ADVANCED TRIBOLOGY DESIGN TOOLS FOR SPACE MECHANISMS

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ABSTRACT

The purpose of this paper is to report on the current status of, and updates to, three well-established ESTL design aids and tools which are frequently used in the design of spacecraft mechanisms. The design aids covered are:

Space Tribology Handbook
DOLLS: a database on space oils and greases
CABARET: a ball bearing analysis code

The Space Tribology Handbook has become established as the definitive guide to space tribology. This paper reports on updates made to the Handbook and the plans to incorporate it into ECSS Guidelines.

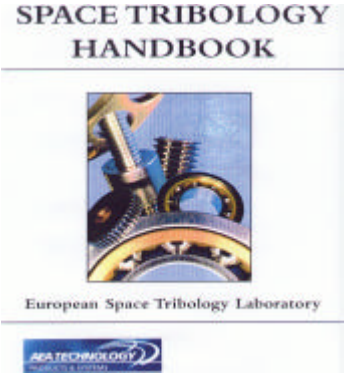
The database known as DOLLS provides the fundamental information needed for selection of a fluid lubricant for space applications. The database is being upgraded to include details on new oils and greases and, where available, new data on the characteristics of listed fluid lubricants.

The bearing analysis code, CABARET, allows the prediction of bearing performance for a range of applications from low-speed mechanisms to high-speed turbo-pumps. Its predictive capabilities include torque, contact stress, stiffness thermal effects, cage motion, and fatigue life.

Each design aid and its current status are discussed further below.

SPACE TRIBOLOGY HANDBOOK

The Space Tribology Handbook is based principally on ESTL's experience in this field in a period now approaching 30 years. It has been written with the aims of assisting designers and engineers in the implementation of sound tribological practices and to help them determine how best to treat and lubricate components for their given application. Additionally, the Handbook offers guidance on the ground testing of tribo-components either in isolation or as part of their parent mechanisms.



The Handbook was first published in 1997 and the areas covered were as listed in Table 1. A 2nd edition has now been produced with the following additions.

- New section on solvent cleaning of tribo-components
- Additional data on solid lubricants including: further tribological properties of bonded lubricants; further data on effects of contact stress and environment on behaviour of MoS2-lubricated bearings; updated Tables on in-vacuo and in-air friction and wear properties of polymer composites materials; data on performance of hybrid polymeric and cageless bearings.
- New data on torque behaviour of grease-lubricated bearings (giving bearing torque as a function of speed, temperature and quantity of grease)
- New chapter on Ball Bearing Procurement Specification

The intention is ultimately to transfer the Handbook into an ECSS Guideline Document: this work is ongoing and is expected to be completed in 2002.

In the meantime details on how to obtain a copy of the current edition of the Space Tribology Handbook are given at the end of this paper.

Table 1 Contents of Space Tribology Handbook

1. **Basic Tribology**. Topics include: surfaces and interfaces; friction and wear mechanisms; principles of fluid and solid lubrication; space and spacecraft environment.
2. **Tribo-component Selection, Design and Performance**. Topics include: rotary, rolling element bearings; plain, spherical and rod-end bearings; ball, roller and plain screws; linear bearings; gears; sliding electrical contacts, separation surfaces; end-stops; threaded fasteners; safety factors.
3. **Selection of Lubricant Type**. Topics include - guide to selection: dry versus fluid lubrication; enhancing lubricant performance.
4. **Solid Lubricants**. Topics include: selection of solid lubricant; solid lubricant coatings; bulk solid lubricants.
5. **Fluid Lubricants**. Topics include: selection of fluid lubricant; fluid lubricant database; tribological properties of fluid lubricants; fluid loss, retention and replenishment; handling, cleaning and lubrication procedure.
6. **Materials for Tribological Components and Surfaces**. Topics include; properties of materials; engineering the surface; materials selection for tribo-components.
7. **Component and Mechanism Testing**. Topics include: test level hierarchy; test environments; test facilities; guidance and component testing; guidance on mechanism testing; verification requirements.

DOLLS DATABASE

DOLLS is an oil and grease database which provides the fundamental information needed for selection of a fluid lubricant for space applications. The database contains known information for the physiochemical and tribological properties of fluid lubricants that have been used for, or are candidate materials for, space satellite applications.

Specifically, the database includes information on:

Viscosity; pour point; maximum temperature of operation; molecular weight; surface tension; density; vapour pressure (at 3 temperatures); TML, RML & CVCM; specific heat; thermal conductivity; and pressure/viscosity coefficient.

The database is currently being updated to include information on products which have appeared on the market since the last version was issued in 1996. Thus the recently introduced Maplub range of greases is included as is the new EF (environmentally friendly) series of Braycote greases. Recently made independent VCM measurements by ESTEC on these new formulations are also included.

CABARET

CABARET is a PC-based bearing analysis code which is applicable to ball bearings operating at all speeds under general loading. Its use permits design and selection of bearings, materials and lubricants as well as prediction of bearing performance for a range of applications from low-speed mechanisms to high-speed turbo-pumps. CABARET integrates analyses for a number of features important in ball-bearing performance in a single code.

The basis of CABARET is the so-called “quasistatic analysis” of bearing internal loads and motions. This enables the prediction of stiffness (or deflection) and contact stresses within single bearings or bearing pairs under generalised loading. In addition, CABARET can model:

Coulombic Torque

This is the load-dependant torque primarily applicable to solid-lubricated ball bearings, but also relevant in liquid lubricated bearings under low speed conditions where viscous losses are negligible.

Thermal and Centrifugal Strain Effects

These modify bearing/shaft or housing fits and so the effective bearing preload. CABARET can predict both these changes and the resulting bearing torque.

Cage Motion

CABARET has a 3 degree of freedom cage motion simulation which enables qualitative assessment cage stability and estimation of cage-ball and cage-land collision forces.

Fatigue Life

CABARET can estimate the fatigue life of bearings based on both the classical Lundberg-Palmgren method and the SKF model which incorporates the effects of material properties and the sub-surface contact stress distribution.

Flash Temperature

The localised “flash temperatures” generated at asperity contacts due to both microslip and skidding can also be estimated.

Fluid Power Losses

For bearings immersed in fluid (e.g. LOX or LH2 in turbo-pump bearings), CABARET has the ability to estimate the fluid power losses based on empirical equations.

Vibration Analysis

CABARET has a basic vibration analysis capability, which predicts the vibration frequency and forces generated by lobing of inner or outer races, together with the effects of variable compliance vibration.

Sensitivity Analysis

One of the most useful features of CABARET is the ability to carry out a sensitivity analysis. This feature allows designers to quickly generate curves which show the sensitivity of predicted output values to single input parameters (e.g. to predict the effects of variation of bearing conformity number on torque or deflection).

Features which are not presently covered and which are currently being included are:

- Hertzian and EHL analysis: this facility will permit users to calculate a derived specific film thickness and lubrication regime and hence help to establish the validity of any accelerated tests using liquid lubrication.

- analysis of low-speed non-identical pairs: non-identical bearing combinations are used to facilitate easy assembly in some types of scan mechanism. The code is currently being updated to allow analysis of such combinations.

- addition of a “g-vector” to the cage model currently implemented enabling qualitative assessment of cage stability to be made for horizontal and vertical axis bearing operation. Cage stability has recently become an issue of some importance and this modification will permit use of CABARET to predict behaviour in at least a qualitative manner.

FURTHER INFORMATION

For further information about obtaining the latest versions of the above design aids and tools please contact the author directly at the address given at the top of this paper.

ACKNOWLEDGMENTS

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