FRICTION, WEAR AND LUBRICATION

MEMM 1343

Mechanical–dynamic tests

Mechanical–dynamic testing has become an essential element in the development of modern tribology, to appoint where standardized tribological, mechanical–dynamic test rigs and test methods play decisive roles in the development of machine elements, and especially for coatings, lubricants, and additives.

Standardized test methods represent the basic means of achieving the required performance of original equipment manufacturer (OEM) specifications for lubricants.

A variety of so-called “house-internal” methods complete the range of today’s tribological, mechanical dynamic testing.

Currently, the wide range of tribological, mechanical–dynamic test machines and test methods that are available includes simple laboratory instruments and field tests conducted under “real” conditions.

The different types of tribological test are classified, among others, by the German DIN 50 322, as shown in Figure 1.

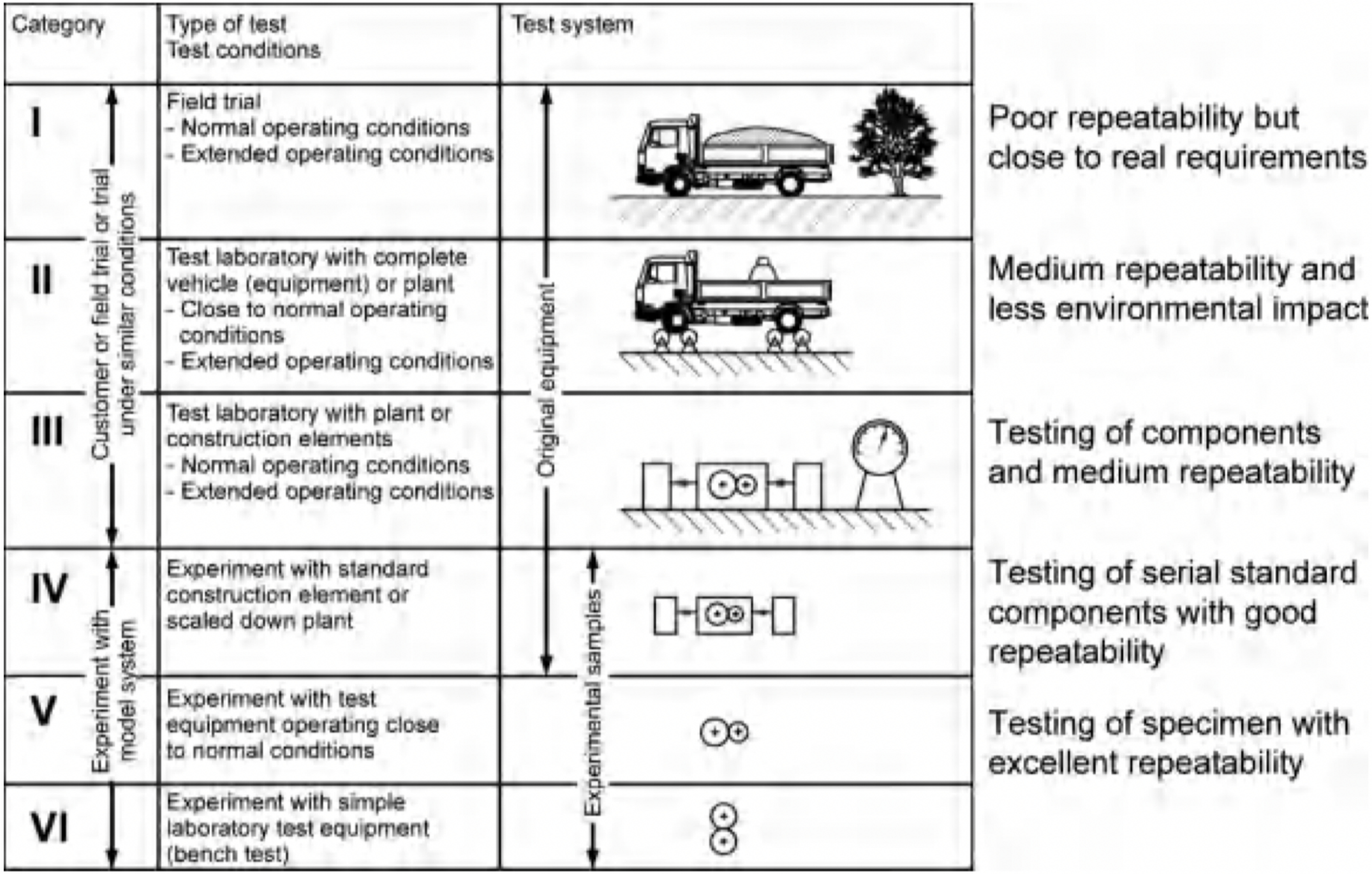

Figure 1: Tribological system categories within mechanical–dynamic testing

However, the continuing, gradual reduction of the test-sequence plan from a field test to a simple friction contact may lead to substantial improvements in the repeatability and reproducibility of a test method, and the validity of results from a simple screening test will decrease proportionally.

One major problem of the classification according to DIN 50 322 is the allocation of certain test devices and methods to their corresponding categories.

The transitions between such categories must be considered as fluent, and enable an overlapping or a combination of two categories in a single test method.

Fourball tribotester

The fourball apparatus is one of the oldest and best-known simple test benches for liquid and solid lubricants. The fourball geometry is a popular test method, because the specimen is inexpensive and wear measurement is simple.

This machine enables the precise determination of antiwear (AW) properties and the coefficient of friction ($miu = \mu$).

As shown in Figure 2, this simple geometry also enables the determination of the extreme pressure (EP) characteristics of greases and lubricating oils, based on welding tests that are standardized worldwide (see Table 1).

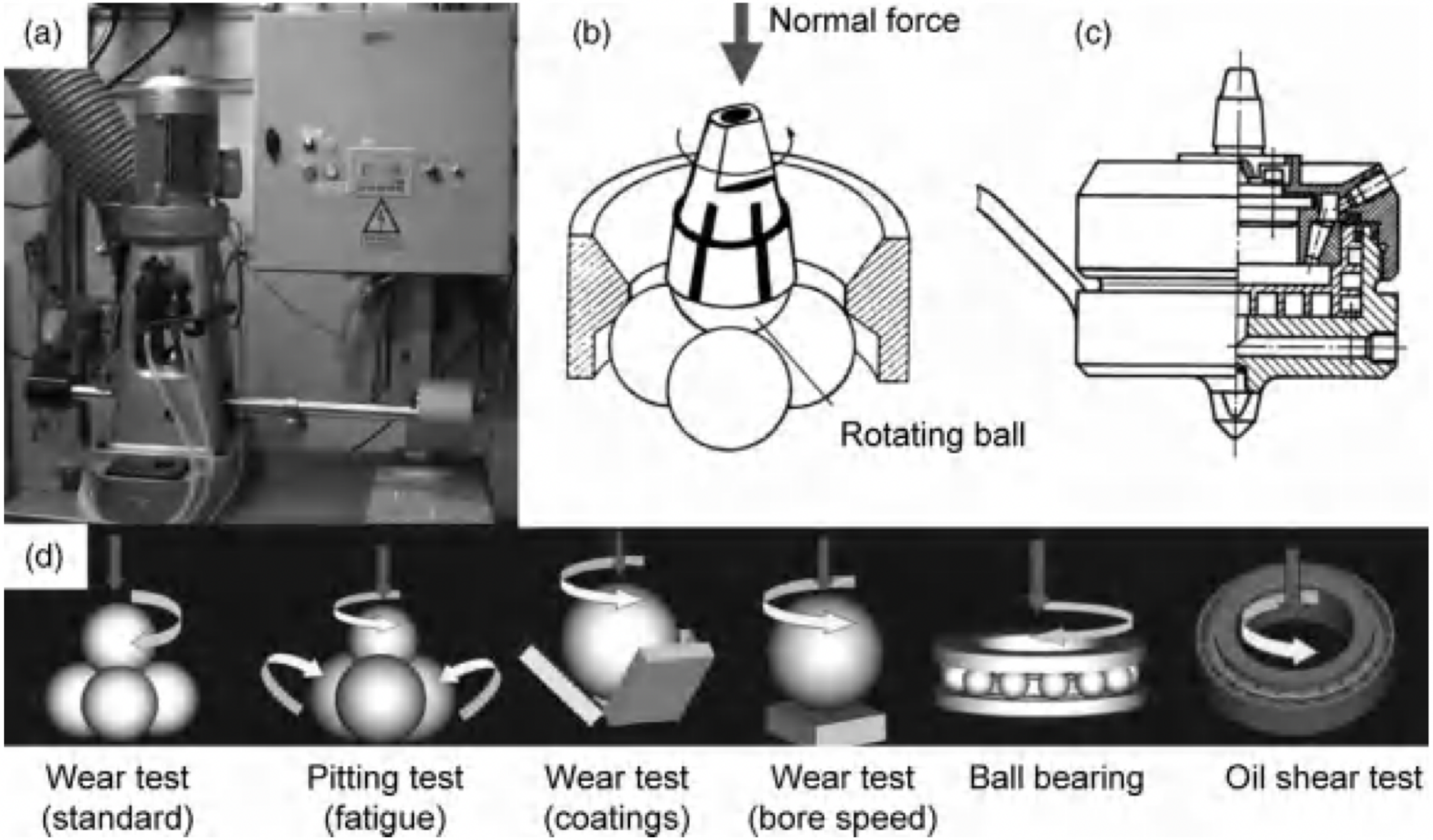

Figure 2: (a) The four-ball apparatus; (b) Test principle of the four-ball apparatus; (c) Test adapter for determination of shear stability of lubricants containing polymers; (d) Examples of the variety of four-ball test adaptations.

Table 1: Fourball apparatus test standards.

Standard test method for wear-preventive characteristics of lubricating fluids	ASTM D 4172
Wear-preventive characteristics of lubricating grease (four-ball method)	ASTM D 2266
Standard test method for the determination of the friction coefficient of lubricants using the four-ball apparatus	ASTM D 5183
Measurement of EP properties of lubricating fluids (four-ball method)	ASTM D 2783
Measurement of EP properties of lubricating grease (four-ball method)	ASTM D 2596
Standard test method for determination of load-carrying capacity and mean Hertz load	FTMS No, 791 b Method 6503.2
Determination of EP and AW properties of lubricants – four-ball apparatus	IP 239/85

Table 1: Fourball apparatus test standards.

Standard test method for lubricants using the Shell four-ball apparatus	DIN 51 350
General working principles	DIN 51 350, Part 1
Weld load of liquid lubricants	DIN 51 350, Part 2
Wear load of liquid lubricants	DIN 51 350, Part 3
Weld load of solid lubricants	DIN 51 350, Part 4
Wear load of solid lubricants	DIN 51 350, Part 5
Shear stability of polymer-containing lubricants	DIN 51 350, Part 6
Viscosity shear stability of transmission lubricants – tapered roller bearing	CEC L-45-T-98
Testing of lubricants – Determination of shear stability of lubricating oils containing polymers– Testing in the four ball tester	ISO/WD 998 877
Mechanical shear stability of engine oils	VW-PV-1450
Pitting load capacity of solid lubricants	VW-PV-1417
Pitting load capacity of liquid lubricants	VW-PV-1444
Standard test method for temperature increase in the axial thrust ball bearing adapter (ARKL)	VW-PV-1454

In the fourball test, a roller bearing ball is allowed to rotate under pressure and at a constant speed on three fixed steel balls, with the contact lubricated using an oil or a solid lubricant. The gradual increase of the normal force (contact pressure) then enables an accurate determination of the weld load, the AW protection, and the friction coefficient of the lubricant.

During these tests, the driving or rotating ball wears down the load dependently, seizes, and then welds to the three stationary balls. This indicates that the wear marks or the extreme pressure (EP) level of the lubricant have been exceeded on the three stationary balls, and leads to the effects of different oils and additives.

During recent years, several adaptations of the fourball apparatus have been developed to acquire additional information on the pitting load capacity and the shear stability of polymer-containing lubricants. In this case, surface-modified steel balls (see VW-PV-1444) and a variety of tapered roller bearings (VW-PV-1417, DIN 51 350 part 6 or CEC L-45-T-98) are used (see Figure 2d). In addition, further modifications of the test adapters enable the determination of coefficient of friction values and the temperature behavior of a lubricant within the roller bearing.

In accordance with test procedure VW-PV-1454, the test adapter used determines the steady-state operating temperature, temperature increase, and the friction of the test bearing in relation to the respective lubricant, using an axial thrust ball bearing.

More recent results obtained using this test adapter have shown that the steady-state oil sump temperatures measured can be transferred to transmissions and industrial gears, depending on the lubricant, after being adjusted to the realistic load and speed ratio referring to the application.

As ever, today's numerous specifications for gear and hydraulic lubrication oils and for all types of grease and paste require fourball data for most lubricants. The most common test standards used for the fourball apparatus are listed in Table 1.

Pin on disk tribotester

Friction and wear (typically wear rates and wear resistance) characterization of materials is typically performed using various types of tribometers, while pin on disk test being probably one of the most common, as shown in Figure 3.

The popularity of the method is due to its relative simplicity and abundance of the tribological contacts that can be well described by the a simple pin on disk motion: from dry contacts of bolt screws to rail wheels to rail contact and to lubricated contact of biological implants.

The test typically allows to test several motion modes, such as unidirectional, fretting modes and recently any other complex motion patterns.

Typically, the tests are performed under the following testing standards:
ASTM G99, ASTM G133 and ASTM F732.

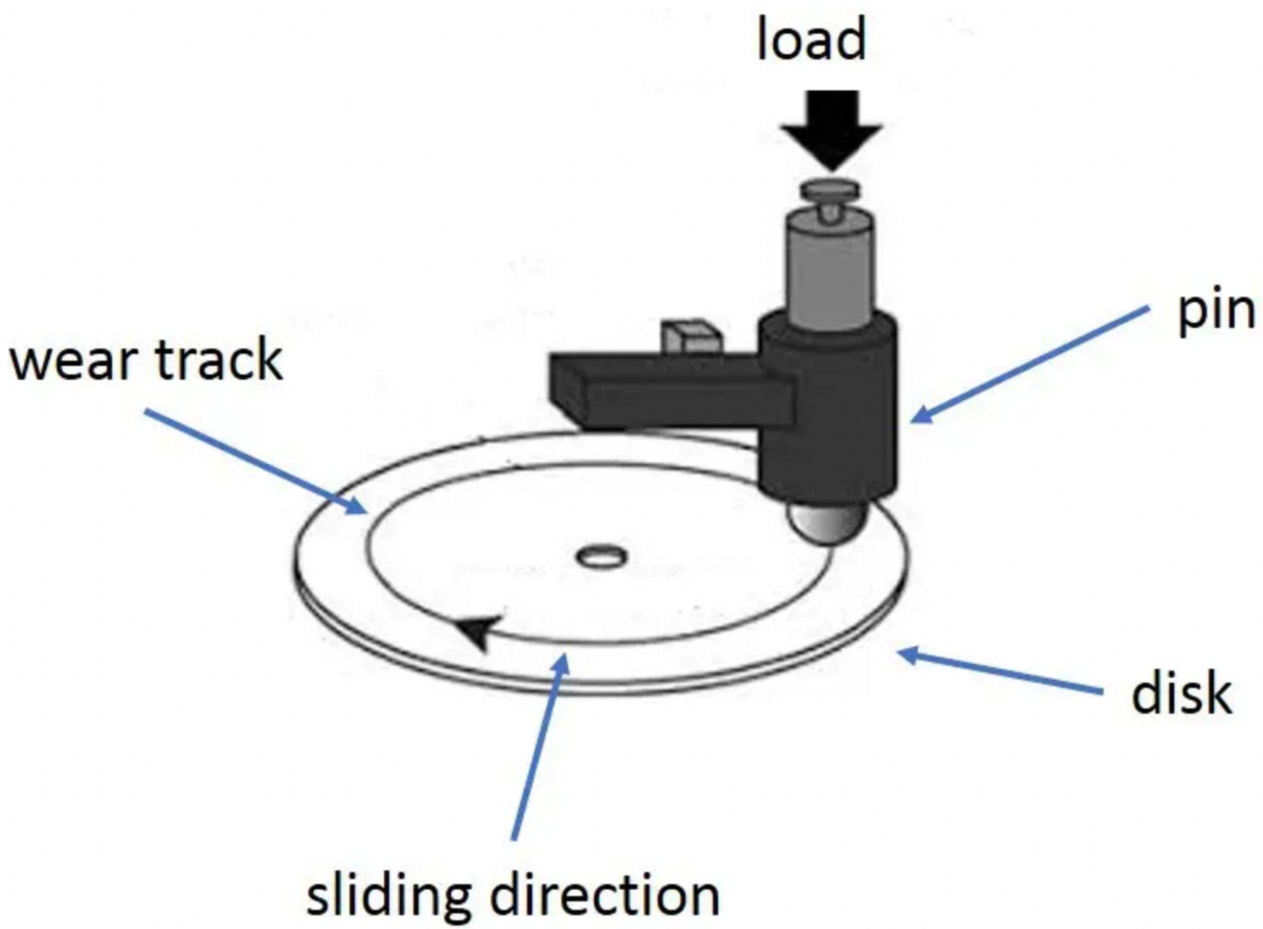

Figure 3: Schematic diagram for pin on disk tribotester.

Schematically, the pin on disk test is depicted in Figure 1. The stationary pin is pressed against rotating disk under the given load. The pin can be of any shape, however, the most popular shapes are spherical (ball or lens) or cylindrical due to ease of alignment of such pins (flat pins are typically subject to certain misalignment which can lead to non-uniform loading and difficulties for theoretical analysis).

During the test, the friction force, wear and temperature are continuously monitored.

At the start of the test, the measured coefficient of friction (COF) is high and with further progress drops.

This behavior is typical friction measurements and is attributed to a running-in phenomenon. During the running-in, the surface topography changes, chemical reactions takes place until the system comes to a steady-state state. This steady state COF is then usually reported.

The test can be performed in dry and lubricated conditions. In lubricated case, the pin is typically submerged in the lubricant bath or with lubricating oil supply system.

After a certain amount of cycles the test stops and typically further data processing steps include surface topography analysis to determine wear volume and surface roughness evolution, Scanning Electron Microscopy / Energy Dispersive X-Ray analysis for chemical composition/particles analysis, tribofilms, micro-structural analysis.

If the test was performed in lubricated condition, the oil can be also analyzed for the wear particles size and additives deterioration.

Important factors and test conditions

The following factors should be considered when designing pin on disk wear test procedure:

Pin shape:

Typically, the pin can be of any shape. Ball on disk test uses a ball pin or a lens. Flat pin or chip shaped pins can also be used.

Pin alignment:

If the pin is flat ended, the alignment should be ensured, since otherwise non-uniform loading occurs resulting in non-uniform wear and possibly overloaded conditions. The edges of the flat specimens should not be sharp, otherwise the chipping may occur.

Pin material:

The choice of the pin material is very important. It should be noted, that typically, the tribological behavior for the same pair of materials is different depending on which material is used for the pin and which material is used for the disk.

This is specifically true for the case of the contact between “soft” and “hard” materials. This difference comes from the fact that the wear occurs mainly on the softer material. If the ball on disc case is considered, if the ball is softer it will be worn faster and form a flat on flat contact with pressure profile significantly different for the initial one. If the disk is softer, than the groove will form on the disk and plouging wear will occur.

Pin location:
It is possible to place a pin on the top of the disk. However, in many cases the pin is pressed against the disk from the bottom. It is typically done to avoid getting the wear particles back into contact once they are formed or to collect the wear particles for further analysis. Due to gravity, the wear particles will be falling down.

Wear scar/wear rate/wear volume analysis:
In the modern tribometers, the wear scars can be analyzed using inline imaging systems, such as optical profilometers, Atomic Force Microscopes, etc.

This analysis can also be performed several times during the test, thus giving the opportunity to measure the wear rate, wear volume and surface roughness evolution in time. This information can be used to develop accurate wear models and move towards predictive tribology.

Pin on disk testing standards

In research of materials, coatings and lubricants, standardized tests are used to improve the reproducibility and for simplicity. The data collected using standard tests can also be used to compare the results obtained by various laboratories. The standards in tribology were developed by ASTM, DIN as shown below.

ASTM G 99 – Standard Test method for wear testing on a pin-on-disk test apparatus.

DIN 50324 – Testing of friction and wear.

DIN ISO 7148-1 – Testing the tribological behavior of material for sliding bearings Part 1: Testing of bearing materials, test procedure A, pin on disk.

DIN ISO 7148-2 – Testing the tribological behavior of plastic materials for sliding bearings, test procedure A, pin on disk.

Linear reciprocating tribotester

High frequency reciprocating rig (HFRR)

The HFRR is a microprocessor-controlled reciprocating friction and wear-test system which enables the rapid, repeatable assessment of the performance of fuels and lubricants. The schematic sketch of the linear reciprocating tribotester is shown in Figure 4.

It is particularly suitable for wear-testing for lubricants and for boundary friction measurements of engine oils, greases, and other compounds.

Other test standards based on the HFRR system are listed in Table 2.

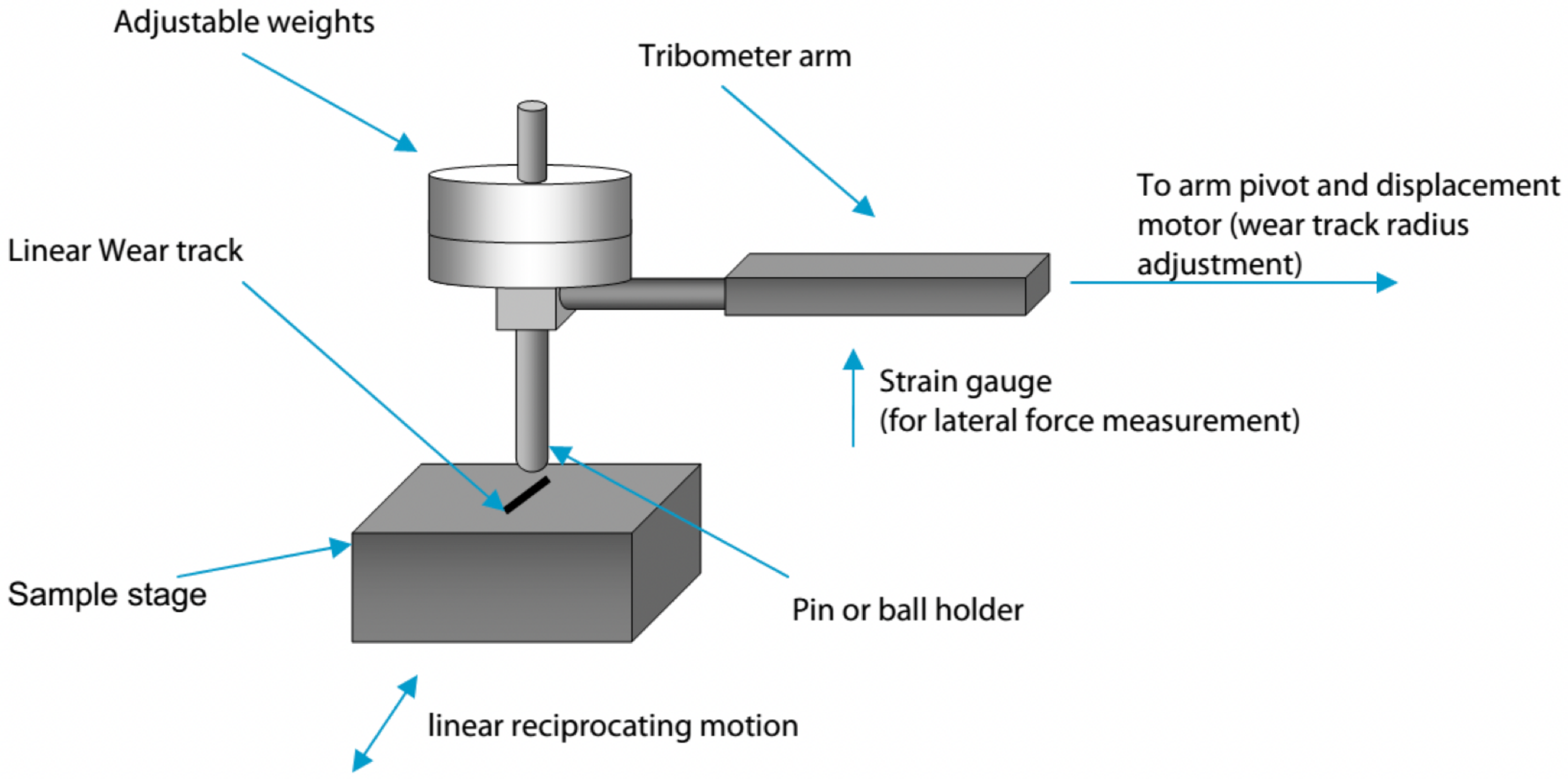

Figure 4: Schematic sketch of the linear reciprocating tribotester.

Table 2: Test standards for high-frequency reciprocating test machines.

HFRR	Measurement of diesel fuel lubricity	CEC F-06-A-96
	Standard test method for evaluating the lubricity of diesel fuels by use of the high-frequency reciprocating rig (HFRR)	ASTM D 6079 IP 450/2000
	Assessment of lubricity by use of the high-frequency reciprocating rig (HFRR) Part 1 test method	BS ISO 12 156-1
	Automotive fuels – diesel – requirements and test methods	EN 590
	Gas oil – testing method for lubricity	JPI 5S-50–98

Table 2: Test standards for high-frequency reciprocating test machines.

SRV	Standard method for measuring the friction and wear properties of EP lubricating oils by use of the SRV test machine	ASTM D 6425
	Standard test method for determining the EP properties of lubricating greases by use of a high-frequency linear oscillation (SRV) test machine	ASTM D 5706
	Standard test method for measuring the friction and wear properties of lubricating grease using a high-frequency, linear-oscillation (SRV) test machine	ASTM D 5707

Table 2: Test standards for high-frequency reciprocating test machines.

Tribological test method using a high-frequency, linear-oscillation test machine (SRV);	DIN 51 834
General working principles	DIN 51 834, Part 1
Determination of measured friction and wear quantities for lubricating oils	DIN 51 834, Part 2
Determination of the tribological behavior of materials in reaction with lubricants	DIN 51 834, Part 3
Definition of data formats for test results	DIN 51 834, Part 5
Tribological test method for solids using a high-frequency, linear-oscillation test machine (SRV)	DIN 51 834, Part 6
Textile machinery and accessories – needle and sinker lubricating oils for weft knitting independent needle machines – part 2 Minimum requirements synthetic oil-based	DIN 62 136, Part 2

Journal bearing tribotester

The application of using rotary machines to convert the rotating energy from different sources to useful energy is well known. For these rotating machines, there is always one rotating part that is separated from the stationary portion of the machine.

This is fulfilled by using the bearings.

The bearings help in allowing the surfaces of the rotating part to slide relative to the stationary part. Journal bearings are the most commonly used bearings in most mechanical applications.

Definition

Journal bearings are the simplest types of bearings that allows the shaft to rotate freely within a supporting sleeve. The part of the shaft which is fit in these bearings is called a journal hence the name journal bearing, as shown in Figure 5.

These bearings do not have rollers to support the radial loads however they are capable of supporting these weights which is due to the weight of shafts.

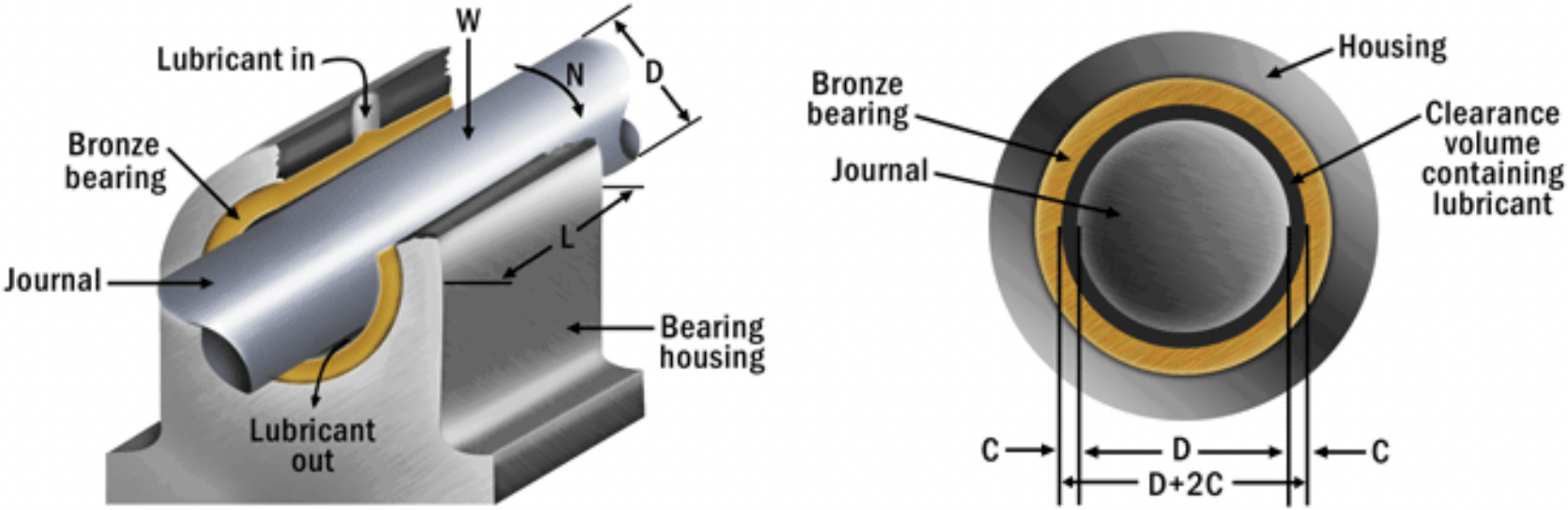

Figure 5: Schematic diagram of the journal bearing tribotester.

Working principle

Journal bearings operate in both boundary and hydrodynamic lubrication regimes, it operates at the boundary lubrication regime at the start and shutdown of the bearings.

At the start and shut down of the bearing operation there is metal-to-metal contact leading to boundary contacts.

After the start, the oil is supplied at the junction that causes the pressure and hydrostatic lift thus it operates at the hydrodynamic lubrication regime, as shown in Figure 6.

The hydrodynamic fluid film helps in higher load support and also operates at high rotational speeds.

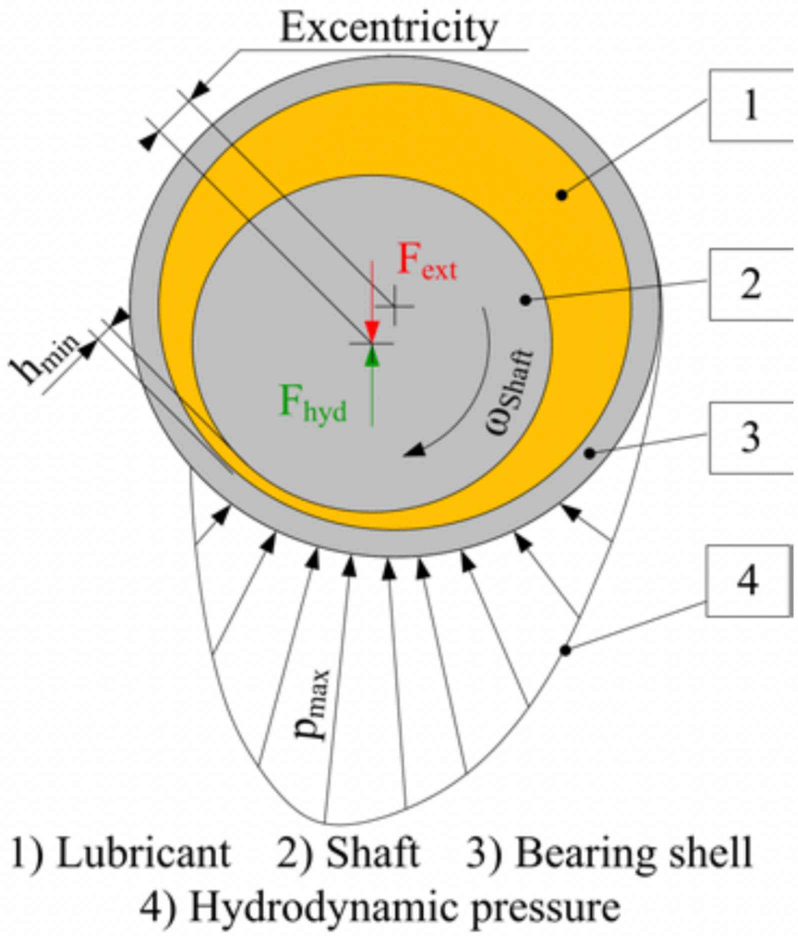

Figure 6: Schematic representation of journal bearings working principle.

Types of journal bearings

There are mainly two types based on their assembly or setup. They are integral or plain bearings and two-piece bearings.

Plain or integral bearings

In this type of bearing it is assembled into the object as a hole that acts as a bearing surface. The most commonly used is the pillow block bearing, as shown in Figure 7.

In this bearing the materials used inside and on the bearing surfaces are different. The housing of these bearings is made of cast iron and the surface of the bearing is made of chromium steel alloys.

The lubrication in these bearings is supported by the grease nipples which supply the lubrication thereby maintaining the good lubrication property.

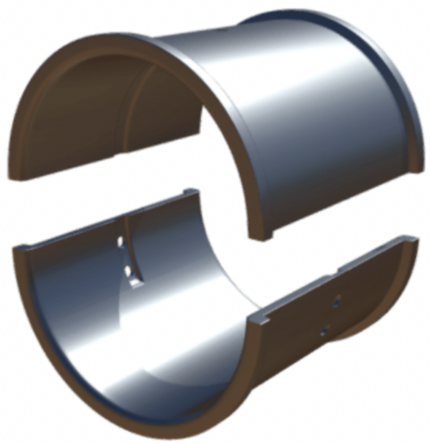

Figure 7: Schematic representation of plain journal bearing.

Two-piece bearings

In this type of bearing they have two parts lower and upper parts; where the lower part of the bearing is positioned on the application and the upper part is removable, as shown in Figure 8.

These parts upper and lower are also referred to as shells which are used on large diameters as in the case of a crankshaft. These bearings are usually manufactured larger than their housing and are compressed to fit the application during installation.

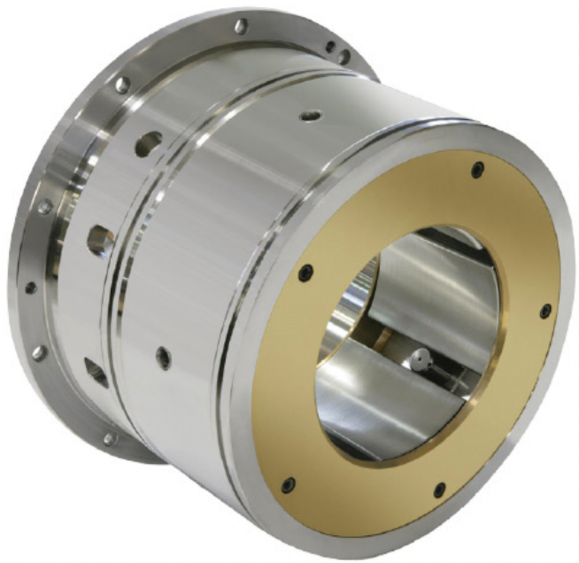

Figure 8: Schematic representation of a two-piece journal bearing.

Lubrication in journal bearings

The lubrication in bearings is important to protect their surfaces from corrosion and seal them against contamination. The lubrication also helps in creating the barrier between the rolling contact and sliding surface and helps in providing heat transfer. Thus bearing lubrication should be understood for its better functionality in various applications.

Oil lubrication:

The requirement of oil lubrication in journal bearing is used for cooling and clearing debris and contaminants. In case of the high-speed applications, oil lubrication is preferred over grease. The oil viscosity used in different bearing applications depends on the rotating speeds, operating temperature, and applied load.

Grease lubrication:

Grease lubrication is used in the journal bearing when cooling of the bearing is not considered and in case of low-speed conditions. This lubrication is mostly suited when there is a frequent start-stop in the bearing operation to prevent shock loading. In case of high temperatures, low speed, and higher loading applications then the greases with higher viscosity base oil can be used. Whereas in case of low-temperature applications then the grease with lower viscosity base oil can be used.