



ESDU 96015

Issued December 1996

With Amendment A

May 2010

Design and material selection for dry rubbing bearings (Use of computer program A9615)

Associated software: ESDUpac A9615

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The Tribology Steering Group, which first met in September 1973, is continuing the work that was previously the responsibility of the former Bearing and Lubrication Committee, which first met in July 1964.

DESIGN AND MATERIAL SELECTION FOR DRY RUBBING BEARINGS (USE OF COMPUTER PROGRAM A9615)

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DESIGN AND MATERIAL SELECTION FOR DRY RUBBING BEARINGS (USE OF COMPUTER PROGRAM A9615)

1. INTRODUCTION

ESDUpac A9615 provides a computer program for the selection of bearing materials suitable for dry rubbing conditions. The program can also be used to analyse the performance of a dry rubbing bearing of known material. Use of the program for both selection and analysis is described in this Data Item.

The dry rubbing bearings dealt with by the program comprise a "self lubricating" material rubbing against a metallic or ceramic counterface. Wear of the bearing material is inevitable and the friction will usually be higher than with alternative types of bearings. Dry rubbing bearings are, however, often the first choice for applications where the operating conditions do not allow a liquid lubricant film to be maintained (*e.g.* high loads and low speeds). Typical operating regimes for various bearing types are shown in Sketch 2a of ESDU 87007. Dry rubbing bearings are also used when the ambient conditions are unsuitable for a conventional lubricant (*e.g.* high temperatures, vacuum, radiation or presence of solvents) or when contamination of the surroundings by the lubricant must be avoided (*e.g.* food handling). Sometimes, even when a liquid lubricant is present, a bearing material suitable for dry rubbing is used as a safeguard in case the fluid film breaks down or the lubricant supply fails.

The ESDUpac program described in this Data Item implements the analysis and selection methods of the previously issued Item, ESDU 87007, entitled "Design and material selection for dry rubbing bearings". In order to use the program effectively, that Data Item should be referred to for the theoretical limitations of the methods and for discussion of practical considerations. The methods apply for both journal and thrust bearings with either continuous rotation or oscillatory motion. Other dry rubbing bearings, such as might be used for reciprocating motion, can also be analysed. Corrections for intermittent operation, in which the bearing is periodically stationary, can be applied. The computer program allows flexibility in the specification of bearing geometry as explained later in this Data Item.

Dry rubbing bearing materials are often based on a polymer matrix incorporating various fillers intended to modify both the mechanical and tribological properties. Bearing materials based on bulk carbon/graphites and on metals with solid lubricant additions are also available. ESDUpac A9615 includes a database that covers all these basic types of materials. The database incorporates the results of tests on polymer based bearing materials carried out at the National Centre of Tribology's own laboratories. These results consist of a set of friction and wear data based on more than six years' work representing over 150 000 test hours (Derivation 3). Inevitably, some of the materials tested by NCT will no longer be available and also new materials will have subsequently become available. However, the program can be run with alternative databases the preparation of which is explained in this Data Item.

Issued December 1996 – 77 pages
With Amendment A, May 2010 – 77 pages
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2. NOTATION AND UNITS

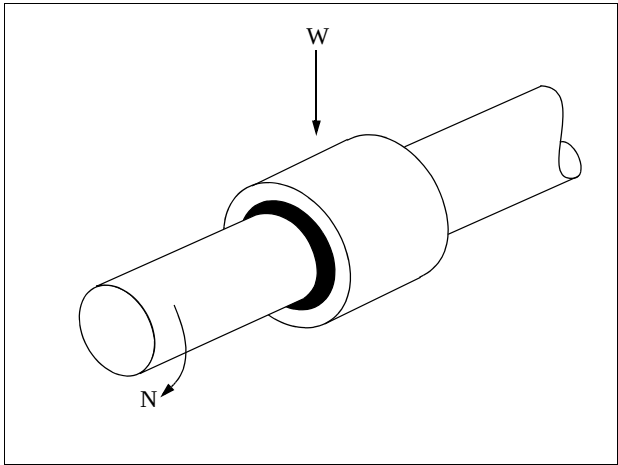
The symbols (parameter names) used in the input and output files for ESDUpac A9615 and in the associated database files, of necessity, differ from those used in ESDU 87007. Only the symbols used in these program files are listed in this Notation. Note also that the International System of units is used.

<i>Symbol</i>	<i>Description</i>	<i>Units</i>
A	bearing area (see Sketches 2.3 and 2.4)	m ²
airH	housing air access rating	—
airM	mating surface air access rating	—
b	axial length of journal bearing (see Sketch 2.3)	m
bdRat	bearing length to diameter ratio	—
bearM	other bearing proximity rating	—
bulKM	bulky mating surface rating	—
cfT	wear correction factor for pressure-temperature	—
cfR	wear correction factor for counterface roughness	—
cfV	wear correction factor for rubbing speed	—
cMu	coefficients for friction	—
cPT	coefficients for pressure-temperature boundary	—
cR	coefficients for roughness correction	—
cV	coefficients for rubbing speed correction	—
cW	coefficients for wear correction	—
d	inside diameter of journal bearing or thrust face (see Sketches 2.3 and 2.4)	m
DdRat	outside to inside diameter ratio	—
Dout	outside diameter of thrust bearing face (see Sketch 2.4)	m
desDat	name of descriptions database file	—
desMax	threshold number of candidate materials	—
disH	journal housing dissipation rating	—
envDat	name of environment database file	—
envID	environmental factor(s) identifier	—
forceH	housing forced air cooling rating	—
h	predicted depth of wear	m
hA	allowable depth of wear (after bedding-in)	m
hMax	limiting wear depth for material	m
hotH	housing hot structure rating	—
hotM	mating surface heat sources rating	—
		—

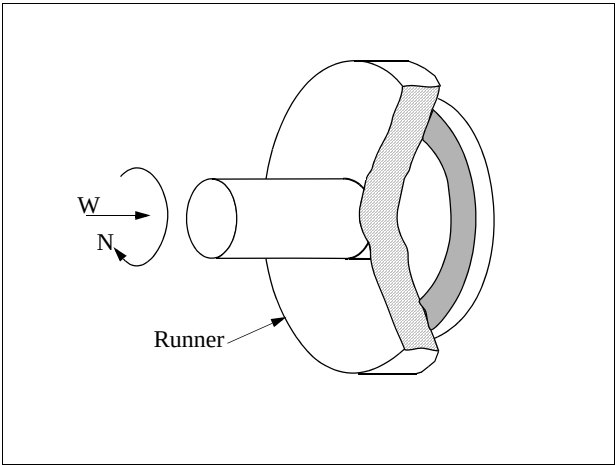
hRat	housing rating	–
Hf	frictional power loss of bearing	W
k	specific wear rate	m ² /N
k0	uncorrected specific wear rate of material	m ² /N
kC	thermal conductivity of counterface material	W/m K
kM	thermal conductivity of bearing material	W/m K
kPV	linear wear rate = $k \cdot P \cdot V$	m/s
logF	name of selection log file	–
matDat	name of properties database file	–
matID	bearing material(s) identifier	–
mRat	mating surface rating	–
mu	coefficient of friction	–
N	frequency of rotation or oscillation, <i>i.e.</i> revolutions per second or cycles per second (see Sketches 2.1, 2.2 and 2.5)	Hz
P	specific bearing load (bearing pressure) = W/A	N/m ²
R0	uncorrected thermal resistance constant	m ² K/W
Ra	counterface surface roughness value	m
res	required environmental resistance rating	–
sinkM	mating surface heat sink rating	–
sf	safety factor on life (t/t_R)	–
Ts	bearing rubbing surface temperature	degC
Ta	ambient temperature	degC
theta	angle between limits of oscillatory motion (see Sketch 2.5)	degree
Tlow	lowest expected environmental temperature	degC
Tmin	minimum working temperature for material	degC
Tmax	maximum allowable temperature for material at a particular specific load	degC
tOff	time stationary for intermittent motion	s
tOn	time in motion for intermittent motion	s
t	predicted bearing life	s
tR	required bearing life	s
V	effective rubbing speed	m/s
V50	datum limiting rubbing speed for bearing material (on counterface with thermal conductivity of 50 W/m K)	m/s
Vmax	limiting rubbing speed for material	m/s

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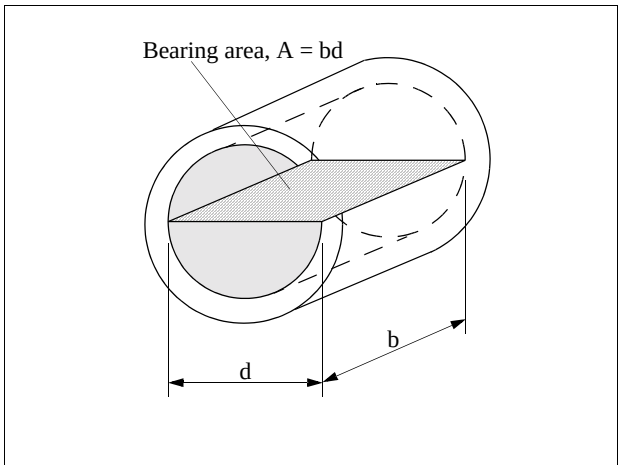
VH	counterface hardness (VPN)	—
VHmin	minimum acceptable counterface hardness (VPN)	—
W	bearing load (see Sketches 2.1 and 2.2)	N
waterH	housing water cooling rating	—



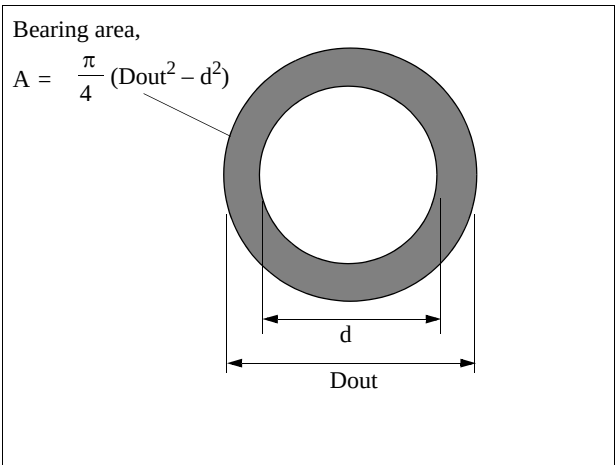
Sketch 2.1 Journal bearing configuration



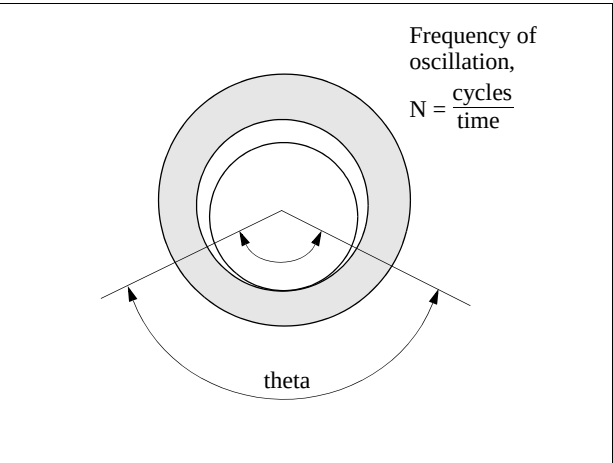
Sketch 2.2 Thrust bearing configuration



Sketch 2.3 Journal bearing dimensions



Sketch 2.4 Thrust bearing dimensions



Sketch 2.5 Typical oscillatory motion

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3. RUNNING THE PROGRAM

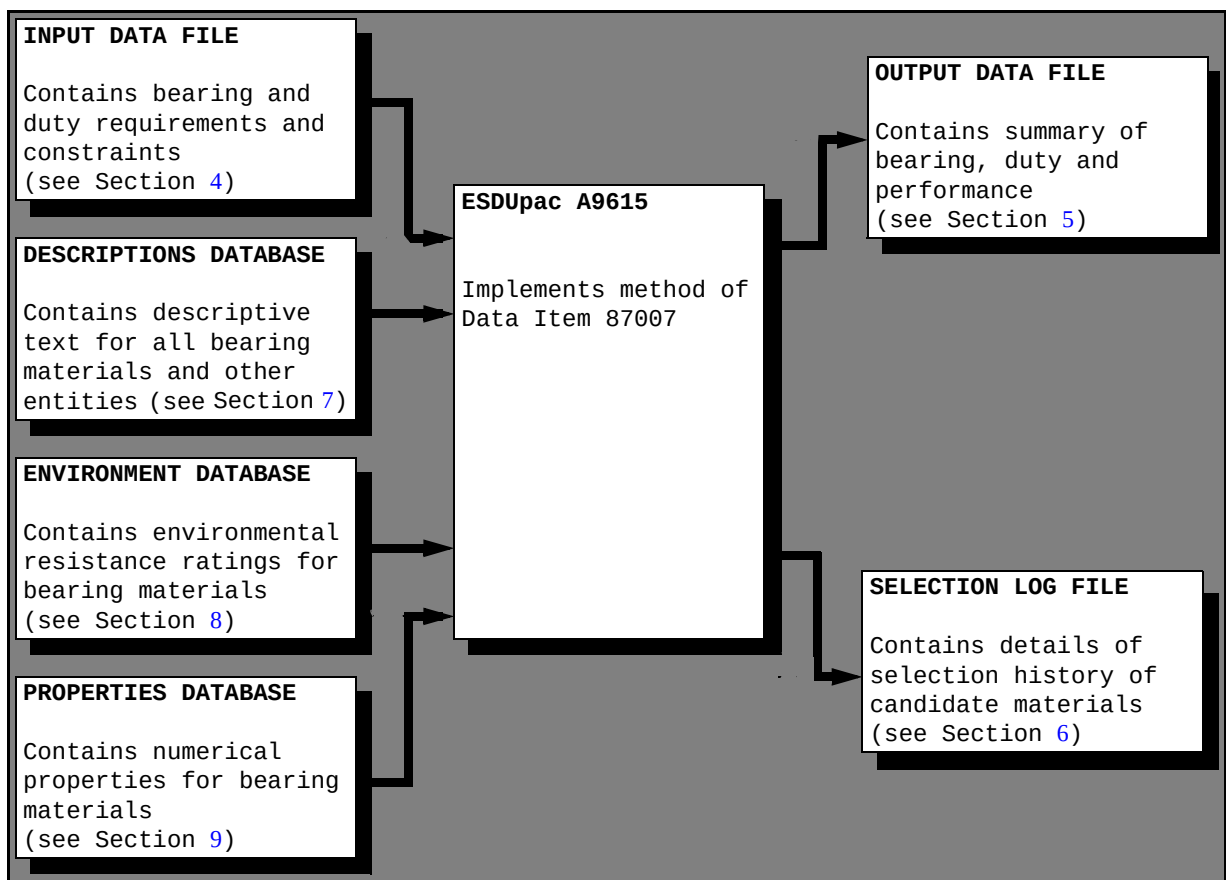
The supplied executable version of the ESDUpac program is suitable for Microsoft Windows operating systems.

To run the executable version of the program from the keyboard, type the program name[†], A9615V10, at the operating system prompt and press return. The program will prompt for the name of the input data file and the name of the output data file. Alternatively, the name of the input data file and the name of the output data file can be specified on the command line using the operating system redirection symbols as in,

```
A9615V10 < EXP1.IN > EXP1.OUT
```

If a problem occurs in reading the data from the input file or if the data are invalid in any way, error messages are recorded in the output file. These error messages describe the error and, where applicable, indicate the line number at which the error occurred in the input data file.

A number of example input data files are supplied with the program (files with the extension ".IN"). These input files and the corresponding output data files (with the extension ".OUT") can be examined using a text editor. Three database files, 'DRBDES.DAT', 'DRBENV.DAT' and 'DRBMAT.DAT' are also provided. These files too can be examined using a text editor. All of these files are described in the following sections and an overview of the purpose of each type of file is shown here.



[†] The program name used here is that of Version 1.0 (V10) which may not be the latest.

4. THE INPUT DATA FILE

The input data file provides the specification of the bearing and duty requirements for the application being considered. Input data files are prepared using a text editor and, in most cases, new input files will be produced by editing existing input files.

In order to run the ESDUpac program, it is only necessary to specify the area of the bearing, A , the effective rubbing speed, V , and the applied load, W . All values are expected to be in SI units as defined in the Notation of Section 1. An example minimal input file is shown here.

```
ESDU A9615
A      0.900 E-03
V      94.2  E-03
W      800
```

In most cases, however, the input data file will include additional requirements and constraints. An example input data file, which includes wear depth and wear life requirements and which incorporates comments for documentation purposes, is shown here.

```
ESDU A9615
* EXAMPLE BEARING
* ~~~~~
* In this example, the area of the bearing and the effective rubbing speed
* have been specified directly.
* Bearing size, speed and load
* ~~~~~
A      bearing area ..... = 0.900 E-03 m^2
V      bearing rubbing speed ..... = 94.2 E-03 m/s
W      bearing load ..... = 800 N
* Life and wear requirements
* ~~~~~
tR     required bearing life ..... = 1.8E6 s
hA     allowable depth of wear ..... = 500E-6 m
```

All ESDUpac programs in the Tribology Series allow free format specification of input data in the sense that input parameters can be specified in any order and comments can be placed in the input file for documentation purposes. In the example input file, the input parameters have been grouped under two separate headings inserted as comments. The file, however, would be equally valid if the input parameters were arranged in an entirely different order. The only mandatory requirement, as far as the order of information is concerned, is that the first non-comment line must identify the name of the ESDUpac program, A9615 in this case, that is to be used for the analysis. The following observations apply (a formal specification of the input file format is given in Appendix A).

- (i) All lines beginning with an asterisk, '*', are comment lines. Such comments can be freely inserted for documentation purposes.
- (ii) The first non-comment line in the input file specifies the name of the ESDUpac program that is to be used for the analysis. The keyword 'ESDU' is used for this purpose and the line must be present in all input files.
- (iii) Each input parameter has an identifying symbol. The explanatory text following the parameter symbol may be omitted in which case the '=' sign is not strictly necessary. Input parameters can be specified in any order.

- (iv) Units have been stated in the file purely for documentation purposes. Extra text following the actual numerical value is ignored.

In this ESDUpac program, default values are provided for certain input parameters (see Section 4.7) and, accordingly, not all input parameters need be specified. Some other parameters can be left unspecified if they are not known or are not relevant for the application being considered. An input parameter may be left unspecified in one of three ways.

- (i) Put a question mark, '?', in place of the parameter value.
- (ii) Comment-out the parameter specification by placing an asterisk, '*', at the start of the line.
- (iii) Omit the parameter specification entirely.

In the example input files considered so far, only very brief details of the bearing and the application have been specified. The area of the bearing has been specified directly even though the program allows the actual dimension of the bearing, journal or thrust, to be specified as explained in the following sections. The effective rubbing speed of the bearing has been specified directly as well even though the program allows the details of the motion, continuous or oscillatory, to be specified. Also the example input files contain no details of the bearing assembly consisting of housing and mating surface which are of significance for heat dissipation from the bearing. ESDUpac A9615 provides defaults for the constructional parameters of the bearing housing and mating surface and so their omission from the input files is of no great consequence for many applications. More importantly, however, the example input files include no information about the operating environment of the bearing nor the level of environmental resistance required of any bearing material used. Even so, the ESDUpac program is able to offer a list of candidate bearing materials if run with these input files. The following example input file includes a more detailed problem specification for improved accuracy (see Section 4.3 for guidance on housing and mating surface ratings).

```
ESDU A9615

* EXAMPLE BEARING
* -----
* In this example input file, a journal bearing is specified along with
* details of the bearing assembly and the operating environment of the
* bearing.

* Bearing size, speed and load
* -----
d      inside diameter of bearing ..... = 0.03      m
b      axial length of bearing ..... = 0.03      m
N      frequency of rotation ..... = 1.0      Hz
W      bearing load ..... = 800      N

tOn    time in motion for intermittent motion .... = 10      s
tOff   time stationary for intermittent motion ... = 10      s

* Housing and mating surface
* -----
airH   housing air access rating ..... = Good
disH   journal housing dissipation rating ..... = Moderate
forceH housing forced air cooling rating ..... = No
waterH housing water cooling rating ..... = No
hotH   housing hot structure rating ..... = Good

airM   mating surface air access rating ..... = Moderate
bulkM  bulky mating surface rating ..... = Yes
sinkM  mating surface heat sink rating ..... = No
bearM  bearings proximity rating ..... = Good
hotM   mating surface heat sources rating ..... = No
```

(continued)

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```
* Environmental factors
* ~~~~~
Ta    ambient temperature ..... = 40          degC
Tlow  lowest expected environmental temperature .. = -20        degC

envID environmental factor identifier(s) ..... = water, rad
res   required environmental resistance ..... = 3

* Life and wear requirements
* ~~~~~
tR    required bearing life ..... = 1.8E6        s
hA    allowable depth of wear ..... = 500E-6      m
```

The additional information in this file specifies details of the housing and mating surface of the bearing assembly and also specifies that the bearing will operate intermittently in an environment involving water immersion and gamma radiation.

As with other ESDUpac programs in the Tribology Series, ESDUpac A9615 allows additional cases to be appended to the initial input data with the use of the '\$CASE' keyword. Any number of these additional cases can be appended and they, effectively, allow the ESDUpac program to repeat the calculations with the initial input data modified in some way. A single parameter, or several parameters, can be specified for each additional case and the specified values overwrite the values that existed for the previous case. Additional cases appended with \$CASE provide a convenient way of performing a sensitivity analysis in which the effect of changing one or, perhaps, two parameters would be explored. This use of the program for sensitivity analysis is illustrated in Section 10.

4.1 Database Files

This particular ESDUpac program requires access to three database files that provide information on the environmental resistances, the wear rates and the duty limits of the bearing materials from which a selection will be made. The three database files supplied with this ESDUpac are called "DRBDES.DAT", "DRBENV.DAT" and "DRBMAT.DAT". The names of the database files that are to be used by the program are specified in the input data file as shown in the following input file fragment.

```
* Names of database files
* ~~~~~
desDat name of descriptions database = C:\ESDU\DATBAS\DRBDES.DAT
envDat name of environment database  = C:\ESDU\DATBAS\DRBENV.DAT
matDat name of properties database   = C:\ESDU\DATBAS\DRBMAT.DAT
```

Note that the database files need not reside in the directory from which the ESDUpac program is being run but the full path to the file must then be specified. Also, if only the supplied databases are to be used, (alternative databases can be prepared as explained in Sections 7, 8 and 9) and if they reside in the directory from which the ESDUpac program is being run, there is no need to specify the file names in the input file because the program will open the supplied databases by default.

4.2 Bearing Geometry, Load, and Motion

Before a bearing can be analysed and before suitable bearing materials can be selected, the rubbing area of the bearing, the effective rubbing speed and the bearing specific load must all be established. With a conventional bearing geometry, such as a journal or thrust bearing, these three parameters can be established by the program from specified bearing dimensions, rotational frequency and applied load. With less conventional geometries, the parameters are not so easily established. Further complications arise if the motion is oscillatory rather than continuous and if the bearing is operated intermittently.

With journal bearings, the diameter of the journal, d , and the axial width of the bearing, b , are specified. With thrust bearings, the inside diameter of the thrust face, d , and the outside diameter of the thrust face, D_{out} , are specified. With both bearing types, and if the motion is continuous, the speed of the bearing is specified by the rotational frequency, N . The following input file fragment specifies a journal bearing assembly with continuous rotational motion and a steady load[†].

```
* Dimensions, speed and load for a journal bearing
* ~~~~~
d      diameter of journal      = 0.25      m
b      axial length of bearing  = 0.075     m
N      rotational frequency     = 4.0       rev/s
W      bearing load             = 1000      N
```

A thrust bearing, also with continuous rotational motion and steady loading, would be specified similarly.

```
* Dimensions, speed and load for a thrust bearing
* ~~~~~
d      inside diameter of thrust face = 0.25      m
Dout   outside diameter of thrust face = 0.75      m
N      rotational frequency           = 4.0       rev/s
W      bearing load                   = 1000      N
```

Note that the type of bearing does not have to be specified explicitly in the input file because the program detects automatically which bearing type is intended. If both of the parameters b and D_{out} were specified, the program would issue an error message indicating that the bearing specification was inconsistent.

With both journal bearings and thrust bearings, the rotational motion can be oscillatory instead of continuous in which case the angle between the limits of the motion must be specified. The following input file fragment specifies a journal bearing with a 90 degree oscillatory motion.

```
* Dimensions, speed and load for a journal bearing
* ~~~~~
d      diameter of journal      = 0.25      m
b      axial length of bearing  = 0.075     m
N      rotational frequency     = 4.0       rev/s
W      bearing load             = 1000      N
theta  angle between limits of oscillation = 90        degree
```

Bearings that are not conventional journal or thrust bearings can still be analysed but estimates of the area of the bearing and the effective rubbing speed must then be specified directly in the input file. In the following input file fragment, a linear reciprocating bearing is specified.

[†] ESDUpac A9615 can only deal with steady loading. The bearing material manufacturers should be consulted in all applications involving varying loads, rotating loads or shock loads. However, a technique for dealing with slowly varying loading is illustrated in Example 3 (Section 10.3).

```
* Area, velocity and load for a reciprocating bearing
* ~~~~~
* Reciprocating at 3 Hz over a stroke of 0.2 m gives V = 2 x 0.2 x 3.0 m/s
*
A      bearing area           = 0.25      m^2
V      effective rubbing speed = 1.20      m/s
W      bearing load           = 1000      N
```

In all of the above example input file fragments, the bearing is assumed to be operated continuously. If the bearing is operated intermittently, it is necessary to specify the time periods during which the bearing is in motion and during which the bearing is stationary. In the following input file fragment, intermittent operation is specified for the example reciprocating bearing. Intermittent operation of a journal or thrust bearing would be specified similarly.

```
* Area, velocity and load for a reciprocating bearing
* ~~~~~
* Reciprocating at 3 Hz over a stroke of 0.2 m gives V = 2 x 0.2 x 3.0 m/s
*
A      bearing area           = 0.25      m^2
V      effective rubbing speed = 1.20      m/s
W      bearing load           = 1000      N

tOn    time in motion for intermittent operation = 10.0      s
tOff   time stationary for intermittent operation = 15.0      s
```

4.3 Bearing Housing and Mating Surface

The performance and life of a dry rubbing bearing are influenced strongly by the rubbing surface temperature of the bearing material. In general, this rubbing surface temperature is above ambient due to frictional heat generation, balanced against heat dissipation. Frictional heat is dissipated from a bearing assembly through both the housing and the mating surface. Consequently the design of both can affect the bearing surface temperature.

ESDUpac A9615 uses heat dissipation ratings, one for the bearing housing and one for the mating surface, to estimate the thermal resistance of the bearing assembly. The program defaults to typical values for these ratings and so, for a preliminary analysis, they do not have to be specified. Where the housing or the mating surface is known to be unusual, however, consideration should be given to specifying the ratings. For example, if the housing material is plastic, rather than the usual metallic, heat dissipation will be very poor and a housing rating, `hRat`, of zero is appropriate. The following example input file fragment includes such a specification.

```
* Housing and mating surface ratings
* ~~~~~
* Housing material is plastic so heat dissipation is very poor
*
hRat   housing rating           = 0
```

A housing made from plastic is a particularly extreme example for which direct specification of the housing rating is appropriate. In many cases the housing and mating surface ratings will be unknown and it is then advisable to specify the details of the assembly so that the program can calculate appropriate values.

The details of the bearing housing can be specified by the parameters `airH`, `hoth`, `dish`, `forceH` and `waterH` according to the following guidance. Not all of the parameters need be specified, only those known to be atypical.

- (i) Heat removal from the bearing is facilitated by the provision of unrestricted access of the surrounding air to as much as possible of the surface of the assembly. The parameter, **airH**, can be specified as Poor, Moderate or Good to indicate the level of air access to the bearing assembly.

Poor	Air has unrestricted access to less than 40% of assembly surface.
Moderate	Air has unrestricted access to between 40% and 70% of assembly surface.
Good	Air has unrestricted access to more than 70% of assembly surface.

- (ii) Heat removal from the bearing is detrimentally affected by the proximity of structures or components that are at a temperature significantly above ambient. The parameter, **hotH**, can be specified as Poor, Moderate or Good to indicate the proximity, or otherwise, of such structures.

Poor	Adjacent structures are hot.
Moderate	Adjacent structures are hot but insulated from housing.
Good	None of adjacent structures is hot.

- (iii) For journal bearings only, joints between the housing and the rest of the structure will act as boundaries of the housing if they lie across the direction of heat flow and have low conductivity. Severe reductions in cross section can also act as boundaries. The parameter, **disH**, can be specified as Poor, Moderate or Good to indicate the effectiveness of the journal housing heat dissipation.

Poor	There are joints or other restrictions within 1.5 journal diameters of bearing.
Moderate	Any joints or other restrictions are more than 1.5 journal diameters from bearing but are closer than 3 diameters.
Good	Any joints or other restrictions are more than 3 journal diameters from bearing.

- (iv) Heat removal from the bearing is facilitated by forced air cooling, often conveniently achieved by means of a fan on the shaft. The parameter, **forceH**, can be specified as Yes or No to indicate if there is any forced air cooling.

No	There is no forced air cooling.
Yes	There is forced air cooling.

- (v) Heat removal from the bearing is facilitated by the provision of extra cooling methods such as internal water cooling passages. The parameter, **waterH**, can be specified as Yes or No to indicate if there is any water cooling or other equally effective cooling.

No	There is no water cooling or other cooling.
Yes	There is water cooling or other cooling.

In the following input file fragment, the details of an example bearing housing have been specified.

```
* Housing and mating surface ratings
* ~~~~~
*
airH  housing air access rating      = Good
hotH  housing hot structure rating   = Good
disH  journal housing dissipation rating = Moderate
forceH housing forced air cooling rating = No
waterH housing water cooling rating    = No
```

In a similar fashion, the details of the mating surface can be specified by the parameters `airM`, `bearM`, `bulkM`, `sinkM` and `hotM` according to the following guidance. Again, not all of the parameters need be specified, only those known to be atypical.

- (i) Heat removal from the bearing is facilitated by the provision of unrestricted access of the surrounding air to as much as possible of the mating surface of the bearing. The parameter, `airM`, can be specified as Poor, Moderate or Good to indicate the level of air access to the mating surface.

Poor	Air has unrestricted access to less than 20% of mating surface.
Moderate	Air has unrestricted access to between 20% and 50% of mating surface.
Good	Air has unrestricted access to more than 50% of mating surface.

- (ii) Where bearings share a common shaft, the individual effective shaft surface areas may be reduced, resulting in decreased heat dissipation from each bearing assembly. The parameter, `bearM`, can be specified as Poor, Moderate or Good to indicate the proximity, or otherwise, of other bearings.

Poor	There are other bearings closer than 3 times the inside diameter of the bearing.
Moderate	Any other bearings are more than 3 times the inside diameter from the bearing but are closer than 6 diameters.
Good	There are no other bearings within 6 times the inside diameter of the bearing.

- (iii) Heat removal from the bearing is facilitated by a substantial increase (40% or more) in the cross section of the mating surface component close to the bearing. The parameter, `bulkM`, can be specified as Yes or No to indicate if there are any such increases in cross section.

No	There is no substantial increase in cross section within 3 times the inside diameter of the bearing.
Yes	There is a substantial increase in cross section within 3 times the inside diameter of the bearing.

- (iv) Heat removal from the bearing is facilitated by the mating surface component being in contact with any other structure or component that can be considered to act as a heat sink. The parameter, `sinkM`, can be specified as Yes or No to indicate if there are any such heat sinks.

No	The mating surface is not in contact with a heat sink.
Yes	The mating surface is in contact with a heat sink.

- (v) Heat removal from the bearing is detrimentally affected by external inputs of heat to the shaft or mating surface. Thermal insulation or other means of cooling can prevent such inputs of heat. The parameter, `hotM`, can be specified as Yes or No to indicate if there are any such heat inputs.

No	There are no external heat inputs or heat input is prevented by insulation.
Yes	There are external inputs of heat.

The following input file fragment includes details of a complete bearing assemble, housing and mating surface. Note that it is permissible to specify just the first letter of the ratings. For example, instead of specifying 'Moderate' it is permissible to specify just 'M'[†].

[†] ESDUpac A9615 interprets specifications for enumerated parameters, such as these housing and mating surface parameters, by matching, in a case insensitive manner, the characters of the specified "value" with the possible values. Thus, 'm', 'M' and 'Mod' can all be used in the input file to signify 'Moderate'.

```
* Housing and mating surface ratings
* ~~~~~
*
airH  housing air access rating           = G
hotH  housing hot structure rating        = G
disH  journal housing dissipation rating  = M
forceH housing forced air cooling rating   = N
waterH housing water cooling rating        = N

airM  mating surface air access rating    = M
bearM  other bearing proximity rating     = G
bulkM  bulky mating surface rating        = Y
sinkM  mating surface heat sink rating    = N
hotM  mating surface heat sources rating  = N
```

Three other parameters associated with the mating surface, although not associated with establishing a heat dissipation rating, are the counterface thermal conductivity, kC , the counterface surface roughness value, Ra , and the counterface hardness (VPN), VH .

The counterface thermal conductivity (see Reference 1) is used to establish a limiting rubbing speed based on information provided in the properties database (see Section 9). If not specified, a default value (see Table 4.2) corresponding to a low carbon steel counterface is assumed. If the counterface is not low carbon steel it is advisable to specify a value for kC in the input file. For example, a suitable value for a stainless steel counterface would be 18 W/m K while a suitable value for a plastic counterface might be as low as 0.3 W/m K. In the following input file fragment a stainless steel counterface is specified with a surface Ra value of 0.5 μm and a hardness of 250 VPN.

```
* Stainless steel counterface, 0.5 um Ra
* ~~~~~
kC    thermal conductivity for counterface = 18      W/m K
Ra    counterface surface roughness value = 0.5E-6    m
VH    counterface hardness (VPN)..... = 250
```

Bearing materials incorporating abrasive fillers, such as glass fibre, require a harder counterface than unfilled polymers or composites with only mildly abrasive fillers, such as cotton or synthetic fibres. If the hardness of the counterface is specified, as in the example input file fragment, the ESDUpac program rejects any bearing materials that require the counterface to be harder than the specified value. If the counterface hardness, VH , is not specified it is assumed that an adequately hard counterface will be provided for whatever bearing material is used.

The wear rate of polymers and their composites is affected by the roughness of the counterface. Usually there is an optimum surface finish for any particular bearing material and accelerated wear rates can be expected with both rougher and smoother surfaces. If the counterface surface roughness, Ra , is not specified an optimum surface finish is assumed by the program and no wear rate correction is applied. Sometimes, however, the counterface surface finish will be dictated by other factors and the value should then be specified in the input file. The wear rate correction applied by the program when the surface finish has been specified assumes a counterface hardness at least equal to the recommended minimum hardness for the bearing material (see ESDU 87007, Figure 4.3). Some reduction in bearing material wear rate can be obtained by using a softer counterface, especially when the bearing material incorporates abrasive fillers, but there is then a danger that the counterface will wear preferentially.

4.4 Bearing Environmental Requirements

Environmental factors such as operation in a vacuum, the presence of solid or liquid contaminants, high levels of ionising radiation, or very high or low temperatures may greatly restrict the choice of bearing and counterface materials.

The effect of water, and of some other solvents, is complex. Some types of polymers, especially when unfilled, are prone to swell in the presence of water which could lead to loss of bearing clearance (see Sketch 4b of Derivation 2). PTFE based bearing materials have good chemical resistance but the presence of a liquid such as water can impair their performance. Reinforced thermoset materials and solid lubricant impregnated metals, on the other hand, are tolerant of the presence of water and may even benefit.

The effect of abrasive particle contamination is invariably detrimental and difficult to quantify. Thin layer bearing materials and carbon/graphites are not usually recommended for abrasive conditions while reinforced thermoset materials and solid lubricant impregnated metals are usually regarded as relatively tolerant. Further general guidance on environmental factors can be found in Derivation 2.

Information on the resistances of the bearing materials to a range of environmental factors is held in the environment database (see Section 8). The environment database supplied as part of this ESDUpac uses a resistance rating of from 1 to 5 where 5 indicates excellent resistance and 1 indicates no resistance (see Section 7.3) and provides the value of the rating for a number of broad classes of environment including water immersion and gamma radiation. The environmental factors that are present and the minimum level of resistance that the bearing material is required to have to these environmental factors can be specified in the input file by the parameters `enVID` and `res`. In the following input file fragment a minimum resistance rating of 4 (corresponding to good resistance) to water immersion has been specified.

```
* Good resistance to water immersion required
* ~~~~~
enVID  working environment identifier      = water
res    environmental resistance rating     = 4
```

For some applications a certain amount of judgement will be required in specifying the required resistance rating and it might then be advisable to investigate the effect of changing the rating by rerunning the program.

If more than one environmental factor is to be taken into account, a comma delimited list of environment identifiers can be specified. In the following example input file fragment both water immersion and gamma radiation have been specified.

```
* Good resistance to water immersion and gamma radiation required
* ~~~~~
enVID  working environments identifier      = WATER, RAD
res    environmental resistance rating     = 4
```

Note that the case (upper or lower) of the environmental identifiers specified is unimportant but only those identifiers declared in the currently loaded databases will, of course, be recognised by the program (see Section 7). Although more usefully employed to specify ranges of bearing materials, as explained in Section 4.5, the '-' characters can be used to specify a range of environments.

Both of the parameters `enVID` and `res` are optional input parameters and if there are no special environmental requirements they should be left unspecified.

The expected environmental temperature of the application is specified by the ambient temperature, T_a , and the lowest expected environmental temperature, T_{low} , as shown in the following input file fragment.

```
* Expected environmental temperatures
* ~~~~~
Ta      ambient temperature      = 40.0      degC
Tlow    lowest expected environmental temperature = -20.0     degC
```

The value of the ambient temperature, T_a , provides the datum for the calculation of the operating rubbing surface temperature of the bearing (see Section 6). Both of the parameters T_a and T_{low} can be left unspecified in which case the program uses the default values indicated in Table 4.2.

4.5 Bearing Life Requirements and Materials

Wear of a bearing is usually the main factor determining its life. In journal bearings, the amount of wear that can be tolerated will, for most applications, be determined by considerations of the accuracy of location required. In thrust bearings, and other bearing types, the allowable wear may be determined by the allowable displacement of the moving component from its nominal location.

For the purposes of selecting a dry rubbing bearing material it is usual to specify the allowable wear depth after an allowance for bedding-in. During the bedding-in period, most materials have relatively high wear rates. However, the duration of the bedding-in is usually short and the total bedding-in wear is relatively small (see ESDU 87007, Figure 7.1). In the following input file fragment, an allowable wear depth, after bedding-in, of 500 μm has been specified.

```
* Require 500 hours life to wear depth of 500 um
* ~~~~~
hA      allowable depth of wear      = 500.0E-6 m
tR      required bearing life        = 1.8E6      s
```

The specified allowable depth of wear, h_A , together with the required life of the bearing, t_R , determines the acceptable wear rate of any material used in the bearing. In the above input file fragment, a life of 500 hours has been specified during which time the bearing wear should not exceed that specified. Note that some bearing materials have only a limited depth of material available to accommodate wear and that might well be less than the allowable wear depth specified in the input file. ESDUpac A9615 makes allowance for such materials, automatically using information from the properties database (see Section 9).

Given a specification of the required life and wear depth, as described above, ESDUpac A9615 selects those bearing materials from the databases that provide acceptably low wear rates and satisfy all other requirements, such as environmental resistance requirements (see Section 4.4). A list of the candidate bearing materials is included in the output from the program (see Section 5) and a detailed log of the selection criteria applied is provided in the selection log file (see Section 4.6).

It is not mandatory to specify the allowable depth of wear, h_A , and the required life, t_R , but if either or both are left unspecified the ESDUpac program cannot, of course, apply any wear rate criteria in selecting materials. If both of these parameters are left unspecified, for example, the ESDUpac program calculates the wear rate of the bearing materials under the specified operating conditions. If only the life is specified, the program calculates the depth of wear that would occur over this period. Similarly appropriate calculations are performed if only the wear depth or if both wear depth and life are specified. The information provided by the program in all of these various circumstances is explained more fully in Section 6.

Normally, all of the bearing materials in the databases are considered in any analysis or selection. ESDUpac A9615 is, however, able to analyse a bearing design with just a single bearing material or to analyse and select from a sub-set of materials. If this option of the program is required, the material(s) of interest must, of course, be specified in the input file. Each of the bearing materials in the database files has an identifier (see Section 7) which can be used for this specification purpose. In the following input file fragment, material A4, which is a high density polyethylene, has been specified.

```
* High density polyethylene
* ~~~~~
matID bearing material identifier = A4
```

A number of bearing materials can be specified by using a comma delimited list of identifiers as shown in the following input file fragment.

```
* Materials A1 to A4
* ~~~~~
matID bearing material identifiers = A1, A2, A3, A4
```

A range of materials can be specified by using the '-' character so that, for example, the materials A1, A2, A3 and A4 specified in the above input file fragment could also be specified as shown here.

```
* Materials A1 to A4
* ~~~~~
matID bearing material identifiers = A1 - A4
```

Finally, commas and '-' characters can be used in combination as shown here.

```
* Materials A1 to A5 and B1 to B11 missing out B6 and B7
* ~~~~~
matID = A1 - A5, B1 - B5, B8 - B11
```

4.6 Other Parameters

In the previous section, it was mentioned that a detailed log of the selection criteria applied to the bearing materials is provided in the selection log file. By default, this log file is named 'DRBLOG.OUT'. If an alternative name is required it must be specified in the input file as shown here. The contents of the log file is described in Section 6. .

```
* A log should be sent to file SELOG.OUT
* ~~~~~
logF name of selection log file = SELOG.OUT
```

It was also mentioned that the output file contains a list of the candidate materials. If there is a large number of candidates, only a short description of each material is provided but if there are only a few candidates, expanded information is provided together with a summary of the performance. The threshold number of candidates defaults to 10 but can be set from the input file. In the following input file fragment, a threshold of 20 candidates has been specified.

```
* Give full information of not more than 20 candidates
* ~~~~~
desMax threshold number of candidate materials = 20
```

4.7 Summary of Input Parameters

Table 4.1 describes all the input parameters. Only a subset of the parameters would, of course, be used in any one input file. More detailed descriptions for the input parameters are given in Appendix B together with comments on their purpose and specification. The allowable values for all input parameters and, where applicable, the default values are summarised in Table 4.2. The program issues error messages stating the valid range if any of the specified input parameters are invalid. Note that ESDUpac A9615 applies further validation checks to many of the input parameters in combination. For example, warnings are issued if the ratio of the length to the diameter of a journal bearing exceeds 1.5 or if the ratio of the outside and inside diameters of a thrust bearing exceeds 2.0. Also note that further validation checks are applied to and originate from the information in the database files used by the program. For example, an error message is issued if an attempt is made to use an environmental factor identifier that has not been declared in the descriptions database (see Section 7).

TABLE 4.1 DESCRIPTIONS OF INPUT PARAMETERS

Symbol	Description
desDat	name of descriptions database file
envDat	name of environment database file
matDat	name of properties database file
A	bearing area
V	effective rubbing speed
d	inside diameter of journal bearing or thrust face
b	axial length of journal bearing
Dout	outside diameter of thrust bearing face
W	bearing load
N	frequency of rotation or oscillation
theta	angle between limits of oscillatory motion
tOn	time in motion for intermittent motion
tOff	time stationary for intermittent motion
hRat	housing rating
mRat	mating surface rating
airH	housing air access rating
hotH	housing hot structure rating
dish	journal housing dissipation rating
forceH	housing forced air cooling rating
waterH	housing water cooling rating
airM	mating surface air access rating
bearM	other bearing proximity rating
bulkM	bulky mating surface rating
sinkM	mating surface heat sink rating
hotM	mating surface heat sources rating
kC	thermal conductivity of counterface material
Ra	counterface surface roughness value
VH	counterface hardness (VPN)
Ta	ambient temperature
Tlow	lowest expected environmental temperature
envID	working environment identifier(s)
res	required environmental resistance rating
tR	required bearing life
hA	allowable depth of wear after bedding-in
matID	bearing material identifier(s)
logF	name of selection log file
desMax	threshold number of candidate materials

TABLE 4.2 ALLOWABLE VALUES AND DEFAULTS

Symbol	Allowable values	Default (if any)
desDat	Valid file name or path	'DRBDES.DAT'
envDat	Valid file name or path	'DRBENV.DAT'
matDat	Valid file name or path	'DRBMAT.DAT'
A	40E-6 to 4.0 m ²	-
V	1.0E-3 to 20.0 m/s	-
d	0.002 to 2.0 m	-
b	0.002 to 2.0 m	-
Dout	0.0022 to 2.0 m	-
W	0.4 to 12.0E9 N	-
N	159.2E-6 to 1592.0 Hz	-
theta	1.0 to 3600.0 degree	-
tOn	1.0 to 600.0 s	-
tOff	0.0 to 2400.0 s	-
hRat	0 to 17	7
mRat	2 to 11	6
airH	Good/Moderate/Poor (G/M/P)	Moderate
hotH	Good/Moderate/Poor (G/M/P)	Moderate
dish	Good/Moderate/Poor (G/M/P)	Moderate
forceH	Yes/No (Y/N)	No
waterH	Yes/No (Y/N)	No
airM	Good/Moderate/Poor (G/M/P)	Moderate
bearM	Good/Moderate/Poor (G/M/P)	Moderate
bulkM	Yes/No (Y/N)	No
sinkM	Yes/No (Y/N)	No
hotM	Yes/No (Y/N)	No
kC	0.2 to 200.0 W/m K	50.0 W/m K
Ra	0.01E-6 to 2.0E-6 m	-
VH	0 to 4000	-
Ta	-273.0 to 1000.0 degC	20.0 degC
Tlow	-273.0 to 1000.0 degC	0.0 degC
envID	Valid identifier(s) (see Section 7)	''*
res	Valid rating (see Section 7)	-
tR	0.0 to 1.0E+8 s	-
hA	0.0 to 0.005 m	-
matID	Valid identifier(s) (see Section 7)	''*
logF	Valid file name or path	'DRBLOG.OUT'
desMax	0 to 1000000	10

* Note that if the parameter envID is left unspecified (blank), it is assumed that there are no special environmental requirements. If the parameter matID is left unspecified (blank), it is assumed that the user has no special material preferences and so wishes all the bearing materials in the database to be assessed for the specified duty.

5. THE OUTPUT DATA FILE

The output data file includes the results of the analysis together with a copy of the corresponding input data (see Section 4). The file can be examined using a text editor. An example output data file is shown here.

```
-----
ESDU International plc.

PROGRAM A9615 Version 1.0
ESDUpac Number:   A9615
ESDUpac Title:    Design and material selection for dry rubbing bearings.
Data Item Number: 96015
Data Item Title:  Design and material selection for dry rubbing bearings.
                  (Use of computer program A9615).
ESDUpac Version:  1.0, November 1996.
-----
Name of input data file
C:\ESDU\DRYRUB\SPEC2.IN

INPUT DATA
~~~~~

* EXAMPLE BEARING
* ~~~~~
* In this example input file, a journal bearing is specified along with
* details of the bearing assembly and the operating environment of the
* bearing.

* Bearing size, speed and load
* ~~~~~
d      inside diameter of bearing ..... = 0.03      m
b      axial length of bearing ..... = 0.03      m
N      frequency of rotation ..... = 1.0      Hz
W      bearing load ..... = 800      N

tOn    time in motion for intermittent motion .... = 10      s
tOff   time stationary for intermittent motion ... = 10      s

* Housing and mating surface
* ~~~~~
airH    housing air access rating ..... = Moderate
disH    journal housing dissipation rating ..... = Moderate
forceH  housing forced air cooling rating ..... = No
waterH  housing water cooling rating ..... = No
hotH    housing hot structure rating ..... = Good

airM    mating surface air access rating ..... = Moderate
bulkM   bulky mating surface rating ..... = Yes
sinkM   mating surface heat sink rating ..... = No
bearM   bearings proximity rating ..... = Good
hotM    mating surface heat sources rating ..... = No

* Environmental factors
* ~~~~~
Ta      ambient temperature ..... = 40      degC
Tlow    lowest expected environmental temperature .. = -20      degC
envID   environmental factor identifier(s) ..... = water, rad
res     required environmental resistance ..... = 3

* Life and wear requirements
* ~~~~~
tR      required bearing life ..... = 1.8E6      s
hA      allowable depth of wear ..... = 500E-6      m

* Other parameters
* ~~~~~
logF    name of selection log file ..... = LOG.OUT
```

(continued)

OUTPUT DATA

BEARING SPECIFICATION

Bearing is journal

d journal diameter = 30.0 E-03 m
b axial length of bearing = 30.0 E-03 m
bdRat bearing length to diameter ratio = 1.00
W bearing load = 0.800 E+03 N

Motion is continuous

N frequency of rotation = 1.00 Hz

A bearing area = 0.900 E-03 m²

V bearing rubbing speed = 94.2 E-03 m/s

P bearing specific load = 0.889 E+06 N/m²

Operation is intermittent

tOn time in motion = 10.0 s

tOff time stationary = 10.0 s

HOUSING RATING AND MATING SURFACE RATING

Housing rating:

airH housing air access rating = Moderate

hotH housing hot structure rating = Good

disH housing dissipation rating = Moderate

forceH housing forced air cooled = No

waterH housing water cooled or other cooling = No

hRat housing rating = 8

Mating surface rating:

airM mating surface air access rating = Moderate

bearM other bearing proximity rating = Good

bulkM bulky mating surface = Yes

sinkM mating surface heat sink = No

hotM mating surface heat sources = No

mRat mating surface rating = 8

kC thermal conductivity of counterface = 50.0 W/m K

Ra counterface roughness assumed optimal.

VH counterface hardness assumed adequate.

BEARING ENVIRONMENT AND MATERIALS

desDat descriptions database :DRBDES.DAT

envDat environment database :DRBENV.DAT

matDat materials database :DRBMAT.DAT

Database title :Materials from Data Item 87007

Ta ambient temperature = 40.0 degC

Tlow lowest expected temperature = -20.0 degC

tR required bearing life = 1.80 E+06 s

hA allowable depth of wear = 0.500 E-03 m

envID environment identifier(s):water, rad

WATER Water immersion

RAD Gamma radiation

res required environmental resistance rating .. = 3

3 Some resistance - some adverse effect but usually tolerable

matID material identifier(s) : Unspecified

(continued)