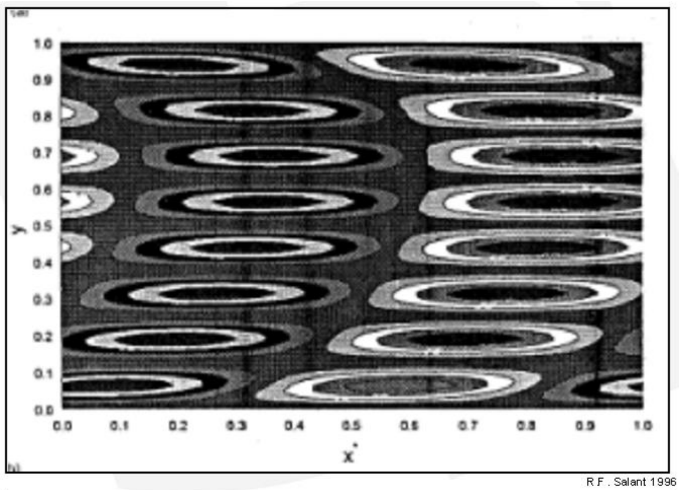


Figure 2 – Shaft Surface Finish

It is important to note that the smoothest surface may not be the optimal surface for lip seals. The small surface imperfections actually aid in sealing. These imperfections, when rotating, will create a small hydrodynamic pump. Another important aspect to consider when machining the sealing surface is the lay of the finish. When creating the sealing surface, the surface lay must be perpendicular to the axis of rotation. The resulting peaks and valleys will act as leakage barriers.

As the shaft continues to rotate, the seal will begin to mirror the surface on which it is running. If the surface lay is parallel to the axis of rotation, it will create a direct leak path. Machining practices must also be considered when fabricating a sealing surface. As the rotating surface is machined, a screw-like trench will be created. This feature will pump the lubricant out of the seal. For this reason, a plunge ground surface finish is usually recommended by seal manufacturers.

When all these factors are within specification for a given lip seal, a small viscous pump is created while the shaft is rotating. This hydrodynamic pumping action is created when the small asperities on the seal lip and the surface of the shaft start to displace lubrication, in a steady and regular direction. Figure 3 is a picture of the asperities and lubrication during the hydrodynamic pumping.



Micro Asperities are Small Viscous Pumps

Figure 3 – Asperities on Seal Lip

In order to have a long-lasting sealing system, these factors must be kept in balance. If any of these factors are less than optimal, the life of the sealing system will be compromised.

<u>Isolator Seal Background</u>

Unlike lip seals, isolator seals are simple in theory. By definition, an isolator is a non-contacting seal that prevents oil from exiting the bearing housing and prevents contamination from entering the bearing housing. There are many types of isolators, from labyrinth type seals to complex hybrid designs. These hybrid seals are a combination of new technologies with standard labyrinth technologies. New technologies include hydrodynamic pumping features, cellular foams, and unique unitizing elements. These hybrid seals are typically used in applications where standard technologies will not perform for an extended period of time.

Standard Labyrinth Isolator

A standard labyrinth type seal uses a torturous path and close clearances to prevent leakage. This torturous path is usually an intricate pathway with abrupt directional changes. An example of this is shown in Figure 4.

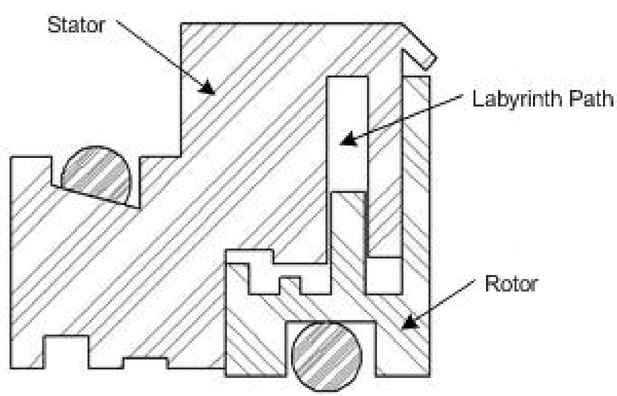


Figure 4 – Typical Isolator Labyrinth Seal

Hybrid Isolators

One type of hybrid isolator seal technology uses unique impeller features on the rotor to create a hydrodynamic pumping action. This type of seal can be seen in Figure 5. As the rotor spins, a negative pressure is generated on the outside portion of the lubrication and environment chambers. The negative pressure on the lubrication side causes any lubricant that enters the seal to flow from the shaft to the expulsion ports. The negative pressure on the environment side allows any contamination that enters the seal to flow from the shaft to the expulsion ports. Cross-contamination is mitigated by the labyrinth path between the two systems.

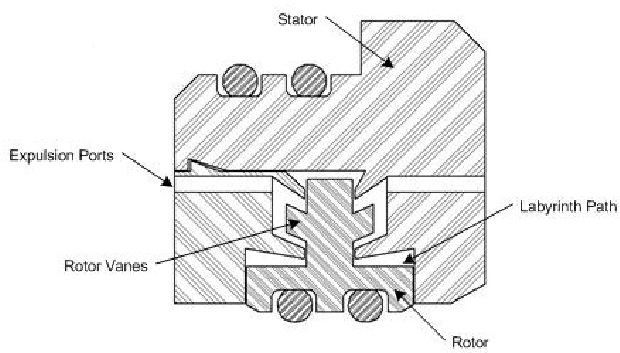


Figure 5 – Hydrodynamic Isolator

In the seal shown in Figure 6, cellular foam is used with standard labyrinth technology to prevent contamination of the bearing. The cellular foam filters out any airborne particulate. It also prevents lubrication leakage by absorbing the fluid into the material. While the foam does have limited capacity, once full, effective sealing will still occur, as the foam will act as a barrier. The type of cellular foam used is application specific, based on the viscosity of the fluid and on the particulate size of environmental contamination. In addition to the cellular foam, designs typically include a labyrinth path to prevent cross-contamination.

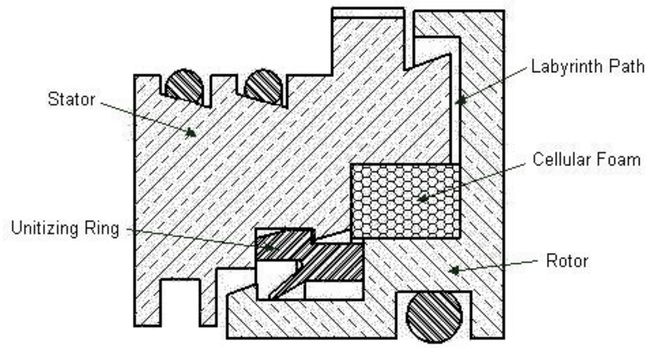


Figure 6 – Cellular Foam Hybrid Seal

Figure 7 is a hybrid labyrinth seal, in which a unitizing element keeps the assembly together. A common misconception is that the unitizing element creates a seal. The isolator actually uses the labyrinth path to prevent contamination ingress, and lubrication egress. The unitizing element simply prevents the rotor and stator from coming into contact with one another during operation, which prevents the generation of damaging particles. If contact were made between the two main components, the particles could contaminate the lubrication system and eventually lead to premature bearing failure.

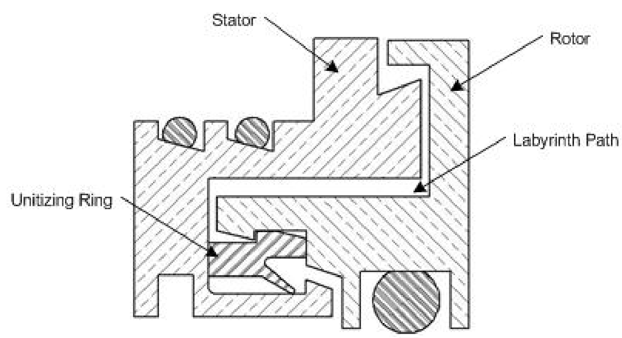


Figure 7 – Hybrid Labyrinth Seal

New Technologies

As stated previously, there is now a wide variety of bearing isolators to choose from. These seals are now offered in a wide variety of material combinations, and in many different styles.

A common challenge of isolator seal applications is the axial space required by the seal. Bearing cavities would historically have to be modified to allow the use of an isolator seal. The housings into which the seals were installed would need to be increased in both the axial and radial direction. The seals themselves would usually be quite large, as the sealing capability would be proportional to the length of the intricate pathway. The easiest way to increase the sealing effectiveness was to increase the width of the seal. However, the new technologies discussed above used in conjunction with a short labyrinth path greatly reduce the space required for the isolator seal.

Most isolators offered today can fit into a space as small as 0.625 inch (16 mm) in width. Some designs, especially those using the unique unitizing ring can fit in an area only 0.375 inch (9.5 mm) wide. Usually this amount of space is already reserved in a bearing system for a lip seal.

Improvements in machining capabilities over the years have increased size of the isolators. Large size bearing isolators are now available, where the only option has historically been lip seals. The use of stainless steel materials for the construction of these bearing isolators is an advantage in hostile environments. Specialty o-ring materials can also be interchanged with the standard fluoroelastomer type to enhance chemical resistance. These technologies combined with low-wear / no-wear components and low motor torque/power requirements result in an isolator solution that can operate maintenance free for many years.

Isolator Seals vs. Lip Seals - Attributes and Performance Characteristics

Seal Selection - Required Input

For any sealing system, all application data should be well understood. The application data typically required by seal manufacturers is as follows:

1. Size – Size of the shaft, the housing bore, and width available to the seal.
2. Temperature – Continuous and maximum operating temperature.
3. Application Parameters – Equipment type, misalignment of the sealing surface to housing bore and dynamic shaft run-out.
4. Media – Type of lubricant and level of lubricant relative to the seal.
5. Pressure – Continuous and maximum pressure that the seal will be exposed to.
6. Surface Speed –Continuous and maximum surface speed of the rotating shaft surface. This is calculated from the shaft diameter and RPM of the shaft.

All customer applications are not the same; hence, performance and anticipated life of seals can not be specifically derived. The best way to determine life of the seal is to perform functional testing of that seal in the specific application. As discussed above, many factors can contribute to the success, or failure, of seals in service. This is where the advantages of labyrinth/isolator technologies can be seen. Table 2 summarizes the differences between lip seals and isolators.

Table 2

Ability to accommodate…	Rubber Lip Seal	Isolator	
Temperature	▪ -40 °F to 400 °F depending on rubber type	▪ PTFE: -40 °F to 400 °F ▪ Metal: -30 °F to 400 °F	
Equipment of use	▪ Rotating - constant and intermittent	▪ Rotating - constant and intermittent	
Different fluids	▪ Different rubber types are chosen depending on the fluid types. ▪ Specific information needed to make a selection.	▪ Good for a broad range of media. ▪ Need only to check for compatibility of o-ring material with fluid.	
Pressure	▪ 3 psig to 7 psig depending on shaft speed	▪ None. Oil sump needs to be vented.	
Shaft Size	▪ 0.250" to 90.000" depending on seal type	▪ 0.875" to 11.000" ▪ New developments for larger seals in progress	
Shaft condition	▪ Rockwell C 30-40 or harder ▪ 10-20 micro-inch Ra, with no machine lead, plunge grinding required. ▪ No surface defects	▪ 32 micro-inch Ra maximum	
Dry running, no lubrication at the seal area	▪ Not recommended. Seal will wear, damage shaft and experience a short life.	▪ No consequence	
Sump lubrication level	▪ Minimum - splash lubrication on the seal. ▪ Maximum - Oil level above the shaft seal	▪ At or below the bottom of the seal.	
Dynamic shaft run-out + Shaft to bore misalignment (Typical Values)	▪ In general 0.015" maximum with each not exceeding 0.010" total ▪ Some types good to 0.125" total ▪ Speed dependent	▪ 0.040" total ▪ Axial up to 0.050" total	
Surface speed (at the shaft surface)	▪ 1,000 to 7,000 FPM depending on rubber type and seal design. ▪ High-speed applications require more frequent replacement due to wear.	▪ PTFE up to 4,500 FPM ▪ Metal up to 12,000 FPM	
Installation	▪ Press fit ▪ Care of the lip is required	▪ Hand press in place, o-ring interference fit	
Price - Compared to basic rubber lip seal design made with various rubber types	Basic Lip Seal	Standard Isolator - PTFE	Hybrid Isolator-Bronze
	NBR	2X	4X
	HNBR	Same	2X
	Silicone	0.7X	1.5X
	FKM	0.5X	Same

Installation

The advantages of isolator seals can also be seen in the installation and maintenance of the sealing system. Lip seals are usually retained in the housing bore by a press fit of either rubber-to-metal or metal-to-metal. The force of installation can be great, as some press fits can be up to 0.010 inch (0.25mm). Besides the force required, a press fit can result in metal shavings entering the bore housing. This can lead to lubrication contamination and premature bearing failures. If the shaft surface over which the seal will slide has nicks, burrs, or scratches, damage to the lip can occur. Usually a mounting tool is used to prevent damage and lip roll over. If the lip becomes damaged, leakage will occur.

By comparison, an isolator is easy to install. Commonly, the seals have o-rings on the inner diameter to seal on the shaft, and o-rings on the outer diameter to seal against the bore. Care must be taken to clean the sealing surfaces on both the shaft and the bore to prevent damage to the o-rings, but this requirement is not as rigid as the surface finish requirements for lip seals. Since o-rings are static not dynamic seal elements they are not subject to wear. Once the equipment is inspected and cleaned, the isolator can usually be installed by hand pressure alone.

Testing

A lip seal was compared to two types of isolators, a standard labyrinth path, and a hybrid that uses a special unitizing ring.

Purpose
Determine power consumption of a rubber lip seal and an isolator seal.

Set-Up
Each seal was installed into a controlled test machine. A bore plate of 3.938 in (100 mm) was utilized to simulate the equipment bore. A shaft sleeve of 2.562 in (65.1 mm) was used as the sealing surface. Each seal had an appropriate level of lubrication in the bearing sump chamber. The lip seal oil sump was filled until half of the shaft was submerged; for the isolators the sump was filled to the bottom of the seal. Figures 8a and 8b show the test setup.

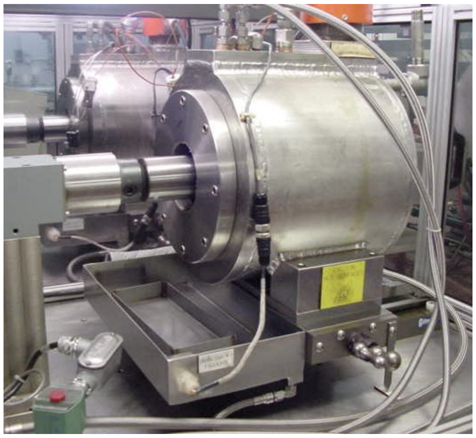


Figure 8a – Test Stand Head

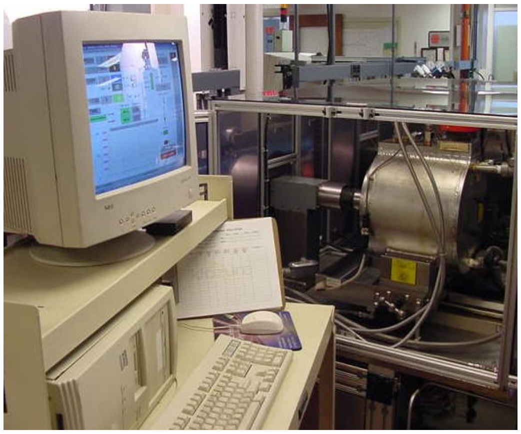


Figure 8b – Test Machine

Procedure

Each seal was run for 3 hours, and then stopped for 30 minutes. The cycle then repeated for 315 hours. The stop / start cycle simulates the extremes of extended life, with a series of shutdowns.

Results

The lip seal required an average of 285 watts of power. During startup, the power requirements spiked as high as 670 watts. By contrast, a standard labyrinth isolator seal required an average of 120 watts of power, with spikes up to 149 watts during startup. The hybrid isolator seal required an average 140 watts of power, with spikes up to 274 watts during startup. See Chart 1.

All data can be seen in Appendix A.

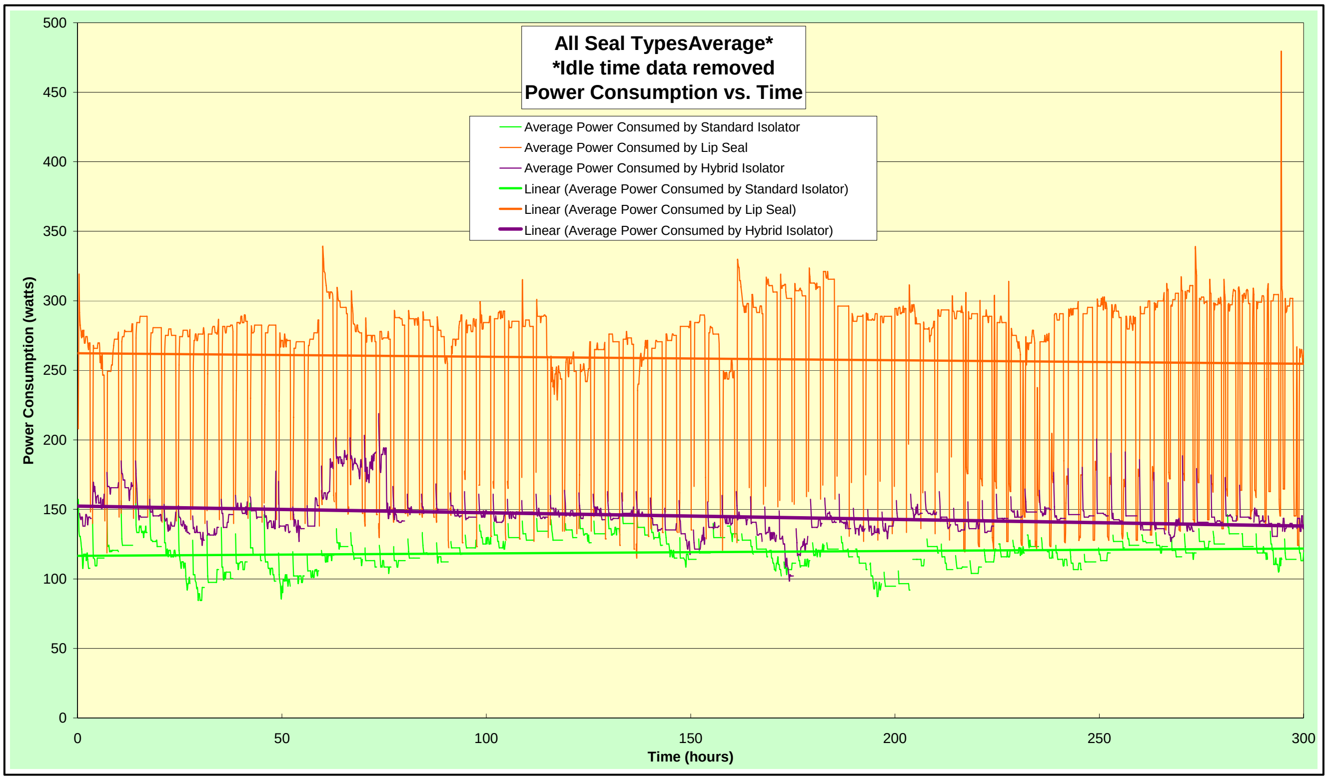


Chart 1 - Power Consumption*

**Data showing no power consumption during the 30 minute off period has been removed*

Field Experiences and Life Expectancy

The following are from field records of isolator seals and rubber lip seals in rotating equipment.

Case 1

Background Information		Rubber Lip Contact Seal	Non-Contacting Isolator
Industry	Steel Production	Life: 2 to 4 weeks. Frequent seal changes required to maintain protection of bearing lubricant.	Life: 5 years and continuing. First installed April 2000 and still in service. Effectively protecting bearing lubricant, increasing time between required maintenance.
Equipment	Hot Strip Mill Motors		
Temperature	Ambient		
Media	Oil		
Pressure	None, oil sump vented		
Shaft Size	3.250", 3.500" and 4.250"		
Surface Speed at the Shaft	723 FPM to 1001 FPM* *Based on 850 to 900 RPM		
Run Time	24 hours/day 6 days/week 52 week/year		
Seal Life Improved 65X Using Isolators			

Case 2

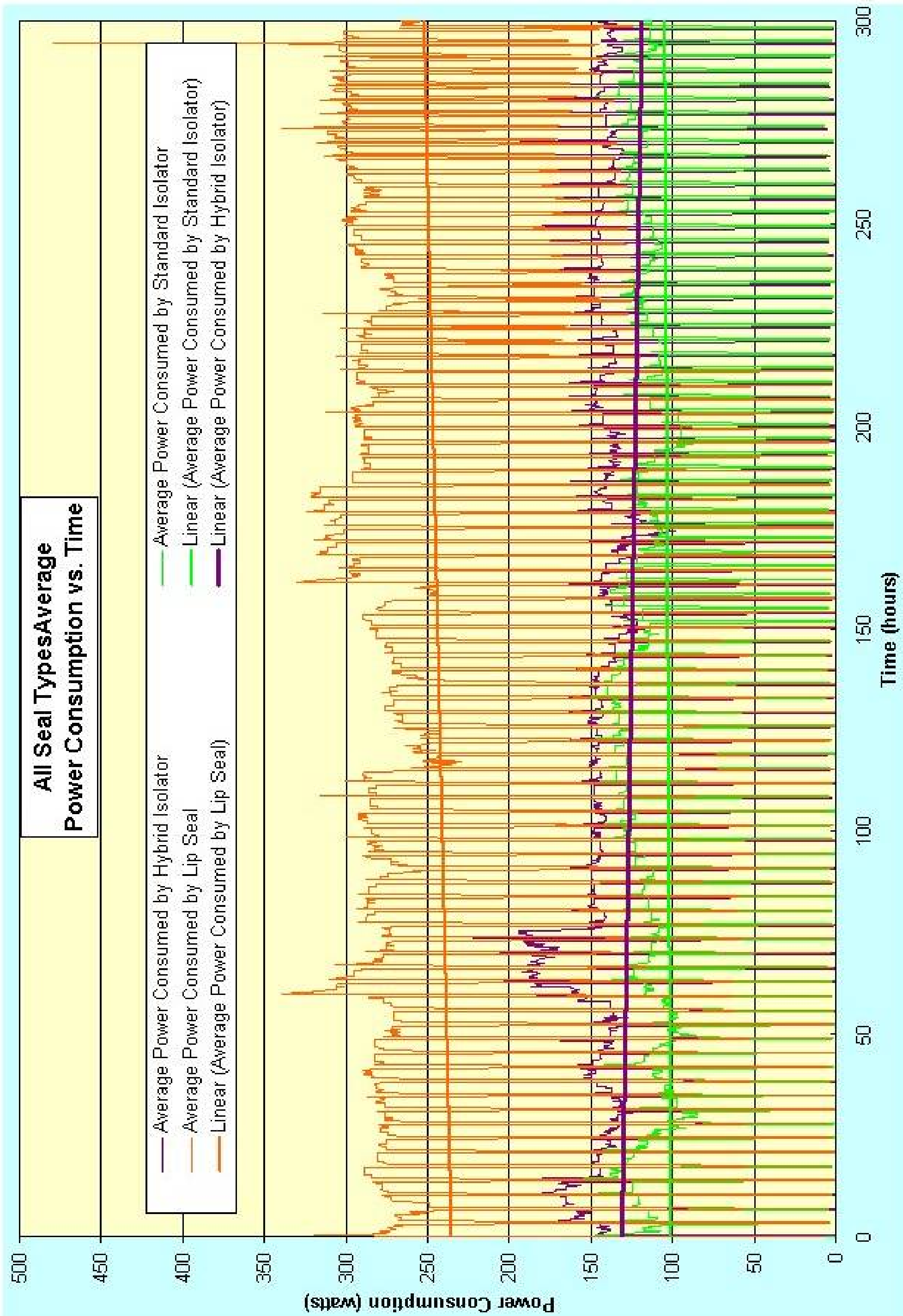
Background Information		Rubber Lip Contact Seal	Non-Contacting Isolator
Industry	Pulp & Paper Production	Life: Weeks to months. Lip seals damaged shafts and did not effectively seal out water during wash down. Seals would wear and allow contaminants and water to compromise the lubricant and damage the bearings.	Life: 4 to 5 years 1990's - began using hydrodynamic isolators 1998 to present - standard isolator design Seals were replaced when they were damaged during pump rebuild. **In all cases isolators have been replaced for reasons not related to seal performance or wear.**
Equipment	Centrifugal pumps		
Temperature	Ambient		
Media	Bearing lubricant, water from wash-down, and air-borne contaminates.		
Pressure	None, oil sump vented		
Shaft Size	Ranging diameters from 0.875" to 4.250"		
Surface Speed at the Shaft	825 to 1947 FPM* *Based on 0.875" shaft at 3600 RPM and 4.25" shaft at 1750 RPM		
Run Time	24 hours/day 7 days/week 52 weeks/year		
Seal Life Improved 5X to 65X Using Isolators			

Case 3

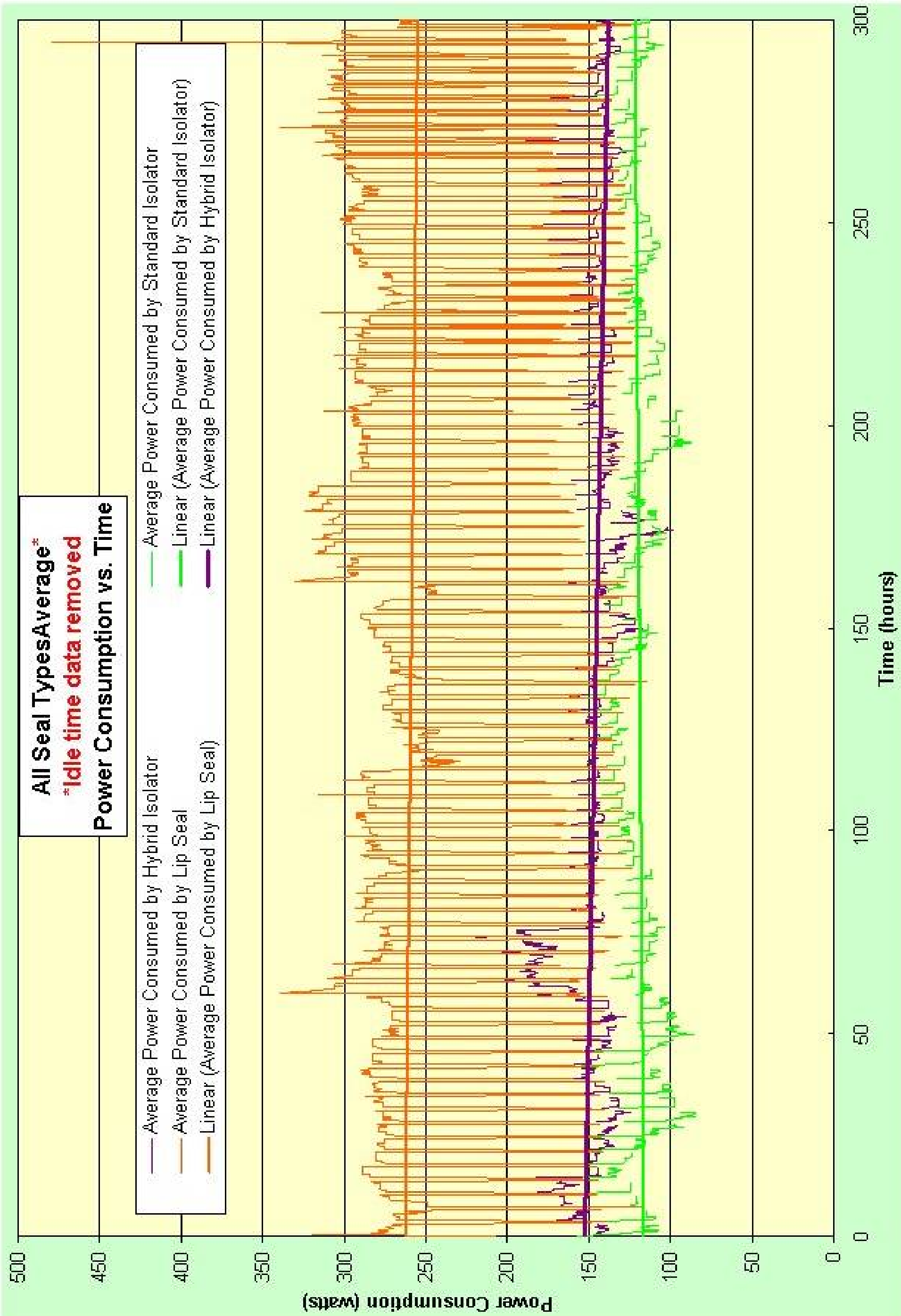
Background Information		Rubber Lip Contact Seal	Non-Contacting Isolator
Industry	Pulp & Paper Production	Life: 3 months. Lip seals leaked due to exposure to water spray and paper stock.	Life: 3 years Installed 1999. Service ended when machinery was removed in 2002. Seals operated with no issue during the 3 year span.
Equipment	Mixer		
Temperature	150 °F		
Media	Water and paper stock		
Pressure	None, oil sump vented		
Shaft Size	6" diameter		
Surface Speed at the Shaft	785 FPM* *Based on 6" shaft at 500 RPM		
Run Time	24 hours/day 7 days/week 52 weeks/year		
Seal Life Improved 12X Using Isolators			

Appendix A

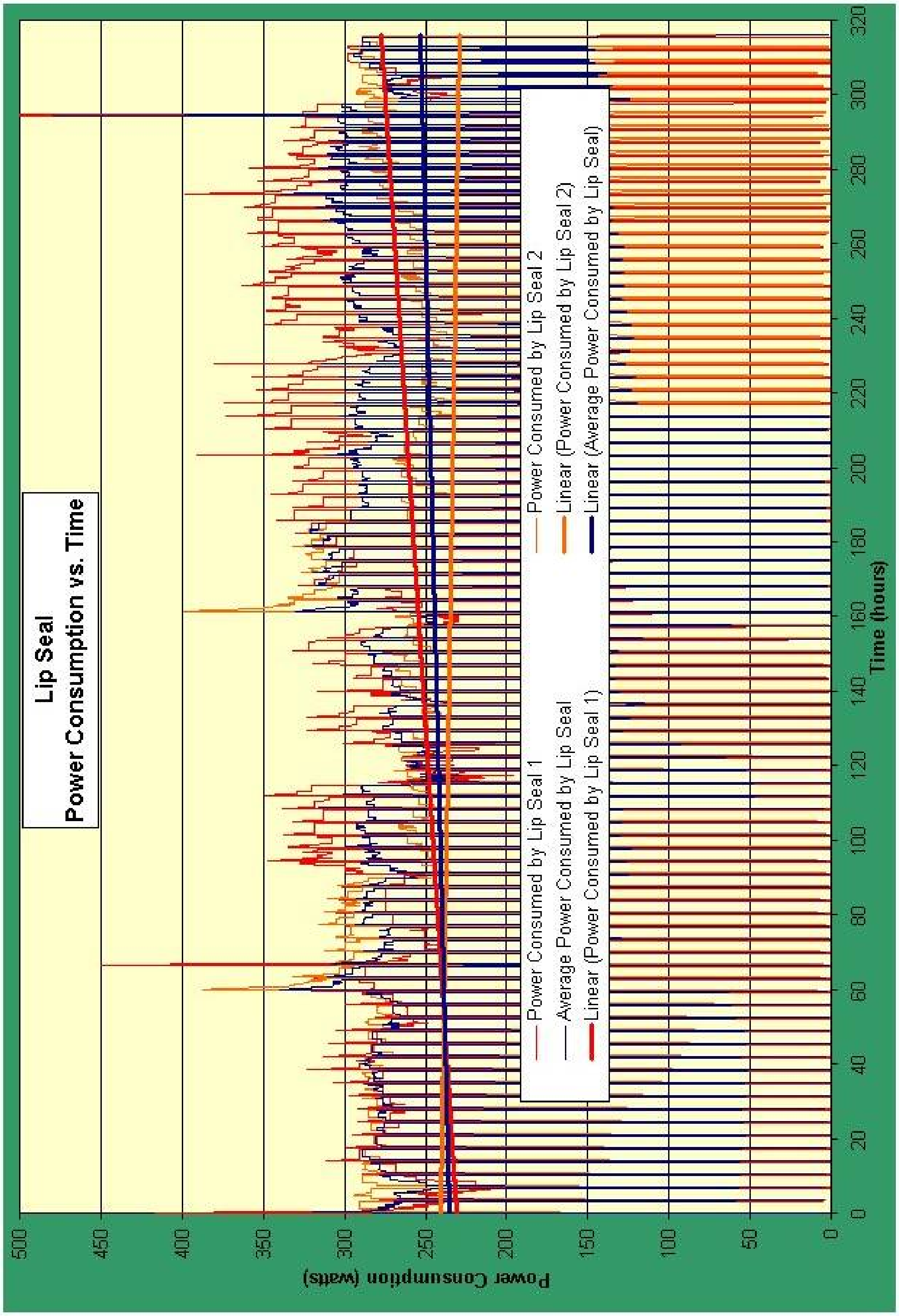
Seal Test Data



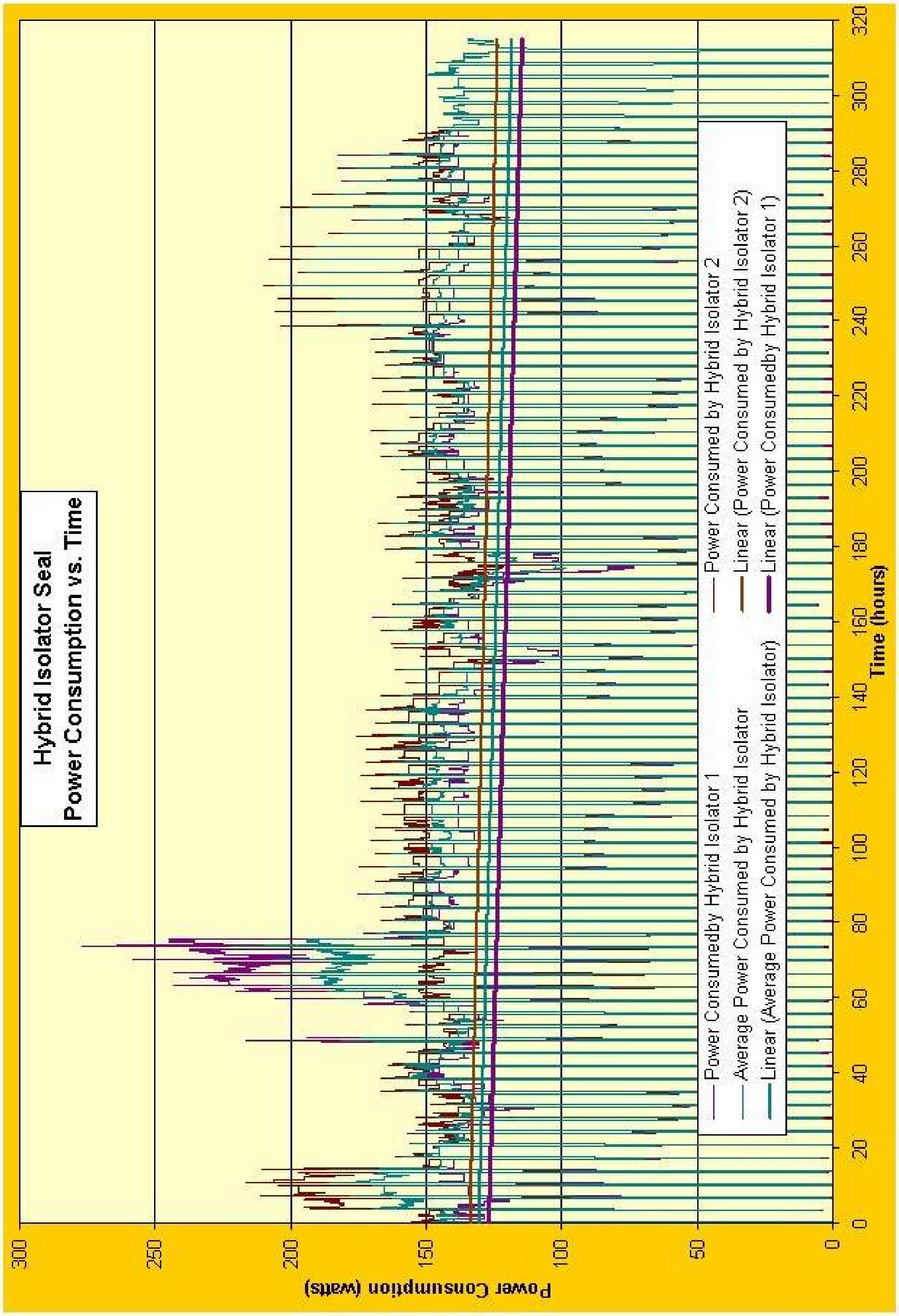
	Avg. Hybrid	Avg. Std. Isolator	Avg. Lip Seal
Mean	125	103	245
Median	142	118	279
Std. Deviation	51	42	79
Number of Data Points	1893	2141	1893



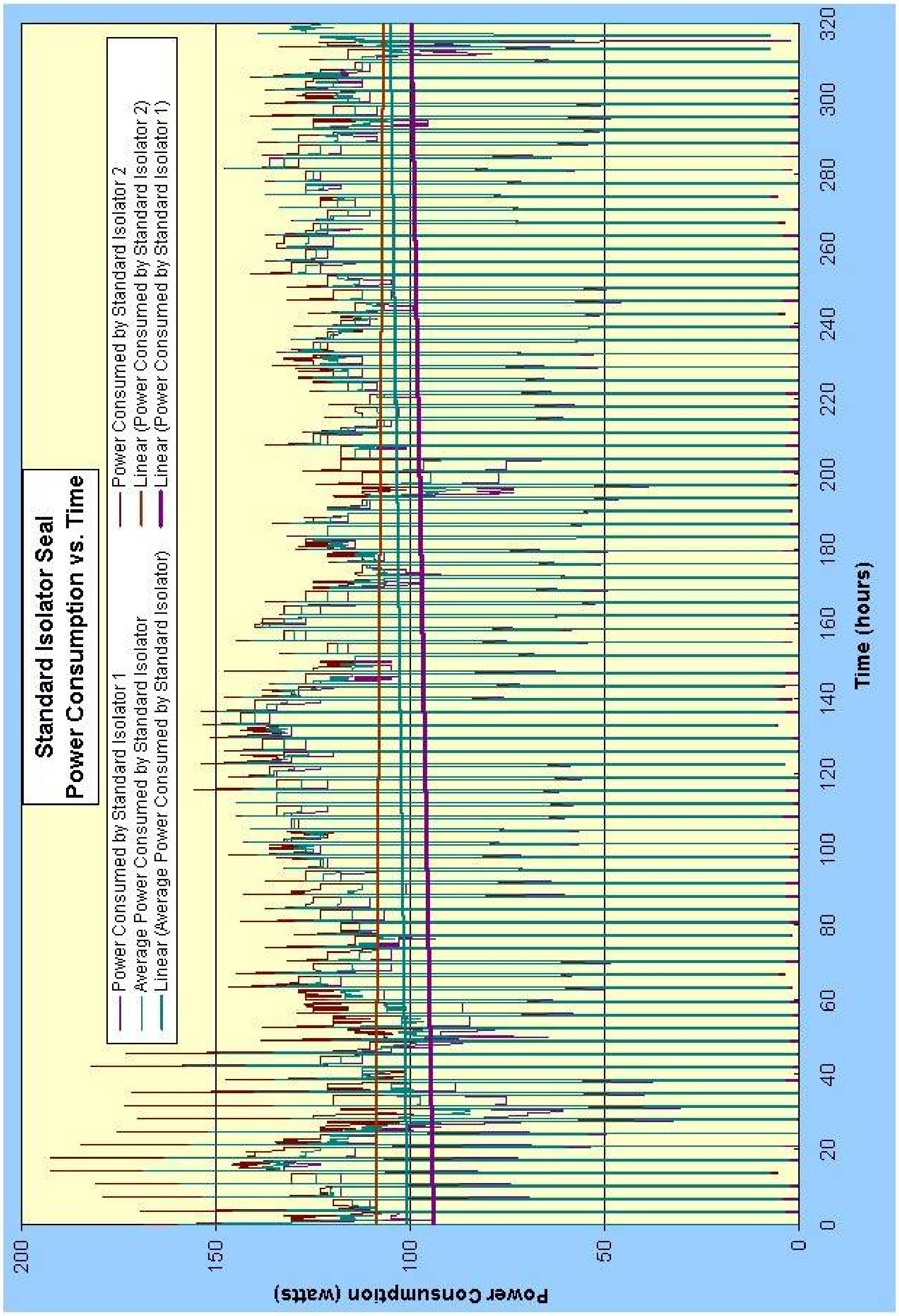
Idle time data removed	Avg. Hybrid Isolator	Avg. Std. Isolator	Avg. Lip Seal
Mean	145	120	258
Median	144	121	281
Std. Deviation	13	11	56
Number of Data Points	1624	1837	1793



	Lip Seal 1	Lip Seal 2	Average 1 and 2
Mean	254	234	244
Median	289	261	278
Std. Deviation	109	97	79
Number of Data Points	1897	1897	1897



	Hybrid Isolator 1	Hybrid Isolator 2	Average 1 and 2
Mean	121	129	125
Median	136	147	142
Std. Deviation	52	53	51
Number of Data Points	1892	1748	1892



	Std. Isolator 1	Std. Isolator 2	Avg. of 1 and 2
Mean	97	108	103
Median	110	123	118
Std. Deviation	41	43	42
Number of Data Points	1893	2141	2141