

ELEVATED TEMPERATURE PERFORMANCE OF GREASES IN ROLLING ELEMENT BEARINGS

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Grease lubrication is widely applied to rolling element bearings. Increasingly, rolling element bearings are required to operate at higher speeds, loads, and temperatures and for extended re-lubrication intervals. This imposes severe performance related demands on the greases and it is necessary to accurately predict the lubricating life or the re-lubrication interval to prevent lubrication or component failure. There is a requirement for a reliable test method that can assess the lubricating life of the grease at such conditions as also the upper temperature service limit for the grease. This paper describes a study done using the FAG FE9 test rig on some greases to assess these aspects.

1.0 INTRODUCTION

There is a growing trend in increased performance demands for greases used in rolling element bearings. The demands are placed for requirements to operate at higher speeds, loads, and temperatures and for extended relubrication intervals. This imposes severe demands on the grease used in such bearings. Besides it becomes necessary to accurately predict the lubricating life or the relubrication interval to prevent lubrication or bearing failure. In this context, several researchers have looked at the factors influencing the service life of greases, as well as the tendency of greases to lubricate satisfactorily at high temperatures.

Various papers have been published into the basic mechanisms of grease lubrication and failure in rolling element bearings and the relationship to the bulk grease properties. In rolling element bearing applications, grease is subject to high operating temperatures and severe shear stresses. During the extended running of the bearing, the grease undergoes both mechanical and chemical degradation that results in the failure of the lubrication action and, ultimately, the bearing. High operating temperatures are seen to be the most significant factor leading to failures. Since the life of grease is thought to be shortened substantially under high temperature conditions (Booser, **(1)**). The usual figure quoted is a 50% reduction in grease life for every 10°C increase (Bartz **(2)**). The Grease lubricating life at high temperatures is usually dependent upon the oxidation stability of the base oil (Araki, et al. **(3)**); however, other factors including the thickener type, the presence of additives, and the bearing operating conditions also have an effect. Lubrication failure in bearing tests is indicated by a rapid increase in torque or the temperature which is the crux of all the bearing tests used for the evaluation of High temperature life of greases in rolling element bearings. It is usually assumed that this is due to the lubricating film dropping below a certain critical thickness, and thus the friction increases. Depending upon the severity of this condition, this is usually accompanied by surface

damage and debris formation. With this, we can conclude that the mechanism of film generation has failed and this might be due to a reduction in the amount of lubricant available (Ito and Suzuki **(4)**) or a change in the lubricant properties.

Carr'e**(5)** give the most comprehensive analysis of grease degradation changes in bearing tests. Other studies (Bailey and Pratt **(6)**;Komatsuzaki, et al. **(7)**; Hosoya and Hayano **(8)**) lead to the following conclusions regarding the chemical and Physical Deterioration experienced by the grease.

1. Grease undergoes both chemical and physical deterioration during use.
2. Chemical changes include:
 - _ Loss of antioxidant due to the oxidation reactions rather than evaporation
 - _ Increase in acidity (after depletion of the antioxidant)
 - _ Formation of oxidized hydrocarbon species leading to the formation of acidic and/or high viscosity products
 - _ Loss of carboxyl bands of soap thickener
3. Physical deterioration includes:
 - _ Increase in bleeding rate and oil leakage
 - _ Destruction of the thickener structure, either due to working or the chemical breakdown
 - _ Loss of the base oil due to evaporation or loss of volatile oxidation products.

There is limited published research into the effects of grease additives on lubrication life. It is to be expected that the antioxidant additives will have the greatest effect. One of the most comprehensive studies was by McClintock **(9)**, who carried out lubrication life tests for a range of greases (both model and commercial) and additive packages. Typical increases in grease life of 30-80% were observed for additized greases. Oxidation inhibitors generally increased the lubrication life and this was found for both peroxide decomposers and radical inhibitors, although the response does depend on the thickener type (Cann and Lubrecht **(10)**). EP/AW additives also increased life, probably because they reduce the severity of contact conditions and thus the operating temperature.

Snyder **(12)** indicates the impact during the recent years which have seen a substantial increase in sealed-for-life bearing applications. These are applications in which bearings are expected to function satisfactorily for the life of the equipment in which they are mounted. In such cases the grease life is expected to be more than the bearing life at the operating temperature. This needs to be evaluated for the selection of the right grease.

Across the world, various bearing manufacturers like SKF and FAG (now Schaeffler) have devised their own bearing testers to be able to assess the service life of bearing greases when used in rolling element bearings. Some of these methods have become international standards like the DIN 51821 and DIN 51825 standards using the FAG FE9 test rig **(11,13,14,15)**. This test rig uses five bearings in one test for greases and use the data generated to calculate the Weibull L10 and L50 life of the grease in the bearings. The FE9 tester incorporates the sealed for life methodology in using bearing which has shields in one of the configuration. SKF has developed a SKF ROF Test rig for

assessment of the Bearing life which uses a deep groove ball bearing run at high temperature and high speed conditions and uses a similar Weibull distribution for assessment of the L10 and L50 life of the grease in the bearings.

2.0 DESCRIPTION OF THE FAG FE9 TEST RIG:

The FAG FE9 test rig with its test units is intended exclusively for examining the service life of greases in ball bearings. The examinations comply with DIN 51821. This test is carried out in a modified angular contact ball bearing FAG 529689A. These bearings are specially made and inspected with a thermal stabilisation up to 300°C and incorporating special tolerances in the bearing component dimensions.

Each test rig is provided with independently running five test units to keep the testing times short. Bearing temperatures from room temperature up to 250°C are ensured by external heating. The test is run using various load studs to enable axial loads of 1.5, 3.0 and 4.5 kN as per the test requirements. A three-phase motor is used to run the bearing at different test speeds. Connection disks enable a variety of mounting variants to be tested, e.g. open-type bearings, covered bearings and covered bearings with additional grease depot. The test shaft is supported on an Auxiliary bearing of the same size as test bearing, arranged mirror-inverted to the test bearing.

Variable Test parameters for the studies are the running speed, temperatures, axial test load. Once the Frictional moment in the bearing is exceeded based on the starting value, the test is stopped and the hours to failure are noted.

To be able to quantify the qualitative difference in terms of grease service life, comparative tests on greases are carried out on the FE9 test system at various, mostly higher temperatures. During this process, the thermal strain of the grease is generally kept high to reach justifiable run times and to keep the test costs within limits.

3.0 TEST METHODOLOGY DESCRIPTION

The FE9 test system comprises five identical test devices which can be individually operated (**Fig 1**). The shaft in the test bearing and in the auxiliary bearing is supported in the housing of the test device. Both bearings are secured on the shaft by the shaft nut. The bearing load acts in the axial direction (**Fig 2**). The axial load direction has been chosen because the lubricant in the ball bearing is subjected to higher stress by axial than by mere radial load. An electric motor drives the shaft by means of a belt. The test head can be heated electrically. The control unit of the electric motor, the temperature control for the test head heating and the registration of the bearing run-times are carried out in the PC which is incorporated into the control cabinet. Each test device is equipped with an automatic shut-down device for the moment of friction of the bearing. As a result, any destruction of the test bearing or damage to the test head can be prevented. The bearing temperature, the run-time, the change of the

moment of friction of the test bearing or the recorded driving power and the lubricant condition serve as measuring and assessment variables. Bearing temperature and power consumption can be recorded with a PC. The run-time of each test bearing is recorded on elapsed-hour meters. The driving power of the test bearing is taken into consideration for the bearing failure. A rise to double the steady-state value of the power consumption indicates a bearing failure, as we know from experience. The moment of friction of the test bearing cannot be measured directly. However, since the connection between motor rating and motor torque has been determined by calibration for each individual motor, and since the moment of friction of the oil-lubricated auxiliary bearing does not change during the run-time, the moment of friction of the test bearing can be concluded from the rise in the motor rating (increase in the power loss of the test bearing). The lubricant condition, the lubricant distribution and the functional surfaces of the bearing are visually examined after the test.

Using Connection disks, a variety of mounting variants can be incorporated, e.g. open-type bearings- **Test Variant A**, covered bearings (simulating Sealed bearings)- **Test Variant B** and covered bearings with additional grease depot – **Test Variant C**. These are depicted in **Figure 4**.

When testing ball bearing lubricants, the ball bearing itself is suitable as a test element. The lubricant changes during the application time (ageing). Since the trials must last until the failure of the lubricant, there is a long run-time for each individual test. A typical test for different grease with different running time is shown in **Figure 3**. In addition, there is a degree of scatter in the trial results. The tests must therefore be repeated several times in order to ensure the total result for statistical purposes. An assessment of the lubricant can only be made after a test requiring a lot of time and material. To enable this process, each test rig has 5 testing units to generate 5 data points for failure life of the grease. The statistical analysis is done using a Weibull distribution which is generally followed for most life analysis.

The test rig offers several options for adapting the test conditions to the conditions of use. These include a variety of test loads, speeds and mounting variants. Consequently, a Field Simulated test means that the test conditions are similar to the conditions of use. Experience with running test systems based on lubrication technology shows that the dispersion caused by the system and lubrication cannot be avoided. Consequently, the test system comprises five test units which increase the testing capacity and mean that a test with sufficient statistical safety can be carried out within a short period of time.

4.0 GREASES EVALUATED:

Greases meant for high temperature performance were selected for this study. Four greases with details given in **Table 1** were evaluated for their service life as per the DIN 51821 condition A (open type bearings with no side plate) at a speed of 6000 rpm, and axial load of 1500 N. The failure times were measured at three

different temperatures of 140 Deg C, 160 Deg C and 180 Deg C to assess their service life. The test results are shown in **Table 2**.

Table 1 : Greases Selected:

Sr No	Grease	Description	Consistency	Drop Point deg C
1	Grease A	Li Base Grease with VG 100	2	260
2	Grease B	Polyurea Grease	2	280
3	Grease C	Calcium Complex Grease	2	260
4	Grease D	Li Complex Grease with ester /Group II Base oil	2	250

The data obtained from the above greases are given below in Table 2

Service temperature range*, [°C] approx. 140 to 180 in an interval of 20 deg C

FAG FE9 test run, DIN 51821 T02,

$n = 6,000 \text{ min}^{-1}$, $F_a = 1,500 \text{ N}$, F_{50} running time, [h/°C]

Table 2 : L10 and L50 Service life of various Test Greases:

Sr No	Grease	Test Temperatures	Condition	Service Life L50 in Hours	Service Life L10 in hrs
1	Grease B	140 Deg C	A	310.8	225.6
2	Grease B	160 Deg C	A	60.63	36.27
3	Grease B	180 Deg C	A	20.6	18.03
4	Grease C	140 Deg C	A	160	148.06
5	Grease C	160 Deg C	A	35.54	27.54
6	Grease D	140 Deg C	A	75.8	67.9
7	Grease A	140 Deg C	A	209	170.89
8	Grease A	160 Deg C	A	85	72.5

5.0 OBSERVATIONS AND DISCUSSIONS

Tests were run on different greases with an aim to find out their failure life as per DIN 51821 test standard at different elevated temperatures in hours. Besides with a view to offer information to the user, the upper temperature limit as per DIN 51825 test method K was assessed. As per this standard, the upper temperature service limit is the temperature at which the grease has a L50 life of 100 hours minimum.

During the test, it was found that the initial running torque was low of about 100-150 W. This was measured and on the basis of this a cut off limit was generated in the control circuit for detection of failure due to increase in the running torque with the deterioration of the grease. When the test bearing ran for more than a few minutes at that increased running torque, the control circuit caused the tripping of the machine. There was an appreciable increase in the sound levels generated due to the dry or poorly lubricated running of the bearing close to the failure of the test bearing.

From the test data obtained, it was found that as expected for all the greases, the service life in hours decreases as the temperature of the test was increased. For Grease B (Polyurea grease), the L50 service life reduced to as much as 1/5th for a test temperature increase from 140 to 160 deg C. For an increase of temperature from 160 to 180 deg C, the service life reduced to 1/3rd.

As per DIN 51825 test standard, for Grease B (polyurea grease), the upper temperature grease limit can be taken as 140 deg C, since at 160 Deg C, the L50 service life was lower than 100 hours.

These graphs of the service life of the Grease B (polyurea grease) are shown in **figure 7-9**. The same graphs have been also generated for other greases like the Grease D with synthetic ester and group II base oil (**fig 6**), and the Grease A (**fig 10**) as well as the Grease C (**fig 11**). The Grease A had an upper temperature service limit of 140 Deg C. Grease D had an upper temperature service limit below 140 Deg C since it had a life below 100 hours for the test at 140 Deg C, so it was not evaluated at 160 and 180 Deg C. The Grease C had the same upper temperature limit of 140 Deg C with service life above 100 hours for the test at 140 Deg C. Its results are shown in **Figure 11**. The upper temperature limits of all the greases as per DIN 51825 are shown in **Table 3**.

The test bearings after test were photographed and shown in **Figure 12**. The greases have turned black due to oxidation and form a hard caky residue in the bearings.

6.0 CONCLUSIONS

- (1) The Weibull distribution for service life of greases predicts the life using statistically correct methods based on a five data point assessment with experimental data. The test data analysed statistically is able to classify the grease on the basis of their high temperature service life.
- (2) The service life of the grease drops by a great extent as the test temperature increases, the life going down by as much as 40-50% for every 10 deg C increase in temperature
- (3) The test method is able to get information about the upper temperature limit for various greases. The value is about 100-120 deg C below the drop point for various greases. This may be attributed to the dynamic shearing experienced by the grease in the bearing in addition to the temperature.
- (4) The grease degrades due to the physical and chemical degradation of the grease. The grease forms an oxidized hard dry mass on failure at elevated temperatures in the bearings. The sound levels were also very high due to dry poorly lubricated bearing surfaces due to the deterioration of the greases.
- (5) The test has been useful in classifying greases for their elevated temperature performance.

7.0 FUTURE WORK:

- (1) Studies on synthetic base oils for effect on service life will be conducted.
- (2) Studies on effect of addition of EP additives which have known to give increase in service life will be carried out.
- (3) More chemistries of greases like Calcium Sulphonate, Clay based greases, and addition of Molybdenum disulphide to various greases will be carried out.

8.0 REFERENCES:

- (1) Booser E.R., 1974, "Grease Life Forecast for Ball Bearings", *Lubrication Engineering*, pp. 536-541.
- (2) Bartz, W. J. (1993), "Long-Life and Life-Time Lubrication—Possibilities and Limitations," *Lubrication Engineering*, **49**, p 518.
- (3) Araki, C., Kanzaki, H. and Taguchi, T. (1995), "A Study on the Thermal Degradation of Lubricating Greases." *NLGI Spokesman*, **59**, p 15.

- (4) Ito, H. and Suzuki, T. (1988), "Physical and Chemical Aspects of Grease Deterioration in Sealed Ball Bearings," *Lubrication Engineering*, **44**, p 872.
- (5) Carr´ e, D. J., Bauer, R. and Fleischauer, P. D. (1983), "Chemical Analysis of Hydrocarbon Grease from Spin-Bearing Tests." *ASLE Trans.*, **26**, p 475.
- (6) Bailey,W. and Pratt, S. (1982), "Dynamic Oxidation Stability of Lubricating Greases," *NLGI Spokesman*, **46**, p 15.
- (7) Komatsuzaki, S., Uematsu, T. and Kobayashi,Y. (2000), "Change of Grease Characteristics to the End of Lubricating Life," *NLGI Spokesman*, **63**, p 22.
- (8) Hosoya, S. and Hayano,M. (1989), "Deterioration of Lithium Soap Greases and Functional Life in Ball Bearings," *NLGI Spokesman*, **53**, p 246.
- (9) McClintock, R. (1980), "ALaboratory Study of Wheel Bearing Grease High Temperature Life," *NLGI Spokesman*, **43**, p 414.
- (10) Cann, P. M. and Lubrecht, A. A (1999), "Analysis of Grease Lubrication in Rolling Element Bearings," *Lubrication Science*, **11**, p 227.
- (11) Kugelfischer Georg Schaefer and Company FAG. "The Lubrication of Rolling Bearings." Publication No. 81 103EA. Schweinfurt, Germany, 1977.
- (12) Snyder Dan, "Sealed for Life bearing To Lubricate of Not" , *Tribology & Lubrication Technology*, December 2004, pp 32-40.
- (13) (15) DIN 51821-1 Testing of lubricants; test using the FAG roller bearing grease testing apparatus FE9; general working principles
- (14) DIN 51821-2 Testing of lubricants; test using the FAG roller bearing grease testing apparatus FE9; test method A/1500/6000 Deutsches Institut Fur Normung E.V. (German National Standard) / 01-Mar-1989 / 3 pages
- (15) DIN 51825 standard, "Lubricants - Lubricating greases K - Classification and requirements (FOREIGN STANDARD).

Table 3: Upper Temperature Service Limits for Greases

Sr No	Grease	Upper Temperature Limits (deg C)
1	Grease A	120
2	Grease B	140
3	Grease C	140
4	Grease D	140

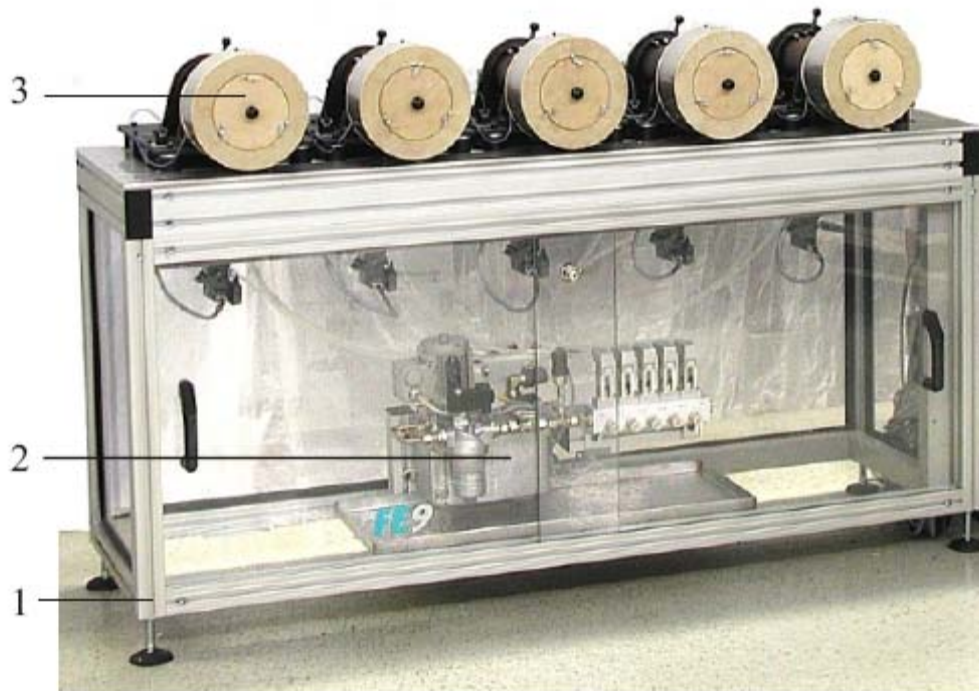


Figure: FE9 test rig with 5 test units

No. Name of component

- 1 Frame*
- 2 Oil unit*
- 3 Test units (5 pcs.)*
- 4 Cooling aggregate (option)*
- 5 Control cabinet with operating panel*

Figure 1: FE9 Test machine

- 1 Test bearing
- 2 Cup springs for axial test load
- 3 Auxiliary bearing

Abbildung 1.1

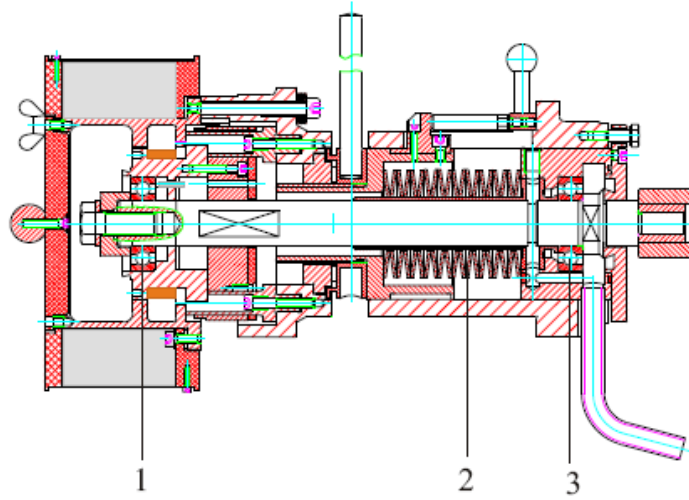


Fig 2 Bearing Test Schematic for FE9 Test rig

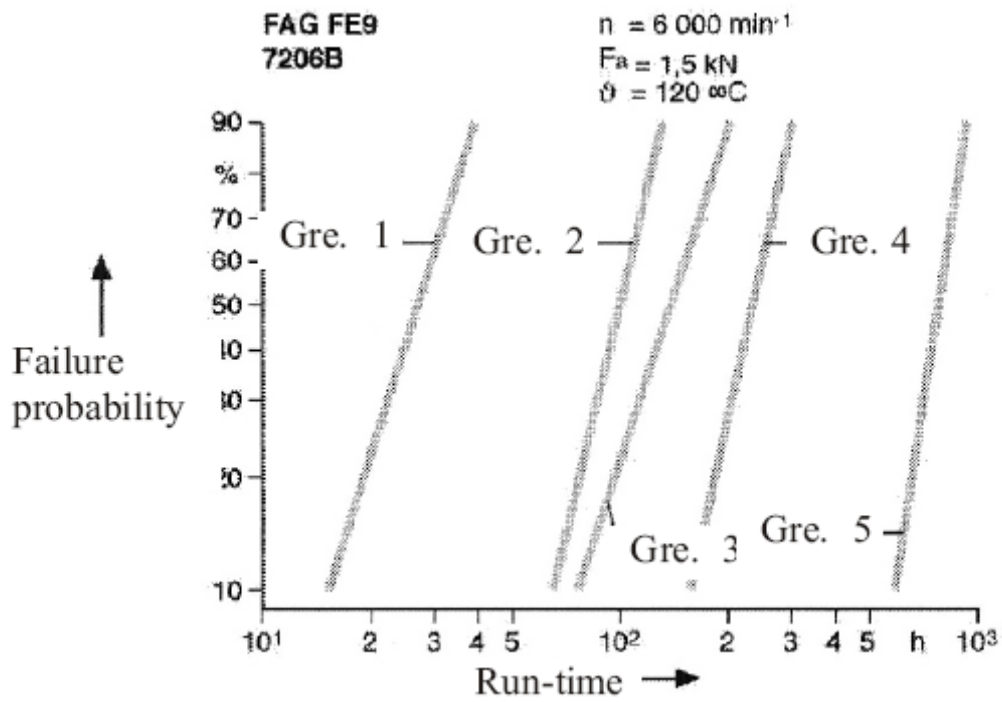


Figure 3: Running times of different greases

Abbildung 2.3

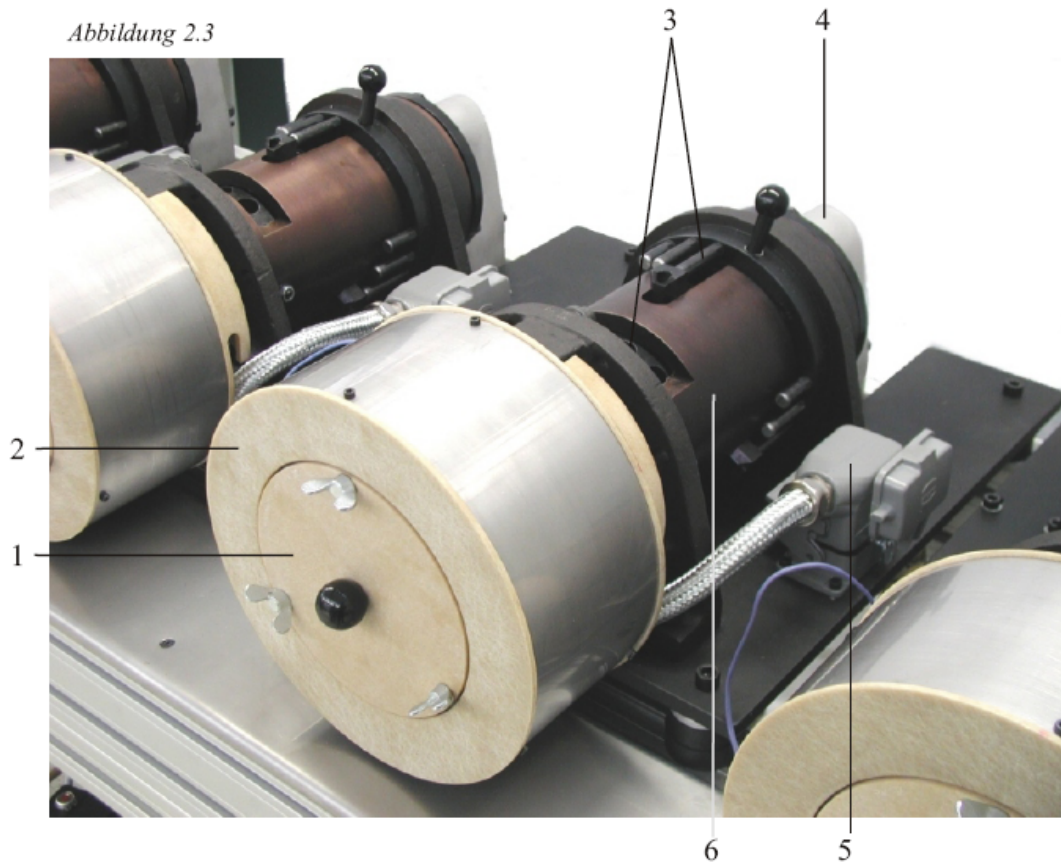
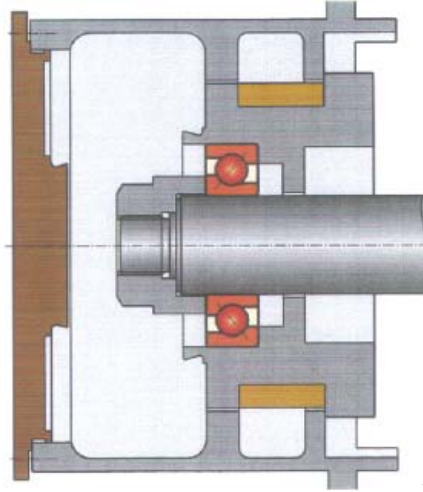


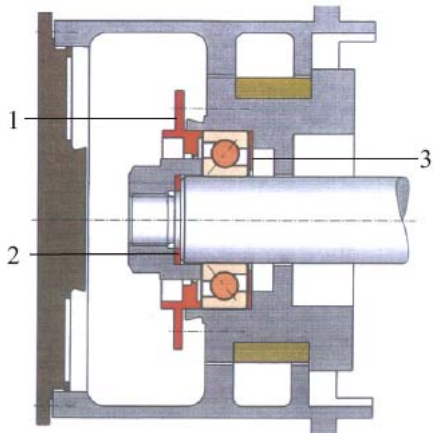
Fig.: Photo of a test unit

- 1 Housing lid
- 2 Thermal insulating hood of the heating system
- 3 Preclamping device for axial load
- 4 Encasement for belt drive
- 5 Power supply cord for the heating
- 6 Housing

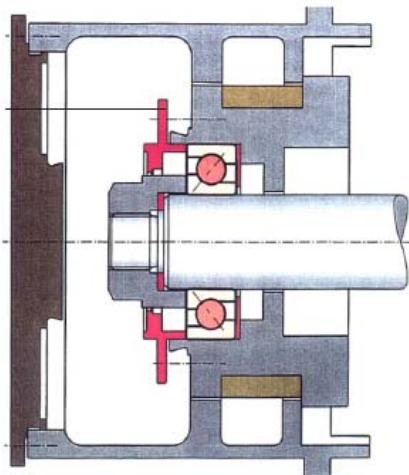
Figure 4: Single Test Unit



Mounting A



Mounting B



Mounting C

Figure 5 : Different Mountings possible on FE9 Test rig

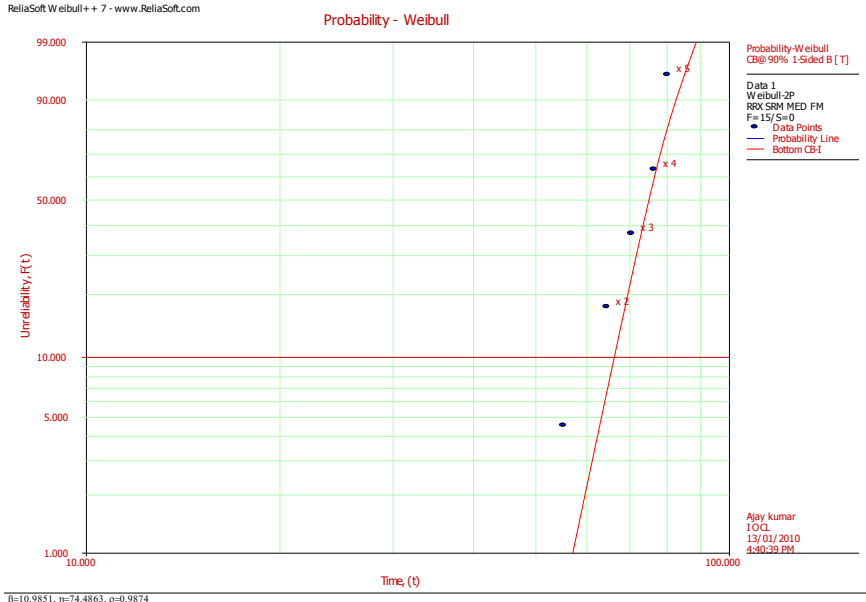


Fig 6 Grease D at 140 deg C

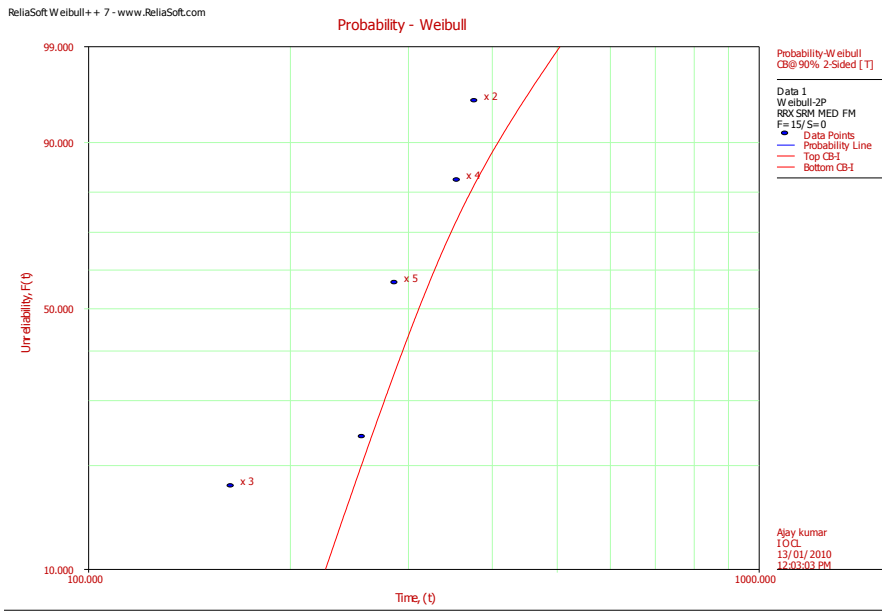


Fig 7: Grease B at 140 deg C

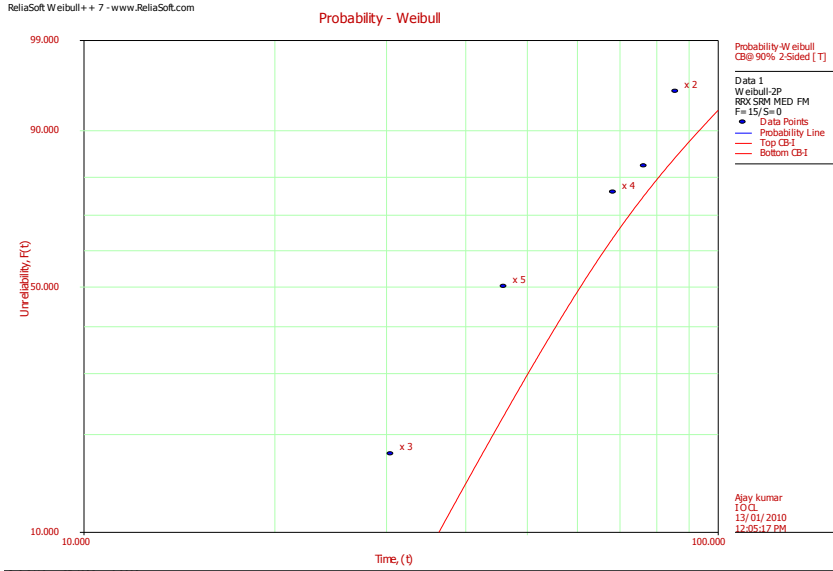


Fig 8: Grease B 160 deg C

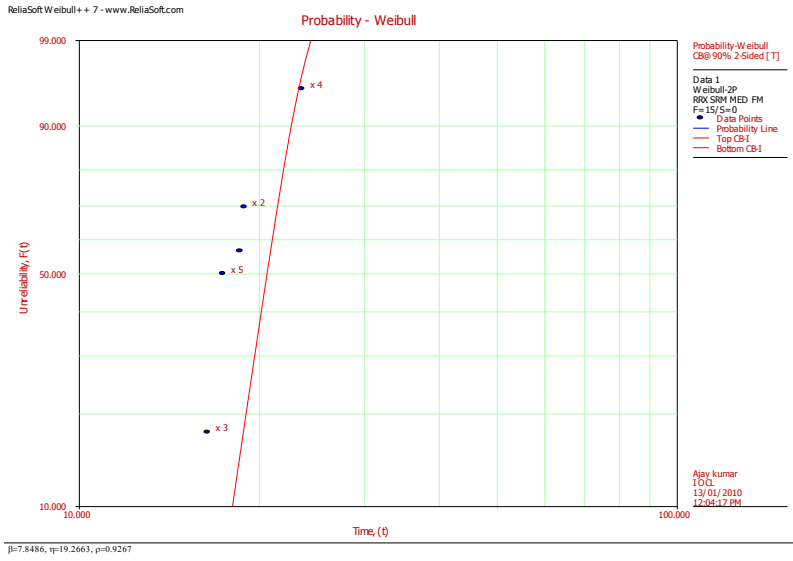


Fig 9: Grease B 180 deg C

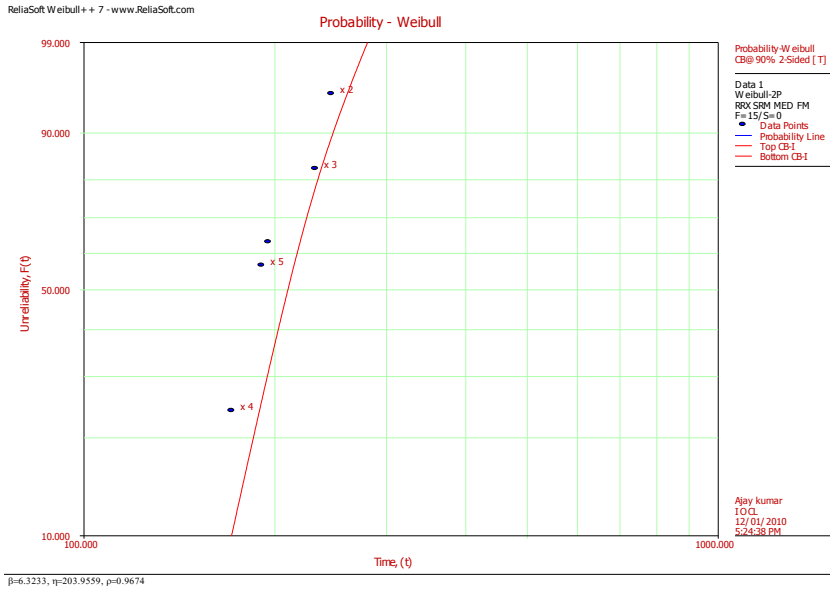


Fig 10:Grease A at 140 Deg C

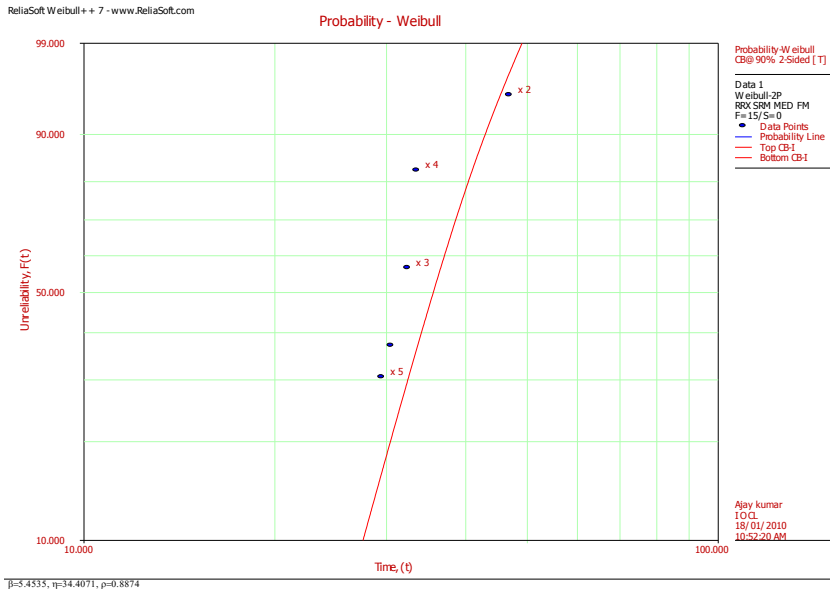


Figure 11: Grease C at 160 Deg C



Figure 12: Test Bearings after test showing caky black grease