



ESDU 93005

Issued August 1993

With Amendment A

May 2010

Calculation methods for steadily loaded axial groove hydrodynamic journal bearings (Guide to use of computer program A9305)

Associated software: ESDUpac A9305

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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.

CALCULATION METHODS FOR STEADILY LOADED AXIAL GROOVE HYDRODYNAMIC JOURNAL BEARINGS (GUIDE TO USE OF COMPUTER PROGRAM A9305)

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CALCULATION METHODS FOR STEADILY LOADED AXIAL GROOVE HYDRODYNAMIC JOURNAL BEARINGS (GUIDE TO USE OF COMPUTER PROGRAM A9305)

1. INTRODUCTION

ESDUpac A9305 is a FORTRAN 77 computer program for the design and analysis of axial groove hydrodynamic journal bearings. The program implements the calculation methods of ESDU 84031 entitled "Calculation methods for steadily loaded axial groove hydrodynamic journal bearings". The program also implements the calculation methods of ESDU 85028 entitled "Calculation methods for steadily loaded axial groove hydrodynamic journal bearings. Superlaminar operation". In order to use the program effectively, ESDU 84031 and ESDU 85028 must be referred to for the theoretical limitations of the method and for discussion of practical considerations.

2. NOTATION AND UNITS

The symbols (variable names) used in the source code for ESDUpac A9305 and in the associated data files (see Section 4) conform to the requirements of FORTRAN 77 and, in general, differ from those used in ESDU 84031 and ESDU 85028. Both sets of symbols are listed in this Notation. Note also that the International System of units is used.

Symbol used by ESDUpac A9305	Symbol used by ESDU 84031 and ESDU 85028	Description	Units
a	<i>a</i>	axial length of lubricant groove	m
abRat	—	groove length to bearing length ratio, <i>a/b</i>	—
b	<i>b</i>	axial length of bearing	m
bdRat	—	bearing length to diameter ratio, <i>b/d</i>	—
beta	β	angular misalignment	rad
Cd	<i>c_d</i>	diametral clearance	m
CdRat	—	diametral clearance ratio, <i>C_d/d</i>	—
d	<i>d</i>	diameter of journal	m
dg	—	recommended minimum groove depth	m
eccRat	ε	eccentricity ratio for aligned bearing	—
eLoad	—	journal displacement in load direction	m
eTrans	—	journal displacement in transverse direction	m
H	<i>H</i>	total power loss of bearing	W

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hmin	h_{edge}	minimum film thickness (at edge of bearing)	m
hs	h_s	safe allowable minimum film thickness	m
kappa	κ	thermal diffusivity of lubricant	m ² /s
lubDat	—	name of lubricant database file	—
lubID	—	identifier for lubricant used	—
M	M	rotor mass associated with bearing	kg
N	N	frequency of shaft rotation	rev/s
Ncrit	N_{crit}	critical speed for half-speed whirl	rev/s
Nmax	—	maximum continuous operating speed	rev/s
Pe	Pe	Peclet number for calculation of temperature	—
Pf	p_f	lubricant feed pressure	N/m ²
Prun	p_{mean}	running specific loading	N/m ²
psi	ψ	attitude angle	deg
Pstart	—	start-up specific loading	N/m ²
Q	Q	total lubricant flow rate	m ³ /s
Ra	Ra	recommended maximum surface roughness value	m
Re	Re	bearing Reynolds number	—
ReCrit	$(Re)_{crit}$	critical Reynolds number for half-speed whirl	—
rho	ρ	density of lubricant	kg/m ³
rhoC	—	volumetric heat capacity of lubricant	J/m ³ K
Tf	T_f	lubricant feed temperature	deg C
theta	$\Delta\theta$	angular extent of lubricant groove	deg
Tmax	T_{max}	maximum bearing surface temperature	deg C
Tout	T_{out}	outlet lubricant temperature	deg C
W	W	total running load	N
wg	w	circumferential width of groove	m
Ws	—	total start-up load	N

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[†], A9305V11, 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,

```
A9305V11 < 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 sent to the output file. These error messages describe the error and indicate the number of the line at which the error occurred in the input data file. Note that most operating systems have a set of special file names that refer to devices. If, for example, it is required to send program output directly to the printer, the printer device name should be specified in place of the output file name.

A number of example input data files are supplied with the program (files with the extension “.IN”). The corresponding output data files (with the extension “.OUT”) can be examined using a text editor.

[†] The program name used here is that of Version 1.1 (V11) which may not be the latest.

4. THE INPUT DATA FILE

Input data files are prepared using a text editor and, in most cases, new input files will be produced by editing existing input files. If ESDUpac A9305 is to be used to analyse the performance of an existing bearing design then it is necessary to provide a full specification for the bearing in the input data file. An example input data file for a complete bearing specification is shown here.

```

ESDU A9305

* This input file contains a full specification for a bearing.

* Lubrication parameters:
* ~~~~~
lubDat name of lubricant database          = C:\ESDU\MIN.DAT
lubID  lubricant identifier                = VG32
Tf     lubricant feed temperature          = 50.0      deg C
Pf     lubricant feed pressure             = 1.0E5      N/m^2

* Bearing dimensions:
* ~~~~~
d      diameter of journal                 = 0.20      m
b      axial length of bearing             = 0.05      m
a      lubricant groove length             = 0.04      m
wg     circumferential width of groove     = 0.524E-01 m
Cd     diametral clearance (minimum case)  = 0.28E-3   m

* Operational parameters:
* ~~~~~
N      frequency of rotation of journal    = 60.0      rev/s
W      running load on bearing             = 20E3      N
Ws     start-up load on bearing            = 20E3      N

beta   angular misalignment               = 0.0      rad
M      rotor mass associated with bearing  = 20E2      kg
    
```

The following points should be noted.

- (i) All lines beginning with an asterisk, “*”, are comment lines. Such comment lines may 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. This line must be present in all input data files.
- (iii) Input parameters can be specified in any order and each parameter has an identifying symbol. The explanatory text following the parameter symbol may be omitted in which case the “=” sign is not strictly necessary.
- (iv) This particular ESDUpac program requires access to a lubricant database file, the name of which is specified in the input file. The lubricant database file supplied with this ESDUpac program is called “MIN.DAT” and can be examined using a text editor capable of handling text lines longer than 80 characters. Full instructions on editing the file (to add further lubricants, for example) are included as comments within the file.
- (v) Each of the lubricants in the lubricant database file has an identifier and the identifier of the required lubricant can be specified in the input file. The identifiers for other lubricants can be seen by examining the file with a text editor.

- (vi) Instead of specifying the bearing length, b , directly it is permissible to specify the ratio of the bearing length to the bearing diameter. Likewise, the ratio of the groove length to the bearing length can be specified instead of a and the diametral clearance ratio can be specified instead of Cd .

Also, the angular extent of the lubricant groove can be specified instead of wg . Thus the specifications of b , a , wg and Cd in the above example input data file could be replaced by, for example,

bdRat	bearing length to diameter ratio	=	0.25
abRat	groove length to bearing length ratio	=	0.8
theta	angular extent of lubricant groove	=	30 deg
CdRat	diametral clearance ratio	=	0.14E-2

If ESDUpac A9305 is to be used to design a bearing then only the expected operating parameters and the design requirements should be specified in the input data file. Thus, some or all of the bearing dimensions that were fully specified in the previous example input data file will be left unspecified. The program will then assign preliminary values to these unspecified bearing dimensions before analysing the performance. An example input data file for a required bearing design is shown here.

```

ESDU A9305

* This input file specifies the design requirements for a bearing.
* Lubrication parameters:
* ~~~~~
lubDat name of lubricant database          = C:\ESDU\MIN.DAT
lubID  lubricant identifier                = ?
Tf     lubricant feed temperature          = 40.0      deg C
Pf     lubricant feed pressure             = 1.0E5      N/m^2

* Bearing dimensions:
* ~~~~~
d      diameter of journal                 = ?          m
b      axial length of bearing             = ?
a      groove axial length                = ?
wg     circumferential width of lubricant groove = ?
Cd     diametral clearance (minimum case)  = ?

* Operational parameters:
* ~~~~~
N      frequency of rotation of journal    = 6.67      rev/s
Nmax   maximum expected operating speed   = 10        rev/s
W      running load on bearing            = 38E3      N
Ws     start-up load on bearing           = 38E3      N

beta   angular misalignment               = 2.0E-4    rad
M      rotor mass associated with bearing  = 3800      kg

$CASE
* Maximum speed case
* ~~~~~
N      frequency of rotation of journal    = 10        rev/s

```

The following points should be noted.

- (i) The lubricant has been left unspecified by placing a “?” in place of the identifier. The program determines a suitable mineral oil viscosity grade according to the advice given in ESDU 84031.
- (ii) The bearing dimensions have been left unspecified by placing a “?” in place of the value. The

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program determines suitable values for these dimensions (using the preliminary design method of ESDU 84031) before proceeding to analyse the performance of the bearing.

- (iii) The maximum expected operating speed, $N_{\max}$, has been specified. Whenever, as here, the program is required to choose a preliminary value for the diametral clearance, C_d , it is advisable to specify this parameter (see Section 4.1).
- (iv) An additional case, that for the maximum expected operating speed, has been appended to the initial data. Whenever the bearing performance is to be checked over a range of operating conditions, further cases can be appended to the initial data with the key-word "\$CASE". Any number of additional cases can be appended and the key-word "\$CASE" must be used for each one. A single parameter, or several parameters, may be specified for each additional case and the values of the specified parameters overwrite the values existing for the previous case.

The program is capable of determining a preliminary design given only the rotational speed, N , and the applied load, W . In most situations, however, some other constraint, such as a preferred bearing diameter, d , will have been imposed. Table 4.1 summarises the status of all the input parameters. More detailed guidance on the specification of individual parameters is given in Section 4.1.

TABLE 4.1 INPUT PARAMETER STATUS

Parameter symbol	Status and default values	
a	}	Optional. Defaults to abRat of 0.8.
abRat		
b	}	Optional. Preliminary values determined if unspecified.
bdRat		
beta		Optional. Defaults to zero.
Cd	}	Optional. Preliminary values determined if unspecified.
CdRat		
d		Optional. Preliminary value determined if unspecified.
lubDat		Optional. Defaults to database file "MIN.DAT".
lubID		Optional. Lubricant grade suggested if unspecified.
M		Optional. Gravitational loading assumed if unspecified.
N		Mandatory.
Nmax		Optional. Defaults to nominal speed, N .
Pf		Optional. Defaults to $1.0E5 \text{ N/m}^2$.
Prun		Optional. Defaults to $4.0E6 \text{ N/m}^2$.
Pstart		Optional. Defaults to $2.5E6 \text{ N/m}^2$.
Tf		Optional. Defaults to 50 deg C.
W		Mandatory.
Ws		Optional. Defaults to zero.
theta	}	Optional. Defaults to $\theta = 30 \text{ deg}$.
wg		

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4.1 Specification of Input Data

Input parameters can be specified in any order and each parameter has an identifying symbol. Input parameters are specified with the symbol of the parameter followed by the value (with optional comment text). 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 by placing an asterisk, “*”, at the start of the line.
- (iii) Omit the parameter specification entirely.

The input parameters for this ESDUpac program fall naturally into three groups and the following table, arranged in the format of an input data file, includes comments on the purpose of all input parameters.

```
ESDU A9305

* Lubrication parameters:
* ~~~~~
* ESDUpac A9305 requires access to a lubricant database file the name of
* which can be specified in the input data file (see lubDat below). The
* lubricant database file supplied with this ESDUpac is called
* 'MIN.DAT'. The lubricant database file can be examined using a
* text editor capable of handling text lines longer than 80 characters.
* Each lubricant in the lubricant database file has an identifier of up to
* 6 characters (see lubID below).

lubDat  name of lubricant data-base file          = C:\ESDU\MIN.DAT
*       The name of the lubricant database file that is to be accessed
*       for lubricant properties can be specified as simply a file name
*       or a path. If lubDat is left unspecified then the default
*       database name, 'MIN.DAT', is assumed.

lubID    lubricant identifier                      = VG22
*       The lubricant is sometimes specified to suit the design
*       requirements of another component. If lubID is left unspecified,
*       the program chooses a lubricant grade according to the guidance
*       given in Data Item 84031.

Pf       lubricant supply pressure                 = 2.0E5      N/m^2
*       The lubricant supply pressure may need to be specified to suit
*       the requirements of other hydrodynamic bearings or components.
*       In most circumstances feed pressures between 0.05 MN/m^2 and
*       0.35 MN/m^2 will be found to be adequate. A default value of
*       1.0E5 N/m^2 is assumed for Pf if left unspecified.

Ts       lubricant supply temperature               = 50        deg C
*       The lubricant supply temperature provides the datum used in
*       calculating the overall temperature rise through the bearing.
*       A default value of 50 deg C is assumed for Tf if left
*       unspecified.

* Bearing dimensions:
* ~~~~~
* When analysing the performance of an existing design all of the bearing
* dimensions will be known and should, accordingly, be specified in the
* input data file. When designing a bearing it is convenient to start with
* an approximate design arrived at by the use of broad assumptions (see
* Section 5 of Data Item 84031). Accordingly, the bearing dimensions
* may be left unspecified, in which case the program will determine
* preliminary values. As the design proceeds it is likely that constraints
* will be placed on the design by specifying preferred values for some of
* the bearing dimensions. Section 7 of this Guide Data Item includes a
* number of worked examples that illustrate this incremental imposition of
* design constraints.
```

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```

d      bearing diameter                      = 0.104      m
*      The journal diameter is usually predetermined by considerations
*      of shaft strength or rigidity. If d has not been specified then
*      the program estimates the required bearing diameter using a method
*      based on the preliminary design method of Data Item 84031.

b      bearing axial length                  = 0.52E-01      m
*      If analysing an existing design the length of the bearing will
*      be known. The bearing length can be specified directly (as here)
*      or indirectly as the ratio to the bearing diameter, bdRat.
*      If b has not been specified in either way then the program
*      estimates the required bearing length according to the
*      preliminary design method of Data Item 84031.

bdRat  bearing length to diameter ratio, b/d = 0.2
*      The bearing length, b, can be specified directly (see above) or
*      indirectly as the ratio to the bearing diameter. If b has not
*      been specified in either way then the program estimates the
*      required bearing length according to the preliminary design
*      method of Data Item 84031.

a      axial length of lubricant groove      = 0.104E-1      m
*      If analysing an existing design the length of the lubricant
*      groove will be known. The groove length can be specified directly
*      (as here) or indirectly as the ratio to the bearing length, abRat
*      If a has not been specified in either way then the program
*      assumes a abRat value of 0.8.

adRat  groove length to bearing diameter ratio = 0.8
*      The groove axial length, a, can be specified directly (see above)
*      or indirectly as the ratio to the bearing length. If a has not
*      been specified in either way then abRat is assumed to be 0.8.

wg      circumferential width of lubricant groove = 0.01      m
*      If analysing an existing design the circumferential width of the
*      lubricant groove will be known. The groove width can be specified
*      directly (as here) or indirectly as the angular extent, theta.
*      If wg has not been specified in either way then the program
*      assumes a theta value of 30 deg.

theta  angular extent of lubricant groove    = 30      deg
*      The groove width, wg, can be specified directly (see above) or
*      indirectly as the angular extent, theta. If wg has not been
*      specified in either way then the program assumes a theta value
*      of 30 deg.

Cd      diametral clearance                  = 0.634E-04      m
*      If analysing an existing design the diametral clearance will be
*      known. The diametral clearance can be specified directly (as
*      here) or indirectly as the ratio to the bearing diameter, CdRat.
*      If not specified in either way the program assumes a value
*      according to the guidance given in Section 5.2 of Data Item 84031.

CdRat  diametral clearance ratio              = 0.792E-04
*      The diametral clearance can be specified directly (as above) or
*      indirectly as the ratio to the bearing diameter. If not specified
*      in either way the program assumes a value according to the
*      guidance given in Section 5.2 of Data Item 84031.

* Operational parameters:
* -----
N      frequency of rotation                  = 100.0      rev/s
*      The frequency of rotation must be specified and is assumed to be
*      constant.

W      total applied load                    = 22.0E3      N
*      The total applied load must be specified and is assumed to be
*      steady.

Ws     total start-up load                    = 22.0E3      N
*      The total start-up load can equal the total applied load but is
*      often smaller. A default value of zero is assumed for Ws if
*      left unspecified. (ie. negligible start-up load).

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