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Calculation methods for steadily loaded fixed-inclined-pad thrust bearings (Guide to use of computer program A9234)

Associated software: ESDUpac A9234

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THE PREPARATION OF THIS DATA ITEM

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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 FIXED-INCLINED-PAD THRUST BEARINGS (GUIDE TO USE OF COMPUTER PROGRAM A9234)

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CALCULATION METHODS FOR STEADILY LOADED FIXED-INCLINED-PAD THRUST BEARINGS (GUIDE TO USE OF COMPUTER PROGRAM A9234)

1. INTRODUCTION

ESDUpac A9234 is a FORTRAN 77 computer program for the design and analysis of fixed-inclined-pad thrust bearings. The program implements the calculation method of ESDU 82029 entitled "Calculation methods for steadily loaded fixed-inclined-pad thrust bearings". In order to use the program effectively, ESDU 82029 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 A9234 and in the associated data files (see Sections 4 and 5) conform to the requirements of FORTRAN 77 and, in general, differ from those used in ESDU 82029. Both sets of symbols are listed in this Notation. Note also that the International System of units is used.

Symbol used by ESDUpac A9234	Symbol used by Data Item 82029	Description	Units
b	<i>b</i>	pad radial width	m
beta	β	taper rise of thrust pad	m
betaH	—	ratio of pad rise to film thickness, β/h	—
biOp	—	flag indicating bi-directional operation	—
bLRat	—	pad width to length ratio, b/L	—
DdRat	—	outer to inner diameter ratio of pads, D/d	—
dIn	<i>d</i>	inside diameter of thrust pads	m
dLub	—	flag indicating directed lubrication	—
Dout	<i>D</i>	outside diameter of thrust pads	m
Drun	D_R	diameter of runner	m
ds	d_s	shaft diameter	m
h	<i>h</i>	pad outlet film thickness	m
Hch	H_{ch}	churning power loss	W
Hf	<i>H</i>	total film power loss	W

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hmin	h_{min}	minimum allowable pad film thickness	m
Ht	H_t	total power loss for whole bearing	W
kappa	κ	thermal diffusivity of lubricant	m ² /s
L	L	length of pad at mean diameter	m
land	—	length of land as fraction of pad length	—
lubDat	—	name of lubricant database file	—
lubID	—	identifier for lubricant used	—
N	N	frequency of rotation	rev/s
np	n	number of thrust pads	—
Pland	P_l	land pressure during start-up	N/m ²
Prun	P_{mean}	mean pad pressure (running)	N/m ²
padF	—	pad complement (see Section 5.2.1 of ESDU 82029)	—
Q	Q	total lubricant feed rate to bearing	m ³ /s
Qr	—	flow rate for adequate lubrication	m ³ /s
Ra	R_a	surface roughness value	—
rho	ρ	density of lubricant	kg/m ³
rhoC	—	volumetric heat capacity	J/m ³ K
Tin	T_{in}	lubricant temperature at inlet to housing	deg C
Tmax	T_{max}	pad maximum temperature	deg C
Tout	T_{out}	lubricant temperature at outlet from housing	deg C
tRun	t	runner thickness	m
W	W	total load	N
Ws	W_s	total start-up load	N

3. RUNNING THE PROGRAM

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

To run the executable version of the program from the keyboard, type the program name[†], A9234V11, 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,

```
A9234V11 < 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.

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 value 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 A9234 is to be used to analyse the performance of an existing bearing design, 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.

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

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* Lubrication parameters:
* ~~~~~
lubDat  name of lubricant data-base file    = C:\esdu\lub.dat
lubID   lubricant identifier                = VG22
dLub    directed lubricant (Y/N)            = Y
biOp    bi-directional operation (Y/N)      = N

Tin     lubricant supply temperature        = 50          deg C
Q       lubricant flow rate                 = 1.16E-3      m^3/s

* Bearing dimensions:
* ~~~~~
dIn     inside diameter of thrust pads      = 0.104        m
b       pad radial width                   = 0.547E-01    m
L       length of pad at mean diameter      = 0.547E-01    m
np      number of thrust pads               = 7

beta    taper rise of thrust pad            = 0.14E-03     m
land    land length as a fraction of pad length = 0.3

ds      shaft diameter                     = 0.09         m
Drun    diameter of runner                 = 0.219        m

* Operational parameters:
* ~~~~~
N        frequency of rotation              = 100.0        rev/s
W        total applied load                 = 22.0E3       N
Ws       total start-up load                = 4.4E3        N
```

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 "LUB.DAT" and can be examined using an ASCII 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 must be specified in the input file. The identifiers for other lubricants can be seen by examining the file with a text editor.

If ESDUpac A9234 is to be used to design a bearing, 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 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.

* This input file specifies the design requirements for a bearing.

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lubDat	name of lubricant database	=	C:\esdu\lub.dat	
lubID	lubricant identifier	=	VG22	
dLub	directed lubrication (Y/N)	=	Y	
Tin	lubricant supply temperature	=	50	deg C
Tout	required lubricant outlet temperature	=	75	deg C
W	total load	=	22.0E3	N
Ws	total start-up load	=	4.4E3	N
N	rotational speed	=	100.0	rev/s
Prun	design running mean pad pressure	=	2.0E6	N/m ²
Pland	design land pressure	=	0.7E6	N/m ²
ds	shaft diameter	=	0.09	m

The following points should be noted.

- (i) The bearing dimensions have been left completely unspecified. The only direct constraint on the bearing dimensions is that imposed by the specified shaft diameter (*i.e.* the inner diameter of the thrust pads cannot be less than 0.09 m). In general unspecified bearing dimensions are determined according to the preliminary design method of ESDU 82029.
- (ii) Values have been specified for both the running and the start-up mean pad pressures, Prun and Pland, that are to be used in determining the preliminary bearing dimensions. Default values of, respectively, 2.0 MN/m² and 0.7 MN/m² are assumed for these parameters if left unspecified. Default values exist for some other parameters (see Table 4.1).
- (iii) The required lubricant outlet temperature, Tout, has been specified so that the required lubricant flow rate, Q, can be determined by the program.

TABLE 4.1 DEFAULTS FOR UNSPECIFIED PARAMETERS	
Parameter symbol	Default value
lubDat	lubricant database file "LUB.DAT" is assumed
dLub	flood feed lubrication is assumed
biOp	uni-directional operation is assumed
Tin	50 deg C inlet temperature is assumed
Tout	75 deg C required outlet temperature is assumed
Prun	running design mean pad pressure of 2.0 MN/m ² is assumed
Pland	start-up land pressure of 0.7 MN/m ² is assumed
Ws	zero total start-up load is assumed

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 any 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.

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* Lubrication parameters:	
* ~~~~~	
* ESDUpac a9234 requires access to a lubricant database file the name of	
* which can be specified in the input data file (see lubDat below). The	
* name of can be specified in the input data file (see lubDat below). The	
* name of the lubricant database file supplied with this ESDUpac is called	
* 'LUB.DAT'. The lubricant database file can be examined using an ASCII	
* 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\lub.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, 'LUB.DAT', is assumed.	
lubID lubricant identifier	= VG22
* The identifier corresponding to the required lubricant in the	
* lubricant database file must be specified.	

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dLub	directed lubricant (Y/N)	= Y
*	High speed applications sometimes require directed lubrication in	
*	which each pad is individually fed (see Section 8.1 of Data Item	
*	82029) in which case dLub should be specified as Y. If dLub is	
*	left unspecified then flood feed lubrication is assumed.	
biOp	bi-directional operation (Y/N)	= N
*	For bi-directional operation a tapered region at both ends of	
*	each pad is necessary (see Section 8.3 of Data Item 82029) in	
*	which case biOp should be specified as Y. If biOp is left	
*	unspecified then uni-directional operation is assumed.	
Tin	lubricant supply temperature	= 50 deg C
*	The lubricant supply temperature provides the datum used in	
*	calculating the overall temperature rise through the bearing.	
*	With directed lubrication the temperature of the lubricant	
*	available to the thrust pads is assumed to be equal to Tin (see	
*	Section 4.3 of Data Item 82029). A default value of 50 deg C is	
*	assumed for Tin if left unspecified.	
Tout	required lubricant outlet temperature	= 80 deg C
*	The required lubricant outlet temperature can determine the	
*	required lubricant flow rate, Q. With flood feed lubrication the	
*	temperature of the lubricant available to the thrust pads is	
*	assumed to be equal to Tout (see Section 4.3 of Data Item 82029).	
*	A default value of 70 deg C is assumed for Tout if left	
*	unspecified.	
Q	lubricant flow rate	= 1.16E-3 m^3/s
*	The lubricant flow rate, if specified, determines the drain	
*	temperature, Tout, of the bearing (see Section 7.2 of Data Item	
*	82029). If left unspecified, the program determines the required	
*	lubricant flow rate. This flow rate will be dictated by the need	
*	to maintain the required lubricant outlet temperature, Tout, or,	
*	if directed lubrication has been used, by the need to ensure	
*	adequate lubrication (see Section 8.1 of Data Item 82029).	
* 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 82029) and, accordingly, all of 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.	
dIn	inside diameter of thrust pads	= 0.104 m
*	If analysing an existing design the inside diameter of the pads	
*	will be known. If left unspecified, however, the program	
*	determines the required inside diameter according to the	
*	preliminary design method of Data Item 82029.	

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b	pad radial width	= 0.547E-01 m
*	If analysing an existing design the width of the pads will be known. If left unspecified, however, the program determines the required pad width according to the preliminary design method of Data Item 82029.	
*		
*		
*		
L	length of pad at mean diameter	= 0.547E-01 m
*	If analysing an existing design the length of the pads will be known. If left unspecified, however, the program determines the required pad length according to the preliminary design method of Data Item 82029.	
*		
*		
*		
np	number of thrust pads	= 7
*	If analysing an existing design the number of pads will be known. If left unspecified, however, the program determines the required pad number according to the preliminary design method of Data Item 82029.	
*		
*		
*		
beta	taper rise of thrust pad	= 0.14E-03 m
*	The ratio of the pad taper rise to the film thickness, beta/h, is important for the satisfactory operation of the bearing. If left unspecified the program determines the value of beta required to give a beta/h ratio of 3.0 (see Section 6.1.2 of Data Item 82029)	
*		
*		
*		
land	land length as a fraction of pad length	= 0.3
*	If known, the land length should be specified as a fraction of the pad length. If left unspecified the program assumes a 20 per cent land unless start-up requirements have dictated the bearing design, in which case a land length up to 30 per cent may be assumed (see Section 5.1.2 of Data Item 82029).	
*		
*		
*		
ds	shaft diameter	= 0.09 m
*	The shaft diameter determines the allowance made for misalignment (see Section 7.1 of Data Item 82029). The specified value of ds also acts as a constraint on the minimum possible inner diameter of the pads, dIn, during preliminary design. If left unspecified the program assumes a shaft diameter 15 per cent smaller than the inner diameter of the thrust pads, dIn.	
*		
*		
*		
*		
Drun	diameter of runner	= 0.219 m
*	The runner diameter is used when determining the churning losses in flood feed bearings (see Section 8.2 of Data Item 82029). The specified value of Drun also acts as an overall space constraint on the bearing during preliminary design. If left unspecified the program assumes a runner diameter 3 per cent larger than the outer diameter of the thrust pads.	
*		
*		
*		
*		
*		
*	Operational parameters:	
*	~~~~~	
N	frequency of rotation	= 100.0 rev/s
*	The frequency of rotation must be specified and is assumed to be constant. Example 4 in Section 6 of this Guide Data Item illustrates the investigation of "off design" conditions.	
*		
*		
W	total applied load	= 22.0E3 N
*	The total applied load must be specified and is assumed to be steady. Example 4 in Section 6 of this Guide Data Item illustrates the investigation of an "off design" load condition.	
*		
*		
*		

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Ws	total start-up load	= 4.4E3	N
*	The total start-up load can equal the total applied load but is		
*	often smaller. A default value of 0.0 is assumed for Ws if left		
*	unspecified (ie. negligible start-up load).		
Prun	design running mean pad pressure	= 1.0E6	N/m ²
*	When designing a bearing, the mean pad pressure that is to be		
*	assumed for the preliminary design can be specified (see Section		
*	5.1.1 of Data Item 82029). A default value of 2.0E6 N/m ² is		
*	assumed for Prun if left unspecified.		
Pland	design land pressure	= 0.5E6	N/m ²
*	When designing a bearing, the land pressure that is to be assumed		
*	for the preliminary design can be specified (see Section 5.1.2 of		
*	Data Item 82029). A default value of 0.7E6 N/m ² is assumed for		
*	Pland if left unspecified.		

This computer program assumes either flood feed lubrication in which the whole bearing is immersed in an oil bath or directed lubrication with an individual feed for each thrust pad. With flood feed, the temperature of the lubricant at entry to the thrust pads is assumed to be equal to the lubricant temperature at outlet from the housing, Tout. With directed lubrication the pad entry temperature is assumed to be equal to the lubricant supply temperature. In practice, however, it is usual to supply the lubricant to the inner diameter of the bearing so that it flows radially outwards between the pads. In such an arrangement it is likely that the pad entry temperature will lie somewhere between the supply temperature and the housing outlet temperature. It is, therefore, recommended that the performance of such bearings be analysed for both lubrication arrangements.