TECH TALK

MOTION & CONTROL™ NSK

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ROLLER BEARING LIFE IN HIGH TEMPERATURES

A common question maintenance personnel ask bearing companies when their equipment temperature is high or rises is, "What is the maximum temperature that your rolling bearings can handle?" The better question to ask is, "What is the maximum temperature that the bearing system can handle?" When thinking about temperatures it is important to think in terms of a complete bearing system.

A complete rolling bearing system includes a rolling bearing, a lubricant, and in most cases a lubricating system. The lubrication of ball and roller bearings is accomplished with oils, greases, or dry solid films [graphite, molybdenum disulfide (MoS2), polytetrafluoroethylene (PTFE), oil impregnated polymer oil, etc]. Rolling bearings carry the load of rotating equipment, but can not function for very long without a lubricant. If the lubricant fails the bearing will fail shortly thereafter. Lubricants are often the root cause of failure when a bearing system's temperature rises.

The Reaction of AISI 52100 Bearing Steel to Heat

The steel used in rolling bearings, both through hardened and case carburized steels, is processed to a minimum hardness of Rockwell C 60. According to the American Bearing Manufacturers Association (ABMA) the maximum operating temperature of through hardened steels, AISI 52100 is 160°C (320°F), 440-C is 180°C (356°F), and M50 is 320°C (600°F). In general for all steels, as the temperature exceeds 200°C (392°F) the hardness begins to decrease. Thus, the rolling bearing life decreases as temperatures rise beyond 200°C (392°F). See charts A & B for AISI 52100 properties at various temperatures.

CHART A | AISI 52100 Hardness vs. Temperature & Time

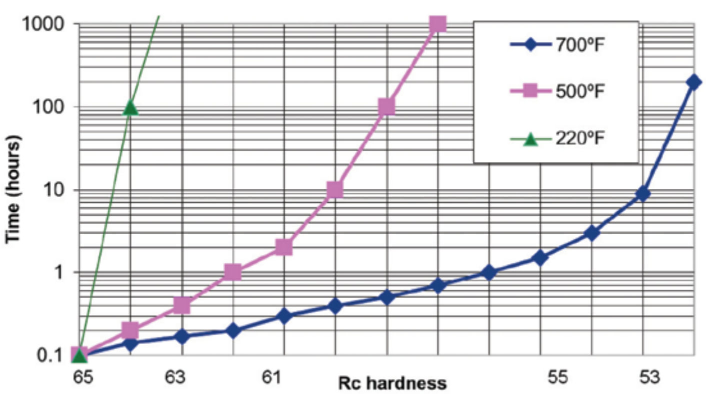


CHART B | AISI 52100 - Temp, Color & Hardness

Steel Color	Temperature °C	Temperature °F	Rockwell C Hardness
shiny	< 120	< 248	> 60
shiny	150	302	> 60
shiny/yellow	160	320	> 60
yellow	200	392	59
blue	300	560	58
dark blue	400	750	53
black	540	1000	like butter
red	> 815	> 1550	flows

Dimensional Stability vs. Temperature

As any metal heats up a material phase change occurs and the dimensions become unstable. In other words the bearing parts expand. See charts C & D below for the maximum dimensionally stable temperature for various steels used in rolling bearings.

Since the most common method to measure the temperature of a bearing is by reading the temperature on the outside of the housing, it is important to remember that the temperature at the bearing housing surface is 10°F to 15°F lower than bearing temperature.

Lubrication in a Bearing System

Rolling bearings can't function reliably without a lubricant. A rolling bearing system includes a rolling bearing, a good lubricant, and a lubricating system. The lubrication of ball and roller bearings is accomplished with oils, greases, or dry solid films. When a machine's temperature rises, the main concern for maintenance personnel should not be the maximum allowable temperature the rolling bearing can accomodate. The main concern should be the maximum temperature the entire bearing system can handle. The main focus should be on the maximum temperature that the lubricant and/or the lubricating system can endure because their failure will cause the rolling bearing to fail. A lubricant's failure due to a high temperature is difficult to detect. Therefore, it is important to monitor the temperature of a lubricant.

Without a good supply of oil a rolling bearing will fail before its potential life (L10 life) due to friction and wear between the rolling element and the raceways. Oil between the rolling element (ball, spherical roller, cylindrical roller, etc.) and the raceway reduces friction and wear, and thus reduces heat generation.

Oil can be supplied to a rolling bearing either directly or through the use of grease. Oils used to lubricate a rolling bearing include base oil and sometimes additives. Greases are made up of base oil (65-95%), thickener (3-30%), and additives (0-15%). Sometimes up to 5% of a solid lubricant is added to grease. It is the base oil in grease that does the work in a bearing system, not the thickener, nor the additives. A thickener holds the oil and the additives improve the properties of the thickener. The oil does the work for the rolling bearing, the thickener keeps the oil in place, and the additive can enhance the performance of the oil and/or thickener.

Whether oil or grease is used to lubricate a rolling bearing, both can only endure so much heat before they lose their effectiveness in the bearing system. Chart E shows maximum temperatures of various oils.

CHART C

Designation	Dimensionally Stable Temperature		With Heat Treatment (HT)
	˚C	˚F	
JIS SUJ	120	248	
AISI 52100	120	248	
HTF & STF	150	302	
X26	150	302	HT
EA - HPS	200	392	
S11	200	392	HT
X28	200	392	HT
TL	200	392	HT
X29	250	482	HT

NSK steel heat stabilization info:

1) NSK standard steel (JIS SUJ) is 120 degree C (250°F) heat stabilized.
2) Standard carburized steel is 120 degrees C (250°F) heat stabilized. Which part(s) are carburized are specify using the "g" code.
3) S11 steel is 200 degrees C (392°F) heat stabilized inner and outer ring. Rollers are not heat stabilized.
4) X28 steel is 200 degrees C (392°F) heat stabilized inner and outer ring. Rollers are not heat stabilized.
5) X29 is 250 degrees C (482°F) but not available in all sizes.
6) TL steel is 200 degrees C (392°F) heat stabilized inner ring unless a "g" code is specified to indicate other parts need heat stabilization. Note with TL in the p/n the inner would still be TL even if "g" code is used.
7) HTF is 150 degrees C (302°F) heat stabilized. Which part(s) is carburized are specify using the "g" code.

CHART D

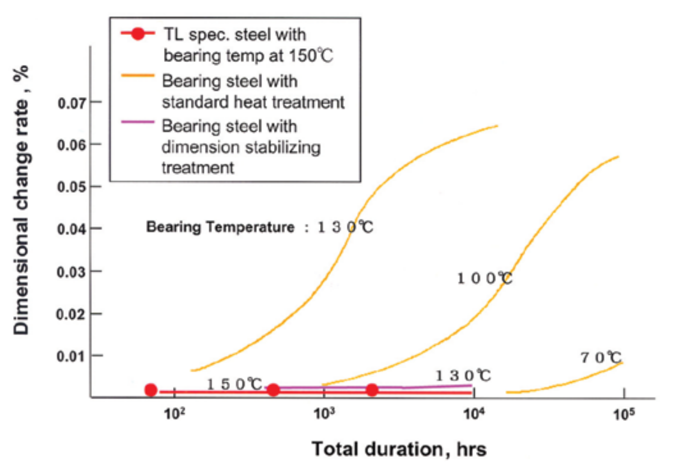


CHART E

Oil Type	Mineral Oil (PAO)		Polyalphaolefin (water insoluable)		Polyglycol		Ester		Silicone oil		Alkoxy fluoro oil	
	˚C	˚F	˚C	˚F	˚C	˚F	˚C	˚F	˚C	˚F	˚C	˚F
Max. temp. for oil sump lubrication	100	212	150	302	100 to 150	212 to 302	150	302	150 to 200	302 to 392	150 to 220	302 to 428
Max. temp. for circulating oil lubrication	150	302	200	392	150 to 200	302 to 392	200	392	250	482	240	464
Viscosity at 40ºC (cSt, mm^2/s)	2 to 4500		15 to 1500		20 to 2000		7 to 4000		4 to 100,000		20 to 650	
Suitability for high temp. (=150ºC, 302ºF)	moderate		good		moderate to good*		good*		very good		very good	

* Depending on the oil type.

The type and amount of thickening agent used (organic, inorganic, metal soap) and the base oil type (mineral or synthetic oil) and its viscosity determine the upper and lower operating temperature limits of lubricating greases. Charts F, G & H show the maximum temperatures of greases by thickener, base oil, and soap, and a comparison of thickeners.

CHART G | Thickener Comparison

Thickner	Application Temperature		With Heat Treatment (HT)	
	˚C	˚F	˚C	˚F
Lithium	120 to 140	250 to 285	175 to 205	350 to 400
Calcium	up to 80	175	90 to 110	195 to 230
Aluminum	70 to 80	160 to 175	110 to 120	230 to 250
Sodium	120	250	160 to 180	320 to 355
Aluminum complex	up to 180	up to 355	250	480
Bentonite	180	355	250	480
Polyureas	180	355	220 to 270	430 to 520

CHART F | Grease Comparison

Thickener Type	Base Oil	Soap	Max. Temperature	
			˚C	˚F
Normal	mineral oil	aluminum calcium lithium sodium	70 50 130 100	158 122 266 212
	PAO	lithium	150	302
	ester	lithium	130	266
Complex	mineral oil	aluminum barium calcium lithium sodium	160 140 140 150 130	320 284 284 302 266
	PAO	aluminum barium calcium lithium	160 160 160 180	320 320 320 356
	ester	barium calcium lithium	130 130 180	266 266 356
	silicone oil	lithium	180	356
Bentonites	mineral oil		150	302
	PAO		180	356
Polyurea	mineral oil		160	320
	PAO		200	392
	silicone oil		200	392
	fluorosilicone oil		200	392
PTFE or FEP	alkoxyfluoro oil		250	482
	fluorosilicone oil		200	392

The chart below gives temperature ranges of solid lubricants.

CHART H

Solid Lubricant	In Air				In Vacuum			
	˚C		˚F		˚C		˚F	
	min.	max	min.	max	min.	max	min.	max
Graphite	50	550	122	1022	n/a	n/a	n/a	n/a
Molybdenum disulfide	-100	320	-148	608	-100	650	-148	1202
Tungsten disulfide	-100	410	-148	770	-100	750	-148	1382
Gold	-100	200	-148	392	-100	200	-148	392
Silver	-100	100	-148	212	-100	600	-148	1112
Lead	-100	210	-148	410	-100	400	-148	752
Fluroresins	-250	200	-418	392	-250	250	-418	482

Oil Viscosity and Temperature

Another thing to consider with high temperatures in a bearing system is the oil's viscosity. Viscosity is the measure of the relative resistance of a fluid to flow at a given temperature. The higher the viscosity, the greater its resistance to flow. Viscosity is measured either in centistokes (cSt) or SUS (Saybolt Universal Seconas). With greases the viscosity number is the flow rate of the base oil, not the thickener.

A viscosity of a lubricant should be sufficient to separate parts under operating conditions, but not so high that extra drag is created.
As the temperature rises the viscosity of oils lowers. The higher the temperature, the higher the viscosity needed in a bearing system.
Viscosity Index is the measurement of the rate of change of viscosity with temperature. The higher the viscosity index, the more gradual the rate of change. See chart I.

Generally in high temperature applications, if the oil or grease used has a lower viscosity, the bearing system will fail prematurely. As can be expected, generally in a high temperature application a higher viscosity oil or grease should be used. See chart J for oil viscosity vs. temperature for various oils.

Temperature Impact on the Life of Oil

The most important property of oil, from a quality standpoint, is its chemical or oxidation stability. Heat is primarily an accelerator of oil oxidation. The rate of any chemical reaction, including the oxidation of hydrocarbons will double for every 18°F (10°C) increase in temperature. It is estimated that the life of an oil is decreased 50% for every 18°F (10°C) temperature rise above 140°F (60°C). At temperatures greater than 248°F (120°C) oxidation greatly affects grease life. The formula for this would be:

Lt = _ * L
where:
Lt = Oil life due to temperature greater than 60°C (140°F)
_ = Temperature life factor
L = Expected life of oil at or below 60°C (140°F)

CHART I | The Rate of Change of an Oil's Viscosity with Temperature

Viscosity Index is the measurement of the rate of chage of viscosity with temperature

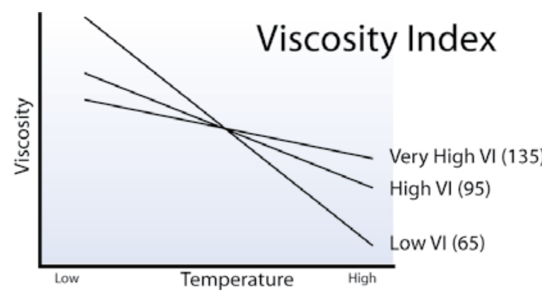


CHART J

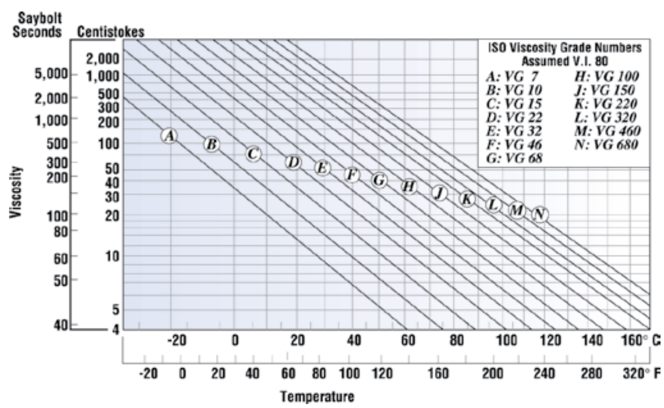


CHART K

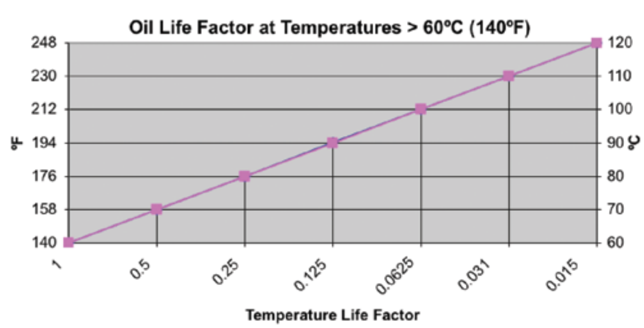
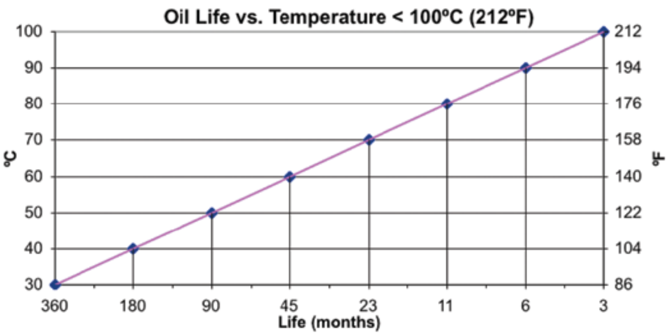


CHART L



Lubrication System Considerations

No matter what is used to lubricate a rolling bearing in a high temperature application and/or environment, the lubrication system can either extend the life of a rolling bearing or decrease it. A bearing system must be designed to assist the bearing in meeting its potential life. Attention to the lubrication system should never be overlooked or ignored.

Several oil systems can be used to remove heat from a bearing system. Grease and dry solid film do not assist in removing heat from a rolling bearing. The primary consideration with greases is the relubrication method and interval.

In the higher speed ranges of operation, too much grease will cause overheating. The amount of grease which is appropriate for a particular high speed application can only be determined by experience. In general, about half to a third of the open area in a bearing should be filled with grease on start up. If excess grease in the bearing causes overheating, it will be necessary to remove some grease from the bearing. A slight show of purged grease at the bearing seals is normal and also helps keep contaminants out of the bearing. More grease can be tolerated and is generally desirable in low speed applications.

When establishing grease re-lubrication schedules, a small amount of grease at frequent intervals is preferable to large quantities at infrequent intervals. Tables M, N, O & P can be used to determine lubrication intervals.

CHART M | Grease Lubrication Intervals (Weeks) for Ball Bearings

Bearing Bore (in)	Operating Speed (rpm)				
	250	500	1000	2000	3000
1	*	*	130	70	40
2	*	160	70	35	20
3	*	150	65	23	9
4	*	100	40	13	4

CHART N | Grease Lubrication Intervals (Weeks) for Ball Bearings Motors

Motor Duty	Motor Horsepower		
	0.5 to 7.5	10 to 40	50 to 150
24 hr/day, 7 days/wk, Clean, Max. amb. Temp. = 100ºF	72	48	36
24 hr/day, 7 days/wk, Poor conditions: hot, dry, or humid	36	16	16
16 hr/day, 5 days/wk, Clean, Max. amb. Temp. = 100ºF	144	96	72
16 hr/day, 5 days/wk, Poor conditions: hot, dry, or humid	72	52	36

CHART O | Grease Lubrication Intervals (Weeks) for Spherical Roller Bearings

Hours Run Per Day	Bearing Speed (rpm)						
	250	500	750	1000	1500	2000	3000
8	12	12	10	7	5	4	3
16	12	7	5	4	2	2	1
24	10	5	3	2	1	1	1

CHART P | Grease Lubrication Intervals (Weeks) Spherical Roller Bearing Temp. and Conditions

Operating Conditions	Bearing Temperatures		Grease Interval
	ºC	ºF	
Clean	0 to 49 49 to 65 65 to 93	32 to 120 120 to 150 150 to 200	24 to 40 4 to 12 1 to 4
Dirty	0 to 65 65 to 93	32 to 150 150 to 200	1 to 4 < 1
Moisture	0 to 93	32 to 200	< 1

There are several lubrication systems when it comes to oil; sump (bath), circulation through sump, circulation through sump with cooling, jet (injection) into bearing, combination of bypass circulation with cooling and jet, and mist (spot). An oil bath system can be used to lubricate a bearing, but in general, it does not assist in removing the heat from a bearing system. The oil level for a sump bearing should come up to the middle of the rolling element when it is at it's lowest position.

The oil flow rate for a circulating oil system can only be determined by experience. For a steel mill's continuous casting machine the following formula can be used:

Fccm = 0.00003 (OD) (W) where:
Fccm = Oil Flow Rate for a Continuous
Casting Machine (cc/hr/bearing)
OD = Bearing Outside Diameter (mm)
W = Bearing Width (mm)
Note: If the result is less then one, then one should be used.

For a paper machine's dryer section charts Q & R can be used. (Note: Oil flow rates are per bearing on drive side of machine. Except where condensate and blow through steam is removed through operating (tending) side journal, flow rate for front bearing is 60-75% of these values.)

Conclusion

A complete rolling bearing system includes a rolling bearing, a lubricant, and in most cases a lubricating system. The lubrication of ball and roller bearings is accomplished with oils, greases, or dry solid films. Rolling bearings carry the load of rotating equipment, but can not function for very long without a lubricant. If the lubricant fails the bearing will fail shortly thereafter. Lubricants are often the root cause of failure when a bearing system's temperature rises. Therefore if your equipment temperature is high or rises consider what is happening to the entire bearing system, not just the bearing.

CHART Q | Paper Machine Dryer Bearing Lubrication

OIL FLOW RATE (PINTS/MINUTE)

Bearing Bore (mm)	Steam Pressure			
	50-100 psi (345-690 kPa)	101-125 psi (600-862 kPa)	126-150 psi (862-1034 kPa)	Over 150 psi (Over 1034 kPa)
< 190	3	4	6	8
191-260	3-4	4-6	6-8	8-10
261-349	4-5	6-7	8-9	10-11
350-500	16	24	26	28
> 500	24-32	40	48	56

Oil flow rates are per bearing on drive side of machine. Except where condensate and blow-through steam is removed through operating (tending) side journal, flow rate for front bearing is 60-75% of these values.

CHART R

SATURATED STEAM PRESSURE		CORRESPONDING STEAM TEMPERATURE	
psi	kgs/sq. meter	ºF	ºC
50	35 150	281	138
60	42 200	293	145
75	52 750	308	153
100	70 300	327	164
125	87 900	344	173
150	150 500	358	181

The information in this article is not presented as a help in choosing a bearing and/or a lubricant for a machine. Rather, this article is designed to help maintenance personal think of maximum temperatures that a bearing system can endure under use, rather than think of temperatures in relation to only a bearing, only the lubricant, and only the lubricant system.

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